NINETEENTH ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

TO THE

SECRETARY OF THE INTERIOR

1897-98

CHARLES D. WALCOTT
DIRECTOR

IN SIX PARTS

PART IV—HYDROGRAPHY

F. H. NEWELL, CHIEF OF DIVISION

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PART IV—HYDROGRAPHY

CONTENTS.

LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Division of Hydrography,
Washington, June 1, 1898.

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 Nineteenth Annual Report of the Survey. The greater portion of this material consists of the results of investigations carried on during the calendar year 1897. The first paper, composite in character, 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 independently prepared have been incorporated in this progress report, after such modification as was necessary to bring them into accord with the scheme. For example, a paper prepared by Prof. Dwight Porter, and intended originally for publication in the Water-Supply and Irrigation series, supplies data concerning the flow of the rivers of Maine, giving also the industrial application of these natural resources. Another paper, by Mr. J. B. Lippincott, upon the development of irrigation in the vicinity of San Bernardino, also prepared originally for independent publication, supplies other needed data concerning the behavior of streams in that region and at the same time brings out the methods of utilization of the water resources of that country. This also has been inserted in its proper geographic order. A considerable amount of data concerning stream flow has also 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 or of engineers cooperating with them.

Following the report of results of stream measurements are two papers treating of the occurrence and utilization of waters obtained from beneath the surface of the earth. This general subject of underground waters is not as yet susceptible of a systematic geographic treatment, but particular problems have been taken up, resulting in wholly independent reports.

The first of these is that by Prof. Edward Orton on the deep wells of Ohio. This was prepared originally with the intention of printing it in the Eighteenth Annual Report, Part IV, with Mr. Frank Leverett's general discussion of the underground waters of Ohio and Indiana, but the ill health of Professor Orton and the pressure of other matters prevented the accomplishment of this project, and the paper, delayed by unavoidable circumstances, is now presented. The other paper is that by Mr. N. H. Darton, geologist, giving the results of his general studies in Nebraska, carried on through two field seasons, and particularly the data acquired during 1897 in the western end of the State, in the portion north of Colorado, adjacent to Wyoming and to the Black Hills region of South Dakota.

In these papers the attempt has been made to present not only the facts disclosed by examination and survey, but to discuss these facts and to give in connection with them examples of what has already been accomplished in the employment of the water resources for power, irrigation, and municipal supply, the aim being not only to give scientific information, but to keep always in touch with the industrial application of the facts presented.

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 1897, INCLUDING PAPERS BY DWIGHT PORTER, J. B. LIPPINCOTT, AND OTHER HYDROGRAPHERS

BY

F. H. NEWELL

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ILLUSTRATIONS.

REPORT OF PROGRESS OF STREAM MEASUREMENTS FOR THE CALENDAR YEAR 1897, ETC.

By F. H. Newell.

INTRODUCTION.

A study of the water resources of the United States has been carried on consecutively for ten years, bringing together data for scientific and industrial application concerning the distribution and the fluctuation of waters, both surface and underground. Previous to 1888 matters of this kind were frequently the subject of special inquiry in connection with topographic or geologic surveying, but it was not until the authority was specifically conferred by the acts of March 20 and October 2, 1888, that the subject became one of separate and continuous inquiry.

Beginning with the organization of the work during the winter of 1888–89, and the operations of the succeeding field season, the work has been continued under the same general plan and under direction of a single individual until the methods, tentative at first, have attained to something of the established routine essential to rapidity and economy of execution. The continuity of purpose through a decade has enabled the accomplishment of results through moderate expenditures which would have been impossible of attainment by larger sums administered with less consistent purpose.

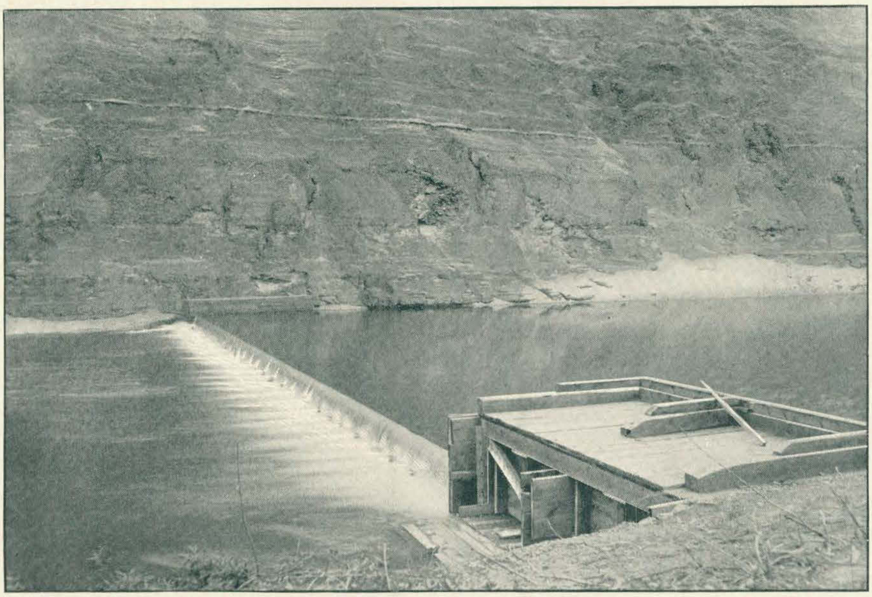
The attempt is made to obtain data concerning the flow of streams in all parts of the United States. It is, of course, impossible with moderate means to measure all the rivers, and therefore choice must be made of those where the best results can be had with the least outlay of time and money. The measurement of the surface flow is, however, only one part of the problem, for the questions pertaining to the underground supplies are often as important as those concerning the visible waters. A survey of the waters beneath the surface offers even more obstacles, and while it is possible to adopt a general geographic arrangement for the discussion of data concerning surface flows, it is not so easy to do so with the underground waters, as the distribution of these is modified by many geologic conditions. Thus it has been found desirable to treat the discussion of the surface supply by itself, incorporating in a somewhat arbitrary geographic arrangement all of the data available, and to supplement this by the individual and somewhat disconnected papers regarding the waters reached by wells in various areas or States.

In the operations of obtaining the figures relating to the discharge of a stream there are two classes of facts required. The first is the statement of what has been done at each locality and the measurements made. From these original observations there is then obtained by office work a second set of data, based on the first, but giving in more or less concise form the probable flow day by day. The facts first mentioned—those resulting from field work—can, of course, be stated immediately after the operations are performed. The resulting computations, however, usually require for accuracy the digestion of the field notes obtained through one or more seasons, and, to be clearly shown, necessitate the preparation of diagrams. From this condition it has been found desirable in the statement of results to make what might be considered double publication. In the first is given briefly and as soon as possible after the close of the calendar year a statement of the field operations and the immediate results of measurements. In the case of the year 1897 these data have been printed as Water-Supply and Irrigation Papers, Nos. 15 and 16. These give a description of each locality at which stream measurements were made, together with the details of bench marks, initial points, character of channel, current-meter measurements, and the record of average height of water day by day. These facts are thus made at once available for the use of hydrographers and other persons concerned with the minor points of method and of the character of the work.

While the data above described are being printed the computations of final results are carried on and diagrams prepared. These form the substance of the present paper. The estimates of daily discharge are not given, being too bulky even for a volume of this description. They may easily be recomputed, however, from the figures given in Water-Supply and Irrigation Papers, Nos. 15 and 16, or may be had from the permanent records of the division of hydrography. The results are given numerically by months, the daily changes being graphically expressed in the accompanying diagrams. With these facts is given a brief description of the river or drainage basin, and there is also inserted, wherever obtainable, additional information bearing upon the utilization of the water or the prospect of its future employment for industrial purposes.

METHODS.

The methods in use have been previously described in the Fourteenth Annual Report, Part II, on pages 96 to 100, and in the Eleventh Annual Report, Part II, on pages 6 to 10. The computations are based almost wholly on measurements of area of cross section and on figures of velocity obtained by use of some one of the many forms of current meter. In all of these forms of meter the water, striking against the



A. MEASURING WEIR IN GENESEE RIVER NEAR PORTAGE, NEW YORK.

B. MEASURING FROM TEMPORARY BRIDGE, GULL RIVER, MINNESOTA.

cups or vanes of a wheel, causes it to revolve with a speed which has been found to bear a definite relation to the rate of movement of the particular part of the stream in which it is immersed. This relation is ascertained previously for each instrument by causing it to advance at various speeds through still water. It is assumed that the pushing of the meter through a body of water not in motion gives a rating which can be applied when the meter is held firmly against an advancing current.

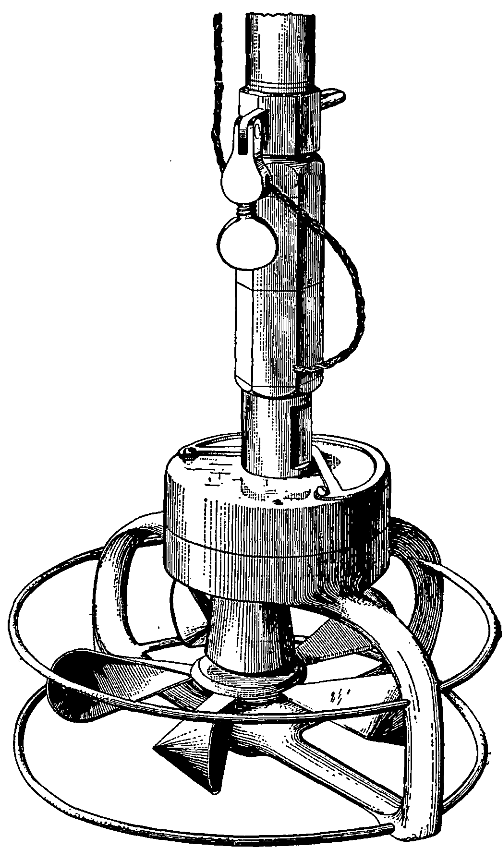


FIG. 1.—The Bailey meter, one of the earlier forms of direct-reading meters.

The various forms of meter are shown by the accompanying plates and figures, several of these being reproduced from earlier reports. As most of these meters are on the market as commercial articles, it is hardly proper to discuss their relative merits; but it is sufficient to say that most of the hydrographers employed by the Survey or acting in cooperation with it prefer the form shown in Pl. IV.

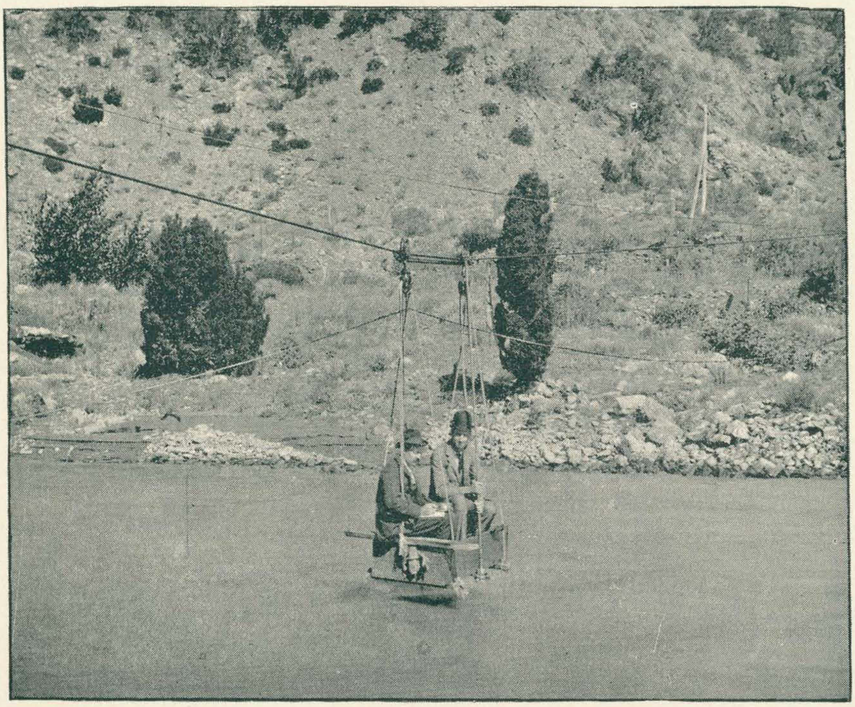
This preference is not necessarily a guaranty of special merit, but may be dependent largely upon ease of handling and of securing prompt repairs or alterations by the maker when needed for particular purposes.

The purposes of the investigation have to a large extent confined the measurements to the use of instruments of this description. It is not necessary to limit the operations to a designated point, for, there being many times as many streams and localities where results are desired as there are funds to carry on the work, it is possible to choose the places where the conditions are most favorable; on the other hand, it is not practicable to incur considerable expense to secure artificially good conditions, and therefore search must be made for a spot naturally favorable. The attempt is made, therefore, to find a place on the stream to be measured where the bed and banks are comparatively stable and where the current is neither sluggish nor extremely swift.

If the streams were mainly small—such, for example, as would be sufficient for the water supply of a large city—it might be practicable and desirable to erect a weir or short rating flume, but with the great variation in height of water and velocity on most of the important streams of the country this is out of the question. On the other hand, the various empirical formulæ based upon experimental data have not been considered practicable, as the streams vary so greatly, and the element of personal opinion or judgment as to the choice of some one or more constants affects the results widely. An illustration of a locality where a weir has been effectively used is that noted on Pl. I, *A*, erected in the Portage gorge of Genesee River and described in the report of the State engineer and surveyor of New York.

The use of floats is often resorted to in the miscellaneous measurements made during a general reconnaissance along a stream. In cases of this kind, where no permanent bench marks have been established, and therefore there is no means of determining the exact height of water, the comparatively rough approximation by means of floats is amply sufficient for all practical purposes. A rise or fall in the surface of an inch or two causes a change of discharge well within the accuracy of float measurements. For this purpose a course is chosen where the stream is nearly straight and is flowing with a comparatively uniform velocity, without sudden rapids and stretches of still water. Here a space of 100 to 300 feet is laid off as near as possible to the edge of the water, and range poles are stuck into the ground, two at each end of the measured distance. They may be both on one bank, or in the case of narrow streams on opposite sides, and are so arranged that in looking across each of the pair the line of sight passes as nearly as possible at right angles to the general current of flow. The width of the stream must be ascertained by direct measurement or by simple triangulation, and the depth by sounding. This is usually done at the upper end, middle, and lower end of the course, and the average taken to obtain the area of cross section. Floats are then placed in the water and the number of seconds they require to pass from the upper to the lower range poles is noted. For small streams these are usually sticks or chips which can be easily seen. It is possible for one man to perform the entire operation. He goes above the upper range poles and tosses a chip into the middle or side of the stream; then going down to the first set of range poles he notes the time of passage of the line of sight, and then going down to the lower end, obtains the number of seconds required for the chip to reach the second line of sight. The average velocity of the stream is usually assumed to be about eight-tenths of the average surface velocity. This operation is susceptible of great refinement; for example, by employing a number of men and by making submerged floats or loading short sticks so that they will stand nearly upright, the lower end just clearing the bed of the river and the upper end appearing above the surface. This

A.



B.

CARS USED IN MEASURING VELOCITY OF RIVER WATER.

A, Shenandoah River near Millville, West Virginia; *B*, Arkansas River at Canyon, Colorado.

involves, however, an equipment and expenditure of time which is not usually possible on reconnaissance measurements, and for great accuracy necessitates conditions which are seldom found to exist.

In using current meters, the first consideration is that of getting to the water. In the case of a shallow stream, it is practicable to wade out into it and hold the meter in position. In cold weather this is made possible by wearing various forms of rubber boots or fisherman's waders. It is, however, a clumsy operation at best, and can not be resorted to in time of flood. For larger streams the first thought is a boat. This must be held in position by anchoring successively at points across the stream, or, better, by attachment by sliding pulley to a cable suspended above the water, as shown in Pl. III, *B*. In the case of measurements made at intervals of weeks or months, it is usually impossible to maintain a boat in good condition, and in high floods a boat held in position is dangerous. For these reasons recourse is had as often as possible to some device suspended above and clear of the water, leading to the development of the suspended box or car, which, running backward and forward across the river upon a cable, can be placed in any desired position and raised or lowered.

At the selected point on the river supports and anchorage for a cable are prepared on each bank. The anchorage usually consists of logs or timbers buried deeply in the soil, the ends of the cable being securely wrapped around these and being held from slipping by suitable clamps. Between the anchorage and the river a stout piece of timber or shears is erected to a height sufficient to hold the cable above the surface of high water after allowing for a moderate amount of drop at the center. Wherever possible a stout tree is used for supporting one or both ends of the cable, or solid stumps are utilized for anchorage. At one end the cable is held by means of a strong turn-buckle, allowing any stretch to be taken up. The cables employed are usually from five-eighths to three-fourths of an inch in diameter, and are of the kind known as "standing," as distinguished from the more flexible wire ropes used in hoisting. This cable is used in spans up to 500 feet or more in length. On the cable are fastened two ordinary pulley blocks, from which is suspended a stout box about 3 feet square or of larger dimensions, according to the individual wishes of the hydrographer (see Pl. II, *A*). A stout half barrel is sometimes used, or in some cases a long box, in which two men may be seated comfortably, as shown in Pl. II, *B*. This can be pulled from one side of the river to the other by reaching up and grasping the cable overhead or by a line running from the pulleys to each shore and passing over other pulleys, the ends being brought back to the car. In some cases, where there is considerable drop in the center of the cable, the cars are raised and lowered by means of tackle on each side (see Pl. V). Sitting in the car, the hydrographer moves from point to point, sounds the depth of the water, and obtains the velocity by means of the current meter.

Wherever it happens that bridges are available these are employed, but it is often the case that the piers of the bridge obstruct the flow or the foundations catch driftwood, resulting in complications which render it impossible to make accurate measurements either of depth or velocity. Wherever a good, clear span can be had it is usually possible to make measurements with considerable accuracy and with rapidity and comfort (see Pl. III, *A*). Sometimes it is possible to erect on small, shallow streams a temporary bridge like that shown in Pl. I, *B*.

The method of holding the meter or supporting it at a given point in the stream is dependent largely on the facility for getting near the surface of the water. In the case of wading or of using the meter

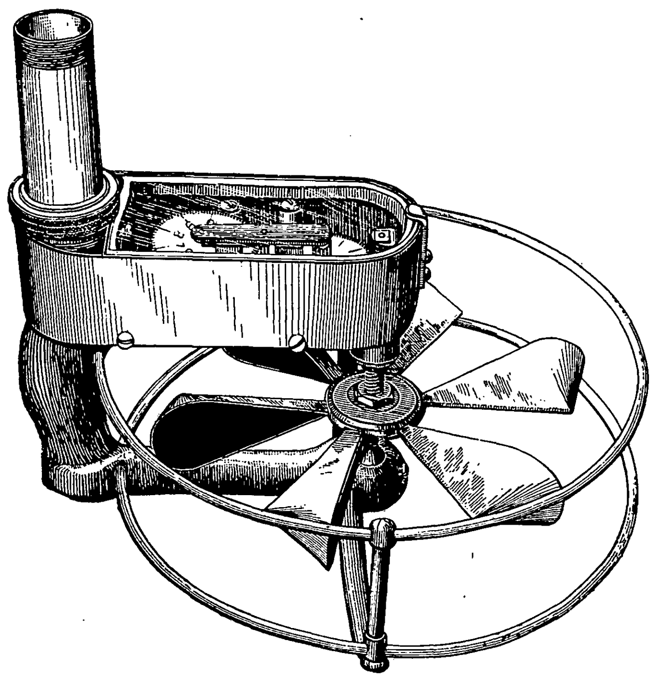
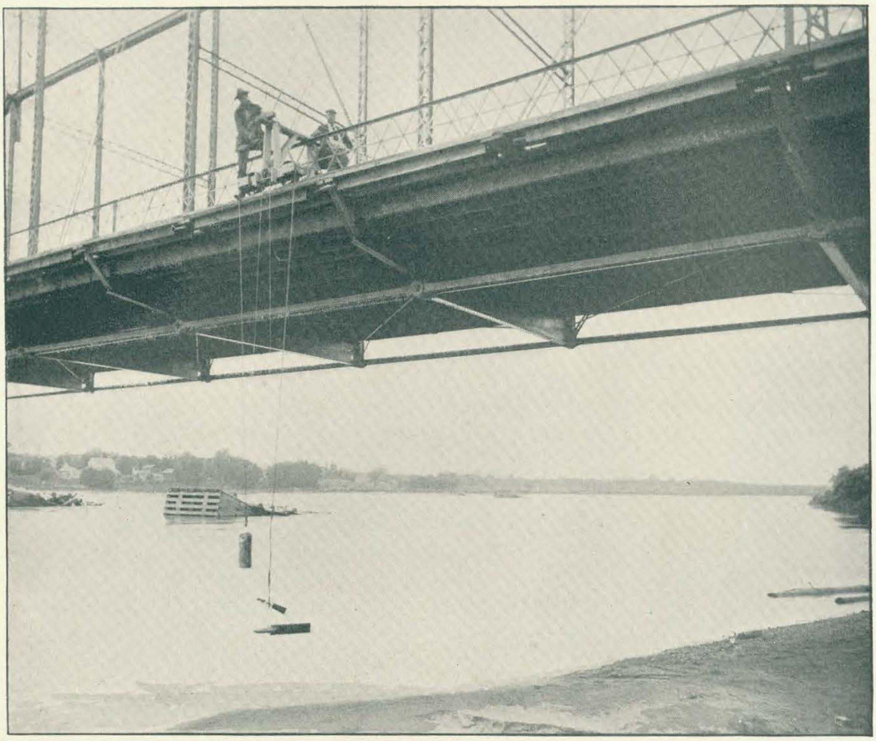


FIG. 2.—The Lallie meter, an improved form of direct-reading meters. One-half natural size.

from a low bridge, the meter is usually fastened on the end of a pole or metal rod, as shown in Pls. II and V. When the hydrographer works from a high bridge or from a car hung at some distance above the water, it is usually necessary to suspend the meter from a cord or rope of some kind. When the water is not too swift, the suspending material consists merely of the double-conducting insulated wire, which serves at the same time to make electric connection between the meter and the recording or sounding devices in the hands of the hydrographer. The ordinary cotton-covered incandescent-light cord is used for this purpose, it being found that the cotton covering does not wear so rapidly as silk covering.



A.

B.

MEASURING VELOCITY OF WATER IN MISSISSIPPI RIVER.

A. From bridge at Anoka, Minnesota, in August, 1897 (Ellis meter); *B*, Above mouth of Crow Wing River, Minnesota, in September, 1896.

For convenience of computation of the results the space across the channel of the stream is divided into short distances of known length, usually 10 or 20 feet. In case of a bridge these are indicated by making suitable permanent marks, inconspicuous if necessary, on the railing or floor beams. Where the work is done from a boat or suspended car, it is customary to place a tagged wire a short distance above the cable and parallel with it. For this purpose the ordinary twisted barbed-fence wire has been found most desirable, as the tags can be fastened firmly so that they can not slip from side to side, and barbed wire is less likely to be stolen than the ordinary smooth form. The difficulty in putting this up is usually more than compensated by its permanence. The tags used consist of small pieces of metal, 3 to 4 inches in width, usually deeply notched or cut in such conspicuous forms as to give at a glance the distance from the initial point. This latter is usually some easily identified object on shore, such as a stone monument, a permanent stump, or a bridge pier. Soundings are made at each tag, and at intermediate intervals, if necessary, the depth being measured by a pulley or by a small stout line provided with a lead sinker. Velocities may be observed at each tag, or at every second or third in case of uniform cross section.

When the velocity of the water is considerable, as, for example, over 5 or 6 feet per second, the sounding line and meter are apt to be swept backward down the stream. In such cases it is often necessary to provide an additional stay line. This consists of a second cable or smooth wire stretched across the stream at a distance of from 50 to 100 feet above the bridge or cable from which measurements are made. A small twisted wire clothesline or sash cord may be used for this purpose. It is anchored at both ends and supported in a manner similar to that of the main cable. On this smooth wire is a small pulley, which travels freely from side to side of the river, and from the pulley there is a small flexible cord leading diagonally downstream. This may be attached to the end of the sounding rod, holding it in position, or a fine wire may be similarly fastened near the head of the meter, so that when the instrument is lowered it is held from being carried backward or tilted by the force of the current. The stay line usually adjusts itself as the hydrographer moves from one side of the stream to the other.

Some of the meters in use have self-registering devices, the dials being read before and after the instrument is immersed. The kind, however, most generally used by this Survey is provided with a simple make-and-break circuit device, this being connected by suitable wires to a telegraphic sounder or some form of recording apparatus. Nearly all engineers taking up work of this kind at first prefer the somewhat elaborate and cumbersome instruments which record the readings upon dials, some of these giving the time in seconds as well as the number of revolutions of the meter wheel. The more experienced men, however, prefer to reduce their equipment to the simplest possible form, and, instead of reading dials, count the clicks or noise made by the miniature sounder, keeping the time by watching the second hand of an ordinary watch while it marks off fifty seconds. Many forms of stop watch have been tried, but these are so liable to injury or to get out of order and repairs are so costly, that, as a rule, their use is soon abandoned in favor of the watch ordinarily carried. The form of sounder usually preferred is made up of a small hard-rubber battery cell with zinc pole passing through the rubber stopper. This cell is about 1¾ inches wide, 1¼ inches thick, and 2 inches high. It is charged each time by inserting from 2½ to 3 grams (or 38 to 46 grains) of mercuric bisulphate, the cell then being filled with water. After using it may be washed out. This cell is placed in a small sole-leather case, having on the outside a very small electro-magnet with armature set upon a spring, this device being protected by a metal cover about 1½ inches in diameter. The whole instrument weighs only a few ounces, and when attached to the end of the double-conducting electric cord does not add appreciably to the weight. The instrument being so small and stout, it is possible for the hydrographer, when working from bridges,

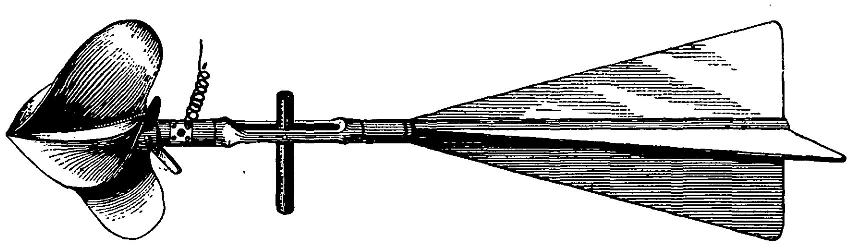
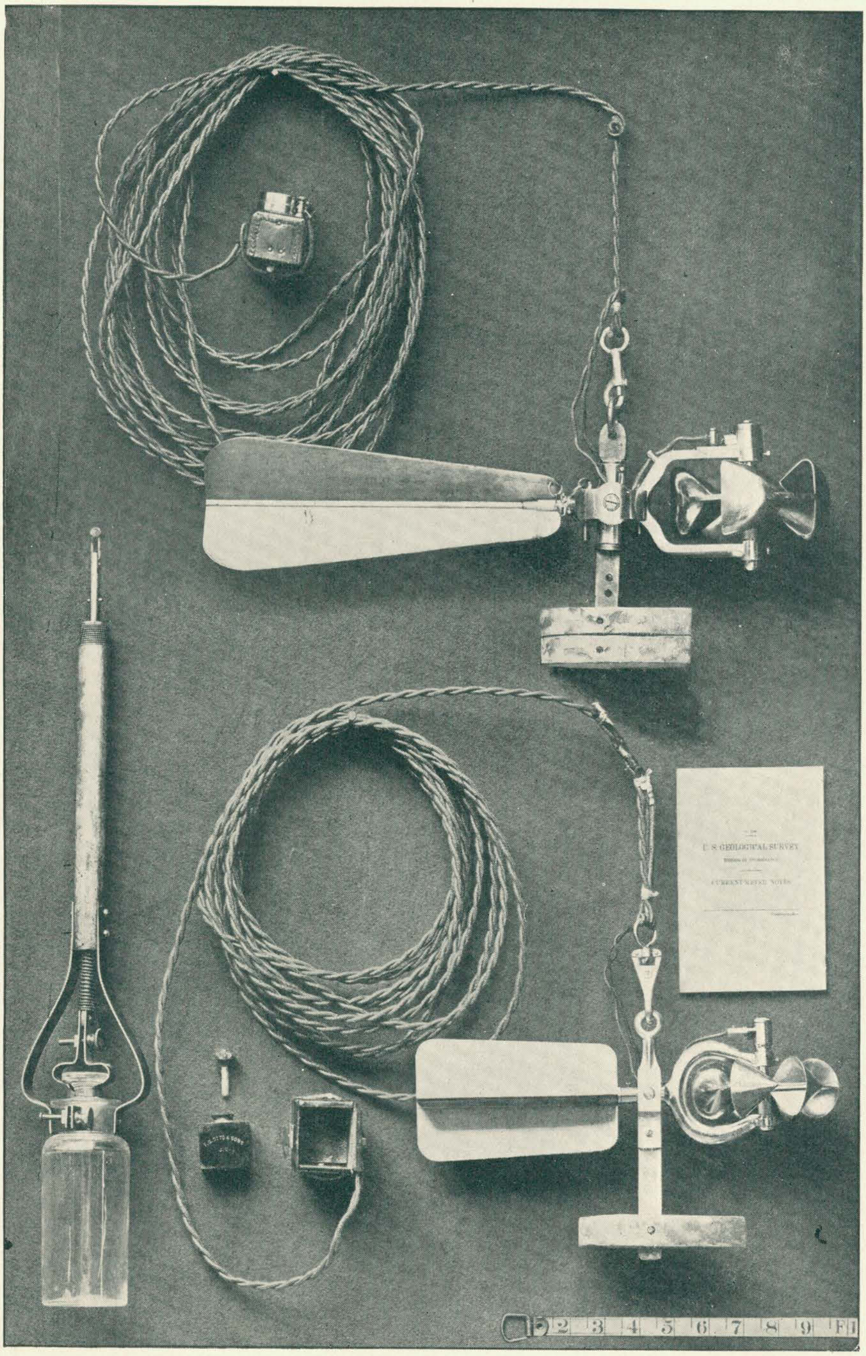


FIG. 3.—Haskell electric current meter, large form.

to toss the end of the wire around beams or braces, and thus to swing his meter along around piers and projections without the necessity of disconnecting the wires.

On Pl. IV are shown two of the electric meters in common use by this Survey in its river measurements. The upper one is the ordinary Price electric meter, made by W. & L. E. Gurley, Troy, New York, and the lower a smaller modification of the same instrument, made especially to fill the needs of this Survey. With each of these instruments is shown a coil of common cotton-covered double incandescent electric-light wire, which serves to support the instrument and to conduct the electric current. In each case the cord terminates at the battery and buzzer in the upper portion of the picture, this being shown complete and closed for use. On the lower half of the plate the leather battery box is shown open, with the cell removed, and slightly to the left and above this the zinc pole.

On the lower left-hand side is shown a device for taking water samples, consisting of a clutch holding a wide mouthed glass bottle. This is so arranged that the device can be screwed to the end of ordinary gas pipe and lowered into the stream to the desired depth. The stop-



PRICE ELECTRIC CURRENT METERS, WITH BUZZERS.

per of the bottle is then drawn by pulling a cord which runs through the pipe; the bottle being filled immediately, the stopper is forced back into position by the spring shown above the stopper. On being withdrawn from the water the bottle, with the stopper in it, may be quickly removed from the clutch by loosening the set screws, and another empty bottle, sterilized if necessary, may be immediately inserted. Other meters in use are illustrated by figs. 3 and 4.

The results of stream measurements are stated in cubic feet per second, or *second-feet*, as the term is abbreviated; therefore the linear measurements are made in feet, and the results of the use of the current meter, primarily in revolutions per second, are converted by the rating table prepared for each instrument into velocity in feet per second. If the tags at the river station are 10 feet apart, the average depth as

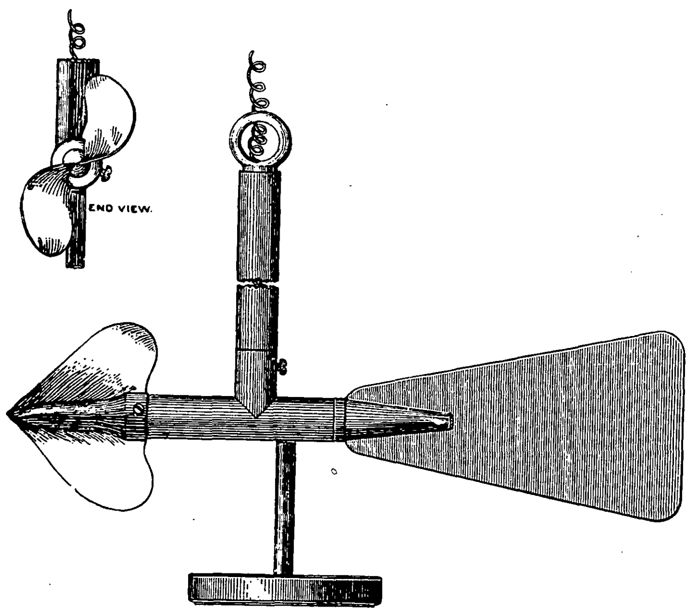


FIG. 4.—Haskell electric current meter, small form. One-fourth natural size.

obtained by sounding is multiplied by 10 feet, giving the area in square feet of this portion of the section, and this in turn is multiplied by the average velocity as ascertained by use of the current meter. The total of the fractional discharges thus obtained is taken as the total discharge, and this latter divided by the total of the fractional areas gives the mean velocity in feet per second. In computing the discharge for the end or shore portions of the cross section of a stream, special attention must be paid to sluggish or back water and due allowance made for the shape of the banks.

The result of any one discharge measurement gives simply the quantity of water passing at that time and place. In order to estimate the amount passing day by day it is necessary either to make daily measurements or to compute what these should be by assumptions based on the height of the water. In the case of the ordinary unnavigable stream, where the banks and bed are not being rapidly eroded and sediment is not being deposited, it is safe to assume that for a given height of water the discharge is fairly constant, although, as a matter of fact, when the river is rising there may be more water passing downstream at a given arbitrary height than when falling. This difference, however, is usually negligible. If, therefore, the quantity of flowing water can be ascertained for each small interval of rise of the stream, it is practicable to construct a table showing for any given height the amount flowing. This is what is actually done in the case of each regular station, and, in addition, the height of water day by day or morning and evening is recorded, the estimated quantity in the river being taken from the table and set opposite the corresponding figures for height.

At some favorable point near or a short distance above or below the place where the measurements are made, a gage is erected and readings are taken at regular intervals. Where an observer can be found whose occupation or duties are such that he can readily examine the gage, it is customary to have these readings made twice a day; if there are no houses in the vicinity and a trip of a mile or more must be made for each reading, this may be made once a day, or even in some cases only every other day, except during times of flood or rapid change. The readings on the gage are noted in a small book and are copied upon the postal cards sent to the field men or the local office at the end of each week.

The gage may consist of a simple vertical scale divided conspicuously into feet and tenths and nailed to a pier or post in the water; or it may be an inclined stick of timber following the general slope of the bank and marked by means of a level to equivalent vertical feet and tenths. This latter form, while more expensive and difficult to install firmly, has the advantage that the readings are always at the edge of the water and are easily made. When measurements are made from a bridge, in place of the vertical scale, or in addition to it if it can not be easily seen, there is sometimes put in position a long flexible wire with a weight at the lower end. For the wire, galvanized sash cord is employed. This passes over a pulley and is allowed to run out until the weight just touches the surface of the water. The cord above the pulley extends horizontally, and the handle at the end is so arranged that it can be placed against a horizontal scale located so as to give the same reading as the gage on the pier. As soon as the weight touches the water the reading is made. The wire is then pulled back horizontally, hoisting the weight up against the bottom of the bridge, the handle being usually locked to some brace so that the device can not be disturbed, the wire being usually out of sight or difficult of access.

MEASURING VELOCITY OF WATER FROM SUSPENDED PLATFORM, ON RUM RIVER ABOVE MILL POND AT ANOKA, MINNESOTA, AUGUST, 1897.

As all gages are liable to change, injury, or even destruction, during times of high flood, it it essential that some permanent mark or marks be placed on the ground and connected by careful lines of level, so that the gage may be tested or restored. In the case of inclined gages, frost is liable to alter the relation of the readings, and the wire gages may stretch. The bench marks used may be any solid objects easily found, as, for example, a mark on the stone foundation of a building or bridge pier, a spot smoothed off on a rock, or even a notch cut in a solid stump or log. From season to season it is desirable by means of a Wye level to verify the measurements previously made.

The relation between the quantity of water flowing in a stream and its height from some arbitrary gage being once established, it has been found that this remains fairly constant through a number of seasons. Measurements are made, however, at short intervals to verify this fact or to modify the rating table in case of slow progressive changes. After an unusual flood it is not uncommon for the conditions to be so greatly changed that a new rating table is necessary. During the period for which the rating table is constructed its values are applied to the record of height, giving a statement of the daily discharge. These figures of daily flow are not published in the following report, but in their place are given the maximum and minimum for each month and the average, this being stated in cubic feet per second. The total for the month is also given in *acre-feet*, that is, in quantities equivalent to the given number of acres 1 foot in depth, 1 acre-foot being equivalent to 43,560 cubic feet. This total monthly flow is also expressed in terms of the area drained, that is, in depth in inches, assuming that the water came from all parts of the catchment basin, and in cubic feet per second per square mile of tributary territory. The daily fluctuations are also shown in diagrams, since these give at a glance and in the most concise manner the character of the stream.

RATING THE METERS.

The relation between the revolutions of each meter and the speed of the water is a matter which, as before stated, must be determined for each instrument and tested at short intervals while in use. In order to run the meter at uniform velocities through still water, it is necessary that the instrument be supported on some sliding object. Several devices have been adopted, two of which are illustrated in the accompanying plate (Pl. VI). In the view marked *A* is shown the apparatus for rating meters at Chevy Chase, Maryland. This consists of the platform, about 200 feet in length, built along the edge of a small deep pond whose waters are practically stagnant. On the outer edge of this platform are small iron rails, on which is placed an ordinary mine car or truck, with outrigger such that the meter can be held vertically over the water and immersed to the desired depth. On the platform a measured course of 100 feet is laid off and the car is pushed by hand, care being taken to pass over every 10 or 20 feet in a uniform number of seconds, so that the same velocity may be maintained from start to finish. In the view a meter is shown suspended from the car on the right-hand side, and another meter in the background against the door of the house in which the car and smaller tools are stored.

In the view *B* is shown the apparatus used at Los Angeles, California. This consists of a cement-lined trough along the edge of the reservoir. Above this is stretched an iron cable, suitably supported,

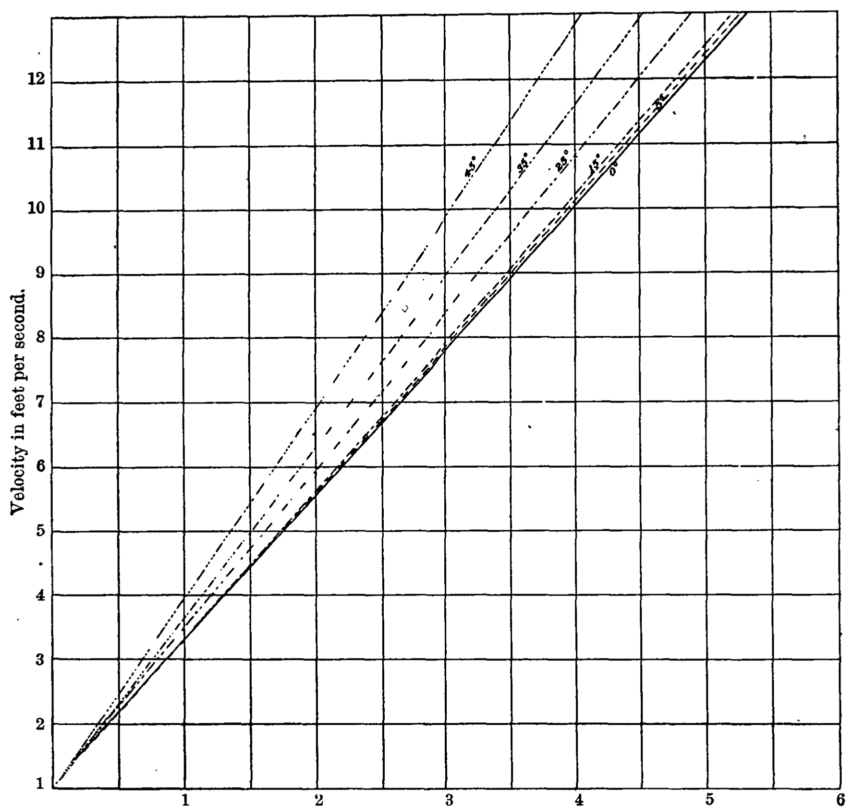


FIG. 5.—Results of rating meters when inclined at various angles.

and on the latter is a trolley with two wheels, by means of which the meter is supported beneath the surface of the water.

By means of such a device the meter is propelled through the water over a measured course, usually of 100 feet, for 20 or more times in succession, the speed varying from less than one-half foot per second up to 6 or 8 feet per second, or even more, the number of revolutions per hundred feet and the number of seconds being noted. There is thus obtained the feet per second and the revolutions per second at different speeds. When these data are plotted upon cross-section

A.

B.

APPARATUS FOR RATING METERS.

A, At Chevy Chase, Maryland; *B*, At Los Angeles, California.

paper, it is found that for higher velocities the points lie in nearly a straight line, but for lower velocities there is a tendency for the revolutions per second to decrease, owing to the slight friction in the instrument. A broken or somewhat curved line is therefore sketched for the lower velocities, and from this curve values are taken to make the arbitrary table of the relation between revolutions of the meter per second and speed of the water. This table is found to be fairly constant until the meter becomes injured or the friction notably increases by the wearing away of the more delicate points of the bearings.

INCLINATION OF THE METER.

In using current meters, especially those suspended from a cord or line, it is frequently the case that in swift water the instruments are swept backward and tipped at an angle from the horizontal, either momentarily or for a considerable interval of time. In order to obtain data concerning the reliability of results under such conditions, a series of tests were made at the rating station at Chevy Chase, Maryland. A small Price current meter was used, held rigidly at various angles as measured from a horizontal line. The results are shown in the accompanying table, and graphically on the diagram, fig. 5.

In the first case, at zero, the meter was held firmly parallel to the surface of the water and caused to move through the water at uniform rate, the speed per second and revolutions per second being ascertained as in the ordinary operation of rating the instrument. Various velocities were used and figures obtained from which a rating table was constructed graphically. The meter was then inclined at an angle of 5 degrees and the operations repeated, obtaining a complete rating table for the meter when inclined for this angle. The same series of observations were made at inclinations of 15 degrees, 25 degrees, 35 degrees, and 45 degrees. The various lines showing the relation between velocity per second and revolutions per second are shown on the accompanying figure (fig. 5), each being marked with the corresponding angle. On examination of this it appears that the divergence of the rating is relatively slight, even when the meter is inclined at angles of from 10 to 15 degrees, but increases with considerable rapidity for higher angles of inclination. The rating tables derived from these lines are shown below in condensed form. At a velocity, say, of 4 feet per second the revolutions per second at zero and at 5 degrees are the same, 1.76; at 15 degrees are slightly less, 1.74; at 25 degrees are notably less, 1.62, decreasing still more for 35 degrees and 45 degrees.

Rating observations with meter inclined at different angles, at Chevy Chase, Maryland, June 30, 1898.

Velocity (feet per second).	0°.	5°.	15°.	25°.	35°.	45°.
	Revolutions per second.	Revolutions per second.	Revolutions per second.	Revolutions per second.	Revolutions per second.	Revolutions per second.
1......	0.42	0.43	0.43	0.39	0.39	0.35
2......	.86	.87	.87	.80	.77	.69
3......	1.31	1.31	1.30	1.21	1.15	1.03
4......	1.76	1.76	1.74	1.62	1.52	1.37
5......	2.21	2.20	2.17	2.03	1.90	1.70
6......	2.65	2.64	2.61	2.44	2.28	2.04
7......	3.09	3.08	3.04	2.85	2.65	2.37
8......	3.54	3.52	3.48	3.26	3.03	2.71
9......	3.98	3.96	3.91	3.67	3.41	3.05
10......	4.43	4.40	4.35	4.08	3.78	3.39
11......	4.87	4.84	4.78	4.49	4.16	3.73
12......	5.32	5.27	5.22	4.90	4.53	4.07

At an angle of 5 degrees, with a velocity below 4 feet per second, the meter apparently revolves a trifle faster than when horizontal. In other words, at moderate speeds and at low inclination this form of current meter may indicate a slightly higher velocity than actually exists. At high speeds, however, and a high inclination the reverse is the case, as the meter turns somewhat more slowly than when held perfectly parallel to the current. When depressed beyond 25 degrees the resistance to the current approaches that offered by the tail and the meter swings about in a position nearly at right angles to the current, causing the head to approach the normal or zero angle.

ORDINARY FLOW OF A STREAM.

The question is frequently asked: What is the ordinary or usual flow of a given stream? This question, at first sight simple, is, upon further consideration, found to be susceptible of a variety of answers. By examining any of the numerous diagrams of daily discharge published in this and preceding volumes it will be seen that the fluctuations from day to day and from year to year are so great that the stream can scarcely be said to flow with regularity for any considerable period. An exception to this may occur during the summer droughts, when the river gradually shrinks or maintains its flow through deep-fed springs or seepage. For this season there may be said to be an ordinary flow, but this amount is not applicable to the whole year.

In the computations of discharge the average flow has been estimated by months, and from this by years; but this average does not fulfill the conception of ordinary or usual flow, since it is notably increased by floods. An arbitrary definition has been suggested in Rankine's Civil Engineering.[1] According to the rule there given the discharges, as observed daily, are arranged in the order of their magnitude, without regard to dates. For a full year there would thus be 365 figures, arranged in order from the smallest to the largest. The list thus arranged is divided into an upper quarter, a middle half, and a lower quarter; or, in other words, the first 91 figures are taken out to represent low-water conditions and the last 91 to represent flood conditions. The average of the middle half is taken, and is used in place of each of the 91 high, or flood, values. The mean of the whole list is thus taken as the ordinary or average discharge, exclusive of flood waters. It is claimed that the ordinary discharge, as computed in this manner for a number of streams in hilly districts, has ranged from one-third to one-fourth of the mean discharge, including floods.

In order to exhibit the results of this method of treatment of the figures of a given discharge, a diagram, fig. 29, page 124, has been prepared. This should be compared with the diagram of discharge arranged in sequence of dates and given in fig. 28, on page 123. To prepare this figure, the table of daily discharges has been examined. From this it appears that for 11 days in 1897 there was a flow of less than 4,500 cubic feet per second; for 11 days additional the discharge was between this amount and 4,800 second-feet; for 10 days additional the discharge was between this latter amount and 5,400 second-feet, and so on, there being near the end of the list 2 days during which the discharge was 48,600 second-feet, and, finally, 4 days in which the flow was nearly 50,000 second-feet. Plotting these quantities, there is obtained a somewhat irregular curve, having on the left-hand side the duration and length of the low-water flow, the line indicating this gradually rising to exhibit the extent of the floods. Vertical lines have been drawn at the 91st day and at the 274th day, the middle half, or 183 days, being included between these. The horizontal line drawn between these vertical lines indicates the average discharge for the 183 days, this average being 22,889 second-feet. The horizontal line beneath this, toward the right, indicates the ordinary flow as obtained by the rule mentioned above, in which the average, 22,889, has been substituted for the days during the last or flood quarter of the year. This ordinary flow is 18,894 second-feet. In comparison with this is to be noted the average flow for the whole year, 32,132 second-feet, as given on page 127, this being indicated by the upper horizontal line. In the case of streams rapidly fluctuating in quantity a diagram of this character is of advantage in showing at a glance the number of days of drought or high water, but for most purposes it is considered that the diagram showing the fluctuations as they occur has greater value.

[1] Manual of Civil Engineering, by William John Macquorn Rankine, London, 1885, p. 698.

ACKNOWLEDGMENTS.

Thanks are due to a number of individuals and corporations, both private and public, for assistance rendered in bringing together the data given in this report. This material is of such composite character that it is impossible to assign due credit for each item. In particular, however, it should be pointed out that the first portion of the report, that having to do with the water-power streams of Maine, has been prepared by Prof. Dwight Porter, of the Massachusetts Institute of Technology, Boston, Massachusetts; and the last part, that relating to the San Bernardino Valley, by Mr. J. B. Lippincott, of Los Angeles, California. The principal parts of the text of the intermediate portion have been brought together by Mr. Cyrus C. Babb, while the data have been compiled from material sent in by resident hydrographers and others, the work in the office having been performed by various assistants. In particular, mention should be made of the services of Mr. Gerard H. Matthes, hydrographic aid, in computations, of Mrs. Jennie T. Davis, statistical expert, in tabulation, and of Miss Flora Knowlton, in preparing manuscript.

The field work has in general been under the immediate supervision of skilled engineers, some of whom are connected with educational institutions, and others in private practice. A list of these hydrographers is as follows:

Arizona: W. A. Farish, civil engineer, Phœnix; Albert T. Colton, civil engineer, Florence.

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

Colorado: Filmore Cogswell, succeeded by A. L. Fellows, deputy State engineer, Denver.

Georgia and Alabama: Prof. B. M. Hall, civil engineer, Atlanta.

Idaho: F. J. Mills, State engineer, Boise.

Kansas: W. G. Russell, civil engineer, Russell; Prof. E. C. Murphy, State University, Lawrence; Prof. O. P. Hood, Agricultural College, Manhattan.

Montana: Roe Emery, Bozeman.

Nebraska: Prof. O. V. P. Stout, State University, Lincoln; Charles P. Ross, civil engineer, North Platte.

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

New Mexico: P. E. Harroun, civil engineer, Santa Fe.

North and South Carolina: Prof. J. A. Holmes, State geologist, Chapel Hill.

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

Utah: Samuel Fortier, civil engineer, Corinne.

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

Washington: Sydney Arnold, civil engineer, North Yakima; A. Judson Adams, civil engineer, Port Angeles.

Wyoming: Clarence T. Johnston, civil engineer, Cheyenne.

As in past years, cooperation has been had with various organizations and railroad companies, as noted on pages 14 and 15 of Part IV of the Eighteenth Annual Report. In particular reference should be made to the following:

In California, Mr. William Hood, chief engineer of the Southern

Pacific Company; Mr. Walter James, chief engineer of the Kern County Land Company; Mr. H. N. Savage, chief engineer of the San Diego Land and Town Company; Mr. Burt Cole, chief engineer of the South Antelope Valley Water Company; and Mr. H. F. Parkinson, water superintendent of the San Gabriel canals. In the preparation of the data regarding Southern California Mr. Lippincott was materially assisted by Mr. Z. O. Smith, of Highlands; Mr. S. Williams, secretary of the Redlands Domestic Water Company; Mr. H. H. Sinclair, manager of the Southern California Power Company; and Messrs. Adolph Wood and H. B. Hedges, of the Arrowhead Company, as well as by many others who contributed information.

In Colorado the State engineering department has cooperated fully and assistance has been rendered by the Denver and Rio Grande Railroad, the Union Pacific, Denver and Gulf Railway, and the Colorado Midland Railway. Thanks are also due to the Fort Lyons Canal Company, to Messrs. J. H. Hodgson and S. W. Cressy, water commissioners, to Mr. Porter J. Preston, and to various employees of the Denver and Rio Grande Railroad Company.

In Georgia and Alabama Prof. B. M. Hall and Mr. Max Hall, resident hydrographers, have been assisted by transportation furnished by the following railroads: Atlanta, Knoxville and Northern Railway; Seaboard Air Line; Atlanta and West Point Railroad; Western Railway of Alabama; Georgia Railroad; Macon, Dublin and Savannah Railroad; Florida East Coast Railway; Southern Railway; and the Western and Atlantic Railroad.

Prof. W. S. Yeates, State geologist of Georgia, has paid the observers at Macon, Oakdale, Westpoint, Resaca, Canton, Carey, Molina, Carleton, and Almon, Georgia, and Seaboard Air Line bridge on Savannah River in Georgia, near Calhoun Falls, South Carolina.

Dr. Eugene A. Smith, State geologist of Alabama, has paid observers at Riverside and Milstead, Alabama. Col. S. M. Carter (now deceased) had the gage at Carters, Georgia, maintained without charge, and his executor has continued the same arrangement. The gage heights at the following stations have also been furnished without charge: Chattanooga, Tennessee, by Mr. L. M. Pindell, of the United States Weather Bureau; Tuscaloosa, Alabama, by Messrs. R. C. McCallo, jr., and W. S. Wyman, jr., of the Corps of Engineers, U. S. A.; Lock No. 4, Lock No. 5, and Wetumpka, Alabama, on Coosa River, by Major Mahan and Mr. D. M. Andrews, of the Corps of Engineers, U. S. A.; Augusta, Georgia, on Savannah River, by Mr. H. A. Davidson, city engineer, and Mr. C. A. Maxwell, superintendent of Augusta Canal.

Courtesies have been extended by Messrs J. B. Marbury, D. Fisher, and F. P. Chaffee, and other officials of the United States Weather Bureau, and by the commisioner of agriculture and the secretary of state of Georgia.

In Montana assistance has been rendered by the Northern Pacific Railway and the Great Northern Railway. The Missouri River Commission have also furnished data, and the Helena Dam and Electric Company, at Canyon Ferry, have given access to their gage readings.

In New Mexico transportation has been furnished Mr. P. E. Harroun by the Atchison, Topeka and Santa Fe Railway and by the Denver and Rio Grande Railroad.

In Virginia and West Virginia assistance has been given to Prof. D. C. Humphreys by the Chesapeake and Ohio Railway Company, and by the Norfolk and Western Railway Company. Thanks are also due to Mr. F. B. Isaacs, assistant engineer of the Chesapeake and Ohio Railway, for profile along James River and other data.

In Washington especial thanks are due to Mr. Thomas Cooper, western land agent of the Northern Pacific Railway, for personal assistance, and to the railway company for transportation.

In Wyoming assistance has been rendered by Mr. Frank Trumbull, receiver of the Union Pacific, Denver and Gulf Railway, and by Mr. J. W. Lacey, of Cheyenne, attorney for the Union Pacific Railroad.

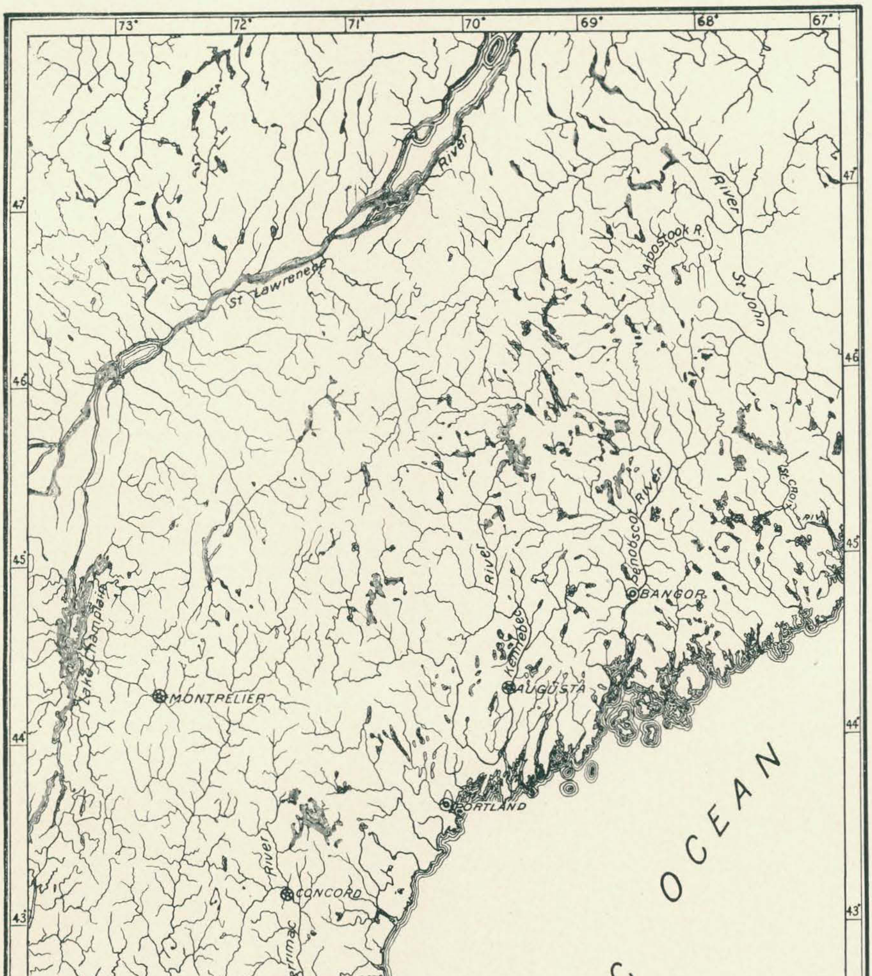
WATER-POWER STREAMS OF MAINE.

By Dwight Porter.

GENERAL STATEMENT.

The following report relates to St. Croix, Penobscot, Kennebec, Androscoggin, Presumpscot, and Saco rivers, the principal water-power streams in southern Maine. The relative position of these streams is shown on the map, Pl. VII. The St. John, which drains the northern portion of the State, but which lies largely in an inaccessible, sparsely settled region, and appears to possess no water powers demanding present attention, was not examined.

The object sought in the investigation has been in particular to obtain all accessible data bearing upon the volume of the rivers and the yield of their watersheds, and furthermore to supplement and bring up to date such information regarding the fall of the principal streams, their actual utilization, and their facilities for further development as has been presented by other writers in previous reports. Two such reports have appeared in the past: The Water-Power of Maine, prepared by Walter Wells, in accordance with an order from the legislature of the



MAP OF NEW ENGLAND RIVERS.

State, and published in 1869; and a report by Prof. George F. Swain, forming a portion of the general reports on water power contained in Volumes XVI and XVII of the Tenth Census (1880) of the United States. Each of these valuable reports was very complete in detail, and I have frequently drawn upon them for information presented in the following pages, where it seemed advisable to do so. Even since the later of them, however, very great increase has taken place in the use of water power upon the Maine rivers, and data of much importance as to fall and discharge have been accumulated which were not then in existence, the principal features of which it has been endeavored to present here.

The means at command for this work were believed not to warrant so detailed an examination of the rivers as would suffice for a complete description of the improvements and the undeveloped falls upon them, and it was rather in the nature, therefore, of a reconnaissance. The principal points on the streams described, with the exception of the St. Croix, were visited in August, 1896, by an assistant, Mr. Howard E. Smith, a recent graduate of the Massachusetts Institute of Technology, and further examinations were made at sundry points by the writer in the summer of 1897. From notes thus obtained, based on direct observation and on interviews with manufacturers, engineers, and others, and from information obtained by correspondence, these reports have been prepared. Some discrimination as to accuracy should evidently be observed between the various data here offered. While the writer has sought to use due care in accepting and presenting facts and figures, it was not possible to obtain all of equal accuracy or precision. Figures regarding flow and elevations have been treated with special care both in gathering, analyzing, and discussing them, and by much correspondence every effort has been made to free them from all ambiguity. On the other hand, statements as to the position and available fall of undeveloped water privileges, and as to the power in use at those developed, and much other information obtained of a general or descriptive nature, it was not practicable to verify, and reliance had to be placed upon seeking the facts from those presumably most competent to give them. Figures as to the horsepower in use at mills are particularly incomplete and uncertain. Where given by the manufacturer or his superintendent they probably most often refer to the nominal power of the turbines installed, running under the usual fall and at full gate; but often, in the case of old wheels, even the nominal horsepower is not well known, and in some cases there was a refusal to state the power used, a difficulty for which there was no remedy. Nevertheless, reasonably approximate statements upon these matters, if properly used, are believed to have value, and have been presented.

DATA OF STREAM DISCHARGE.

As might, perhaps, have been expected, comparatively few records of actual stream measurements have been found, although no pains were spared to discover them. For the Penobscot no measurements could be learned of, excepting two isolated ones made in low stages in the autumns of 1884 and 1886 by Prof. George H. Hamlin. On the Kennebec tolerably complete and accurate measurements of the flow past Waterville have been recorded since the beginning of 1893; and on the Cobbosseecontee, a tributary of the Kennebec, records of the monthly flow since June, 1890, were obtained. A considerable record of the flow of the Androscoggin at Rumford Falls, extending over about three years, from May, 1892, to May, 1895, was also secured. The most complete set of figures for flow acquired for any of the streams was for Presumpscot River, at the outlet of Sebago Lake, the average monthly discharge having been recorded continuously since January, 1887. For the Saco substantially no figures as to actual flow could be found.

With few exceptions the data for flow here given are based either upon the computed discharge through gates, the capacity of which under varying conditions of head and opening has been independently determined, as in the case of the outlet of Sebago Lake, or upon the computed discharge over a dam, treated as a weir, or upon the computed flow through the turbines, which, if properly rated, may serve very well as water meters, or upon combinations of these methods, usually subject to sundry corrections for one reason or another. In no case are the figures for continuous records of flow based upon observations of height of water at a known cross section of river for which, by instrumental means, the curve of discharge has been determined. In so far as they are based upon observations upon well-rated gates or turbines they would seem to be satisfactory. But when based, as most frequently on large streams, in part at least upon the flow over the crest of a dam, uncertainty often results, partly from the lack of knowledge as to the proper weir coefficient to apply in each particular case, and more especially, where flashboards are in use, from the irregular, varying, and perhaps unknown condition of the actual crest afforded by the flashboards, which may not only allow a large leakage at all times, but are likely in high water to be carried away altogether. Moreover, because of the varying draft during the day upon the storage in the mill pond at the point in question, in the dry season, and the irregularities in the receipts of water stored at points farther upstream, it is difficult to choose a time, for the single observation ordinarily made, which shall closely give the average flow for the working hours or for the twenty-four hours. For all these reasons the results of the ordinary measurements are to be accepted only as reasonable approximations to the average flow which they seek to represent, and subject at times to considerable error. They are, nevertheless, of very great value, and it is only by means of them, in the absence of more accurate figures, that plans for extensive water-power development can be safely and economically matured.

In presenting such figures for flow as have been obtained, the results are first given in complete detail in average cubic feet per second, and usually also in the equivalent values in inches on watershed per month and in average cubic feet per second per square mile of watershed. In succeeding tables the flow is averaged by months, and finally, wherever warranted, the attempt is made to deduce the important and interesting relation between rainfall and run-off. To derive this relation properly we need to know three things—the yield of the streams, concerning the measurements of which I have already spoken, the area of the drainage basin above the point considered, and the proper rainfall to charge against the basin. The determination of the area of the drainage basin is subject to the inaccuracies and incompleteness of detail of existing maps of the State, which in the case of the smaller basins may doubtless often lead to errors in result exceeding 10 per cent. In deciding upon the rainfall to be assigned to a given basin difficulty is encountered from the paucity of stations and incompleteness of their records. Those records which are complete and long continued are mainly for stations rather near the coast, and are far from being certainly representative of the river basins as a whole, stretching far up into the elevated and mountainous interior of the State. The results obtained, however, are of sufficient accuracy, it is believed, to be of interest and value.

LAKE STORAGE.

Perhaps no single feature in connection with the flow of the streams, as affecting their value for power, is of more importance than the effects brought about, or possible to be brought about, in maintaining the dry weather volume by means of artificially controlled storage in the lakes. Maine is a splendidly watered State, and includes within the watersheds of her rivers almost innumerable lakes and ponds, generally capable of easy control, and many of them constituting magnificent reservoirs. The Rangeley chain, covering 90 or more square miles, at the head waters of the Androscoggin; Sebago Lake, with its 50 square miles, supplying Presumpscot River; Moosehead Lake, comprising 120 square miles, the largest inland body of water in New England, and forming the direct source of Kennebec River; Chesuncook and other lakes in the upper basin of the Penobscot; and the chains of lakes feeding the St. Croix, are famous examples. But, in addition, scattered over the State, are great numbers of smaller lakes, ranging in surface area from 20 square miles downward to a few acres, and storing in the aggregate a vast volume of water. Wells, in The Water-

Power of Maine, p. 29, credits the six basins alone which form the subject of this report with between 1,100 and 1,200 lakes and ponds of sufficent size to have been represented on the maps, the combined water surface of these being nearly 1,700 square miles, or between 7 and 8 per cent of the total drainage area of the streams, as follows:

Lake area tributary to six principal rivers.

River.	Number of lakes.	Aggregate water surface.	Drainage area of river.
		Sq. miles.	*Sq. miles.*
St. Croix	61	150	1,630
Penobscot	467	585	8,500
Kennebec	311	450	6,330
Androscoggin	148	313	3,700
Saco	109	84	1,750
Presumpscot	45	97	700
Total	1,141	1,679	22,610

What is possible of attainment in exceptionally favorable conditions through artificial control, for even a very considerable drainage area, is well illustrated in the case of Sebago Lake, which covers nominally 50 square miles and drains 470 square miles. Comparing the flow in the outlet of this lake with that in Penobscot River, a stream fed also by many and large lakes, but which are to but little extent controlled with reference to water-power interests, we find that while the dry-weather flow of the Penobscot at Orono sinks in very low stages to about one-third of a cubic foot per second per square mile of drainage area, the average flow during the working days of the month from Sebago Lake has in no month in ten years fallen below seven-eighths of a cubic foot per second per square mile; for three-fourths of the entire period it has not varied more than 20 per cent either way from an average of $1\frac{3}{4}$ cubic feet per second per square mile; and in an especially favorable year the entire range of flow has been not more than 5 per cent either way from the mean for that year.

While the results already obtained from increasing and controlling the storage of the lakes have been of much value in maintaining the dry-weather flow of the streams, they are small compared with what might be realized from complete, systematic, and cooperative control. One serious difficulty in the way of securing the best results has been the nearly direct opposition of interests between lumbermen and manufacturers as regards the release of stored water from the lakes. The lakes fill in the spring, and in order to maintain along the rivers the uniformity of power which is generally required the stored water should be released in gradually increasing amount until the succeeding winter or spring, so as to compensate for the gradually failing yield from the watershed. But for the purposes of log driving it is required that the accumulated water shall be delivered almost at once after it has been collected, in order to float the logs down the streams to the mills or booms, and thus in one or two months as much water may be allowed to flow away as would suffice to maintain the lake outlets at an average stage for the balance of the year. This is well illustrated in a diagram elsewhere given of a year's flow from Moosehead Lake. Of course complete control of the freshet waters is not generally practicable unless from a very limited watershed, and it is also partly in the interest of the paper manufacturers themselves that the logs are driven downstream to be converted into pulp. Nevertheless, there is an evident diversity of interest as regards the delivering of this important element of power—the stored water—which much curtails the benefits that might otherwise be received by the water powers.

TOPOGRAPHY AND FOREST RESOURCES.

The territory drained by the streams under consideration should be classed as in the main moderately hilly, the general elevation rising northerly from the coast, and from east to west toward the interior, becoming greatest as one approaches the White Mountains, toward the head waters of the Saco and the Androscoggin, where the hills are succeeded by mountains and the slopes become steep and rocky. Otherwise stated, a plateau extends in a northeasterly direction across the State, originating in the White Mountain region of northern New Hampshire, and ending to the south of Aroostook River on the New Brunswick border. The main divide gradually sinks in elevation from 1,800 feet above tide on the western boundary of the State to 600 feet on the eastern. From this plateau, and mainly from its southern slope, rise the principal mountains of the State, in isolated or clustered peaks and short ranges. All are of moderate height, the summit of Mount Katahdin, the highest, rising but 5,385 feet above sea level. In this elevated region the principal rivers have their sources, often interlocking, and the great reservoir systems of their upper waters are found. The northern slope of the plateau is characterized by a very gentle and uniform descent, giving to the streams of the St. John Basin sluggish flow and relatively small water power. The southern slope has a much more pronounced descent, especially in the western part of the State, creating the chief water powers of Maine.

The surface material is of drift formation—gravel, sand, and clay—of comparatively shallow depth, with frequent outcrops of granitic and slaty rocks. Only in the Aroostook region, in the northeastern part of the State, is the soil of so fertile a character as to fit it preeminently for agriculture; elsewhere it is seldom sufficiently deep or rich over large areas. Thus the natural covering of timber, easily and rapidly renewed in the moist climate, seems likely to furnish permanently the most profitable use of the land and to insure to it the endurance of an essentially forest character. Forests still cover largely the interior and northern portions of the State, and, while the territory adjacent to the coast and the lower portions of the immediate river valleys have been cleared, the upper basins are heavily clothed with timber, in spite of the inroads made for supplying the lumber and pulp mills.

Inexhaustible as the supplies of pine and spruce in the State of Maine have seemed, the cutting of these has been sufficiently great to arouse well-founded anxiety as to the future, and to set on foot careful investigations as to the condition of the forests of the State, and as to the best means for maintaining them in permanent productiveness. Valuable information upon these questions has already been secured by Mr. Austin Cary and presented by Mr. Charles E. Oak, forest commissioner of Maine, in his annual reports for 1894 and 1896.

The original pine forests of the State are practically gone, and the existing growth is relatively inferior in quality. Scattered groves of pine, it is true, spring up readily upon tracts of burnt and abandoned lands throughout the State, and are especially numerous in the southwest, but the decline in the pine-lumber industry as a whole is perhaps well enough indicated by the figures for the lumber cut upon the Penobscot, which for the period 1851 to 1855 averaged 115,000,000 feet per year and for 1891 to 1895 only 25,000,000 feet per year.

The spruce forests—the great and almost the sole source of supply for the pulp mills—are heaviest and of finest quality in the Upper Androscoggin Basin in New Hampshire and Maine, decreasing in size and quality of timber, as well as in density of growth, to the east and south, beyond the rugged White Mountain and Rangeley regions and toward the lower and more fertile borders of the Maine plateau. About two-thirds of the whole area of the State, however, is classed by Mr. Cary as spruce bearing on a commercial scale. This section includes, substantially, all the State except that portion lying west of Penobscot River and south of a line running up Piscataquis River and thence southwesterly through Bingham and Rumford Falls into New Hampshire. Even in the country thus excluded much spruce is found along the coast. Upon the mountains of the Rangeley region a pure growth of spruce is found, but elsewhere it is generally mixed with hard wood.

From the report of the forest commissioner for 1896 it appears that during the five years 1891 to 1895 the annual cut of spruce on the Penobscot averaged about 100,000,000 feet. Mills taking their logs from the Kennebec require annually, as indicated by the figures for 1895, about 120,000,000 feet of spruce, nearly one-third of this being needed for pulp mills and the balance for sawmills. Over 90 per cent of the whole is cut within the Kennebec Basin. The mills on the Androscoggin consumed nearly 200,000,000 feet of spruce in 1895, somewhat more than three-fifths being used at pulp mills and the balance at sawmills. All but a small percentage came from within the basin.

These figures, given for but a part of the State, are sufficient to indicate the magnitude of the present consumption of spruce timber. While in the view of Mr. Cary the annual production of spruce in the State as a whole is perhaps not yet overcut, he foresees that exhaustion of the original stock upon the larger rivers will in time certainly be reached. A wise husbanding and management of the newer growth would, in his judgment, render such a result of no disadvantage; but if, as in the Androscoggin Basin, for example, the extremely thorough cutting there practiced and the present rate of growth in the pulp business should continue, local exhaustion of the spruce supply, or else a rise in its value beyond the economical limit of manufacture into pulp, is entirely possible.

The extensive cutting of the forests of Maine has doubtless produced some local effect upon the flow of certain of the smaller streams. It is to be doubted, however, if this has yet been the case with the larger rivers. A great proportion of the State will probably always have a forest covering, which will be quickly renewed after the cutting of timber, except where serious fires destroy the soil. Such figures as to the flow of the rivers as are available cover periods far too short to serve for drawing any conclusions as to the result of forest cutting. Even were a considerable effect produced, the low-stage flow, in which it should be most perceptible, is so largely dependent upon artificial conditions produced by the development and management of lake storage that the influence would probably be disguised beyond recognition.

PRINCIPAL USES OF THE WATER POWER.

The rivers considered in this report derive their intrinsic value for water power not only from their large and relatively well-sustained flow and from the storage facilities existing, as already explained, but also from their large and rapid descent and its frequent concentration in abrupt falls and pitches over beds of unyielding granite. A conspicuous example of this is seen at Rumford Falls, where the Androscoggin descends about 175 feet in a mile, creating a power with few equals in magnitude within the United States.

The actual utilization of power on these rivers is mainly for the manufacture of wood pulp, paper, and lumber, with a large amount of power also devoted to cotton manufacturing at Lewiston and at some other points near tide water on the Androscoggin, Kennebec, Saco, and St. Croix rivers. A considerable power in the aggregate is converted into electricity and used for lighting, for operating street railways, and occasionally, as at Cumberland Mills on the Presumpscot, and at Rumford Falls on the Androscoggin, for manufacturing purposes. The development of the manufacture of wood pulp and paper by water power upon these streams has been most remarkable, especially upon the Androscoggin, where nearly 50,000 horsepower is now utilized in this way. The generation of electricity for city lighting from water power frequently results in the employment of what would otherwise be waste power, since electricity is required mainly at night—a time when for most manufactures the power of the streams is not needed and commonly goes to waste. An illustration of this is seen at Brunswick, on the Androscoggin, where the Cabot Manufacturing Company uses 1,700 horsepower by day in its extensive cotton mills, but leases 1,000 horsepower at night for electric lighting. Statistics of the total power in use on the six main rivers here treated, taking no account of that in use on their tributaries, are known only approximately, either for the present time or for that of the census of 1880, when such figures were last presented. Such results as are at command, however, indicate an increase for the intervening period of at least 200 per cent—from about 35,000 to above 100,000 horsepower. The main facts as to fall and utilized power are briefly set forth in the following table:

Power statistics of Maine rivers.

River.	Section.	Corresponding limits of drainage area.	Length of section.	Approximate fall in section.	Approximate fall embraced in existing water-power improvements.	Approximate power of turbines installed, August, 1897.
		Square miles.	*Miles.*	*Feet.*	*Feet.*	*Horsepower.*
St. Croix....	Foot of Schoodic Lake to tide water at Calais.	420-1, 530	55	383	70	2, 500-3, 000
Penobscot...	Foot of Chesuncook Lake to head of Pamedecook Lake.	1, 440-1, 640	18	400	None.	None.
Do	Foot of Twin Lakes to below mouth of Mattawamkeag River.	1, 990-4, 810	29	288	None.	None.
Do	Mouth of Mattawamkeag River to tide water at Bangor.	4, 810-7, 910	60	177	78	11, 500
Kennebec ...	Moosehead Lake to head of Carritunk Falls.	1, 250-2, 900	56	720	None.	None.
Do	Head of Carritunk Falls to tide water at Augusta.	2, 900-5, 770	60	314	142	24, 000

Power statistics of Maine rivers—Continued.

River.	Section.	Corresponding limits of drainage area.	Length of section.	Approximate fall in section.	Approximate fall embraced in existing water-power improvements.	Approximate power of turbines installed, August, 1897.
		Square miles.	*Miles.*	*Feet.*	*Feet.*	*Horsepower.*
Androscoggin	Umbagog Lake to head of Berlin Falls.	1,180–1,480	31	208	None.	None.
Do	Head of Berlin Falls to foot of Rumford Falls.	1,480–2,220	52	628	*a* 327	*b* 70,000
Do	Foot of Rumford Falls to tide water at Brunswick.	2,220–3,700	75	420	*b* 201	
Presumpscot	Sebago Lake to tide water.	470–700	22	265	110	6,000
Saco	Head of Great Falls to tide water at Biddeford and Saco.	856–1,734	41	343	*c* 130	5,500–6,000

a Including entire fall of 177 feet at Rumford Falls, only a portion of which is actually used.
b Including the 18 feet of fall and 6,000 horsepower being developed at Petersons Rips.
c Including 35 feet at dams used only for storage purposes.

Were it possible, it would be of great interest to state also the total horsepower further available on the different rivers. To compute this with suitable accuracy would require, however, more complete knowledge than is now at command, both of the volume of flow at different points on the streams and of the amount of fall which it would be practicable to develop. From such figures for flow as are given for some of the streams, in connection with the tributary drainage area, anyone may estimate the power to be realized at a given stage and for a given fall in an adjacent section of the stream; and it is to be hoped that, as time goes on, the data upon which to base such estimates will be greatly extended.

ST. CROIX RIVER.

St. Croix River, which, if traced to its head waters, forms nearly one-half the eastern boundary of Maine, separating that State from New Brunswick, is in one important feature pertaining to water power—its lake system—foremost among the larger rivers of Maine. Its total drainage area, shown in fig. 6, is about 1,630 square miles; but of this, 960 square miles, or 60 per cent, is tributary to the great reservoir systems controlled by dams at Vanceboro and Princeton, on the East and West branches, respectively. These systems comprise approximately 55 square miles of lake surface above the Vanceboro dam, and

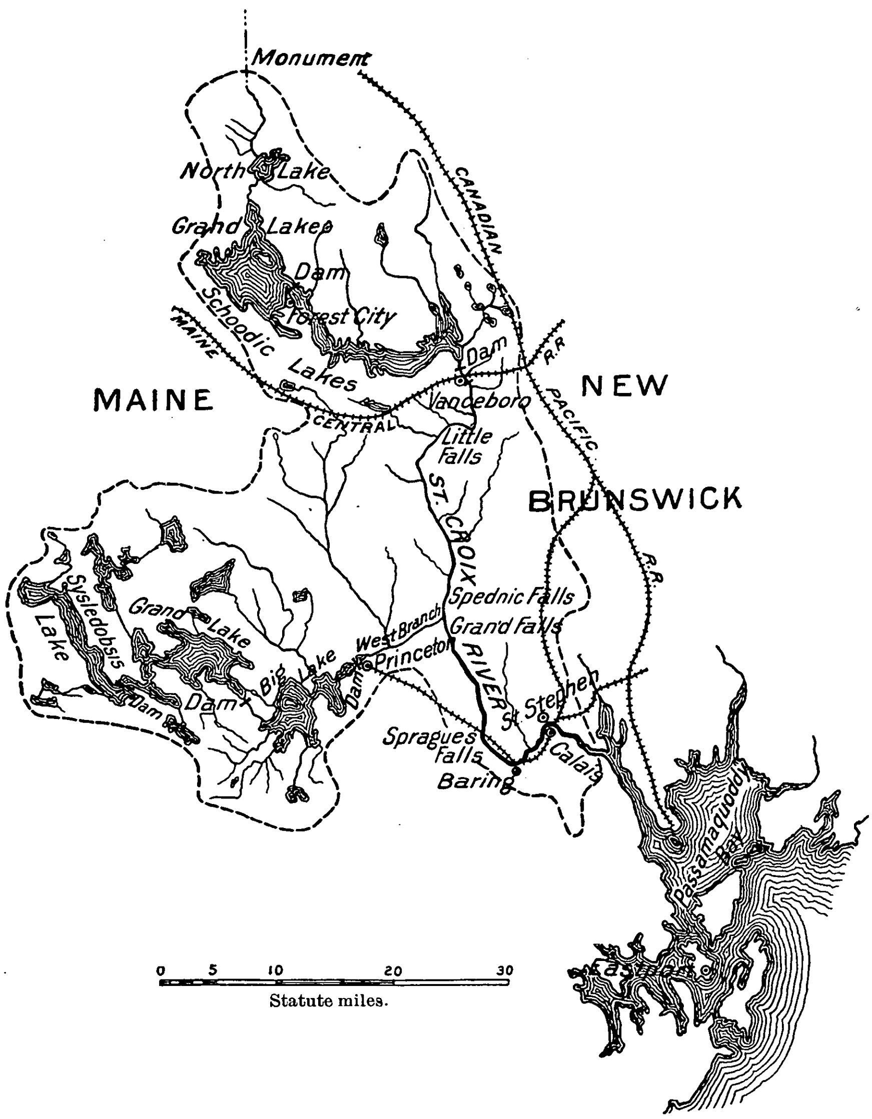


FIG. 6.—Drainage basin of St. Croix River.

70 square miles above that at Princeton, considering only the principal lakes and ponds; indeed, above the points mentioned each branch of the main river is simply a succession of lakes almost to the extreme head waters. Wells estimated the total lake surface of the St. Croix

at not less than 150 square miles, or nearly one-tenth of the whole drainage area. The topography of the basin is favorable to the easy development of extensive artificial storage, the surface being to a large degree low and flat, as indicated by the Indian name "Schoodic," signifying low, swampy ground, which is applied specifically to the lakes above Vanceboro, but sometimes in a general way to the whole St. Croix region. The drainage areas, as measured on Colton's map of Maine, are as follows:

Drainage areas of St. Croix River.

	Square miles.
Vanceboro dam, foot of Schoodic lakes	420
Little Falls	500
Immediately above mouth of West Branch	650
Immediately below mouth of West Branch	1,400
Spragues Falls	1,450
Calais, lower dam	1,530
Mouth of river, eastern border of town of Calais	1,630
West Branch, at Princeton dam	540
West Branch, at confluence with main river	750

Without railroad communication, except as afforded by the east and west line of the Maine Central, continued east of Vanceboro by the Canadian Pacific, and a short road running up from Calais to Princeton, the main portion of the basin is practically a wilderness, visited only by lumbermen and sportsmen. The cities of Calais, situated where the St. Croix becomes a tidal and navigable estuary, and St. Stephen, directly across the river in New Brunswick, have a population, respectively, of about 8,000 and 3,000. These are points of supply and trade for the surrounding country, and the valuable water power afforded by this portion of the river has here been utilized for sawing the greater part of the logs cut upon the upper basin, as well as for other important manufacturing purposes. There is a small settlement at the village of Baring, a few miles above Calais; a population of 1,000 or more at Princeton, on the West Branch, and nearly the same at Vanceboro, on the East Branch or main river; but elsewhere, on both these streams, there is no habitation, except at long intervals a farm house or a log-driver's camp.

Substantially all the timber now standing in the St. Croix Basin is said to be controlled by the sawmill owners at Calais and St. Stephen. This is a consideration of some importance, if an attempt be made to develop the manufacture of wood pulp, inasmuch as a bargain must be made with these owners for a supply of logs. There is reason to believe, however, that a satisfactory arrangement could be made with certain of them. The timber now being cut in this basin is mainly spruce and hemlock. Twenty years ago the amount annually cut was as much as 100,000,000 feet; but for various reasons it has fallen away to 25,000,000 feet, although it is estimated that, under improved business conditions, the product would perhaps rise to 35,000,000 feet. Smaller logs than formerly are now accepted. Some of the sawmills have gone to decay, and others which were burned have not been replaced.

FACILITIES FOR LAKE STORAGE.

The storage in the principal reservoirs of the St. Croix is controlled by the St. Croix Log Driving Company, a chartered association comprising the various mill owners upon the river. This company has a monopoly of log driving upon the river, inasmuch as no one can drive logs unless he comply with its conditions and share in the expenses assessed by it. Its office is to maintain the dams at certain lakes, to drive the logs down to Baring, and to assess equitably upon the members the cost of these operations. While the purpose of the company is primarily to facilitate log driving, and water is drawn from the lakes for that purpose in whatever amount is needed for a period of perhaps fifty or sixty days, for the balance of the season the log-driving company seeks to utilize lake storage as far as possible for the water-power interests of the river.

In the West Branch Basin the company maintains dams controlling the storage in Big Lake, Grand Lake, and Sysledobsis Lake. The dam at the foot of Big Lake and its prolongation through Long and Leweys lakes is situated at Princeton and gives about 5 feet of available storage, the three lakes being credited by Wells[1] with about 16 square miles of surface. The tributary drainage area is large, amounting to 540 square miles, and every spring there is wastage at the dam. Grand Lake, which is situated the next above on this branch, between 80 and 90 feet higher than Big Lake, is controlled by a dam giving 6 or 7 feet of storage, extending back over Grand, Compass, Junior, and some other smaller connecting lakes. The area of water surface commanded can not be given with any accuracy, but from Wells's figures would appear to be upward of 25 square miles. Still above, at the outlet of Sysledobsis Lake, is a dam giving a storage of approximately 8 feet in that lake, which is stated by Wells to have 7 square miles of surface.

On the East Branch, or main St. Croix River, the dam at Vanceboro commands 13½ feet of storage over about 27 square miles comprised in the lower Schoodic Lake; while above, at Forest City, another dam gives a few feet of storage over the 25 square miles of the upper Schoodic, or Grand Lake.

There are also private dams on most of the minor streams, but the storage in each case is small in comparison with that obtained at the above lakes. Such dams are not kept in good repair, and the reservoirs receive no further attention after having been drawn down for the season. Much might be accomplished to improve the storage of the river as a whole by bringing these numerous private reservoirs under a general

[1] Water-Power of Maine, p. 119.

system of control, if this were found practicable. It is doubtless also possible greatly to increase the storage in many existing reservoirs by raising the dams. The country surrounding the lakes is flat, and even low dams produce extensive flowage. While such improvements, however, could have easily been secured many years ago, when the flowed tracts were woodland, they are not now so feasible in the case of the larger lakes, because of the altered uses of the land and the consequent increased damages which would be incurred for flowage.

No measurements of the flow of the river have ever been made, so far as can be ascertained, and the experience of the mills now in operation throws the only light to be had on the amount of flow. The level, wooded surface of the basin, and the large extent of lake and swamp area, naturally result in a well-sustained low-season flow, in spite of the subordination of water power to log-driving interests in the management of the storage. On the other hand, the freshet rise is not excessive. the extreme range between high and low water amounting to 6 feet upon the Baring dam, and probably not exceeding 8 feet anywhere on the river.

FALL IN THE RIVER.

A monument marking a point upon the State boundary at the extreme head waters of the St. Croix proper is 538 feet above tide, from which there is a descent of nearly 100 feet to Grand Lake. From Grand Lake to the lower Schoodic Lake, or Chiputneticook, as it has also been called, there is a fall of about 60 feet, and at the dam controlling the former lake, at Forest City, some power is utilized, the particulars of which were not learned. At the Vanceboro dam, at the foot of the lower Schoodic Lake, no power is used; but half a mile or so farther downstream there is another dam, at which a fall of about 8 feet is employed for nine turbines operating the machinery of the International Leather Company's tannery. From this point no dam is encountered on the St. Croix before reaching Baring, nearly 50 miles below, excepting an occasional wing dam built by the log drivers for controlling the channel. In spite of the relatively low elevation of St. Croix Basin the river has a good slope, averaging about 7 feet per mile, and amounting to more than 350 feet from below the lower Vanceboro dam to mean tide at Calais. Of this amount approximately two-fifths in the aggregate, or say 140 feet, is concentrated at Spednic Falls, Grand Falls, Spragues Falls, and Calais, the balance being spread over the various rips and smooth-flowing sections of the stream. While at the falls the banks are generally rocky and of good height, elsewhere they are commonly low and succeeded by wide, level stretches of wooded land. Here and there, as noticeably above Canoose Rips, the river widens out almost to the dimensions of a lake, running for miles 1,000 feet or more in width, with gentle current. The distribution of the entire fall of the river as determined by Anson's survey, made prior to 1840, and quoted by Wells in Water-Power of Maine, p. 115, is set forth in the following table and in the diagram, fig. 7. The figures given are perhaps subject to minor changes, however, at the upper and lower extremities of the stretch considered, due to the construction of dams since the survey was made.

Fall in St. Croix River.

Locality.	Distance from Calais bridge.	Height above approximate low tide.[a]	Fall between points.	Distance between points.	Average fall per mile between points.
	Miles.	*Feet.*	*Feet.*	*Miles.*	*Feet.*
Schoodic Lake, at foot	54.62	382.6			
			9.7	0.56	
Foot of Kill-me-quick Rips	54.06	372.9			
			14.6	3.04	
Head of Mile Rips	51.02	358.3			
			22.9	1.00	
Foot of Mile Rips	50.02	335.4			
			83.2	10.07	
Head of Rocky Rips	39.95	252.2			
			24.8	3.38	
Foot of Rocky Rips	36.57	227.4			
			1.0	0.63	
Head of Meetinghouse Rips	35.94	226.4			
			7.7	1.06	
Foot of Meetinghouse Rips	34.88	218.7			
			0.2	1.00	
Head of Haycock Rips	33.88	218.5			
			6.0	0.39	
Foot of Haycock Rips	33.49	212.5			
			0.6	2.88	
Head of Canoose Rips	30.61	211.9			
			11.2	0.56	
Foot of Canoose Rips	30.05	200.7			
			10.7	7.30	
					7.00
Head of Spednic Falls	22.75	190.0			
			20.1	0.53	
Foot of Spednic Falls	22.22	169.9			
			3.9	2.25	
Grand Falls, head of upper pitch	19.97	166.0			
			20.0	0.56	
Grand Falls, lower pitch	19.41	146.0			
			17.8	7.93	
Head of Enochs Rips	11.48	128.2			
			9.6	0.69	
Head of Spragues Falls	10.79	118.6			
			25.4	0.36	
Foot of Spragues Falls	10.43	93.2			
			6.7	5.05	
Baring bridge	5.38	86.5			
			13.9	3.60	
Milltown, upper bridge	1.78	72.6			
			72.6	1.78	
Calais bridge	0.00	....			

[a] Mean rise and fall of tide about 20 feet.

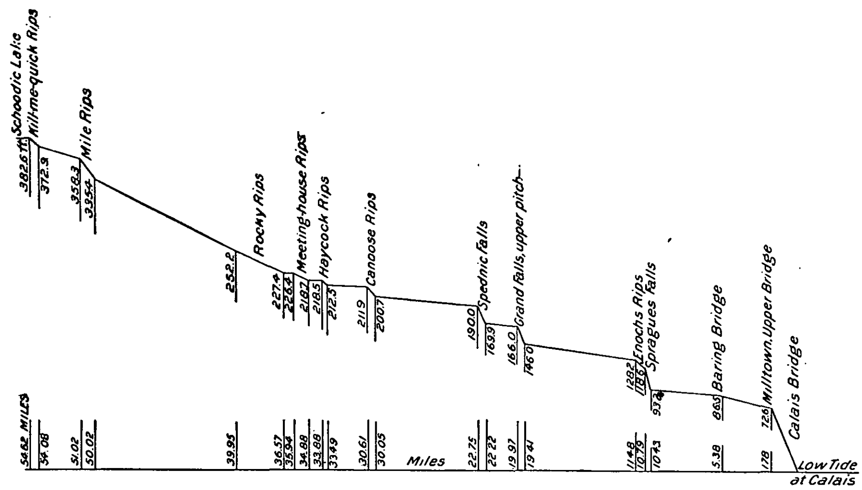


FIG. 7.—Profile of St. Croix River from Vanceboro to Calais, Maine.

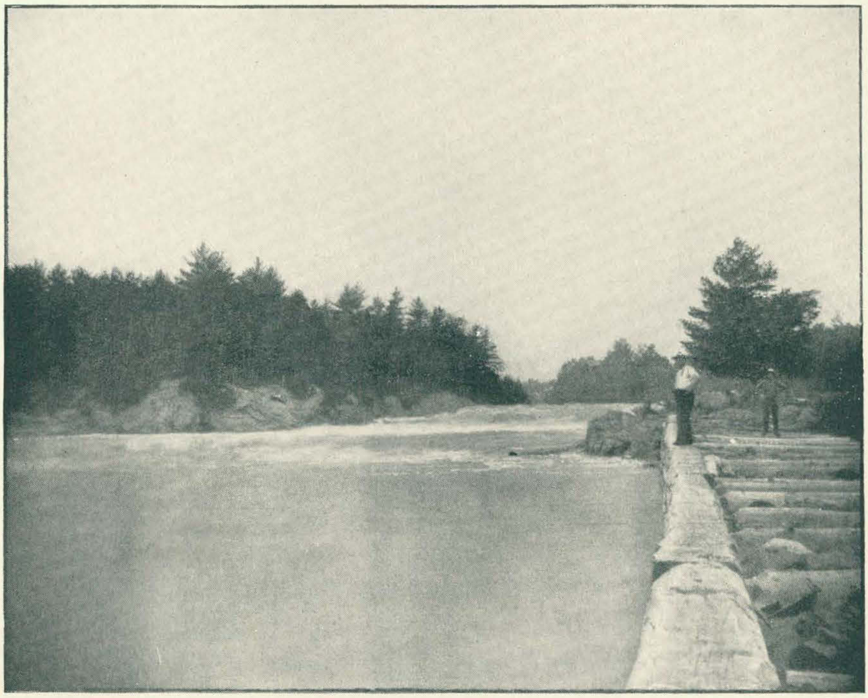
Passing below the village of Vanceboro, the first important pitch encountered is that at Little Falls, some 8 miles downstream, although rapids occur at intervals in the intervening stretch, the most noticeable of these being Mile Rips. At Little Falls the river descends over ledges perhaps 3 or 4 feet in as many hundred. The banks are high and rocky, and the site appears excellent for a dam of moderate height, which probably need not be more than 200 feet long, and which would give a fine pondage over the wide and sluggish stretch of river above. For the first 6 or 8 miles below Little Falls there is a rapid succession of rips of varying degrees of roughness. The river then becomes wide and sluggish, probably measuring 800 or 1,000 feet between banks, and in the 4 miles from Keene Place to Canoose Camp is broken only by the rips near Rideout's. At Canoose Rips, which are some 12 miles below Little Falls, the descent is considerable, amounting, according to the table elsewhere given, to 11 feet in about half a mile. Less than half a mile below Canoose Rips are Dog Island Rips, short but heavy, and thence, for the succeeding 8 miles to Spednic Falls, the river is almost uniformly smooth.

The Spednic Falls are not more than 2 miles above the mouth of the West Branch of the St. Croix and form an important water privilege. The river here descends in a succession of pitches and rapids, mainly comprised within 1,000 feet, and with a total fall of about 20 feet in half a mile. The banks are rocky, though not high at the head of the falls, and the main channel is narrow. One or more side channels through which also the stream naturally flowed have already been dammed by the lumbermen.

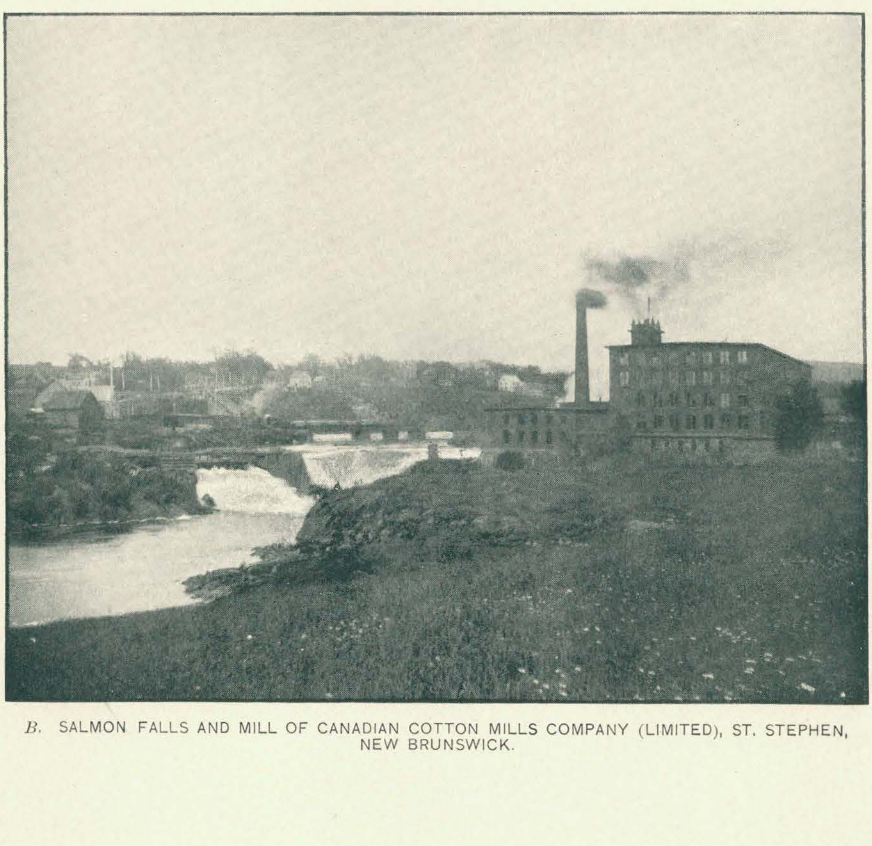
Almost immediately below the mouth of the West Branch are Grand Falls, comprising what are known as the upper and lower pitches, perhaps half a mile apart, and each covering a fall of 15 or 20 feet. At the upper pitch there is an abrupt fall of about 6 feet, followed by heavy rapids. The river is naturally divided by a rocky island, but by a log wing dam its flow has been confined within a single main channel. The lower falls are a close counterpart of the upper in all their principal features, and both are to be regarded as important sites for power.

Below Grand Falls there are only occasional light rips for 8 miles. Then are encountered Enochs Rips, closely succeeded by Spragues Falls, shown in Pl. VIII, *A*, the latter undoubtedly constituting the principal undeveloped water power of the river. The St. Croix and Penobscot Railroad, running from Calais to Princeton, skirts the east bank of the river opposite the falls, and crosses a short distance upstream. There is a resemblance to the sites at Grand and Spednic falls, in that the river is divided by a rocky island. The channel to the right of this has been closed, for log-driving purposes, by a long and high wing dam, forcing the river between the island and the left or east bank. This channel is 150 or 200 feet wide, and at the head of the falls the facilities seem excellent for the construction of a dam, which would have for abutments the ledges of the island and the left main bank, both of which are of sufficient height. Approaching the falls from above there are heavy rapids for 500 feet, then an abrupt pitch of 6 or 8 feet, followed by rapids and minor pitches for 800 or 1,000 feet farther, the total descent, according to Anson's old survey, amounting to 25 feet in a third of a mile, or, if combined with Enochs Rips, 35 feet in a mile. On all accounts the water power at Spragues Falls is a fine one. No very close estimate, however, can be made as to the available power. The drainage area is not materially different from that at Calais, and, judging from the experience of the mills in that city, the power probably would not, in an extreme drought like that of 1895, exceed 40 or 50 net horsepower per foot of fall, continuous for the 24 hours, or, say, from 1,000 to 1,200 net horsepower for the entire fall of 25 feet. The shortage of 1895 is attributed in part to unwise management of the lake storage, and it seems quite certain that throughout all ordinary years the power at Spragues Falls is much in excess of the figures above given.

In the 5 miles from Spragues Falls to Baring, the river has but slight fall, but therefore affords large pondage and valuable storage space for logs. At Baring there is an old, dilapidated, and leaky dam, built from ledge to ledge and affording a head of 8 or 10 feet at the mills, although from the ordinary level of the mill pond to the foot of the rips below the dam the fall is stated to be about 12 feet. Thirty years ago a large amount of lumber was sawed here and eight or ten gang saws were in operation; but the old mills have been burned and not rebuilt, and the manufacturing is now confined to two small establishments on the American side of the river, making shingles, barrel heads, and box shooks.



A. UPPER PITCH OF SPRAGUES FALLS, ST. CROIX RIVER.



B. SALMON FALLS AND MILL OF CANADIAN COTTON MILLS COMPANY (LIMITED), ST. STEPHEN, NEW BRUNSWICK.

POWER UTILIZED AT CALAIS AND VICINITY.

The next and last power on the river is that at Calais and vicinity. The St. Croix, which above this point has in general run between low banks and been depressed but little below the level of the adjacent country, now appears to have worn its channel much below that level and in less than 2 miles, from the surface of the upper pond at Milltown to tide water at the lower Calais bridge, descends about 54 feet measured to ordinary high tide, or about 20 feet more than that if measured to ordinary low tide. Calais and its upper suburb of Milltown lie on the American bank, and St. Stephen with its suburb, also called Milltown, lies across the river. Manufacturing is conducted at four different dams, three of which appear to be old and leaky. All are of log construction.

At the upper dam the fall is 12 feet, and the power is all owned by H. F. Eaton & Sons, who operate a sawmill on each bank, that on the Canadian side being equipped with four gang saws and a planing mill, and that on the American side with three gang saws, a planing mill, and a box machine. These mills have a combined capacity for sawing more than 25,000,000 feet of lumber in a season, but on account of dull times only four gang saws were in operation in July, 1897. A short distance below, a wing dam on the American side, commanding a part only of the flow of the river, gives a fall of 9 feet, the power corresponding to which is used in James Murchie & Sons' mill, equipped with three gang saws, a planing mill, and shingle mill. On the opposite side of the river is a dam in a dilapidated condition, giving a few feet of fall, now used only for operating a shingle mill.

The next privilege occurs at what are known as the Salmon Falls, shown in Pl. VIII, *B*, and is the most important and the best developed at this locality. It is owned by the Canadian Cotton Mills Company, Limited, having a fine mill on the New Brunswick bank, equipped with 34,000 spindles and 1,100 looms, and employing 725 hands. The dam is a tight and costly structure of log cribs packed with stone, and develops a normal fall of about 21 feet. Three 54-inch Hercules turbines are installed, but only from 1,000 to 1,100 horsepower is actually employed. For this there has been no shortage except in the summer or fall of 1895. The mill is dependent upon the continuous flow of the stream, the pond being small and no material aid being received from storage of night flow either here or at the dams above.

The last dam on the river is near the head of tide water. It gives a fall reckoned as normally 10 feet, but varying, with the season, from 8 feet at times in dry weather to 12 or 13 feet in freshets. The ordinary tidal rise and fall below the dam is 1 or 2 feet, and that in spring tides 3 or 4 feet. The entire privilege is owned by Mr. Frank Todd, who operates mills on both banks, ordinarily sawing in the aggregate 8,000,000 or 10,000,000 feet of lumber per annum. He also owns the electric-light station, at which 500 horsepower of turbines is installed, with about 200 horsepower in present use, and proposes also to build on the American bank a sulphite pulp mill. Below this dam heavy rapids are exposed at low tide, but the power is naturally of little consequence.

WEST BRANCH OF ST. CROIX RIVER.

The West Branch has a materially larger drainage area than the East Branch, or what has been called the main St. Croix River, comprising 750 square miles at the confluence of the two streams, and 540 square miles at Princeton. No power is used, however, except at Princeton dam, at the foot of Big Lake, or, perhaps more properly, at the foot of the eastern extension known as Leweys Lake. This dam is an old structure, clearly allowing much leakage, and gives a head at the mills amounting at a favorable stage of water to about 9 feet. Power is used for F. Mercer & Sons' grist mill, box mill, and sawmill, the latter manufacturing from 7,000,000 to 8,000,000 feet during the season, and for S. L. Peabody's one-set woolen mill.

From Princeton to the mouth of the West Branch is a distance of about 8½ miles, in which the fall amounts to between 12 and 13 feet, according to Anson's survey. The stream runs much of the way between low banks, from 250 to 350 feet wide in the narrower portions of its course, but spreading out in places to a much greater width. The current is gentle and the surface smooth, broken only by Tomah and Black Cat rips, neither of them so strong that they can not be ascended readily by poling in a canoe. Above Big Lake the outlet stream from Grand Lake has a fall, by Anson's survey, of 82 feet in its length of 2¾ miles, doubtless furnishing good water powers, but at present removed from settlement and from railroad communication.

PENOBSCOT RIVER.

The largest river basin in Maine is that of the Penobscot, shown on Pl. IX, which comprises about 8,500 square miles, or somewhat more than one-fourth the entire area of the State. It extends about 135 miles northward from the coast and in its upper portion stretches nearly an equal distance east and west, reaching almost entirely across the central part of the State, from the New Brunswick border on the east to the Quebec on the west. In the main, the eastern part of the basin, including the drainage areas of the East Branch and the Mattawamkeag, has a gently undulating surface, insensibly blending into the valley of the Aroostook on the north at an average height above tide probably not exceeding 1,000 feet. To the westward the surface becomes broken and much diversified by hills, detached peaks, lakes, ponds, and swamps; and finally, as described on page 103 of Wells's report, "The valley becomes merged with that of the Kennebec on the south and the Allaguash on the north, and terminates on the northwest at the highland boundaries of the State and in the swamps and lagoons

DRAINAGE BASINS OF PENOBCOT AND KENNEBEC RIVERS.

which form the common reservoir of the St. John and Penobscot." Mount Katahdin, the highest peak in Maine, lies about 10 miles north of the river in the central part of the State, but the basin as a whole is less elevated than that of either the Kennebec or the Androscoggin. Slate is the principal surface rock over the upper basin, succeeded by schists, granite, and gneiss to the east and south, while the soil is mainly gravel, clay, and loam. The country drained by the Penobscot is heavily timbered, and the lumber industry is the most important in the valley, the drive of logs for the season of 1896 being estimated at about 110,000,000 feet, more than half of this coming from the West Branch.

Drainage areas, Penobscot River and principal tributaries. (a)

River.	Locality.	Drainage area.
		Sq. miles.
Penobscot	Opposite northwest extremity of Moosehead Lake, township of Seeboomook, immediately below mouth of Nulhedus Creek.	600
Do	Entrance into Chesuncook Lake	870
Do	Outlet of Chesuncook Lake	1,440
Do	Outlet of Twin Lakes	1,990
Do	Immediately below mouth of East Branch of Penobscot.	3,160
Do	Immediately below mouth of Mattawamkeag River.	4,810
Do	Immediately below mouth of Piscataquis River.	6,590
Do	Oldtown, above mouth of Pushaw River	7,240
Do	Bangor	7,910
Do	Mouth	8,550
Caucomgomoc	Entrance into Chesuncook Lake	230
East Branch of Penobscot.	Mouth	1,170
Mattawamkeag	Immediately below outlet of Baskahegan Lake.	190
Do	Mouth	1,530
Piscataquis	Dover	380
Do	Immediately below outlet of Sebec Lake	750
Do	Mouth	1,500
Passadumkeag	Mouth	400

a Measured on G. W. & C. B. Colton & Co.'s map of Maine, published in 1883.

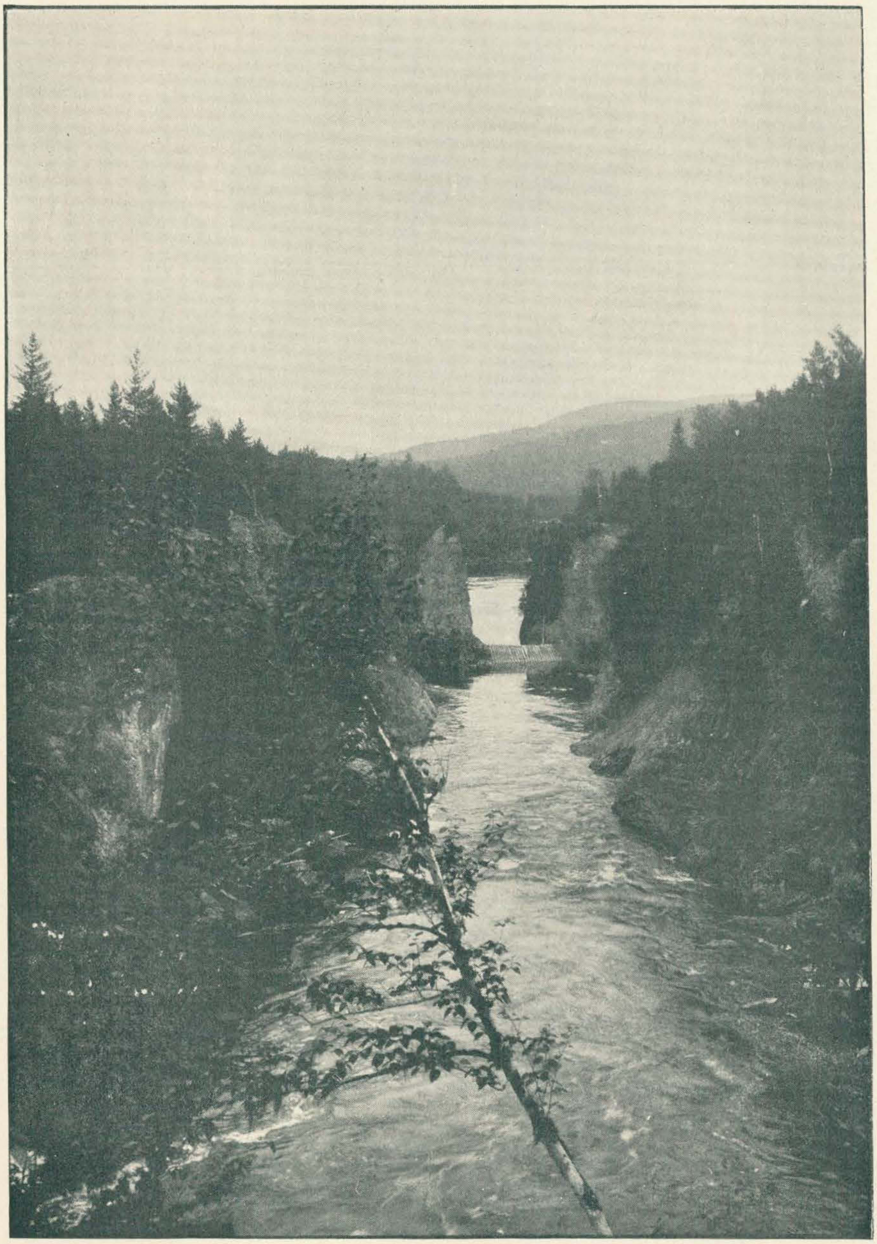
FALL IN THE RIVER.

The remote sources of the Penobscot are adjacent to the head waters of the Chaudière, St. John, and Kennebec rivers, and are more than 200 miles by water from the outlet into Penobscot Bay. The divide in the extreme northwest averages perhaps 1,800 feet above sea level. In the 50 miles from the head of the Southwest Branch to Chesuncook Lake there is a descent of about 600 feet, but the stream there is small and relatively inaccessible. After issuing from Chesuncook Lake the river has a further fall of about 400 feet in less than 20 miles before entering Pamedecook and Twin lakes, but still lies in a wilderness, with no direct railroad communication. The "Great Arches," at Ripogenus, below Chesuncook Lake, are shown in Pl. X. The tributary drainage area has increased from 1,440 square miles at the foot of Chesuncook Lake to 1,990 square miles at the foot of Twin Lakes. In the next 30 miles, or thereabouts, below Twin Lakes to the mouth of the Mattawamkeag River, the Penobscot descends 288 feet; and because of this rapid fall, the enlarged drainage area, and the extensive storage facilities offered by the lakes, this section possesses water power of great intrinsic value, although a demand for its development has not yet arisen.

Fall in Penobscot River.

Locality.	Distance from mouth of river.*a*	Height above mean tide.	Fall between points.	Distance between points.	Average fall per mile between points.	Authority for elevations.
	Miles.	*Feet.*	*Feet.*	*Miles.*	*Feet.*	
Penobscot Lake, head of SW. Branch.	218	1,509	475	25	19.0	Wells: Water-Power of Maine, p. 101.
Off NW. angle of Moosehead Lake.	193	1,034	134	24	5.6	
Head of Chesuncook Lake.	169	900				
Foot of Chesuncook Lake.	151	900	400	18	22.2	
Head of Pamedecook Lake.	133	500±				
Foot of Twin Lakes..	116	500±	......	......	......	
Bangor and Aroostook R. R. crossing below foot of Twin Lakes.	116	465	288	29	9.9	Moses Burpee, chief engineer, Bangor and Aroostook R. R.

a Measured on Colton's map of Maine, scale about 8¾ miles to the inch.



THE GREAT ARCHES AT RIPOGENUS, BELOW CHESUNCOOK LAKE, PENOBSCOT RIVER.

Fall in Penobscot River—Continued.

Locality.	Distance from mouth of river.	Height above mean tide.	Fall between points.	Distance between points.	Average fall per mile between points.	Authority for elevations.
	Miles.	*Feet.*	*Feet.*	*Miles.*	*Feet.*	
Canadian Pacific Rwy. crossing near mouth of Mattawamkeag River.	87	*a* 177	71	31	2.3	P. A. Peterson, chief engineer, Canadian Pacific Rwy.
Mouth of Passadumkeag River.	56	106	45	17	2.6	Wells: Water-Power of Maine, p. 101.
Maine Central R. R. crossing at Oldtown.	39	*b* 61	61	12	5.1	H. C. Robinson, asst. engineer, Maine Central R. R.
Bangor	27	0				

a Adjusted for water surface and mean tide from elevation of track, 220 feet above extreme low water at St. John, New Brunswick.

b Adjusted for water surface and mean tide from elevation of track, 95 feet above mean low tide at Bangor.

Below the mouth of the Mattawamkeag the tributary drainage area comprises 4,810 square miles. Hitherto the river has been pursuing an easterly or southeasterly course, but it now turns southerly, and in the 60 miles to tide water at Bangor falls 177 feet. Throughout this section it is closely followed by the Maine Central Railroad, and below Bangor the river is navigable for the 27 miles to the mouth during about eight months of the year, being closed by ice the remaining time. The fall in the above stretch is unevenly distributed, nearly or quite one-half occurring in the 14 or 15 miles from the head of Cookis Rips, above Oldtown, to tide water at Bangor. It is to this latter portion of the river that the use of water power has thus far, with one exception, been confined, dams having been constructed in the main channel at five different localities, developing an aggregate fall of between 55 and 60 feet, while there are three dams on what is known as the Stillwater Branch, at Oldtown and Orono. Above this stretch there is a single fall in use, that at Montague, approximately midway between Oldtown and Mattawamkeag, amounting to 20 feet, and surveys have also recently been made with a view to the future development of still another fall, a mile or two below Mattawamkeag.

UTILIZATION OF POWER.

Probably first in importance with respect to the amount of power used are the pulp mills, of which there are three operated by water power, together using at full capacity not far from 6,500 horsepower of turbines. There is a single paper mill, that of the Webster Paper Company, at Orono, which manufactures about 25 tons of news paper per day.

For many miles above Oldtown the river contains numerous islands, some of large size. The channels thus formed, and the long stretches of smooth water which exist, have proved very favorable for the storage and handling of logs to be sawed at the various mills below, and a large force of men is kept busy during the season in sorting and driving these logs. The sawmills, of which there are seven operated by water power from the Penobscot and its Stillwater Branch, doubtless rank, with their accompanying machinery in the way of planing, shingle, lath, clapboard machines, etc., next to the largest users of power, in the aggregate, on the river, although it is impossible to state the horsepower of water wheels employed by them. According to statistics obtained by individual inquiry, they manufacture a total of upward of 75,000,000 feet of lumber in a season of good business. The sawing season, however, lasts for but about six months, from May to November, the river being frozen over the balance of the time, and thus precluding the handling of logs in the customary manner.

At Veazie, 2 or 3 miles above Bangor, is the important electric power and lighting station of the Public Works Company, of Bangor, operated by about 1,500 horsepower of turbines; 120 horsepower, or thereabouts, is used at an electric-lighting station at Oldtown, and 250 horsepower for the municipal lighting plant at the Bangor pumping station. Moderate powers are also in use for pumping public water supplies from the river at Oldtown, Veazie, and Bangor. These works, together with those already enumerated, a single woolen mill at Oldtown, and a cant-dog shop at Orono, comprise all using water power from Penobscot River.

From the measurements which have been made of the flow of the river, and which will be given later, it appears probable that 300 net horsepower per foot of fall, average for the twenty-four hours, can be realized below the Piscataquis throughout most years, under existing conditions of the river, with a possible fall to 200 horsepower in a very exceptional season. The large drainage area, the comparative uniformity of its surface, the great forest covering, and the extensive system of lakes and swamps combine to give the main river a fairly well-sustained flow. The extreme freshet height observed on the Bangor dam has been 11¾ feet.

DISCHARGE MEASUREMENTS.

The only measurements of the flow of the Penobscot of which information could be obtained were made by Prof. George H. Hamlin, of Maine State College, in the fall of 1884 and in the fall of 1886. On September 20, 22, and 23, 1884, respectively, the main river opposite Vinals Landing, Orono, the East Branch of the Stillwater at the foot of Orono Island, and the West Branch of the Stillwater at the foot of

Orono Island, were measured by subsurface floats, and the discharge of the entire river thus ascertained to be 3,480 cubic feet per second, corresponding to 0.48 cubic foot per second for each of the 7,240 square miles of tributary drainage area. About 85 per cent of the discharge was through the main river. The result thus obtained is considered by Professor Hamlin to represent "average extreme low water discharge."

Again, on September 7, 1886, the East and West branches of the Stillwater were measured at the place noted above, and on October 23, at a substantially identical stage of water, the main river was measured about a quarter of a mile below the works of the Penobscot Chemical Fiber Company. The Ellis current meter was used for these measurements, and the discharge of the entire river was found to be 2,470 cubic feet per second, equivalent to 0.34 cubic foot per second per square mile. This discharge Professor Hamlin regards as corresponding to "extreme low water." He states that the river has been lower than it was at that time, but only slightly so and at rare intervals. In the measurements both of 1884 and of 1886 it is believed that the results obtained represented average flow for the twenty-four hours.

The only extended rainfall record in the basin appears to be that for Orono, 10 or 12 miles above Bangor, showing 46 inches yearly average for the period 1871 to 1891 (Weather Bureau, Bulletin C, 1894).

STORAGE FACILITIES IN THE BASIN.

A very important feature from a hydrographic point of view, and one which must be intimately connected with the future utilization of the power of the river, lies in the opportunities for storage offered by the tributary lakes and ponds. At present, in so far as control is exercised over these, the main purpose is to facilitate log driving in the late spring and early summer, and is thus entirely at variance with the requirements which would accompany a complete development of the river for power. Wells, in Water-Power of Maine, p. 106, states the number of lakes and ponds in the Penobscot Basin, which have been mapped, as 467. Less than half of these, but including the principal ones, have a combined surface area of approximately 480 square miles, distributed as follows:

Surface area of principal lakes and ponds in the Penobscot Basin.

Draining to—	Square miles.
Piscataquis River	85.90
Passadumkeag River	31.25
Mattawamkeag River	53.35
East Branch of Penobscot	42.30
Penobscot River above outlet of Chesuncook Lake	80.65
Penobscot River, thence to outlet of Twin Lakes	64.25
Penobscot River, thence to Bangor	54.50
Total	412.20

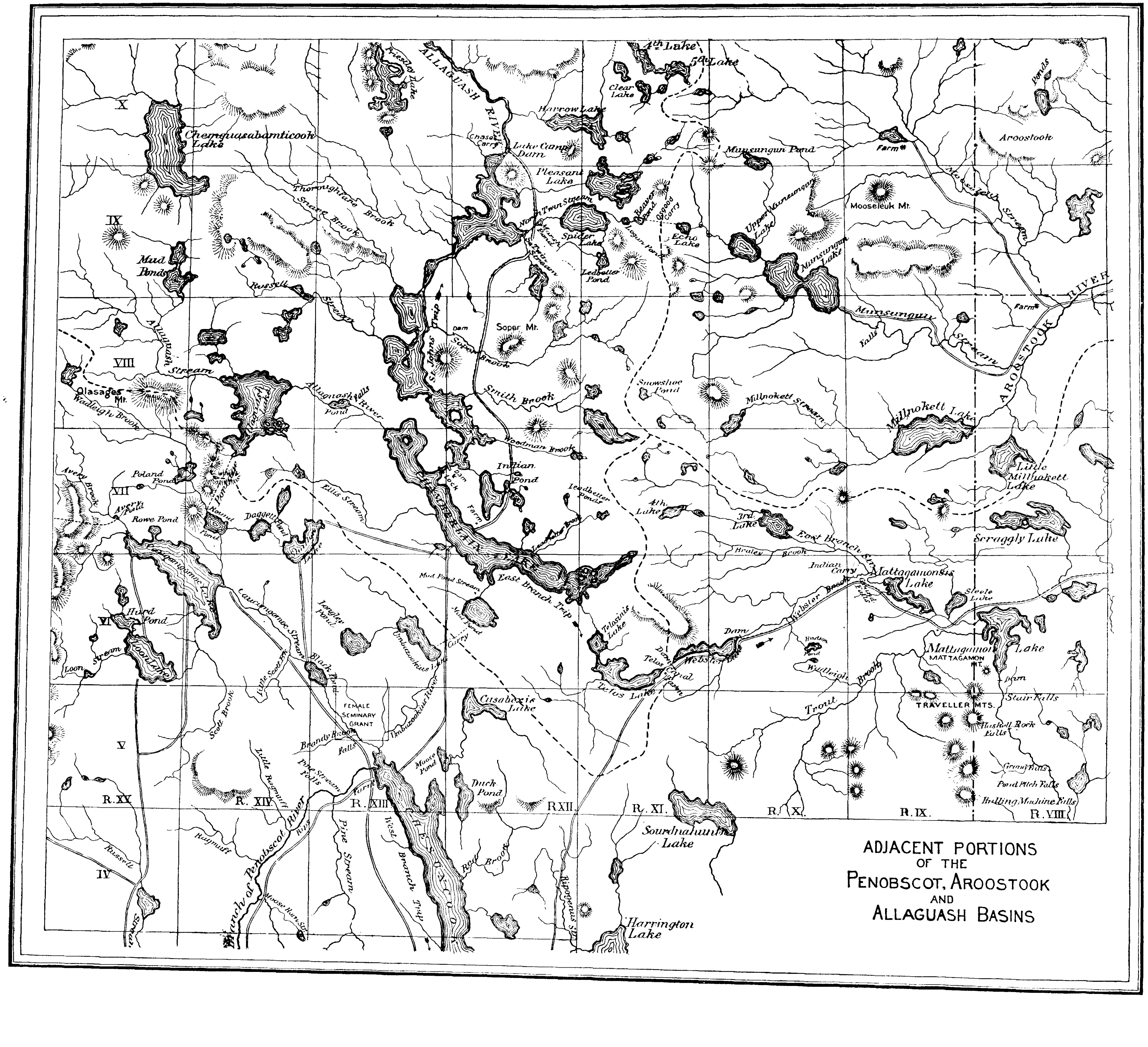
The area of these lakes, together with about 40 square miles diverted from the Allaguash and about 30 square miles tributary below Bangor, make up the 480 square miles previously mentioned. The lakes range in size from about 22 square miles, in the case of Chesuncook, downward, nine of them comprising each 10 square miles or more of surface. In general, however, the lakes and ponds are of rather small size, and the development of large storage is not so simple as in the Kennebec or the Androscoggin basin. Yet the opportunities for artificial reservoirs are said to be unusually good in the upper basin of the Penobscot, although involving extensive flowage. Every additional foot of available storage over the 450 square miles of lake surface above Bangor is equivalent to an additional continuous flow of about 800 cubic feet per second for six months in the year at that place.

DIVERSION OF FLOW FROM THE ALLAGUASH.

So low are the divides between the upper Penobscot and the St. John and Kennebec basins that a diversion of water to or from the former river is comparatively easy. More than forty years ago an artificial connection had been established between the upper waters ot the Allaguash, a tributary of the St. John, and the East Branch of the Penobscot. This was brought about by means of a dam at the northern or outlet end of Chamberlain Lake, a feeder of the Allaguash, as shown on Pl. XI. The waters of that lake were thus turned back through two connecting lakes, Telosmis and Telos, and from the latter through an artificial cut to Webster Lake, in the Penobscot Basin. There was also a dam farther down the Allaguash, at the foot of Churchill Lake, flooding the latter back into Heron Lake, from which locks permitted the floating of logs up into Chamberlain Lake and thence to the Penobscot; but these works have long since gone to decay. The dam at the outlet of Chamberlain Lake and that at Telos Lake, however, are still in use. The waters of Chamberlain Lake, at the time of the spring drive, are turned through the Telos Cut into the East Branch of the Penobscot to facilitate the passage of the drives down that river. At the close of the driving season the gates at Chamberlain Dam are opened, and the water of that lake is allowed passage both ways. All timber, therefore, which is delivered below Chamberlain Lake on the Allaguash waters must go down to St. John; while that delivered at Chamberlain Lake, although it can go either way, is driven down the Penobscot to market.

SLUICING OF LOGS TO MOOSEHEAD LAKE.

Again, the main upper branch of the Penobscot flows within 2 or 3 miles of the head of Moosehead Lake, which is the direct and principal source of Kennebec River; and so slight are the barriers separating river and lake that many years ago a canal, to be called the Seeboomook sluiceway, was planned to unite them, in order to provide a more direct passage for logs toward the coast. This sluiceway was never built; but although no water is diverted from the Penobscot into Moosehead


ADJACENT PORTIONS
OF THE
PENOBSCOT, AROOSTOOK
AND
ALLAGUASH BASINS
Chemquasabamticook Lake
Mud Ponds
Allaguash Stream
Olasages Mt.
Wadleigh Brook
Poland Pond
Avery Brook
Rowe Pond
Round Pond
Daggett Pond
Hurd Pond
Loon Stream
Thoroughfare Brook
Snare Brook
Russell Stream
Allaguash Falls
Ellis Stream
Caucomgomoc Stream
Lowley Pond
Black Pond
Female Seminary Grant
Umbazooksus
Mud Pond Stream
Casabexis Lake
Duck Pond
Moose Pond
Brandy Brook
Pine Stream Falls
Pine Stream
West Branch
Little Scott Brook
Scott Brook
Little Ragmuff
Ragmuff
Moose Horn Str.
Russell
Ripogenus St.
Harrington Lake
Sourdnahunk Lake
Allaguash River
Churchill Lake
Lake Camp Dam
Chase Carry
Pleasant Lake
Harrow Lake
Clear Lake
4th Lake
5th Lake
Munsungun Pond
Spider Lake
Leadbetter Pond
Echo Lake
Beaver Pond
Upper Munsungun Lake
Munsungun Lake
Mooseleuk Mt.
Aroostook
Farm
Mooseleuk Stream
Munsungun Stream
Aroostook River
Soper Mt.
Soper Brook
Smith Brook
St. Johns Trip
Dam
Snowshoe Pond
Millnokett Stream
Millnokett Lake
Little Millnokett Lake
Woodman Brook
Indian Pond
Leadbetter Ponds
4th Lake
3rd Lake
East Branch Str.
Scraggly Lake
Hraley Brook
Indian Carry
Mattagamonsis Lake
Steele Lake
Webster Brook
Mattagamon Lake
Mattagamon Mt.
East Branch Trip
Telosinis Lake
Telos Canal
Telos Lake
Webster Lake
Wadleigh Brook
Trout Brook
Traveller Mts.
Stair Falls
Haskell Rock Falls
Grand Falls
Pond Pitch Falls
Hulling Machine Falls
X
IX
VIII
VII
VI
V
IV
R. XV
R. XIV
R. XIII
R. XII
R. XI
R. X
R. IX
R. VIII

Lake, timber is transported across by means of an endless chain and a sluice. A dam was built across the Penobscot, setting the water back into Meadow Pond. (See fig. 8.) Logs coming down the river are sorted above the island, and those destined for the Kennebec are driven through the cut into Meadow Pond. From this pond they are lifted by an endless chain carrier, very much as ice is transported from a pond into an icehouse, to the upper end of a V-shaped sluiceway which leads down the southern slope to Moosehead. This sluiceway is fed with water from Carry Pond, a small body of water higher than the

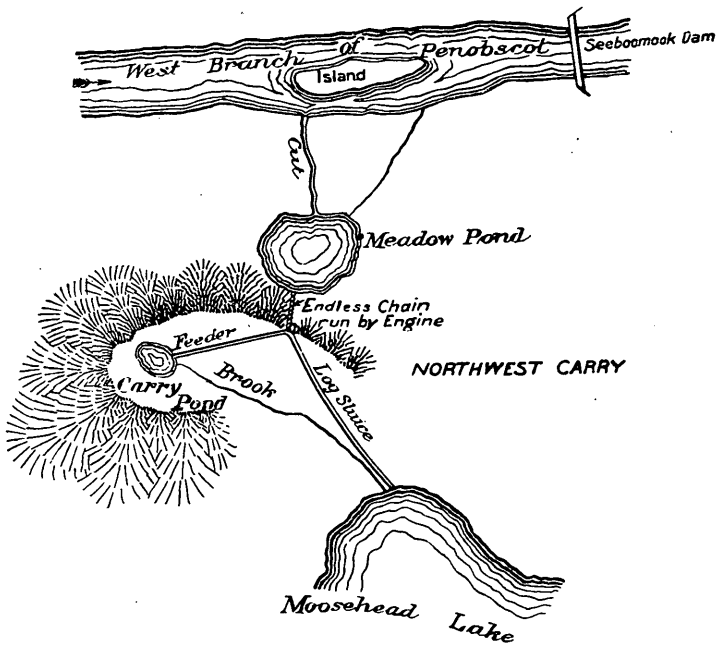


FIG. 8.—Arrangement for conveying logs from Penobscot River into Moosehead Lake.

upper end of the sluice. The logs brought up by the endless chain are dropped into the upper end of the sluice, down which they pass, one after another, to Moosehead Lake, the average run being said to amount to about one-third of a million feet per day.[1]

CONTROL OF STORAGE AT TWIN DAM.

The uppermost point at which the Penobscot is at present directly touched by a railroad is Twin dam, at the outlet of North Twin Lake. Here is controlled, for log-driving purposes, the splendid storage afforded by North Twin, South Twin, Pamedecook, Ambajejus, and other connecting lakes. The dam by which this is effected is a timber structure some 400 feet long, with perhaps 100 feet of embankment at

[1] For facts regarding the upper waters of the Penobscot, I am indebted to Mr. E. S. Coe, of Bangor.

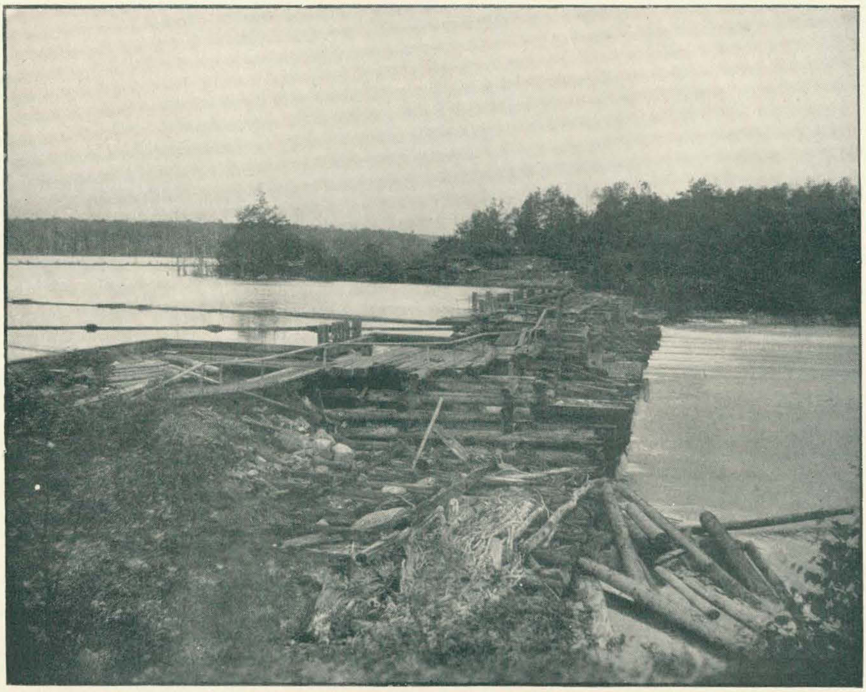
each end (shown in Pl. XII, *A*). It consists of a series of log and stone cribwork piers alternating with gates and sluiceways, and is a very old structure, in a somewhat dilapidated but perhaps sufficiently serviceable condition. From the top of the cross timbers to the bottom of the gates is about 17 feet, which substantially measures the depth of storage afforded by the dam. The lake fills up regularly in the spring, and by May or June water is overflowing the dam. In the lake the logs driven down from the upper Penobscot and from other tributary streams are finally collected and towed in rafts to the vicinity of North Twin dam. Here a few are sent from day to day through the smaller sluiceways, until finally, when the main drive has been collected, the timbers which have closed the principal sluiceway, some 40 feet wide and 17 feet high, are cut away, and in the torrent which then pours from the lake the remaining logs are rapidly carried out. After the passage of the drive the regulating gates are left open, and the natural flow of the river continues for the remainder of the season. This dam is controlled by the Penobscot Log Driving Company, which also maintains dams farther up the Penobscot, at the foot of Ripogenus and Chesuncook lakes, as well as at the outlet of Millnokett Lake, which drains into the Penobscot some 6 miles below North Twin dam. At the outlets of most of the other and lesser lakes there are also dams maintained for log-driving purposes by individual owners.

WATER POWERS.

Below North Twin dam the Penobscot is from 350 to 400 feet wide, and presents very rough water for the next 15 miles, to Medway; while at Grand Falls, 5 miles below North Twin dam, there is an abrupt pitch of 12 feet over ledges. From Medway to Mattawamkeag the water is relatively smooth, although with a swift current.

A short distance below the mouth of the Mattawamkeag, the Penobscot, there about 500 feet wide, is crossed by the Canadian Pacific Railway; but there is neither bridge nor dam elsewhere upon its course below Twin Lakes until the immediate vicinity of the mouth of the Piscataquis is reached. In the stretch from the Mattawamkeag to the Piscataquis the river has a good current, with rapids at what are known as Five Island Rips, opposite the village of Winn, and the upper and lower Mohawk Rips, opposite South Lincoln. At Winn the rapids are heavy; the river bed is composed of ledge, which here and there rises above the water surface; the banks are of good height, and the site appears to be an important one for the development of power. At the lower Mohawk Rips the river is probably 800 or 1,000 feet wide, the bed partly of ledge and strewn with bowlders, the banks gravelly and of fair height, but the site appears of much less consequence than that at Winn.

Between the towns of Enfield and Howland, and a quarter of a mile or more above the mouth of the Piscataquis, is the uppermost devel-



A. NORTH TWIN DAM, CONTROLLING STORAGE ON PENOBSCOT RIVER, IN MOOSEHEAD LAKE.

B. EAST OUTLET DAM, MOOSEHEAD LAKE, AS SEEN FROM CANADIAN PACIFIC RAILWAY BRIDGE.

oped water power on Penobscot River—that of the Piscataquis Falls Pulp and Paper Company, whose mill has a capacity for manufacturing 40 tons per day of mechanical wood pulp. This privilege was developed six or eight years ago, and substantially the same company that owns it also has a mill at Great Works, below Oldtown. The dam, like almost all the dams on the rivers of Maine, is a log cribwork, and is packed with stone. Its length is about 1,000 feet, and, as is necessary upon a river so largely utilized for log driving, a sluiceway for logs is provided in the central part of the structure. The hydraulic canal follows the east bank for 1,000 feet, more or less, to the mill, taking the course of an old navigation canal by which steamboats formerly passed the falls. At the mill a head of 20 feet is obtained for the turbines, of which 2,500 horsepower are installed; there is no lack of water, except occasionally to a slight degree in the latter part of August or early in September.

Below the Piscataquis no dams are encountered before reaching Oldtown, but there are occasional rapids offering possible sites for the development of power. Where confined within a single channel the river appears generally to be nearly or quite 1,000 feet in width, but it is frequently divided into several channels by islands. The Passadumkeag Rips are close to the mouth of the river of the same name. Here the banks are of good height and there is considerable exposed ledge in the east bank and on the river bed, but it is questionable whether a dam of suitable height could be built without causing a setback upon the privileges on the main river and the Piscataquis at Howland. A more promising site is that at Birch Island Rips, perhaps 2 or 3 miles below the mouth of Olamon Stream. These rips are short but strong, and the river is divided by a rocky island.

Above and in the vicinity of Oldtown, as has elsewhere been noticed, the Penobscot is divided by many islands, differing greatly in size; the channels between them are variously controlled and utilized in the operations of sorting, storing, and driving logs. Opposite Oldtown the waters become confined to substantially two channels, the main Penobscot River and the Stillwater Branch, between which the flow in low stages appears, from measurements made ten or twelve years ago by Prof. George H. Hamlin, to be divided in the ratio of from 5 to 8 parts in the former to 1 part in the latter, and on which the water-power improvements at Oldtown and Orono are situated.

On the main river the upper privilege at Oldtown is owned by the Bodwell Water Power Company, which leases power to the present users. The dam is a log cribwork from the left bank to an exposed ledge in the center of the stream, and thence to the right bank is built of squared timbers, the spaces filled in with stone. The influence of this dam extends upstream a mile or more, and is there terminated by short but heavy rips in the channels into which the river is subdivided. On the left bank the fall available at the mills is stated as 15 feet, and power is used by the sawmills of B. B. Thatcher & Co., and the Jordan Lumber Company, together manufacturing from 20,000,000 to 25,000,000 feet of lumber during the season, and by the Oldtown Electric Light Company, using upward of 100 horsepower. On the right bank water is admitted through a substantially constructed bulkhead to a canal 40 or 50 feet wide, inclosed by a heavy wall on the river side and carried downstream as far as required for the present works. The head obtained on the turbines is 11 feet, and power is utilized by the Oldtown Woolen Company, which has an 8-set mill, and by the Public Works Company, of Bangor, for operating pumps for the public water supply, the delivery being about 600,000 gallons per day.

The next privilege below, on the main river, is that at Great Works, owned by the Penobscot Chemical Fiber Company, which manufactures about 25 tons of wood pulp per day. The fall amounts to 14 feet, and the above company operates 1,040 horsepower of turbines on the west bank and occasionally a single wheel of 146 horsepower on the east bank. Power is also leased to Messrs. Mullen & Engels for a sawmill having a capacity for manufacturing 20,000,000 feet of lumber during the season.

On the Stillwater Branch are three dams. The uppermost of these is at the village of Stillwater (Ward 5, Oldtown), where a fall of 18 feet is obtained. The entire privilege is owned by Mrs. W. B. Hayford, of Bangor, from whom power is rented by Messrs. Pierce & Sutton for operating a sawmill containing two gang saws, a single saw, and various machines for the manufacture of shingles, clapboards, laths, etc., the capacity of the mill being about 10,000,000 feet of manufactured lumber per season.

The second and third dams are close together, and but little above the confluence of the Stillwater with the main river. They lie in the town of Orono, between Orono village on the west bank and what is locally known as Webster on the east bank. The principal use of power is in the pulp mill of the Webster and Ring Pulp Company, which combines the fall past both dams into a single fall, amounting to 26 or 27 feet, and has 3,000 horsepower of turbines installed. In the low stages of late summer flow not more than half this amount of power is obtained. The pulp is manufactured into paper on the opposite or Webster bank by the Webster Paper Company, whose daily product is about 25 tons of news paper. This company uses the lower fall only, and has 300 horsepower of turbines. Power is further utilized at these dams for the sawmills of William Engels & Co., and Adams & Co., together manufacturing from 12,000,000 to 20,000,000 feet of lumber annually, and at Mansfield & Co.'s shop for the manufacture of cant-dogs.

Passing below the junction of the Stillwater Branch with the main Penobscot, the first privilege is that at the point locally known as Basin Mills, in the town of Orono. Here a long log dam across the principal channel diverts water through a small channel formed by an island to the sawmills of James Walker & Co., the continuation of the channel serving as tailrace, and the conditions thus being peculiarly favorable for the safe and convenient utilization of the river. The head obtained is 10 feet, and there is manufactured about 13,000,000 feet of lumber per season.

The next dam is 3 or 4 miles farther downstream, at Veazie, about 5 miles above Bangor. Here the power was originally utilized by sawmills, which have now been discontinued and succeeded by the extensive electric plant of the Public Works Company, of Bangor. The working head obtained on the turbines ranges from 7 to 11 feet, according to the stage of river in different seasons. Under the larger head the wheels at present installed furnish, in the aggregate, 1,650 horsepower, of which 1,500 horsepower is used for generators and 150 horsepower for pumps furnishing the water supply of Veazie and Brewer. There is a steam plant of equal capacity with the turbines, for use in case of need, and some steam power is found necessary at times in summer. The electricity developed at this station is utilized for street lighting at Brewer, lying across the Penobscot from Bangor; for private incandescent and arc lighting in Bangor, and for operating the city electric-car lines in Bangor, as well as the suburban lines running northward to Oldtown and southward to Winterport. In the summer of 1897 additional turbines were being installed for local electric lighting in Veazie.

The final water privilege on the Penobscot is a mile or more above the business portion of Bangor, and is utilized for the municipal water supply and electric-lighting plant of that city. There is considerable oscillation below the dam, due to the tide, and the head on the turbines ranges from 4 to 8 or 9 feet, according to stage of river and of tide. There are at present five turbines in use, rated at 125 horsepower each under an 8-foot head. One of these is used continuously for operating the mechanical filter plant; four are needed during the day for the general demands of pumping, while at night two are devoted to the street lighting of Bangor. Considerable improvements and enlargements of the plant are in progress.

While the figures at hand for the volume of the lower river are few, and those for the fall are neither definite nor probably very accurate, the latter seem to give a fall from the head of the Stillwater Branch above Oldtown to mean tide at Bangor of from 80 to 85 feet. Combining with this fall the figures elsewhere given for flow, it appears that the power of this portion of the river is equivalent in practically its lowest stages to from 18,000 to 20,000 net horsepower, with continuous use for the twenty-four hours. Although the actual power now employed can not be stated, it is evident that the full power of the river is far from being utilized. Of the 80 feet or thereabouts of fall above mentioned, only about 56 feet is embraced in the falls at the dams on the main river, the balance being represented mainly at the scattered rips between the head and the foot of Stillwater Branch. Whether a portion of this balance could be utilized to advantage in an independent privilege, or to what extent it could be incorporated in existing privileges, can only be determined by further investigation.

TRIBUTARIES OF PENOBSCOT RIVER.

Ascending the Penobscot, the larger tributaries in point of drainage area are, in order: the Passadumkeag, 400 square miles; the Piscataquis, 1,500 square miles; the Mattawamkeag, 1,530 square miles; and the East Branch of the Penobscot, 1,170 square miles.

PASSADUMKEAG RIVER.

The Passadumkeag, which enters the main river from the east about 30 miles above Bangor, though small, is fed by a number of lakes which offer facilities for storage, and is itself reported to have considerable concentrated fall. Its present utilization for power is slight.

PISCATAQUIS RIVER.

The Piscataquis discharges from the west 4 miles above the Passadumkeag. This stream has the advantages of being followed by a railroad through a large part of its course, of receiving the discharge from several lakes of important size (the aggregate lake surface for the basin being between 80 and 90 square miles), and of possessing considerable fall, amounting to about 140 feet in the 20 miles below the mouth of the Sebec, at which latter point the drainage area is 750 square miles. Undoubtedly the largest single power in use on the stream is that close to the mouth, where the works of the Howland Falls Pulp Company are situated, with turbines developing 800 horsepower on the fall of 15 feet. Power is in use at Dover, some 32 miles above the mouth, at Guilford, 6 or 8 miles above Dover, and possibly at some other points; at the places mentioned the drainage area is considerably less than 400 square miles. The lake storage above them is not large, and the powers are not, therefore, of great importance. Not far above this section the valley of the stream becomes narrow, and its course lies through a broken, mountainous country, as the divide about Moosehead Lake is approached. On the whole, perhaps the most important present use of the stream is for log driving, but by proper control of the tributary lakes its value for water power can be greatly enhanced.

MATTAWAMKEAG RIVER.

The Mattawamkeag, which joins the Penobscot from the east 60 miles above Bangor, is followed through its lower course by the Maine Central Railroad, and from Bancroft to the mouth—a distance, by river, of 23 miles—falls 145 feet, from 322 to about 177 feet above mean tide.

The river drains one large lake, Baskahegan, presenting about 18 square miles of surface, and a number of small ones; but it is utilized for power by a few small mills only, and its most important employment at present is for log driving.

EAST BRANCH, OR MATTAGAMON RIVER.

The East Branch, or Mattagamon River, rises from 20 to 30 miles to the north of Mount Katahdin, and joins the Penobscot 12 miles above the Mattawamkeag. In the 30 miles from Mattagamon Lake, which is about 850 feet above tide, there is a fall of about 550 feet to the Bangor and Aroostook Railroad crossing, some 10 miles from the mouth, where the water surface is 300 feet above tide, according to railroad surveys; but the stream lies in an unsettled region, is touched by railroad at but one point, and is not now utilized for power.

KENNEBEC RIVER.

Moosehead Lake, the largest in New England, having a water surface of 120 square miles and lying somewhat west of the center of the State of Maine, is the immediate source of the Kennebec River. This lake is in turn fed by Moose River, the remote sources of which are on the western border of the State, and by sundry minor streams. The northern extremity of the lake is within 2 or 3 miles of the main branch of Penobscot River, as has already been noticed in describing the latter stream. Including the surface of the lake itself, the area tributary at its outlet is about 1,250 square miles. From Moosehead Lake, which is approximately 1,050 feet above sea level, the Kennebec pursues a southerly course to the ocean, passing over a distance of about 140 miles and finally discharging into Merrymeeting Bay, 35 miles northeast of Portland. The river is navigable during two-thirds of the year from the mouth to Augusta, 26 miles; it is also closely followed by railroad throughout its course until within 45 miles of Moosehead Lake, and close to the lake is also crossed by the east and west line of the Canadian Pacific Railway.

The drainage basin measures 150 miles in length north and south, and is from 50 to 80 miles wide in the main portion, embracing a total area of about 6,330 square miles. The upper basin is still 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. The head waters of the tributaries in the northwest, such as Sandy, Dead, and Moose rivers, lie at elevations of from 1,800 to 3,000 feet above tide. Granite is easily obtained throughout the basin, with clay slate as the prevailing rock in the north. In the mountainous portions the soil is sandy and gravelly, succeeded by a greater proportion of loam and clay to the southward.

Drainage areas, Kennebec River and principal tributaries.

River.	Locality.	Drainage area.
		Sq. miles.
Kennebec	Outlet of Moosehead Lake	1,250
Do	Immediately below mouth of Dead River	2,570
Do	Carritunk Falls	2,900
Do	Madison	3,330
Do	Norridgewock	4,030
Do	Somerset Mills	4,380
Do	Waterville, above mouth of Sebasticook River.	4,410
Do	Waterville, below mouth of Sebasticook River.	5,470
Do	Augusta	5,770
Do	Mouth of river, head of Merrymeeting Bay	6,330
Moose	Outlet into Moosehead Lake	660
Dead	Mouth	1,000
Sandy	Farmington	340
Do	Mouth	650
Sebasticook	do	1,060
Messalonskee	do	205
Cobbosseecontee	do	230

Fall in Kennebec River.

Locality.	Distance from mouth of river.*a*	Height above mean tide.	Fall between points.	Distance between points.	Average fall per mile between points.	Authority for elevation.
	Miles.	*Feet.*	*Feet.*	*Miles.*	*Feet.*	
Canadian Pacific Railway crossing at outlet of Moosehead Lake.	142	*b*1,034				P. Alex. Peterson, chief engineer, Canadian Pacific Rwy.
			720	56	12.8	
Somerset Railway crossing at Carritunk Falls.	86	*c*314				John Ayer, president, Somerset Rwy.
			69	11	6.3	
Somerset Railway crossing at Madison.	75	*c*245				Do.
			98	8	12.2	
Somerset Railway crossing at Norridgewock.	67	*c*147				Do.
			81	22	3.7	
Maine Central Railroad, upper crossing at Waterville.	45	*d*66				H. C. Robinson, assistant engineer, Maine Central R. R.
			66	19	3.5	
Augusta	26	0				

a Measured on Colton s map of Maine, scale about 8¾ miles to the inch.
b Canadian Pacific Rwy. levels (high water, 1,038.6; low water, 1,033.6).
c Adjusted for water surface above dam and for mean tide from profile elevation of Somerset Rwy.
d Adjusted for water surface from elevation of track, 87 feet above mean tide.

TRIBUTARY LAKES.

Moosehead Lake constitutes a reservoir of magnificent proportions. Furthermore, its elevation is such that the fall thence to tide water is exceeded, for a like distance from tide, by that of the Androscoggin only among the large rivers of the State. Although there appears to be no other lake in the Kennebec Basin exceeding 10 square miles in area, there are many of less size, giving an aggregate water surface of nearly 360 square miles, according to Wells,[1] distributed as follows:

Tributary to—	Square miles.
Messalŏnskee River	27.45
Sandy River	10.10
Carrabassett River	10.20
Dead River	24.75
Moose River	31.60
Sebasticook River	48.30
Wesserunsett River	5.35
Kennebec River (Moosehead Lake)	120.00
Kennebec River (at sundry points above Augusta)	53.25
Kennebec River (below Augusta)	25.85
Total	356.85

In spite of the excellent natural facilities for storage offered by this basin, it is important to notice that these have been but imperfectly developed, and that the storage already controlled is not employed in the manner most favorable to water-power interests. There is a natural conflict in this matter. For the purposes of log driving it is desirable to open the gates at the lakes in the spring and early summer, when the normal flow of the stream is already large, so as to flush the logs down to the mills; while the economical use of stored water for power requires it to be held back in the lakes until midsummer and gradually drawn down from that time through the fall and winter. An association of the manufacturers upon the river has been formed and chartered under the name of the Kennebec Power Company, with a view to the systematic development and control of the storage of this basin, but no important results have yet been attained.

Moosehead Lake[2] fills during the winter and spring, especially with the melting of the snow, the last of which is usually wasted and forms part of the freshet flow. Between about the 20th of May and the 1st of June, whenever the logs arrive in sufficient numbers at the lake dam, usually about ten days after the ice leaves the lake, the outlet gates are opened and from that time water is steadily drawn. During June the draft is from 3,000 to 6,000 cubic feet per second, after which it decreases, and by the middle of autumn or sometimes earlier the available storage is practically exhausted.

[1] Water-Power of Maine, p. 94.

[2] For information concerning Moosehead Lake I am especially indebted to Mr. Sumner Hollingsworth, of Boston.

In fig. 9 is shown graphically the discharge from the lake for a period of eleven months, April 1, 1895, to February 28, 1896, corrected for estimated leakage. This diagram clearly reveals the excessive draft upon the lake from the middle of May to the middle of July incident to log driving. The amount drawn in excess of 2,000 cubic feet per second, from May 18 to July 9, 1895, if it had been held back and suitably delivered after the latter date, would have maintained the run-off at 2,000 cubic feet per second until December. The storage in the lake is controlled by the Kennebec Log Driving Company. The dams at the two outlets, known, respectively, as the east and the west outlet, are of log cribwork filled with stone and buttressed by heavy piers of similar construction. The spaces between the piers are controlled by 36 gates at the east outlet (Pl. XII, *B*) and 5 gates at the west outlet, while one space in the former, used as a log sluice, is closed

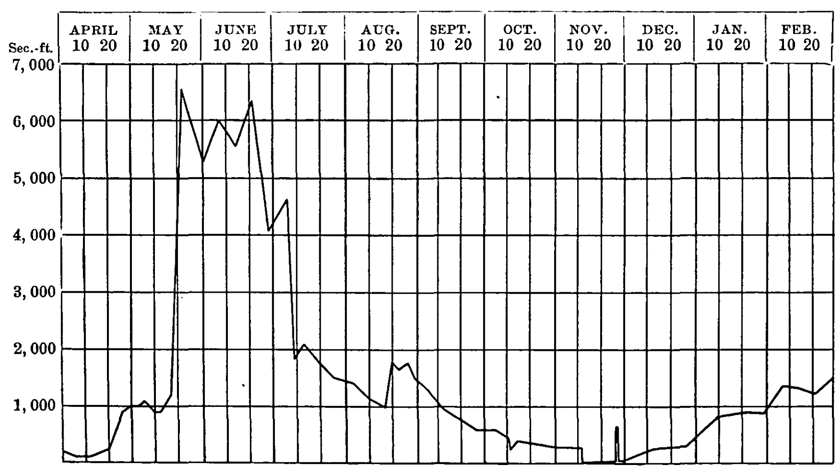


FIG. 9.—Flow from east-outlet dam, Moosehead Lake, April 1, 1895, to February 28, 1896.

by logs which are cut away when the work of sluicing begins. Nominally, the lake has been raised 7½ feet by the dams above the original low-water level, but it can not now be drawn much lower than within a foot of that level, and the actual yearly range between high and low water is from 5½ to 6 feet. The tributary drainage is not entirely controlled, and a large wastage past the dams occurs nearly every year. It is probably practicable to increase the available storage by cutting down the outlet and raising the dams, but whether the necessary outlay would be warranted can not now be stated.

THE RIVER BELOW MOOSEHEAD LAKE.

Excepting by a little sawmill at the outlet dam, the Kennebec is not utilized for power for 50 miles. For nearly all of this distance it is without railroad facilities and runs through a wilderness. Its fall is rapid, however, amounting to more than 700 feet in the distance mentioned—that is, from the lake to Carritunk Falls. According to Wells, 500 feet more or less of this occurs in the 23 miles from the lake to The Forks, where Dead River is received. For a considerable part of that distance the river is described as running between steep, rocky walls from 20 to 50 feet high, and as a torrent in character. At the Canadian Pacific Railway crossing, less than a quarter of a mile from the outlet dam, the Kennebec is about 300 feet wide, with a swift current. In the 4 miles from the lake to an enlargement of the river known as Indian Pond, I am informed that railway surveys have shown a fall of 93 feet. At Indian Pond, which is 4 or 5 miles long, the stream from the west outlet of Moosehead Lake joins the main river. Below the pond the river is described as having a continuous heavy fall for 7 miles. The drainage area increases from 1,250 square miles at the outlet of Moosehead Lake to 2,570 below the mouth of Dead River and to 2,900 at Carritunk Falls. There is evidently a large power in this stretch of river available for future development.

In the succeeding 11 miles from Carritunk Falls to Madison, between the crossings of the Somerset Railway above the respective dams, the fall is about 70 feet, and in the next 8 miles to Norridgewock it is about 100 feet. Thence to tide water at Augusta the average descent becomes much less, the fall amounting to 147 feet in 41 miles, or about 3½ feet per mile.

The uppermost utilized power on the Kennebec is that at Carritunk Falls, some 60 miles above Augusta. Including this, there are at present seven developed water powers on the river, utilizing a probable aggregate of 24,000 effective horsepower, and covering about 142 feet of the 314 feet actual fall of the river.

The water power at Carritunk Falls has been developed by the Moosehead Pulp and Paper Company, which has about 3,500 horsepower of turbines installed. The conditions there have been concisely described in a paper presented by Samuel McElroy before the American Society of Mechanical Engineers (see Transactions, Vol. XVII). There is a natural cascade at this point, with a pitch of 28 feet through a narrow gorge, above and below which the river widens out. The dam was built in the winter of 1890–91 and makes the available fall 30 feet.

Passing downstream the next dam is at Madison, where about 2,500 horsepower is utilized under a fall of 16 feet by the sulphite fiber mill of the Manufacturing Investment Company, the mills of the Indian Spring Woolen Company, and the Madison Woolen Company, and the pumping station of the Madison Water Company. There is a natural fall of about 80 feet in pitches and rapids in the river at this point, so that only a small portion of the available power is employed. From the figures for flow at Waterville, elsewhere given, it appears fair to estimate the power of the river at Madison in practically the minimum stage for a series of years, as 75 net horsepower per foot of fall, available continuously throughout the twenty-four hours.

At Norridgewock, some 3 miles above the Somerset Railway bridge, there is a natural fall of 8 feet in the Bombazee Rips, and with a dam a fall of 12 feet is considered practicable. The privilege is owned by the Bombazee Water Power Company, but has not been improved.

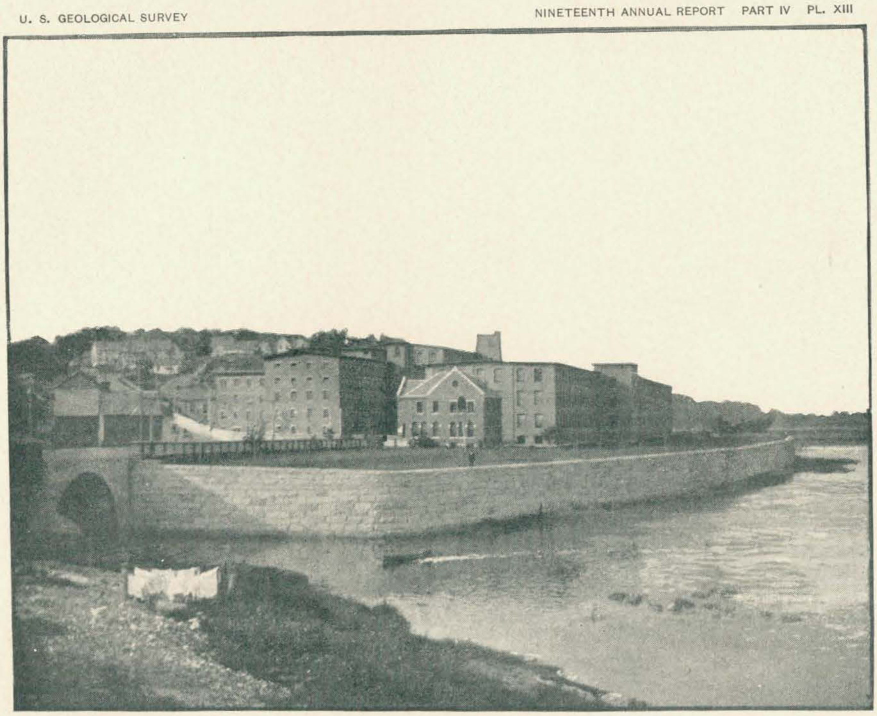
The next dam is at Skowhegan, where the power is controlled by the Skowhegan Water Power Company. The average fall at this point is 17 feet, and 28 water wheels of an aggregate of 5,100 horsepower are in use by the various works. Of this amount 2,900 horsepower is employed in pulp manufacture, 750 horsepower exclusively for electric lighting and power, and the balance by grist, saw, planing, and woolen mills, and sash-and-blind and scythe factories, some of the turbines operating factories by day and electric lights by night.

At Somerset Mills, in the town of Fairfield, a fall of 12 feet has been used by a sawmill, but, as elsewhere stated, the dam was carried away early in 1896 by a freshet and had not been rebuilt when the site was visited.

Kendalls Mills, also in the town of Fairfield, furnishes the next instance of utilized power. Here a fall of 22 feet, controlled by the Kendalls Mills Power Company, is employed to the extent of about 1,000 horsepower, nearly one-half of this being used by an electric-light plant, in addition to which there is a furniture factory, a pulp mill, a sawmill, and a recently constructed woolen mill.

At Waterville and Winslow is encountered the largest development of power upon the Kennebec. The upper privilege, owned by the Hollingsworth & Whitney Company, paper manufacturers, occupies the site of what were formerly known as the College Rapids, and embraces a fall of 20 feet, upon which are operated 42 turbines, of an aggregate of 5,260 horsepower. The lower privilege, at Ticonic Falls, is owned by the Lockwood Company, at whose cotton mills about 2,400 horsepower is used. A dam 750 feet long raises the river surface 7 feet, and a further natural fall of 13 feet over a slate ledge gives a total head of about 20 feet.

At the head of tide water at Augusta the last dam on the river is reached, a cribwork structure 17 feet high and 950 feet long, ponding the water some 17 miles upstream to Waterville. On the west bank the Edwards Manufacturing Company uses about 2,500 horsepower in its cotton mills, shown in Pl. XIII, *A*, while on the east bank 1,500 horsepower is employed by the Cushnoc Fibre Company and the Kennebec Light and Heat Company, the latter furnishing the municipal lighting for Augusta, and other lighting in that city, Hallowell, Gardiner, and Togus. The fall is affected a foot or so by the tide.



A. COTTON MILLS OF EDWARDS MANUFACTURING COMPANY, AUGUSTA, MAINE. DAM AT EXTREME RIGHT.

B. FALLS AT OAKLAND, MAINE, ON THE MESSALONSKEE RIVER.

RECORD OF DISCHARGE.

The only long-continued observations upon the volume of the Kennebec are those which have been made at Waterville by the Hollingsworth & Whitney Company, and the results of which were kindly furnished by Mr. Sumner Hollingsworth, president of the company. The manufacturing works are located above the mouth of Sebasticook River, the tributary drainage area of the Kennebec being about 4,410 square miles as measured on Colton's map of Maine. Of the figures for discharge those prior to June 20, 1893, are from computations by weir formula of the quantity flowing over the dam; those subsequent to June 20, 1893, at which time the mill began running, are from computations of the flow through the turbines, based upon assumed ratings, to which has been added any excess passing over the crest of the dam,

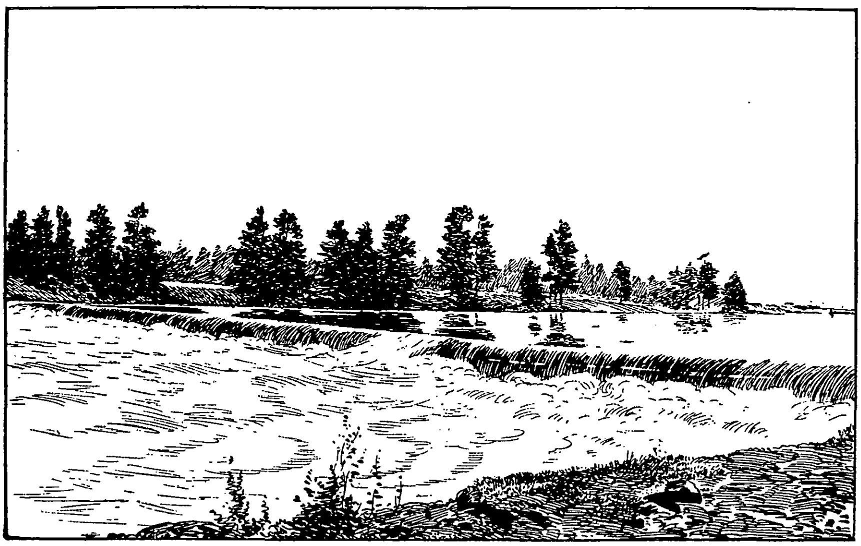


FIG. 10.—Dam at Waterville, Maine, on Kennebec River.

the length of which is 734 feet. The figures really represent the flow at 12 o'clock noon on each day, this hour having been chosen, after some investigation, as a time when the flow is least affected by storage at dams upstream and as giving most nearly the average for the day.

The results of these observations are presented in figs. 11 and 12, and the fluctuations in flow are thus graphically shown. An inspection of these diagrams and of the values upon which they are based will reveal very sudden and large variations in volume during the spring months, consistent with the mountainous character of the upper watershed. Thus the discharge increased from 30,700 cubic feet per second May 17, 1893, to 83,500 cubic feet per second on the following day, and dropped to 46,100 on the next day. The illustration, fig. 10, shows the

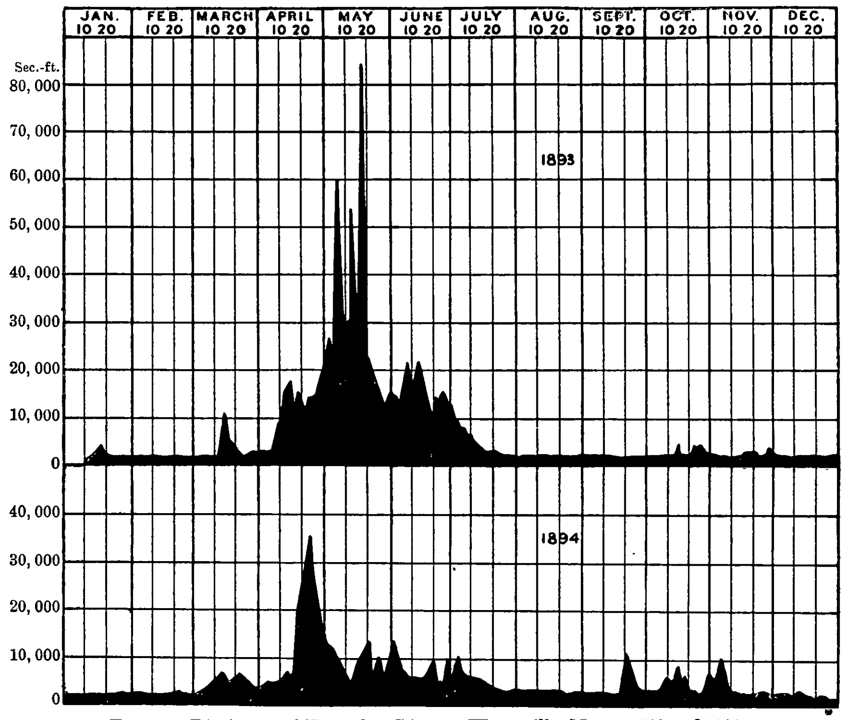


FIG. 11.—Discharge of Kennebec River at Waterville, Maine, 1893 and 1894.

dam of the Hollingsworth & Whitney Company, over 700 feet long, during this freshet, with about 9 feet of water passing over its crest. The variations of discharge, in cubic feet per second, were in detail as follows:

Rate of discharge of Kennebec River at Waterville, Maine, in May, 1893.

		Cubic feet per second.
May 17,	10.00 a. m	30,700
	6.30 p. m	49,200
May 18,	7.00 a. m	83,500
	8.40 a. m	82,800
	9.15 a. m	81,900
	10.40 a. m	79,500
	11.40 a. m	79,500
	12.00 m	77,600
	1.00 p. m	76,000
	3.00 p. m	71,900
	5.00 p. m	66,500
May 19,	7.00 a. m	49,300
	12.00 m	46,100
May 20,	7.00 a. m	37,100

Again, in April, 1895, the discharge rose from 24,000 cubic feet per second on the 14th to about 86,000 cubic feet per second on the 15th, or to more than three and one-half times its previous amount. Through the spring and early summer numerous minor fluctuations of discharge are also produced by the artificial drawing down of the lakes for log driving. The small lakes are thus frequently drawn in April, while the gates at Moosehead are usually opened in the latter part of May, as previously noticed. The figures for Sunday flow, where given, as in

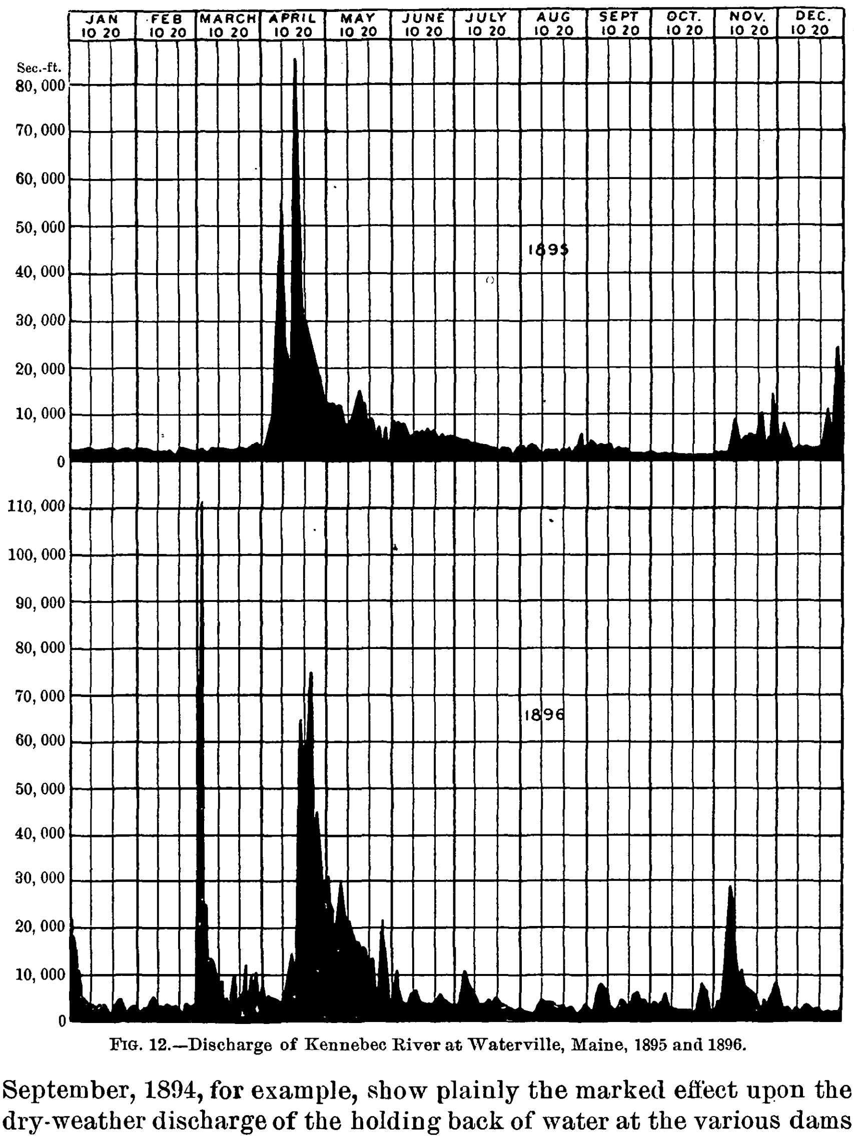


FIG. 12.—Discharge of Kennebec River at Waterville, Maine, 1895 and 1896.

September, 1894, for example, show plainly the marked effect upon the dry-weather discharge of the holding back of water at the various dams above Waterville.

SUMMARY OF YIELD.

In the succeeding tables the figures for discharge have been averaged and analyzed with the view of bringing out the distinguishing features of the flow by calendar months. The column for "maximum day" shows the freshets of the year and the months in which they occur. From the column for "minimum week," on the other hand, may be learned the value of substantially the low-water discharge of the year, as well as that of the various calendar months. The "minimum week," as used here, is the period of seven consecutive days, not necessarily beginning with Sunday, giving the minimum average discharge, and is taken in preference to the minimum day as being of more practical importance than the latter, inasmuch as it avoids the extreme and misleading figures resulting from the holding back of water on certain days at the various dams. Other columns give the average discharge for the respective calendar months in cubic feet per second, and the equivalent in inches on drainage area (shown graphically in fig. 13), and in cubic feet per second per square mile of drainage area. Considering the methods employed in determining the discharge and the uncertainty as to the true size of the drainage area, it is necessary to admit that some of the results here presented are subject to possible errors of 5 or even 10 per cent, the greatest accuracy probably accompanying the low-stage figures. As to low-water discharge, the important fact will be noticed that for the four years 1893 to 1896 the average for the minimum week of the entire period was about 1,100 cubic feet per second, equivalent to about 0.25 cubic foot per second per square mile of tributary drainage area. Finally, the percentage relation is computed between yearly run-off and yearly rainfall. In order to avoid the errors introduced into such a comparison by varying amounts of snow lying upon the surface and of storage held in the lakes on January 1, which would otherwise be taken as the beginning of the yearly period, October 1 has been chosen as the beginning, since at that time there is no snow and the lakes are likely to be uniformly at a low stage. Nevertheless, the percentage results obtained must be regarded as subject to considerable possible error, because of the uncertainty as to the true rainfall to charge against the basin. The only rainfall station within the basin at which regular records were made for the years here considered was Fairfield, at the extreme southern limit. The results obtained by the volunteer observer at this station are reputed to be trustworthy, but can scarcely be truly representative of the 4,000 square miles in question to the north of it. The figures used, however, indicate for the three years from October 1, 1893, to October 1, 1896, an average annual run-off of nearly 60 per cent of the rainfall.

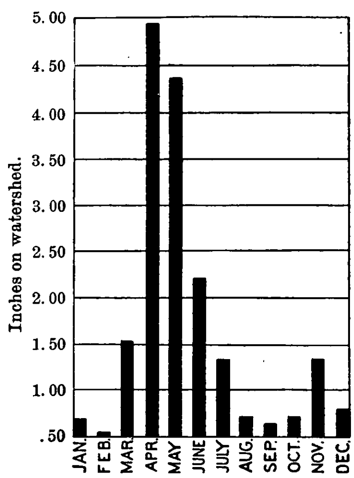


FIG. 13.—Average monthly discharge of Kennebec River at Waterville, Maine, 1893 to 1896, inclusive.

Analysis of discharge of Kennebec River at Waterville, by calendar months, 1893 to 1896.

[Drainage area, 4,410 square miles.]

Year and month.	Maximum day, average for the 24 hours.	Average for minimum week, 24 hours per day.	Average for month, 24 hours per day.	Equivalent in inches on drainage area for month.	Equivalent in cubic feet per second of continuous flow per square mile of drainage area.
1893.	*Cubic feet per second.*	*Cubic feet per second.*	*Cubic feet per second.*		
January (12 to 31)	5,000	2,140	2,650	0.69	0.60
February	3,000	2,180	2,350	0.55	0.53
March	11,300	2,330	4,180	1.09	0.95
April	19,800	3,960	11,660	2.95	2.64
May	83,500	15,760	30,520	7.98	6.92
June	23,500	12,480	15,290	3.87	3.47
July	11,230	2,450	5,770	1.51	1.31
August	2,430	2,200	2,270	0.59	0.51
September	2,680	1,750	2,040	0.52	0.46
October	4,000	1,810	2,330	0.61	0.53
November	3,980	1,980	2,230	0.56	0.51
December	2,780	1,440	1,580	0.41	0.36
Year	83,500	1,440	*a* 7,280	21.33	1.65
1894.					
January	1,910	1,550	1,640	0.43	0.37
February	1,910	1,740	1,780	0.42	0.40
March	6,660	1,810	4,020	1.05	0.91
April	35,280	4,650	14,680	3.71	3.33
May	15,650	6,740	9,570	2.50	2.17
June	12,930	5,540	7,790	1.97	1.77
July	10,020	3,650	5,720	1.50	1.30
August	3,300	2,530	2,970	0.78	0.67
September	12,100	1,960	2,740	0.69	0.62
October	9,040	1,870	3,750	0.98	0.85
November	10,510	2,260	3,760	0.95	0.85
December	2,600	1,480	1,930	0.50	0.44
Year	35,280	1,480	*a* 4,930	15.48	1.12
1895.					
January	2,510	1,590	2,040	0.53	0.46
February	2,440	1,580	1,800	0.43	0.41
March	2,770	1,810	2,000	0.52	0.45
April	86,200	4,650	23,930	6.05	5.43
May	16,170	6,800	9,580	2.50	2.17
June	9,820	5,350	6,430	1.63	1.46

a Average flow for year.

Analysis of discharge of Kennebec River at Waterville, by calendar months, 1893 to 1896—Continued.

Year and month.	Maximum day, average for the 24 hours.	Average for minimum week, 24 hours per day.	Average for month, 24 hours per day.	Equivalent in inches on drainage area for month.	Equivalent in cubic feet per second of continuous flow per square mile of drainage area.
	Cubic feet per second.	*Cubic feet per second.*	*Cubic feet per second.*		
1895.					
July	5,040	2,630	3,520	0.92	0.80
August	5,090	2,070	2,690	0.70	0.61
September	2,870	1,160	1,780	0.45	0.40
October	1,590	1,120	1,250	0.33	0.28
November	15,900	1,650	5,610	1.42	1.27
December	26,670	2,230	6,030	1.58	1.37
Year	86,200	1,120	*a*5,610	17.06	1.27
1896.					
January	21,880	2,390	4,340	1.13	0.98
February	4,630	2,360	2,830	0.69	0.64
March	111,250	5,640	13,140	3.44	2.98
April	74,470	5,510	27,400	6.93	6.21
May	30,880	6,240	17,060	4.46	3.87
June	11,000	4,680	5,520	1.40	1.25
July	11,680	3,870	5,330	1.39	1.21
August	4,740	2,480	3,150	0.82	0.71
September	7,980	2,780	3,410	0.86	0.77
October	8,960	2,300	3,660	0.96	0.83
November	29,860	5,420	9,120	2.31	2.07
December	8,050	1,800	2,750	0.72	0.62
Year	111,250	1,800	*a*8,160	25.11	1.84

a Average flow for year.

Discharge of Kennebec River at Waterville, averaged by calendar months for entire period, 1893 to 1896.

Month.	Average for month, 24 hours per day.	Equivalent in inches on drainage area for month.	Equivalent in cubic feet per second of continuous flow per square mile of drainage area.	Rainfall.
	Cubic feet per second.			*Inches.*
January (*a*)	2,670	0.69	0.60	1.65
February	2,190	0.52	0.49	1.77
March	5,830	1.52	1.32	2.64
April	19,420	4.91	4.40	1.91
May	16,680	4.36	3.78	3.14
June	8,760	2.22	1.99	1.96
July	5,080	1.33	1.15	2.78
August	2,770	0.72	0.62	3.20
September	2,490	0.63	0.56	3.04
October	2,750	0.72	0.62	2.72
November	5,180	1.31	1.17	2.67
December	3,070	0.80	0.70	2.28
Year	*b* 6,400	19.73	1.45	29.76

a First 11 days in 1893 lacking. *b* Average flow throughout year.

Summary of yield of Kennebec Basin at Waterville, 1893 to 1896.

Period.	Run-off.	Rainfall. (*a*)	Ratio of run-off to rainfall.
	Inches.	*Inches.*	*Per cent.*
October 1, 1893, to October 1, 1894	14.6	29.8	49
October 1, 1894, to October 1, 1895	16.2	25.7	63
October 1, 1895, to October 1, 1896	24.5	37.4	65

a From records for Fairfield only, situated near extreme southern limit of drainage area here considered.

Monthly discharge of Kennebec River at Waterville, Maine, for the year 1897. (*a*)

[Drainage area, 4,410 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum day.	Minimum day.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	18,504	1,650	3,587	220,556	0.94	0.82
February	6,225	2,302	3,705	205,766	0.88	0.84
March	6,345	2,007	3,970	233,038	0.99	0.86
April	66,907	6,334	25,385	1,510,513	6.41	5.75
May	41,284	10,818	26,942	1,656,599	7.05	6.11
June	18,204	7,399	12,970	771,769	3.28	2.95
July	55,634	5,218	13,115	806,410	3.44	2.98
August	13,656	4,000	7,298	448,737	1.90	1.65
September	9,689	2,801	4,595	273,422	1.20	1.08
October	6,323	967	2,635	162,020	0.69	0.60
November	13,399	1,889	5,702	339,293	1.44	1.29
December	14,005	2,541	5,331	327,790	1.39	1.21
The year	66,907	967	9,588	6,955,913	29.61	2.18

a Results received since the writing of the above report.

TRIBUTARIES OF KENNEBEC RIVER.

MOOSE RIVER.

Moose River, drainage area 660 square miles, the principal feeder of Moosehead Lake, and Dead River, drainage area 1,000 square miles, joining the Kennebec from the west 23 miles below Moosehead Lake, presumably possess considerable power; but they are too remote from markets to have much present importance. The former is followed by the Canadian Pacific Railway for most of its course, but the basin of Dead River is not directly reached by rail.

SANDY RIVER.

Sandy River, which flows into the Kennebec from the west between 45 and 50 miles above Augusta, heads near Rangeley Lake. It drains 650 square miles and has a rapid fall, amounting to more than 1,600 feet. It is closely followed by rail throughout its upper course, and, although small powers are in use at Farmington Falls and New Sharon, the flow of the stream is small in dry weather and very variable, and the river can not be regarded as of especial importance at present.

SEBASTICOOK RIVER.

Sebasticook River, with a drainage area of 1,060 square miles, enters the Kennebec from the east opposite Waterville. In the 45 miles from Moose Pond to the mouth there is a fall of 170 feet. The stream is followed closely by rail and possesses a number of good water powers, perhaps the most important being that of the Kennebec Fiber Company, some 5 miles from the mouth, which utilizes 1,400 horsepower under an average head of 26 feet.

MESSALONSKEE RIVER.

Messalonskee River is a small stream draining 205 square miles and discharging into the Kennebec from the west at Waterville. It is fed from extensive lakes with an aggregate surface of between 25 and 30 square miles, which render its flow very constant and give it considerable value for power. The fall is stated to be 164 feet in the 5 or 6 miles from the lowest lake to the mouth. Near the mouth power is utilized to the extent of about 250 horsepower for the Waterville pumping station and several molding and planing mills. Farther upstream, in Oakland, are several excellent powers, one of them shown in Pl. XIII, *B*, with falls of 14, 40, 15, and 12 feet, successively, which are partially utilized.

COBBOSSEECONTEE RIVER.

Cobbosseecontee River drains a group of lakes lying from 5 to 15 miles westerly from Augusta, and empties into the Kennebec 8 miles below that city at Gardiner, its drainage area amounting to about 230 square miles. From the ordinary surface of Lake Maranacook, which is one of the upper lakes, to mean tide at the mouth of the river the fall is 206 feet, according to a profile elevation of the Maine Central Railroad, and in the lower three-quarters of a mile the fall is stated on good authority to be 136 feet. From above the uppermost of the eight dams which are found in this latter distance the municipal supply for Gardiner is drawn, and pumped by water power. Account is kept both of the quantities thus required and also of such additional water as passes the dam through a wastegate, for the delivery of which tables have been prepared. The sum of these quantities represents the yield of the drainage area at the upper dam, a record of which yield has been kept for a series of years by Messrs. S. D. Warren & Co., and has been furnished by their engineer, Mr. A. H. Twombly. These figures are presented in the accompanying tables.

In the first table are given the figures for flow by calendar months for the whole period, June, 1890, to December, 1896, first the average cubic feet per second for the working days of each month, and then the equivalent flow in inches on drainage area and in cubic feet per second per square mile. From existing maps the tributary drainage area can not be determined with great accuracy, and the results here given must be considered as subject to possible errors from all causes of at least 5 or 10 per cent. The gates are closed on Sundays and legal holidays, and no water is then allowed to run down the stream unless the lakes are full.

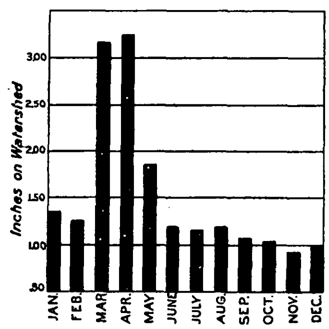


FIG. 14.—Average monthly discharge of Cobbosseecontee River, 1891 to 1896, inclusive.

In the second table the monthly discharge is averaged for the six years, 1891 to 1896, the results being also graphically portrayed in fig. 14. It is apparent from this diagram that for nine months in the year the flow in the outlet is very uniform, the value for power purposes of a stream fed by artificially controlled reservoirs being well illustrated, while nevertheless for the three spring months there is considerable wastage.

In the third and last table a summary of the discharge is given by years, for the purpose of determining the relation of run-off to rainfall. After 1892 the rainfall records used are those of the station at Gardiner, at the mouth of the Cobbosseecontee, while from 1890 to 1892, records for that station being wanting, those for Lewiston, 25 miles to the westward, have been employed. For the same reasons as in the case of the Kennebec, October 1 has been chosen for the beginning of the yearly periods in this computation. For the whole period from October 1, 1890, to October 1, 1896, from an average annual rainfall of about 42 inches, the average annual run-off from the drainage area appears to have been somewhat over 18½ inches, or about 45 per cent. In some years the departure from this mean is abnormally large and the accuracy of the corresponding percentages seems doubtful. For example, the figures indicate a run-off equal to 57 per cent of the rainfall for the year October 1, 1890, to October 1, 1891, and only 27 per cent for the following twelve-month period. Whether these deviations are due to varying depths of storage in the lakes or to other causes can not be stated. The result for the entire period covered by the records of flow, although somewhat low, appears not unreasonable.

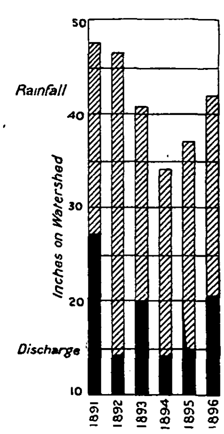


FIG. 15.—Average annual rainfall and discharge of Cobbosseecontee River, 1891 to 1896, inclusive.

Discharge of Cobbosseecontee River at dam of Gardiner Water Company, 1890 to 1896.

[Drainage area, 230 square miles.]

Year and month.	Average discharge during working days of month, 24 hours per day.	Equivalent in inches on drainage area for month.	Equivalent in cubic feet per second of continuous flow per square mile of drainage area.	Rainfall for month.
1890.	*Cubic feet per second.*			*Inches.*
June	325	1.58	1.42	3.71
July	300	1.26	1.09	4.83
August	290	1.22	1.06	3.47
September	290	1.22	1.09	5.13
October	310	1.56	1.35	5.47
November	355	1.73	1.73	1.89
December	298	1.26	1.09	5.55
1891.				
January	515	2.59	2.25	8.10
February	570	2.59	2.49	3.89
March	1,380	6.93	6.01	7.03
April	1,270	6.17	5.53	2.89
May	300	1.26	1.09	2.60
June	300	1.26	1.13	3.64
July	290	1.22	1.06	5.27
August	285	1.20	1.04	2.97
September	270	1.14	1.02	1.00
October	250	1.09	0.95	2.40
November	(*a*)	....	....	2.66
December	(*a*)	....	....	5.27
Year	540±	27.10±	2.00±	47.72
1892.				
January	260	1.10	0.95	5.52
February	280	1.13	1.05	2.21
March	280	1.22	1.06	2.43
April	280	1.19	1.07	1.05
May	280	1.18	1.02	4.62
June	280	1.18	1.06	7.22
July	280	1.18	1.02	3.18
August	280	1.22	1.06	8.11
September	280	1.18	1.06	4.48
October	280	1.18	1.02	1.81
November	280	1.13	1.01	4.54
December	280	1.18	1.02	1.49
Year	280	14.07	1.04	46.66

a Disharge smaller than that covered by rating of gates, and not measured; probably 200+ cubic feet per second.

Discharge of Cobbosseecontee River at dam of Gardiner Water Company, 1890 to 1896—Continued.

Year and month.	Average discharge during working days of month, 24 hours per day.	Equivalent in inches on drainage area for month.	Equivalent in cubic feet per second of continuous flow per square mile of drainage area.	Rainfall for month.
1893.	*Cubic feet per second.*			*Inches.*
January	280	1.18	1.02	2.70
February	280	1.09	1.05	4.79
March	415	2.08	1.80	3.18
April	650	3.16	2.83	2.52
May	1,020	5.12	4.44	4.66
June	280	1.18	1.06	2.56
July	280	1.13	0.98	1.12
August	270	1.18	1.02	3.27
September	250	1.05	0.94	3.23
October	220	0.93	0.81	5.90
November	220	0.89	0.80	1.83
December	220	0.89	0.77	5.13
Year	400	19.88	1.46	40.89
1894.				
January	220	0.96	0.83	3.30
February	220	0.86	0.83	1.99
March	360	1.81	1.57	1.44
April	310	1.51	1.35	1.86
May	285	1.25	1.08	5.84
June	300	1.26	1.13	1.18
July	280	1.13	0.98	2.30
August	280	1.22	1.06	3.08
September	270	1.09	0.98	3.81
October	250	1.09	0.95	4.25
November	250	1.01	0.90	2.21
December	250	1.01	0.88	2.80
Year	280	14.20	1.05	34.06
1895.				
January	250	1.09	0.95	2.50
February	220	0.86	0.83	1.64
March	220	0.93	0.81	2.48
April	780	3.79	3.40	4.83
May	280	1.22	1.06	1.50
June	280	1.13	1.01	2.01

Discharge of Cobbosseecontee River at dam of Gardiner Water Company, 1890 to 1896—Continued.

Year and month.	Average discharge during working days of month, 24 hours per day.	Equivalent in inches on drainage area for month.	Equivalent in cubic feet per second of continuous flow per square mile of drainage area.	Rainfall for month.
1895.	*Cubic feet per second.*			*Inches.*
July	280	1.18	1.02	4.55
August	270	1.18	1.02	3.28
September	230	0.93	0.83	1.21
October	(*a*)	....	....	1.82
November	(*a*)	....	....	6.85
December	220	0.89	0.77	4.40
Year	300±	14.90±	1.10±	37.07
1896.				
January	270	1.14	0.99	0.87
February	270	1.09	1.01	5.25
March	*b*1,200	6.03	5.23	7.19
April	750	3.64	3.26	2.02
May	280	1.18	1.02	2.80
June	280	1.18	1.06	1.94
July	280	1.18	1.02	3.18
August	270	1.14	0.99	2.88
September	250	1.05	0.94	7.60
October	230	1.01	0.88	2.64
November	230	0.89	0.80	4.12
December	250	1.05	0.91	1.52
Year	410	20.58	1.52	42.01

a Discharge smaller than that covered by rating of gates, and not measured: probably 200+ cubic feet per second. Average 220 for four days of October, and same for latter half of November.

b Ranged during month between 685 and 2,700.

Discharge of Cobbosseecontee River, averaged by calendar months for entire period, 1891 to 1896.

Month.	Average discharge during working days of month, 24 hours per day.	Equivalent in inches on drainage area for month.	Equivalent in cubic feet per second of continuous flow per square mile of drainage area.	Rainfall.
	Cubic feet per second.			*Inches.*
January	300	1.34	1.16	3.83
February	310	1.27	1.21	3.29
March	640	3.17	2.75	3.96
April	670	3.24	2.91	2.53
May	410	1.87	1.62	3.67
June	290	1.20	1.07	3.09
July	280	1.17	1.01	3.27
August	280	1.19	1.03	3.93
September	260	1.07	0.96	3.55
October	*a* 240	1.03	0.89	3.14
November	*a* 230	0.92	0.82	3.70
December	*a* 240	0.98	0.85	3.43
Year	*b* 350	18.45	1.36	41.39

a Based partly on estimate.
b Average discharge during working days throughout year, 24 hours per day.

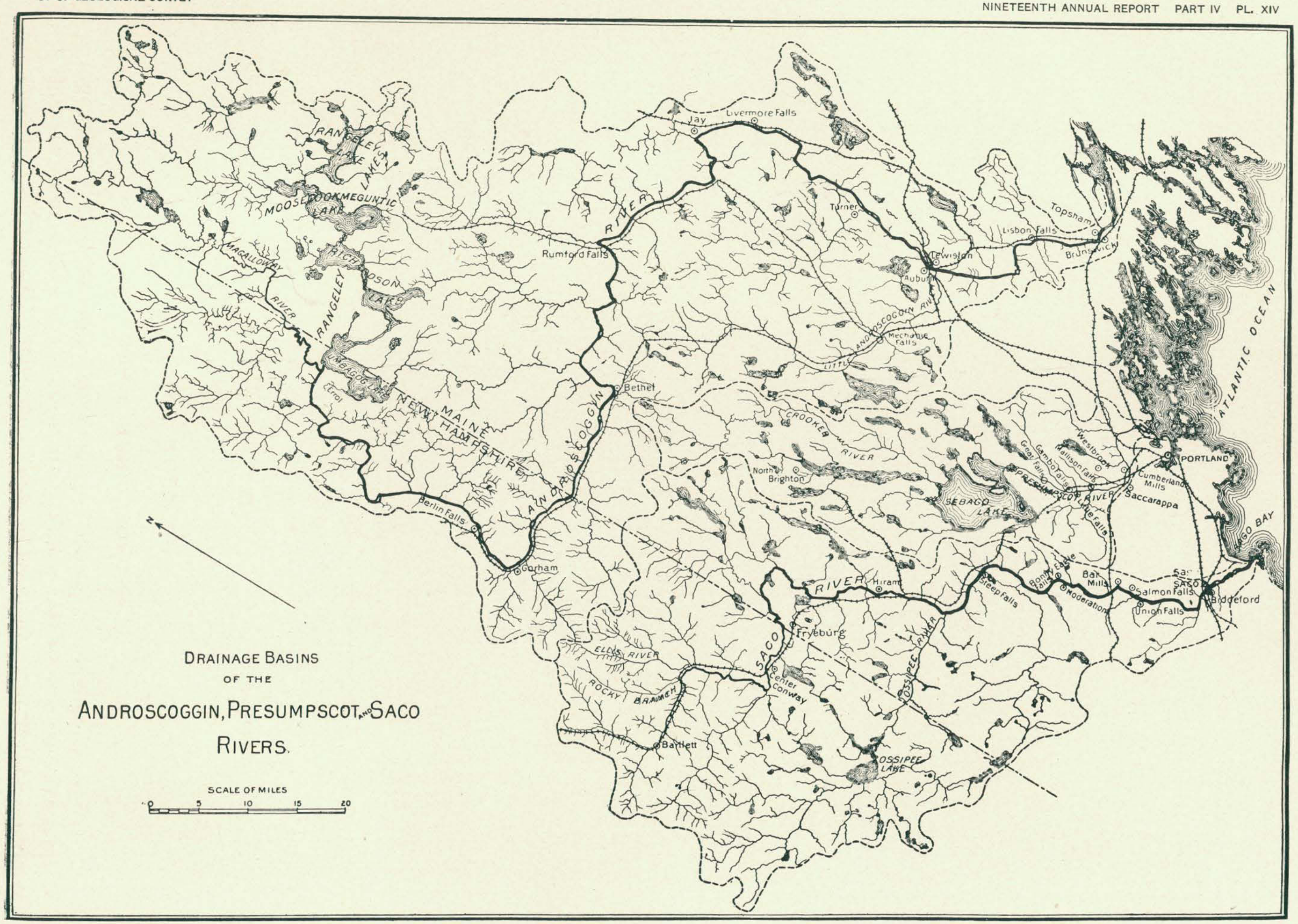
Summary of yield of Cobbosseecontee River, 1890 to 1896.

Period.	Run-off.	Rainfall.	Ratio of run-off to rainfall.
	Inches.	*Inches.*	*Per cent.*
October 1, 1890, to October 1, 1891	28.9	50.3	57
October 1, 1891, to October 1, 1892	*a* 13.3	49.2	27
October 1, 1892, to October 1, 1893	20.7	35.9	58
October 1, 1893, to October 1, 1894	13.8	37.7	37
October 1, 1894, to October 1, 1895	15.4	33.3	46
October 1, 1895, to October 1, 1896	*a* 20.2	46.8	43
Average per year, October 1, 1890, to October 1, 1896	18.7	42.2	45

a Based partly on estimate.

ANDROSCOGGIN RIVER.

Androscoggin River proper begins at the outlet of Lake Umbagog, in northeastern New Hampshire, close to the dividing line between that State and Maine, and 40 to 50 miles northeast of Mount Washington.


DRAINAGE BASINS
OF THE
ANDROSCOGGIN, PRESUMPSCOT, AND SACO
RIVERS.
SCALE OF MILES
0 5 10 15 20
N
MAINE
NEW HAMPSHIRE
ATLANTIC OCEAN
SACO BAY
RANGELEY LAKES
MOOSELOOKMEGUNTIC LAKE
RICHARDSON LAKE
UMBAGOG LAKE
MAGALLOWAY RIVER
RANGELEY
ANDROSCOGGIN RIVER
LITTLE ANDROSCOGGIN RIVER
CROOKED RIVER
SEBAGO LAKE
PRESUMPSCOT RIVER
SACO RIVER
OSSIPEE RIVER
OSSIPEE LAKE
ELLIS RIVER
ROCKY BRANCH
Jay
Livermore Falls
Turner
Topsham
Lisbon Falls
Brunswick
Lewiston
Auburn
Rumford Falls
Mechanic Falls
Bethel
Errol
Berlin Falls
Gorham
North Brighton
Westbrook
Cumberland Mills
Saccarappa
PORTLAND
Hiram
Steep Falls
Bar Mills
Moderation
Salmon Falls
Union Falls
Saco
Biddeford
Fryeburg
Center Conway
Bartlett

(Pl. XIV). There the outlet of the lake is joined by the Magalloway, the extreme sources of which are adjacent to the head waters of the Connecticut. From the head of the Magalloway to a point 35 miles below Umbagog outlet the course of flow is nearly due south and directly toward the White Mountains. Then the stream bends sharply and runs somewhat north of east for a distance of about 60 miles, which carries it well into the State of Maine; there is then another abrupt turn, to the south and southeast, and after a farther run of some 60 miles the river reaches the coast 30 miles northeast of Portland. The drainage basin of the Androscoggin measures 3,700 square miles at the falls at Brunswick, which are near the mouth, 80 per cent of the above area lying within the State of Maine. Its greatest length is about 110 miles, and its greatest width 70 miles, while the river itself measures about 200 miles in length from the remote sources of the Magalloway to the coast.

The following drainage areas of the main river at various points and of several of its largest tributaries are substantially as given by Professor Swain in Volume XVI, Tenth Census of the United States, p. 101; but, owing to the imperfections of existing maps of this territory, the areas are to be regarded as subject to possible errors of several per cent.

Drainage areas, Androscoggin River and principal tributaries.

River.	Locality.	Drainage area.
		Sq. miles.
Androscoggin	Immediately below junction of Umbagog outlet and Magalloway River.	1, 180
Do	Berlin Falls	1, 480
Do	Rumford Falls	2, 220
Do	Livermore Falls	2, 690
Do	Lewiston	3, 120
Do	Brunswick	3, 700
Little Androscoggin	Mouth	380
Magalloway	Mouth	420
Umbagog outlet	Immediately above junction with Magalloway River.	760

Wells states the general elevation of the basin to be greater than that of any other important hydrographic area in the State of Maine, and it is perhaps greater than that of any other on the Atlantic coast. The sources of the Magalloway are from 2,600 to 2,900 feet above the sea, and the lakes of the Umbagog-Rangeley chain, the great reservoirs of the Androscoggin, are at elevations of from 1,200 to 1,500 feet. The lower part of the basin is hilly and moderately wooded, while the upper two-thirds is very broken and mountainous, heavily timbered, and with a gravelly and sandy soil. Granite, gneiss, and mica-schist abound along the main course of the river, with clay slate in the upper waters. Below Berlin Falls the stream is nowhere more than 10 miles from a railroad, and for considerable portions of its course is immediately skirted by railroads. Tide water and navigation extend some 6 miles above the mouth to the falls at Brunswick.

The entire fall of the river, from the level of Umbagog Lake to tide water at Brunswick, amounts to about 1,250 feet, and in the various stretches for which figures in detail are at command ranges generally between 4.5 and 7.5 feet per mile. At three important points, however, there are large concentrated falls, namely, at Lewiston, where a natural fall of 38 feet in 600 feet is increased to 50 feet by the dam; at Rumford Falls, where there is a natural descent of 177 feet in about a mile; and at Berlin Falls, where the fall is said to amount to nearly 200 feet in a mile.

Fall in Androscoggin River.

Locality.	Distance from tide water at Brunswick.	Height above mean tide.	Fall between points.	Distance between points.	Average fall per mile between points.	Authority for elevation.
	Miles.	*Feet.*	*Feet.*	*Miles.*	*Feet.*	
Foot of Umbagog Lake.	158	1,256				Wells: Water-Power of Maine, p. 79.
			208	31	6.7	
Head of Berlin Falls..	127	1,048				
			281	6	47.0	
Gorham, New Hampshire.	121	*a* 767				Joseph Hobson, chief engineer, Grand Trunk Rwy.
			77	11	7.0	
State line	110	690				Wells: Water Power of Maine, p. 79.
			70	12	5.8	
Bethel	98	620				
			23	22	1.0	
Head of Rumford Falls	76	597				C. A. Mixer, engineer, Rumford Falls Power Co.
			177	1		
Foot of Rumford Falls	75	420				
			256	53	4.8	
Lewiston, head of falls.	22	*b* 164				H. C. Robinson, assistant engineer, Maine Central R. R.
			164	22	7.5	
Brunswick	0	0				

a Water surface at summer stage at Grand Trunk Railway crossing.
b Corrected for water surface from elevation of track at Maine Central Railroad bridge.

STORAGE IN UMBAGOG-RANGELEY LAKES.

The magnificent fall which the Androscoggin presents for water-power development is greatly enhanced in value by the facilities which also exist for water storage, especially those furnished by the Umbagog-

Rangeley chain of lakes, at the head of the river. Here are four distinct bodies of water, discharging one into another and finally into the Androscoggin, commanding at the foot of the chain a drainage area of 760 square miles without the Magalloway, or 1,180 square miles including that stream, and comprising a combined water surface of at least 80 or 90 square miles. At the foot of the chain is the Errol dam, located on Androscoggin River below the mouth of the Magalloway, the discharge of the latter stream being thus commanded and set back into Umbagog Lake. The control of these storage reservoirs is in the hands of the Union Water Power Company of Lewiston, subject to such legal rights as may belong to the log drivers.

The annual variation in level in Rangeley Lake, the highest of the chain, is seldom so great as 3 feet; but from Mooselucmaguntic, the second lake, 25 feet lower than Rangeley, the available draft from high-water level is stated as 11 feet; from Richardson Lake, the third, lying some 30 feet lower than the preceding, 20 feet; and from Umbagog, the last of the chain, lying about 200 feet lower than Richardson Lake, 12 feet.

Besides the lakes of the Umbagog-Rangeley chain, there are many others of less size in the Androscoggin Basin, ranging in extent from 6 or 8 square miles downward, and covering in the aggregate, according to Wells,[1] about 136 square miles of surface.

The exceedingly mountainous character of the upper basin, with its extensive exposures of bare rock, tend to give the river a high freshet discharge and a variable flow, a tendency which is very greatly offset by the dense forest covering, the large lake storage already noticed, and the holding back of freshet waters above Rumford Falls. Wells gives the range between high and low water as 8 or 10 feet on the falls at Brunswick and Lewiston, 20 feet at Rumford Falls, and from 22 to 28 feet at Bethel.

INCREASE IN UTILIZED POWER.

While precise figures are not at command, it is evident that since the United States census report on water power in 1880 there has been a very great increase in the amount of power utilized upon the Androscoggin. At the former date the returns credited the main river with the use of 13,000 or 14,000 horsepower, while at the present time incomplete returns indicate an aggregate of approximately 70,000 horsepower. It seems likely, therefore, that the increase in power utilized has been greater in the last fifteen years on this river, and that the total amount now used is greater, than upon any other single stream in New England. Probably more than two-thirds of the whole amount of power is employed in the manufacture of wood pulp and paper, and it is almost exclusively in this line that the development of the river in recent years has taken place.

[1] Water-Power of Maine, pp. 83-85.

This growth seems natural when it is considered that the upper Androscoggin Basin contains the finest spruce forests in New England. The report of Mr. Austin Cary to the forest commissioner of Maine[1] places the net area of spruce-producing land in the Androscoggin Basin in that State at 830 square miles, of which not more than one-half has yet been cut for spruce, while all of the 850 square miles or thereabouts of gross area of the basin lying in New Hampshire is, or has been, a spruce-bearing region. The consumption of spruce at the various mills along Androscoggin River from Berlin to Brunswick for the year 1895 is given as 123,000,000 feet for pulp and paper and 73,500,000 for sawing, of which amounts all but about 12,000,000 feet was cut within the basin of this river.

WATER POWERS AT AND BELOW LEWISTON.

Ascending from the mouth of the Androscoggin, the first fall is encountered at the head of tide water, at Brunswick. Here there is a dam giving a fall of about 15 feet, which is liable to a reduction of some 3 feet from the tide. The largest user of power is the Bowdoin Paper Manufacturing Company, employing 750 horsepower on the north bank, where there is also a sash, door, and blind factory. At the south or Brunswick end of the dam are the Androscoggin Pulp Company, a gristmill, sawmill, sash and blind factory, and ferrule shop. The aggregate power used at these concerns could not be learned.

The second or upper dam at Brunswick is a little way above the one just mentioned and gives a fall of 18 feet. This privilege is owned by the Cabot Manufacturing Company, which uses 1,700 horsepower in its cotton mills and leases power to the Brunswick Electric Light Company, lighting Brunswick and Topsham and employing two 500-horsepower turbines. No lack of water at this privilege has ever been experienced.

Half a mile above the Cabot Manufacturing Company's dam are rapids with a fall of 7 feet; and a few miles farther is the Pejepscot Mills privilege, developed within the last three or four years for the manufacture of pulp and paper, and at which a fall of 20 feet and 4,000 horsepower are in use.

At Lisbon Falls, about 11 miles below Lewiston, there are two dams. At the lower, 14 feet of fall and 875 horsepower are utilized by the Lisbon Falls Paper Manufacturing Company; while at the upper, 13 feet of fall and 1,050 horsepower are employed, about three-quarters of this being in the woolen mill of the Worumbo Manufacturing Company.

The next power is that at Lewiston, 22 miles by river above tide water at Brunswick, owned by the Union Water Power Company. At this point the river had naturally a fall over a rocky bed of about 38 feet in a few hundred feet, and by a dam at the head of the falls this

[1] Third Annual Report of Forest Commissioner, p. 150.

has been raised to 50 feet. Above the dam the pond is only 1½ miles in length, and is of insufficient capacity to store completely the night flow in dry weather.

The power is used on the left bank from two levels, the upper canal being 4,200 feet long and the lower canal 1,600 feet. The city of Lewiston has the right to 450 horsepower net for pumping its water supply from the river, and 150 horsepower net for the purpose of electric street lighting. The water power company also maintains a mill on the lower level, in which it leases considerable quantities of power. The main employment of power, however, is by large cotton mills—comprising the Continental, Androscoggin, Bates, Hill, Lewiston, Lincoln, and Avon—the Lewiston bleachery and dye works, and the Cowan & Co., Columbia, and Cumberland woolen mills.

Power is leased by the water-power company at rates varying, according to circumstances, from $5 to $12.50 per horsepower per annum, being cheaper for the original corporations. The price applies to net power on the shaft, assuming the latter to be 75 per cent of the gross power corresponding to a given quantity of water and fall. The mills run sixty hours a week, and measurements of the waterpower used by them are made daily. Some auxiliary steam power is also in use at certain of the mills.

The total demand for water from the upper level when all the plants as equipped in January, 1897, are running at full capacity is between 3,100 and 3,200 cubic feet per second for about 60 hours per week. Assuming 3,150 cubic feet per second used on the full fall of 50 feet, we find the corresponding power to be about 18,000 gross or 13,500 net horsepower, but as some water is used on only a part of the total fall, the utilized power is reckoned at from 15,000 to 16,000 gross or say 12,000 net horsepower sixty hours in the week. For a large part of the year the available power is, of course, much in excess of the figures here given.

Passing upstream, unutilized powers are found 2 or 3 miles above at Deer Rips, where 30 feet or more of fall, depending upon the height of dam to be built, is said to be available, and is owned by the Union Water Power Company; at Crooked Rips, 5 or 6 miles above the city of Lewiston, where there is a dam, built a few years ago, giving a moderate fall, but now serving no useful purpose whatever; and at other points opposite the town of Turner.

The next utilized power is at Livermore Falls, about 25 miles above Lewiston, where some 3,000 horsepower is in use, 2,500 of this in the mills of the Livermore Falls and Umbagog pulp companies, and the balance in a sawmill, gristmill, etc. The head realized is about 16 feet, but rapids extending downstream indicate that a considerable additional fall is available.

In the 25 miles between Livermore Falls and Rumford Falls are three large water powers devoted to the manufacture of pulp and paper. At Otis Falls 22 feet of fall and 7,000 horsepower are employed by the Otis Falls Pulp Company, which in the summer of 1896 was also developing 18 feet of fall farther upstream, at Petersons Rips, where 6,000 horsepower was to be used. Between these two privileges, at Jay, the Jay Paper Manufacturing Company uses 15 feet of fall and 3,700 horsepower.

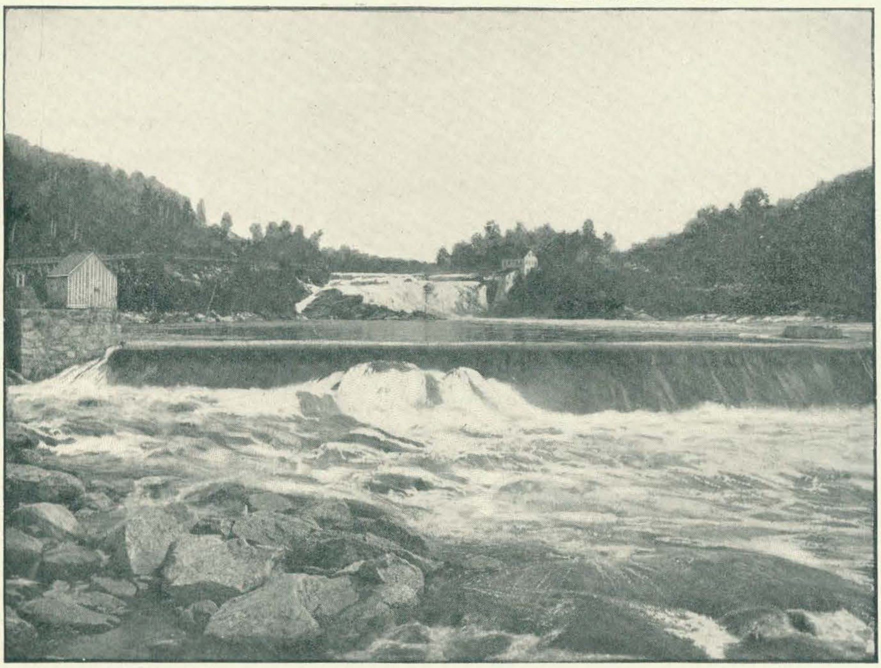
WATER POWER AT RUMFORD FALLS.

The magnificent power at Rumford Falls is of recent development. Here the Androscoggin, after running for more than 20 miles with slight fall, suddenly descends 177 feet in about 1 mile, in successive pitches over granite ledges. The scheme of improvements contemplates the use of power from three levels—a high-level canal, with a fall of 97 feet thence to the middle level, the latter receiving also a direct and independent supply of water from the river; water to be used from the middle-level canal and discharged after a fall of 50 feet into the low level, from which in turn there is a final drop of 30 feet to the river. Dams have been built at the entrance of the high- and middle-level canals. Water first began to be used in any important amount for power in the summer of 1893, and its use increased from time to time, until in the fall of 1897 turbines to the extent of about 9,000 horsepower were in operation, over 80 per cent of this being utilized in the manufacture of pulp and paper.

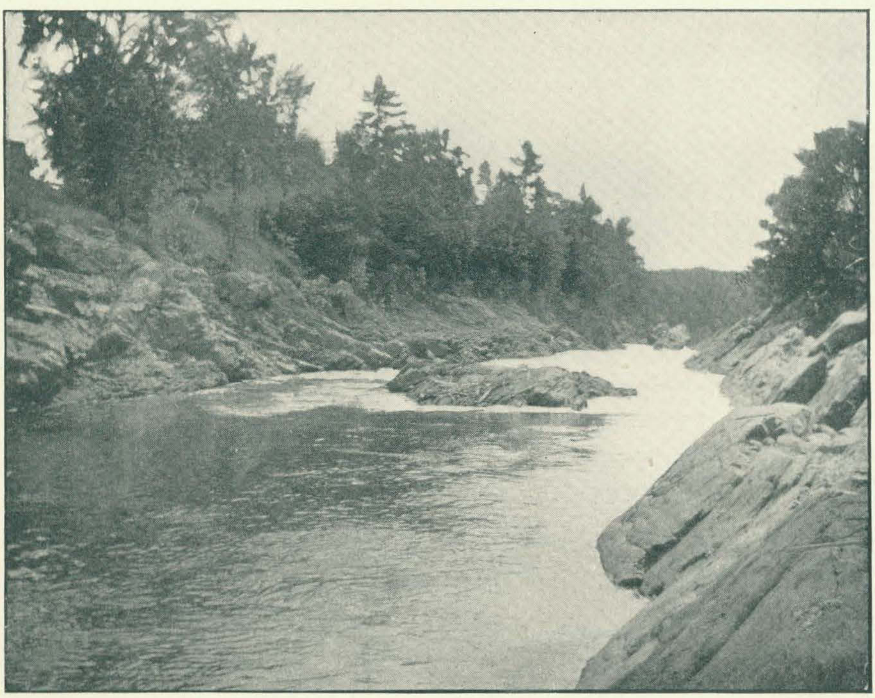
The upper dam, at the head of the falls, is a log structure, built primarily to provide boomage for logs and to prevent trouble from anchor ice. It causes slack water in the river for about 8 miles and thus creates a fine storage, which, however, is of somewhat minor importance on this privilege, inasmuch as most of the turbines are run continuously through the week. A timber sluiceway has been constructed from the pond above the dam down the right bank to the middle-level canal, for the purpose of sluicing down logs for the use of the mills; and at small filter buildings on the right and left banks, respectively, water taken from the vicinity of the dam is cleared for the use of the paper mills and for the public supply. The high-level canal has not yet been built, however, and no power is used in connection with the upper dam.

There is a rapid descent from this dam to the principal falls, which are a few hundred feet below. Opposite these a short wing dam, extending out from the left bank, diverts water to the turbines of an electric light and power station. In addition to the work of lighting, electric power is transmitted thence for operating the Rumford Falls Woolen Company's mill, a machine shop, gristmill, molding mill, woodworking shop, and for various minor uses.

Below the main falls is a pool of large size formed by the lower dam, shown in Pl. XV, *A*, a quarter of a mile or more beyond which are the lower falls, in two principal pitches, succeeded by heavy rips. The dam just mentioned diverts water through gate openings in a heavy



A. LOWER DAM, RUMFORD FALLS, AT ENTRANCE TO MIDDLE LEVEL CANAL.



B. SACO RIVER BELOW SALMON FALLS DAM.

masonry bulkhead to the middle-level canal, supplying the principal users of power on this privilege, the Rumford Falls Paper Company, the Rumford Falls Sulphite Company, and the Electro-Chemical Company, manufacturing bleaching powders, etc.

Sufficient data as to the flow of the river are not at hand for forming a complete, or perhaps an entirely just estimate of the power of this important privilege. The figures given elsewhere for flow, which are declared to embrace the extremes for a quarter of a century, indicate a minimum of somewhat over 100 net horsepower per foot of fall—an amount to be considered as available twenty-four hours a day in all seasons and in all years. Further, if these figures, embracing about three years from May, 1892, be taken as a criterion, it appears that for about three-quarters of the time, in the average of years, the available power may be reckoned at substantially twice the above amount, or about 200 net horsepower per foot of fall. For the entire fall of 177 feet these figures give as available 18,000 and 35,000 net horsepower, respectively.

Rumford Falls is distant 85 miles by rail from Portland. For pulp and paper manufacture not only does it have the advantage of Androscoggin River for floating down pulp timber to the mills from the sources of supply in the upper basin, but by the Rumford Falls and Rangeley Lakes Railroad and its contemplated extension into the Megantic region magnificent spruce forests will be made tributary by rail. Whatever the exact figures may be, Rumford Falls apparently stands foremost, in the amount of its available power, among the water-power privileges of New England.

Above Rumford Falls the next use of power is at Berlin Falls, New Hampshire, where the Androscoggin has a rapid descent over a rocky bed, stated to be nearly 200 feet in a mile. The first power met is that of the Glen Manufacturing Company, which has three dams in succession on the river, giving falls of 22, 22, and 38 feet, respectively, the power being employed in the manufacture of paper and pulp. Then follows an unimproved privilege, succeeded by the works of the Burgess Sulphite Fiber Company, using a fall of 16 feet. Above these are the paper, pulp, and saw mills of the Berlin Mills Company, which obtains power from three dams with an aggregate fall of about 50 feet.

The mills at Berlin are among the largest of their kind in the country. They employ in the aggregate about 20,000 horsepower of turbines, and their combined output comprises about 140 tons per twenty-four hours of wood pulp, 210 tons of sulphite fiber, and 160 tons of finished news paper; in addition to which the Berlin Mills Company manufactures some 40,000,000 feet per annum of finished lumber.

Above Berlin Falls no power is used from the Androscoggin, and the stream is without immediate railroad facilities. There is a dam, however, at Pontoocook Falls, some 10 or 12 miles above Berlin, used for logging purposes, and within a couple of miles of which there is said to be 60 or 70 feet of fall in the river; and another at Errol, serving to control the storage in Umbagog Lake, as elsewhere noticed.

RECORDS OF DISCHARGE AT RUMFORD FALLS.

Substantially no figures regarding the flow of Androscoggin River are accessible, except those resulting from a series of observations begun at Rumford Falls in May, 1892, during the progress of developments at that place, and continued to the present time, although only the results up to the close of April, 1895, have been computed and made available for study. Until January, 1893, the discharge was determined from the computed flow over the dam as given by Francis's ordinary weir formula; subsequent to which time, as water came to be used for power, additions were made to the computed flow over the dam of the amounts assumed to pass through the turbines. The gage readings are taken at the lower dam, and at first were made once a day, later four times a day, and now every two hours. Flashboards are not used upon the dam. There is but little fluctuation during the twenty-four hours in the quantity passing the wheels, nor, indeed, is there much anywhere upon this river except at and below Lewiston. There a large proportion of the mills run only in the daytime, while elsewhere they run continuously through the week. At Rumford Falls many of the turbines run throughout the week without change of gate, and some run a month or two at a time without stopping.

Notwithstanding the fact that a high degree of accuracy is not to be expected, and doubtless is not claimed, for results obtained as above, in which, for example, the proper weir coefficient to be used is in doubt, nevertheless the series of figures at command for Rumford Falls are of high value for revealing the general characteristics of flow of the Androscoggin and for giving a good approximation to its absolute amount. The results hereafter given have been very kindly placed at disposal for this report by Mr. Charles A. Mixer, resident engineer of the Rumford Falls Power Company.

In the following tables an analysis is made of the daily discharge for each month, with a view to revealing not only extremes of flow, but also the average, with corresponding values in inches on drainage area and in second-feet per square mile. The daily discharges are graphically set forth in figs. 16 and 17.

Analysis of discharge of Androscoggin River at Rumford Falls, by calendar months, 1892 to 1895.

[Drainage area, 2,220 square miles.]

Year and month.	Maximum day, average for the 24 hours.	Minimum day, average for the 24 hours.*a*	Average for month, 24 hours per day.	Equivalent in inches on drainage area for month.	Equivalent in cubic feet per second of continuous flow per square mile of drainage area.	Rainfall.*b*
1892.	*Cubic feet per second.*	*Cubic feet per second.*	*Cubic feet per second.*			*Inches.*
May *c*	11,700	4,940	7,610	....	3.43	3.19
June	19,900	3,830	7,410	3.73	3.34	8.74
July	17,500	2,820	7,350	3.81	3.31	3.66
August	8,500	2,600	4,840	2.51	2.18	8.38
September	5,860	2,580	4,030	2.03	1.82	2.74
October	2,940	2,700	2,780	1.44	1.25	1.88
November	24,500	2,330	5,720	2.88	2.58	4.91
December	3,830	2,820	3,200	1.66	1.44	1.55
1893.						
January	3,830	2,940	3,180	1.65	1.43	1.86
February	2,990	2,990	2,990	1.40	1.35	4.78
March	4,130	2,750	3,190	1.66	1.44	2.89
April	8,050	2,750	5,030	2.53	2.26	2.70
May	38,060	5,010	16,910	8.78	7.62	3.30
June *d*	9,700	4,450	5,890	2.96	2.65	3.12
July	3,630	2,120	2,800	1.45	1.26	2.36
August	12,300	1,400	3,290	1.71	1.48	4.46
September	3,760	1,300	2,660	1.34	1.20	2.67
October	13,000	1,900	3,830	1.99	1.73	3.27
November	4,830	1,900	3,070	1.54	1.38	1.80
December	3,820	1,900	2,660	1.38	1.20	3.05
Year	38,060	1,300	4,640	28.39	2.09	36.26
1894.						
January	3,890	2,130	2,720	1.41	1.23	3.35
February	3,310	1,590	2,000	0.94	0.90	4.95
March	7,090	1,570	4,030	2.09	1.82	2.30
April	22,230	3,300	9,470	4.76	4.27	2.05
May	19,230	4,550	8,240	4.28	3.71	3.37
June	9,830	3,100	5,090	2.56	2.29	4.58
July	5,310	1,680	2,490	1.29	1.12	3.47
August	2,480	1,380	1,930	1.00	0.87	1.94
September	5,880	1,630	2,220	1.12	1.00	2.87
October	5,580	1,460	2,500	1.30	1.13	2.54
November	7,380	1,380	3,040	1.53	1.37	4.52
December	2,890	1,460	2,090	1.08	0.94	3.67
Year	22,230	1,380	3,820	23.36	1.72	39.61

a Sunday flow not measured.

b Station at West Milan, New Hampshire. See bulletins of New England Climate and Crop Service, U. S. Weather Bureau.

c Flow recorded for last 15 days only.

d Flow recorded for first 20 days only.

Analysis of discharge of Androscoggin River at Rumford Falls, by calendar months, 1892 to 1895—Continued.

Year and month.	Maximum day, average for the 24 hours.	Minimum day, average for the 24 hours. *a*	Average for month, 24 hours per day.	Equivalent in inches on drainage area for month.	Equivalent in cubic feet per second of continuous flow per square mile of drainage area.	Rainfall. *b*
	Cubic feet per second.	*Cubic feet per second.*	*Cubic feet per second.*			*Inches.*
1895.						
January	2,530	1,330	1,800	0.93	0.81	2.93
February	1,230	1,230	1,230	0.68	0.55	1.42
March	1,230	1,230	1,230	0.64	0.55	1.47
April	55,230	1,230	12,000	6.04	5.41	3.87

a Sunday flow not measured.
b Station at West Milan, New Hampshire.

The figures and diagram indicate on the whole a very constant discharge for this river, maintained more than one-half the time between

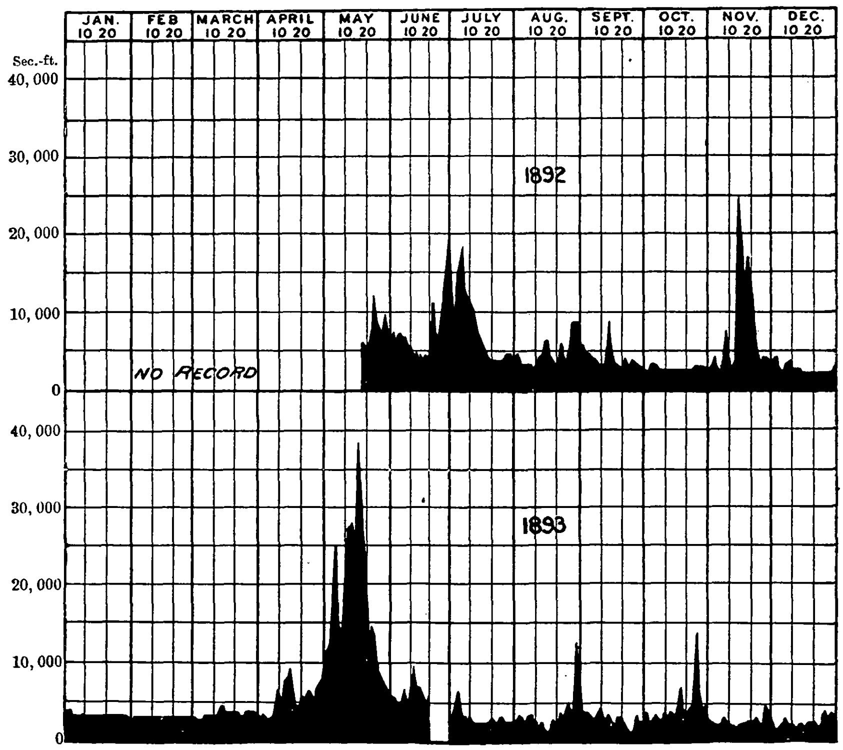


FIG. 16.—Discharge of Androscoggin River at Rumford Falls, 1892 and 1893.

2,000 and 4,000 cubic feet per second, or between substantially 1 and 2 cubic feet per second per square mile of drainage area. It is true that during February and March, 1895, the discharge continued as low as about 1,200 cubic feet per second, or 0.55 cubic foot per second per square mile. This is described, however, as a very unusual condition, resulting from the withdrawal of lake storage in the early winter, until it was exhausted, for the first time since the dams were built at the lakes, or twenty-five years, followed by severe and continued cold weather, holding all surface moisture in the form of snow and ice, and even checking the springs. On the other hand, within ten days from the close of this period of low flow, or in April, 1895, the river was

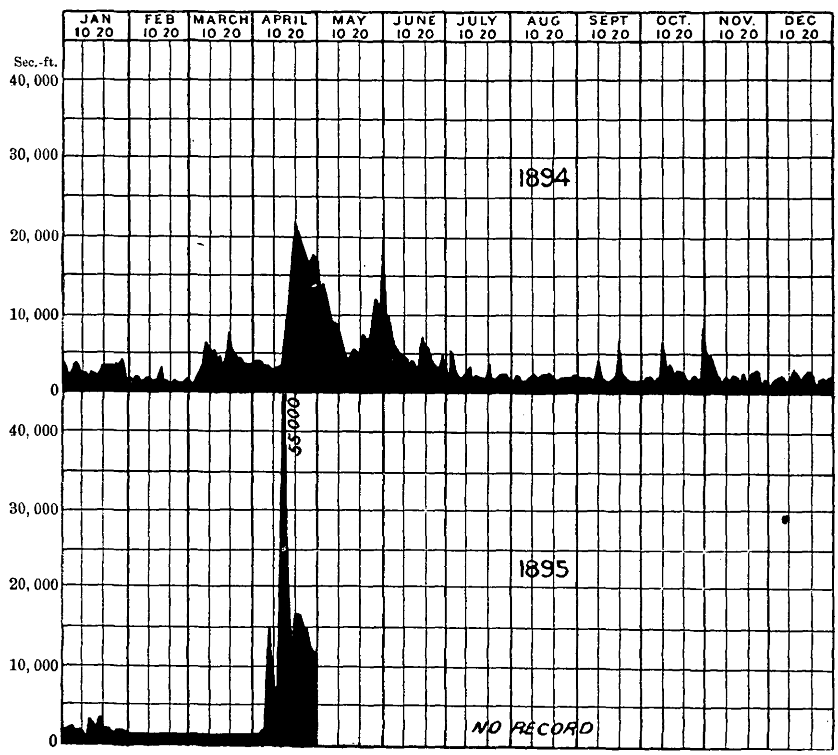


FIG. 17.—Discharge of Androscoggin River at Rumford Falls, 1894 and 1895.

visited by a freshet described by Mr. Mixer as the highest in thirty years, although it seems probable that even this must have been surpassed in the spring of 1896. At the date first mentioned the discharge rose to 55,000 cubic feet per second, or about 25 cubic feet per second per square mile of drainage area. The ratio of these extremes, about 45 to 1, is probably not unlike that for other reservoir-fed streams of New England, such as the Merrimac and Connecticut, but is wonderfully different from that of Southern nonreservoir streams, such as the Potomac.

In fig. 18, where the discharge is plotted by days without respect to their calendar order, the distribution of the flow with respect to time is best seen, and the relations already mentioned may be discerned.

As to the relation between the annual yield of the stream at Rumford Falls and the rainfall upon the tributary area, the records at command are too short to warrant any very definite conclusions. No

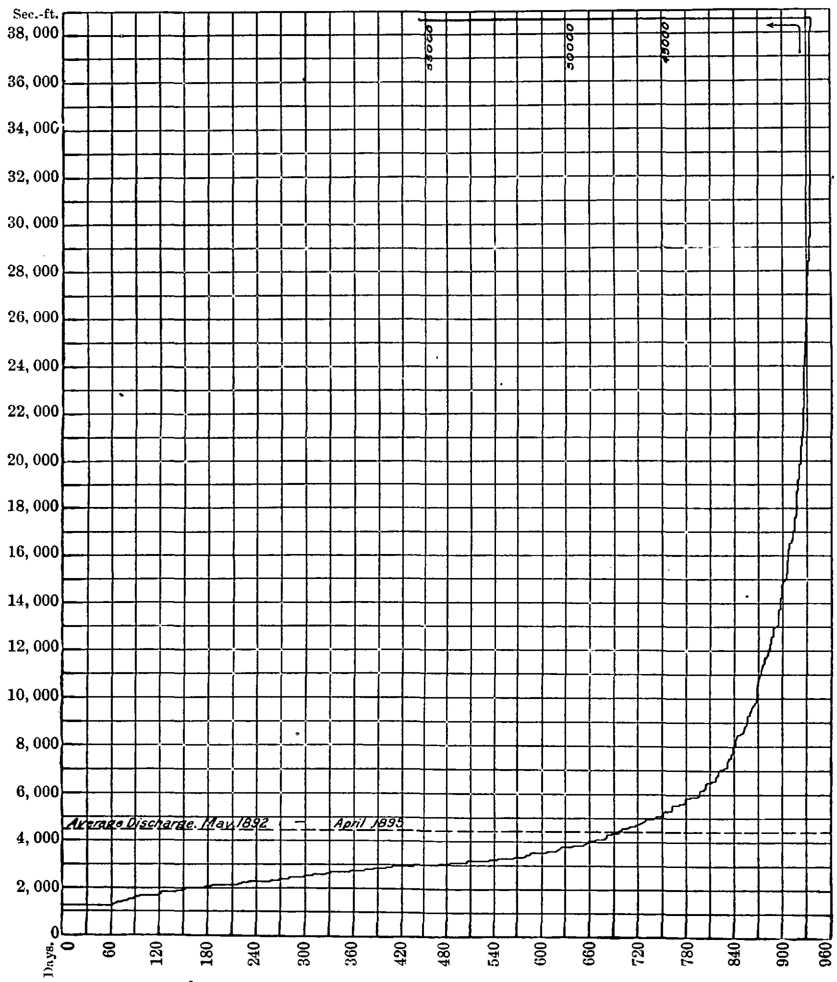


FIG. 18.—Discharge of Androscoggin River at Rumford Falls. Values arranged without reference to calendar order.

rainfall observations made directly within the drainage area are on record, and those given by the volunteer observer at West Milan, lying a few miles west of the watershed, contained in the United States Weather Bureau bulletins, have been employed. Taking periods beginning and ending with October 1, as has been done for the other rivers of Maine, for the twelve months from October 1, 1892, to

October 1, 1893, the rainfall appears to have been 36.5 inches and the run-off 29.5 inches. These figures give a ratio expressed by 81 per cent, a value so high that it ought not to be accepted without confirmation, which it is not practicable here to give. The large value for run-off is seen to result from the abnormal yield of May, 1893, which was apparently 8.78 inches. For the twelve months succeeding October 1, 1893, the figures for rainfall and run-off are 37 inches and 24.4 inches, respectively, giving a ratio of 66 per cent; while for the entire period from June, 1892, to April, 1895, inclusive, the run-off appears to have been 67 per cent of the rainfall for the same time.

LITTLE ANDROSCOGGIN RIVER.

This stream, which drains an area of about 380 square miles and joins the Androscoggin from the west immediately below the falls at Lewiston, is the only tributary of that river of present importance for utilized power. It heads some 30 miles to the northwest of Lewiston, and, being fed by numerous lakes, has a comparatively steady flow. At the two dams nearest the mouth the power is owned by the Little Androscoggin Water Power Company and leased to the users. At the lower dam are the Barker woolen mills, having 35 feet of fall with 400 horsepower of wheels, and several small woodworking and other establishments, using in the aggregate about 250 horsepower. At the upper dam the fall is 26 feet, and the power is used by the Auburn and Lewiston Electric Light Company. The privilege is regarded as good for 300 horsepower at all times. The last-named company also leases the power at the third dam, where it has installed two 310-horsepower turbines, working under a fall of about 23 feet.

At Mechanic Falls, 10 miles above the mouth of the river, the Poland Paper Company uses 30 feet of fall and has turbines rated at 1,200 horsepower, while at the succeeding privilege a dam was being built in August, 1896, to develop power for the Mechanic Falls Electric Light and Power Company. Above this point there is but little use of power.

PRESUMPSCOT RIVER.

On account of its large fall, all within a short distance from tide water, and especially because of its considerable and well-sustained flow, Presumpscot River is, in proportion to its length and the size of its drainage area, one of the most attractive of the water-power streams of New England. The immediate source of the river is in Sebago Lake, a magnificent sheet of water covering, according to Wells,[1] some 50 square miles of surface, and lying 17 miles northwest of Portland. Crooked River, the principal feeder of the lake, heads 35 miles farther toward the north and within 2 or 3 miles of Androscoggin River. From Sebago Lake the Presumpscot flows southeasterly about 20 miles,

[1] Water-Power of Maine, p. 143.

discharging into Casco Bay a few miles north of Portland. The basin includes 470 square miles, as measured on Colton's map of Maine, at the outlet of Sebago Lake, and 700 square miles at the mouth of the main river. The northern portion is mountainous and wooded, while the southern part is moderately hilly and cleared; granite, gneiss, and mica-schist appear at many points, and the soil is gravelly or sandy.

According to a survey made by Mr. Joseph A. Warren, of Cumberland Mills (see fig. 19), the fall from the crest of the stone dam at the foot of Sebago Lake to mean low tide at the foot of the lower falls is 265.16 feet in a distance of 21.65 miles, or an average of 12.25 feet per mile. In the lower two-thirds of this distance, or from Gambo

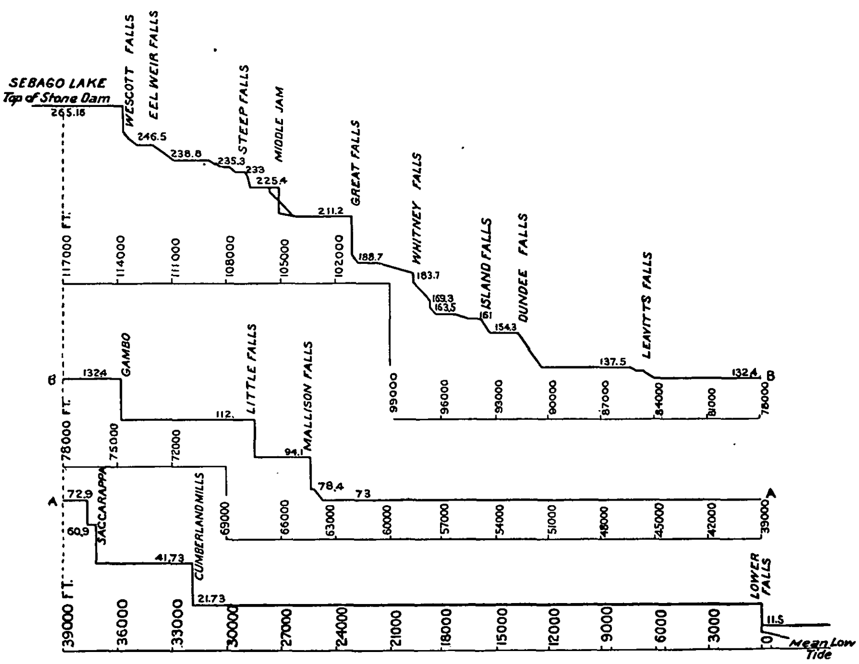


FIG. 19.—Profile of Presumpscot River from Sebago Lake to tide water. Figures on water surfaces give elevations above mean low tide.

Falls to tide water, nearly seven-eighths of the whole fall of 132 feet has been improved, and an aggregate probably exceeding 6,000 net horsepower is in use. The balance of the fall, however, between Gambo Falls and Sebago Lake, amounting to 133 feet, is either unimproved or but slightly utilized. At Great Falls, in this stretch, there is a descent of 22 feet, which has been used in the past, but is now idle; it is proposed, however, to employ the power in the generation of electricity for delivery in Portland.

By far the largest users of power on the river are Messrs. S. D. Warren & Co., paper manufacturers, at whose plant at Cumberland Mills about 3,000 horsepower is used from all sources. Of this amount

1,500 horsepower is from water direct, there being a fall of 20 feet here, and the balance is from steam and electricity, the latter being transmitted from the Lower Falls, 6 miles downstream, at which point there is a dam giving a fall varying with the tide from 11 to 21 feet.

Passing above Cumberland Mills, the next power is at Saccarappa, where there are two dams giving falls of 19 and 12 feet, respectively. Here are the cotton mills of the Westbrook Manufacturing Company and the Dana Warp Company, the power house of the Westbrook Electric Light and Power Company, and several other smaller mills, the total water power used by all the establishments, when in full operation, being about 1,900 horsepower. At Mallison Falls about 300 horsepower, under a head of 20 feet, is used at the woolen mill of the Robinson Manufacturing Company, and at Little Falls 1,600 horsepower, with a head of 18 feet, is employed by the Sebago Wood Board Company.

RECORDS OF DISCHARGE FROM SEBAGO LAKE.

Since January, 1887, the flow from Sebago Lake has been regularly ascertained and recorded, the quantity being deduced from the openings in the regulating gates at the dam, the discharging capacity of which under different conditions of head has been determined and tabulated by Mr. Hiram F. Mills, of Lowell. Since January, 1872, a continuous record has also been kept of the level of the lake surface, the last ten years of which record are graphically represented in fig. 20. An unusually complete and valuable series of data has thus been obtained, which has courteously been furnished for this report by Messrs. S. D. Warren & Co.

From the diagram it will be seen that the lake fills rapidly after the 1st of March, attaining its maximum height between the middle of April and the 1st of June, and then gradually subsides as water is withdrawn for mill purposes, until a minimum stage is reached, sometimes in the autumn, but usually in the winter. For the past ten years the average range for the calendar year between extremes of lake level has been about 5¾ feet.

It will be shown later that the average flow from the lake for a series of years has been about 820 cubic feet per second, and the minimum about 400 cubic feet per second. Assuming 400 and 800, respectively, as approximate values for the flow; also assuming roughly 225 feet as the net fall in the Presumpscot capable of development, 75 per cent as the efficiency of turbines, and not taking into account additions to the volume of the stream below Sebago Lake—we have above 7,500 net horsepower as the constant available power of the river, and above 15,000 net horsepower as the average, that is, the power to be realized about one-half the time.

The first of the accompanying tables records the delivery from the lake in average flow for the working days of each calendar month from

1887 to 1896, inclusive, with the equivalent in inches upon drainage area, and in cubic feet per second of continuous flow per square mile of drainage area. From this table alone it may be seen how thoroughly the yield of the basin is under control, and how relatively uniform a discharge is maintained from this remarkable reservoir. For the entire

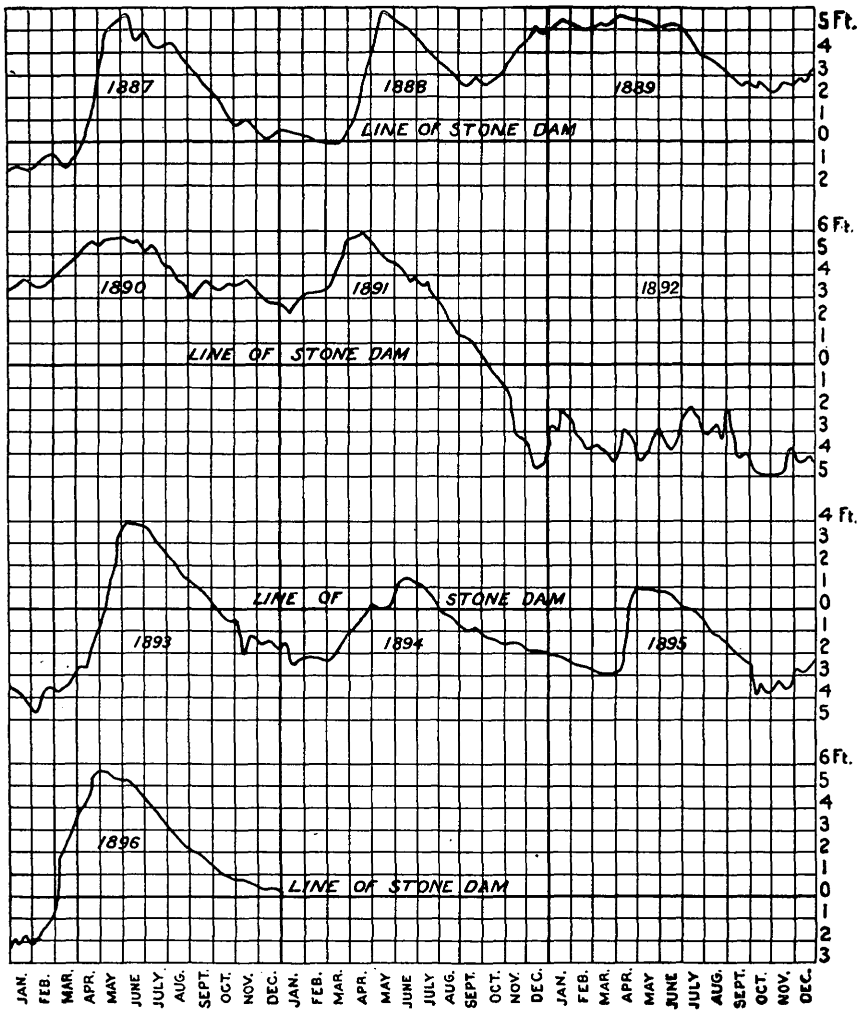


FIG. 20.—Surface levels in Sebago Lake, 1887 to 1896.

period of the ten years under consideration the average flow, as already noticed, was 820 cubic feet per second, the minimum 400, and the maximum 1,670. For one-third of the entire period, however, the flow varied not more than 10 per cent from the above average, and for nearly three-fourths of the period it varied not more than 20 per cent from the average. These relations may easily be seen from the diagram, fig. 21, in which the flow is plotted by months without reference to calendar order, and on which it is, therefore, apparent for how long a time in the aggregate the flow stood at or above any given figure.

In the succeeding table the flow is averaged by calendar months for

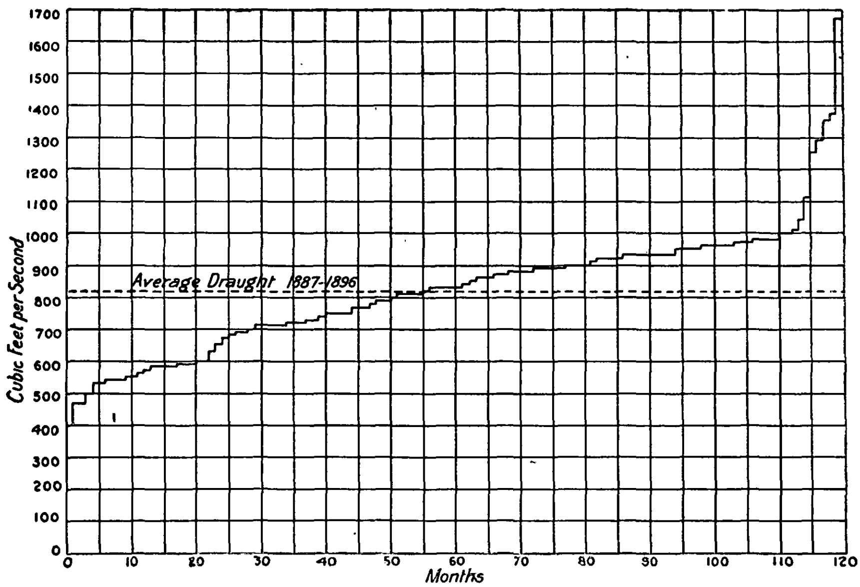


FIG. 21.—Rate of flow from Sebago Lake, arranged by months, without regard to calendar order.

the period under discussion. Finally, in the third table the attempt is made to bring out in a summary the relation between run-off and rainfall, the various results of the tables being shown to the eye by the diagrams, figs. 22, 23, and 24. There is but a single rainfall station

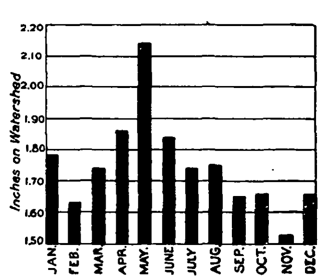


FIG. 23.—Average monthly flow from Sebago Lake, in inches, on watershed, 1887 to 1896, inclusive.

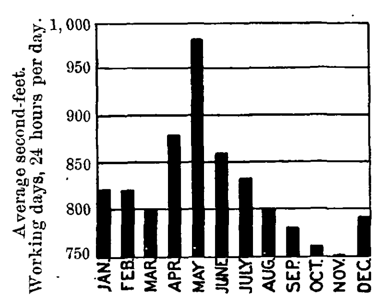


FIG. 22.—Average monthly flow from Sebago Lake during working days, 1887 to 1896, inclusive.

directly within the tributary basin, that at North Bridgeton, maintained by a volunteer observer, the record covering a period of three years only. The rainfall records of the United States Signal Service station at Portland have therefore been used, as being of the highest authority and because the distance of the station from the center of the basin, 35 or 40 miles, does not greatly exceed that of the nearest volunteer stations outside the basin. Using the Portland figures, it appears that for the entire period of ten years, 1887 to 1896, inclusive, the average annual rainfall was 45 inches, and the average annual run-off 21 inches or 47 per cent of the rainfall. In investigating the variations in percentage of run-off from year to year the natural divisions between the years have been disregarded, and in order to avoid as far as possible the influence of varying amounts of snow or of lake storage upon the apparent yield twelve-month periods have been selected, at the beginning and end of each of which the lake level was nearly the same and the ground was free from snow. For seven periods thus chosen, covering most of the time under discussion, the percentage of run-off ranged from 43 to 53.

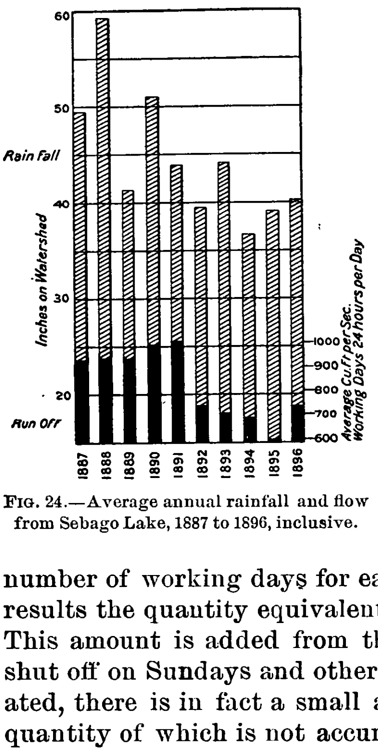


FIG. 24.—Average annual rainfall and flow from Sebago Lake, 1887 to 1896, inclusive.

In the following table the first or left-hand column of figures gives the average flow during the working days of the month, excluding Sundays and holidays. In other words, it gives the flow as it comes to the mills for use. When water is not needed it is found practicable, on account of the great size of Sebago Lake, to control the flow of the river. The working days evidently make up a varying percentage of the total number of days, being dependent upon the number of Sundays and holidays in each particular month. The figures in the next or second column are derived directly from those in the first column by applying the proper number of working days for each particular month and adding to the results the quantity equivalent to about the flow of one working day. This amount is added from the fact that, while nominally all flow is shut off on Sundays and other days when the mills are not being operated, there is in fact a small amount of water permitted to flow, the quantity of which is not accurately determined. It is sufficient, however, to consider this to be the equivalent above stated of the discharge during one working day. The figures in the third column are derived from those in the second column, and are not obtained directly by dividing the average flow as given in the first column by the extent of the drainage area as expressed in square miles.

Flow of water from Sebago Lake, 1887 to 1897.

[Drainage area, 470 square miles.]

Year and month.	Average flow during working days of month, 24 hours per day.	Equivalent in inches on drainage area for month. *a*	Equivalent in cubic feet per second of continuous flow per square mile of drainage area.	Rainfall for month.
1887.	*Cubic feet per second.*			*Inches.*
January	900	1.92	1.66	3.89
February	930	1.85	1.77	5.73
March	930	2.06	1.79	4.15
April	920	1.97	1.77	4.96
May	980	2.10	1.82	1.93
June	960	2.05	1.84	4.07
July	890	1.82	1.58	4.70
August	920	2.05	1.78	6.56
September	930	1.99	1.79	0.70
October	930	1.99	1.73	2.47
November	930	1.92	1.72	4.74
December	950	2.03	1.76	5.17
Year	930	23.75	1.75	49.07
1888.				
January	970	2.07	1.80	6.05
February	860	1.76	1.63	5.40
March	890	1.98	1.72	3.72
April	930	1.92	1.72	3.80
May	1,370	3.04	2.64	3.36
June	980	2.09	1.87	2.79
July	880	1.82	1.58	1.90
August	830	1.85	1.60	4.36
September	890	1.84	1.65	8.22
October	740	1.64	1.42	7.47
November	890	1.84	1.65	7.46
December	960	1.97	1.71	4.71
Year	930	23.82	1.75	59.24
1889.				
January	950	2.10	1.83	3.47
February	1,000	1.98	1.89	2.74
March	1,110	2.38	2.06	2.68
April	1,000	2.14	1.91	2.39
May	980	2.18	1.89	2.65
June	930	1.92	1.72	3.26

a Corrected for Sunday flow.

Flow of water from Sebago Lake, 1887 to 1897—Continued.

Year and month.	Average flow during working days of month, 24 hours per day.	Equivalent in inches on drainage area for month. *a*	Equivalent in cubic feet per second of continuous flow per square mile of drainage area.	Rainfall for month.
1889.	*Cubic feet per second.*			*Inches.*
July	930	1.99	1.73	3.10
August	900	2.00	1.73	2.76
September	850	1.75	1.57	2.49
October	860	1.91	1.65	3.47
November	870	1.80	1.61	7.95
December	880	1.81	1.57	4.96
Year	940	23.96	1.77	41.92
1890.				
January	910	2.03	1.76	2.89
February	980	1.94	1.86	4.04
March	920	1.97	1.70	6.24
April	1,250	2.68	2.40	2.51
May	1,350	3.07	2.66	6.10
June	960	1.98	1.78	4.53
July	810	1.73	1.50	3.58
August	830	1.78	1.55	2.99
September	870	1.86	1.67	4.88
October	970	2.16	1.87	6.82
November	970	1.92	1.72	2.31
December	1,010	2.16	1.88	5.08
Year	990	25.28	1.86	51.97
1891.				
January	950	2.11	1.83	7.71
February	960	1.91	1.83	4.31
March	1,040	2.23	1.93	5.48
April	1,670	3.57	3.20	1.89
May	1,290	2.75	2.39	3.47
June	960	2.05	1.84	2.77
July	860	1.83	1.59	4.78
August	880	1.89	1.64	1.15
September	900	1.92	1.72	1.94
October	920	2.03	1.76	3.22
November	820	1.63	1.46	2.38
December	750	1.60	1.39	4.17
Year	1,000	25.52	1.88	43.27

a Corrected for Sunday flow.

Flow of water from Sebago Lake, 1887 to 1897—Continued.

Year and month.	Average flow during working days of month, 24 hours per day.	Equivalent in inches on drainage area for month. *a*	Equivalent in cubic feet per second of continuous flow per square mile of drainage area.	Rainfall for month.
1892.	*Cubic feet per second.*			*Inches.*
January	790	1.70	1.47	4.22
February	810	1.67	1.55	2.18
March	770	1.70	1.47	2.27
April	710	1.53	1.37	1.04
May	730	1.55	1.35	4.41
June	710	1.52	1.36	4.60
July	880	1.82	1.58	2.68
August	830	1.85	1.60	8.14
September	730	1.56	1.39	2.89
October	600	1.29	1.12	1.64
November	570	1.17	1.05	3.76
December	580	1.23	1.07	1.32
Year	730	18.59	1.37	39.15
1893.				
January	590	1.26	1.09	2.19
February	590	1.16	1.12	4.51
March	590	1.31	1.13	3.58
April	540	1.11	0.99	3.71
May	710	1.57	1.36	7.59
June	830	1.78	1.59	3.62
July	770	1.58	1.37	0.96
August	750	1.65	1.44	2.74
September	790	1.69	1.51	2.33
October	750	1.61	1.40	5.13
November	720	1.48	1.33	1.83
December	840	1.74	1.51	5.42
Year	710	17.94	1.32	43.61
1894.				
January	830	1.85	1.60	3.13
February	780	1.53	1.47	2.70
March	630	1.39	1.21	1.97
April	580	1.20	1.08	2.55
May	690	1.53	1.33	7.33
June	720	1.54	1.38	2.01
July	800	1.65	1.43	2.96
August	680	1.50	1.30	3.27
September	560	1.16	1.04	2.76

a Corrected for Sunday flow.

Flow of water from Sebago Lake, 1887 to 1897—Continued.

Year and month.	Average flow during working days of month, 24 hours per day.	Equivalent in inches on drainage area for month. *a*	Equivalent in cubic feet per second of continuous flow per square mile of drainage area.	Rainfall for month.
1894.	*Cubic feet per second.*			*Inches.*
October	550	1.22	1.06	4.65
November	540	1.12	1.00	2.05
December	670	1.39	1.20	1.75
Year	670	17.08	1.26	37.13
1895.				
January	750	1.67	1.45	2.47
February	710	1.41	1.35	0.94
March	650	1.39	1.21	3.37
April	550	1.18	1.06	5.95
May	710	1.57	1.37	1.59
June	690	1.42	1.27	1.97
July	580	1.24	1.08	3.59
August	540	1.20	1.04	4.72
September	580	1.20	1.07	1.79
October	530	1.17	1.02	1.91
November	400	0.83	0.74	7.18
December	470	0.96	0.84	3.30
Year	600	15.24	1.12	38.78
1896.				
January	500	1.07	0.93	2.00
February	530	1.10	1.02	5.27
March	470	1.01	0.88	8.02
April	600	1.29	1.16	1.65
May	950	2.03	1.76	3.21
June	900	1.92	1.72	2.23
July	890	1.90	1.65	3.10
August	810	1.72	1.50	2.57
September	700	1.50	1.34	9.57
October	720	1.60	1.39	3.19
November	770	1.53	1.37	2.45
December	810	1.74	1.51	2.18
Year	720	18.41	1.36	45.44
1897.				
January	817	1.75	1.51	4.09
February	775	1.53	1.47	2.60
March	749	1.66	1.44	4.55

a Corrected for Sunday flow.

Flow of water from Sebago Lake, 1887 to 1897—Continued.

Year and month.	Average flow during working days of month, 24 hours per day.	Equivalent in inches on drainage area for month. *a*	Equivalent in cubic feet per second of continuous flow per square mile of drainage area.	Rainfall for month.
1897.	*Cubic feet per second.*			*Inches.*
April	545	1.16	1.04	2.60
May	681	1.45	1.26	5.87
June	823	1.76	1.58	4.97
July	908	1.94	1.68	2.62
August	1,110	2.37	2.06	1.41
September	973	2.08	1.86	2.34
October	973	2.08	1.80	0.46
November	850	1.75	1.57	6.69
December	883	1.89	1.64	4.22
Year	841	21.42	1.58	42.42

a Corrected for Sunday flow.

Flow of water from Sebago Lake, 1887 to 1896, averaged for calendar months.

Month.	Average flow during working days of month, 24 hours per day.	Equivalent in inches on drainage area during month.	Equivalent in cubic feet per second of continuous flow per square mile of drainage area.	Rainfall for month.
	Cubic feet per second.			*Inches.*
January	820	1.78	1.54	3.80
February	820	1.63	1.55	3.78
March	800	1.74	1.51	4.15
April	880	1.86	1.67	3.04
May	980	2.14	1.86	4.16
June	860	1.83	1.64	3.18
July	830	1.74	1.51	3.14
August	800	1.75	1.52	3.93
September	780	1.65	1.47	3.76
October	760	1.66	1.44	4.00
November	750	1.52	1.36	4.21
December	790	1.66	1.44	3.81
Year	820	20.96	1.56	44.96

Summary of yield of Sebago Lake for selected twelve-month periods.

Period.	Rainfall.	Run-off.	Ratio of run-off to rainfall.
	Inches.	*Inches.*	*Per cent.*
Oct. 1, 1887, to Oct. 1, 1888	51.98	24.31	47
Oct. 1, 1888, to Oct. 1, 1889	45.18	23.89	53
Sept. 1, 1889, to Sept. 1, 1890	51.75	24.45	47
Oct. 1, 1891, to Oct. 1, 1893 (mean for two years)	40.07	18.48	46
Dec. 1, 1893, to Dec. 1, 1894	40.80	17.43	43
Aug. 1, 1894, to Aug. 1, 1895	34.36	16.27	47
Yearly average, Jan. 1, 1887, to Jan. 1, 1897	44.96	20.96	47

SACO RIVER.

The remote source of Saco River is in the White Mountain region of New Hampshire, within a quarter of a mile of the Crawford House, at an elevation of nearly 1,900 feet above the sea. Thence the stream flows southeasterly into Maine, and after running 105 miles, measured from its source, discharges into Saco Bay, 15 miles to the southwest of Portland. The drainage basin contains about 1,750 square miles, equally divided between Maine and New Hampshire. The upper portion is mountainous and heavily wooded, succeeded lower down by less rugged, undulating surfaces, and finally subsiding, as the sea is approached, into a level and cleared country. The surface covering is mainly sand and gravel, but granite crops out abundantly throughout the basin.

For the first 12 miles from its source the Saco is a mountain rivulet in summer and a torrent in spring, falling over 1,100 feet in the entire distance, or about 90 feet per mile. In the next 18½ miles the average slope in successive intervals steadily diminishes from 28.5 feet per mile to 6.8 feet per mile, the fall in the entire distance from the western boundary of the town of Bartlett to the railroad crossing at Conway Center amounting to 333 feet. Next follows a long stretch of dead water, with a fall of only 69 feet in 28 miles, or 2.5 feet per mile. Then are encountered the Great Falls, at the town of Hiram, where the Saco descends 72 feet in about 900 feet; and finally, for the 40 miles to tide water at Biddeford and Saco, the fall amounts in the aggregate to 271 feet, or about 6.6 feet per mile as an average. The details of drainage area at different points and of fall, substantially as given by Prof. George F. Swain in Volume XVI, Tenth Census of the United States, are presented below:

Drainage areas of Saco River.

	Sq. miles.		Sq. miles.
Fryeburg	439	Salmon Falls	1,628
Great Falls, at Hiram	856	Union Falls	1,677
Highland Rips	1,366	Saco and Biddeford	1,734
Bonny Eagle Falls	1,578	Mouth	1,753

Fall in Saco River.

Locality.	Distance from mouth of river.	Height above tide.	Fall between points.	Distance between points.	Average fall per mile between points.
	Miles.	*Feet.*	*Feet.*	*Miles.*	*Feet.*
Source of river	104	1,880	1,135	12.5	90.8
Western boundary of Bartlett	91.5	745	185	6.5	28.5
Mouth of Rocky Branch	85	560	49	2	24.5
Mouth of Ellis River	83	511	65	5	13
Portsmouth, Great Falls and Conway R. R. crossing	78	446	34	5	6.8
Conway Center, R. R. crossing	73	412	69	28	2.5
Head of Great Falls	45	343	72	900 feet.	....
Foot of Great Falls	44.8	271	271	40.8	6.6
Mouth of Ossipee River	40	266			
Tide water at Biddeford and Saco	4	0			

The important portion of the river, as regards water power, is that extending from Great Falls to tide water, covering, as has been noticed, 271 feet of fall in about 40 miles, with a drainage area increasing from 856 to 1,734 square miles. The principal owner of power is the Saco Water Power Company, controlling privileges at Biddeford and Saco, Union Falls, Salmon Falls, and Hiram.

UTILIZED POWER.

At Biddeford and Saco the river falls over trap ledges, giving a total descent from above the upper dam to tide water of about 40 feet, fluctuating somewhat with the tide. At the upper dam, where the fall is 6½ feet, the power is used only by a sawmill. The remaining fall of 33 or 34 feet, constituting the principal power, is utilized by three cotton manufacturing companies. The York Manufacturing Company, whose mill is on an island in the river, owns 11 mill powers, corresponding with 30 feet of fall to 275 cubic feet per second of water, or 937 gross horsepower. Of the remaining power the Pepperell Manufacturing Company owns four-sevenths and the Laconia Manufacturing Company three-sevenths. These two companies control the Saco Water Power Company, the nominal owner of the power. Their mills are on the south bank of the river, where by a dam across the south arm the total fall of 33 or 34 feet is divided into two falls of about equal amount, the Pepperell company using the upper and the Laconia the lower. The two companies have a total of about 4,500 horsepower of turbines, but can obtain the full capacity of these probably not more than two-thirds of the year, during the rest of the time having to rely largely upon steam power, of which they have 3,700 horsepower. The pondage here is small, but is sufficient at points upstream to store all the night flow in low stages.

At Union Falls, some 8 miles above Saco, a fall of 15 feet is caused by a dam maintained for the purpose of holding storage above. This dam is owned by the Saco Water Power Company, as is also the succeeding one, 20 feet high, at Salmon Falls; but the power at both of them, as well as that represented in considerable rapids below the dams, is unutilized. At Salmon Falls, shown in Pl. XV, *B*, the total descent is said to be 62 feet in 3,500 feet, the river running through a narrow, rocky channel, with almost vertical banks. The next privilege is at Bar Mills, at which point the Portland and Rochester Railroad crosses the river. A fall of 18 feet is available here, and the power is partly utilized by a furniture factory, a gristmill, and two sawmills. Four or five miles above are Moderation Falls, at which a head of 16 feet is obtained, the power being used for small woolen mills and sawmills. A mile or two farther upstream, and somewhat less than 20 miles due west of the city of Portland, are Bonny Eagle Falls, the power at which is for sale by the E. T. Burrowes Company, of Portland. A small sawmill situated on an island at the head of the falls is the only present user of power. Below the dam heavy rapids extend for perhaps half a mile downstream, giving a total fall on the privilege of 48 feet. The power is an important one, and the site presents favorable features with respect to pondage and facilities for improvement.

Five or six miles above Bonny Eagle are heavy rapids extending a third of a mile along the stream, constituting what are known as Limington Falls; and again, about a mile farther up the river, are other rapids a quarter of a mile in length. The fall at these two localities is given by Wells[1] as 65 feet and 26 feet, respectively, but the figures seem much too high. At the head of the lower or principal falls the banks are rather low on each side, but a short distance downstream there is a rocky island and the river banks are also of ledge, offering a favorable location for a dam. The river is probably from 250 to 350 feet wide in this portion of its course. The next water power is at Steep Falls, about 2 miles up the river from the upper rapids just mentioned, and some 25 miles above the power at Saco and Biddeford. At this point a log dam, seventy-five years old, gives a fall of about 12 feet at the maximum, power being used by a gristmill, heading mill, and shingle mill. Above Steep Falls there are said to be occasional rapids along the river, probably the most prominent being Highland Rips, before reaching Great Falls, in Hiram, shown in Pl. XVI, which are about 45 miles above the mouth of the river. Here the Saco descends in successive pitches a total of 72 feet in 900 feet. An island divides the stream at the head of the falls, the banks are of ledge, and the topography appears favorable for the development and utilization of the power. The Maine Central Railroad from Portland to Conway

[1] Water-Power of Maine, p. 338.

GREAT FALLS ON SACO RIVER, AT HIRAM, MAINE.

skirts the east bank of the river at the foot of the falls. This privilege, which is one of exceptional importance, is owned by the Saco Water Power Company, and is entirely unimproved.

Above Great Falls there is quiet water for some 30 miles, constituting valuable pondage for the privilege just described; but beyond this stretch the river has too small a drainage area and too variable a flow to demand attention here.

CHARACTERISTICS WITH RESPECT TO FLOW.

No records are available of actual measurements of the Saco. In his report of 1869 Wells states[1] that in a summer drought the discharge at Saco was equal to 300 cubic feet per second, average for the twenty-four hours; and in his report of 1880 Professor Swain estimated[2] the minimum flow there at not far from 250 cubic feet per second, average for the twenty-four hours. Owing to the mountainous character of the upper basin, that part of the river is subject to excessive fluctuations in volume, which are reduced, however, in the lower river by the natural holding back of the floods at the head of Great Falls and by the effect of the gentler slopes of the lower basin and the storage in its lakes and ponds. The extreme range between high and low water is given by Wells as 12 feet at Great Falls, 6 feet at Bonny Eagle Falls, and from 8 to 10 feet at Saco. The lakes in the basin are numerous, though not large, and, according to Wells, comprise 84 square miles of surface. The Saco Water Power Company itself controls Great Ossipee Lake, covering 3,809 acres, with 5 feet of storage; Moose Lake, covering 1,648 acres, with $9\frac{5}{8}$ feet of storage; and four other ponds, ranging in size from 150 to 525 acres and in depth of storage from 4 to 9 feet.

The largest tributary of the Saco is the Ossipee, which discharges from the west not far below Great Falls. It heads in Ossipee Lake, in New Hampshire, and has a length of about 20 miles, with a drainage area of 470 square miles. The storage in Ossipee and other lakes serves to render the flow quite uniform, and this fact, combined with the considerable fall, amounting to 142 feet below the source, gives the stream value for power.

NORTHERN ATLANTIC STREAMS OTHER THAN THOSE OF MAINE.

MERRIMAC RIVER.

A record of the daily discharge of Merrimac River at Lawrence, Massachusetts, has been kept for a series of years by Mr. Hiram F. Mills, engineer of the Essex Company. In Bulletin No. 140, p. 34, were published the monthly estimates for the years 1892 to 1895, inclusive. The record for 1896 and 1897 has also been obtained from Mr. Mills and his assistant, Mr. R. A. Hale, and is given herewith, together with revised figures for the years 1890 to 1895, inclusive.

Mr. Hale calls attention to the fact that the minimum discharge in

[1] Water-Power of Maine, p. 76. [2] Tenth Census U. S., Vol. XVI. Part I, p. 72.

second-feet does not have the same significance as in the case of a river not so completely controlled by dams. During dry months the lowest flow or quantity in the river usually occurs on Sunday, when the water is held back by the Lawrence dam and by other milldams at points above. The quantity flowing at these times is merely the leakage through the canals and other structures. Thus the minimum discharge recorded at this time has no connection with the natural flow of the stream, as in times of drought an attempt is made to hold all of the water. If the ponds are drawn down on Saturday there may be no flow on the following day. Thus for purposes of comparison it is desirable to take not the minimum flow per day but rather that for a week or ten days in succession.

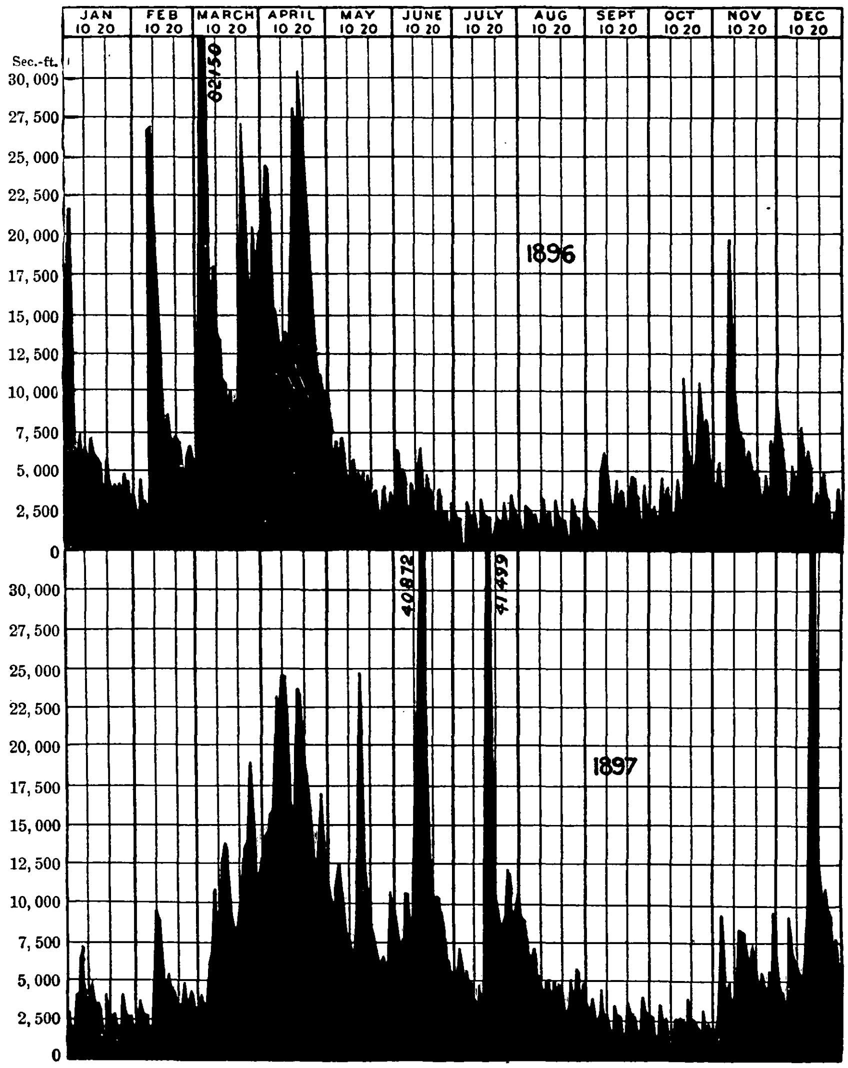


FIG. 25.—Discharge of Merrimac River at Lawrence, Massachusetts, 1896 and 1897.

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.		Depth in inches.	Second-feet per square mile.
1890.						
January	10,480	4,280	6,955	427,646	1.76	1.53
February	21,300	3,750	7,721	428,802	1.77	1.70
March	25,200	8,150	15,667	963,326	3.97	3.44
April	24,350	11,630	17,244	1,026,089	4.23	3.79
May	24,500	7,980	14,285	878,350	3.62	3.14
June	13,900	2,850	7,881	468,952	1.93	1.73
July	6,560	620	3,161	194,362	0.79	0.69
August	12,700	590	3,406	209,426	0.86	0.75
September	22,990	3,350	8,397	499,656	2.05	1.84
October	31,450	4,480	12,314	757,158	3.11	2.70
November	15,260	4,130	8,871	527,861	2.18	1.95
December	13,560	3,660	6,573	404,158	1.66	1.44
The year	31,450	590	9,373	6,785,786	27.93	2.06
1891.						
January	32,200	4,760	13,298	817,662	3.37	2.92
February	29,800	7,870	13,499	749,696	3.08	2.96
March	41,200	11,750	23,618	1,452,214	5.98	5.19
April	31,700	11,480	21,519	1,280,469	5.28	4.73
May	11,270	4,540	7,347	451,749	1.86	1.61
June	7,600	2,430	4,542	270,268	1.11	1.00
July	4,040	730	2,895	178,007	0.74	0.64
August	5,120	640	2,460	151,259	0.62	0.54
September	3,830	580	2,544	151,378	0.62	0.56
October	2,680	450	2,137	131,399	0.54	0.47
November	5,400	280	2,469	146,916	0.60	0.54
December	14,130	760	4,113	252,899	1.04	0.90
The year	39,000	280	8,370	6,033,916	24.84	1.84
1892.						
January	20,400	3,170	8,524	524,120	2.16	1.87
February	7,170	1,890	4,302	247,454	1.01	0.94
March	13,510	3,790	7,330	450,704	1.86	1.61
April	16,600	4,410	8,150	484,959	2.00	1.79
May	24,800	4,300	10,233	629,203	2.59	2.25
June	14,120	2,960	5,819	346,255	1.43	1.28
July	13,030	360	4,757	292,497	1.21	1.05
August	21,600	505	4,807	295,570	1.22	1.06
September	8,260	565	3,944	234,684	0.97	0.87

Estimated monthly discharge of Merrimac River at Lawrence, Massachusetts—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1892.						
October	3,195	225	2,136	131,338	0.54	0.47
November	21,900	1,995	6,494	386,419	1.60	1.43
December	5,830	2,640	3,931	241,708	0.99	0.86
The year	24,800	225	5,869	4,264,911	17.58	1.29
1893.						
January	6,869	710	2,949	181,327	0.75	0.65
February	11,493	1,142	4,995	277,409	1.15	1.10
March	25,808	3,096	10,723	659,331	2.72	2.36
April	20,100	11,270	15,563	926,063	3.82	3.42
May	44,800	7,230	19,504	1,199,254	4.93	4.28
June	6,845	3,115	4,404	262,056	1.08	0.97
July	3,665	305	2,389	146,893	0.60	0.52
August	6,554	435	2,582	158,761	0.66	0.57
September	6,246	1,211	2,782	165,540	0.68	0.61
October	11,380	286	3,614	222,215	0.91	0.79
November	6,290	1,430	3,366	200,291	0.82	0.74
December	8,445	3,240	5,329	327,667	1.35	1.17
The year	44,800	286	4,850	4,726,807	19.47	1.43
1894.						
January	5,000	1,000	3,022	185,815	0.76	0.66
February	9,600	1,000	4,274	237,336	0.98	0.94
March	27,900	3,100	14,375	883,884	3.64	3.16
April	20,880	6,720	11,085	659,603	2.71	2.43
May	19,130	2,540	6,992	429,921	1.78	1.54
June	15,150	2,310	6,033	358,988	1.48	1.33
July	3,712	223	2,278	140,069	0.58	0.50
August	2,524	193	1,695	104,221	0.43	0.37
September	4,063	104	1,831	108,951	0.45	0.40
October	3,589	209	2,254	138,593	0.58	0.50
November	5,935	1,479	3,549	211,180	0.87	0.78
December	5,198	961	3,033	186,491	0.77	0.67
The year	27,900	104	5,035	3,645,052	15.03	1.11
1895.						
January	4,078	710	2,887	177,514	0.72	0.63
February	3,432	877	2,319	128,790	0.53	0.51
March	10,480	1,595	5,857	360,133	1.48	1.28

Estimated monthly discharge of Merrimac River at Lawrence, Massachusetts—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1895.						
April	65, 300	6, 740	19, 840	1, 180, 561	4. 85	4. 35
May	9, 950	2, 649	6, 233	383, 252	1. 58	1. 37
June	4, 701	569	3, 038	180, 773	0. 74	0. 67
July	4, 274	257	2, 583	158, 822	0. 66	0. 57
August	3, 409	307	2, 180	134, 043	0. 55	0. 48
September	2, 974	71	1, 673	99, 551	0. 41	0. 37
October	11, 959	429	4, 010	246, 565	1. 01	0. 88
November	19, 100	3, 422	9, 558	568, 740	2. 34	2. 10
December	17, 100	4, 580	9, 404	578, 229	2. 38	2. 06
The year	65, 300	71	5, 799	4, 196, 973	17. 25	1. 27
1896.						
January	21, 600	3, 335	6, 546	402, 497	1. 66	1. 44
February	27, 000	2, 160	9, 109	523, 956	2. 16	2. 00
March	82, 150	8, 100	21, 054	1, 294, 560	5. 33	4. 62
April	30, 100	9, 120	18, 234	1, 084, 998	4. 46	4. 00
May	8, 040	1, 920	4, 438	272, 882	1. 13	0. 98
June	5, 720	1, 080	3, 518	209, 335	0. 85	0. 77
July	3, 278	203	2, 042	125, 557	0. 52	0. 45
August	3, 209	183	2, 019	124, 143	0. 51	0. 44
September	5, 919	620	3, 122	181, 785	0. 74	0. 67
October	10, 749	2, 282	5, 186	318, 875	1. 31	1. 14
November	19, 573	3, 564	6, 662	396, 416	1. 63	1. 46
December	8, 046	1, 520	4, 359	268, 025	1. 10	0. 96
The year	82, 150	183	7, 187	5, 203, 029	21. 40	1. 58
1897.						
January	7, 325	1, 721	3, 409	209, 611	0. 86	0. 75
February	9, 427	1, 902	4, 571	253, 862	1. 05	1. 01
March	18, 717	3, 636	10, 571	649, 985	2. 68	2. 32
April	24, 513	10, 947	17, 612	1, 047, 928	4. 32	3. 87
May	24, 681	5, 676	10, 117	622, 070	2. 56	2. 22
June	40, 872	5, 246	12, 708	756, 179	3. 11	2. 79
July	41, 499	3, 370	10, 799	664, 004	2. 74	2. 37
August	9, 220	2, 860	5, 072	311, 865	1. 29	1. 12
September	4, 460	1, 044	2, 759	164, 172	0. 68	0. 61
October	3, 805	176	2, 207	135, 703	0. 55	0. 48
November	9, 714	2, 374	5, 827	346, 731	1. 43	1. 28
December	36, 800	3, 216	10, 376	637, 995	2. 63	2. 28
The year	41, 499	176	8, 002	5, 800, 105	23. 90	1. 76

CONNECTICUT RIVER.

The daily flow of Connecticut River at Holyoke, Massachusetts, has been computed by engineers of the Holyoke Water Power Company The results of their computations have been obtained through the kindness of Mr. A. F. Sickman. The figures, by months, from 1880 to 1895 are published in Bulletin No. 140, on pages 37 to 41. The principal facts for the flow during the years 1896 and 1897 are contained in the following table, and the daily fluctuations are shown in fig. 26. The quantities obtained from Mr. Sickman are the average daily amount drawn from the pond above the dam, and represent the discharge of the river except at such times as the surface falls below the crest of the dam when the water is ponded over night and during Sunday.

Estimated monthly discharge of Connecticut River at Holyoke, Massachusetts.

[Drainage area, 8,660 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1896.						
January	47, 350	5, 800	10, 882	669, 108	1. 45	1. 26
February	20, 750	4, 800	9, 096	523, 208	1. 13	1. 05
March	112, 050	8, 550	27, 216	1, 673, 446	3. 62	3. 14
April	89, 200	17, 700	42, 363	2, 520, 773	5. 46	4. 89
May	18, 300	4, 850	9, 684	595, 446	1. 29	1. 12
June	8, 850	2, 550	5, 357	318, 764	0. 69	0. 62
July	6, 050	750	3, 684	226, 520	0. 48	0. 42
August	4, 650	450	2, 965	182, 311	0. 39	0. 34
September	8, 450	700	4, 768	283, 715	0. 61	0. 55
October	22, 100	3, 500	10, 971	674, 580	1. 46	1. 27
November	30, 450	7, 900	14, 115	839, 901	1. 82	1. 63
December	17, 900	3, 400	7, 624	468, 782	1. 01	0. 88
The year	112, 050	450	12, 394	8, 976, 554	19. 41	1. 43
1897.						
January	10, 350	2, 300	5, 011	308, 114	0. 67	0. 58
February	14, 250	2, 550	5, 780	321, 005	0. 70	0. 67
March	34, 650	3, 500	14, 471	889, 786	1. 93	1. 67
April	50, 950	21, 900	35, 478	2, 111, 088	4. 58	4. 10
May	44, 050	12, 450	22, 524	1, 384, 946	3. 00	2. 60
June	75, 350	7, 900	22, 320	1, 328, 132	2. 88	2. 58
July	58, 350	7, 650	23, 458	1, 442, 376	3. 12	2. 71
August	22, 350	6, 450	10, 792	663, 574	1. 44	1. 25
September	6, 200	2, 250	4, 313	256, 641	0. 56	0. 50
October	5, 300	1, 300	3, 668	225, 536	0. 48	0. 42
November	29, 550	3, 850	14, 880	885, 422	1. 92	1. 72
December	70, 650	8, 950	21, 779	1, 339, 139	2. 89	2. 51
The year	75, 350	1, 300	15, 373	11, 155, 759	24. 17	1. 78

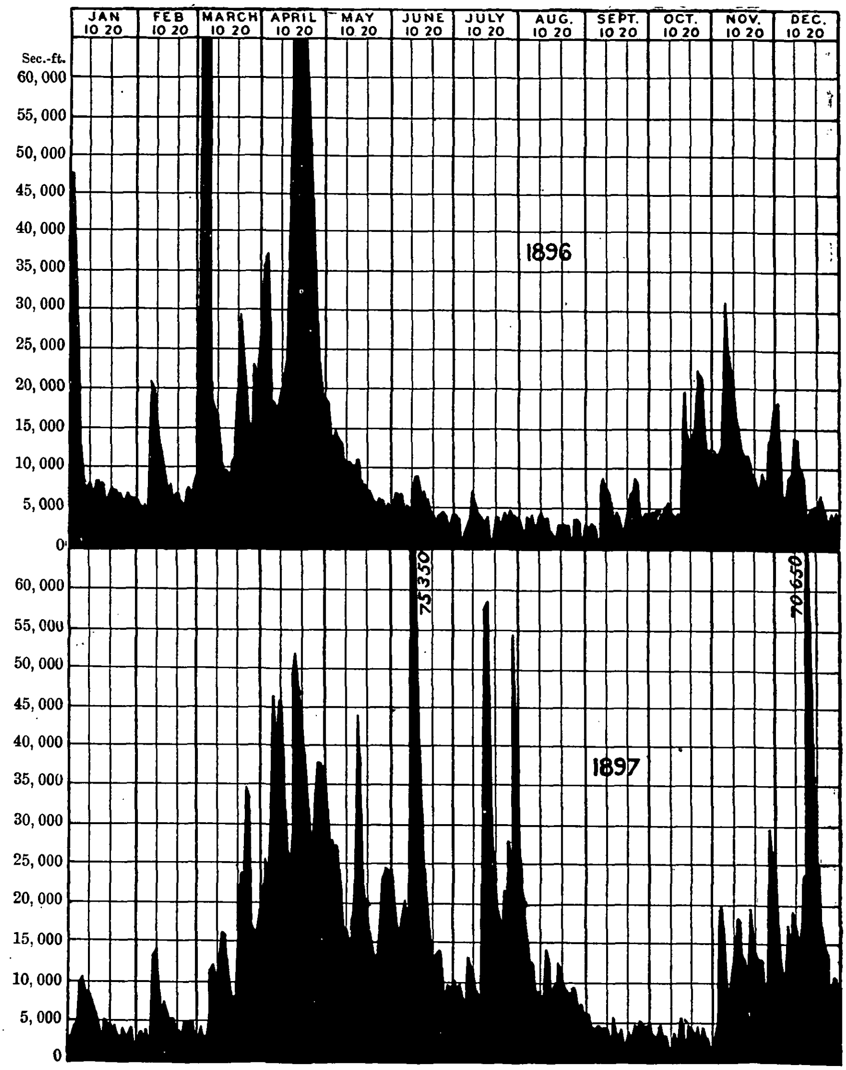


FIG. 26.—Discharge of Connecticut River at Holyoke, Massachusetts, 1896 and 1897.

HUDSON RIVER.

A daily record of the height of water passing over the dam of the Duncan Company at Mechanicville, New York, has been kept, with few omissions, since 1887, as described in the Report on the Upper Hudson Storage, prepared by George W. Rafter.[1]

From this and other records a computation has been made by Mr. Rafter of the daily flow of the river, using the formula derived from East Indian engineers, which, according to his experience, seemed to be

[1] Annual Report of the State Engineer and Surveyor of the State of New York for the fiscal year ending September 30, 1895, Albany, 1896, p. 104.

most applicable to the prevailing conditions. To values thus obtained there has been added the tabulated quantity of water discharged by the different water wheels while in use. The figures for this purpose have been taken from the published tables of the several makers, which show the probable discharge under various heads. The height of water on the crest of the dam has been taken at 7 a. m. and 5 p. m., and the head of water on the wheels has also been obtained from two observations daily. Discharges for Sundays and other days during which the wheels were not running have been obtained by averaging the figures for the day preceding and that following.

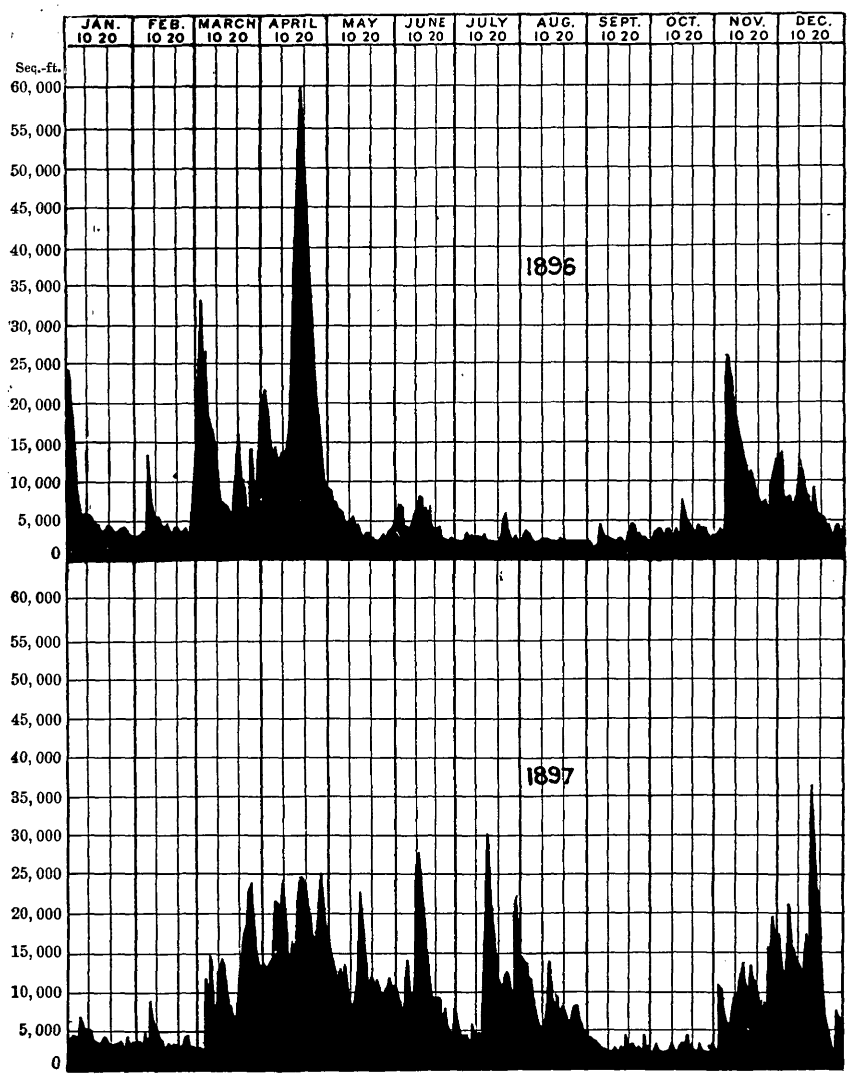


FIG. 27.—Discharge of Hudson River at Mechanicville, New York, 1896 and 1897.

Results of these computations have been published in Pls. III, IV, V, and VI of the Report of the State Engineer for 1895, covering the period from October 1, 1887, to November 30, 1895. Figures for the succeeding period have been obtained from Mr. Rafter. Results by months and years are given in the following table:

Estimated monthly discharge of Hudson River at Mechanicville, New York.

[Drainage area, 4,500 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1890.						
January	19,000	5,500	11,272	693,089	2.89	2.50
February	17,680	4,680	7,813	433,912	1.81	1.74
March	20,430	6,780	11,129	684,296	2.85	2.47
April	21,930	8,630	15,053	895,716	3.74	3.35
May	25,080	12,900	17,931	1,102,533	4.59	3.98
June	11,030	2,630	7,392	439,854	1.83	1.64
July	2,800	1,410	1,950	119,900	0.49	0.43
August	4,880	1,030	2,019	124,143	0.52	0.45
September	26,000	2,200	8,844	526,254	2.20	1.97
October	22,530	3,410	9,215	566,608	2,37	2.05
November	15,500	5,450	9,121	542,738	2.26	2.03
December	5,930	2,200	3,244	199,465	0.83	0.72
The year	26,000	1,030	8,749	6,328,508	26.38	1.94
1891.						
January	21,930	2,630	8,284	509,363	2.12	1.84
February	31,130	5,500	11,664	647,785	2.70	2.59
March	27,730	9,080	17,738	1,090,667	4.54	3.94
April	33,100	10,700	20,021	1,191,333	4.96	4.45
May	9,530	3,630	5,533	340,211	1.42	1.23
June	8,930	1,630	3,200	190,413	0.79	0.71
July	3,450	1,350	2,337	143,696	0.60	0.52
August	10,530	1,210	2,666	163,926	0.68	0.59
September	3,450	1,080	2,040	121,388	0.50	0.45
October	2,380	850	1,472	90,510	0.38	0.33
November	11,100	950	4,088	243,252	1.01	0.91
December	20,530	4,680	8,577	527,380	2.20	1.91
The year	33,100	850	7,302	5,259,924	21.90	1.62

Estimated monthly discharge of Hudson River at Mechanicville, New York—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1892.						
January	33,520	9,920	18,857	1,159,471	4.83	4.19
February	11,620	7,570	9,263	532,814	2.22	2.06
March	15,700	8,350	10,829	665,849	2.78	2.41
April	43,910	12,310	21,554	1,282,552	5.34	4.79
May	30,110	12,210	19,622	1,206,509	5.04	4.37
June	26,310	4,260	12,595	749,455	3.12	2.80
July	18,800	2,710	9,282	570,728	2.38	2.06
August	18,660	2,960	5,485	337,259	1.41	1.22
September	10,310	2,710	4,448	264,674	1.10	0.99
October	3,340	2,440	2,819	173,333	0.72	0.63
November	14,260	2,780	7,604	452,469	1.89	1.69
December	5,610	2,460	4,031	247,856	1.04	0.90
The year	43,910	2,440	10,532	7,642,969	31.87	2.34
1893.						
January	5,010	2,510	3,192	196,269	0.82	0.71
February	8,960	2,860	4,605	255,749	1.06	1.02
March	19,940	2,960	8,850	544,165	2.27	1.97
April	25,740	4,410	17,889	1,064,470	4.44	3.98
May	54,060	7,880	22,285	1,370,251	5.71	4.95
June	8,010	2,910	4,801	285,680	1.19	1.07
July	3,060	1,980	2,521	155,010	0.64	0.56
August	26,360	1,380	5,008	307,930	1.28	1.11
September	15,410	3,070	6,870	408,793	1.71	1.53
October	5,780	2,360	3,865	237,650	0.99	0.86
November	5,031	3,010	3,639	216,536	0.90	0.81
December	15,160	3,060	7,217	443,756	1.84	1.60
The year	54,060	1,380	7,562	5,486,259	22.85	1.68
1894.						
January	11,880	4,710	6,757	415,472	1.73	1.50
February	6,610	3,760	4,836	268,578	1.11	1.07
March	26,560	5,610	14,738	906,204	3.78	3.28
April	18,860	6,110	11,136	662,637	2.76	2.47
May	15,160	4,410	7,566	465,215	1.94	1.68
June	14,910	3,280	7,097	422,301	1.76	1.58
July	4,770	2,120	3,168	194,793	0.81	0.70
August	5,200	1,800	2,454	150,890	0.63	0.55

Estimated monthly discharge of Hudson River at Mechanicville, New York—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1894.						
September	3, 450	1, 170	1, 889	112, 403	0. 47	0. 42
October	7, 850	1, 820	3, 649	224, 368	0. 93	0. 81
November	13, 030	2, 630	6, 379	379, 577	1. 58	1. 42
December	10, 120	2, 670	4, 367	268, 517	1. 12	0. 97
The year	26, 560	1, 170	6, 170	4, 470, 955	18. 62	1. 37
1895.						
January	5, 770	2, 650	3, 876	238, 326	0. 99	0. 86
February	4, 090	2, 770	3, 543	196, 769	0. 82	0. 79
March	5, 960	2, 980	4, 204	258, 494	1. 07	0. 93
April	49, 630	4, 880	23, 822	1, 417, 507	5. 90	5. 29
May	14, 330	3, 730	6, 850	421, 190	1. 75	1. 52
June	4, 230	1, 990	2, 816	167, 564	0. 70	0. 63
July	3, 380	1, 960	2, 559	157, 347	0. 66	0. 57
August	9, 500	1, 960	3, 901	239, 863	1. 00	0. 87
September	3, 430	1, 960	2, 629	156, 437	0. 64	0. 58
October	4, 170	540	2, 631	161, 774	0. 67	0. 58
November	30, 940	2, 250	8, 421	501, 085	2. 09	1. 87
December	21, 297	4, 752	10, 889	669, 538	2. 79	2. 42
The year	49, 630	540	6, 345	4, 585, 894	19. 08	1. 41
1896.						
January	24, 147	3, 177	6, 791	417, 562	1. 74	1. 51
February	13, 327	3, 177	4, 668	268, 506	1. 12	1. 04
March	32, 900	5, 602	13, 600	836, 232	3. 49	3. 02
April	59, 393	9, 477	24, 972	1, 485, 937	6. 20	5. 55
May	9, 050	2, 952	4, 610	283, 458	1. 18	1. 02
June	8, 127	2, 377	4, 738	281, 930	1. 18	1. 05
July	5, 349	2, 324	2, 772	170, 443	0. 72	0. 62
August	3, 099	2, 324	2, 442	150, 152	0. 63	0. 54
September	4, 741	1, 770	2, 879	171, 313	0. 71	0. 64
October	7, 416	2, 916	4, 106	252, 468	1. 05	0. 91
November	25, 735	3, 332	11, 352	675, 490	2. 82	2. 52
December	13, 028	3, 435	6, 913	425, 063	1. 78	1. 54
The year	59, 393	1, 770	7, 487	5, 418, 554	22. 62	1. 66

Estimated monthly discharge of Hudson River at Mechanicville, New York—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	6, 623	2, 875	4, 007	246, 380	1. 02	0. 89
February	8, 450	2, 820	3, 895	216, 318	0. 91	0. 87
March	23, 957	2, 664	12, 214	751, 009	3. 13	2. 71
April	25, 200	12, 906	19, 074	1, 134, 981	4. 73	4. 24
May	22, 550	8, 400	12, 167	748, 119	3. 12	2. 70
June	27, 188	4, 400	11, 855	705, 422	2. 93	2. 63
July	31, 060	3, 932	11, 109	683, 066	2. 85	2. 47
August	14, 290	4, 550	8, 241	506, 719	2. 11	1. 83
September	4, 000	2, 180	2, 756	163, 993	0. 68	0. 61
October	4, 110	2, 150	2, 524	155, 195	0. 64	0. 56
November	19, 456	2, 150	9, 995	594, 744	2. 47	2. 22
December	35, 706	2, 293	14, 382	884, 314	3. 69	3. 20
The year	35, 706	2, 150	9, 352	6, 790, 260	28. 28	2. 08

DELAWARE RIVER.

Delaware River was measured at Delaware Water Gap, Pennsylvania, in 1891, by Prof. Dwight Porter and students. The results show a flow of from 2,000 to 2,200 second-feet during the latter half of June, 1891. This was said to be the lowest June stage for five years. Measurements were made during the drought of 1895 by Mr. L. M. Haupt, by means of current-meter observations above and below the bridge at Point Pleasant, Pennsylvania, near the intake of the Delaware and Raritan Canal feeder. The discharge above the bridge was 1,657 second-feet and below the bridge 1,628 second-feet.

The gaging station at Lambertville, New Jersey, was established July 23, 1897. It is described in Water-Supply and Irrigation Paper No. 15, p. 7. A sufficient number of discharge measurements on which to base a rating table for this station have not been made.

SUSQUEHANNA RIVER.

Observations of the height of water in Susquehanna River have been made for several years at the pump house of the waterworks, located in the western part of the city of Harrisburg, Pennsylvania. The gaging station at Harrisburg, Pennsylvania, is described in Water-Supply and Irrigation Paper No. 15, p. 8. A well is connected directly with the river by means of large water mains, and a float in this well is attached to a cable and counterweight, the height of water being indicated on a painted scale. The record since 1890 has been furnished by Mr. E. Mather, president of the Harrisburg Water Company, and, by means of measurements of discharge made at this point in 1897, the record has been interpreted in daily discharges. The results, by months, are shown in the following tables, and graphically in figs. 28 and 29.

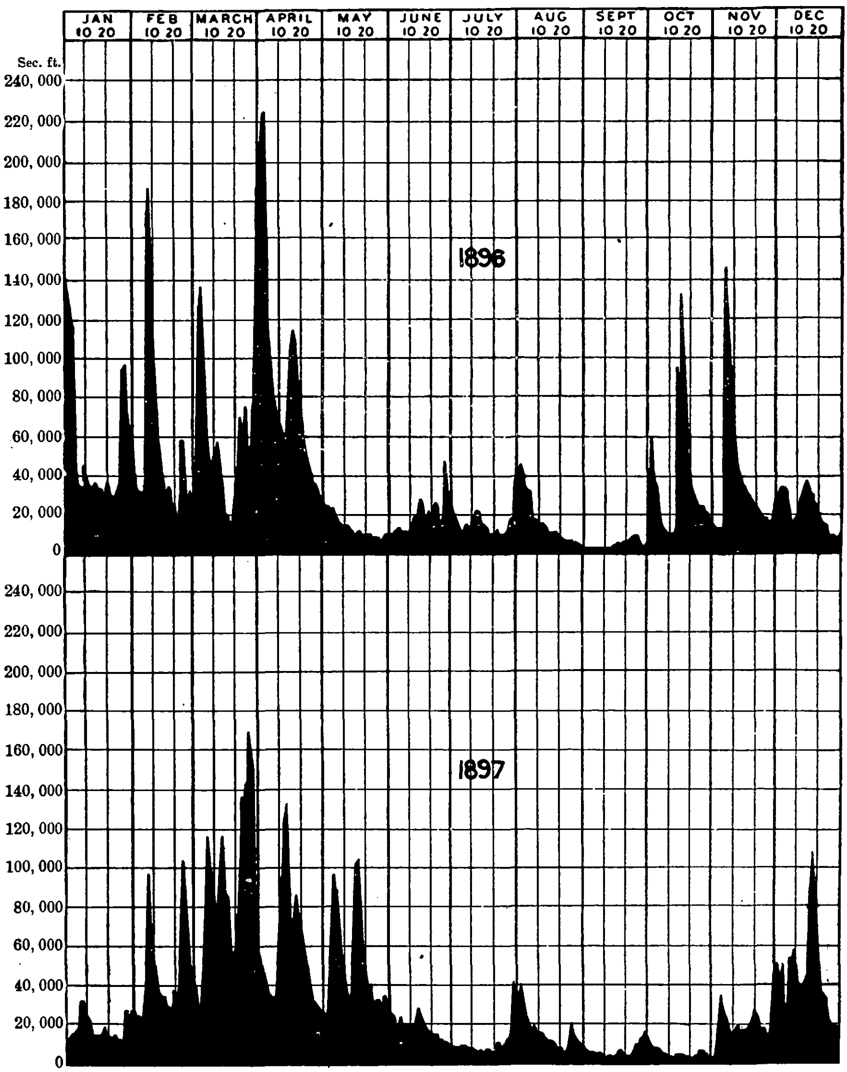


FIG. 28.—Discharge of Susquehanna River at Harrisburg, Pennsylvania, 1896 and 1897.

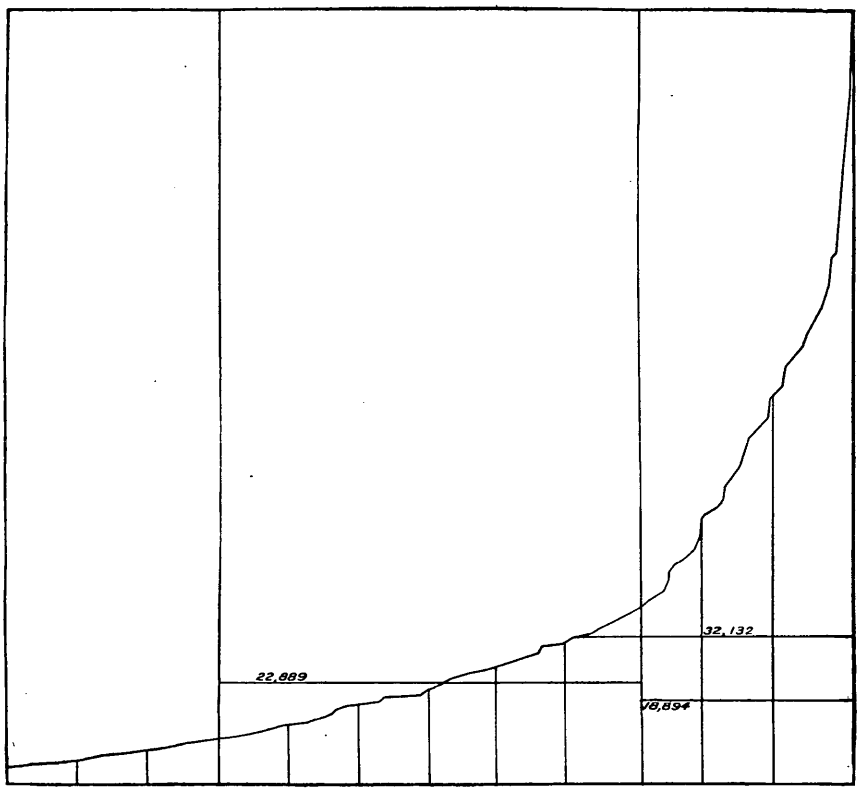


FIG. 29.—Discharge of Susquehanna River at Harrisburg, Pennsylvania, for 1897, arranged in order of quantity and not of date. (See description on page 31.)

Rating table for Susquehanna River at Harrisburg, Pennsylvania, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.0	2,000	2.6	19,300	5.5	61,090	12.0	177,040
0.2	2,800	2.8	21,300	6.0	69,990	12.5	185,990
0.4	3,600	3.0	23,400	6.5	78,890	13.0	194,940
0.6	4,500	3.2	25,550	7.0	87,790	13.5	203,890
0.8	5,700	3.4	27,800	7.5	96,690	14.0	212,840
1.0	6,900	3.6	30,400	8.0	105,590	14.5	221,790
1.2	8,150	3.8	32,800	8.5	114,490	15.0	230,740
1.4	9,450	4.0	35,400	9.0	123,390	15.5	239,690
1.6	10,750	4.2	38,150	9.5	132,290	16.0	248,640
1.8	12,300	4.4	41,150	10.0	141,240	16.5	257,590
2.0	13,900	4.6	44,350	10.5	150,190		
2.2	15,400	4.8	47,700	11.0	159,140		
2.4	17,450	5.0	51,400	11.5	168,090		

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.		Depth in inches.	Second-feet per square mile.
1891.						
January	138, 555	21, 800	73, 052	4, 491, 792	3. 51	3. 04
February	302, 300	62, 880	140, 790	7, 819, 080	6. 10	5. 86
March	159, 140	45, 150	99, 105	6, 093, 728	4. 76	4. 12
April	123, 390	33, 450	81, 044	4, 822, 453	3. 76	3. 37
May	30, 400	13, 900	19, 384	1, 191, 875	0. 93	0. 81
June	72, 675	13, 100	25, 630	1, 525, 091	1. 19	1. 07
July	40, 400	12, 700	21, 752	1, 337, 479	1. 05	0. 91
August	80, 680	13, 900	30, 900	1, 899, 967	1. 49	1. 29
September	45, 150	11, 900	23, 649	1, 407, 214	1. 09	0. 98
October	45, 150	10, 750	18, 810	1, 156, 582	0. 90	0. 78
November	77, 150	13, 900	34, 024	2, 024, 568	1. 58	1. 42
December	132, 290	29, 100	63, 289	3, 891, 489	3. 03	2. 63
The year	302, 300	10, 750	52, 619	37, 661, 318	29. 39	2. 19
1892.						
January	197, 625	14, 600	80, 041	4, 921, 529	3. 84	3. 33
February	48, 600	7, 500	22, 244	1, 279, 489	1. 00	0. 93
March	194, 940	18, 300	51, 578	3, 171, 408	2. 48	2. 15
April	224, 475	25, 025	80, 250	4, 775, 206	3. 73	3. 34
May	120, 755	21, 800	67, 999	4, 181, 095	3. 26	2. 83
June	185, 990	26, 100	65, 704	3, 909, 659	3. 04	2. 73
July	45, 150	9, 450	19, 469	1, 197, 101	0. 93	0. 81
August	37, 450	12, 700	18, 886	1, 161, 255	0. 91	0. 79
September	22, 300	7, 510	11, 713	696, 972	0. 54	0. 49
October	9, 450	4, 000	6, 255	384, 604	0. 30	0. 26
November	30, 400	4, 000	11, 123	661, 865	0. 52	0. 46
December	38, 900	6, 300	16, 436	1, 010, 611	0. 78	0. 68
The year	224, 475	4, 000	37, 641	27, 350, 794	21. 33	1. 57
1893.						
January	21, 800	13, 900	15, 960	981, 342	0. 76	0. 66
February	169, 880	19, 800	56, 053	3, 113, 026	2. 43	2. 33
March	223, 580	18, 300	94, 556	5, 814, 021	4. 53	3. 93
April	157, 350	54, 363	105, 555	6, 280, 959	4. 90	4. 39
May	257, 590	31, 000	91, 246	5, 610, 498	4. 39	3. 80
June	31, 000	10, 750	18, 852	1, 121, 771	0. 87	0. 78
July	16, 775	6, 300	10, 750	660, 992	0. 52	0. 45

Estimated monthly discharge of Susquehanna River at Harrisburg, Pennsylvania—Cont'd.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1893.						
August	24,500	3,400	5,690	349,865	0.28	0.24
September	41,150	10,100	18,948	1,127,484	0.88	0.79
October	58,313	8,475	18,972	1,166,543	0.91	0.79
November	31,000	10,750	15,789	939,511	0.73	0.66
December	120,755	13,900	40,509	2,490,801	1.95	1.69
The year	257,590	3,400	41,073	29,656,813	23.15	1.71
1894.						
January	56,338	17,250	26,921	1,655,308	1.29	1.12
February	69,990	13,900	31,656	1,758,084	1.37	1.32
March	179,725	25,025	70,347	4,325,468	3.38	2.93
April	139,450	20,800	66,354	3,948,337	3.07	2.76
May	454,900	16,775	98,863	6,078,848	4.75	4.11
June	134,975	17,250	50,340	2,995,438	2.34	2.10
July	19,300	6,900	10,548	648,571	0.51	0.44
August	11,125	3,600	6,935	426,416	0.33	0.29
September	63,775	3,000	17,399	1,035,313	0.80	0.72
October	62,880	8,475	25,875	1,590,991	1.25	1.08
November	99,375	18,300	24,655	1,467,075	1.15	1.03
December	76,255	16,775	35,070	2,156,370	1.68	1.46
The year	454,900	3,000	38,747	28,086,219	21.92	1.61
1895.						
January	114,490	23,400	50,101	3,080,590	2.41	2.09
February	87,790	21,800	54,026	3,000,452	2.34	2.25
March	150,190	51,400	81,108	4,987,137	3.89	3.37
April	206,575	29,100	85,979	5,116,106	3.99	3.58
May	40,400	15,850	24,910	1,531,656	1.20	1.04
June	29,100	5,400	11,315	673,289	0.53	0.47
July	22,300	3,600	9,711	597,106	0.46	0.40
August	9,125	3,400	5,402	332,156	0.25	0.22
September	10,750	3,600	5,320	316,562	0.24	0.22
October	4,500	2,200	3,152	193,809	0.15	0.13
November	21,800	2,800	6,143	365,534	0.29	0.26
December	63,775	5,400	18,990	1,167,650	0.91	0.79
The year	206,575	2,200	29,680	21,362,047	16.66	1.24

Estimated monthly discharge of Susquehanna River at Harrisburg, Pennsylvania—Cont'd.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1896.						
January	139,450	23,400	52,692	3,239,904	2.53	2.19
February	185,990	16,775	52,637	3,027,715	2.36	2.19
March	185,990	16,775	65,034	3,998,785	3.13	2.71
April	223,580	26,100	89,469	5,323,776	4.15	3.72
May	23,400	7,825	13,097	805,303	0.63	0.55
June	46,825	9,450	19,387	1,153,607	0.90	0.81
July	40,400	10,750	15,587	958,407	0.75	0.65
August	45,150	3,400	14,621	899,009	0.70	0.61
September	7,850	3,000	4,173	248,311	0.19	0.17
October	132,290	10,100	34,793	2,139,337	1.67	1.45
November	143,030	12,700	35,738	2,126,559	1.66	1.49
December	38,900	9,125	21,573	1,326,472	1.04	0.90
The year	223,580	3,000	34,900	25,247,185	19.71	1.45
1897.						
January	31,000	10,100	18,864	1,159,900	0.91	0.79
February	103,850	23,400	46,304	2,571,590	2.01	1.93
March	168,090	26,100	89,678	5,514,085	4.30	3.73
April	132,290	25,025	56,021	3,333,480	2.60	2.33
May	103,850	24,500	54,106	3,326,850	2.60	2.25
June	29,100	10,100	17,926	1,066,680	0.83	0.75
July	42,750	6,900	11,735	721,560	0.56	0.49
August	40,400	7,825	15,738	967,690	0.76	0.66
September	15,850	4,000	6,991	415,990	0.32	0.29
October	11,900	4,000	6,127	376,730	0.29	0.25
November	49,500	4,800	15,024	893,990	0.69	0.62
December	108,275	18,300	47,068	2,894,100	2.26	1.96
The year	168,090	4,000	32,132	23,242,645	18.13	1.34

OCTORARO CREEK.

Rating table for Octoraro Creek at Rowlandsville, Maryland, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.7	125	3.7	305	5.4	1,220	7.4	3,315
2.8	130	3.8	340	5.6	1,425	7.6	3,525
2.9	135	3.9	380	5.8	1,635	7.8	3,735
3.0	145	4.0	420	6.0	1,845	8.0	3,945
3.1	155	4.2	500	6.2	2,055	8.5	4,470
3.2	170	4.4	580	6.4	2,265	9.0	4,995
3.3	185	4.6	670	6.6	2,475	9.5	5,520
3.4	210	4.8	765	6.8	2,685	10.0	6,045
3.5	240	5.0	880	7.0	2,895		
3.6	270	5.2	1,040	7.2	3,105		

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.		Depth in inches.	Second-feet per square mile.
1896.						
November 22 to 30	540	145	192	3,427	0.29	0.89
December	225	145	158	9,715	0.84	0.73
1897.						
January	2,580	155	329	20,230	1.75	1.52
February	6,150	170	1,021	56,705	4.90	4.71
March	500	170	230	14,142	1.22	1.06
April	2,002	170	370	22,017	1.91	1.71
May	920	170	321	19,737	1.71	1.48
June	1,270	145	222	13,210	1.14	1.02
July	520	135	192	11,805	1.01	0.88
August	960	130	186	11,437	0.99	0.86
September	170	130	136	8,092	0.70	0.63
October	170	130	141	8,670	0.75	0.65
November	1,845	155	298	17,730	1.53	1.37
December	820	185	275	16,909	1.46	1.27
The year	6,150	130	310	220,684	19.07	1.43

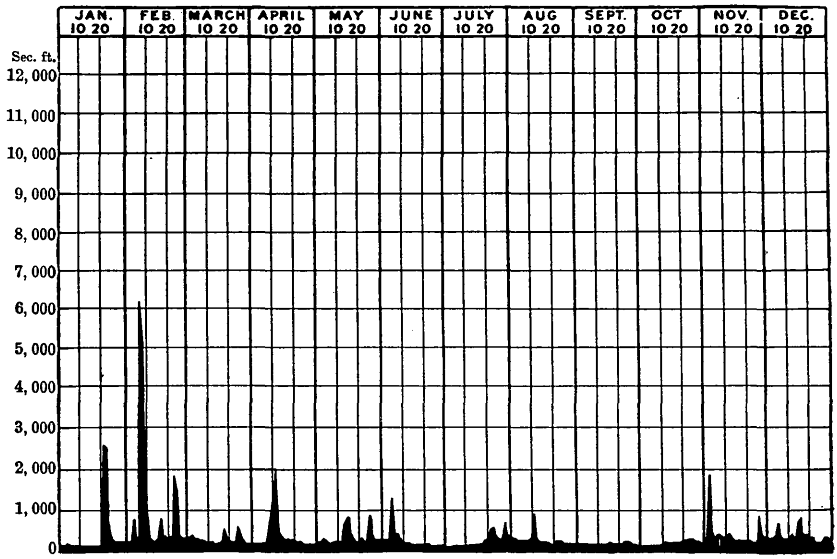


FIG. 30.—Discharge of Octoraro Creek at Rowlandsville, Maryland, 1897.

PATAPSCO RIVER.

Rating table for Patapsco River at Woodstock, Maryland.

Gage height.	Discharge.		Gage height.	Discharge.	
	Aug. 6, 1896, to July 22, 1897.	July 23 to Dec. 31, 1897.		Aug. 6, 1896, to July 22, 1897.	July 23 to Dec. 31, 1897.
Feet.	*Second-feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Second-feet.*
2.9	....	60	4.8	740	925
3.0	....	70	5.0	880	1,075
3.1	....	90	5.2	1,025	1,235
3.2	....	115	5.4	1,175	1,410
3.3	....	140	5.6	1,335	1,600
3.4	50	170	5.8	1,505	1,800
3.5	80	205	6.0	1,680	2,000
3.6	115	240	6.5	2,140	2,512
3.7	150	280	7.0	2,630	3,025
3.8	190	325	7.5	3,160	3,538
3.9	230	375	8.0	3,740	4,050
4.0	275	425	8.5	4,405	....
4.2	375	530	9.0	5,080	....
4.4	485	650	9.5	5,755	....
4.6	610	780	10.0	6,430	....

Estimated monthly discharge of Patapsco River at Woodstock, Maryland.

[Drainage area, 251 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	4,405	80	331	20,355	1.52	1.32
February	5,890	115	783	43,486	3.25	3.12
March	705	230	332	20,414	1.52	1.32
April	740	150	334	19,874	1.48	1.33
May	2,235	210	473	29,084	2.17	1.88
June	915	150	259	15,412	1.15	1.03
July	3,538	130	588	36,155	2.70	2.34
August	3,332	133	598	36,770	2.75	2.38
September	187	65	127	7,557	0.57	0.51
October	280	80	140	8,608	0.63	0.55
November	7,250	240	591	35,167	2.62	2.35
December	1,550	240	503	30,928	2.31	2.00
The year	7,250	65	422	303,810	22.67	1.68

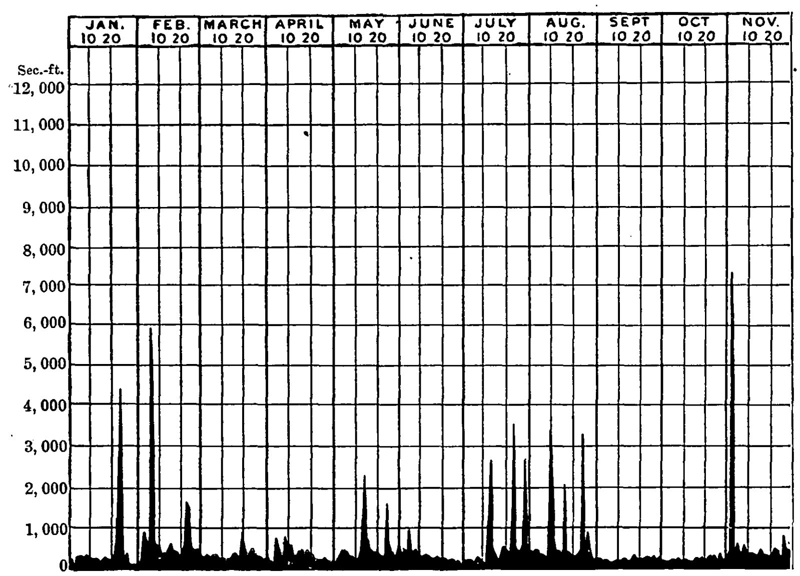


FIG. 31.—Discharge of Patapsco River at Woodstock, Maryland, 1897.

PATUXENT RIVER.

Rating table for Patuxent River at Laurel, Maryland.

[This table is applicable from August 3, 1896, to December 31, 1897.]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.7	0	4.0	70	6.5	329	10.5	2,034
2.8	2	2.2	86	7.0	389	11.0	2,674
2.9	5	4.4	102	7.5	455	11.5	3,314
3.0	10	4.6	120	8.0	545	12.0	3,954
3.2	20	8.8	140	8.5	655	12.5	4,594
3.4	30	5.0	162	9.0	800	13.0	5,234
3.6	42	5.5	217	9.5	1,025	13.5	5,874
3.8	56	6.0	272	10.0	1,400		

Estimated monthly discharge of Patuxent River at Laurel, Maryland.

[Drainage area, 137 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1896.						
August	160	30	117	7,194	0.98	0.87
September	203	30	98	5,831	0.80	0.72
October	165	45	98	6,026	0.83	0.72
November	247	40	129	7,676	1.04	0.94
December	181	50	140	8,608	1.18	1.02
1897.						
January	184	49	120	7,379	1.01	0.88
February	2,418	140	400	22,215	3.04	2.92
March	233	110	162	9,961	1.36	1.18
April	329	63	148	8,807	1.20	1.08
May	1,180	90	203	11,482	1.71	1.48
June	173	49	113	6,724	0.91	0.82
July	4,274	39	320	19,676	2.70	2.34
August	575	82	145	8,916	1.22	1.06
September	261	25	86	5,117	0.70	0.63
October	151	17	92	5,657	0.77	0.67
November	2,034	102	251	14,936	2.04	1.83
December	705	98	199	12,236	1.67	1.45
The year	4,274	17	187	133,106	18.33	1.36

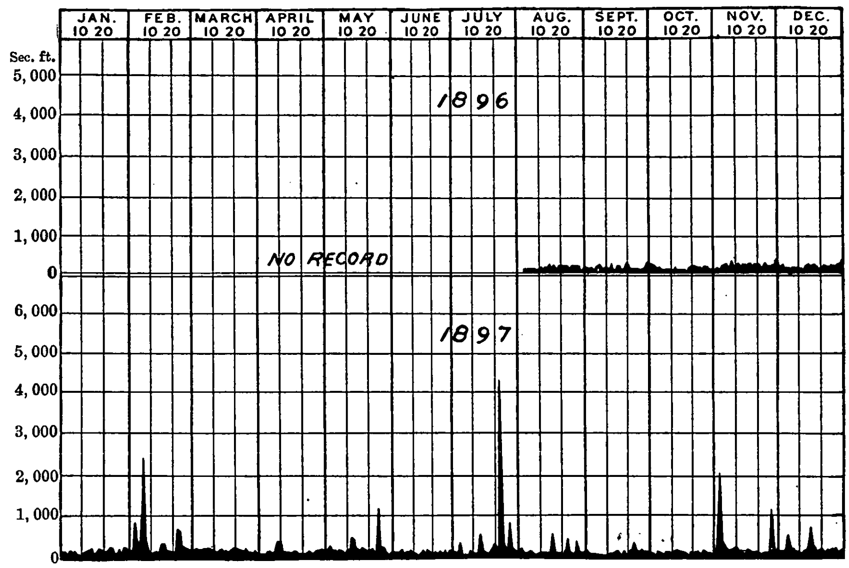


FIG. 32.—Discharge of Patuxent River at Laurel, Maryland, 1897.

POTOMAC RIVER.

The tributaries of Potomac River drain long narrow areas of the Greater Appalachian Valley and extend chiefly in a general northeasterly direction, the tributaries coming from the northern part of the basin draining relatively small areas and being of minor importance. The main river has a general southeasterly direction, cutting through the ranges at nearly right angles, and is located in the northern part of the basin. A map of the drainage basin is shown in fig. 33.

During the fall of 1897 a detailed study of the sources of pollution throughout the basin was made by Messrs. A. P. Davis, E. G. Paul, and G. H. Matthes, the last mentioned of whom has prepared the following description. In order to obtain a general conception of the amount of pollution, samples of water for bacteriological examination were collected in sterilized bottles at the mouths of all tributaries of importance, and at such other points along the rivers as were of special interest. At the same time the discharge of the tributaries was ascertained and a reconnaissance of existing water powers as well as of those still undeveloped was carried on in conjunction with the primary investigation. The results of this work were published in Senate Doc. No. 90, Fifity-fifth Congress, second session, entitled Drainage Basin of the Potomac River, and in Senate Doc. No. 211, entitled Bacteriological Examination of the Potomac River. A summary of the more important facts set forth in these reports is herewith presented together with the results of hydrographic measurements made during the year 1897 at the regular gaging stations maintained in Potomac Basin. These stations, which are described in Water-Supply and Irrigation

Paper No. 15, pp. 15–22, inclusive, are located as follows: Cumberland, Maryland, on the North Branch; Sharpsburg, Maryland, on Antietam Creek; Port Republic, Virginia, on North and South rivers and South Fork of Shenandoah River; Millville, West Virginia, on Shenandoah River; Frederick, Maryland, on Monocacy River; Point of Rocks, Maryland, on Potomac River; and National Zoological Park bridge, District of Columbia, on Rock Creek. Following is a list of the tributaries of

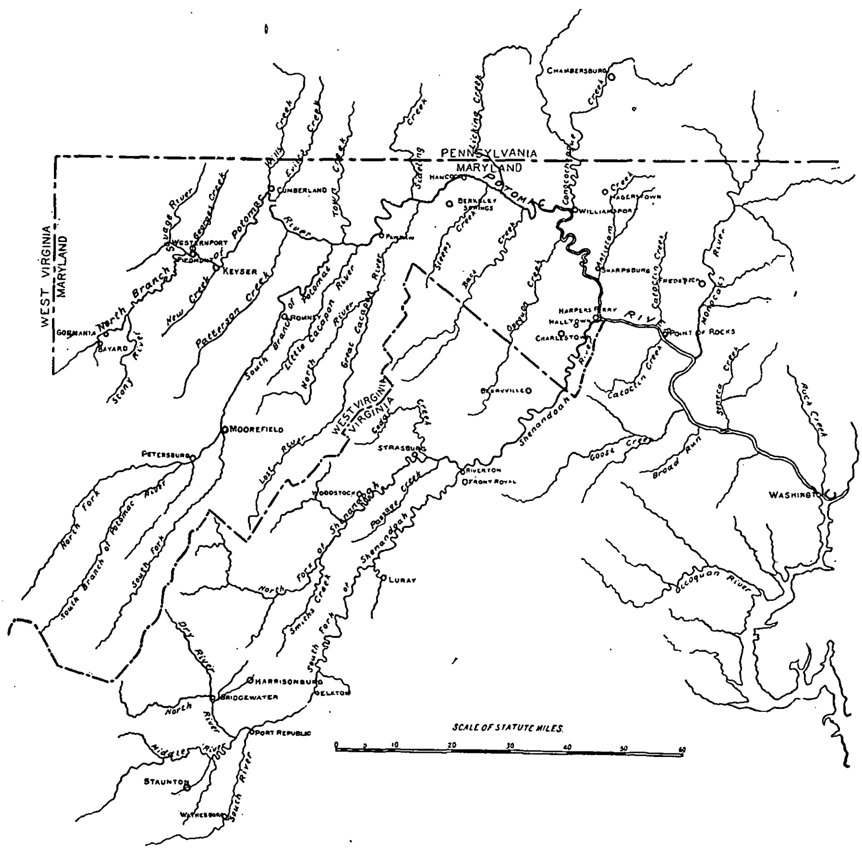


FIG. 33.—Map of Potomac drainage basin.

Potomac River in the order in which they are described, those entering from the south being considered first:

Tributaries from the south:
- South Branch.
- Little Cacapon River.
- Cacapon River.
- Sir Johns Run.
- Warm Springs Run.
- Sleepy Creek.
- Back Creek.
- Opequon Creek.

Tributaries from the south—Cont'd.
- Shenandoah River.
- Catoctin Creek, Virginia.
- Goose Creek.
- Broad Run.

Tributaries from the north:
- North Branch.
- Town Creek.
- Fifteenmile Creek.

Tributaries from the north—Cont'd.
- Sideling Creek.
- Little Tonoloway Creek.
- Big Tonoloway Creek.
- Licking Creek.
- Big Spring Run.
- Little Conococheague Creek.

Tributaries from the north—Cont'd.
- Conococheague Creek.
- Antietam Creek.
- Catoctin Creek, Maryland.
- South Tuscarora Creek.
- Seneca Creek.
- Rock Creek.

TRIBUTARIES FROM THE SOUTH.

The South Branch of the Potomac has its head waters in Pendleton County, West Virginia, and Highland County, Virginia. The main river and its numerous forks pursue northeasterly courses through 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.

Six miles above Petersburg, West Virginia, is the confluence of the North Fork and the South Branch, while at a point 12 miles below Petersburg, at Moorefield, West Virginia, Moorefield River, or South Fork, enters the South Branch. September 24, 1897, the discharges of the three rivers were measured and found to be as follows: South Branch above mouth of North Fork, 96 second-feet; North Fork at mouth, 17 second-feet; South Fork at 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 great measure for the scarcity of industrial enterprises. From the confluence with the North Fork down to the mouth, there are only four flour mills on the South Branch, some of which have facilities for sawing lumber attached. As their capacity is small and little work is done, pollution by them is insignificant. The South Branch was measured September 26 at Romney, and its discharge found to be 205 second-feet. The old gaging station on the river, near Springfield, West Virginia, described in the Eighteenth Annual Report of this Survey, Part IV, p. 19, was discontinued in 1896 and not resumed in 1897 owing to the difficulty of obtaining an observer. The following measurements of discharge were made, however, during the year 1897: June 25, gage height 3.40 feet, discharge 622 second-feet; September 2, gage height 2.40 feet, discharge 132 second-feet.

On the North Fork and on the South Branch, above their confluence, there are only a few small flour mills utilizing water power. The only users of water power along the South Fork are a small flour mill at Fort Seybert, West Virginia, and a flour and planing mill at Moorefield. Pollution from the latter, in the form of sawdust or chips, is trifling. At Petersburg is a tannery, with a capacity of 60 hides a day, which has not, however, been in operation for some time.

Owing to the absence of mines, active tanneries, or manufacturing industries productive of wastes, the South Branch drainage basin contributes little to the contamination of the waters of the Potomac, except what is incident to the natural drainage from farms and fields in the valley areas under cultivation. These latter are, on account of the nature of the topography, of small extent. About Moorefield the river valley is broader and much more fertile than any other section of the basin, and contains some fine farms. The following towns, situated on the river, were visited: Petersburg, West Virginia, with a population of 400; Moorefield, West Virginia, with a population of 500; and Romney, West Virginia, with a population of 700 inhabitants. Only the last-named town is provided with a public water supply from reservoirs. There is no sewerage system, but the natural drainage is into the South Branch. The State Asylum for the Deaf, Dumb, and Blind, at Romney, with an average of 200 inmates, discharges its sewage into Big Run, 1 mile above its junction with the river.

Little Cacapon River has its source in Mineral County, West Virginia, and discharges into the Potomac about 5 miles below the junction of the North and South branches. The discharge on September 29 was about 2 second-feet. At Pawpaw, West Virginia, is a tannery, owned by the United States Leather Company, with an average capacity of 400 hides a day. The wastes are liquids only, all substances being preserved for other purposes and all tan bark utilized as fuel. At the time of visit, September 29, the amount of effluent discharged into the river was 200 gallons per minute.

Cacapon River joins the Potomac a short distance below dam No. 6 of the Chesapeake and Ohio Canal. It has its source in Hardy County, West Virginia, and is known along the upper part of its course as Lost River, due to the fact that it disappears into an underground channel several miles above Wardensville, reappearing under the name of Cacapon River. At Cacapon Forks it receives North River. The discharge of Cacapon River near its mouth on September 29 was 81 second-feet. From inquiry it appears that the water powers of this stream are inconsiderable. A tannery is located at Cacapon Bridge, and discharges refuse into the stream.

Sir Johns Run empties into the Potomac 3 miles below the mouth of Cacapon River. Its discharge October 11 was estimated at 1 second-foot.

Warm Spring Run rises in Morgan County, West Virginia, a few miles above Berkeley Springs, a town of 1,000 inhabitants. Its discharge September 30 was 3 second-feet. It receives the drainage from this town, which has a public water supply. A tannery with a capacity of 250 hides a day also discharges its wastes into the stream.

Sleepy Creek joins Potomac River about 5 miles below Hancock, Maryland. The discharge October 1 was 2.3 second-feet. A few small feed mills make use of the power, but cause no pollution.

Back Creek has its source in Clarke County, Virginia, and discharges into the Potomac 8 miles below Williamsport, Maryland. The discharge on October 8 was 50 second-feet. The power of this stream is used by flour mills. Martinsburg, West Virginia, a town of 8,000 inhabitants, with a public water supply, has no sewerage system, but many private sewers and cesspools drain into a tributary of Opequon Creek.

At Harpers Ferry, West Virginia, the water of the Potomac is used for power by the Shenandoah Pulp Company. With a fall of 22 feet a maximum power of 1,400 horsepower is developed. The pulp is made by a mechanical process from spruce wood. Bark and shavings constitute the only pollution from this mill. The discharge of the Potomac at Harpers Ferry on October 13 was 377 second-feet, nearly all of which was diverted into the pulp company's mill race. The estimated discharge of Shenandoah River above Harpers Ferry is given on page 151.

Shenandoah Valley has always possessed the reputation of having an extraordinary number of perennial springs. This reputation has been confirmed during the very dry season of 1897, as few of these springs became dry or apparently diminished in volume. Some of these springs furnish an abundant supply for the waterworks of towns. Staunton, Front Royal, Riverton, Harrisonburg, Waynesboro, and Elkton are all supplied with spring water either from gravity systems or by pumping to a reservoir. During the drought of 1897 none of these towns was hampered by a lack of water.

The drainage basin covers 3,009 square miles of fertile country, with an undulating topography well adapted for farming. It is bounded on the east by the Blue Ridge, on the west by the North Mountain ranges, and is divided longitudinally by the Massanutten Mountains. Shenandoah River is formed by the confluence of the North and South forks at Riverton, Virginia, at an elevation of 450 feet, and about 54 miles from Harpers Ferry, West Virginia, where it discharges into the Potomac, at an elevation of 240 feet. With the exception of Bulls Falls, 2½ miles, and Littles Falls, about 6½ miles above Harpers Ferry, the main river has a fall averaging 3 feet per mile. The milling enterprises in this part of the basin are mostly small, and utilize the powers along the tributaries. The mills once existing on the river proper are conspicuous only by their absence, and their ruins tell the tale of destruction by the severe freshets to which the river is subject. The following tributaries entering from the west were visited, their discharges measured, and the water powers and pollutions along them investigated: October 7, Crooked Run, discharge 3.4 second-feet; October 9, Stone Bridge Run, discharge 3 second-feet (estimated); October 9, Parkers Creek, discharge 4 second-feet (estimated); October 8, Crystal Run, discharge 3 second-feet (estimated); October 2, Bullskin Run, discharge 7.5 second-feet; October 1, Evitt Run, discharge 12 second-feet; October 25, Flowing Run, discharge 4.5 second-feet. The following tributaries entering from the east were visited: October 4, Happy Creek, discharge 3.1 second-feet; October 7, Wappan Run, discharge 1.1 second-feet. The towns mentioned below were visited.

Berryville, Virginia, with a population of 1,600, contains no manufactories of any kind and possesses no public water supply. Charlestown, West Virginia, with a population of 2,800, is situated on Evitt Run, which is polluted by sewage from back yards, slaughterhouses, a small tannery, and a gas plant.

At Halltown, West Virginia, is the strawboard factory of Eyster & Son, situated on Flowing Run, using steam to the extent of 150 horsepower. The average daily output is 8 tons of cardboard. In the process the straw is washed and bleached with lime. Water for this purpose is taken from the run, and the residue returned, heavily laden with fine particles of straw and lime, which give the water a bright yellow color. No odor is noticeable.

At Harpers Ferry, West Virginia, a fine water power is utilized by the Shenandoah Pulp Company, from which about 1,500 horsepower is obtained with a head of 23½ feet. During the dry season of 1897 this was reduced to 350 horsepower, and the mill had to be stopped at intervals in order to store up head. The daily capacity, which is 20 tons of pulp, was reduced to 9 tons. The pulp is made from spruce wood by a mechanical process, and, so far as could be ascertained, no waste other than bark chips finds its way into the river. The amount of the latter, however, is considerable, and the bed of the river below the mill shows large deposits of this material.

The town of Harpers Ferry has neither a public water supply nor a sewerage system. What little sewage reaches the river comes from a private sewer of one of the hotels, a few privies near the bridge, and the drainage from a stable and a brewery.

The discharge of the North Fork of Shenandoah River was measured October 4 from the highway bridge at Riverton, Virginia, and found to be 140 second-feet. The river between Strasburg and Riverton, a distance of 13 miles, has a fall of nearly 4 feet per mile. It receives along this section Passage Creek from the south and Cedar Creek from the north. The former drains Fort Valley, a small elevated basin inclosed between two parallel ridges, the Massanutten Mountains on the east and Three-Top Mountain on the west. Its discharge on October 15 was 6 second-feet. Cedar Creek was measured October 12 and its discharge found to be 27 second-feet. There are a number of small mills on this stream, but owing to its moderate fall the heads obtained are small and little power is developed. The creek is polluted by the tannery of Hans Rees & Sons, at Zepp, Virginia, which has a capacity averaging 60 hides a day. At Strasburg, Virginia, a town of 900 inhabitants, there is a small tannery. It is not located near the river, and no pollution was noticed.

The course of the North Fork above Strasburg is an extremely tortuous one. Its fall averages about 6 feet per mile. It flows by the towns of New Market, Mount Jackson, Edinburg, and Woodstock, none of which is provided with either public water supplies or sewerage systems. Pollution from these towns is probably trifling or nil. A number of tributaries enter the North Fork above Strasburg, as follows: Linville Creek and Smiths Creek from the south; Holmans Creek, Mill Creek, Stony Creek, Toms Brook, and Tumbling Run, from the north. The water powers along the North Fork and its tributaries are shown in the table on pages 155 and 156, together with the sources of pollution, most of which are of an insignificant character.

The South Fork of the Shenandoah is formed by the confluence of the three tributaries known as the North, Middle, and South rivers at Port Republic, Virginia. Regular gaging stations are being maintained at this point on South River and below the junction of the North and Middle rivers. The stations are described in Water-Supply and Irrigation Paper No. 15, p. 17. Tables of monthly discharge have not been compiled, since there are not sufficient discharge measurements on which to base rating tables. Measurements made November 7 at the stations and on Middle River at Mount Meridian give discharges as follows: North River less Middle River, 153 second-feet; Middle River, 92 second-feet; South River, 173 second-feet. Similar measurements made March 22 and 23, 1897, by D. C. Humphreys, gave discharges of 841, 625, and 426 second-feet.

The South Fork was measured October 4 at Riverton, Virginia, the discharge being 572 second-feet, and October 31 at Elkton, Virginia, the discharge being 389 second-feet. At Riverton are the Riverton Mills, which develop 70 horsepower with a fall of 6 feet. The timber dam is one of the finest on the river. There is no pollution at this point. In the 96 miles of its course from Port Republic to Riverton, the South Fork has an average fall of 6 feet per mile, and receives a number of tributaries of little importance. The following, all entering from the east, were measured: October 6, Gooneys Creek, discharge 2.3 second-feet; October 6, Flint Run, discharge 3.2 second-feet; October 27, Hawksbill Creek, discharge 71 second-feet; October 30, Naked Creek, discharge 25 second-feet; October 31, Elk Creek, discharge 5.5 second-feet. Gooneys, Hawksbill, and Elk creeks are badly polluted by tan liquor. At Browntown, Virginia, is F. P. Cover's tannery, located on the creek first named. It has a capacity averaging 60 hides per day. Besides wasting tan liquor, the surplus of tan bark is also disposed of in the creek. At Luray, Virginia, is the tannery of the Deford Company, with a capacity of 400 hides in twenty-four hours. All tan bark is utilized as fuel. Fleshings, scrapings, and hair are saved to be sold, while the liquid wastes are collected in cesspools, where all solid materials carried in suspension are allowed to settle, and whence these can be recovered to be used as fertilizer. The overflow from the cesspools drains into Hawksbill Creek, discoloring the water of the latter all the way down to its mouth. While there is no doubt that such cesspools are of benefit by preventing much refuse from reaching the creek, they have the disadvantage of emitting very foul odors. This becomes a source of annoyance to the inhabitants of Luray whenever the wind blows from the northeast, carrying the odor into the town.

At Elkton, Virginia, on Elk Creek, is the tannery of J. R. Cover, with a capacity of 21 hides a day. The amount of liquor which drains off toward the creek is estimated at 1,000 gallons a day. Near Elkton are the Manganese Ore Works of Kendall & Flick. The water for washing the ore is pumped from the river and after it is used runs off into the latter highly charged with a fine dark-brown sediment. The amount discharged daily is estimated at 70,000 gallons. The capacity of the works is 225 tons of ore per month. In winter operations are suspended, the ore when frozen being too hard to permit proper washing. A large number of mills derive power from the South Fork and its tributaries, although those situated on the latter are seriously hampered by lack of water during the dry season.

The three rivers forming the South Fork have considerable fall, and together with their tributaries furnish power to no less than 53 mills, the majority of which are flour mills and gristmills. Some fine powers have been developed on South River. J. L. Koiner's flour mill at Crimora, Virginia, and J. A. Patterson's flour mill at Waynesboro, Virginia, utilize each 100 horsepower with a head of 9 feet. About 1 mile above Waynesboro the hydraulic-ram factory of Rife & Schoppert with a head of 8 feet develops 75 horsepower.

The city of Waynesboro has an estimated population of 2,000. There are a number of industries, few of which are in proximity to the river, and these do not pollute the water. A public water supply is under construction and a sewerage system to drain into the river is under consideration.

Lewis Creek, one of the tributaries of Middle River, receives much filth and sewage on its way through Staunton, a city of 11,000 inhabitants. There is no regular sewerage system, but a number of private sewers discharge into the creek. The city has a public water supply derived partly from Lewis Creek by pumping into a reservoir and partly from a separate gravity system.

North River is polluted by several industries, notably by a tannery owned by J. P. Houck, located at Harrisonburg, Virginia, on Blacks Run, a tributary of Cooks Creek, which discharges into North River near Mount Crawford, and by a woolen mill of the Bridgewater Manufacturing Company at Bridgewater, Virginia. The tannery has a capacity of 200 hides a day, and although much economy is practiced with tan liquor, the wastes are decidedly obnoxious, due mainly to the imperfect manner in which they are allowed to run off in open surface drains across vacant lots and public thoroughfares. Harrisonburg, with a population of 3,500, has a public water supply but no sewerage system.

In general it may be said of Shenandoah Valley that the drainage from the small towns and from the farms of this agricultural region is small; that in proportion to the water discharged through the Shenandoah and the area drained the pollutions are not important; and that the river may be considered as furnishing a large bulk of potable water to Potomac River.

The water powers of the Shenandoah and its numerous tributaries have been well developed, as will be seen from the table of industries and sources of pollution. A large majority of the mills are grist and flouring mills doing a limited local business, utilizing the powers offered by the small mountain streams, preferably by means of overshot wheels. A systematic study of these mills has led to the conclusion that the great facility with which head is obtained on mountain streams has induced many millers to build mills in localities where the supply throughout a large part of the year is at the best unsatisfactory. The common failing observed among the milling enterprises in this region, however, is found in the cheap forms of milldams, such as brush and loose-rock dams, which do not remain tight except by continual repairing, and are a constant source of annoyance.

Catoctin Creek, Virginia, has its source in Loudoun County, and discharges into the Potomac 1 mile above Point of Rocks, Maryland. Its discharge October 15 was about 7 second-feet. No pollution was observed.

Goose Creek enters Potomac River opposite Edwards Ferry, Maryland. Its discharge October 14 was 19 second-feet. This creek has its head waters in Fauquier County, Virginia, and offers a number of mill sites, some of which are occupied by gristmills, while others are not being utilized. There is no pollution along this stream.

Broad Run has its head waters in Loudoun County, Virginia, and empties into the Potomac at a point 4 miles below the mouth of Goose Creek. Its discharge October 14 was estimated to be 1 second-foot. No pollution was observed.

TRIBUTARIES FROM THE NORTH.

The country tributary to the North Branch of Potomac River, comprising an area of 1,365 square miles, is of a hilly character and for the larger part thickly wooded. The head waters of the North Branch proper are near Fairfax Stone, on the West Virginia and Maryland State line, at an elevation of about 3,000 feet. Thence the river flows in a northeasterly direction for about 46 miles, forming the dividing line between Garrett County, Maryland, and Grant County, West Virginia, to the confluence with Savage River, where its elevation is about

950 feet (see Pl. XVII, *A*). It then flows southeasterly a distance of 6 miles to Keyser, West Virginia, where it resumes its northeasterly course for 23 miles, reaching Cumberland, Maryland, at an elevation of 600 feet. At this point the river makes a sharp bend, and after flowing southerly for 12 miles unites with the South Branch to form Potomac River.

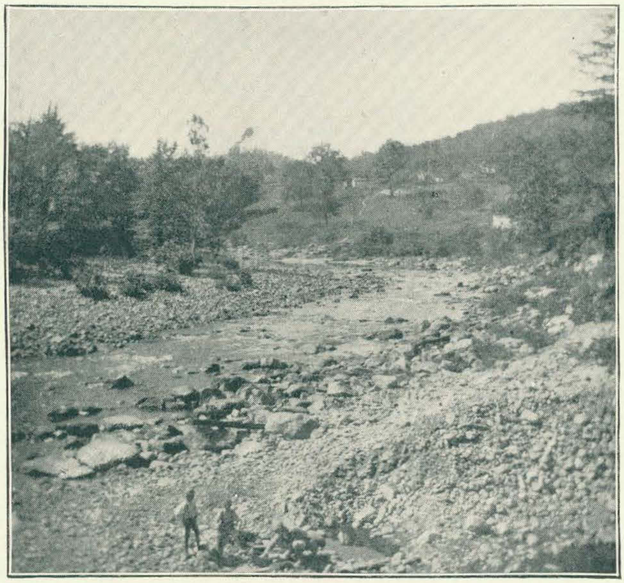
Along the upper part of its course, down to the twin towns of Westernport, Maryland, and Piedmont, West Virginia, the North Branch flows through a narrow and tortuous valley, the steep and wooded hillsides of which afford little opportunity for settlement. The roads are few and bad, and the West Virginia Central and Pittsburg Railway affords the only means of transportation. The extensive lumber trade in this region is responsible for a number of small settlements along the river and the existence of the two towns of Bayard, West Virginia, with an estimated population of 700, and Gormania, West Virginia, with an estimated population of 600 inhabitants.

Owing to its considerable fall along this section, which averages 46 feet per mile, but in some portions exceeds 60 feet per mile, the river assumes much the nature of a mountain torrent, presenting one continuous series of riffles and falls, the latter in some instances having a drop of 5 feet and over. There seems to be little opportunity for developing the water powers of this stream, however considerable they may be. Freshets are frequent and heavy, and would inflict serious damage to 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, waste weirs 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 following discharge measurements, made in September and October of 1897, will serve to throw light upon the capacity of the river during the dry season: September 23 a measurement made at Gormania, West Virginia, gave a discharge of 54 second-feet. On September 25 the discharge of the river at Schell was 136 second-feet. Measurements made above the junction with Savage River on September 27 and October 27 gave discharges of 122 and 102 second-feet, respectively, the latter fairly representing the capacity of the North Branch at this point during the severe drought of 1897. These results, together with the large amount of available head and the fact that the river does not freeze over in winter, seem to indicate that there would be ample power at all times for average milling purposes. The fact that no attempt has been made by any of the sawmills and tanneries along the river to make use of water power has, however, sufficient explanation. The first-named enterprises use steam by preference, because they are primarily of a temporary character, liable to be shifted whenever it may be found advantageous to shorten the distance which the raw materials are to be hauled, and also because they are supplied with an abundance of fuel, at no cost, in the form of sawdust. The tanneries, though of a more permanent character, invariably prefer steam power, because, besides being able to utilize tan bark as fuel, they require the use of steam in their processes.

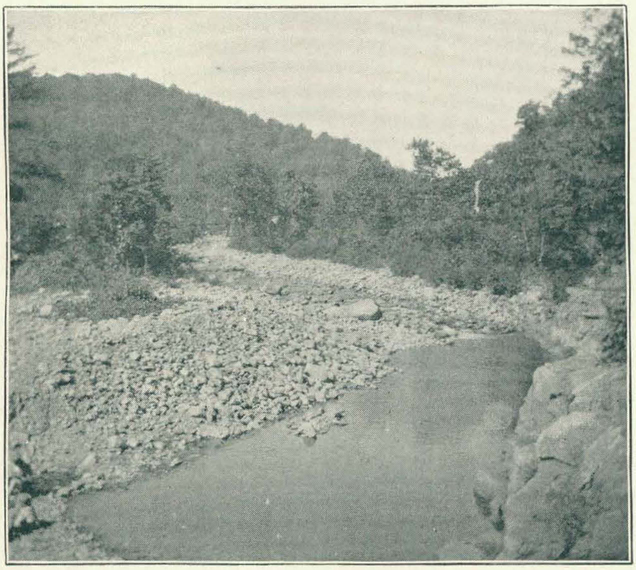
A small water power has been developed by two mills at Blaine, West Virginia, but the amount is trifling in comparison with what might be obtained at that point. One 15-inch and one 18-inch turbine under $7\frac{1}{2}$ feet head furnish about 8 horsepower to a small woolen mill. On the same mill race is situated a sawmill and gristmill combined, which obtains about 25 horsepower from one 36-inch turbine under 9 feet head. Water is taken from the river at a point about one-half mile above the mills, where there is a low natural dam across the river.

The more important tributaries were visited and the discharges measured. September 24 the discharge of Buffalo Creek at Bayard, West Virginia, was found to be 23 second-feet. The water was heavily laden with sawdust from the Buffalo Lumber Company. Stony River, the principal tributary above the mouth of Savage River, was visited September 25. Its discharge was 38 second-feet. This stream flows through a hilly region, covered with thick timber growths, and has no settlements along it except a few logging camps. The head waters rise in the highest part of the Potomac Basin, at an altitude of 4,000 feet. September 25 Abram Creek showed a discharge of 7.4 second-feet. The water of this creek carries much coal dust from the mines at Elk Garden, West Virginia, and also receives sawdust from a sawmill at Emory, West Virginia.

The North Branch all along this upper section is polluted by large quantities of sawdust produced by fourteen sawmills (see appended table, pp. 155–156), some of which discharge the sawdust directly into the river, and others into the tributaries. The more important of these are the sawmill of the J. L. Rumbarger Company, at Dobbin, West Virginia, with a capacity of 100,000 feet of lumber a day; the saw and planing mills of M. N. Wilson, at Wilson, Maryland, with a capacity of 20,000 feet of lumber a day, and of the Buffalo Lumber Company, at Bayard, West Virginia, with a capacity of 50,000 feet of lumber a day. It furthermore receives the wastes from two tanneries—those of the Middlesex Leather Company, at Bayard, West Virginia, with a capacity of from 600 to 800 hides a day, and the J. T. Hoffmann's Sons Company, at Gormania, West Virginia, with a capacity of 300 hides a day. The wastes from the latter establishments consist of tan liquor, lime water, and a certain amount of tan bark, which is washed from the banks at times of high water. The total amount of this pollution is such that the river, especially during the dry season, has a foul appearance in spite of its dashing course over the bowlders of its rough but picturesque bed. The water has a dark-brown tinge, very suggestive of contami-



A. NORTH BRANCH OF POTOMAC RIVER AT CONFLUENCE WITH SAVAGE RIVER.



B. SAVAGE RIVER, NEAR MOUTH.

nation by tan liquor, and particles of sawdust are extremely plentiful and are carried for long distances. In many places where irregularities in the current have caused accumulations of sawdust, small banks and bars composed of solid strata of sawdust are to be found. It is a noteworthy fact that Stony River, though free from artificial pollution, exhibits to a certain degree the same dark color peculiar to the waters of the main river. It is stated by the older inhabitants of the region that the color had been observed in the waters of the North Branch long before the erection of sawmills and tanneries, and in all probability must be accounted for by the presence of decaying vegetable matter from the forests.

About 2 miles above Westernport, Maryland, Savage River empties into the North Branch (see Pl. XVII, *B*). It is a small stream of great purity, having its head waters in Garrett County, West Virginia. Only two small sawmills are located on its banks, and the pollution caused by them is insignificant. A discharge measurement made October 27 at the mouth of the stream, above the intake of the Piedmont water supply, gave a discharge of 11.3 second-feet.

The town of Piedmont and part of Westernport are supplied with drinking water by a gravity system, from a reservoir which is kept filled by pumping water from Savage River. The quantity pumped daily is estimated at 375,000 gallons.

One-half mile above Westernport, at Luke, Maryland, is the factory of the Piedmont Pulp and Paper Mill Company, which has a daily capacity of 40 tons of book paper and 50 tons of pulp. In the process of manufacturing the pulp from spruce and poplar wood the wood fiber is disintegrated by treating with bisulphite of lime, and a number of chemical residuals are formed which are discharged into the river. These chemicals consist principally of sulphates and sulphites of calcium, some free sulphuric and sulphurous acids, chloride of calcium used in bleaching the fiber, and a large amount of resinous matter. An analysis, made of a sample of the effluent from one of the digesters, shows acids as follows:

	Grams per liter.
SO_3 (sulphuric acid and sulphates)	1.030
SO_2 (sulphurous acid, sulpho-acids, etc.)	8.800
Total SO_3 after complete oxidation	12.030

It further appears from the analysis that but little of the acid occurs in a free state, being chiefly combined with organic matter contained in the effluent.

Besides these chemical compounds, wastes of a more solid nature are discharged into the river at this point. A small amount of pulp is lost in the washing of the fiber; its escape is more or less accidental, signifying a loss against which the owners of the mill keep careful watch. The sediments from the filter tanks, representing the materials carried in suspension by the river water, are screened out before the water can be used in the process of manufacturing pulp and paper, and are returned into the river. The filtering plant, established solely for this purpose, was put in at a cost of $35,000. The water of the North Branch is, therefore, hardly fit for industrial purposes, much less for domestic use. The action of the acids on the clay contained in the water, together with the small amount of pulp referred to, form a gray compound which is found to coat the stones in the bed of the river below the mill, and is frequently spoken of as waste pulp.

The North Branch, in passing the towns of Piedmont and Westernport, receives a large amount of impurity in the form of sewage and garbage, and is badly polluted by the water of Georges Creek, which enters the river at Westernport (see Pl. XVIII). This small stream, in its course of 17 miles, receives the effluents of a number of coal mines, besides the drainage and sewage of several towns, the most important of which are Frostburg, Lonaconing, and Westernport, Maryland, with populations of 6,000, 4,200, and 2,000, respectively.

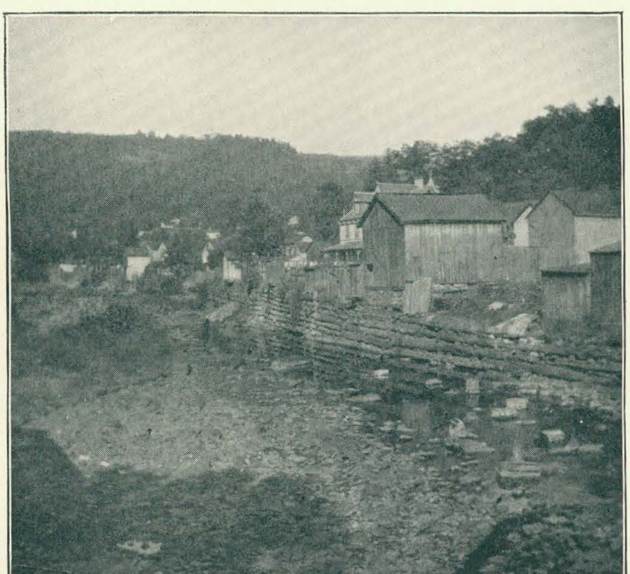
When measured at Westernport September 28, the discharge of Georges Creek was found to be 6 second-feet, a very low stage. The water, which is very clear, possesses such acidity that horses and cattle refuse to drink it, and no living organisms can be seen in it. An analysis shows acids as follows:

	Grams per liter.
Combined sulphuric acid, as SO_3	0.7350
Free sulphuric acid, as SO_3	0.1047
Sulphurous acids and sulphites	None.

The water also contains a large quantity of alumina. The presence of the sulphuric acid and sulphates is due to the large percentage of ferric sulphate contained in the coal-mine effluent. Being an unstable compound, it breaks up when acted upon by the oxygen of the air, parting with the iron which settles on the rocks in the bed, forming a coating of ferric hydroxide which gives to the entire stream a very rusty appearance.

The North Branch, between Westernport, Maryland, and Keyser, West Virginia, has little fall. Near the latter town it passes over an old milldam. The fall, though slight, causes a thick froth to form on the water, covering the entire river below the dam with a white coat of scum several inches deep, a strong evidence of the foulness of the water. The town of Keyser, which has an estimated population of 3,500, although not situated on the banks of the North Branch, adds materially to the pollution of the latter. New Creek, a tributary of the North Branch, passes through the town and carries off besides sewage the effluents from the Keyser Woolen Mills. The waste water resulting from the washing of the wool with sal soda and soap probably constitutes the most obnoxious element in this effluent, containing as it does much animal matter subject to decay. The pollution from this source alone is estimated at 1,200 gallons a day. Besides this, a variety of chemicals are discharged into the water, together with much coloring matter used in dyeing the wool. On New Creek 6

A.



B.

VIEWS OF GEORGES CREEK AT WESTERNPORT, MARYLAND.

A, From a point near the confluence of the creek with the North Branch of Potomac River, looking upstream from the West Virginia Central and Pittsburg Railroad bridge; *B*, Looking upstream from the Washington street bridge.

miles above Keyser is situated a tannery owned by the United States Leather Company with a capacity of 60 hides a day. All waste tan liquor is discharged into the creek, the waters of which are discolored for a distance of 3 miles below the tannery. There are two small sawmills on this stream, but the sawdust discharged by them is insignificant in amount. The discharge of New Creek was measured near its mouth on September 29, and found to be 3.5 second-feet.

There are a number of mills and manufactories of various kinds at Keyser, all of which were visited, but none were found to contribute in any measure to the pollution of the river. At the Baltimore and Ohio car shops, at the time of visit, a sewer to drain the sewage of the shops into the North Branch was under construction. The number of hands employed aggregates 160. Along the 23 miles of its course from Keyser down to Cumberland, Maryland, the North Branch receives no pollution other than that from natural sources. A distillery on Cranberry Run and the works of the Cumberland Cement Company, both situated near Pinto post-office, were visited, but no wastes observed at these points. The river along this section has an average fall of 12 feet per mile and riffles are few in number.

At Cumberland, Maryland, the North Branch assumes a totally different aspect. A tight dam maintained across the river at this point by the Chesapeake and Ohio Canal Company for diverting the water of the river into the head of the canal, impounds the water over a distance of a mile, causing back water for about 3 miles up the river (see Pl. XX). Above this dam is the mouth of Wills Creek, which flows through the city (see Pl. XIX), receiving a large quantity of sewage and refuse from a paper mill, a brewery, a distillery, cement works, a tannery, dye works, and a gas plant. The city of Cumberland has a population of about 15,000. The mayor states that about one-half of the houses in the city are provided with sewers which drain directly or indirectly into the Potomac. A supply of 2,500,000 gallons of water is furnished daily to the people of the city, and the resulting drainage must be more than 1,000,000 gallons per day, most of which is discharged into Wills Creek. Along this stream are located a number of coal mines, the drainage of which also reaches the creek. A discharge measurement made September 28 above the paper mill gave a discharge of 12.5 second-feet. As may be expected, the refuse thrown into Wills Creek, the polluting substances carried by the waters of the North Branch as enumerated above, and the sewage from the city of Cumberland accumulate in the pond above the dam as if in a settling basin. This is the case especially in seasons of low water, when no water passes over the crest of the dam. About 400 yards above the dam is the intake of the Cumberland waterworks; the water is pumped from the river directly into the water mains and is served to the inhabitants without being purified through filter beds or other artificial means. Serious complaints have arisen from year to year during the dry season, when the water, besides being unpalatable, is scarcely clean enough for laundering purposes. Of the large percentage of impurities which the water contains at such times, a portion is doubtless made up of sewage from the city that has backed up to the point of intake. The city authorities have for several years looked about for a better source of supply, but as yet no improvements have been made.

Between Cumberland and the confluence with the South Branch the North Branch receives no artificial pollution so far as could be ascertained. It receives through this section two tributaries, Evitts Creek, entering from the north, and Patterson Creek, from the south. The discharge of the former when measured at its mouth, September 25, 1897, was 21 second-feet; that of the latter, 12.3 second-feet. There are a few small mills along these streams, but no indication of any source of contamination.

A regular gaging station has been maintained for several years on the North Branch at Cumberland, at the West Virginia Central and Pittsburg Railway bridge. A description of the station and the location of the gage rod is contained in Water-Supply and Irrigation Paper No. 15, p. 15, together with a table of daily gage heights for 1897 and a list of the discharge measurements made during the year. Observations at this station were discontinued in November, 1897.

Rating table for North Branch of Potomac River at Cumberland, Maryland.

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

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.5	80	3.4	835	4.3	3,015	5.2	5,535
2.6	86	3.5	990	4.4	3,295	5.5	6,375
2.7	110	3.6	1,165	4.5	3,575	6.0	7,775
2.8	140	3.7	1,365	4.6	3,855	7.0	10,575
2.9	180	3.8	1,615	4.7	4,135	8.0	13,375
3.0	255	3.9	1,895	4.8	4,415	9.0	16,175
3.1	375	4.0	2,175	4.9	4,695	10.0	18,975
3.2	525	4.1	2,455	5.0	4,975	11.0	21,775
3.3	680	4.2	2,735	5.1	5,255		

WILLS CREEK AT CUMBERLAND, MARYLAND.

Estimated monthly discharge of North Branch of Potomac River at Cumberland, Maryland.

[Drainage area, 891 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	2,175	525	836	51,404	1.08	0.94
February	20,375	835	3,610	200,489	4.21	4.05
March	7,775	1,165	2,744	168,720	3.55	3.08
April	6,095	180	1,570	93,421	1.96	1.76
May	11,975	180	2,162	132,936	2.79	2.42
June	255	80	165	9,818	0.21	0.19
July	525	85	199	12,236	0.25	0.22
August	990	85	256	15,741	0.33	0.29
September (*a*)	525	10	70	4,165	0.09	0.08
October (*a*)	110	20	40	2,460	0.04	0.04

a Approximate.

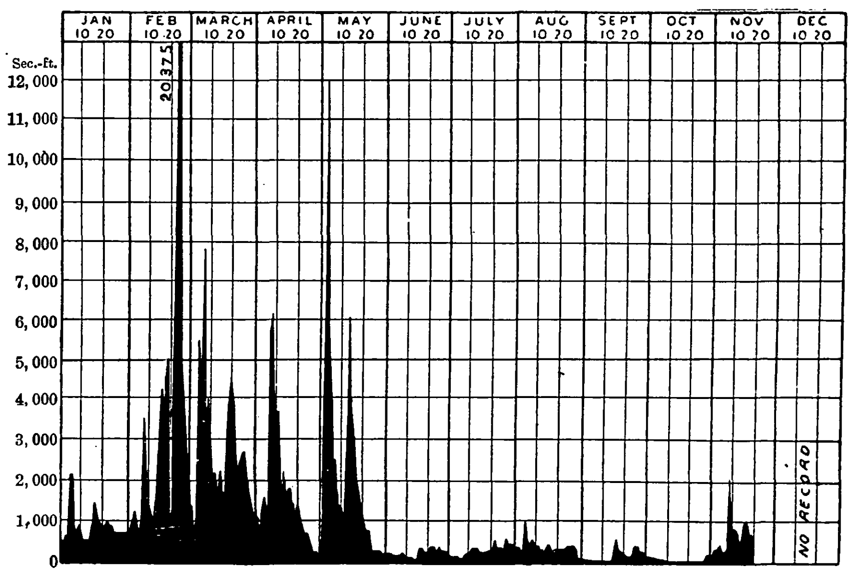


FIG. 34.—Discharge of North Branch of Potomac River at Cumberland, Maryland, 1897.

Town Creek, which rises in Bedford County, Pennsylvania, and empties into the Potomac a few miles below the confluence of the North and South branches, has good and clear water, bearing no evidence of pollution. There are two mills on the creek, besides several good but small water powers as yet undeveloped. The discharge September 25 was 11 second-feet.

Pursley Run, which discharges opposite Pawpaw, and Fifteenmile Creek, which discharges near Little Orleans, Maryland, are small streams with turbid waters. Each had a discharge September 26 of 0.5 second-foot.

Sideling Creek rises in Bedford County and furnishes power to several gristmills and sawmills. Its waters are clear and are not polluted. The discharge September 26 was 1 second-foot.

Little Tonoloway Creek rises in Fulton County, Pennsylvania, and discharges into the Potomac near Hancock, Maryland. Its discharge October 11 was 5.4 second-feet. There are two small flour mills on the creek, but no sources of pollution.

Big Tonoloway Creek rises in Fulton County, Pennsylvania, and empties into the Potomac 1 mile below Hancock. The discharge October 1 was 5.6 second-feet. The power is utilized to drive flour mills.

Licking Creek rises in Fulton County, Pennsylvania, and discharges into the Potomac 8 miles below Hancock. The discharge October 1 was 22 second-feet.

Big Spring Run is a short stream with a discharge October 7 of about 4 second-feet. It empties into the Potomac near Clearspring, Maryland, where a fall of 18 feet is obtained for mill power.

Little Conococheague Creek rises in Washington County, Maryland, and empties into the Potomac 8 miles above Williamsport at John Charles's mill, which utilizes its power with a fall of 16 feet. The discharge October 7 was estimated to be 2.5 second-feet.

Conococheague Creek rises in Franklin County, Pennsylvania, and empties into the Potomac at Williamsport, Maryland. The discharge October 2 was 197 second-feet. A large tannery has been started at Williamsport, the refuse of which discharges directly into the river. The town has a population of 1,500, but has neither a public water supply nor a drainage system. A large sawmill at this point derives water power from the Chesapeake and Ohio Canal, and discharges its sawdust into the river. The Conococheague is badly polluted by the sewage from Chambersburg, Pennsylvania, a city of 10,000 inhabitants, provided with a public water supply derived from reservoirs, the water being pumped from the creek. There is no sewerage system, but there are many private sewers. Further pollution is caused by a mill of the Chambersburg Woolen Company, which derives 50 horsepower with a fall of 22 feet from a tributary of the creek, besides several slaughterhouses located on its banks. The power of the creek at this place is used by Wolf & Co. in the manufacture of milling machinery, and by Sierer & Co., manufacturers of furniture, the aggregate fall utilized being 13 feet.

Antietam Creek has its source in Franklin County, Pennsylvania, and discharges into the Potomac about 8 miles above Harpers Ferry, West Virginia. The discharge, October 12, as measured near its mouth, when the gage at the regular gaging station at Sharpsburg, Maryland, read

DAM AT CUMBERLAND, MARYLAND, FOR DIVERTING WATER INTO THE CHESAPEAKE AND OHIO CANAL.

1.7 feet, was 120 second-feet. The power of the stream is utilized by several flour mills, and at one point by the paper mill of Stonebraker & Co. The stream drains large areas of highly cultivated lands, but the greatest source of pollution is likely to be Marsh Run, a small tributary flowing through and draining Hagerstown, Maryland, which has a population of 16,000. The town is supplied with water by a private corporation which guarantees to furnish 75 gallons per capita a day. The water is pumped to a reservoir from a spring about 8 miles from town. Hagerstown is not provided with a public sewer system, but private cesspools exist and there is a system of public drains, discharging into Marsh Run, the effluent of one being of an exceedingly offensive character. Marsh Run had a discharge, October 9, of 4 second-feet.

Following are the results of observations and discharge measurements made on Antietam Creek at the regular gaging station established June 24, 1897, and described in Water-Supply and Irrigation Paper No. 15, p. 16:

Rating table for Antietam Creek at Sharpsburg, Maryland, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.2	38	1.7	138	2.2	304	2.7	470
1.3	45	1.8	171	2.3	337	2.8	503
1.4	60	1.9	205	2.4	371	2.9	537
1.5	80	2.0	238	2.5	404	3.0	570
1.6	105	2.1	271	2.6	437		

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.		Depth in inches.	Second-feet per square mile.
1897.						
July	271	92	160	9,838	0.63	0.55
August	570	60	168	10,329	0.66	0.57
September	205	60	112	6,664	0.43	0.38
October	171	60	106	6,518	0.41	0.36
November	470	60	147	8,746	0.56	0.50
December	404	105	237	14,573	0.93	0.81

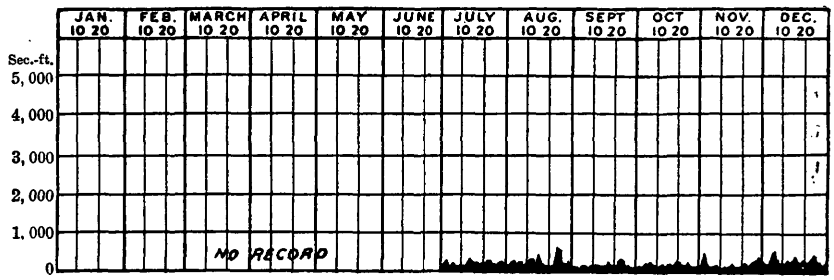


FIG. 35.—Discharge of Antietam Creek at Sharpsburg, Maryland, 1897.

The principal station for ascertaining the quantity of flow of Shenandoah River is at Millville, West Virginia, at a point about 4 miles above Harpers Ferry. The station is described in Water-Supply and Irrigation Paper, No. 15, p.19. The bulletin referred to also contains the daily gage heights for 1897 and the discharge measurements made during the year. With the aid of these and measurements from previous years a rating curve was constructed and a rating table computed.

Rating table for Shenandoah River at Millville, West Virginia, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.3	600	1.6	1,650	3.6	5,800	5.6	11,970
0.4	620	1.8	1,960	3.8	6,280	5.8	12,700
0.5	650	2.0	2,310	4.0	6,800	6.0	13,430
0.6	710	2.2	2,700	4.2	7,320	6.2	14,160
0.7	780	2.4	3,100	4.4	7,900	6.4	14,890
0.8	850	2.6	3,500	4.6	8,510	6.6	15,620
0.9	920	2.8	3,930	4.8	9,160	6.8	16,350
1.0	990	3.0	4,370	5.0	9,830	7.0	17,080
1.2	1,160	3.2	4,840	5.2	10,530		
1.4	1,390	3.4	5,320	5.4	11,240		

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

[Drainage area, 2,995 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	1,650	990	1,185	72,863	0.46	0.40
February	28,310	1,070	10,107	561,315	3.51	3.37
March	6,040	2,310	4,579	281,552	1.76	1.53
April	3,100	1,390	2,374	141,263	0.88	0.79
May	25,290	1,390	5,579	343,040	2.14	1.86
June	2,130	920	1,391	82,770	0.52	0.46
July	3,500	850	1,267	77,905	0.48	0.42
August	1,390	710	886	54,478	0.35	0.30
September	1,215	620	661	39,332	0.24	0.22
October	920	610	684	42,058	0.26	0.23
November	1,270	650	791	47,068	0.29	0.26
December	3,700	710	1,420	87,312	0.54	0.47
The year	28,310	610	2,577	1,830,956	11.43	0.86

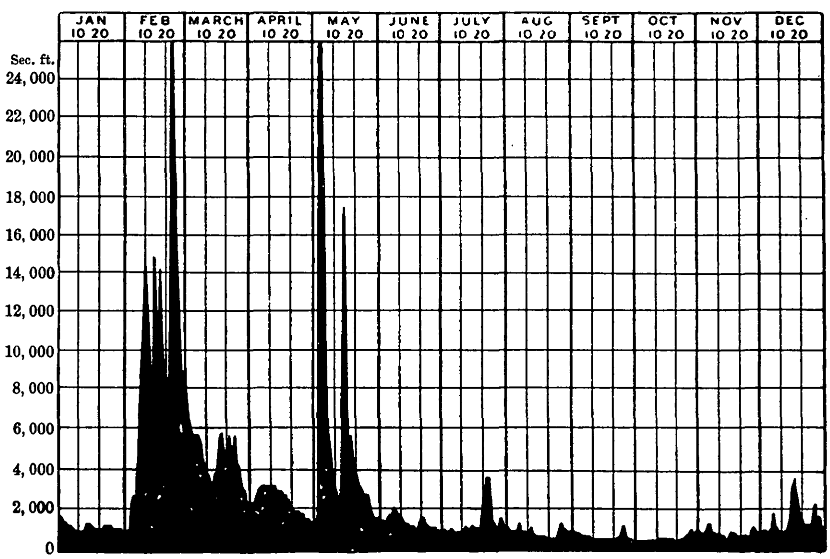


FIG. 36.—Discharge of Shenandoah River at Millville, West Virginia, 1897.

Catoctin Creek of Maryland has its source in Frederick County, and joins the Potomac 3 miles above Point of Rocks. The discharge October 14 was 20 second-feet. There are two small flour mills on the creek.

Measurements of flow and daily observations on Potomac River proper were made at the regular gaging station at Point of Rocks. The rating table for 1897 is the same as that for 1896, published in the Eighteenth Annual Report, Part IV, p. 31. In Water-Supply and Irrigation Paper No. 15, p. 21, where a description of the station is given, it is stated that the gage wire had stretched, but that the heights had been corrected, those in August and September being approximated. It was subsequently found that the correction should be applied earlier, beginning April 1, 1897, and that the discharges for this station, as published in Senate Doc. No. 90, Fifty-fifth Congress, second session, are in error. They have been corrected in the following table:

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

[Drainage area, 9,654 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	8,950	3,050	4,985	306,515	0.60	0.52
February	187,640	7,150	41,690	2,315,344	4.50	4.32
March	29,100	11,650	20,157	1,239,405	2.41	2.09
April	28,000	7,150	12,314	732,734	1.43	1.28
May	99,280	7,150	22,605	1,389,927	2.70	2.34
June	8,050	4,500	6,320	376,066	0.72	0.65
July	9,850	3,400	5,424	333,509	0.64	0.56
August	5,900	2,400	3,574	219,757	0.43	0.37
September	2,400	1,000	1,350	80,330	0.16	0.14
October	1,400	800	935	57,490	0.12	0.10
November	5,200	1,400	2,720	161,851	0.31	0.28
December	18,860	3,400	7,140	439,022	0.85	0.74
The year	187,640	800	10,768	7,651,950	14.87	1.12

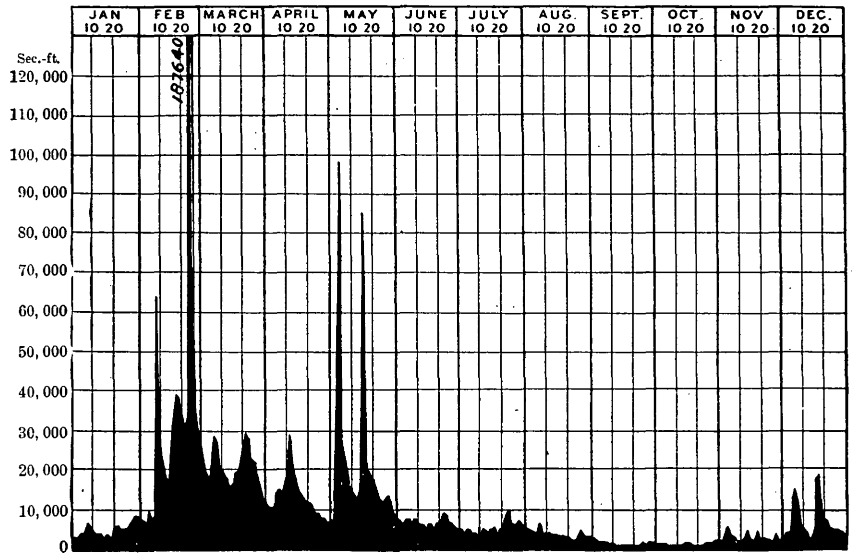


FIG. 37.—Discharge of Potomac River at Point of Rocks, Maryland, 1897.

South Tuscarora Creek, a small stream with a discharge October 15 of 3 second-feet, has its source in Frederick County, and joins the Potomac 4 miles below Point of Rocks.

Monocacy River rises in Adams County, Pennsylvania, and has a drainage area of about 1,000 square miles, the greater portion of it being a rolling limestone country of highly cultivated farms. Its waters consequently carry much muddy matter in suspension and appear turbid. The greatest pollution received by it comes from Carroll Creek, which in its course through Frederick, Maryland, a town of 10,000 inhabitants, receives a large amount of sewage and surface drainage. Frederick is supplied with water by direct pumping, the average consumption being 50 gallons per capita a day. There is no sewer system, but private cesspools and public surface drains abound. Pollution is further caused by two tanneries, each with a capacity of 50 hides a week, dyestuffs and washings from the Union Knitting Mills, and sewage from the Frederick County almshouse. Carroll Creek had a discharge October 14 of 6 second-feet. A flour mill located on the creek obtains water power with a 14-foot fall. There are few good mill sites on the Monocacy, owing largely to its moderate fall; but some of its tributaries are more favorable in this respect, and furnish power to a number of mills. The discharge of the Monocacy October 15, measured at its mouth, 7 miles below Point of Rocks, was 219 second-feet, when the gage at Frederick read 4.4 feet. This station is described in Water-Supply and Irrigation Paper No. 15, p. 20. Following are the results of observations and discharge measurements made at the station during the year 1897:

Rating table for Monocacy River at Frederick, Maryland, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
3.6	45	6.0	1,020	8.4	3,084	10.8	5,148
3.8	90	6.2	1,192	8.6	3,256	11.0	5,320
4.0	150	6.4	1,364	8.8	3,428	11.5	5,750
4.2	210	6.6	1,536	9.0	3,600	12.0	6,180
4.4	270	6.8	1,708	9.2	3,772	12.5	6,610
4.6	340	7.0	1,880	9.4	3,944	13.0	7,040
4.8	420	7.2	2,052	9.6	4,116	13.5	7,470
5.0	500	7.4	2,224	9.8	4,288	14.0	7,900
5.2	600	7.6	2,396	10.0	4,460	14.5	8,330
5.4	700	7.8	2,568	10.2	4,632	15.0	8,760
5.6	800	8.0	2,740	10.4	4,804	15.5	9,190
5.8	900	8.2	2,912	10.6	4,976	16.0	9,620

Estimated monthly discharge of Monocacy River at Frederick, Maryland.

[Drainage area 665 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	750	150	324	19,922	0.56	0.49
February	8,760	270	2,012	111,741	3.15	3.03
March	4,288	600	1,435	88,235	2.47	2.14
April	3,858	340	932	55,458	1.56	1.40
May	9,276	240	1,598	98,257	2.77	2.40
June	2,310	210	515	30,645	0.85	0.77
July	4,374	210	734	45,132	1.27	1.10
August	9,792	180	939	57,737	1.61	1.40
September	825	105	193	11,484	0.32	0.29
October	255	77	134	8,239	0.23	0.20
November	8,631	322	1,007	59,921	1.70	1.52
December	8,717	575	1,976	121,500	3.43	2.97
The year	9,792	77	983	708,271	19.92	1.48

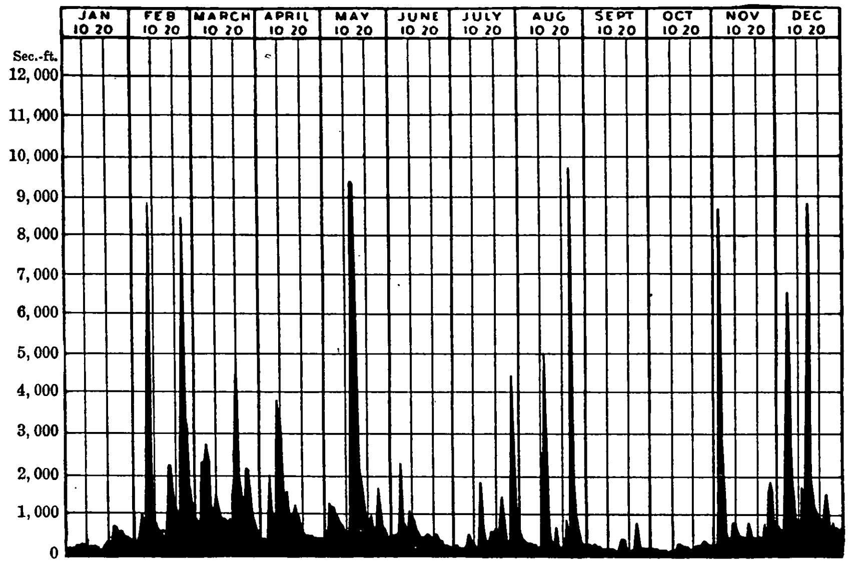


FIG. 38.—Discharge of Monocacy River at Frederick, Maryland, 1897.

Seneca Creek has its head waters in Montgomery County, Maryland, and empties into the Potomac 10 miles above Great Falls. Its discharge October 15 was 25 second-feet. It furnishes power to several mills, one near its mouth utilizing a fall of 14 feet. No pollution was observed.

Rock Creek has its source in Montgomery County, and discharges into the Potomac at Washington, District of Columbia. In its course through Georgetown it receives much sewage and refuse. There are no mill sites on it of any importance. A regular gaging station is maintained at the bridge in the National Zoological Park, a description of which, containing also the daily observations and discharge measurements made during the year 1897, will be found in Water-Supply and Irrigation Paper No. 15, p. 22. There was not a sufficient number of measurements on which to base a rating table.

Table of industries and sources of pollution along the North Branch of Potomac River.

Stream.	Locality.	Industry.	Pollution.
North Branch	Cedar Cliff, W. Va	Cement mill	None.
Do	Pinto, Md	do	Do.
Do	Keyser, W. Va	B. and O. car shops	Sewage.
New Creek	do	Woolen mill	Dyes, wool washings.
Do	do		Sewage.
Do	New Creek, W. Va	Tannery	Tan liquor, limewater.
Do	Mineral County	2 sawmills	Sawdust (amount insignificant).
North Branch	Piedmont, W. Va		Sewage and garbage.
Georges Creek	Westernport, Md		Do.

Table of industries and sources of pollution along the North Branch of Potomac River—Continued.

Stream.	Locality.	Industry.	Pollution.
Georges Creek	Lonaconing, Md		Sewage and garbage.
Do	Between Westernport and Frostburg, Md.	25 coal mines	Iron oxides and sulphates.
North Branch	Luke, Md	Pulp mill	Waste pulp, sulphites, sulphates.
Savage River	Frankville, Md	Sawmill	Sawdust.
Do	New Germany, Md	do	Do.
North Branch	Empire, W. Va	Coal mine	Iron oxides and sulphates.
Do	Windom, W. Va	do	Do.
Do	Linwood, W. Va	Sawmill	Sawdust.
Do	Shaw, W. Va	do	Do.
Three Forks Run	Chaffee, Md	do	Do.
North Branch	Blaine, Md	Woolen mill *a*	Insignificant.
Do	do	Grist and saw mill *a*	Sawdust.
Do	Near Harrison, W. Va	Sawmill	Do.
Abram Creek	Emory, W. Va	do	Do.
Do	Elk Garden, W. Va	Coal mines	Iron oxides and sulphates.
North Branch	Maple Run, W. Va	Sawmill	Sawdust.
Do	Schell, Md	do	Do.
Do	Bradshaw, Md	do	Do.
Do	Gormania, W. Va	Tannery	Waste liquor, limewater, and tan bark.
Nydegger Run	Near Gorman, Md	Sawmill	Sawdust.
Buffalo Creek	Bayard, W. Va	do	Do.
North Branch	do	Tannery	Tan liquor, limewater.
Do	Wilson, Md	Sawmill	Sawdust.
Do	Dobbin, W. Va	do	Do.
Do	Wilsonia, W. Va	do	Do.

a Steam power is made use of by the above industries, with the exception of the mills at Blaine; the woolen mill utilizes a fall of 7½ feet and the grist and saw mill one of 9 feet, the powers obtained being 8 and 25 horsepower, respectively.

Table of water powers and sources of pollution in the Shenandoah Basin.

[Mills using steam power are marked with an asterisk (*) in the column headed "Total fall utilized."]

Stream.	Locality.	Industry.	Pollution.	Number of mills.	Total fall utilized.	Total net horsepower utilized.
					Feet.	
Shenandoah River	Harpers Ferry, W. Va.	Pulp mill	Wood and bark chips.	1	24	1,500
Flowing Run	Halltown, W. Va	Strawboard factory.	Effluent from straw washing.	1	(*)	
Do	do	Gristmill	None	1	14	10
Shenandoah River	Millville, W. Va	Flour mill	do	1	15	70
Evitt Run	Charlestown, W. Va.	Pumping plant	do	1	16	18
Do	do	Tannery	Tan liquor	1	(*)	

Table of water powers and sources of pollution in the Shenandoah Basin—Continued.

Stream.	Locality.	Industry.	Pollution.	Number of mills.	Total fall utilized.	Total net horsepower utilized.
					Feet.	
Evitt Run	Charlestown, W. Va.	Gas plant	Gas water (amount insignificant).	1		
Do	Jefferson County	Flour and grist mills.	None	2	36	45
Bullskin Run	Kabletown, W. Va.	Flour and saw mill.	do	1	14	8
Long Marsh Run	Jefferson and Clarke counties.	Flour and grist mills.	do	2	(?)	(?)
Crystal Run	Clarke County	Flour, grist, and saw mill.	Sawdust	1	25	25
Do	do	Flour and grist mill.	None	1	20	18
Spring on left bank of Shenandoah.	8½ miles upstream from Castlemans Ferry.	do	do	1	31½	8
Parker Creek	Millwood, Va.	Flour and grist mills.	do	2	34	45
Stone Bridge Run	Milldale, Va	do	do	2	35	35
Wappan Run	Warren County	do	do	2	37	15
Crooked Run	do	do	do	2	20	18
Happy Creek	do	do	do	3	48	30
South Fork	Riverton, Va	Flour mill	do	1	6	70
Gooneys Creek	Browntown, Va	Tannery	Tan liquor and limewater.	1	(*)	
Do	Warren County	Flour and grist mills.	None	5	55	50
Flint Run	do	do	do	1	13	10
South Fork	Near Bentonville, Va.	Gristmill	do	1	5	10
Overall Run	Overall, Va	Barrel-stave factory.	Tan liquor (amount trifling).	1	(*)	
Do	do	Sawmill	Sawdust	1	(?)	(?)
Dry Run	Page County	do	do	1	14	10
Jeremiah Run	Rileyville, Va.	Flour and grist mill.	None	1	13	12
South Fork	Near Rileyville, Va.	do	do	1	4	8
Hawksbill Creek	Page County	do	do	5	60	68
Pass Run	Springfield, Va	do	do	1	15	15
Do	Page County	do	do	4	(?)	(?)
Dry Run	do	do	do	1	15	12
Mill Creek	do	Grist and saw mill.	do	1	16	10
South Fork	Near Massanutten, Va.	Flour and grist mill.	do	2	8	18
Do	Newport, Page County.	do	do	1	(?)	(?)

Table of water powers and sources of pollution in the Shenandoah Basin—Continued.

Stream.	Locality.	Industry.	Pollution.	Number of mills.	Total fall utilized.	Total net horsepower utilized.
					Feet.	
South Fork	Grove Hill County	Flour and grist mill.	None	1	(?)	(?)
Naked Creek	Rockingham County.	do	do	3	30	35
Elk Run	Elkton, Va	Tannery	Tan liquor and limewater.	1	(*)	
South Fork	do	Manganese Ore Co.	Ore washings	1	(*)	
Do	Millbank, Va	Flour and grist mill.	None	1	7	70
Do	Riverbank, Va	do	do	1	6	40
Do	Yancey, Va	do	do	1	(?)	15
Do	Almond, Va	do	do	1	(?)	(?)
Cub Run	Pen Laird, Va	do	do	1	26	25
Do	Keezletown, Va	Gristmill	do	1	(?)	(?)
Do	do	Tannery	Insignificant	1	(*)	
Do	do	Barrel-stave factory.	do	1	(*)	
Do	do	Grist and saw mill.	Sawdust	1	27	14
South Fork	Lynwood, Va	Flour and grist mill.	None	1	8	66
South River	Port Republic, Va.	do	do	1	10½	60
Do	do	Tannery	Tan liquor, limewater, and tan bark.	1	(*)	
Do	Grottoes, Va	Flour and grist mill.	None	1	7	60
Do	Harriston, Va	Grist and shingle mill.	Sawdust	1	7	15
Do	Koiner Store, Va	Grist and saw mill.	do	1	8	12
Do	Crimora Station, Va.	Flour and grist mill.	None	1	9	100
Do	do	Gristmill	do	1	(?)	(?)
Do	Doom Station, Va.	Grist and saw mill.	Sawdust	1	7	15
Do	do	Flour mill	None	1	7½	51
Do	Below Basic City, Va.	Gristmill	do	1	(?)	(?)
Do	Waynesboro, Va	do	do	1	9	100
Do	do	Hydraulic-ram factory.	do	1	8	75
Do	2 miles above Waynesboro, Va.	Flour and grist mill.	do	1	7	42
Back Creek	Augusta County	Gristmill	do	2	12	20
South River	Lyndhurst, Va	Flour and grist mill.	do	1	12	40
Mill Creek	Goods Mill, Va	do	do	1	23	22

Table of water powers and sources of pollution in the Shenandoah Basin—Continued.

Stream.	Locality.	Industry.	Pollution.	Number of mills.	Total fall utilized.	Total net horsepower utilized.
					Feet.	
Mill Creek		Grist and saw mill.	Sawdust	1	10	15
Middle River	Mount Meridian, Va.	do	do	1	4½	10
Do	Knightly, Va	Flour and saw mill.	do	1	11	45
Do	New Hope, Va	Flour and grist mill.	None	1	8	40
Long Meadow Creek.	Augusta County	Grist and saw mill.	Sawdust	1	(?)	(?)
Christian Creek	do	Flour and grist mills.	None	2	22	45
Lewis Creek	Staunton, Va	Bone and plaster mill.	do	1	12	14
Do	do	Ice factory	do	1	29	46
Do	do		Sewage	1	(*)	
Middle River	Verona, Va	Flour mill	None	1	9	88
Do	Longglade, Va	Flour and grist mill.	do	1	(?)	(?)
Do	(?)	do	do	1	6	25
Jennings Branch	Near Churchville, Va.	Gristmill	do	1	(?)	(?)
Do	do	Flour and grist mill.	do	1	12	10
Do	Churchville, Va	do	do	1	12	15
Whisky Creek	Near Churchville, Va.	Grist and planing mill.	Sawdust	1	9	6
Do	do	Gristmill	None	1	12	
Do	do	Grist and shingle mill.	Sawdust	1	12	
Middle River	South of Churchville, Va.	Flour and grist mill.	None	1	14	27
Do	do	Barrel-head mill.	Sawdust	1	7	22
Do	do	Carriage factory.	None	1	16	(?)
Do	Valley Mills, Va	Flour and grist mill.	do	1	18	42
Do	Near Swoope, Va	do	do	2	(?)	(?)
North River	Weyer Cave Station, Va.	Flour mill	do	1	5	45
Naked Creek	Burketown, Va	do	do	1	18	15
Do	Stonewall, Va	Flour and grist mill.	do	1	19	15
North River	Mount Crawford Station, Va.	do	do	1	8	35
Cooks Creek	Mount Crawford, Va.	Grist and saw mill.	Sawdust	1	9½	10
Do	Dayton, Va	Flour and grist mill.	None	1	7	5
Do	do	do	do	1	(?)	(?)

Table of water powers and sources of pollution in the Shenandoah Basin—Continued.

Stream.	Locality.	Industry.	Pollution.	Number of mills.	Total fall utilized.	Total net horsepower utilized.
					Feet.	
Blacks Run	Harrisonburg, Va.	Tannery	Tan liquor, limewater, etc.	1	(*)	....
North River	Mount Crawford, Va.	Flour and grist mill.	None	1	6	25
Do	Bridgewater, Va.	do	do	2	16	120
Do	do	Woolen mill	Dyes, wool washings, etc.	1	10	18
Do	do	Carriage shops	Sawdust, etc.	1	10	32
Dry River	Near Bridgewater, Va.	Flour and grist mill.	None	1	10	18
Do	Montezuma, Va.	Cider press	Apple pomace	1	(*)	....
Do	do	Grist and saw mill.	Sawdust	1	10	16
Mossy Creek	Mossy Creek, Va.	Flour, grist, and cider mill.	Apple pomace	1	10	44
Do	Mount Solon, Va.	Flour and grist mill.	None	1	15	16
North Fork	Riverton, Va.	Grist and saw mill.	Sawdust	1	7	12
Passage Creek	Near mouth	Flour and grist mill.	None	1	14	10
Do	Buckton, Va.	Gristmill	do	1	13	15
Do	do	Flour and saw mill.	Sawdust	1	20	30
Do	Dilbeck, Va.	do	do	1	9	18
Branch of Passage Creek.	Fort Crossroads, Va.	Grist and saw mill.	do	1	14	10
Passage Creek	Near Fort Crossroads, Va.	Flour and saw mill.	do	1	11	8
Do	Edith, Va.	Flour and grist mill.	None	1	18	5
Do	do	Grist and saw mill.	Sawdust	1	7	5
Cedar Creek and tributaries.	Shenandoah County.	Flour and grist mills.		10	172	130
Cedar Creek	Zepp, Va.	Tannery	Tan liquor	1	(*)	....
Spring	Near Strasburg, Va.	Gristmill	None	1	24	12
Do	Strasburg, Va.	Tannery	Tan liquor (amount trifling).	1	(*)	....
Tumbling Run	Fishers Hill, Va.	Flour and grist mill.	None	1	26	18
Toms Brook	Toms Brook, Va.	Barrel-stave factory.	Tan liquor	1	(*)	....
Do	Shenandoah County.	Flour and grist mills.	None	4	72	36
Stony Creek	Edenburg, Va.	do	do	3	38	110
Do	Lantz Mill, Va.	Flour, grist, and saw mill.	Sawdust	1	13	18

Table of water powers and sources of pollution in the Shenandoah Basin—Continued.

Stream.	Locality.	Industry.	Pollution.	Number of mills.	Total fall utilized.	Total net horsepower utilized.
					Feet.	
Stony Creek	Lantz Mill, Va.	Grist and saw mill.	Sawdust	1	(?)	(?)
Do	Columbia Furnace, Va.	Gristmill	None	1	15	15
Do	Liberty Furnace, Va.			1	(?)	(?)
North Fork	Hawkinstown, Va.	Flour, grist, and saw mill.	Sawdust	1	8	40
Mill Creek	Mount Jackson, Va.	Flour and grist mills.	None	2	40	55
Do	do	Sawmill	Sawdust	1	12	(?)
Do	do	Woolen mill	None	1	12	(?)
Do	Rinkerton, Va	Flour, grist, and saw mill.	Sawdust	1	16	20
Do	Mount Clifton, Va	Flour and grist mill.	None	1	6	8
Linville Creek	Broadway, Va.	Machine shop	do	1	12	8
Do	do	Grist and saw mill.	Sawdust	1	9	15
Do	do	Flour and grist mill.	None	1	16	20
Do	Rockingham County.	do	do	4	(?)	(?)
Smiths Creek	Lacey Springs, Va.	do	do	1	14	33
Do	Tenth Legion, Va.	Gristmill	do	1	12	(?)
Do		Flour and grist mills.	do	2	(?)	(?)
Holmans Creek	Quicksburg, Va.	Sawmill	Sawdust	1	(?)	(?)
North Fork	Newmarket, Va.	Flour and grist mill.	None	1	7	33
Spring	Near Newmarket, Va.	do	do	1	16	30
North Fork	Timberville, Va.	do	do	1	12	64
Do	do	do	do	1	7	20
Do	Dovesville, Va	do	do	1	(?)	(?)

NORTH RIVER.

A gaging station on North River is located 1 mile above its mouth, at Glasgow, Virginia, and is described in Water Supply and Irrigation Paper No. 15, p. 23. The 1896 rating table, published in the Eighteenth Annual Report, Part IV, p. 37, was found applicable to the 1897 measurements.

Estimated monthly discharge of North River at Glasgow, Virginia.

[Drainage area, 831 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	720	350	454	27,915	0.63	0.55
February	10,450	475	3,181	176,665	3.99	3.83
March	3,650	1,040	1,672	102,810	2.32	2.01
April	1,370	507	889	52,900	1.19	1.07
May	9,450	507	2,035	125,130	2.83	2.45
June	630	300	463	27,550	0.62	0.56
July	1,425	180	362	22,259	0.51	0.44
August	350	180	222	13,650	0.31	0.27
September	197	150	177	10,533	0.23	0.21
October	250	150	197	12,113	0.28	0.24
November	442	180	245	14,579	0.32	0.29
December	1,425	300	521	32,036	0.72	0.63
The year	10,450	150	866	618,140	13.95	1.05

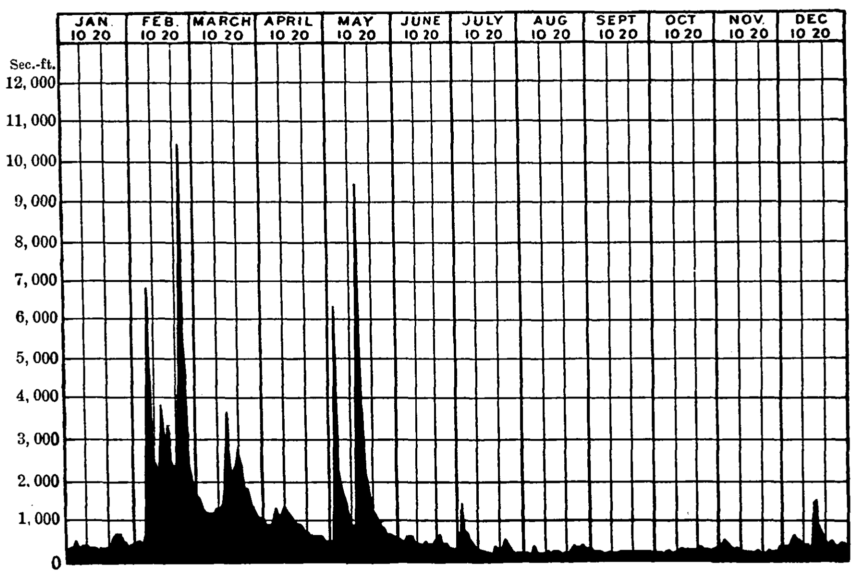


FIG. 39.—Discharge of North River at Glasgow, Virginia, 1897.

JAMES RIVER.

The last river draining into Chesapeake Bay is the James. A gaging station is located on this river at Buchanan, Virginia, about 20 miles above the mouth of North River, and described in Water-Supply and Irrigation Paper No. 15, p. 24. The combined flow at this station and

PROFILE of JAMES RIVER from Richmond to Clifton Forge, Virginia.

1897

D. C. Humphreys.

that at Glasgow, Virginia, on North River, is practically the flow of James River at Balcony Falls, where it passes through the Blue Ridge.

The State of Virginia built a canal along James River from Richmond to Buchanan, with a branch up North River from its mouth, at Balcony Falls, to Lexington. The canal proved expensive to maintain, owing to the heavy fall in the river and the resulting large number of dams and locks. The State transferred all its rights in the canal to the Richmond and Alleghany Railroad Company on condition that the company should build a railway from Richmond to Clifton Forge, with a branch from Balcony Falls to Lexington.

The railway was built and was subsequently purchased by the Chesapeake and Ohio Railway Company, which now owns all rights that the old James River and Kanawha Canal Company possessed in the dams and water power. In the construction of the canal a large number of good dams were built which are now available for water power. A small part only of the power thus made readily available has been taken up, and the remaining dams, now in a state of more or less dilapidation, afford excellent sites for mills and factories.

There is no place in the State where water power is so readily available and where there are so few complications from backwater flooding farming lands and other troubles incident to dam building. The dams are leased by the Chesapeake and Ohio Railway to users at a nominal sum.

To collect information in regard to the water resources of James River a trip was made in canoes down North River from Lexington to the mouth, and then, after taking the canoes to Clifton Forge by railway, down James River to the top of the falls at Richmond.

The principal results of this examination of the river are shown on the accompanying profile and in the following pages, the statements being condensed from a report prepared by Prof. D. C. Humphreys, of Washington and Lee University, at Lexington, Virginia.

The party consisted of D. C. Humphreys, F. H. Anschutz, and W. A. Shepherd, each paddling his own canoe. The canoes were canvas, 16 feet long and 32 inches beam, and the average weight was about 80 pounds. These boats were decked over, and in the center was the cockpit, 8 feet long and 22 inches wide; from the top of the cockpit to the bottom of the boat was about 14 inches. The hatches which covered the cockpit could be easily removed for loading and unloading and to make room at night for sleeping. At night each boat was lifted out on the bank, the tent erected over the cockpit, the boat wiped out with a sponge; the large oiled canvas bag, in which the bed and bedding was carried, was spread in the bottom to keep the dampness from the bed; the mattress was laid on top of this, thus making a comfortable and dry bed. The illustration on Pl. XXII gives a good idea of the construction of the boats. First a framework was built and then the heaviest duck canvas stretched over it. On the outside strips were placed to protect the canvas from rocks, which proved generally effective. The canvas was very tough and hard to snag, and when a hole was made it was an easy matter to patch it with a piece of canvas by using melted rosin and lard as a cement.

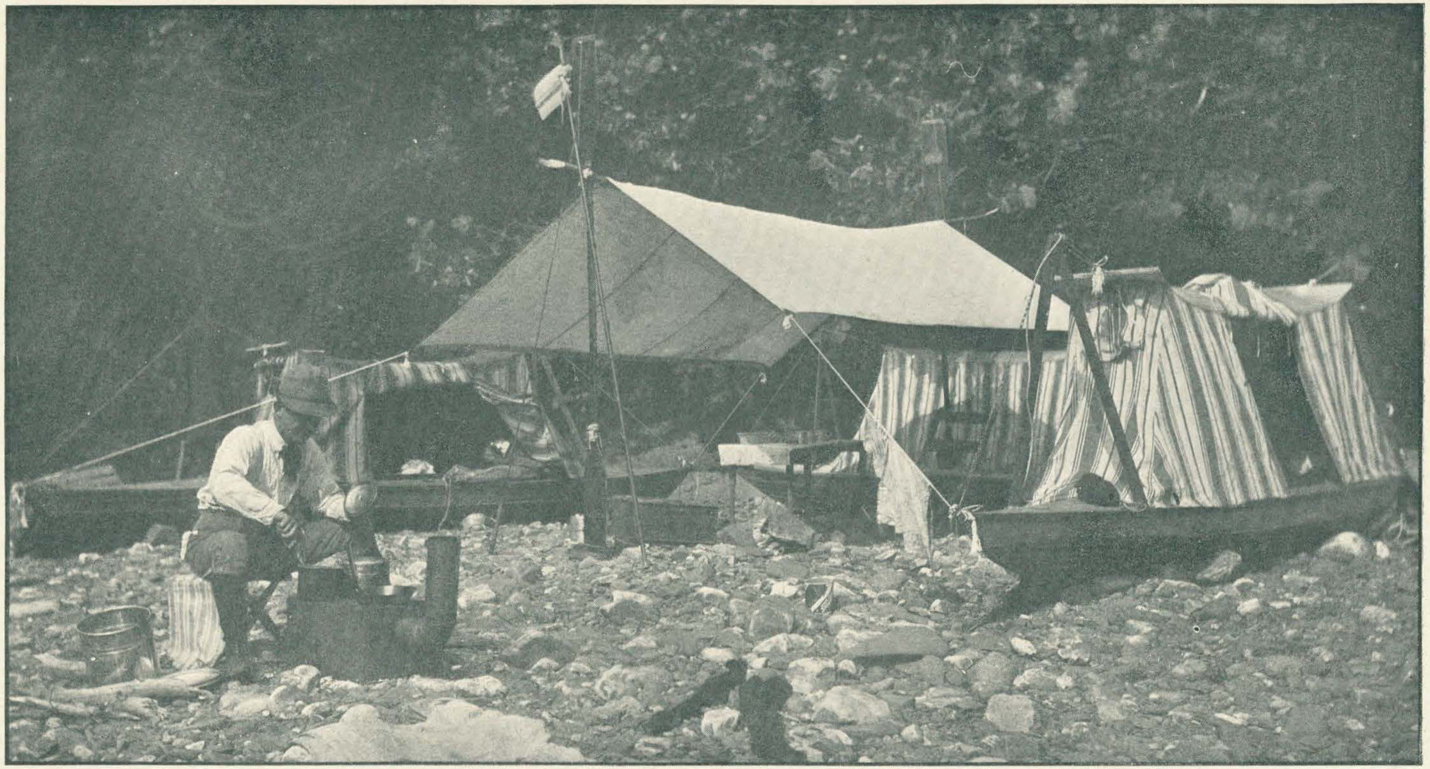
When under way on the river, as shown in Pl. XXIII, the hatches were kept down and only a small hole left, in which the single occupant sat. In running rapids the canoeman pulls the oiled apron up around him, and thus prevents the water from the waves that may dash over the deck from getting into the boat. While under way a rubber coat, the tails of which are spread out on the deck, affords complete protection from rain. At night the tent is an ample protection. All belongings were carried in oiled canvas bags, and the large bag which held the mattress was folded up for a seat.

The instrumental equipment consisted of a large Haskell meter attached to a light wooden rod, graduated for the purpose of making soundings, a light level which could be used on the tripod of the camera, together with a folding level rod and steel tapes.

An attempt was made to obtain the level of the low-water surface at each dam and at intermediate points not more than 5 miles apart, to photograph each structure, and to obtain full information concerning the present condition of the dams and their use or the possibility of their future employment. Measurements of the flow of the main stream and of the principal tributaries were also made wherever practicable. To facilitate the work a condensed profile of the Chesapeake and Ohio Railroad was made: This gave the elevation of the top of the ties and furnished a datum for levels run to the low-water surface. Great precision was not possible under the circumstances, but the results are sufficiently accurate for general discussion and for the completion of the accompanying profile, Pl. XXI. On this is given the location and the height of the dams; the dotted lines indicate former conditions and the full lines the present slope. On the portion relating to James River the names of the dams are given, while on North River the dams are numbered. The following description is arranged in the order in which the localities were visited:

Dam No. 10, on North River, was formerly called Reid's dam, but is now known as the Lexington Light and Power Company's dam. The available head is 11.75 feet. The crest is 15 feet below the railway. The dam was built of dry rubble masonry, and the upper side and top was sheeted with plank to hold water. It was found necessary to replace this sheeting in 1896. At the time of the erection of the electric plant, in 1892, the dam was lowered 3 feet nearly all the way across to prevent the backing of water into the tail race of the mill at Lexington. The power at this dam is fully utilized and is very satisfactory. It has been noticed here that the river holds its own remarkably well in extremely dry weather.

Dam No. 9, South River dam, is located immediately above the mouth of South River; its crest is 9.55 feet below the railway and its height is 17.2 feet. This was a dry rubblestone dam, sheeted on the upper side and top. About two years ago the sheeting rotted and caused the dam to break. The break is in the middle of the dam and is as yet not very extensive. It could be easily repaired and the power utilized at the old mill site, which is on the left bank near the railway. On July 8, 1897, the discharge of the river, measured a short distance above this dam, was 160 second-feet, and in extreme low water it does not fall below about 90 second-feet.



EQUIPMENT OF FIELD PARTY MAKING RECONNAISSANCE ALONG JAMES RIVER, VIRGINIA.

FIELD PARTY IN CANOES.

Dam No. 8, located 13.7 miles from the mouth of North River, was built of logs and is broken all the way across. The fall in the water at the dam is now only 2.4 feet, and the water below the dam is 18.1 feet lower than the railway. The original height of this dam must have been at least 8 feet.

Dam No. 7, Buena Vista Electric Plant dam (Pl. XXIV, *B*), is 13.1 miles above the mouth of North River, and the crest of the dam is 11.5 feet below the railway. The available height is 12 feet. This dam is of dry rubble masonry, sheeted on the upper side and on top. It needs resheeting for it leaks badly. This dam is below the mouth of South River, and the discharge of the river when measured was about 216 second-feet. In extreme dry weather the discharge is probably slightly more than half of this. The photograph of the dam shows the method of passing the canoes down over the dam. The available power here in dry weather is fully used.

Dam No. 6, Buena Vista Paper Mill dam, is 12.2 miles from the mouth of North River; the crest is 10.8 feet below the railway and the height is 15 feet. This dam is built of dry rubblestone masonry, sheeted on the upper side and on top. It is in very good order and the low water power is fully utilized by the paper mill, for which it only furnishes about half the power needed, the rest being derived from a steam engine.

Dam No. 5 is 9.2 miles from the mouth of North River; the crest of the dam is about 14 feet below the railway and the height is 6.8 feet. The fall in the water at the dam now is 3.5 feet. This dam was built of logs, with stone filling, and is now washed out all the way across the river. The foundation and head walls are in good order.

Dam No. 4 is 7.9 miles from the mouth of North River; the crest is about 14 feet below the railway and the height is 8 feet. The dam was built of dry rubble masonry, sheeted on the upper side and on top. It is in a good state of preservation, except that the sheeting has rotted and there is a small break in it. The river has cut a channel around the dam, between it and the Chesapeake and Ohio Railway, which is narrow and could be filled up without much difficulty. The Norfolk and Western Railway runs along the right bank of the river here and at all other dams below Buena Vista on North River, thus giving a mill located at any of these places the advantage of transportation over two railways.

Dam No. 3, Goose Neck dam, is 6.7 miles above the mouth of North River; the crest of the dam is 15.8 feet below the Chesapeake and Ohio Railway and the height of the dam is 15 feet. It is built of dry rubble masonry, sheeted on the upper side and on top; the sheeting, however, is rotten, allowing the entire river, except in high water, to run through the dam between the cracks in the dry masonry wall. It is a question of only a short time when this dam will break like the others. There is no place on either James or North rivers where power, now unused, could be so cheaply developed. The low water power that could be developed here is about 300 horsepower.

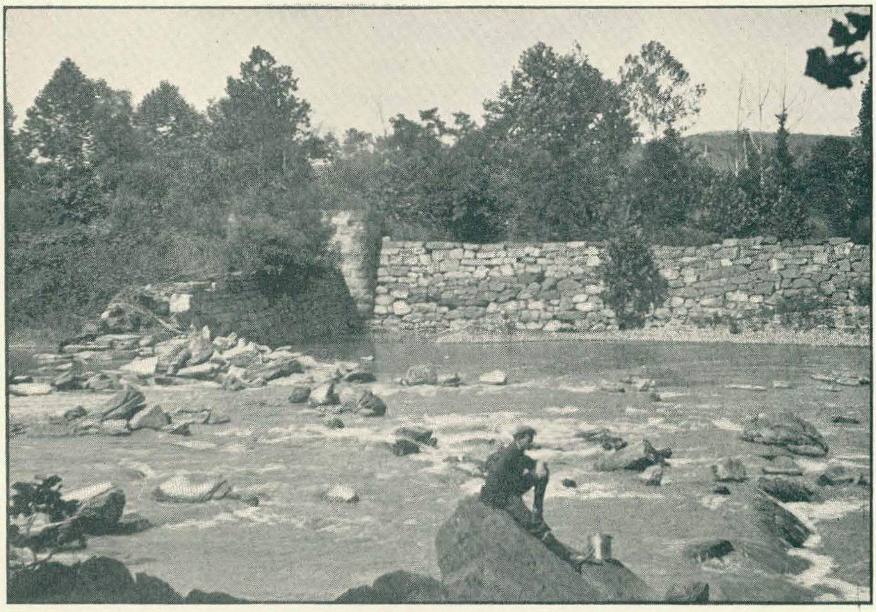
Dam No. 2, Devils Steps dam (Pl. XXIV, *A*), is 5.5 miles from the mouth of North River; the crest of the dam is about 10 feet below the Chesapeake and Ohio Railway, the height is 11 feet, and the present drop in the water surface is 2.4 feet. This was a stone dam, like most of the others on North River, and more than half is washed away. The head wall on the left bank is good, and on the right bank there is a solid rock ledge, which served as a head wall and which gave the dam its name.

Dam No. 1, Miller's dam, is 5.2 miles from the mouth of North River; the crest of the dam is about 10 feet below the Chesapeake and Ohio Railway and its height is 10 feet. This dam was built of logs, with stone filling, and is now nearly destroyed, except the head walls, which are good. This was the lowest dam on North River. Blue Ridge dam, on James River, just below the mouth of North River, ponds the water in North River for over a mile.

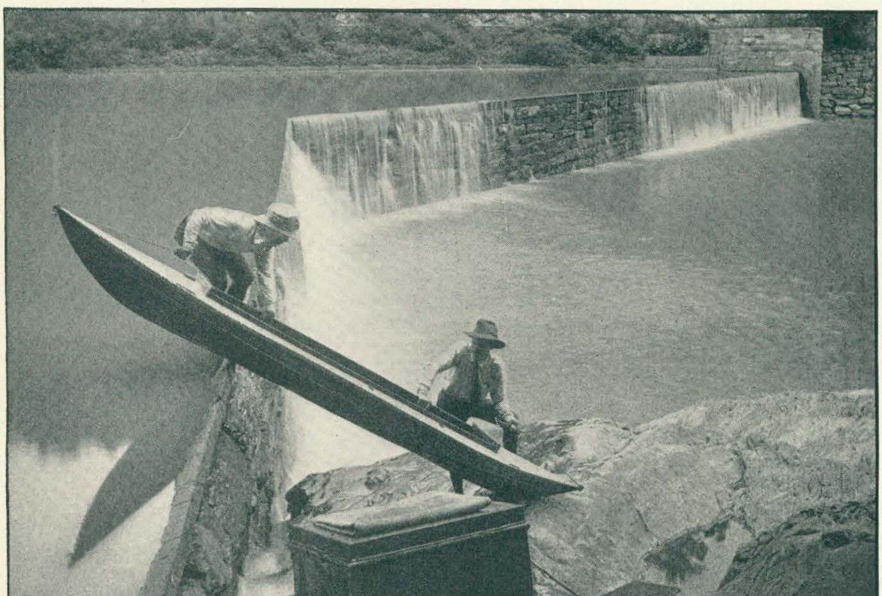
In the "Report on the water power of the Middle Atlantic watershed," Tenth Census of the United States, Vol. XVI, Part I, pp. 531–551, valuable information is given concerning the James River and its tributaries. From that report the following table is reprinted:

Table of statistics regarding dams of the James River and Kanawha Canal Company on James River.

Name of dam.	Dam.							Pond.		Remarks.
	Distance from Richmond.	Length.	Height.		Material.	Date of erection.	Cost.	Length.	Whether used for navigation.	
			Above foundation.	Above surface.						
	Miles.	*Feet.*	*Feet.*	*Feet.*				*Miles.*		
Grants	3.0	1,700	4	4	Wood	1855 (?)	$20,000		Feeder only	Dam does not extend entirely across river. No water power.
Boshers	9.0	902	12	9	Cut granite in cement	1857-1858	70,000	10	Navigated	
Maidens Adventure	29.0	1,026	12	10	do	1852-1853	80,000	5	Navigated 5 miles	
Seven Island					Wood	1840			Feeder only	Low dam. Enables boats to enter canal from opposite side of river. Does not extend entirely across. No water power.
Tye River	109.0	550	12	10	Cut granite in cement	1860	60,000		Navigated 2½ miles	
Joshua Falls	135.5	600	12	9	do	1870	50,000	3	do	Rebuilt in 1870.
Lynchburg	148.5				Partly stone, partly wood	1839		2	Navigated 2 miles	Extends in a broken line from island to island.
Judiths	152.0	725	33	25	Cut stone in cement	1850-1851	100,000 or over.	4	Navigated 4 miles	
Bald Eagle	157.0	498	14	14	do	1849-1851	35,000	2½	Navigated 2½ miles	
Pedlar	160.0	454	18	12	do	1849-1851	35,000	2	Navigated 2 miles	
Colemans Falls	162.5	572	18	14	218 ft. stone, 354 ft. wood	1849-1851	30,000	3	Navigated 3 miles	
Big Island	166.5	683	12	12	Stone	1849-1851	35,000	2	Navigated 2 miles	
Cushaw	170.5	843	10	10	Wood	1849-1851	20,000	1		Boats cross river in pond.
Blue Ridge	176.0	455	13	13	150 ft. stone, 305 ft. wood	1849-1851	20,000	3 and 1½	3 miles on James; 1½ miles on North	At confluence of North River. Stone part in front of old wooden part.



A. DEVILS STEPS DAM ON NORTH RIVER, VIRGINIA.



B. BUENA VISTA ELECTRIC PLANT DAM ON NORTH RIVER, VIRGINIA.

Quarry Falls	178.5	582	13	13	136 ft. stone, 446 ft. wood	1849-1851	25,000	2½	Navigated 2½ miles	Not very favorable for power.
Varneys Falls	185.5	488	18	14	Wood	1849-1851	20,000	3	Navigated 3 miles	Not so favorable for power as the two below.
Indian Rock	189.5	613	19	16	do	1849-1851	30,000	2	do	Easy to utilize for water power.
Wasp Rock	194.0	384	20	15	do	1849-1851	30,000	3	do	Do.

This table shows only the dams below Buchanan, or on the completed portion of the canal. It was the intention to extend the canal eventually to the Ohio River, and for this purpose surveys were made and two dams located and built above Buchanan, which have never been used. Beginning at Clifton Forge and coming down Jacksons and James rivers, the dams, taken in order, are described below:

Old Forge dam is 210 miles from Richmond. The crest of the dam is 13.9 feet below the Chesapeake and Ohio Railway, and the height, as measured, was 18.6 feet. This dam, which was substantially built of stone laid in cement, was probably never entirely completed. The head walls, about half the dam, and the foundations, are in good order, and it would not be very expensive to restore the dam. The low water discharge of the river here is about 350 second-feet.

Cabell's dam is about 106 miles from Richmond, and was built of wood on a stone foundation, 5 feet high. It is almost entirely gone, except the head walls, which seemed to be in fairly good order, as they were built of stone. No levels were obtained here, connecting the dam with the railway, and there is no drop in the water surface at the site of the dam.

Wasp Rock dam has a crest 19 feet below the railway, its height being 15 feet. It is completely washed out except the head walls, which are in good order and well built, and the foundation, part of which remains. The river cut a channel around the dam on the left bank, next to the Chesapeake and Ohio Railway, which has been filled up by the railway company with a strong embankment protected by riprap.

The crest of Indian Rock dam is about 19 feet below the railway, and its height was 16 feet. Most of this dam has been washed away.

Varneys Falls dam has a crest 9.1 feet below the railway, its height being 14 feet, while at present the drop in the water surface at the dam is 4 feet. This dam is only partially gone, and there is excellent masonry on the left bank, where the old lock still stands. On the right bank, which is occupied by the Norfolk and Western Railway, there is a ledge of rock. On the left bank there is an excellent location for a mill to use the power.

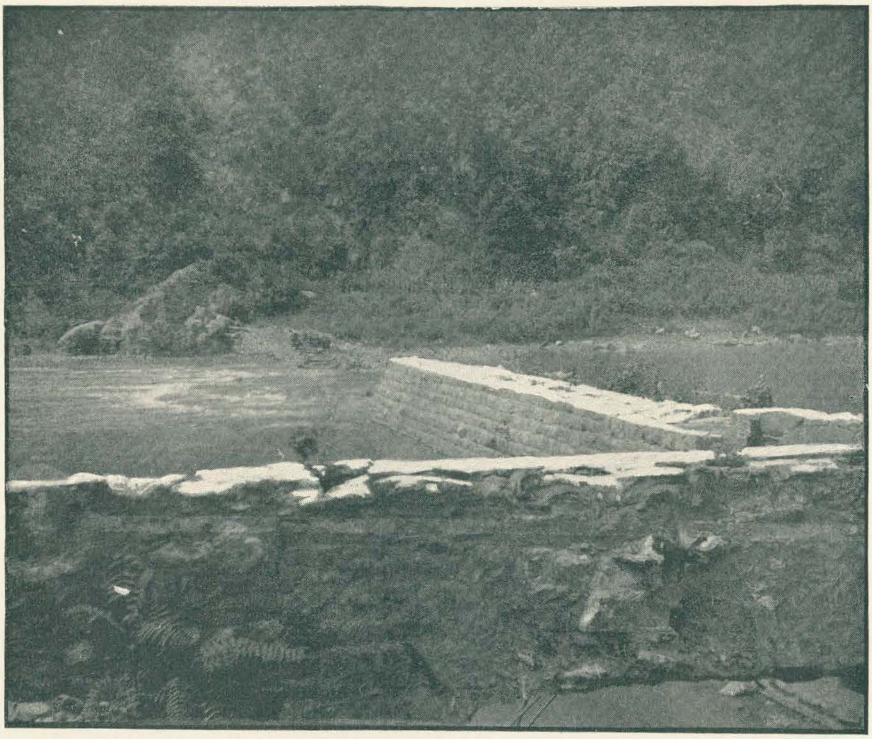
At Quarry Falls the crest of the dam is 10 feet below the railway, and the height is 13 feet. This dam is mostly standing, the river running through a small break near the center. A part of the timber is rotten and will have to be replaced if the dam is repaired for use. There is a good mill site on the left bank at the lock for utilizing the power. This dam is about a mile below Natural Bridge station, where the Norfolk and Western Railway crosses James River and the Chesapeake and Ohio Railway.

Blue Ridge dam (Pl. XXV, *A*), at Balcony Falls station, has a crest about 14 feet below the railway; its height, which is 13 feet, may be increased by digging a tail race, for there is considerable fall below the dam. This is an admirable location for the development of water power. The plan of the dam was made in 1891; since that time the old cement mill has been removed and the wooden part of the dam has broken near the middle. The site is immediately below the mouth of North River, and the low water discharge is about 700 second-feet. On July 8, 1897, it was 1,489 second-feet.

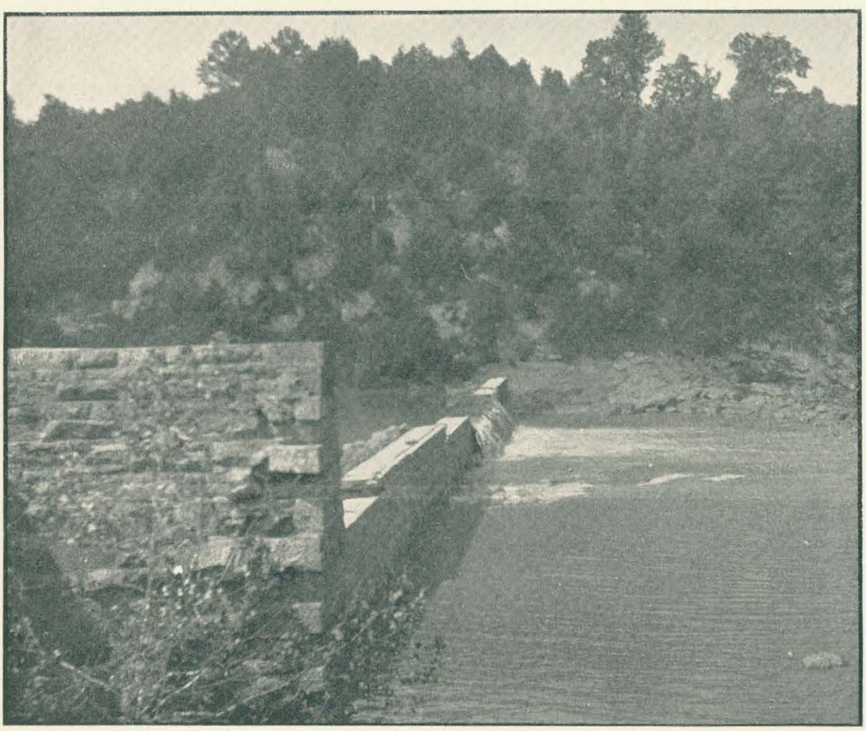
Near Rope Ferry is Cushaw dam. The old crest of the dam was 15.75 feet below the railway and the height was 10 feet. No part of this dam is standing, and nothing but the foundation remains.

The crest of Big Island dam is 14.3 feet below the railway and the height, as measured, is 11 feet. This dam is intact and the power has been used by a paper mill, situated on the right bank beside the railway. The mill has not been operated for several years.

Colemans Falls dam has a crest 14.9 feet below the railway, with a height of 14 feet. It is in part broken; the stone portion is fairly good, while the wooden portion has been mostly washed away.



A. BLUE RIDGE DAM ON JAMES RIVER AT BALCONY FALLS, VIRGINIA.



B. PEDLAR DAM ON JAMES RIVER 16 MILES BELOW BALCONY FALLS, VIRGINIA.

The crest of Pedlar dam is 15.5 feet below the railway and the height is 14 feet (see Pl. XXV, *B*). This dam has been restored and the entire power of the river utilized within the last year by a very complete plant for the manufacture of calcium carbide, erected by the Wilson Aluminium Company, of Spray, North Carolina.[1]

Of Bald Eagle dam there is nothing left standing and no levels were obtained. The crest of Judith dam is 14.5 feet below the railway and the height, as measured, is 24.3 feet. This dam is the highest on the river and is in excellent condition. A part of the power was used at the nail mills at Reusens, which is about half a mile below, but these works have not been operated for a number of years. At the time of visit no use seemed to be made of this power, but it is reported that an electric company in Lynchburg utilizes power from the canal that leads from this dam for street railway and other purposes.

The crest of the Lynchburg dam is 8.8 feet below the Chesapeake and Ohio Railway and the height, as measured, was 16 feet. Since the above table was compiled this dam has been improved, the conflicting interests of the city and of the railway have been adjusted, and the full power of the dam is now being utilized. The Chesapeake and Ohio Railway Company agrees to maintain the dam perpetually and to furnish water for a consideration to the pumping plant of the Lynchburg water works, and also to the various mills in Lynchburg.

Of the Joshua Falls dam nothing is standing except a part of the old wall on the railway side. Tye River dam is at Norwood station. The water below the dam was 35.6 feet below the railway at Tye River bridge, the dam was 10 feet high, and the drop in the water surface now is 1.8 feet.

The Middleton Mills dam does not seem to have been one of the canal dams. Its crest is 10.2 feet below the railway and its height is 3.2 feet.

At Maidens Adventure dam no abutments are now standing, the dam is broken about the middle, and the masonry is very much dilapidated.

The trip came to an end just above Bosher's dam, which stands at the head of the falls of the James at Richmond. Here, in a distance of 14 miles, the river has a fall of 124 feet, and in the last 3 miles the fall is 84 feet. On September 8, 1897, during a very dry season, Mr. Anschutz measured the discharge at Cartersville, 47 miles above Richmond, and found it to be 603 second-feet. This seems too small, for the combined discharges of James River at Buchanan and of North River at Glasgow were at that time about 600 second-feet. Taking the Cartersville measurement as the minimum flow, the 124 feet of fall would give about 8,500 gross horsepower. Not more than half the total power that could probably be made available has been developed.

Where the streams were sufficiently large the current meter was used in measuring the discharge, and when the water was not too deep the method of wading was used. A line was stretched across the river, and starting from the bank distances were measured with a tape. The rod to which the meter was attached was graduated and used for making soundings. The wading method gives the observer accurate knowledge of the bottom. Where the stream was too deep to wade, such as the James, at Glasgow, a tagged galvanized-wire clothesline was used and the meter was let down from one of the canoes, one man in the canoe keeping it in place by holding the line. This method worked well, but great difficulty was experienced in getting the line across and stretched close to the water. The pull on the line was so great that it was difficult to fasten the ends securely. The party was not equipped with an instrument for the indirect determination of distances, so that no measurements were made of the main river below Balcony Falls where North River empties into the James. The impracticability of measuring the main stream easily and quickly, when too deep to wade, was a weak point in the equipment. The

[1] See article by Mr. Temple, the engineer in charge of erection, published in Engineering News, April 14, 1898.

measurement at Cartersville was made by letting the meter down from the bridge in the usual way. Following is a list of stream measurements made during the trip:

Table of stream measurements, made in 1897, of James River and its tributaries.

Distance from Richmond.	Name of stream.	Discharge.	Bank (right or left).	Date.	Remarks.
Miles.		*Sec.-ft.*		1897.	
230.6	Smiths Creek	12.3	L.	July 14	At Clifton Forge.
226.5	Cowpasture River	140.7	L.	July 15	Head of James River.
226.5	Jacksons River	288.7	R.	....do ...	Head of James River.
226.5	James River	438.0	....	....do ...	Head of James River.
216.6	Mill Creek	10.4	L.	July 16	At Gala Water.
213.4	Craigs Creek	79.6	R.	....do ...	
208.5	Catawba Creek	81.0	R.	July 19	Muddy; somewhat swollen.
205.4	Saltpeter Creek	2.5	L.	....do ...	At Allens Mill.
199.5	Lipses Run	3.0	R.	July 20	Or Spreading Spring Creek.
198.6	Davids Run	0.5	R.	....do ...	
197.3	Back Creek	19.2	R.	July 21	Or Looney Creek.
189.7	Jennings Creek	20.1	R.	July 22	
188.6	Rocky Run	1.2	L.	....do ...	
187.0	Sprouts Run	2.1	R.	July 23	
181.3	Cedar Creek	2.7	L.	....do ...	
179.7	Back Run	2.2	R.	....do ...	
178.7	....	1.0	L.	....do ...	At Natural Bridge station.
177.7	Arnolds Creek	12.3	R.	July 24	
176.4	James River	1,188.0	....	July 28	At Glasgow.
174.7	North River	310.0	L.	July 27	At Glasgow River station.
170.0	Rocky Row Run	1.1	L.	July 30	
169.1	Snow Creek	0.6	R.	....do ...	
167.5	Peters Creek	2.3	R.	July 31	
167.3	Otter Creek	2.9	L.	....do ...	
167.0	Battery Creek	2.8	R.	....do ...	
165.5	Hunting Creek	5.5	R.	....do ...	At Big Island.
164.4	Reed Creek	13.8	R.	....do ...	
159.4	Pedlar River	35.8	L.	Aug. 2	
156.0	Salt Creek	0.4	L.	Aug. 3	
153.0	Widemouth Creek	0.9	R.	....do ...	
151.0	Judith Creek	5.3	R.	....do ...	
148.0	Harris Creek	10.4	L.	Aug. 4	
146.0	Ivy Creek	30.0	R.	....do ...	
144.5	Fishing Creek	2.0	R.	Aug. 5	
143.5	Rallings Run	2.8	L.	....do ...	
141.7	Opossum Creek	3.0	R.	....do ...	
140.5	Beaver Creek	13.7	R.	Aug. 6	
140.0	Archer Creek	1.4	R.	....do ...	
136.0	Joshua Creek	1.0	R.	Aug. 7	
134.9	Stovalls Creek	11.4	L.	....do ...	
133.3	Porridge Run	4.4	L.	....do ...	
131.5	Stonewall Creek	3.1	R.	....do ...	
127.4	Bells Creek	0.9	L.	Aug. 9	
124.0	Wreck Island Creek	15.2	R.	....do ...	
120.3	Allen Creek	4.1	L.	....do ...	
118.2	Bent Creek	10.2	R.	Aug. 10	

Table of stream measurements, made in 1897, of James River and its tributaries—Cont'd.

Distance from Richmond.	Name of stream.	Discharge.	Bank (right or left).	Date.	Remarks.
Miles.		*Sec.-ft.*		1897.	
116.0	David Creek	6.6	R.	Aug. 10	
112.0		1.3	R.	....do ...	1 mile below Greenway.
111.0	Owens Creek	6.5	L.	Aug. 11	
108.7	Tye River	168.1	L.	....do ...	Swollen by rains.
106.5	Nigger Creek	1.7	R.	Aug. 12	
106.3		0.9	L.	....do ...	
106.0	Mallorys Creek	0.9	R.	....do ...	
96.0	Miller Run	0.6	R.	Aug. 13	Opposite Manteo.
93.9		0.3	R.	....do ...	Opposite Highlands.
91.3	Rockfish River	36.5	L.	....do ...	At Hardware.
88.5		0.5	L.	Aug. 14	
88.5		0.5	R.	....do ...	
86.3	Ballinger Creek	1.9	L.	....do ...	
85.3	Rock Island Run	3.3	R.	....do ...	
81.5	Tooters Creek	0.7	L.	Aug. 16	
76.0	Georgia Creek	0.2	R.	....do ...	
73.4	Hardware River	21.4	L.	Aug. 17	
67.6	Slate River	41.5	R.	Aug. 18	
65.6	Bear Garden Creek	8.6	R.	....do ...	
59.0		4.1	L.	Aug. 19	
57.2	Rivanna River	48.0	L.	Aug. 20	
52.4	Byrd Creek	2.9	L.	....do ...	
48.3	Willis River	29.6	R.	Aug. 21	
47.0	James River	603.0	....	Sept. 8	At Cartersville.
45.9	Muddy Creek	1.9	R.	Aug. 23	Bed of a large creek.
44.4		1.2	L.	....do ...	½ mile above Stokes.
40.0	Sally Creek	58.3	R.	Aug. 24	Much swollen.
34.0	Leckinghole Run	20.2	L.	Aug. 25	
29.0	Jule Creek	0.4	R.	Aug. 28	Very low.
26.6	Beaverdam Creek	2.9	L.	Aug. 30	
24.7	Fine Creek	1.6	R.	....do ...	
22.5	Genito Creek	3.7	L.	....do ...	
20.5	Dover Creek	3.0	L.	....do ...	
17.6	Jones Creek	8.2	R.	Aug. 31	
NORTH RIVER AND ITS TRIBUTARIES.					
17.0	Burdens Run	1.0	R.	July 8	
17.0	North River	159.7	....	....do ...	Above South River Dam.
16.3	South River	56.2	L.	....do ...	At mouth.
10.0	Mountain Branch	1.2	L.	July 9	
5.5	Buffalo Creek	49.6	R.	July 10	Slightly flush.

Rating table for James River at Buchanan, Virginia, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.2	280	3.8	2,170	6.4	5,770	9.0	11,100
1.4	340	4.0	2,390	6.6	6,130	9.5	12,350
1.6	440	4.2	2,620	6.8	6,490	10.0	13,700
1.8	540	4.4	2,860	7.0	6,850	10.5	15,075
2.0	660	4.6	3,100	7.2	7,210	11.0	16,600
2.2	780	4.8	3,360	7.4	7,600	11.5	18,375
2.4	910	5.0	3,640	7.6	8,000	12.0	20,250
2.6	1,050	5.2	3,920	7.8	8,400	12.5	22,250
2.8	1,210	5.4	4,200	8.0	8,800	13.0	24,700
3.0	1,370	5.6	4,500	8.2	9,230	13.5	27,200
3.2	1,550	5.8	4,800	8.4	9,690	14.0	30,000
3.4	1,740	6.0	5,100	8.6	10,150		
3.6	1,950	6.2	5,420	8.8	10,610		

Estimated monthly discharge of James River at Buchanan, Virginia.

[Drainage area, 2,058 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	1,290	720	858	52,756	0.48	0.42
February	30,000	1,130	7,414	411,750	3.75	3.60
March	8,600	1,740	3,390	208,445	1.90	1.65
April	2,620	750	1,629	96,933	0.88	0.79
May	14,940	1,015	3,312	203,645	1.86	1.61
June	1,460	720	948	56,410	0.52	0.46
July	1,690	720	969	59,580	0.54	0.47
August	910	540	630	38,737	0.36	0.31
September	600	340	438	26,063	0.23	0.21
October	515	300	403	24,779	0.23	0.20
November	540	300	377	22,434	0.20	0.18
December	1,330	490	972	59,766	0.54	0.47
The year	30,000	300	1,779	1,261,298	11.49	0.86

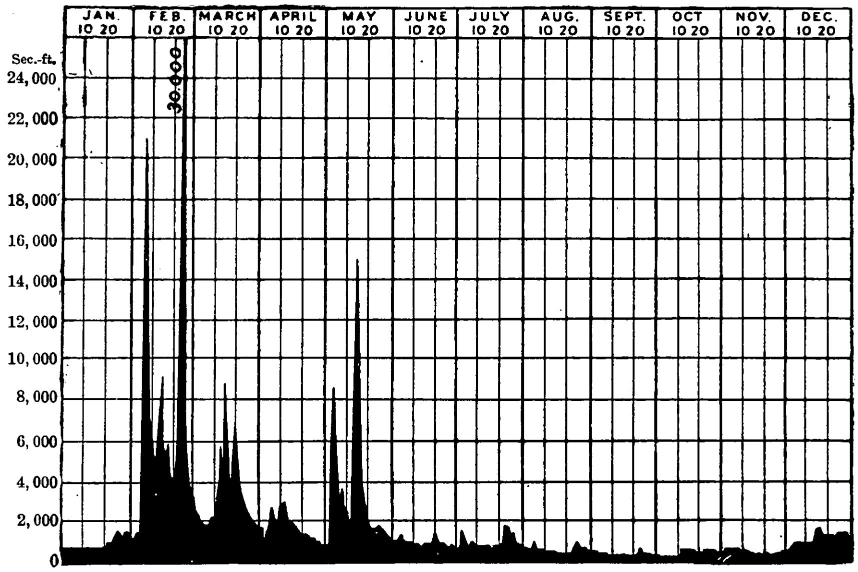


FIG. 40.—Discharge of James River at Buchanan, Virginia, 1897.

MISCELLANEOUS STREAM MEASUREMENTS.

Miscellaneous stream measurements were made by Prof. D. C. Humphreys in 1897 with meter No. 77 (see Bulletin No. 140, United States Geological Survey), an English meter, which has the advantage of being light, and was carried on a bicycle. Measurements were made by wading, the rivers being at ordinary low-water stage. In the case of North River, measured on September 2, it is probable that the ponding of water at a dam 3 miles above made the stage abnormally low.

List of miscellaneous discharge measurements in James River and adjacent basins.

Date.	Stream.	Locality.	Discharge.
1897.			*Second-feet.*
August 14	Poague Run	At mouth	3
Do	Buffalo Creek	do	38
August 23	Tinker Creek	Vinton, Virginia	56
August 25	Back Creek	At mouth	15
Do	Roanoke River	Above mouth of Back Creek	137
August 26	North Fork of Roanoke River.	At mouth	25
Do	South Fork of Roanoke River.	do	62
August 27	Little River	Graysonville, Virginia	159
August 28	Big Red Island Creek	At mouth	235
Do	Little Red Island Creek	do	80
August 30	Cripple Creek	Near mouth	51
August 31	Reed Creek	Turnpike crossing	56
September 2	South River	Near mouth	26
Do	North River	Near mouth of South River	51

SOUTH ATLANTIC WATERSHED.

ROANOKE RIVER.

Four gaging stations were maintained: one station at Roanoke, Virginia, on the Roanoke River; two stations at Clarksville, Virginia, one on the Dan and the other on the Staunton; and one, Neal station, on the main Roanoke River. These are described in Water-Supply and Irrigation Paper No. 15, pp. 25–28, inclusive. Roanoke River, in Virginia, is simply the head-water tributary of Staunton River. After this latter stream makes a junction with Dan River it is again known as Roanoke River through North Carolina. At the upper station at Roanoke a sufficient number of discharge measurements were not made in 1897 on which to base a rating curve. Tables of discharge and run-off are given, however, for the three remaining stations.

The following statements regarding the use of the water power are from a report prepared by Prof. J. A. Holmes:

The first power developments met on ascending the Roanoke are near Weldon, North Carolina, where the stream crosses the fall line. The fall here is about 84 feet in a distance of 9 miles above the town; the river within this distance is very rocky and rapid, the channel very tortuous, and the bed of the river interspersed with rocks and islands, most of which are submerged at high water. The bed of the river is almost solid rock, and the banks are generally abrupt, especially along the upper part for several miles below the head of the falls, where they are from 40 to 50 feet high, of hard granitic rock, often extending almost perpendicularly to the water's edge.

Fifty years ago the Roanoke Navigation Company extended navigation around these falls by constructing a canal on the south side of the river between Weldon and Rock Landing, 9 miles above. This canal was 30 feet wide at the top and 3 feet deep, dimensions sufficiently large for the small boats then in use on the river. As a navigation enterprise this was never a great financial success, and with the building of railroads to Petersburg and Norfolk the upper river navigation declined steadily until it finally ceased and the works were allowed to fall into disuse. The canal was kept open only sufficiently to furnish water necessary to run one or more small mills. The General Assembly of 1874–75 authorized the dissolution of the old Roanoke Navigation Company and ordered the sale of the property. It was purchased by the Roanoke Navigation and Water Power Company, which has cleaned out and repaired the canal and has begun its development as a source of power.

The canal originally was substantially built; it crosses several small creeks by means of aqueducts, all of which, as well as the locks, were built of stone and are in good condition, although the gates of the locks are gone. Toward the upper end of the canal extensive masonry walls in places on the river side, which were rendered necessary by the abruptness of the banks, are still in good condition. At the upper end of the canal there was a guard lock, and probably a dam, but the gates of the lock are gone and the dam now consists only of a few stones piled up roughly. The bed rock at this place is said to be very favorable for the construction of a dam across the river. Nearly 4 miles below the head of the canal there was a descent in four canal locks with a total lift of 36 feet. The total fall at these locks now practically available for power is 31 feet. The land in the vicinity offers good building sites.

At the lower end of the canal a fall of 48 feet between the level of the canal and the river was overcome, at the time the canal was used for purposes of navigation, by a flight of six locks with 8 feet lift each. These locks have since been abandoned and removed. At the lower end of the canal the company has erected a corn mill, having a daily capacity of 2,000 bushels, with a grain elevator of 50,000 bushels capacity attached, and a cotton-seed oil mill with a capacity of 35 tons per twenty-four hours. The two mills use about 250 horsepower. The total available low-water fall for power at this point is 45 feet. All these mills discharge the water directly into the river, and are situated from 100 to 200 yards above the old locks. They can run full capacity all the year, except occasionally at times of high water. There is no trouble from ice.

The recent development which was completed a few years ago consists of the enlargement of the prism of the original canal to the following dimensions: 23 feet at bottom, 35 feet wide at normal surface of water, and 4 feet deep; the construction of head gates with the necessary masonry, the raising and repairing of waste ways and waste gates, the construction of a wasteweir and gates at the foot of the basin at Weldon, the raising and repairing of the masonry of the Chockeotte Creek aqueduct, and the raising and strengthening of the banks of the canal throughout its length. The canal, with the foregoing dimensions, with smooth surfaces, and with a bottom grade of 1 foot a mile, has a capacity for carrying 259 cubic feet of water per second. It is constructed in two reaches or levels, the first or upper one extending from the head of the canal to the combined locks, a distance of about 3¼ miles, securing a fall of 31 feet at said locks. The second level extends a distance of about 5½ miles from the locks to the terminus of the canal at Weldon, where a fall of 45 feet can be secured when the water in the river is at low-water stage.

The development work of the Roanoke Rapids Water Power Company also lies on the south side of Roanoke River between Weldon and Gaston, beginning 1½ to 2 miles below the upper end of the Roanoke Navigation and Water Power Company's canal, on the same side of the river, and terminating nearly 2 miles below in the great bend of the river, where the factories are located. The upper 1 mile of the canal is formed by the right bank and a chain of islands, which are connected by dams made of wood and stone. The longer of these connecting dams has a length of 1,465 feet and a height of from 4 to 7 feet, and the dam connecting the lower end of the lowest island with the outer end of the bulkhead is 685 feet long and about 11 feet high, built of log frame with rock filling and planked above (Pl. XXVI, *B*). Along the top of these islands dikes are thrown up to prevent the escape of water into the river.

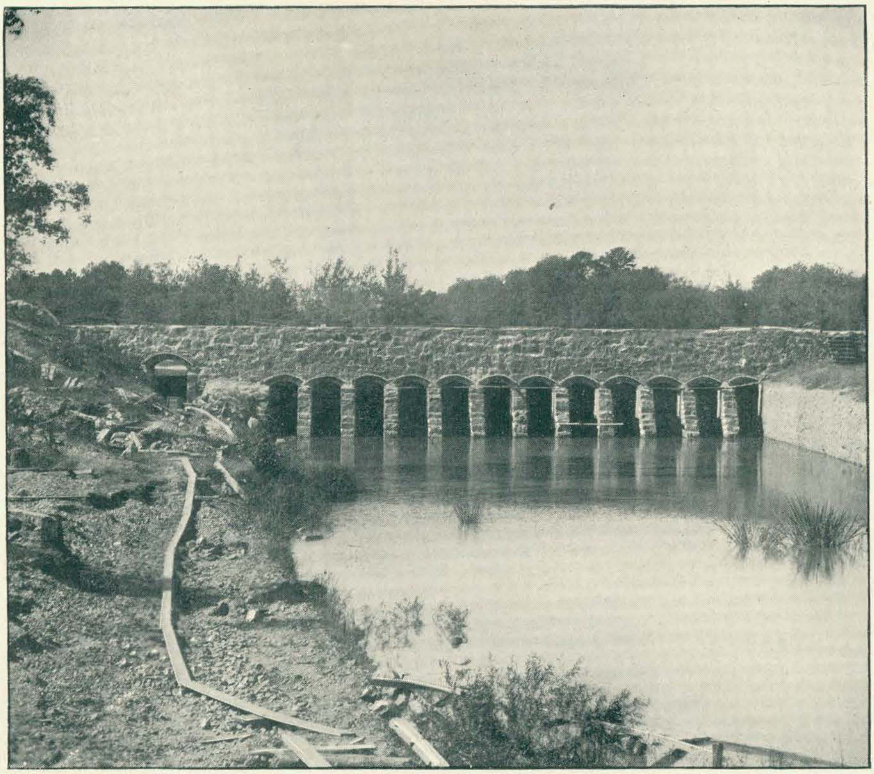
The bulkhead (Pl. XXVI, *A*) is of stone masonry, 150 feet long, 24 feet high at its outer or northern end, and 15 feet thick, and is penetrated by 13 gates for the admission of water into the canal. This canal is three-fourths of a mile long from the bulkhead to its lower end, 90 feet wide at the top, 60 feet wide at the bottom, and 10 feet deep; and when the canal contains its normal supply of water, the cross section below the water surface is 750 square feet. The fall at the lower end of the canal during ordinary stages of the water is said to be 27 feet. In dry seasons the fall is 30 feet and the capacity of the canal is stated as 6,100 horsepower. Only a small part of this power is being used at the present time, but two substantial factories have been constructed and are now in operation.

The knitting mill of the United Industrial Company, located immediately against the side of the canal at its lower end, contains 2,310 spindles, 5 sets of cards, 30 knitting machines, and 75 sewing machines. Its power is developed by two Leffel 40-inch turbines on a horizontal shaft, supplied with water through an iron penstock direct from the canal, and, it is claimed, capable of developing 800 horsepower with the dry-season head of 30 feet. Of this, however, only about 150 horsepower is now being utilized.

The cotton mill of the Roanoke Mill Company, located 100 yards east of the above, and at a slightly greater distance from the canal, has a capacity of 18,000 spindles and 550 looms. It has now in operation only 12,096 spindles and 320 looms, and is using about 400 horsepower, although its two McCormick 36-inch turbines on a horizontal shaft, with a normal head of 28 feet, are said to develop 640 horsepower. The water is supplied to these wheels through an iron penstock 9 feet in diameter and 480 feet long. A smaller single turbine, said to be capable of developing 125 horsepower, supplies power for electric lighting, fire pump, etc. As will be seen from the above statement, there is at this point ample power for additional manufacturing establishments, and until it is fully utilized there need be no fear of scarcity of water during dry seasons, and there will be but little trouble with high water except during the larger freshets.

Dan and Staunton rivers are the principal tributaries of the Roanoke, draining together an area of 7,344 square miles.

Dan River at the Riverside Mills, Danville, Virginia, is about 925 feet wide. There are two dams, the upper one of which is of stone, about 14 feet high. From this dam two races, one on each side of the river, one about 100 yards and the other about three-eighths of a mile in length, carry the water to the mills. A short distance below this upper



A.

B.

WORKS OF ROANOKE RAPIDS WATER POWER COMPANY, ON ROANOKE RIVER NEAR WELDON, NORTH CAROLINA.

A, Bulkhead; *B*, Wing dam.

dam is a second dam, 12 feet high, running in a triangular form across the river. From the pond formed by this lower dam a race course about 100 yards long leads to mill No. 6, and furnishes 700 to 800 horsepower.

The upper dam and pond furnish about 2,000 horsepower when the river is at its normal stage of flow, but considerably less during the dry season. The cotton mills operated by this power are seven in number, five on the north side and two on the south side of the river, and in addition to these there is a flouring mill, box factory, ice factory, gristmill, foundry and machine shop, and the city electric-light plant, all operated by water power afforded by the river when at normal stage of flow. When the water is low the power is supplemented by auxiliary steam plants. The several mills contain an aggregate of 67,700 spindles and 2,771 looms.

On Smiths River, a tributary of the Dan, 1½ miles above its mouth, in the town of Spray, the Leaksville Cotton Mill, the Leaksville Woolen Mill, the mill of the Spray Mercantile Company, and the Spray Cotton Mill are located.

The Leaksville Cotton Mill, which contains 400 looms, makes colored cloths exclusively, using about 135 horsepower developed by a turbine wheel 32½ inches in diameter, working under a head of 23 feet and capable of developing 180 horsepower. The mill of the Spray Mercantile Company is a roller flour mill of 50 barrels capacity per day, and a corn mill of two-run of stone. The power is furnished by a turbine wheel 25 inches in diameter, working under a head of 19 feet, and an overshot wheel working under a head of 14 feet, together developing about 50 horsepower. The Spray Cotton Mill, containing 12,064 spindles, is driven by water power alone; it derives about 300 horsepower from twin Leffel turbines 36 inches in diameter, on a horizontal shaft, working under a head of 30 feet. The Leaksville Woolen Mill is a two-set mill using about 50 horsepower obtained from a 25-inch Perfection turbine working under a head of 19 feet.

These mills all draw their water from the same race, which is 16 feet wide at the top, 4½ feet deep, 4,200 feet long, with a bottom grade of 39 inches in this distance, and estimated to be large enough to carry a quantity of water giving 600 horsepower, with a head of 30 feet. The dam is 7 feet high, of triangular wooden frames bolted to the bed of the river and planked over. The bulkhead is of solid rubble masonry laid in cement, and is 12 feet wide and 13 feet high. This dam, which extends across and obliquely up the stream, backs the water about one-fourth of a mile to the foot of another shoal owned by the same company. Plans are now being developed to build a dam on this upper shoal, where it is claimed a fall of 12 feet and 250 horsepower can be obtained. This power is to be transmitted electrically to Spray to be used to run the Leaksville cotton and woolen mills, and the corn and flour mill, while the entire power developed by the canal below, with a fall of 30 feet at its lower end, will be used to operate the Spray mill. A new mill, containing 400 looms, has recently been built at this place.

On the Mayo River, 1½ miles above its junction with the Dan, are the Mayo mills, 2 miles from the town of Madison. The mill contains 23,000 mule spindles and 51 revolving top cards. It manufactures hosiery and underwear yarns, using about 400 horsepower, obtained from water alone during the entire year, and there is said to be a large amount of surplus water. The power is developed by two McCormick turbines of 30 inches diameter, on a horizontal shaft, developing 846 horsepower under a head of 36 feet. There is also a turbine of 20 inches diameter, developing 100 horsepower under the same head as the main wheels, used for the lighting plant, fire pump, etc.

The dam, which is some distance below the head of the shoal, is of wood, 12 feet high and 400 feet long, and backs the water about 1 mile. The bulkhead is of brownstone laid in cement, and is 150 feet long and 6 feet thick at the gates. The canal is three-fourths of a mile long, and gives a fall of 36 feet at the mill. There is never any trouble from high water.

A short distance above this shoal there is another of about the same fall, which will soon be developed. The length of the two shoals is 2¾ miles, and the total natural fall in this distance is 63.41 feet.

Rating table for Dan River at Clarksville, Virginia, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
—1.5	400	0.4	890	3.8	6,704	7.5	15,066
—1.4	420	0.6	990	4.0	7,156	8.0	16,196
—1.3	440	0.8	1,100	4.2	7,608	8.5	17,326
—1.2	460	1.0	1,240	4.4	8,060	9.0	18,456
—1.1	480	1.2	1,400	4.6	8,512	9.5	19,586
—1.0	500	1.4	1,620	4.8	8,964	10.0	20,716
—0.9	520	1.6	1,900	5.0	9,416	10.5	21,846
—0.8	540	1.8	2,250	5.2	9,868	11.0	22,976
—0.7	560	2.0	2,636	5.4	10,320	11.5	24,106
—0.6	580	2.2	3,088	5.6	10,772	12.0	25,236
—0.5	600	2.4	3,540	5.8	11,224	12.5	26,366
—0.4	620	2.6	3,992	6.0	11,676	13.0	27,496
—0.3	645	2.8	4,444	6.2	12,128	13.5	28,626
—0.2	670	3.0	4,896	6.4	12,580	14.0	29,756
—0.1	700	3.2	5,348	6.6	13,032		
0.0	730	3.4	5,800	6.8	13,484		
0.2	810	3.6	6,252	7.0	13,936		

Estimated monthly discharge of Dan River at Clarksville, Virginia.

[Drainage area, 3,798 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	7,269	1,135	2,565	157,715	0.78	0.68
February	27,044	2,340	9,212	511,610	2.53	2.43
March	10,998	2,749	6,030	370,770	1.83	1.59
April	7,382	1,820	3,481	207,135	1.02	0.92
May	10,094	1,900	5,014	308,298	1.52	1.32
June	2,075	1,100	1,326	78,902	0.39	0.35
July	3,201	1,045	1,404	86,330	0.43	0.37
August	1,320	830	984	60,504	0.30	0.26
September	890	730	755	44,926	0.22	0.20
October	4,896	400	1,609	98,933	0.48	0.42
November	10,320	750	1,703	101,335	0.50	0.45
December	7,382	990	2,231	137,180	0.68	0.59
The year	27,044	400	3,026	2,163,638	10.68	0.80

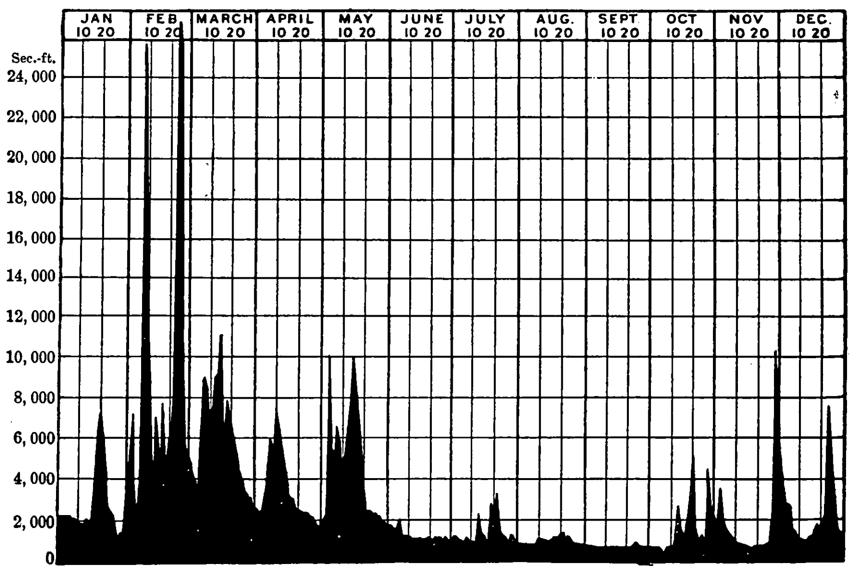


FIG. 41.—Discharge of Dan River at Clarksville, Virginia, 1897.

Rating table for Staunton River at Clarksville, Virginia, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
—0.7	540	1.8	3,496	5.0	11,560	8.2	19,624
—0.6	560	2.0	4,000	5.2	12,064	8.4	20,128
—0.5	580	2.2	4,504	5.4	12,568	8.6	20,632
—0.4	600	2.4	5,008	5.6	13,072	8.8	21,136
—0.3	625	2.6	5,512	5.8	13,576	9.0	21,640
—0.2	650	2.8	6,016	6.0	14,080	9.5	22,900
—0.1	675	3.0	6,520	6.2	14,584	10.0	24,160
0.0	700	3.2	7,024	6.4	15,088	10.5	25,420
0.2	800	3.4	7,528	6.6	15,592	11.0	26,680
0.4	1,000	3.6	8,032	6.8	16,096	11.5	27,910
0.6	1,220	3.8	8,536	7.0	16,600	12.0	29,200
0.8	1,470	4.0	9,040	7.2	17,104	12.5	30,460
1.0	1,760	4.2	9,544	7.4	17,608	13.0	31,720
1.2	2,100	4.4	10,048	7.6	18,112	13.5	32,980
1.4	2,530	4.6	10,552	7.8	18,616	14.0	34,240
1.6	2,992	4.8	11,056	8.0	19,120	14.5	35,500

Estimated monthly discharge of Staunton River at Clarksville, Virginia.

[Drainage area, 3,546 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	11,686	1,540	5,773	354,970	1.88	1.63
February	29,326	4,504	10,593	588,306	3.11	2.99
March	11,938	3,118	6,459	397,150	2.10	1.82
April	7,906	1,685	3,584	213,265	1.13	1.01
May	10,804	1,760	5,367	330,004	1.74	1.51
June	*a*8,410	*a*1,220	*a*2,301	136,920	0.72	0.65
July	3,118	900	1,378	84,730	0.45	0.39
August	1,470	720	983	60,442	0.32	0.28
September	900	625	705	41,951	0.22	0.20
October	5,008	550	1,540	94,691	0.49	0.43
November	10,804	600	1,640	97,587	0.52	0.46
December	10,300	950	2,401	147,631	0.78	0.68
The year	29,326	550	3,560	2,547,647	13.46	1.00

a Approximate.

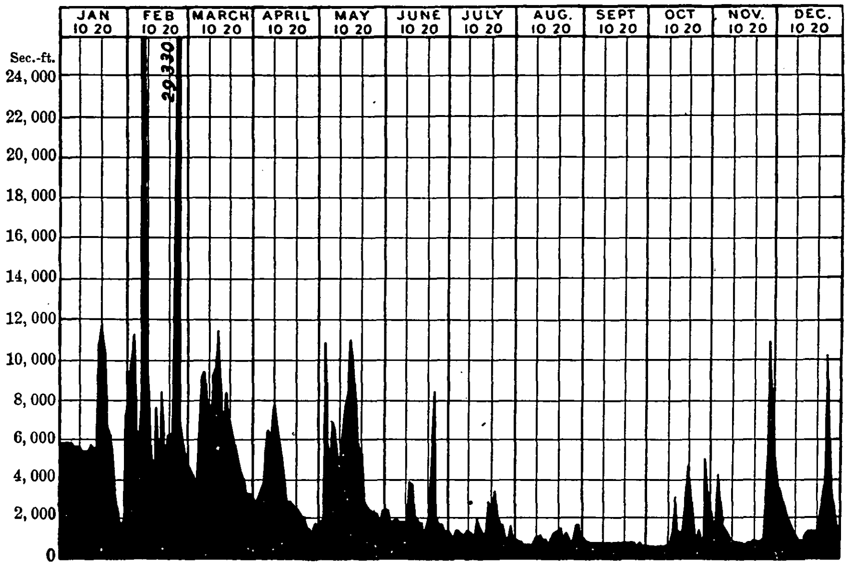


FIG. 42.—Discharge of Staunton River at Clarksville, Virginia, 1897.

Rating table for Roanoke River at Neal, North Carolina, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.0	2,000	4.2	3,300	8.4	6,060	16.5	15,950
0.2	2,020	4.4	3,400	8.6	6,240	17.0	16,750
0.4	2,040	4.6	3,500	8.8	6,420	17.5	17,565
0.6	2,060	4.8	3,600	9.0	6,600	18.0	18,400
0.8	2,100	5.0	3,700	9.2	6,780	18.5	19,310
1.0	2,140	5.2	3,805	9.4	6,960	19.0	20,300
1.2	2,190	5.4	3,915	9.6	7,140	19.5	21,380
1.4	2,240	5.6	4,025	9.8	7,320	20.0	22,500
1.6	2,290	5.8	4,135	10.0	7,500	20.5	23,720
1.8	2,340	6.0	4,245	10.5	8,000	21.0	25,000
2.0	2,400	6.2	4,355	11.0	8,500	21.5	26,320
2.2	2,475	6.4	4,465	11.5	9,040	22.0	27,700
2.4	2,540	6.6	4,585	12.0	9,600	22.5	29,190
2.6	2,610	6.8	4,705	12.5	10,190	23.0	30,800
2.8	2,680	7.0	4,850	13.0	10,800	23.5	32,570
3.0	2,750	7.2	5,010	13.5	11,460	24.0	34,550
3.2	2,830	7.4	5,180	14.0	12,150	25.0	39,200
3.4	2,915	7.6	5,350	14.5	12,860	26.0	44,800
3.6	3,005	7.8	5,520	15.0	13,600	27.0	52,500
3.8	3,100	8.0	5,700	15.5	14,370	28.0	64,300
4.0	3,200	8.2	5,880	16.0	15,150		

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

[Drainage area, 8,717 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	12,010	2,790	4,501	276,755	0.60	0.52
February	64,300	2,915	28,178	1,564,930	3.36	3.23
March	37,700	7,320	22,824	1,403,390	3.02	2.62
April	22,270	4,525	8,440	502,215	1.08	0.97
May	21,160	4,410	8,707	535,350	1.15	1.00
June	9,040	3,005	4,252	253,010	0.55	0.49
July	7,410	2,790	3,956	243,245	0.52	0.45
August	3,650	2,240	2,673	164,360	0.36	0.31
September	3,150	2,000	2,217	131,920	0.28	0.25
October	4,465	2,010	2,561	157,470	0.33	0.29
November	8,710	2,340	3,095	184,165	0.40	0.36
December	10,190	3,250	5,520	339,410	0.72	0.63
The year	64,300	2,000	8,077	5,756,220	12.37	0.93

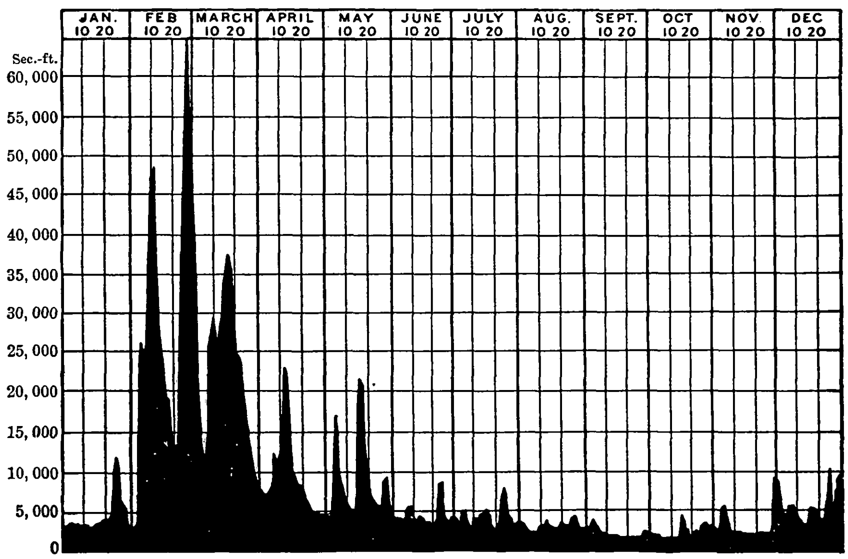


Fig. 43.—Discharge of Roanoke River at Neal, North Carolina, 1897.

TAR RIVER.

The only important power developed on this river is at the fall line and at the town of Rocky Mount, North Carolina. The dam extends entirely across the stream in a slightly broken line, with an excellent rock foundation. It is built of granite, 600 feet long, and averages 11 feet high. The bed of the river is of solid rock and the banks moderately high, affording a safe development. The race is 191 feet long, and the head on the wheels is 24 feet. The mills are three in number, contain 25,000 spindles, and use, it is said, about 1,000 horsepower, developed during nine months of the year by water alone, while during the dry season, not exceeding three months, a deficiency in water is supplied by the auxiliary steam plant. It is said that this power is capable of still further development by raising the dam and deepening the tail-race. There is very little trouble with freshets and none at all with ice.

Measurements were made in 1897 on Tar River at the gaging station located at Tarboro, North Carolina, described in Water-Supply and Irrigation Paper No. 15, p. 29.

Rating table for Tar River at Tarboro, North Carolina, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
—1.0	170	0.8	470	9.0	4,950
—0.9	177	1.0	540	10.0	5,650
—0.8	185	1.5	730	11.0	6,370
—0.7	192	2.0	950	12.0	7,180
—0.6	200	2.5	1,180	13.0	8,050
—0.5	210	3.0	1,430	14.0	8,950
—0.4	220	3.5	1,680	15.0	9,900
—0.3	230	4.0	1,935	16.0	10,900
—0.2	240	4.5	2,197	17.0	11,900
—0.1	255	5.0	2,460	18.0	12,900
0.0	270	5.5	2,735	19.0	13,900
0.2	310	6.0	3,015	20.0	14,900
0.4	360	7.0	3,600		
0.6	410	8.0	4,250		

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

[Drainage area, 2,290 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	4,460	1,155	1,814	111,539	0.91	0.79
February	8,725	1,480	4,888	271,466	2.22	2.13
March	14,600	2,197	6,789	417,440	3.41	2.96
April	9,800	1,280	3,636	216,357	1.77	1.59
May	3,915	690	1,580	97,150	0.79	0.69
June	1,280	360	689	40,999	0.33	0.30
July	3,725	310	1,198	73,665	0.60	0.52
August	860	247	399	24,533	0.20	0.17
September	2,460	196	490	29,155	0.23	0.21
October	770	170	295	18,139	0.15	0.13
November	2,250	347	674	40,105	0.32	0.29
December	3,072	770	1,430	87,928	0.71	0.62
The year	14,600	170	1,990	1,428,476	11.64	0.87

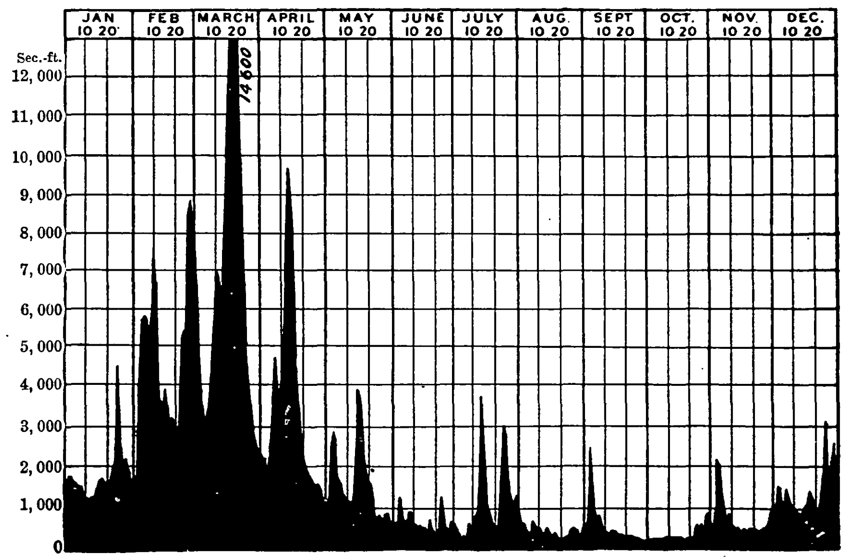


FIG. 44.—Discharge of Tar River at Tarboro, North Carolina 1897.

NEUSE RIVER.

The first power site of importance on this river, only partially developed, is at Milburnie or Neuse mills, about 25 miles above Smithfield and 6 or 7 miles northeast from Raleigh. There is an open frame dam across the river, 8 feet high and 250 feet long, developing about 300 horsepower at mean low water. The bed here is of solid rock, very favorable for a dam, and the race had to be blasted out. The banks are abrupt on the right but are more sloping on the left; the location is said to be safe, and it is expected that this site will be utilized in a short time. The next power development on the river is the paper mill of the Raleigh Paper Company. This mill is located 3 miles above the crossing of the Seaboard Air Line, 13 miles north of Raleigh. The open frame dam, which extends entirely across the river, is of wood, 410 feet long and 6 feet high, backing the water about 10 miles, the depth averaging perhaps 8 feet. A race about 1,000 feet long leads to the mill, where the fall is 18 feet. The power used is said to be 300 horsepower, but it is evident that this power can only be obtained during eight or nine months of the year.

Measurements were made on the Neuse in 1897. A gaging station is located on this river at Selma, North Carolina, described in Water-Supply and Irrigation Paper No. 15, p. 30.

Rating table for Neuse River at Selma, North Carolina, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
—0.5	70	2.2	698	5.6	1,700	10.5	3,950
—0.4	75	2.4	754	5.8	1,760	11.0	4,260
—0.3	92	2.6	810	6.0	1,830	11.5	4,570
—0.2	110	2.8	866	6.2	1,900	12.0	4,880
—0.1	127	3.0	922	6.4	1,970	12.5	5,190
0.0	145	3.2	980	6.6	2,040	13.0	5,500
0.1	165	3.4	1,040	6.8	2,110	13.5	5,810
0.2	185	3.6	1,100	7.0	2,190	14.0	6,120
0.4	230	3.8	1,160	7.2	2,270	14.5	6,430
0.6	275	4.0	1,220	7.4	2,350	15.0	6,740
0.8	325	4.2	1,280	7.6	2,430	15.5	7,050
1.0	375	4.4	1,340	7.8	2,510	16.0	7,360
1.2	425	4.6	1,400	8.0	2,590	16.5	7,670
1.4	475	4.8	1,460	8.5	2,825	17.0	7,980
1.6	530	5.0	1,520	9.0	3,075		
1.8	586	5.2	1,580	9.5	3,355		
2.0	642	5.4	1,640	10.0	3,650		

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

[Drainage area, 1,175 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	3,243	400	846	52,020	0.83	0.72
February	5,624	558	2,302	127,846	2.04	1.96
March	7,856	810	2,903	178,500	2.85	2.47
April	6,430	586	811	48,258	0.77	0.69
May	3,414	475	920	56,570	0.90	0.78
June	1,830	252	570	33,920	0.54	0.48
July	1,700	230	658	40,460	0.64	0.56
August	586	165	232	14,265	0.23	0.20
September	185	92	145	8,627	0.13	0.12
October	230	75	126	7,747	0.13	0.11
November	726	145	265	15,768	0.26	0.23
December	1,830	375	795	48,882	0.78	0.68
The year	7,856	75	881	632,863	10.10	0.75

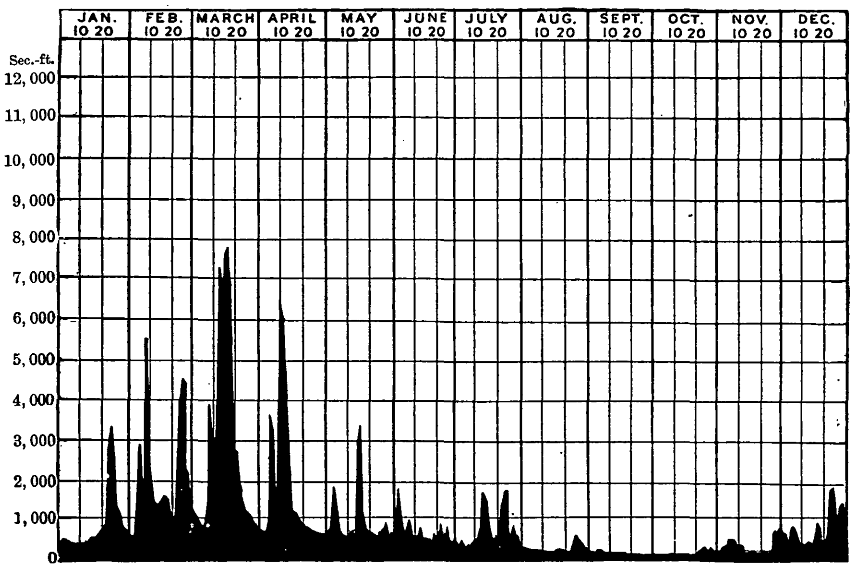


FIG. 45.—Discharge of Neuse River at Selma, North Carolina, 1897.

CAPE FEAR RIVER.

At what may be designated as the fall line of Cape Fear River, 30.5 miles above Fayetteville, there is a fall of 27 feet in a distance of 3.5 miles, known as Smileys Falls. The bed is rock, and the facilities for dams and races, as well as for building, are said to be good. Stone-filled wooden dams were built here many years ago to make the river navigable, and the falls are now being surveyed with a view of developing the water power, which is claimed to be one of the finest in this section of the State. The site offers many advantages for manufacturing enterprises. Fuel in the shape of timber and coal is abundant in the immediate neighborhood, and there is also fine wood and stone for building materials.

About 11 miles above Smileys Falls are the Buckhorn Falls, the next in importance on the river. At the head of the falls are the remnants of a wooden dam, about 1,000 feet long and 3 to 4 feet high. It is V-shaped with the apex upstream, one arm being nearly at right angles to the banks, terminating on the east side at an island, behind which it turns a portion of the water as into a natural race, extending for a distance of a mile or so between the bank and a succession of islands connected by a series of slough dams. At the end of the last island a slough dam connected it with the bank, and navigation was at one time continued by means of a canal about half a mile long, 40 feet wide at the surface, and 6 feet deep, provided with three locks, giving a total lift of 22 feet.

These falls constitute an excellent power, with location perfectly safe and easily available. The existing canal constitutes a race ready for use, and by utilizing the lift of the guard lock and discharging the water directly into the river at the works a fall of about 20 feet may be rendered continuously available except during severe freshets. The canal is in fair condition and might be made perfect at small cost. If necessary, it could easily be widened so as to increase its capacity.

Rockfish Creek, one of the small tributaries of the Cape Fear,[1] which joins it on the south side some 10 miles below Fayetteville, is one of the sand-hill streams, so called from the belt of sandy hills in this part of the country which they traverse. The drainage basin of Rockfish Creek lies below the fall line. There are no falls, but a gradual declivity. Of the available power on this stream but a small proportion is being utilized. Formerly there were one or two sawmills located on it below the mouth of Little Rockfish Creek, but these have all disappeared. Above this point there is one cotton mill, Hope Cotton Mill No. 2, a few small saw and grist mills, and several promising but undeveloped powers. The cotton mill contains 210 looms and 10,000 spindles, operated entirely by water power, about 200 horsepower being required. The supply of water is ample even during the driest years. Besides this mill, there are on the tributaries of this creek three other mills operating a total of 341 looms and 12,900 spindles.

Haw River, the largest tributary of the Cape Fear, has had many water-power

[1] Data compiled from a report prepared by Prof. J. A. Holmes, State geologist of North Carolina.

developments along its course, of which the following are the most important, commencing at the mouth of the river:

The first power is situated just below the mouth of New Hope River and is known as the Bland Mill site. The fall here is about 7 feet. The wooden dam built to develop power for a large gristmill has been nearly destroyed. About 2 miles farther upstream is a power known as Hartsaws site, where the available fall is said to be 6 feet. Three miles above Hartsaws is Moore's mill. There is no dam here, but a race some 200 yards long leads to the mill, where a fall of some 10 feet is obtained. The shoal is about 1 mile long and the total fall is said to be about 22 feet.

One and one-half miles above Moore's mill is Williams's mill, where there is a fall of 7 feet, but the dam could easily be raised and 3 to 4 feet additional fall obtained.

The site is not a good one for a mill of any size, as the river is very wide and is here divided by an island half a mile or more long. The pond is about 450 yards long, and starting from its head there is a fall of 12 to 14 feet in the next three-fourths of a mile. Two miles above this is the power known as the Seven Island Shoal, where the fall is said to be 7 feet. The next site is at Henley's mill, 12 or 13 miles from the mouth of the river. The fall here is about 8 feet at the mill, and the total fall in the shoal is estimated at 16 feet.

The most important power on this part of the river is that at Bynums, 4 miles above Henley's mill and 17 miles above the mouth of the river. Here are located the cotton mill of the Odell Manufacturing Company, containing 4,500 spindles, a cotton gin, corn mill, and roller flour mill, all operated by water from the same race. The dam is 3½ feet high and 500 feet long, ponding the water over 10 or 12 acres. A race 600 feet long leads to the mill, where the fall is 16 feet and the power developed is about 125 horsepower, notwithstanding more or less waste of water.

A short distance above Bynums is Pace's mill. The dam here is 8 feet high and 100 feet long, and from it a race 450 feet long leads to the mill, where a fall of 14 feet is used. Upon this property there are said to be two other sites not used, one below the mill with 10 feet fall, and one above with 13 feet fall, which can be rendered available by a dam 4 feet high and 600 feet long and a race 600 feet long. Within the next 3 miles there are several sites not used At Loves is a mill utilizing a fall of 11 feet, and at Saxapahaw is located the Saxapahaw Cotton Mill containing 4,704 spindles and 100 looms. There is a dam extending across the river about 375 feet long and 3 feet high. The fall at the mill is said to be 19 feet, and the power developed is about 160 horsepower. Three miles above Saxapahaw and 41 miles above the mouth of the river is Newlin's gristmill. The dam is of wood and stone, 900 feet long and 5 feet high, and from it leads a race 400 yards long and 10 feet wide, carrying the water to the mill, where the fall is said to be 9 feet.

The next power is an undeveloped one owned by the Virginia Cotton Mills Company, of Swepsonville, Alamance County. The available fall here is some 6 or 7 feet and it is proposed to develop this shoal and transmit the power electrically to the cotton mill above. One mile above this site and 45 miles above the mouth of the river is the cotton mill of the Virginia Cotton Mill Company, which contains 200 looms and 4,160 spindles. The dam is of wood, 550 feet long, 7 feet high, and from it a race 450 yards long leads to the mill, where the fall is 13 feet and the power used about 160 horsepower developed by two 61-inch turbine wheels. Full capacity can be obtained all the time except in the very driest seasons.

Fifty miles above the mouth of the river are the Granite Cotton Mills, owned by the Thomas M. Holt Manufacturing Company, of Haw River, located just above the crossing of the North Carolina Railroad. These mills contain 8,500 spindles and 436 looms, all operated by water power. The dam is of wood and stone, 640 feet long and 12 feet high, and backs the water about 1¾ miles. There is no race, the mill being located directly at the dam. The head is 12 feet and the power developed is 450 horsepower, furnished by two 60-inch turbines. These mills are frequently troubled with lack of water during dry seasons for two or three months each year and have an auxiliary steam plant. At the head of the pond of the Granite mill is Seller's mill site, not now used, where the fall is said to be 12 feet.

Fifty-five miles above the mouth of the river are the Juanita Cotton Mills, containing 6,300 spindles. The fall here is 14 feet, 7 being given by the dam, which is of wood, 467 feet long, backing the water for three-fourths of a mile. The race is 200 feet long and the power developed is 140 horsepower, given by two 58-inch turbines. One mile above, and 56 miles above the mouth of the river, is the Carolina Cotton Mill, which operates 58 looms and 3,070 spindles. The dam is 200 feet long and 6 feet high, giving a fall of 15 feet at the mill through a race three-fourths of a mile long. One hundred and fifty horsepower is used.

One mile above the latter are the Glencoe Cotton Mills, containing 186 looms and 3,500 spindles. The dam is 320 feet long and 9 feet high, giving a fall of 15 feet through a race 400 yards long. It is claimed that 160 horsepower can be secured for at least 90 per cent of the time.

The highest power on the river is the site of the Altamaha Mills, located about 5 miles from Gibsonville station, on the North Carolina Railroad. This mill contains 394 looms and 6,500 spindles. The dam is 350 yards above the mill and is 300 feet long and 15 feet high and backs the water 3 miles. The fall at the mill is 20 feet and 300 horsepower is used, 50 of which is furnished by an engine in use all the time.

Among the tributaries of Haw River are a few small streams that deserve mention on account of the power developments on them. The first considerable tributary met with in ascending the river is New Hope River, which enters from the west, after flowing through Orange and Chatham counties, draining an area of 317 square miles. On it have been developed only small grist and saw mill sites. Cane Creek is the next important tributary. There was formerly located on this stream one factory, the Clover Orchard Cotton Factory, which utilized about 50 horsepower from a fall of 23 feet. A mile or more above this old site is the Snow Camp Woolen Mill, containing 11 looms and 400 spindles. A dam 12 feet high and 70 feet long gives a fall of 16 feet and develops, it is claimed, 40 horsepower during the greater part of the year.

The next important tributary is Alamance Creek. There are only two considerable powers on the stream utilized by the Alamance and the Bellemont cotton mills. The Alamance mill contains 94 looms and 960 spindles, using about 50 horsepower. The dam is of stone, 10 feet high and 125 feet long, with a race 250 yards long, and gives a fall of 12½ feet at the mill. The Bellemont mill is located about 5 miles from Burlington. It contains 126 looms and 2,592 spindles, and uses about 150 horsepower, developed during nine months of the year by water alone; for the rest of the year it is necessary to supplement the water power with steam. The dam is 11 feet high and 100 feet long, built of wood, and has no race.

The Reedy Fork of Haw River and the other tributaries and forks in the upper part of the drainage basin offer powers utilized to some extent by saw and grist mills, and one cotton mill (the Ossipee). The country is flat in the upper part of the basin, and no falls occur in the streams.

The Ossipee mill is located on the south side of Reedy Fork, about 1½ miles above the junction of this stream with Haw River. It contains 300 looms and 3,600 spindles. The dam is 10 feet high and 150 feet long, giving a fall of 11 feet at the mill and developing 160 horsepower for nine months in the year. This is supplemented by steam during the dry season.

Deep River, the second tributary of the Cape Fear in size, like Haw River, has along its course a number of water-power developments. The first power met with on ascending the river is at Lockville, about 2 miles from the mouth. The falls, known as Pullins Falls, were overcome by the navigation company and navigation established around them by means of two dams, and a canal leading down the river from the lower one, with an outlet lock into the river at the lower end of the town, the lift being 24 feet. The lower dam is 600 to 700 feet long, 11 feet high, built of cribwork filled with stone, V-shaped with apex upstream, and backs the water with an average width of 700 feet about half a mile to the upper Lockville dam. The foundation is of rock and the dam is not liable to much injury by freshets. This power is now used only by one small mill—a roller flour mill of about 40 barrels capacity per day. The second Lockville dam is located about half a mile above the first, is similar in construction, and extends straight across the river; its height is 16 feet, its length 700 feet, and its pond 2 miles in length, reaching up to the Gorgas Canal, with an average width of 600 feet. The lock at the north end is 115 feet long and 18 feet wide, and the lift is 16 feet. Two and one-half miles above the second Lockville dam, just below the mouth of Rocky River, is located the Gorgas dam, which extends straight across the river, is about 600 feet long and 7 feet high, built of cribs filled with stone, vertical on both sides, and backs the water up to the Endor dam, a distance of about 7 miles, with an average width of about 500 feet. At the Endor dam there is a fall of about 4 feet.

Ten miles above this place is the Gulf dam, about 400 feet long and 10 feet high, which backs the water up to the Carbonton dam, 7 miles above. This power is used only by a gristmill, utilizing about 40 horsepower and a fall of 10 feet. It is said that by a little cleaning out of the river this fall could be increased to 12 feet. At the Carbonton dam there is a fall of 9 or 10 feet, and the dam was about 400 feet long, ponding the water for a distance of 6 miles. The Glendon Flouring Mills are about 6 miles above Carbonton. There is here a 16-foot wooden dam, 300 feet long. There is no natural fall in the river.

At Glenn's Mill, 12 miles above Carbonton, there is reported to be a dam 400 yards long and 17 feet high, built of wood, which gives a fall of 19 feet at the wheels. The dam is V-shaped, apex upstream, and there is a gristmill at one end and a grist and saw mill and cotton gin at the other.

Carbonton is the head of navigation. The foundation of a lock was put in there, but the lock was never completed, and the boats never ascended into the Carbonton pool. A fall of 10 feet can easily be developed there for water power.

At Prosperity, Moore County, 6 miles above Glenn's grist and saw mill, and 47 miles above the mouth of the river, is W. K. Jackson's gristmill. The dam is 350 feet long, 8 feet high, of wood and stone, giving a fall at the mill of 8 feet.

At Big Falls, about 1½ miles above Prosperity, there is a shoal about three-eighths of a mile long, with a dam at its head 350 feet long and 4 feet high. The fall at the mill is 15 feet, it is stated, although a 20-foot fall is said to be available. The stream is about 350 feet wide, with banks and bed of rock. This power is apparently well suited for the operation of some larger manufacturing establishment.

Ritters Falls, 3 miles above, is an unimproved site, where the available fall is said to be 10 feet. One and one-half miles above Ritters Falls and 12 miles below the Enterprise mill is the gristmill of Howard & Moffatt. The head here is 8½ feet, derived from a 7-foot stone-and-wood dam, through a race 150 yards long. The dam is about 300 feet long. Gardners Shoal is the first one above Howard & Moffatt's mill worthy of mention. There is here an available fall of about 10 feet in half a mile. The bed and the banks of the river are of rock.

Moons Shoal, 1¾ miles farther upstream, was the site of an old gun shop. The fall here is 6 feet in about 300 yards, over rock bottom. One and one-half miles above Moons and three-fourths of a mile below the Enterprise mill is an unimproved shoal—Silers Shoal—where the available fall, over a good rock bottom, is said to be about 20 feet in one-fourth of a mile. Three-fourths of a mile above Silers Shoal, and 63 miles above the mouth of the river, are located the Enterprise Cotton Mills, containing 4,000 spindles and using about 150 horsepower. The dam is of cemented masonry, 3½ feet high and 360 feet long, and backs the water three-fourths of a mile. The race is 250 yards long and gives a head of 20 feet on the wheel. There is also a small flour mill operated by water from the same race. The supply of water is ample for all purposes throughout the entire year. One and one-half miles above Enterprise there is a shoal having a fall of about 8 feet in 300 yards, and 1½ miles above this place there is a similar shoal, with a fall of 7 feet in the same distance; both are entirely undeveloped. Two miles above the last mentioned and 1 mile below Ramseur is the Allen shoal. The fall here is 14 feet in half a mile over good rock bed, and with banks suitable for building.

Sixty-nine miles above the mouth of the river is the town of Ramseur, where is located the mill of the Columbia Manufacturing Company, which contains 9,916 spindles and 325 looms. The dam is of stone, 12 feet high and 425 feet long, backing the water up to the mill of the Randolph Manufacturing Company. The race is 300 yards long, the working head is 15 feet, and 180 horsepower is developed. At Franklinville, between 2½ and 3 miles above Ramseur, is the mill of the Randolph Manufacturing Company, which contains 3,500 spindles and 112 sheeting looms, and requires 125 horsepower. The dam is of stone, 8 feet high and about 400 feet long. The race is 100 yards long and carries the water to two turbines, which are said to develop 143 horsepower under a head of 12 feet. Half a mile farther upstream is the cotton mill of the Franklinville Manufacturing Company, which contains 2,500 spindles and 40 bag looms and uses about 90 horsepower. The dam is of stone, 5 feet high and 400 feet long. The race is between 450 and 500 yards long and the head on the wheel is 18½ feet. There are also a gristmill and cotton gin, using about 30 horsepower and drawing water from the same race.

At Cedar Falls, 2 miles above the mill last mentioned and 73½ miles above the mouth of the river, is the cotton mill of the Cedar Falls Manufacturing Company, which contains 3,936 spindles and is operated entirely by water power. The head is 25 feet and the race is about one-half mile long. The dams are three in number, built between islands, one 10 feet high and 150 feet long, and two each 7 feet high and 280 feet long. About 1 mile above this there is an undeveloped shoal, where the fall is said to be from 12 to 15 feet. Two miles above the last-mentioned site is the Central Falls Mill of the Worth Manufacturing Company. The dam here is of wood, 9 feet high and 325 feet long, and backs the water up to the dam of the upper mill, a distance of 3 miles. Three miles above Central Falls is the site of the upper mill of the same company. The dam here is of stone, 17 feet high and 250 feet long. There is no race, and the dam backs the water for 1½ miles. The two mills at Worthville and Central Falls contain together 10,000 spindles and 328 looms. Four miles farther upstream and 84 miles from the mouth is the mill of the Naomi Falls Manufacturing Company of Randleman, North Carolina. These mills contain 5,000 spindles and 298 looms for the manufacture of cotton cloth and cotton bags. The dam is of wood and stone, 13 feet high and 300 feet long, and backs the water about one-half mile. There is no race, the water going directly to the wheels, which are capable of developing about 130 horsepower. This is supplemented at all times by at least 50 horsepower from the steam-power plant.

One mile above Naomi Falls, in the town of Randleman, are located the two mills of the Randleman Manufacturing Company, which contain 5,000 spindles and 270 looms, both mills being operated by water from the same race. The dam here is of stone, 12 feet high and 275 feet long, and backs the water 2½ miles without throwing the river out of its banks. The race is about 500 feet long and the working head is 12 feet, developing 175 horsepower by means of 4 turbine wheels. For about six months in the year there is enough water to run the mills to their full capacity by the use of water power alone. There is said to be a shoal, called the Island Ford Shoal, about 2 miles above Randleman, having a fall of 10 or 12 feet. Four miles above Randleman is Walker's gristmill, which has an 8-foot stone dam 300 feet long, which furnishes a 10-foot working head through a race 110 yards long. Coltrane's gristmill, 3 miles above Walker's, has an 8-foot masonry dam 100 yards long, and a working head of 10 feet. The race is about 100 yards long.

Freemon's gristmill is 5 miles above the last-named site. It was built for a woolen mill and was run as such for some time. The dam is of stone laid in cement, 12 feet high and 130 feet long. There is no race. Five miles above Freemon's mill, 102 miles above the mouth of the river and 1 mile below Jamestown station, on the

Southern Railway, is the cotton mill of the Oakdale Manufacturing Company, which contains 3,320 spindles. The fall here is 25 feet, obtained by a wooden dam 20 feet high and 260 feet long, and a race 250 feet long. The dam backs the water 1 mile with an average width of pond of 100 feet. The powers above this point are inconsiderable.

Rating table for Cape Fear River at Fayetteville, North Carolina, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.0	300	5.8	2,400	11.8	5,780	21.0	13,400
0.1	320	6.0	2,500	12.0	5,900	22.0	14,500
0.2	340	6.2	2,600	12.2	6,020	23.0	15,650
0.4	380	6.4	2,700	12.4	6,140	24.0	16,940
0.6	430	6.6	2,800	12.6	6,260	25.0	18,300
0.8	480	6.8	2,900	12.8	6,380	26.0	19,660
1.0	530	7.0	3,000	13.0	6,500	27.0	21,020
1.2	580	7.2	3,100	13.2	6,640	28.0	22,380
1.4	630	7.4	3,200	13.4	6,780	29.0	23,740
1.6	690	7.6	3,300	13.6	6,920	30.0	25,100
1.8	750	7.8	3,400	13.8	7,060	31.0	26,460
2.0	810	8.0	3,500	14.0	7,200	32.0	27,820
2.2	875	8.2	3,620	14.2	7,340	33.0	29,180
2.4	945	8.4	3,740	14.4	7,480	34.0	30,540
2.6	1,020	8.6	3,860	14.6	7,620	35.0	31,900
2.8	1,100	8.8	3,980	14.8	7,760	36.0	33,260
3.0	1,180	9.0	4,100	15.0	7,900	37.0	34,620
3.2	1,260	9.2	4,220	15.2	8,040	38.0	35,980
3.4	1,340	9.4	4,340	15.4	8,180	39.0	37,240
3.6	1,420	9.6	4,460	15.6	8,320	40.0	38,600
3.8	1,500	9.8	4,580	15.8	8,460	41.0	39,960
4.0	1,580	10.0	4,700	16.0	8,600	42.0	41,320
4.2	1,670	10.2	4,820	16.5	9,000	43.0	42,680
4.4	1,760	10.4	4,940	17.0	9,400	44.0	44,040
4.6	1,850	10.6	5,060	17.5	9,850	45.0	45,400
4.8	1,940	10.8	5,180	18.0	10,300	46.0	46,760
5.0	2,030	11.0	5,300	18.5	10,800	47.0	48,120
5.2	2,120	11.2	5,420	19.0	11,300	48.0	49,480
5.4	2,210	11.4	5,540	19.5	11,800	49.0	50,840
5.6	2,300	11.6	5,660	20.0	12,300	50.0	52,300

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

[Drainage area, 4,493 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	17,688	1,580	3,694	227,140	0.94	0.82
February	33,668	2,255	12,802	710,986	2.97	2.85
March	35,708	3,100	12,233	752,280	3.14	2.72
April	22,788	1,760	6,871	408,850	1.71	1.53
May	9,760	1,580	3,191	196,210	0.82	0.71
June	3,860	750	1,833	109,070	0.46	0.41
July	18,708	780	3,180	195,530	0.82	0.71
August	2,900	875	1,570	96,535	0.40	0.35
September	1,850	360	664	39,510	0.17	0.15
October	875	340	517	31,790	0.14	0.12
November	4,520	630	1,281	76,230	0.32	0.29
December	4,700	1,180	2,165	133,120	0.55	0.48
The year	35,708	340	4,167	2,977,251	12.44	0.93

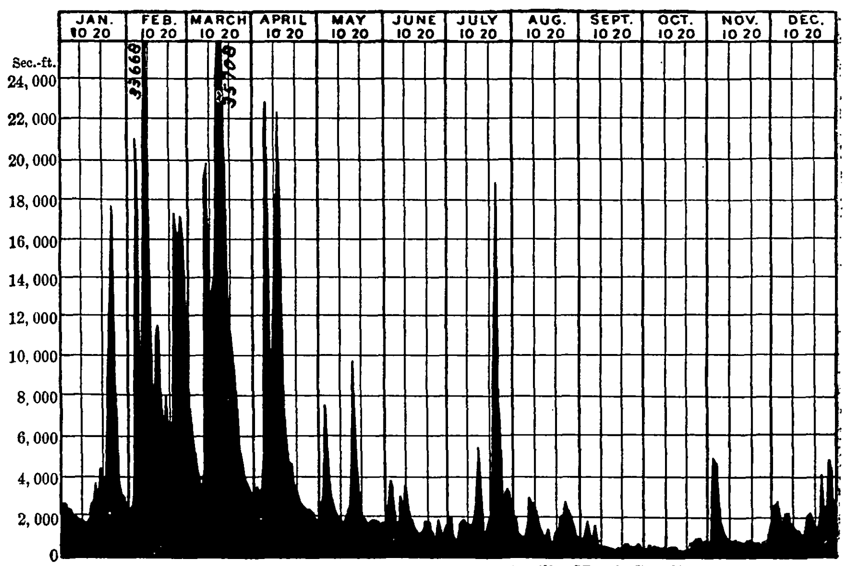


FIG. 46.—Discharge of Cape Fear River at Fayetteville, North Carolina, 1897.

YADKIN RIVER.

Yadkin River, called the Great Pedee below its junction with Uwharie River, takes its rise on the eastern slope of the Blue Ridge, in Caldwell and Watauga counties of North Carolina. It flows first slightly north of east for some distance, then bending abruptly to the right it flows a little east of south, passing into South Carolina, and continuing this same general course empties into Winyah Bay at Georgetown. Following the general course of the stream the distance from its source to its mouth is between 275 and 300 miles, but following all its windings it is much greater, exceeding 400 miles, as nearly as can be estimated by measurement on the map.

As described by Prof. J. A. Holmes in his report, there are no towns of importance on that part of the river where there are facilities for water power. In North Carolina there are no towns on the river with more than a few hundred inhabitants, the principal ones being Elkin, in the southwest corner of Surrey County, and Wilkesboro, the county seat of Wilkes County. The Great Pedee crosses the fall line a little above Cheraw. The fall is not so pronounced as in the case of the Tar and the Roanoke, but consists of a series of rapids extending over a number of miles, with no very great fall in any place or within any short distance. Between the Carolina Central Railroad crossing and the mouth of Uwharie River there are four prominent shoals that may be considered available for water power, and between these there are a number of smaller shoals not worth mentioning in this connection. The total distance is about 47 miles, and the total fall in the river between the two points is about 158 feet. Bluetts Falls, the first of these shoals, is about 18 miles above the State line. It is about 1,000 feet long and has an estimated fall of 8 or 9 feet in this distance. Grassy Island Shoal, about 19 miles above the State line, has an estimated fall of 35 or 36 feet in a distance of 4.5 miles. The river at this place is at least half a mile wide, with an average depth of about 8 inches. Swift Island Shoal, about 56 miles above the State line, has an estimated fall of about 18 feet in a distance of 2.5 miles. There is here a rock dam 4 to 5 feet high, extending across the river in the form of a V, with the apex upstream, from which a race one-half mile long leads to an abandoned cotton factory on the east side of the river. Mills are said to have been in operation at this point for three-quarters of a century. The site is about 8 miles east of the Southern Railway station at Albemarle, the county seat of Stanly County. Gunsmith shoals, about 61 or 62 miles above the State line, is just below the mouth of Uwharie River, and has a fall of 9.5 feet in a little less than half a mile.

About 64 or 65 miles above the State line are the Narrows of the Yadkin, the most famous water power in North Carolina. For 4 or 5 miles above the mouth of the Uwharie the country is entirely different in character from that both below and above this region. Over the shoals just described and those described further on, which occur higher up the stream, the bed of the river spreads out to a width of from 1,000 to 1,500 feet, and at Grassy Islands it is not less than half a mile wide. Before entering the Narrows the river is nearly 1,000 feet wide, from which it suddenly contracts, entering a narrow ravine with rocky and almost perpendicular banks that rise to a height of from 150 to 300 feet. Between these it pours with great violence, preserving for a distance of about a quarter of a mile an average width not exceeding 150 feet, while in some places the width is only 60 feet. Below the Narrows proper the stream expands to a width of from 150 to 300 feet, and flows with a rapid current for the succeeding 2½ or 3 miles through a narrow gorge, the banks on each side being very steep and rocky, except in one or two places where a small lateral valley approaches, affording room for a mill site. About 2 miles below the Narrows proper, but still within the gorge, are the rapids known as Little Falls, and half a mile below are those known as Big Falls. Just below the latter comes a long and narrow stretch called "the Lake," where the river is still confined between rocky and very steep banks, but the fall is very small, the width of the stream only from 100 to 200 feet, and the depth very great. At the lower end of the Lake, which is between a quarter and a half mile long, the river widens out, and from that point down to the mouth of the Uwharie, about 1 mile, the river is interspersed with rocks and islands, with banks 10 to 20 feet high on each side, and behind them flat lands for several hundred yards. The total fall in the river from the falls at the head of the Narrows to the mouth of Uwharie River is 91 feet, and of this 37 feet are concentrated in the Narrows proper, a distance of about 1 mile.

Above the Narrows and between this place and the Southern Railway crossing near Salisbury there are six important shoals and a number of smaller ones. The general width of the river in this portion of its course is from 600 to 1,000 feet. The banks have an average height of about 10 feet above average winter water. Bull Island Shoal, the first above the Narrows, has a total fall estimated at 37 feet in a length of nearly 2 miles, beginning about one-half mile below Pennington's ferry, and ending from 1 to 2 miles above the Narrows and from 66 to 67 miles above the State line. The second important shoal above the Narrows lies between Pennington's ferry and Milledgeville. It has a total fall of 74 feet in a distance of 4½ miles. The Milledgeville Shoal, the third of importance above the Narrows, has a fall of 14 feet in a distance of seven-tenths mile; one plunge of about 6 feet occurs near the bottom of the shoal. It is situated about 6½ miles above the Narrows, 70 or 71 miles above the State line, and a short distance below Stokes ferry. This shoal is utilized to some extent. The Yadkin Falls Manufacturing Company has a cotton factory and gristmill on the east side of the river, using in all 125 horsepower. The wing dam on this side of the river is of stone, about 600 feet long, and gives a

10-foot fall at the factory, which contains 36 cards and 3,160 spindles. On the opposite or west side of the river at this point are located a sawmill, a gristmill, a cotton gin, and a wool-carding mill, using in all about 40 horsepower, supplied with water from a small wing dam extending from the bank across a portion of the river to an island. The fall secured is 8 feet. Motts Falls, the fourth important shoal, about 73 miles above the mouth of the river, has a fall of 13½ feet in about eight-tenths of a mile. Bald Mountain Shoal, 2 miles farther up the river and about 75 miles from the State line, has a fall of about 8½ feet in half a mile. Flat Swamp Mountain Shoal, about 79½ miles above the State line and less than 1 mile below the mouth of Abbott Creek, has a natural fall of 10.2 feet in half a mile. Between the mouth of Abbott Creek and the Southern Railway crossing, a distance of some 10 miles, there are no shoals of importance, and the total fall in this distance amounts to 28.3 feet. Between the railroad crossing and the old Douthit's mill site there are several small falls, some of them occupied by small saw and grist mills. About 135 miles from the State line and 291.5 miles from the mouth of the river is the old Douthit's mill site, just at the crossing of the Winston and Mocksville Railroad; this site is now used by the Fries Manufacturing and Power Company, of Winston-Salem. The dam here is of stone, 10 feet high, extending obliquely across the river. The west abutment of the dam is the pier of the railroad bridge, and at the east end is the power house, which contains 8 turbine water wheels on vertical shafts, developing, it is claimed, 1,000 horsepower under a head of 10 feet. These wheels are geared directly to the main shaft, which carries the generator, a Stanley 3-phase alternator of 750 kilowatts capacity, generating the current at a potential of 11,000 volts. This is transmitted a distance of 13½ miles to Winston-Salem to the transformer station, where, by means of step-down transformers, the current is reduced to a potential of 1,250 volts, and from there distributed to the mills in the vicinity. Two of the mills, distant about 2½ and 3 miles from the transformer station, which have their own transformers, receive the current direct at the potential of 11,000 volts. All the motors are of the Stanley synchronous alternating type. Power from the plant of the Fries Manufacturing and Power Company is supplied to the Arista Mills, the Southside Cotton Mills, the Wachovia Grain Mills, the F. & H. Fries Woolen Mill, the Winston-Salem Electric Company, the wood working establishment of Fogle Bros., the Vance Iron Works, and the Salem Water Supply Company; and the company has also contracts on hand for several hundred additional horsepower. The plans anticipate the enlargement of the plant to double its present size.

Between this point and the head of Bean Shoal, a distance of about 33 miles, there are four shoals with falls varying from 4.5 to 8 feet. The principal shoal on this part of the river is Bean Shoal, situated about 324.7 miles above the mouth of the river and about 168 miles above the State line, the fall in 4 miles being over 39 feet. In the lower part of the shoal there is a fall of about 10 feet in 2 miles. The only part of the shoal now being utilized is near the middle, where Martin's gristmill is situated on the south side of the river. Between 1820 and 1835 the Yadkin Navigation Company did considerable work at these shoals with a view of rendering the river navigable. A dam was built at the head of the shoals and a canal was commenced along the northern side of the river. The only trace of a dam now to be seen is an abutment at the entrance of the canal. The canal was completed for a little more than a mile from the head of the shoal and was from 15 to 45 feet wide at the bottom. At 2,000 feet from the head of the canal are the ruins of a guard lock 12 feet wide. The canal has silted up by the floods and, where it passes through the woods, has been overgrown by trees and bushes. Lime Rock Shoal is about 7½ miles farther up the river and has a fall of 10.62 feet in 2.59 miles. Twelve miles higher up the river and about 35 miles from Wilkesboro is the Devils Staircase and Long Shoal, where in 1.61 miles the fall is 11.18 feet over a rock bottom. The other shoals on the river call for no special remark. Besides those mentioned there are many smaller ones which might equally well be used for power.

Above Wilkesboro the fall of the river continually increases and there are some sites for power. The only considerable power used is that at Patterson, Caldwell County, where Messrs. Gwyn, Harper & Co. have a cotton mill, woolen mill, sawmill, and gristmill. The cotton mill contains 56 looms and 2,288 spindles and is run by water power, supplemented by steam in dry seasons. The dam is of wood and stone, 15 feet high and 300 feet long. The race is of wood, 200 yards long, giving a fall at the factory of 25 feet, which it is claimed develops 80 horsepower by means of a turbine wheel during eleven months in the year, the mill running twelve hours a day. The woolen mill contains 4 sets of cards, 20 looms, and 480 spindles, which are operated by the same water power, supplemented by steam in dry seasons.

A number of the tributaries to the Cape Fear and Yadkin rivers are sand-hill streams, as they are called.[1]

The sand-hill belt consists of broad, flattish swells, well wooded, as a rule, with long-leaf pine, and generally with an undergrowth. The surface deposit of sand varies from 1 or 2 feet to 5 or 6 feet in depth, and is in places 10, 20, or even 100 feet thick. It is underlain by less pervious strata of sand grit and clay of the Tertiary and Cretaceous formations, which is in places very thick, having been bored into for a depth of 175 feet in one place. The smaller streams of the sand hills have not cut out their beds through the sand, and are often sluggish, stagnant, and marshy; but the larger creeks and the rivers have cut away the sand entirely and worn out their beds to the less pervious strata beneath, which shed into the water courses all the water received by percolation.

The rapidity with which the sand hills absorb the rain which falls upon them,

[1] The data contained in the following pages are compiled from a report prepared by Prof. J. A. Holmes, State geologist of North Carolina.

and thus remove it from the direct action of the sun, has the effect of diminishing evaporation, while their thickness in places enables them to absorb considerable water, and give it out gradually as it reaches along the impervious strata beneath, and thus act as storage reservoirs. Hence the depth of the sand hills acts very beneficially; the streams of the class referred to not only discharge a large proportion of the rainfall on their drainage basins, but discharge it very uniformly, and their flow is remarkably constant. The value of the streams is also increased by the fact that the topography of the region is such that large ponds may be easily obtained, and storage room sufficient not only to regulate the flow to some extent during the year, but also to permit the concentration of the entire flow during working hours, and thus render it possible to double the power due to the natural flow of the stream when the mills are run only twelve hours.

Gum Swamp Creek will serve as an illustration of the character of these small streams. It rises among the sand hills of Richmond County, about 8 or 10 miles above the Carolina Central Railroad at Laurel Hill, and within a about 12 miles of its source it furnishes the power to operate three small cotton mills—the Richmond, the Ida, and the Springfield.

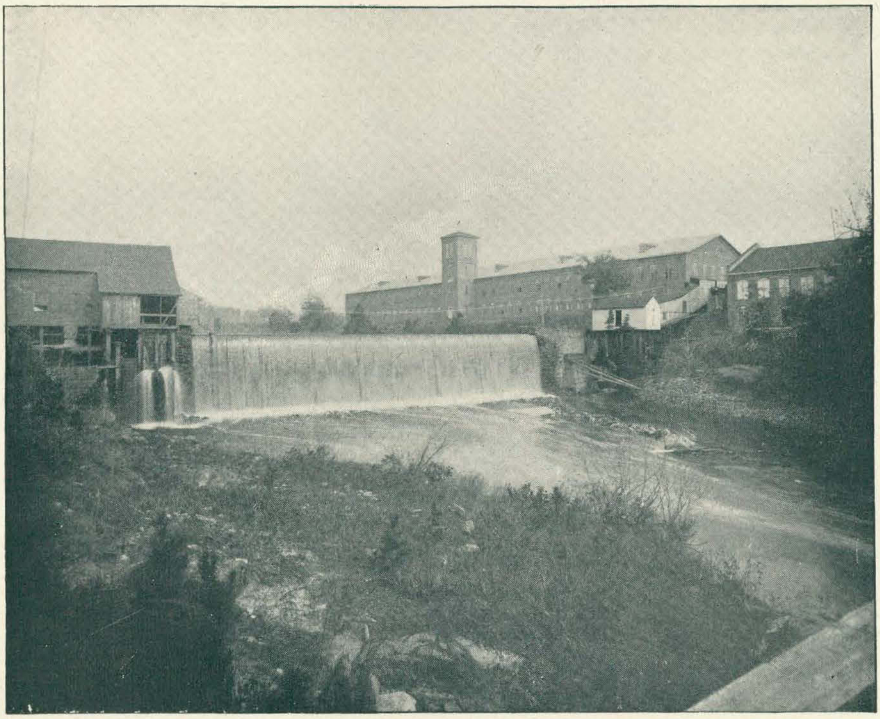
The Richmond Cotton Mill, located on this stream 2 miles north of the railroad and about the same distance from Laurel Hill, contains 2,556 spindles and is operated by about 90 horsepower all the year except that the water gets somewhat low in very long dry seasons. The dam is 12 feet high, 600 feet long; the pond is 1½ miles long and one-third of a mile wide, and the head of the water on the wheel is 10 feet. The mill is run only during the day, and in dry seasons when the water in the pond is lowered during the day it fills up again during the night. The Ida yarn mill, 2½ miles south of the Richmond mill and one-eighth of a mile below the railroad, contains 3,024 spindles, operated by about 110 horsepower throughout the year. The dam is 10 feet high and 900 feet long, producing a pond about 1 mile long and 300 to 400 yards wide. The race is 300 yards long and the working head at the mill is 8 feet. The Springfield Cotton Mill, 1¼ miles below the Ida yarn mill, contains 2,304 spindles and uses about 85 horsepower. The fall of water at the wheel is 7½ feet. The dam is 10 feet high and 525 feet long, causing a pond three-fourths of a mile long and 200 to 300 yards wide. The race is 200 yards long.

The next tributary worth mentioning in North Carolina is Hitchcocks Creek, although there are several streams below it which are favorable for power. This creek flows entirely in Richmond County and has a length in a straight line of only about 16 or 20 miles, draining an area of some 102 square miles. It furnishes, however, the power for five large cotton mills. Steele's cotton mill, containing 10,304 spindles and 300 looms, is the first important power on this creek, 2½ miles above its mouth. The dam is of granite laid in cement, 16 feet high and 69 feet long, developing, it is claimed, without a race, 350 horsepower. The Midway Cotton Mill, about 4 miles above the mouth of the creek, contains 16 cards and 6,200 spindles. The dam is of wood, 13 feet high and 150 feet long. The present wheels develop, it is claimed, about 200 horsepower throughout the year.

The Pedee Manufacturing Company's mill is located 2 miles above the Midway mill and contains 23 cards, 300 looms, and 6,112 spindles. The dam is of stone and dirt, 22 feet high and 107 feet long, giving 22 feet fall, which, it is claimed, furnishes 300 horsepower all the year round except during short and unusually dry seasons. The pond extends over 2 miles upstream.

The Roberdel Cotton Mills (see Pl. XXVII, *A*), 2½ miles above the Pedee mills and 3 miles northeast of Rockingham, contains 24 cards, 300 looms, and 6,000 spindles, all operated by water power. The dam is of stone, 24 feet high and 170 feet long, giving a fall ot 22½ feet at the factory, which is said to generate 300 horsepower throughout the year.

The Ledbetter Manufacturing Company's cotton mill is located 2 miles above the Roberdel mill and operates 2,080 spindles and 2 sets of cards by water from this creek. The dam is of brick, 13 feet high and 140 feet long, giving a fall at the mill of 10 feet. The pond covers about 150 acres. About 100 horsepower is reported to



A. ROBERDEL COTTON MILLS, ON HITCHCOCKS CREEK NEAR ROCKINGHAM, NORTH CAROLINA.

B. DAM AND POWER HOUSE ON SALUDA RIVER AT PELZER, SOUTH CAROLINA.

be developed, of which 75 horsepower is used all the year round except for a few days, when high water interferes. At the opposite end of the dam the company has a corn and flour mill.

On Falling Creek, near its junction with Hitchcocks Creek, is located the cotton mill of the Great Falls Manufacturing Company, three-fourths of a mile above the Midway mill. The factory contains 130 looms and 4,512 spindles, all operated by water power. This water power is one of considerable interest on account of the comparatively large amount of power continuously developed by the small sand-hill stream, with a drainage area of not more than 12 square miles. Where the dam is now located there was originally a natural fall of 25 feet over the bed rock which here underlies the sand-hill formation, and on this rock has been built a dam 18 feet high and 95 feet long, which gives a fall of 43 feet. The pond has an area of 10 to 15 acres, and from this the water is carried to the wheels through an iron flume 75 feet long. The power generated in ordinary years is 150 horsepower throughout the year, the mill running only during the day, so that even in the driest seasons the pond fills up at night and supplies a full head in the morning. In exceptionally dry years there are a few weeks during which the mill can not run on full time with all the machinery. The storage of water has been carried to a greater degree of efficiency on this stream than on any other sand-hill stream in the State. Above the pond at the mill three earth dams have been built across the stream and its tributary branch, thus producing three reservoirs, one of 10 to 15 acres and two of 20 to 30 acres each, all three from 5 to 6 feet deep. These store away a quantity of water, which is turned out from time to time when needed at the factory in dry seasons.

The next most important tributary for power purposes is the South Yadkin. The first mill on the stream is 4 miles from its mouth, at South River (Foard & Lindsay's), and has a fall of 6 feet, with a dam of the same height about 200 feet long. About 30 horsepower is used, but the available power is much greater. The dam backs the water 3 miles, nearly to the foot of the next shoal above—Hairstons Shoal.

Hairstons Shoal is the most important one on the river, and is some 12 miles from Salisbury and above the mouth of Third Creek. The river has, with a dam 3½ feet high, a fall of about 15 to 16 feet in one-fourth of a mile, but the greatest fall, amounting to 13 or 14 feet in 200 yards, is at the upper end.

Of the upper tributaries the first and probably the largest is Ararat River, rising among the spurs of the Blue Ridge Mountains in Patrick County, Virginia, and draining an area of 315 square miles. There are a number of good powers along its course. The Hamburg Cotton Mill, operating 1,600 spindles, a grist and flour mill, and machine shops, are located on the Ararat River about 25 miles above its mouth and one-half mile east of Mount Airy. The wooden dam is 10 feet high and 150 feet long and ponds the water for half a mile up the river. The fall at the mill is 14 feet, and the entire plant uses about 40 horsepower all the year, although the stream develops a larger amount. At Buck Shoals, 2 miles below Mount Airy and 23 miles above the mouth of the river, is a saw and grist mill, with a dam about 6 feet high and 200 feet long and a fall of 15 feet, only a small part of the power of which is utilized. Two miles below, at Tumbling Rock, there is said to be a natural fall of 10 feet. At Flat Shoals (Forge Mills), 3 miles farther down and about 18 miles from the mouth of the river, was a dam about 350 feet long and 8 feet high, which gave a fall of 24 feet, affording what was said to be an excellent power. On Stewarts Creek, a tributary of the Ararat, 4 miles above where it joins the latter stream, is located the Laurel Bluff Cotton Mill—a small factory with 2,500 spindles and a gristmill attached. There is a dam 11 feet high and 125 feet long, giving a fall at the mill of 16 feet, which it is claimed furnishes 100 horsepower nearly all the time. On Lovells Creek, another tributary of the Ararat, about 3 miles from Mount Airy, are located the Alpine Woolen Mills, which operate 20 looms and 432 spindles. There is a dam 150 feet long and 5 feet high, giving a fall of 8 feet. Fishers River and Mitchells River are the other tributaries of the Yadkin in Surry County, and on both there are a number of small water powers available, but none of special value have been reported. Both rivers rise on the slopes of the Blue Ridge and flow through a region that is largely forest-clad and the supply of water is but little affected by the dry seasons.

Elkin Creek, which flows for the greater part of its course in Wilkes County, furnishes power at Elkin for a cotton factory, that of the Elkin Manufacturing Company, which contains 2,000 spindles and 3 sets of cards. From a fall of 22 feet and a dam about 100 feet long and 7 feet high, about 70 horsepower is realized for nine months in the year and about 50 during the remaining time, when the water power is supplemented by steam power. About one-half mile above the Elkin Manufacturing Company's mill is the Elkin Valley mill, which consists of a grist and flour mill, a shoe factory, and a tannery, using in all about 65 horsepower during the greater part of the year. Water is ponded by means of a wood dam 13 feet high and 126 feet long, which gives a fall of 18 feet at the wheels. This site was until 1894 occupied by the woolen mill of the Chatham Manufacturing Company. About 3 miles above the Elkin Valley mills is a site known as Carters Falls, which is an excellent small water power with an exceptionally large fall in a short distance.

In Wilkes County the more important tributaries of the Yadkin—Roaring River, Rock Creek, Mulberry River, Reddies River, Lewis Fork, Stony Fork, and Elk Creek—all rise on the slopes of the Blue Ridge Mountains and flow as rapid mountain streams through forest-covered areas. They all afford numerous small powers, large enough and constant enough to run small factories, sawmills, gristmills, and flouring mills. In the case of the majority of these streams it is probable that near their junction with the Yadkin they afford from 2 to 3 horsepower per foot of fall in dry seasons, and sites can be found that may be developed so as to have falls of 20 to 30 feet.

Rating table for Yadkin River at Salisbury, North Carolina, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.0	560	3.2	7,116	5.4	14,860	7.6	22,604
1.2	900	3.4	7,820	5.6	15,564	7.8	23,308
1.4	1,310	3.6	8,524	5.8	16,268	8.0	24,012
1.6	1,760	3.8	9,228	6.0	16,972	8.5	25,772
1.8	2,300	4.0	9,932	6.2	17,676	9.0	27,532
2.0	2,920	4.2	10,636	6.4	18,380	9.5	29,292
2.2	3,596	4.4	11,340	6.6	19,084	10.0	31,052
2.4	4,300	4.6	12,044	6.8	19,788	10.5	32,812
2.6	5,004	4.8	12,748	7.0	20,492	11.0	34,572
2.8	5,708	5.0	13,452	7.2	21,196	11.5	36,332
3.0	6,412	5.2	14,156	7.4	21,900		

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.		Depth in inches.	Second-feet per square mile.
1897.						
January	12,044	2,600	4,039	248,350	1.37	1.19
February	34,924	4,652	11,597	644,065	3.45	3.41
March	25,068	4,652	10,522	646,970	3.58	3.10
April	31,756	3,948	7,761	461,810	2.54	2.28
May	14,156	3,250	5,776	355,150	1.96	1.70
June	19,788	2,300	5,652	336,320	1.85	1.66
July	11,692	2,600	4,821	296,430	1.64	1.42
August	5,708	1,760	2,943	180,960	1.00	0.87
September	3,250	900	1,785	106,215	0.59	0.53
October	25,772	900	3,557	218,600	1.21	1.05
November	7,116	900	2,708	161,140	0.89	0.80
December	5,708	2,300	3,086	189,750	1.05	0.91
The year	34,924	900	5,354	3,845,760	21.13	1.58

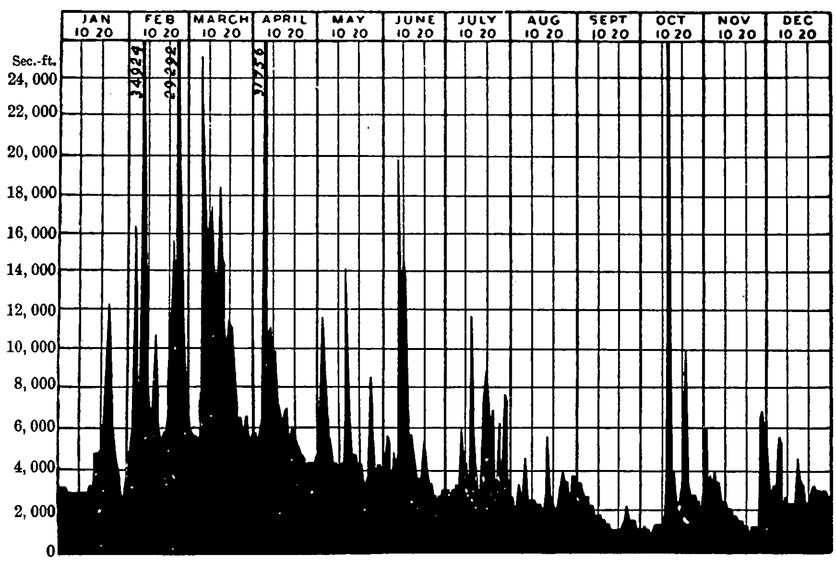


FIG. 47.—Discharge of Yadkin River at Salisbury, North Carolina, 1897.

The following table gives the list of discharge measurements made on Yadkin River at Norwood, North Carolina. The principal facts are also shown in the accompanying figure (fig. 48), in which vertical distances represent the height of water on the gage and horizontal distances the quantity of discharge. The plotted points obtained by measurement are shown by the small circles, which are numbered to correspond with the figures in the left-hand column of the table. Near, or through these, is drawn a smooth curve, from which the values for the rating table have been obtained.

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

No.	Date.	Hydrographer.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
	1896.			*Feet.*	*Square feet.*	*Feet per second.*	*Second-feet.*
1	Sept. 1 ..	E. W. Myers...	2154	1.00	1,859	0.82	1,537
2	Sept. 15.	.....do	2154	1.34	2,211	0.92	2,036
	1897.						
3	Feb. 10..	.....do	2154	3.32	3,779	2.54	9,607
4	Mar. 21..	.....do	2154	3.80	4,517	2.59	11,710
5	Aug. 4...	.....do	2154	1.65	2,544	1.33	3,392
6	Oct. 6 ...	.....do	2154	1.00	1,821	0.82	1,508
7	Oct. 25 ..	A. P. Davis	94	1.48	2,152	1.26	2,715
	1898.						
a 8	Jan. 16 ..	E. W. Myers ...	2154	1.63	2,474	1.22	3,041
9	Mar. 31..	.....do	2154	5.75	6,465	3.84	24,825

a Not plotted.

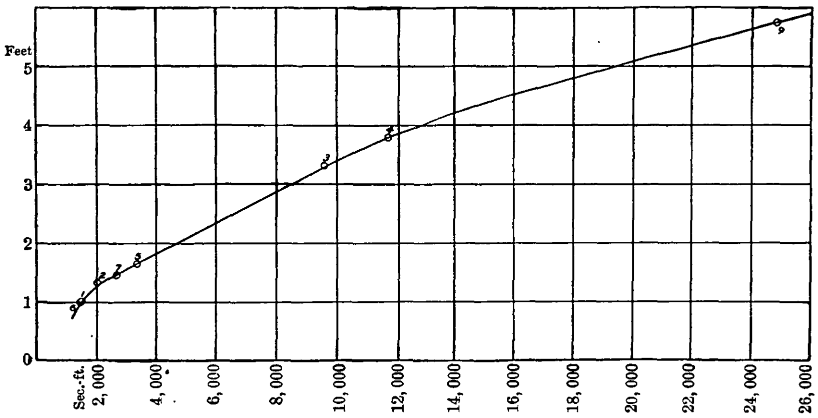


FIG. 48.—Rating curve for Norwood station, on Yadkin River, North Carolina.

Rating table for Yadkin River at Norwood, North Carolina, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.7	1,250	2.6	6,960	4.8	18,000	7.0	34,060
0.8	1,310	2.8	7,720	5.0	19,460	7.2	35,520
0.9	1,380	3.0	8,480	5.2	20,920	7.4	36,980
1.0	1,480	3.2	9,240	5.4	22,380	7.6	38,440
1.2	1,820	3.4	10,000	5.6	23,840	7.8	39,900
1.4	2,400	3.6	10,860	5.8	25,300	8.0	41,360
1.6	3,160	3.8	11,800	6.0	26,760	8.2	42,820
1.8	3,920	4.0	12,800	6.2	28,220	8.4	44,280
2.0	4,680	4.2	13,800	6.4	29,680	8.6	45,740
2.2	5,440	4.4	15,100	6.6	31,140	8.8	47,200
2.4	6,200	4.6	16,540	6.8	32,600	9.0	48,660

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

[Drainage area, 4,614 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	15,810	2,780	4,880	300,060	1.22	1.06
February	50,120	4,300	13,760	764,190	3.10	2.98
March	33,330	5,440	13,017	800,385	3.25	2.82
April	45,010	5,060	9,755	580,465	2.35	2.11
May	14,400	4,300	6,388	392,785	1.59	1.38
June	14,400	3,160	5,397	321,145	1.31	1.17
July	15,810	2,400	5,495	337,875	1.37	1.19
August	6,580	2,400	3,712	228,240	0.93	0.81
September	2,780	1,310	1,774	105,560	0.43	0.38
October	11,800	1,480	2,999	184,400	0.75	0.65
November	8,480	1,820	2,973	176,910	0.71	0.64
December	7,340	2,080	4,171	256,465	1.04	0.90
The year	50,120	1,310	6,193	4,448,480	18.05	1.34

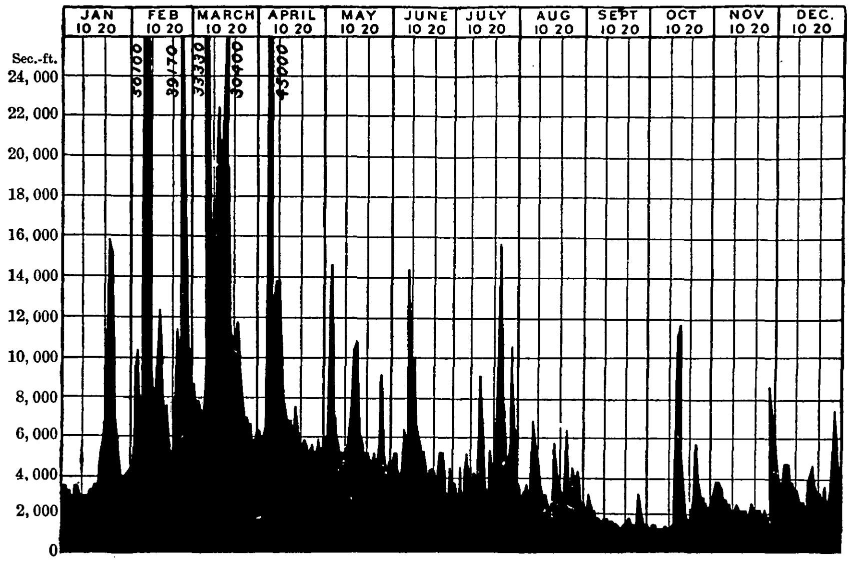


FIG. 49.—Discharge of Yadkin River at Norwood, North Carolina, 1897.

SANTEE RIVER.

Santee River is formed by the junction of Wateree and Congaree rivers in South Carolina. The former stream is known by the name of Catawba River through North Carolina, while the latter is formed at Columbia by the confluence of the Broad and Saluda rivers. The head waters are in the Blue Ridge in the western part of the State, adjoining the tributaries of the Yadkin on the northeast and of the Tennessee on the west. In the following pages are described the principal water powers along these streams and their tributaries.

Gaging stations are being maintained on the Catawba at Catawba, North Carolina, and at Rock Hill, South Carolina; on the Broad at Alston, South Carolina and at Gaffney, South Carolina; on the Saluda at Waterloo, South Carolina. They are described in Water-Supply and Irrigation Paper No. 15, pp. 34–38. In the following pages appear rating tables and estimated monthly discharges for 1897 for these stations, with the exception of Alston and Waterloo, where there were not sufficient discharge measurements on which to base rating tables.

CATAWBA RIVER.

Catawba River, or Wateree, as it is known in its lower reaches, rises on the eastern slope of the Blue Ridge Mountains, in McDowell County, North Carolina, and joins with the Congaree a short distance below Columbia, at the most southerly point of Richland County, South Carolina. The stream is navigable for shallow boats as high as Camden. A short distance above this point begin a series of rapids and shoals which are found at intervals and characterize the upper portion of the river.

The fall line on the river occurs about 5 miles above Camden, where there is a shoal which has an aggregate fall of 52 feet in a distance of a little less than 5 miles. At about the end of the first quarter of the present century the river at this point was made navigable by the State, the fall being overcome by a canal 5 miles in length with a series of locks. In the Tenth Census report on the water powers of the southern Atlantic watershed, Professor Swain describes this development as follows:[1]

The canal is on the west side of the river, which it leaves just below a rocky bluff, from which a dam extends out into the river. This old dam is entirely gone, and I could not ascertain what its height had been; but the fall for the next mile above is probably 10 or 12 feet, according to the pocket level, although the stream is not rocky except for a few hundred feet. The canal had a guard lock about a quarter of a mile from its head, and below that it passes through nearly level or gently rolling bottom lands, and is now entirely overgrown with underbrush and filled up with deposits of all kinds, so that in places the stream is scarcely discernible. It retreats some distance from the river, the bottom between them being on the average several hundred yards wide, and parts of it are subject to overflow in times of high water. Near the foot of the canal is a flight of three locks, and a little farther down the canal passes out into Sawneys Creek by an outlet lock. I was unable to find the sixth lock mentioned by Mills. The principal part of the fall in the river occurs near the lower end, or about two-thirds of the distance from the head, and is utilized for a small gristmill, with two pairs of stones, by means of a rough wing dam and a race a quarter of a mile long, affording a fall of 6 or 7 feet and a fall to the tailrace sufficient to avoid the trouble occasioned by ordinary rises of the water. In a distance of rather over a mile, from a little above the head of the race leading to the gristmill, the fall, as ascertained by the pocket level, is in the neighborhood of 20 feet. Above this the bottom bordering the river is subject to overflow to a considerable extent, while below it is only occasionally flooded. Below the mill, too, the bottom becomes narrower, and is more undulating than above. As regards the most advantageous method of utilizing the power my examination was too superficial to permit of any definite conclusion being reached. To clear the old canal out would require considerable work, although of an easy kind. The capacity of the canal, too, could be easily enlarged if it were considered desirable to utilize the entire power, which might be done by locating the mill at the lower flight of locks, where, if we accept Mills's statement, a fall of some 50 feet could be obtained; and the location here is probably as safe and as favorable as anywhere along the canal.

The Great Falls of the Catawba, about 30 miles above the Wateree Canal, represent the most important water power on the river. There is here a fall of 173 feet in a distance of 8 miles, which would yield a total horsepower, according to Swain,[2] of from 5,000 to 10,000 horsepower in low-water seasons. The State of South Carolina endeavored to render this part of the river navigable by the construction of canals and locks early in the present century. These development works are described by Swain as follows:[3]

The navigation works planned were very extensive. In ascending the river the course of the canal is as follows: Leaving the river about opposite Rocky Mount, on

[1] Report on the water power of the Southern Atlantic watershed: Tenth Census, Vol. XVI, Part I, p. 751.

[2] Ibid., p. 756.

[3] Ibid., p. 752.

the west side, it rises to the level of the bottom (which borders the river at this place) by a flight of two locks, aggregating about 18 feet lift, crosses the bottom, and after passing around a steep and rocky bluff, at which place it was necessary to build the outer wall of the canal of solid masonry for a distance of half a mile or thereabout, within which distance occurs one intermediate lock, with a lift of about 9 feet, it debouches into Rocky Creek, a small stream which flows into the Catawba at a point in the neighborhood of a half or a quarter of a mile above its mouth, opening into it by a guard lock, with a lift of about 8 feet, situated at one end of a wooden dam, which extended across the creek, backing up the water, with a navigable depth, to a distance of about a mile. The first canal is about a mile in length, and has a total rise, according to what has been said, of about 35 feet from low water in the Catawba at the outlet lock to the crest of the dam across Rocky Creek. Between the canal and the river is a bottom, in which the lower part of the canal itself lies, and which is subject to overflow in times of freshet. It was probably on this account that the canal was carried so closely around the bluff. In fact, this part of the river, just below the principal fall, is subject to large rises, much larger than within the next few miles above, where the declivity is great, and down which the water rushes so rapidly that the smaller declivity below is insufficient to carry it off without a considerable rise. This part of the canal, as well as that above, is so overgrown with brush and by trees of half a century's growth that its original dimensions can not be accurately determined. The lock chambers are about 70 feet by 10 feet, and the canal was perhaps 20 or 25 feet wide at the top and 3 or 4 feet deep. The dam across Rocky Creek was probably about 12 or 13 feet high, and its pool, as before mentioned, was navigable for about a mile, at which point the second portion of the canal commenced, leaving the river by a flight of four locks, with together 32 feet lift, by which it rises to the level of a narrow valley running about parallel with the Catawba, but separated from it by a ridge. Along the side of this valley, out of sight of the Catawba, although the latter is only a quarter of a mile distant, and with a ridge nearly a hundred feet high between them, passes the canal for a distance of about 2 miles, at the end of which the valley that it has been following opens out into the river, but at an elevation above it of 20 or 30 feet, having gradually become narrower as the river was approached, and at its upper end being very little more than wide enough to carry the canal without cutting into the hillsides. Within this 2 miles, from the point where it leaves Rocky Creek till it again reaches the river, the canal has, in addition to the four locks already mentioned, two flights of locks, one with four locks, aggregating 36 feet lift, and another with three locks, and in all 27 feet lift, as far as could be ascertained. Both of these flights of locks are situated in the lower part of the valley followed by the canal, and at points where it is several hundred yards wide.

The ridge between the river and the canal is interrupted at a point about a quarter of a mile below where the canal again comes in sight of the river by a narrow ravine, which retreats down to the river, and is not over 100 feet wide. From the point where the canal reaches the bank of the river it proceeds about a mile farther, first skirting the face of a steep and rocky bluff, and then across a bottom, and after rising about 9 feet, by a lock situated in the latter, it opens into the river by a guard lock and a dam, which seems to have extended across to an island, backing up the water between it and the right bank of the river, as well as some distance up Fishing Creek, which enters a short distance above, and enabling boats to pass out into the river, up between the island and the shore, and up Fishing Creek, just as they did below up Rocky Creek. The third portion of the canal, which I did not have an opportunity to examine, leaves Fishing Creek at a point a mile or so from its mouth (according to the map), and after a length of a mile or a mile and a half, in which distance, according to Mills, the fall is 56 feet, opens into the river again, which is navigable from this point to Landsford, a distance of 12 miles or thereabout. As regards the river itself, its fall in a distance of a mile and a half or thereabout, down to the point where the second portion of the canal passes in behind the ridge, as ascertained by the pocket level, is about 35 or 40 feet. At this point there was formerly a small mill. Below this the river is narrower, and the water rushes with great velocity between steep, rocky, and almost vertical banks, falling about 25 feet in less than a quarter of a mile, down to the mouth of the ravine already referred to as running up to the canal, making a total fall to this place from a point not far from the head of the second portion of the canal of, say, 60 feet in a distance of about one and a half miles. Just below the ravine was located a cotton factory, using a fall of some 5 to 7 feet, with a wing dam, and built almost over the water. The banks in this portion of the river are so steep and rocky as to preclude the construction of a canal or of extensive buildings, at least on the west side of the river. The cotton factory was a small building, not more than 50 by 25 feet. From the mouth of the ravine the river falls about 30 feet in the next quarter of a mile, making nearly 100 feet in about 2 miles. These are the Great Falls of the Catawba. The total fall is stated to be 173 feet in 8 miles.[1] The largest fall in a short distance occurs between the old mill site and the ravine, the river at this point being not over 150 feet wide, while its average width for half a mile is not over 200 feet, perhaps, and at the narrowest part it rushes with tremendous force over its rocky bed—a sheet of foam, falling some 10 or 15 feet in 150 or 200 feet.

The enormous power at this place is entirely unutilized at present, but a considerable portion of it could be rendered available without much difficulty, I think, in various ways. I have already mentioned the fact that except for small falls and small buildings there is no opportunity for the utilization of power along that part of the river opposite the second portion of the canal. A building might be erected on the site of the old factory and a fall of 10 feet obtained with ease, but [there is] only room for a small building. It may be mentioned that the dwellings of the factory operatives were on the top of the ridge between the river and the canal. But any scheme for the extensive utilization of the power must, I think, include the use of the old canal, and in this respect various methods may be employed, as follows:

1st. By rebuilding the dam at the head of the second portion of the canal, raising that portion of the canal below the first lock and locating the mills in or near the ravine already described, discharging the water through the same into the river, a fall of at least 50 feet could be obtained, necessitating, however, considerable work in cutting out the ravine for a tailrace, and with poor building facilities. The quantity of water will vary, of course, according to the dimensions given to the canal. If the canal is not raised to the level of the former dam, or nearly so, but is left at the ravine, as it was originally, the fall available will be at least 30 or 35 feet.

2d. At any or all of the three flights of locks mentioned above Rocky Creek the facilities for utilizing a large power are very good, there being ample building room, and the water being discharged into Rocky Creek. This is, in my opinion, the best way of utilizing the power. The available fall of all three flights is 95 feet, and the fall of Rocky Creek would doubtless prevent any danger whatever from freshets or any trouble from backwater; of course there would be no trouble with ice. If the level of the canal were raised, so that it ran (nearly) level from its head to these flights of locks, the available fall would be increased to about 110 feet.

3d. As regards the power on the first (lowest) portion of the canal, below Rocky Creek, the total amount of water brought through the second portion, together with the entire flow of Rocky Creek, could be turned into the canal, provided it were of sufficient capacity and utilized lower on the stream. By raising that portion of the canal below the first lock, an available fall of about 30 or 35 feet could be secured at the lower end; but as this whole bottom, through which the canal passes, is subject to overflow, the facilities for building are not so good as in the last case. Still, there is no reason why this fall could not be utilized, if desired. This site would suffer also more trouble with backwater than the last one described, which would be, in

[1] Mills's Statistics of South Carolina.

fact, almost absolutely free from it. Summing up the lifts of all the locks in the first and second portions of the canal, we see that the total fall is 130 feet and over, as follows:

	Feet.
One guard lock at upper end of second portion, lift, say	—
One lock half a mile below, lift, say	9
Flight of 3 locks, 9 feet each, behind ridge, lift, say	27
Flight of 4 locks, 9 feet each, behind ridge, lift, say	36
Flight of 4 locks, 8 feet each, behind ridge, lift, say	32
Guard lock at head of first portion (lowest), lift, say	—
Lock, half a mile below, close to bluff, lift, say	9
Two locks, outlet to river, 9 feet each, lift, say	18
Total	131+

The following facts are from a report prepared by Prof. J. A. Holmes:

Landford Shoal, 12 or 15 miles above Great Falls, is the next unutilized power of importance. There is said to be here a fall of 40 feet in a distance of 2 miles. At this point there was built by the State of South Carolina a canal nearly 2 miles long, with one guard lock and four lift locks with a total lift of about 35 feet. With a good dam at the head of the canal it is estimated that a fall of 40 feet could be obtained. Between Landford and the North Carolina line, a distance of from 25 to 30 miles, there are no shoals or developments of importance.

Near the State line there are several shoals with falls of from 3 to 5 feet, some of which have been used to a limited extent, but there is so often trouble from high water that these sites are unsuitable for factories. At Ross Falls, located a short distance above the State line, there is said to be a fall of 8.1 feet in a distance of 0.9 mile. At Rock Island Shoal is now located, on the Mecklenburg side of the river, a grist and saw mill. There is a wing dam about 350 feet long and 5 feet high, which gives a fall at the mill of about 9 feet, and the power used is about 60 horsepower. The Rock Island Woolen Mill was formerly located here.

The Tuckaseegee Shoal, about 9 miles above the State line and 1 mile below the Carolina Central Railroad crossing, is a water power of considerable importance, which has been more largely developed than the powers below. The natural fall here is said to be 11.22 feet in a distance of 1.02 miles. The Tuckaseegee Manufacturing Company's cotton mill, located on the Gaston or west side of the shoal, contains 55 cards and 6,000 spindles, and used water power aggregating 150 horsepower. There is a wooden wing dam about 200 feet long, giving a fall of 11 feet at the mill. There is never any trouble from lack of water, but high water interferes with the running of the mill on an average of six days in the year.

The fourth large power on the Catawba is at Mountain Island Shoal, about 3 miles above the railroad and above the mouth of Dutchmans Creek. The fall in the river between a point 1 mile above the factory, or a little above the head of the shoal, and the railroad bridge below is 38 feet, but of this fall nearly 30 feet occurs in the course of 1 mile near the factory. The bed of the river is rock, the banks on the east side are very steep, while those on the west are shelving and very favorable for building, as they are free from danger at high water. The power is utilized to a small extent by the cotton factory of the Catawba Electric Power Company, which contains 6,300 spindles, 100 looms, and 48 cards. At the head of the shoal there are three small islands near the right bank, with a distance of only a few feet between them and the shore, forming a natural canal. The water of the canal is all that is used by the factory, as there is no milldam at the head of the islands except a wing dam of wood, 300 feet long and 4 feet high, which turns the water into this "race." There are also three slough dams, connecting the islands with each other and the lowest with the shore, the first two of which are of rough stone and the third of crib work, about 40 feet long and 8 feet high. From the foot of the lowest island an artificial race leads to the factory. This race is 600 feet long, and the fall of water at the factory is 22 feet, from which about 190 horsepower is obtained. In addition to the above there is a sawmill, a gristmill, and a cotton gin, using together some 50 or 60 horsepower with a fall of 15 to 16 feet. The total distance between the factory and the head of the small islands referred to is about three-fourths of a mile, and the fall down to the factory is in the neighborhood of 26 feet. The whole of this power is easily available on the west bank, with good facilities for buildings and canals.

Of the shoals above Mountain Island but few have been utilized, and these to a small extent.

The first important shoal above Mountain Island is the Cowan Ford Shoal, where the fall is 27.25 feet in a distance of 4.17 miles. This place is 24 miles above the State line.

Beatties Ford Shoal is about 6 miles farther up the river and about 34 miles above the State line. The power is reported to be a good one. It has a fall of 13 feet in 2.38 miles, and 8 feet of this fall is said to occur in 1,000 feet, where the stream has a width of about 100 yards and a rock bottom suitable for the foundation of a dam.

Fifty miles above the State line, 2 miles above Sherrills Ford, and 2 miles below the Buffalo Shoal is the first of the shoals above Mountain Island which is now utilized to any extent. The cotton mill of the Monbo Manufacturing Company, which operates 7 cards, 43 looms, and 1,600 spindles, is located on the west bank of the river, which is at this point about one-fourth of a mile wide and divided by islands. From the Monbo mill a dam 225 feet long and 4 feet high extends across a division of the river to Goat Island, and thence a wing dam 2 feet high extends up the river 800 feet to the lower end of Long Island. This wing dam and island divide the river into two parts; the western portion furnishes power for the Monbo mill, the eastern remains as yet undeveloped. At the Monbo mill there is 6 feet of fall, affording about 60 horsepower; only a small part of the power available is now used.

The Long Island Cotton Mill is located about 1 mile above the Monbo mill, on the west bank of the river. It derives its power from a shoal in that part of the river between Long Island and the west bank. The mill contains 10 sets of cards and 3,000 spindles, using about 60 horsepower, a small part of the power available. The dam is about 300 feet long, extending from the west bank to Long Island, and is from 3 to 6 feet high, giving a fall of water at the mill of 6.5 feet. Buffalo Shoal, about 2 miles above the Long Island Shoal and about 55 miles above the State line, has a fall of about 11.4 feet in a little more than half a mile. About 7 miles above Buffalo Shoal and a less distance above the railroad there is a shoal with a fall of 9.7 feet in a distance of 2.18 miles, and 2 miles higher up the river is another shoal with a fall of 8.5 feet in a distance of 1.32 miles.

Sixty-five miles above the State line is Lookout Shoal, which has the largest fall of all the shoals on the river in North Carolina, the fall being 54.25 feet in a distance of 3.2 miles. About 30 feet of this fall is said to occur in three-fourths of a mile, at a place where the river has a width of about 900 feet. The bed is of rock, and it is said that an abundance of stone for building, and good factory sites, are to be found on both sides of the river. This power is only 6 miles from the Western North Carolina Railroad at Catawba station. About 1⅓ miles above the head of Lookout Shoal, and 65 miles above the State line, between the upper end of Druin Island and the lower end of Three Cornered Island, is a shoal with a fall of 9.7 feet in a distance of 1.16 miles. Between the upper end of this shoal and the mouth of Lower Little River are small shoals having a fall of 3.36 feet in a distance of nearly 1 mile. Canoe Landing Shoal, about 2 miles above the mouth of Lower Little River and 73 miles above the State line, has a fall of 8.94 feet in a distance of 1.87 miles. Great Falls Shoal, immediately above the Canoe Landing Shoal and 75 miles above the State line, possesses a fall of 14.83 feet in a distance of 1.02 miles. These two shoals have a total fall of 23.76 feet in a distance of 2.89 miles. It may be possible to develop the two together into one fine power, but the cost and practicability of this can only be determined by careful survey.

Horse Ford Shoal, 10 miles above Great Falls, 3 miles north of Hickory, and 85 miles above the State line, has a fall of 31.4 feet in a distance of 2.9 miles. The power is being utilized to a limited extent only. On the upper part of the shoal a fall of 6 feet is being used to run the Catawba Lumber Mills; and on the middle portion of the shoal are located the Horse Ford sawmill and gristmill, the latter with three run of stones, using from 25 to 30 horsepower. This is undoubtedly one of the largest and most accessible water powers of the upper Catawba river. Devils Shoal, the lower end of which is 6 miles above the Horse Ford Shoal and 91 miles above the State line, has a fall of 13.78 feet in a distance of 1.01 miles, and is said to be a fine location. Rocky Ford Shoal at Morganton, about 20 miles above Devils Shoal and 102 miles above the State line, has a natural fall of 9.5 feet in a distance of

1,500 feet. This power was formerly used by a gristmill, and there was a dam 2 feet high and 400 feet long, giving a fall of 11.5 feet at the mill. The wheel gave some 60 to 70 horsepower with water wasting all the time. The mill is not now in use.

The first of the tributaries of this river[1] that has much developed power is the South Fork, which joins the main river just at the State line. Stowesville Cotton Mill, 3 miles from Belmont station on the Southern Railway, is utilizing the first important shoal on the river. The mill contains 24 looms, 2,250 spindles, and 16 cards, operated by water power alone. The dam is 5 feet high and 200 feet long, built of wood and stone, giving with a race of from 500 to 600 feet long a head of 16 feet on the wheel, furnishing perhaps some 50 horsepower. Spring Shoal, the next power on the river, is the site of the McAden Mills, located 6 miles above the Stowesville Mill, and just beyond the mouth of Duharts Creek, and 1½ miles from Lowell station on the Southern Railway. The mill contains 320 looms and 15,000 spindles. The dam is 5 feet high and 500 feet long and the fall at the mill is 23½ feet, where it is claimed 700 horsepower can be developed. The fall of the shoal is 24 feet, and it is said that in half a mile a fall of 30 feet can be secured over a bed of solid rock.

The name of Massey Shoal has been applied primarily to the lowest of three shoals so close together that they can be developed as one power. The upper shoal was formerly occupied by the mill of the Woodlawn Manufacturing Company and the middle shoal by the mill of the Lawrence Manufacturing Company. The three shoals have a combined fall of 25.9 feet in a distance of about 1 mile. Spencer Mountain Mill, 3 miles above the Massey Shoal and 12 or 13 miles above the mouth of the river, contains 6,000 spindles and 30 cards, and uses about 100 horsepower. The wooden frame dam, 600 feet long and from 2 to 7 feet high, gives a fall of 13 feet at the wheel, through a race 190 feet long. The fall here might be increased, as the available fall, it is stated, is about 18 feet.

The Friday Shoal is a rock shoal said to have about 10 feet fall and to be a good power. This is the site of the cotton mill of the Harden Manufacturing Company, which contains 2,080 spindles. The dam is 6 feet high and 200 feet long, giving a fall at the mill of 16 feet, where it is said that from 80 to 85 horsepower is available at all times.

High Shoal, the next power, is one of the best on the stream. It is situated between the mouths of Kettle Shoal Creek and Hynes Creek, 7 miles from Lincolnton and 1 mile from the Carolina and Northwestern Railroad, which crosses the river just below the shoal. The stream flows over a ledge of solid gneiss rock, the fall being about 22 feet in 300, but the fall continues below for some distance, amounting to 27 feet in 600 and probably 35 feet in one-fourth of a mile or more. The banks are abrupt on both sides, but there is still an abundance of room for buildings, while the best location is on the left bank. The whole flow of the stream can easily be controlled, as the facilities in all respects are excellent. The width of the stream is 300 feet above the fall and probably more below, as the channel is cut up by rocks and islands. This power was used twenty-five or thirty years ago to drive a rolling mill, a nail factory, and other iron works, together with a grist and saw mill, situated on the left bank and using about 180 horsepower.

The Long Shoals Cotton Mill is situated on a shoal of the same name, just below the mouth of Indian Creek and 4 miles below Lincolnton. The mill contains 5,200 spindles, and is run by water power alone. The dam is of wood and stone, 13 feet high and 300 feet long. The race is 300 feet long and the fall of the water at the mill is 13 feet. It is expected to develop 300 horsepower here during ordinary seasons.

The Lincoln Cotton Mill is located 2 miles above the Long Shoals mill, on the site of the old paper mill formerly owned by W. & R. Tiddy, of Charlotte. The dam is of wood, giving a fall of 13 feet at the wheel. The mill contains 5,000 spindles.

[1] Data compiled from a report prepared by Prof. J. A. Holmes, State geologist of North Carolina.

The Laboratory Cotton Mill is located on the river one-half mile above the paper mill, above the mouth of Indian Creek and below that of Sand Branch. The mill contains 6,500 spindles. The dam is of logs, 6 feet high and 500 feet long, giving a fall of 9 feet at the mill and developing, it is claimed, about 250 horsepower.

Rating table for Catawba River at Catawba, North Caroli: ı, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.5	750	3.8	4,535	6.6	12,795	10.0	22,825
1.6	850	4.0	5,125	6.8	13,385	10.5	24,300
1.7	950	4.2	5,715	7.0	13,975	11.0	25,775
1.8	1,050	4.4	6,305	7.2	14,565	11.5	27,250
1.9	1,160	4.6	6,895	7.4	15,155	12.0	28,725
2.0	1,270	4.8	7,485	7.6	15,745	12.5	30,200
2.2	1,490	5.0	8,075	7.8	16,335	13.0	31,675
2.4	1,730	5.2	8,665	8.0	16,925	13.5	33,150
2.6	1,980	5.4	9,255	8.2	17,515	14.0	34,625
2.8	2,250	5.6	9,845	8.4	18,105	14.5	36,100
3.0	2,560	5.8	10,435	8.6	18,695	15.0	37,575
3.2	2,980	6.0	11,025	8.8	19,285	15.5	39,050
3.4	3,450	6.2	11,615	9.0	19,875	16.0	40,525
3.6	3,960	6.4	12,205	9.5	21,350		

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

[Drainage area, 1,535 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth, in inches.	Second-feet per square mile.
1897.						
January	6,452	1,050	1,647	101,270	1.23	1.07
February	40,230	1,550	7,006	389,095	4.79	4.60
March	17,663	1,550	5,637	346,605	4.24	3.67
April	40,525	2,180	5,014	298,355	3.64	3.26
May	11,025	1,435	2,600	159,870	1.95	1.69
June	3,450	1,270	1,833	109,070	1.33	1.19
July	3,210	1,270	1,774	109,080	1.34	1.16
August	2,560	950	1,321	81,225	0.99	0.86
September	1,380	900	1,017	60,515	0.73	0.66
October	16,925	850	1,787	109,880	1.35	1.17
November	2,560	950	1,233	73,370	0.89	0.80
December	1,850	1,105	1,328	81,656	0.99	0.86
The year	40,525	850	2,683	1,919,991	23.47	1.75

DAM ACROSS BROAD RIVER AT HEAD OF COLUMBIA CANAL, NEAR COLUMBIA, SOUTH CAROLINA.

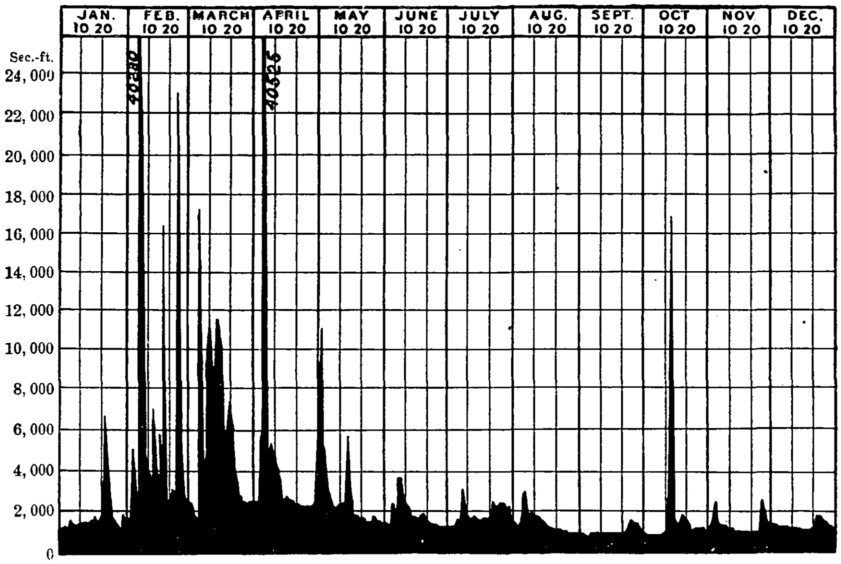


FIG. 50.—Discharge of Catawba River at Catawba, North Carolina, 1897.

Rating table for Catawba River at Rockhill, South Carolina, for 1897.

Gage height.	Discharge.		Gage height.	Discharge.	
	Jan. 1 to Feb. 6.	Feb. 7 to Dec. 31.		Jan. 1 to Feb. 6.	Feb. 7 to Dec. 31.
Feet.	*Second-feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Second-feet.*
1.0	....	1,600	5.0	....	9,800
1.2	....	1,700	5.5	....	11,300
1.4	1,250	1,900	6.0	....	13,000
1.6	1,450	2,200	6.5	....	14,750
1.8	1,700	2,500	7.0	....	16,550
2.0	2,000	2,800	7.5	....	18,500
2.2	2,350	3,100	8.0	....	20,500
2.4	2,700	3,450	9.0	....	25,500
2.6	3,100	3,800	10.0	....	31,000
2.8	3,500	4,200	11.0	....	38,000
3.0	3,900	4,600	12.0	....	45,300
3.5	5,050	5,750	13.0	....	52,700
4.0	6,400	7,000	14.0	....	60,100
4.5	8,050	8,375	15.0	....	67,500

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.		Depth, in inches.	Second feet per square mile.
1897.						
January	5,550	1,575	2,097	128,940	0.81	0.70
February	65,650	1,775	9,277	515,220	3.24	3.11
March	19,300	3,275	7,537	463,430	2.91	2.52
April	54,920	3,100	7,055	419,800	2.63	2.36
May	8,100	2,650	3,571	219,575	1.38	1.20
June	7,825	2,200	3,128	186,130	1.17	1.05
July	10,550	2,050	2,900	178,315	1.12	0.97
August	8,925	1,975	2,587	159,070	1.00	0.87
September	2,200	1,700	1,817	108,120	0.68	0.61
October	9,200	1,700	2,311	142,100	0.89	0.77
November	4,000	1,900	2,186	130,075	0.81	0.73
December	3,100	2,125	2,523	155,135	0.97	0.84
The year	65,650	1,575	3,916	2,806,120	17.61	1.31

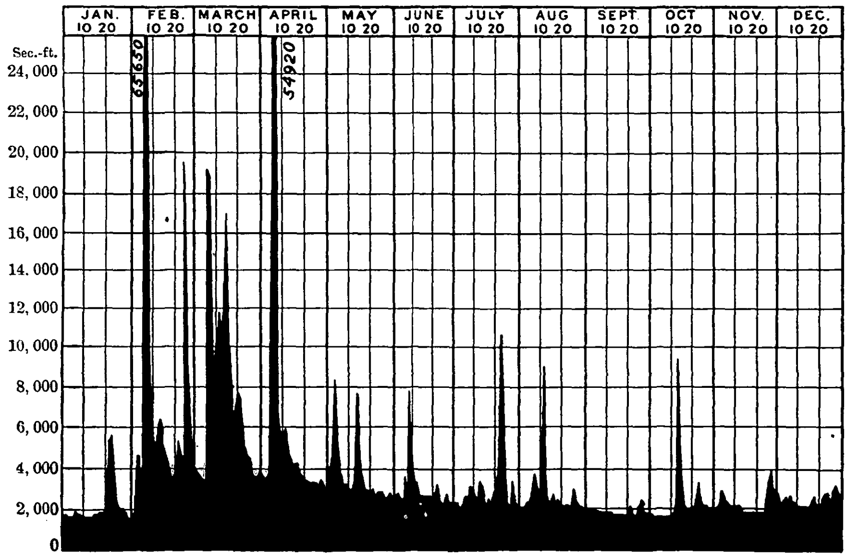
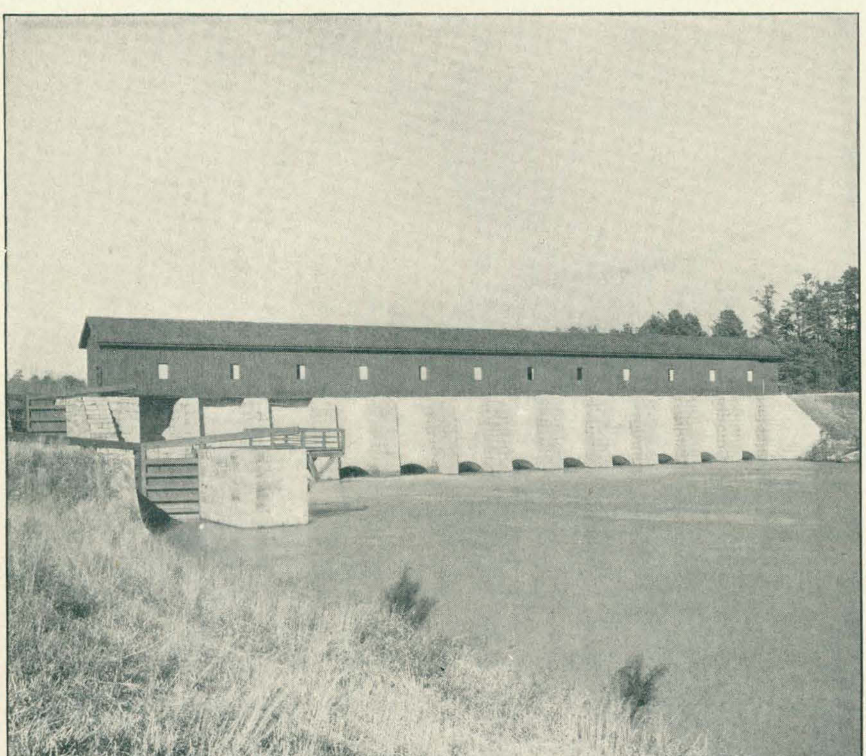


FIG. 51.—Discharge of Catawba River at Rockhill, South Carolina, 1897.

A. POWER HOUSES AT COLUMBIA, SOUTH CAROLINA.



B. BULKHEAD AT HEAD OF COLUMBIA CANAL, NEAR COLUMBIA, SOUTH CAROLINA.

BROAD RIVER.

This stream takes its rise on the eastern slope of the Blue Ridge near Hickorynut Gap, and, flowing in a general southeasterly direction, unites with Saluda River just above Columbia to form the Congaree. The length from source to mouth, measured in a straight line, is about 128 miles, but following the course of the stream it is much greater. The drainage area comprises about 4,950 square miles, of which 3,500 are in South Carolina and 1,400 in North Carolina, its general character resembling that of the Catawba. Broad River receives a number of important tributaries, but there are no towns of importance along it.

The following statements are from a report by Prof. J. A. Holmes:

At Columbia is a shoal 3 miles long, extending 2 miles above Columbia and 1 mile below, with a fall of 41 feet where the river crosses the fall line. The Columbia Canal as it was first constructed was 5 miles in length, 16 feet in width at bottom and 28 feet at surface of water, and 3 feet in depth. The present canal has for its minimum dimensions for a distance of 3½ miles from the bulkhead (see Pl. XXIX, *B*), 110 feet wide at the bottom, 150 feet at the normal surface of the water, and 10 feet deep, giving a waterway of 1,300 square feet; thence in about one-fourth of a mile these dimensions are reduced to 80 feet wide at the bottom and 120 feet at top, and 10 feet deep. The bottom grade is 1 foot per mile, which gives a flow of about 4,830 cubic feet per second, when the water surface in the canal is parallel to the bottom. The capacity of the canal, if used under an average head and fall of 31 feet, is 12,590 horsepower, assuming that wheels are used developing 74 per cent of the theoretical power, which is estimated at 16,988 horsepower. The total cost of the canal has been $912,000.

The dam (see Pl. XXVIII) is 1,000 feet long on the crest and crosses the river in a broken line, slightly V-shaped, apex upstream, built of crib work filled with hand-placed stone. The abutment on the west side of the river is formed by a ledge of granite in place; that on the east side of granite masonry laid in hydraulic-cement mortar. The bulkhead, through which water is admitted into the race, is composed of abutments, piers, arches, and parapet wall of granite masonry laid in hydraulic-cement mortar. The gates are 24 in number, and the clear opening in the bulkhead is 1,344 square feet, which, with the area of the lock opening that may be used for passing water into the race, gives an aggregate area of 1,406 square feet. The power generated is developed in four power houses: The pumping station of the city waterworks, which develops 500 horsepower; the Columbia Electric Street Railway, Light, and Power Company, which develops 500 horsepower; the Columbia Mills Company, which develops 3,000 horsepower, transmitted electrically to their mill, containing 30,000 spindles, located across the canal and about 800 feet distant from the power house; the

Columbia Water Power Company, which has recently completed the installation of a plant of 3,000 horsepower capacity, which may be increased to 10,000 horsepower. The plant consists of three turbines of 1,250 horsepower each, three 750 K. W. generators—3-phase alternators of 3,450 volts each—with their exciters, water governors, switch boards, etc. The Granby mills, located 1½ miles distant, containing 30,000 spindles, 1,400 looms, and using 1,500 horsepower, is the largest customer. The remainder of the power is either used by other establishments or is for sale.

The power plant of the Columbia Mills Company consists of two turbines directly connected to two 500 K. W. 3-phase generators, two 10-horsepower direct-current generators to excite the fields of the large generators, an electric water governor, and a switch board. The current is carried to the mills through cables placed underground and is distributed there to the motors, which are of 45 horsepower each, making 540 revolutions per minute, starting at full load, and not stopping if they are overloaded up to 125 horsepower. In the accompanying view (Pl. XXIX, *A*), the power house of the Columbia Mills Company is seen on the left, the cotton mill being in the background. The power house of the Columbia Water Power Company is seen on the right.

Ninety-nine Island Shoal is 11.5 miles above Columbia, its fall being 17.26 feet in a distance of 2.75 miles. The banks are favorable for building, and the power is no doubt easily available. The river is very wide; in some places over half a mile. Boney Shoal, 17.75 miles above Columbia, is 1 mile long and has a fall of 6 feet. Summers Shoal, beginning 26.25 miles above Columbia and extending 1 mile, has a fall of 11.61 feet. This is said to be a fine site for power. It is 13 miles below the mouth of the Enoree River. Lyles Shoal, 41 miles above Columbia, has a fall of 11.36 feet in 3,930 feet. It is situated 3 miles below the mouth of the Tiger River and 1 mile above the mouth of the Enoree. Neals Shoal, 58.5 miles above Columbia, has a fall of 9.75 feet in 3,300, and the river here is from 250 to 350 yards in width. The next shoal, the first of great importance as a water power, and perhaps the best site on the river, is Lockharts Shoal, situated less than 2 miles above the mouth of Turkey Creek. This shoal is preceded by a short shoal called Gravel Shoal, which has a fall of 6.11 feet in 2,673. Just above this is Lockharts Shoal proper. The lower shoal is 2,955 feet long and has a fall of 15.80 feet, and the upper shoal is 3,000 feet long and has a fall of 31.86 feet, so that the total length of the shoal is 1.41 miles and the total fall 47.66 feet. The width of the stream above the shoal is 200 yards and the depth of the water is from 25 to 30 feet.

Above this shoal there is no power of importance for nearly 25 miles, the next being a long shoal (6.25 miles), generally subdivided into two, the Ninety-nine Island Shoal, 3.2 miles long with a fall of 50.62 feet, and Cherokee Shoal, 2 miles long with a fall of 50.95 feet. The head of the latter is about 3 miles below the crossing of the Southern Railway.

This is the site of the Cherokee Mills, which contain 6,556 spindles and 392 looms, operated by water power alone.

Surratts Shoal, 108 miles above Columbia, is the first shoal above the Southern Railway. It is 1.75 miles long, consists of a continuous series of ledges, and the fall has been stated to be not less than 20 feet to the mile. Gastons Shoal is 2.25 miles above, and is 1 mile long, with a fall of about 10 feet. The Hopper and Blanton shoals are the first shoals in North Carolina. They are located about one-fourth of a mile above the mouth of First Broad River. At this place is the beginning of a horseshoe bend, convex eastward, about 2 miles round, while the distance across the neck is only about 200 yards. This neck is low, rising only about 50 feet above the river at the highest point, and the fall has been roughly measured across it by means of a pocket level and found to be between 25 and 30 feet. On the lower side of this neck there is a short shoal in the river known as the Hopper Shoal; on its upper side there is a similar one known as the Blanton Shoal.

Palmers Shoal, 116.5 miles above Columbia, 1 mile above the mouth of First Broad River and about 7 miles below the mouth of the Second Broad, is said to be the best site above Cherokee Shoal, its entire fall, 18 feet in 0.5 mile, being available for power. Durham Shoal is located 1 mile above Palmers Shoal and 6 miles below the mouth of the Second Broad. The shoal is formed by a ledge of granite extending directly across the river, about 100 yards wide, affording an excellent foundation for a dam. The natural fall here is 7 feet. Above this point there are no shoals of any considerable importance till the mountains are reached; the fall of the river is gradual, though considerable.

The first important tributary of Broad River[1] is the Enoree. Little River, below it, has no powers worthy of special mention. The Enoree rises in Greenville County, flows southeast for about 70 miles, and drains an area of about 730 square miles. The average fall of the river is about 70 feet to the mile. The shoals on the lower part of the river are rapidly filling up. For the first 25 miles there are only two small mills.

The power formerly known as Yarbrough's gristmill is the first power of importance on the river. The fall here is about 16 feet. The next shoal is Mountain Shoal, the most important one on the Enoree. It is situated about 12 miles from Laurens. The stream pours over a ledge of gneiss rock, falling nearly 70 feet in a quarter of a mile, and is divided into two shoals. At the head of the upper shoal a natural dam extends nearly across the stream, which is some 200 feet wide, and a fall 16.5 feet in 500 feet results. After flowing 200 yards with a fall of only 2 feet, the stream falls 52 feet in 250 yards. At the head of this fall the stream is 300 feet wide. The banks on the left are steep and rocky, but those on the right are lower, and at the foot of the shoal there is a bottom which is sometimes overflowed to a depth of 5 or 6 feet. The channel of the river is interspersed with islands. This is the site of the Enoree mills, which contain 30,725 spindles and 820 looms. Above this place there are several small shoals with falls of 6 to 12 feet each.

Van Pattens Shoal, about 15 miles above Mountain Shoal and over 20 miles from Laurens, is the next important power. The river here falls over a ledge of gneiss rock, as at Mountain Shoal, 55 feet in 900 feet.

[1] Data compiled from a report prepared by Prof. J. A. Holmes, State geologist of North Carolina.

The next shoal above is at the site of the mill of the Pelham Manufacturing Company, which contains 10,000 spindles driven entirely by water power from this stream. The dam is of stone, 550 feet long, and the flume which carries the water to the wheels is 65 feet long and 8 feet in diameter. The fall of water at the wheels is 32 feet. The wheels are two in number, one 35-inch vertical and one 25-inch horizontal turbine. It is claimed that the horsepower developed during dry seasons is about 325, and at ordinary seasons about 425 horsepower is developed.

After inquiry no other shoals of importance were discovered on the river. It will be seen that the Enoree River has a succession of shoals, affording considerable power. Crossing the ledges of rock at larger angles than does the Broad River, the falls of all these tributaries are more abrupt.

The next important tributary of the Broad is Tiger River, which enters only 4½ miles above the mouth of the Enoree, and from the same side. The length of Tiger River from the junction of the forks to its mouth is about 36 miles in a straight line, and its drainage area is 720 square miles, almost exactly the same as that of the Enoree, to which this stream is similar in all respects.

On account of the silting up of the stream there are no shoals of importance for 30 to 40 miles from the mouth. The first worth mentioning is the site of Hill's factory. At this place the fall continues for about three-fourths of a mile, but may be divided into three parts—the lowest with a fall of about 12 feet, the middle with a fall of about 15 to 16 feet, and the highest with a fall of 12 to 15 feet.

Four miles above is a grist and saw mill, with a fall of about 9 feet. There are some powers above, one of which is said to have a fall of 15 feet. The North Tiger has one power below its junction with the Middle Tiger where a fall occurs of about 36 feet in 300 yards. The Middle Tiger is also a small stream, with a drainage area at its mouth of 55 square miles. It has a number of shoals where the stream pours over ledges of solid rock, falling from 10 to 20 feet in a short distance, and there are several gristmills and a cotton factory on the river. The Tucapau Mills Company has a cotton mill about 2 miles from Wellford station, on the Southern Railway, which contains 16,000 spindles and 470 looms, operated by combined steam and water power.

The South Tiger is the largest of the three forks and, like the others, has a number of fine shoals, some of which have been improved.

The next tributary of the Broad which is worthy of special mention is Pacolet River, which drains an area of about 475 square miles. The stream is a succession of shoals and affords considerable water power. The first shoal met in ascending the river is Skull Shoal, 4 miles from the mouth, but the fall is only 3 feet. Grindall Shoal, about 14 miles from the mouth, has a fall of about 6 feet.

The first important shoal is Trough Shoal, the most notable power on the river, 23 miles from its mouth, 12 miles from Spartanburg, and 2 miles from Pacolet Station, on the Southern Railway. The total length of the shoal is nearly three-fourths of a mile, and the total fall in that distance is in the neighborhood of 60 feet, as ascertained by a pocket level. At the upper end the stream is contracted, for a distance of 100 feet or more, between two vertical walls of rock, to a width of from 10 to 15 feet, the depth being 16 feet at ordinary stages of the water. The bed of the stream consists of solid rock or bowlders for the entire length of the shoal and the fall is distributed as follows:

For about 500 feet the bed is rough and about 200 feet wide, the fall in this distance being 22 feet; in the next 750 feet the fall is only 5.5 feet, while in the following 350 feet an equal fall occurs between banks which are rocky and very steep. The banks retain the same character for the next 500 feet, with a fall of 11 feet; thence the river has falls of 5.5 feet in three successive distances of 250, 750, and 300 feet, respectively. The fall of the entire shoal amounts to 60 feet. The power is one of the best in this vicinity and is utilized in part by the Pacolet mills, which contain 56,328 spindles and 2,160 looms.

One mile above Pacolet is Brown's mill, where there is said to be a fall of 14 feet, and 2½ miles beyond is another site where the fall is 8 or 10 feet. Thirty miles above the mouth of the river is the shoal known as Hurricane Shoal, formerly occupied by iron works, but now the site of the Clifton cotton factories. These three mills are within a short distance of each other on the river and contain an aggregate of 85,848 spindles and 2,698 looms, operated by water and steam power combined.

Lawsons Fork, which enters the Pacolet several miles below Clifton, has a drainage area of 82 square miles. It contains several falls; the first, of about 15 feet, occurs just below Glendale, and the second at Glendale, 6 miles from Spartanburg. The latter is used by the cotton factory of D. E. Converse & Co., which contains 17,280 spindles and 518 looms, operated by steam and water power combined.

On Buffalo Creek, near the crossing of the Seaboard Air Line, there is a small cotton mill containing 3,000 spindles, operated by the Buffalo Manufacturing Company. The dam is 90 feet long and 25 feet high, giving a fall of 30 feet at the wheel.

On First Broad River the Lauraglen Cotton Mill is situated, 3 miles southwest of Shelby. This factory contains 3,500 spindles and is operated entirely by water power. The dam is 14 feet high and 200 feet long, and the head on the wheel is 15 feet.

Double Shoals, the next important power on the river, is the site of the cotton factory known as the Double Shoals mill, which contains 2,000 spindles, situated about 8 miles north of Shelby and 4 miles east of the Cleveland mills. The dam is 9 feet high and the water falls 15 feet at the mill. Cleveland Cotton Mill No. 2 is also located on this stream, 10 miles north of Shelby and 3 miles north of the Double Shoals mill. The mill contains 4,224 spindles. The dam is 12 feet high and 270 feet long, and the fall of water at the factory is 13 feet.

On Knob Creek, a small tributary which joins the Second Broad at Gardners Ford, is situated the Cleveland Cotton Mill No. 1, about 12 miles north of Shelby. The mill contains 884 spindles. The dam is 15 feet high and 90 feet long, giving a head of 15 feet at the mill.

Second Broad River, the next tributary worth mentioning, rises in McDowell County and flows through Rutherford County, draining an area of 193 square miles. It is a small stream, only 30 feet wide at its mouth, but contains several good powers. Tumbling Shoal, 3 miles from the mouth of the river, has a fall of 11 feet in a distance of 200 yards, and a good building site may also be obtained. The river would probably give from 4½ to 5 horsepower per foot of fall in the low season of dry years.

High Shoals, on which is located Henrietta Cotton Mill No. 1, is 4 miles above the mouth of the river. The original shoal had a fall of 23.4 feet in a distance of about 800 feet. The dam is of stone, 200 feet long, 17.8 feet high, 18 feet base, and 5 feet coping, curving slightly upstream. The race is 300 feet long, 35 feet wide, and 10 feet deep, giving a fall at the wheel of 32 feet. The mill contains 25,000 spindles and 1,000 looms.

The Henrietta Mill No. 2 occupies the next two shoals, about 2 miles above High Shoals. The two shoals have a total natural fall of 18 feet. The dam is placed on the lower shoal and backs water over the upper, giving a fall of 29 feet at the wheel. This mill contains 35,000 spindles and 1,000 looms.

Rating table for Broad River at Gaffney, South Carolina, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.7	780	2.4	3, 028	4.4	7, 788	6.2	12, 072
0.8	790	2.6	3, 504	4.6	8, 264	6.4	12, 548
0.9	810	2.8	3, 980	4.8	8, 740	6.6	13, 024
1.0	845	3.0	4, 456	5.0	9, 216	6.8	13, 500
1.2	940	3.2	4, 932	5.2	9, 692	7.0	13, 976
1.4	1, 070	3.4	5, 408	5.4	10, 168	7.5	15, 166
1.6	1, 250	3.6	5, 884	5.6	10, 644	8.0	16, 356
1.8	1, 600	3.8	6, 360	5.8	11, 120	8.5	17, 546
2.0	2, 076	4.0	6, 836	6.0	11, 596	9.0	18, 736
2.2	2, 552	4.2	7, 312				

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

[Drainage area, 1,435 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	2, 790	800	1, 026	63, 090	0.82	0.71
February	18, 022	970	4, 111	228, 315	2.99	2.87
March	11, 596	1, 719	4, 556	280, 140	3.67	3.18
April	18, 736	1, 957	4, 198	249, 800	3.26	2.93
May	7, 550	4, 694	5, 402	332, 155	4.34	2.76
June	10, 287	3, 623	5, 126	305, 020	3.98	3.57
July	7, 074	2, 076	4, 310	265, 010	3.46	3.00
August	3, 861	1, 070	1, 951	119, 960	1.57	1.36
September	1, 600	790	929	55, 280	0.72	0.65
October	7, 312	790	1, 244	76, 490	1.00	0.87
November	3, 266	845	1, 264	75, 215	0.98	0.88
December	3, 266	940	1, 521	93, 520	1.22	1.06
The year	18, 736	790	2, 970	2, 143, 995	28.01	1.99

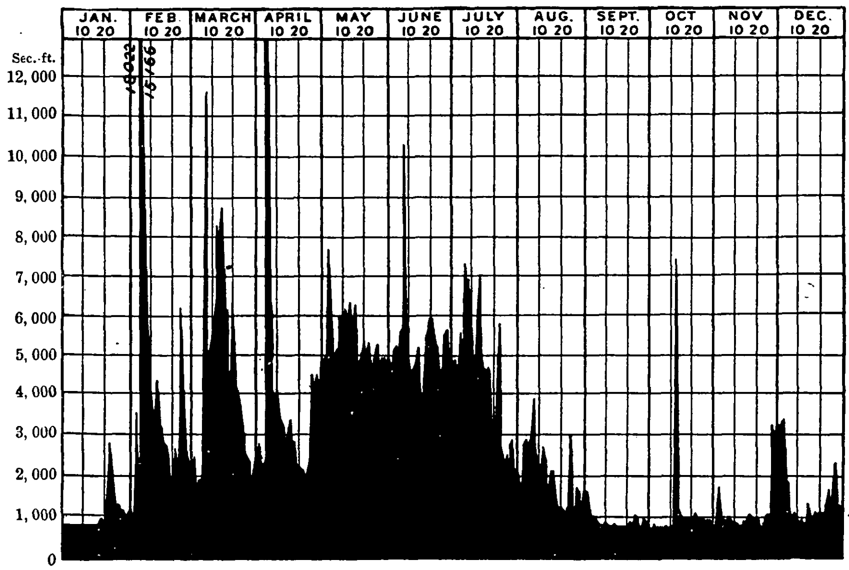


FIG. 52.—Discharge of Broad River at Gaffney, South Carolina, 1897.

SALUDA RIVER.

The Saluda is formed on the boundary between Pickens and Greenville counties, South Carolina, by the union of its North, South, and Middle forks, and flowing southeast unites with the Broad to form the Congaree. The length of the stream in a straight line is about 110 miles and its drainage area is about 2,350 square miles. The general character of the Saluda, which contains numerous shoals and falls, is similar to that of the Enoree and the other tributaries of the Broad. At Beards Falls, 2 miles above Columbia, is the factory of the Saluda Manufacturing Company. The dam is of stone, 900 feet long and 9 feet high, with a race 200 feet long. The fall at the factory is from 14 to 16 feet.

Saluda River was made navigable many years ago by the State, and three canals were constructed, the lowest one being around Beards Falls. The canal was 2½ miles long and had five locks with a total lift of 34 feet, covering the fall of the river between its mouth (where there was a dam across the Broad, in the pool of which boats were floated over to the Columbia Canal) and the head of Loricks Falls, 1½ miles above the Saluda factory. At these falls there is a natural fall in the river of about 6 feet, and their head is 27 feet above the mouth of the river. The available power at the mouth of the Saluda may therefore be considered due to a fall of from 30 to 34 feet, and it is said that the old canal could be put in order without much difficulty.

The next site above Loricks Falls is beyond the mouth of Twelvemile Creek, at Drehers Canal, the second State canal, which was 1 mile long and had four locks, with a total lift of 21 feet. The most important power on this part of the river is at Great Falls, or Wares mill, above the mouth of Reedy River. The shoal is in all about 1 mile long and the fall is 45 feet. At the head was a wing dam on the left bank, and a race one-half mile long gave a fall of 21 feet at a sawmill. About 300 yards below the tailrace was a second wing dam on the right bank, and a race 300 yards long gave a fall of 20 feet at a saw and grist mill.

The next site on the river is a power owned and used by the Pelzer Manufacturing Company (see Pl. XXVII, *B*). The dam here is 700 feet long and gives a fall of 39 feet at the wheels. Five wheel pits, each containing one pair of 39-inch horizontal wheels, develop 1,050 horsepower per pair. Only three pairs of wheels and three generators are at work. The horsepower developed is 3,150 and is carried a distance of 2⅝ miles. The power station is equipped with three 1,000-horsepower, 3-phase, 3,300-volt generators, exciters, and the necessary station apparatus. The installation at mill No. 4 consists of 21 induction motors and 1,200 lights. Mill No. 3 has one 400-horsepower motor and ten 5-horsepower motors. The four mills at Pelzer contain 111,000 spindles and 3,000 looms; of these 75,000 spindles are operated by power electrically transmitted. At Pelzer are located all the mills owned by this company, and here is the second development. The dam is of granite in cement, 250 feet long and 15 feet high, with a race of 200 feet and a fall used at the factory of 21 feet. Six miles above is the factory of the Piedmont Manufacturing Company, but between this and the Pelzer mill is the Allen Shoal, with a natural fall of 14 feet in 250 yards, capable of being increased to 18 feet without interfering with the Piedmont factory, about 2 miles above. The dam at the Allen Shoal is of stone, 217 feet long, 23 feet high, and gives a fall of 28 feet at the mill. The wheels are six in number, three 48-inch vertical and three 54-inch horizontal turbines, developing between 900 and 1,000 horsepower. The mill contains 59,326 spindles and 1,838 looms. Above this point there are several shoals on the river, but none of importance.

Reedy River is the principal tributary of the Saluda below the forks. The length of the stream measured in a straight line is about 50 miles, and its drainage area is 386 square miles. Tumbling Shoal, about 16 miles from the mouth of the river, is the most important on the stream. The shoal is short, and the fall amounts to 10 feet in 75. The next shoal is Cedar Falls, where the fall is stated to be about 20 feet. One mile above is Fork Shoal, at the mouth of Reedy Fork Creek, about 16 miles from Greenville. It is stated that a fall of 20 feet can be obtained here. At Greenville there is a fall of 64 feet in 500 yards.

The Courtenay Manufacturing Company has developed a power located on Little River, about 4 miles from Seneca, on the Southern Railway. The dam is built in a curved line, with a radius of 114 feet, and is 113 feet long, giving 22 feet head through a race 175 feet long, 30 feet wide, and 10 feet deep. There are two 48-inch horizontal turbines, with one small 21-inch turbine for driving fire pump, etc. The total horsepower developed is 750 during low seasons; it is used to drive 400 looms and 17,000 spindles.

SENECA RIVER.

During the latter part of 1895 the Anderson Water, Light, and Power Company, of Anderson, South Carolina, began the transmission of electricity, generated by water power on Seneca River, 6 miles distant. This was the first long-distance transmission plant in the South, and the 200-horsepower Stanley generator, 5,500 volts, was the largest machine in the country of so high a voltage. The current is used for arc lamps, incandescent lamps, and motors. During the last year the Anderson Company has greatly enlarged their transmission plant by installing two 600 K. W., 3-phase, 10,000-volt generators, the distance of transmission being 10 miles.

The current is supplied to three 300-horsepower synchronous motors in the cotton mills at 600 volts, 70 arc lights and 1,500 incandescents, and several small motors in the town. The total horsepower delivered is 1,425.

SAVANNAH RIVER.

Savannah River is formed by the junction of Keowee and Tugaloo rivers about 100 miles above Augusta, Georgia. The head-water tributaries have their source in the Blue Ridge in North and South Carolina. The gaging station on the main river is located at Calhoun Falls at the bridge crossing of the Seaboard Air Line, and is described in Water-Supply and Irrigation Paper No. 15, p. 39. A large number of fine water powers occur on the tributaries and along the main river, the most noted being Tallulah Falls, 335 feet in height, on Tallulah River.

Rating table for Savannah River near Calhoun Falls, South Carolina, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.7	1,450	2.6	3,240	3.5	7,500	4.4	12,000
1.8	1,580	2.7	3,590	3.6	8,000	4.5	12,500
1.9	1,720	2.8	4,000	3.7	8,500	4.6	13,000
2.0	1,875	2.9	4,500	3.8	9,000	4.7	13,500
2.1	2,045	3.0	5,000	3.9	9,500	4.8	14,000
2.2	2,235	3.1	5,500	4.0	10,000	4.9	14,500
2.3	2,445	3.2	6,000	4.1	10,500	5.0	15,000
2.4	2,680	3.3	6,500	4.2	11,000		
2.5	2,940	3.4	7,000	4.3	11,500		

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

[Drainage area, 2,712 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1896.						
August	5,500	1,525	2,126			
September	9,250	1,460	2,360			
October	2,870	1,460	1,821			
November	26,000	1,950	5,644			
December	18,000	2,560	6,468			
1897.						
January	17,000	2,235	4,456	273,990	1.89	1.64
February 13–28	12,000	6,000	9,031	286,604	1.98	3.33
March 17–31	16,750	5,250	9,050	269,250	1.86	3.33
April 8–30	14,750	6,000	8,402	383,295	2.65	3.10
May	18,000	2,235	6,010	369,541	2.56	2.22
June	12,000	2,140	4,698	279,550	1.93	1.73
July	10,250	2,445	4,307	264,830	1.83	1.59
August	4,750	1,875	2,654	163,190	1.13	0.98
September	3,800	1,460	1,873	111,450	0.77	0.69
October	5,250	1,405	2,220	136,505	0.94	0.82
November	7,000	1,650	2,820	167,800	1.16	1.04
December	5,000	2,445	3,355	206,295	1.43	1.24

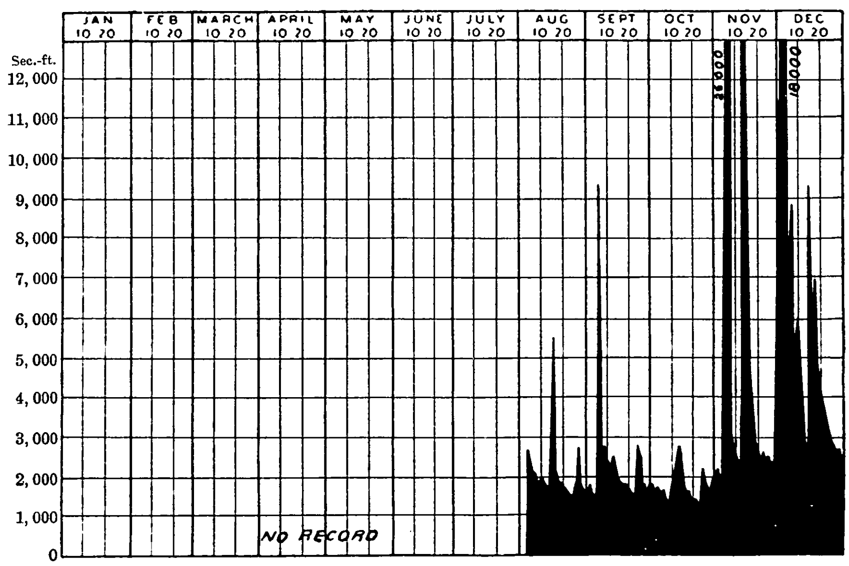


FIG. 53.—Discharge of Savannah River at Calhoun Falls, South Carolina, 1896.

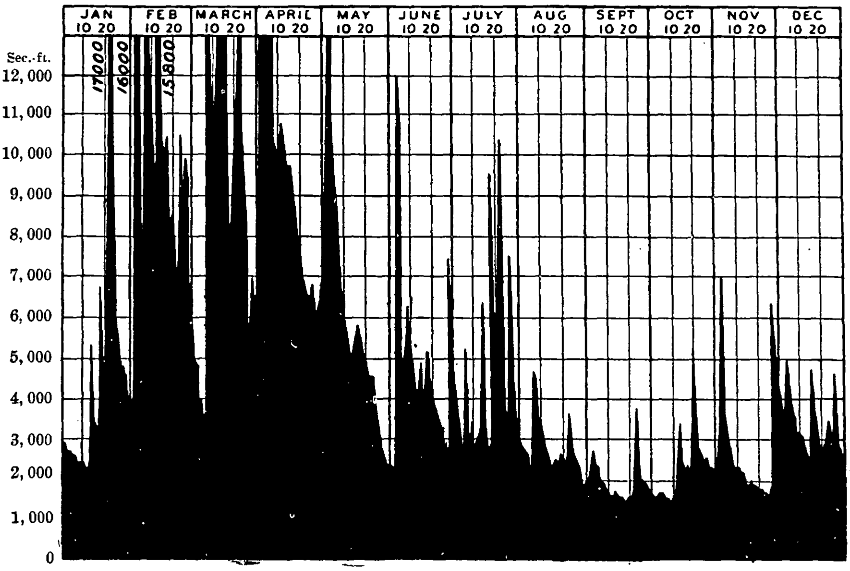


FIG. 54.—Discharge of Savannah River at Calhoun Falls, South Carolina, 1897.

BROAD RIVER IN GEORGIA.

Broad River is an important tributary of the Savannah, which it enters about 13 miles by river below the gaging station on the main river. The results of hydrographic work at Carlton, on this river, will give data for computing the power that can be developed at Anthony Shoals, below, which have a fall of over 70 feet within a short distance. The gaging station was established May 27, 1897, but observations of gage heights were not commenced until July 1, 1897. The fall at Augusta, at the head of navigation, is about 50 feet where the river crosses the fall line. Calhoun Falls and Carlton stations are described in Water-Supply and Irrigation Paper No. 15, pp. 39–40.

From measurements made September 28 on the South Fork at mouth, and of Broad River below the mouth of South Fork, the discharges of which appear in the following table of miscellaneous measurements, it is estimated by B. M. Hall that at low water the North Fork at Carlton discharges about 3.4 times as much water as the South Fork at its mouth, and that a fair approximation of the flow of Broad River below the fork can be obtained by adding 32 per cent to the discharge at Carlton.

Rating table for Broad River at Carlton, Georgia, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.5	315	2.5	973	3.5	1,683	4.5	2,393
1.6	360	2.6	1,044	3.6	1,754	4.6	2,464
1.7	410	2.7	1,115	3.7	1,825	4.7	2,535
1.8	476	2.8	1,186	3.8	1,896	4.8	2,606
1.9	547	2.9	1,257	3.9	1,967	4.9	2,677
2.0	618	3.0	1,328	4.0	2,038	5.0	2,748
2.1	689	3.1	1,399	4.1	2,109	5.5	3,100
2.2	760	3.2	1,470	4.2	2,180	6.0	3,460
2.3	831	3.3	1,541	4.3	2,251		
2.4	902	3.4	1,612	4.4	2,322		

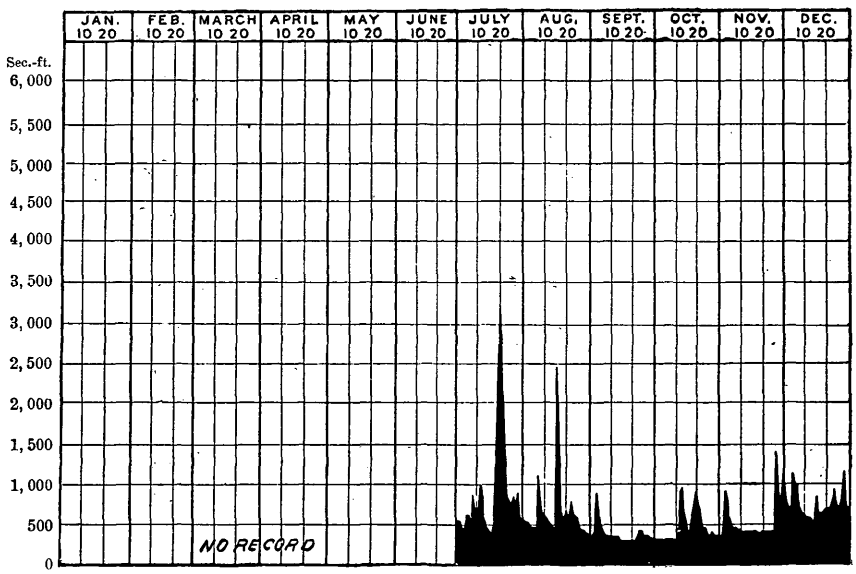


FIG. 55.—Discharge of Broad River at Carlton, Georgia, 1897.

Estimated monthly discharge of Broad River at Carlton, Georgia.

[Drainage area, 762 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
July	3,671	443	979	60,195	1.48	1.28
August	2,428	385	641	39,415	0.97	0.84
September	831	315	380	22,611	0.56	0.50
October	973	150	315	28,778	0.70	0.61
November	1,434	385	547	32,548	0.80	0.72
December	1,115	547	748	45,995	1.13	0.98

List of miscellaneous discharge measurements, Savannah Basin.

Date.	Stream.	Locality.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
1897.				*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
July 15	Savannah River	Augusta, Georgia	92	6.67	3,309	1.24	4,198
Sept. 28	Broad River...	Below mouth of South Fork.	92	1.60	275	1.71	472
Do..	South Fork of Broad River.	At mouth........	92	1.60	55	1.90	150
Sept. 29	Augusta Canal.	Augusta, Georgia	11	....	1,274	2.02	2,576
Do..	Warwick Mill Race.	.....do	11	....	40	1.59	64
Do..	Savannah River	North Augusta bridge.	11	5.17	2,440	1.30	3,180
Nov. 6	.....do	Augusta, Georgia	92	6.20	2,836	1.52	4,311

ALTAMAHA RIVER.

The drainage basin of this river occupies a large area in central Georgia. The Altamaha is formed by the junction of the Oconee and Ocmulgee. The former stream heads near Gainesville, on the southern slope of Chattahoochee ridge, which separates the head waters of this stream from those of Chattahoochee River. The upper gaging station is located at Cary, immediately below the mouth of Apalachee River, described in Water-Supply and Irrigation Paper No. 15, p. 41.

OCONEE RIVER.

The United States Weather Bureau has maintained gage readings on Oconee River at Dublin since 1894. During 1897 a number of discharge measurements were made at this point, but not a sufficient number on which to base a rating curve. The Weather Bureau discontinued its readings at the end of April, but the station will be resumed in 1898 under the direction of this office. A measurement made on the river December 9, 1897, at the Northeastern Railroad bridge near Athens, Georgia, gave a discharge of 172 second-feet.

Rating table for Oconee River at Cary, Georgia, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.0	240	1.6	560	3.2	1,848	4.8	3,450
0.2	260	1.8	675	3.4	2,024	5.0	3,750
0.4	290	2.0	815	3.6	2,200	5.2	4,080
0.6	320	2.2	970	3.8	2,376	5.4	4,500
0.8	350	2.4	1,144	4.0	2,554	5.6	4,950
1.0	380	2.6	1,320	4.2	2,750	5.8	5,410
1.2	415	2.8	1,496	4.4	2,965	6.0	5,870
1.4	470	3.0	1,672	4.6	3,200		

Estimated monthly discharge of Oconee River at Cary, Georgia.

[Drainage area, 1,346 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1896.						
November	1,800	750	867	....	....	....
December	3,610	790	1,232	....	....	....
1897.						
January	10,000	675	2,114	129,985	1.81	1.57
February	7,250	1,232	2,905	161,335	2.25	2.16
March 1-13, 18-31	10,000	1,584	3,482	181,462	2.61	2.59
April 9-30	4,720	1,232	1,955	85,309	1.19	1.45
May	2,554	740	1,130	69,480	0.97	0.84
June	1,232	510	800	47,605	0.65	0.59
July	5,410	335	1,358	83,500	1.16	1.01
August	2,650	415	948	58,290	0.81	0.70
September	740	*a* 250	460	27,370	0.38	0.34
October	1,584	395	740	45,500	0.63	0.55
November	2,112	560	829	49,330	0.69	0.62
December	1,496	815	1,116	68,620	0.95	0.83

a The low-water height reported at Cary from September 7 to September 16, 1897, was probably caused by the opening for repairs of a dam 2 or 3 miles below this point. An inspection of the conditions at Macon and other stations shows that this period did not include the lowest water of the year but that the minimum occurred during the first two weeks in October. Leaving out of account this period of sudden apparent low water, the lowest gage reading at Cary was 1.10 on October 4. A measurement made on that day at 1.08 showed a discharge of 381 second-feet.

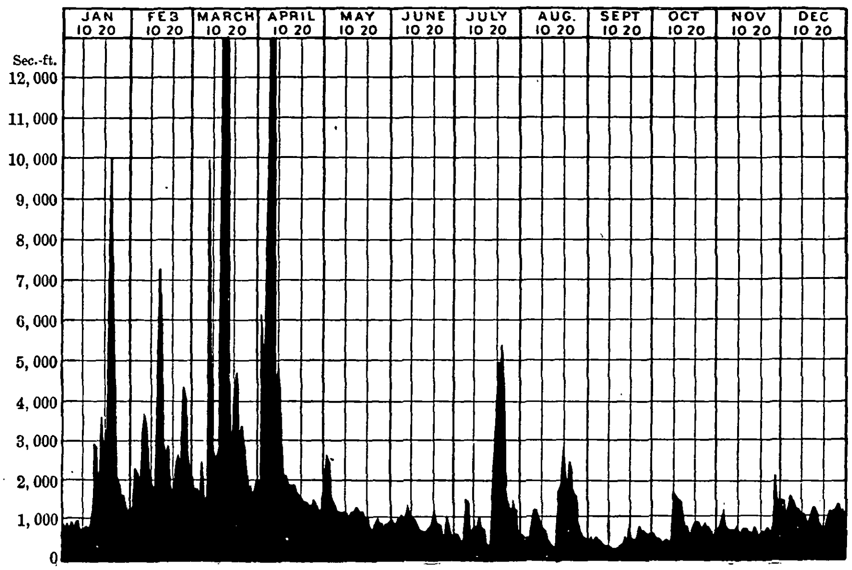


FIG. 56.—Discharge of Oconee River at Cary, Georgia, 1897.

YELLOW RIVER.

Yellow River is an important tributary of the Ocmulgee. Its headwaters are in Gwinnett County, only a short distance from Chattahoochee River. The gaging station was established at Almon, 3 miles west of Covington, Georgia, September 12, 1897. It is described in Water-Supply and Irrigation Paper No. 15, p. 43.

Rating table for Yellow River at Almon, Georgia.

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

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.7	60	1.8	152	2.9	450	4.0	912
0.8	65	1.9	165	3.0	492	4.1	954
0.9	71	2.0	179	3.1	534	4.2	996
1.0	78	2.1	194	3.2	576	4.3	1,038
1.1	85	2.2	211	3.3	618	4.4	1,080
1.2	93	2.3	231	3.4	660	4.5	1,122
1.3	101	2.4	256	3.5	702	4.6	1,164
1.4	110	2.5	290	3.6	744	4.7	1,206
1.5	120	2.6	326	3.7	786	4.8	1,248
1.6	130	2.7	366	3.8	828	4.9	1,290
1.7	140	2.8	408	3.9	870	5.0	1,332

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.		Depth in inches.	Second-feet per square mile.
1897.						
September 12–30	112	93	101	3,806	0.18	0.27
October	174	85	119	7,317	0.36	0.31
November	179	120	141	8,390	0.41	0.37
December	450	160	215	13,219	0.66	0.57

OCMULGEE RIVER.

Ocmulgee River heads in the city of Atlanta, Georgia, as South River, and flows in a general southeasterly direction, crossing the fall line at Macon, Georgia, which is the head of navigation. A gaging station is located at Macon and is described in Water-Supply and Irrigation Paper No. 15, p. 44.

The following table gives the list of discharge measurements on Ocmulgee River at Macon, Georgia. The principal facts are also shown in the accompanying figure (fig. 57), in which vertical distances represent the height of water on the gage and horizontal distances the quantity of discharge. The plotted points obtained by measurement are shown by the small circles, which are numbered to correspond with the figures in the left-hand column of the table. Near or through these is drawn a smooth curve, from which the values for the rating table have been obtained.

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

No.	Date.	Hydrographer.	Meter number.	Gage height.	Area of section.	Mean velocity per second.	Discharge.
	1895.			*Feet.*	*Sq. feet.*	*Feet.*	*Sec.-feet.*
1	Oct. 18	C. C. Babb	76	0.39	784	1.04	813
a2	Oct. 23	do	76	0.20	726	1.06	767
3	Dec. 13	do	62	1.59	1,045	1.46	1,530
	1896.						
4	Jan. 28	B. M. Hall	8	5.52	2,107	1.63	3,436
5	June 12	do	8	−0.10	539	1.47	791
6	June 30	Max Hall	8	−0.82	372	1.19	442
7	Aug. 6	do	16	2.97	1,659	1.23	2,045
b8	Aug. 31	do	11	−0.13	837	0.778	651
9	Oct. 15	do	11	−0.35	741	0.63	572

a The same as No. 1. b The same as No. 5.

List of discharge measurements on Ocmulgee River at Macon, Georgia—Continued.

No.	Date.	Hydrographer.	Meter number.	Gage height.	Area of section.	Mean velocity per second.	Discharge.
	1897.			*Feet.*	*Sq. feet.*	*Feet.*	*Sec.-feet.*
10	Mar. 15	B. M. Hall	91	16.75	5,862	4.356	25,535
11	May 4	.....do	91	4.30	1,612	1.706	2,750
12	May 5	.....do	91	3.50	1,402	1.623	2,275
13	May 18	Max Hall	11	2.10	1,092	1.458	1,592
a 14	June 11	P. A. Dallis	14	2.85	1,325	1.59	2,111
b 15	June 12	.....do	14	1.85	1,045	1.42	1,479
16	June 29	B. M. Hall	91	0.90	829	1.213	1,005
c 17	Sept. 23	Max Hall	92	—0.35	522	0.967	504
c 18	...do	.....do	92	—0.35	602	0.825	497
19	Nov. 7	A. P. Davis	94	0.60	627	1.17	735
20	Dec. 6	Max Hall	92	1.20	948	1.43	1,356
	1898.						
21	Jan. 7	.....do	92	0.42	731	1.23	899

a The same as No. 7. *b* The same as No. 3. *c* The same as No. 9. At new iron bridge.

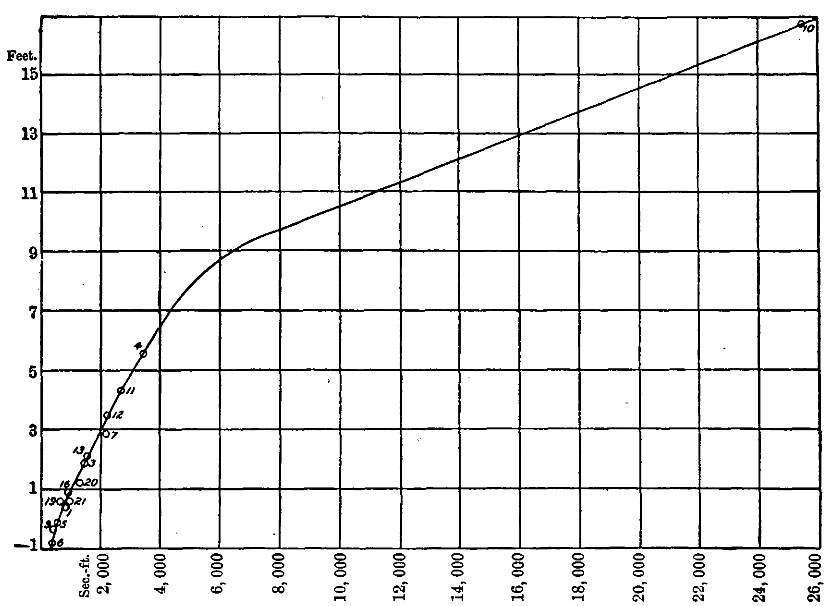


FIG. 57.—Rating curve for Macon station on Ocmulgee River, Georgia.

Rating table for Ocmulgee River at Macon, Georgia, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
—0.6	450	2.0	1,604	5.4	3,351	8.8	6,120
—0.5	481	2.2	1,698	5.6	3,474	9.0	6,430
—0.4	516	2.4	1,793	5.8	3,598	9.5	7,450
—0.3	554	2.6	1,888	6.0	3,722	10.0	8,700
—0.2	594	2.8	1,985	6.2	3,846	10.5	9,950
—0.1	636	3.0	2,083	6.4	3,975	11.0	11,200
0.0	680	3.2	2,182	6.6	4,109	11.5	12,450
0.1	726	3.4	2,280	6.8	4,251	12.0	13,700
0.2	772	3.6	2,379	7.0	4,400	12.5	14,950
0.4	864	3.8	2,478	7.2	4,554	13.0	16,200
0.6	956	4.0	2,577	7.4	4,716	13.5	17,450
0.8	1,048	4.2	2,676	7.6	4,884	14.0	18,700
1.0	1,140	4.4	2,779	7.8	5,053	15.0	21,200
1.2	1,232	4.6	2,886	8.0	5,225	16.0	23,700
1.4	1,324	4.8	2,997	8.2	5,408	17.0	26,200
1.6	1,416	5.0	3,112	8.4	5,616	18.0	28,700
1.8	1,510	5.2	3,230	8.6	5,850		

Estimated monthly discharge of Ocmulgee River at Macon, Georgia.

[Drainage area, 2,425 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	4,400	882	1,369	84,180	0.64	0.56
February	17,450	1,584	4,275	237,422	1.83	1.76
March	28,700	1,604	8,877	545,825	4.22	3.66
April	21,575	1,604	5,463	325,070	2.51	2.25
May	2,221	1,269	1,692	104,040	0.81	0.70
June	2,206	1,094	1,732	103,060	0.79	0.71
July	8,250	781	1,913	117,625	0.91	0.79
August	6,120	772	1,759	108,155	0.84	0.73
September	1,416	481	715	42,545	0.32	0.29
October	1,048	442	622	38,245	0.30	0.26
November	2,132	481	780	46,415	0.36	0.32
December	1,361	864	1,059	65,116	0.51	0.44
The year	28,700	442	2,521	1,817,698	14.04	1.04

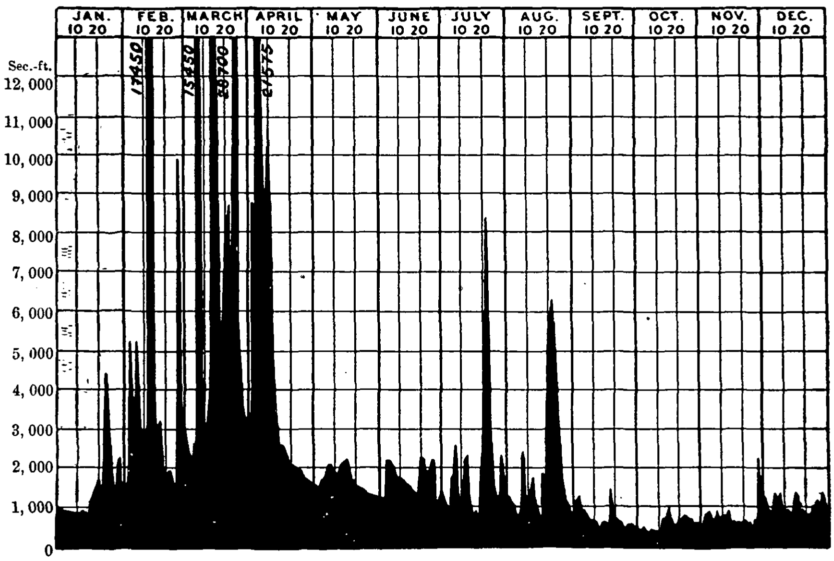


FIG. 58.—Discharge of Ocmulgee River at Macon, Georgia, 1897.

GULF OF MEXICO WATERSHED.

FLINT RIVER.

Apalachicola River is formed by the junction of Chattahoochee and Flint rivers at the Florida State line. The drainage basin of the former river is somewhat peculiar. It is long and narrow, occupies a central portion of the State of Georgia, and extends in a southwesterly direction. By a glance at the map it is seen that the upper Chattahoochee River flows approximately at right angles to the general direction of the rivers of the Altamaha system. The former stream also receives the drainage of nearly the entire eastern slope of the Blue Ridge in the State, cutting this drainage off from the tributaries in the Altamaha Basin. As the result of draining a more mountainous area and one which receives a larger yearly precipitation one would expect the Chattahoochee to have a larger yearly run-off; and an inspection of the run-off tables for 1896 and 1897 shows that this expectation is realized.

June 7, 1897, a gaging station was established on Flint River, near Molina, Georgia, described in Water-Supply and Irrigation Paper No. 15, p. 45. A number of important shoals occur along this river.

List of discharge measurements of Flint River at Molina, Georgia.

No.	Date.	Hydrographer.	Meter number.	Gage height (feet).	Area of section (square feet).	Mean velocity (feet per second).	Discharge (second feet).
	1897.						
1	May 21	B. M. Hall..........	91	1.50	791	0.81	641
2	June 7	Mox Hall...........	91	1.75	869	0.815	707
3	June 23	B. M. Hall..........	91	1.70	837	0.832	697
4	Aug. 25	Mox Hall...........	92	3.30	1,091	2.605	2,843
5	Nov. 8	A. P. Davis.........	94	1.70	816	0.32	264
6	Dec. 7	Mox Hall...........	92	2.10	911	0.645	588
	1898.						
7	Feb. 28	.....do	92	1.80	828	0.553	458
8	Apr. 21	.....do	92	2.00	837	1.05	877
9	May 28	.....do	92	1.25	722	0.43	313

These discharge measurements were carefully made, and there is no doubt that they represent the discharge of the river at the time that they were taken. They show, however, that the discharge at this station has no fixed relation to the gage height. The alternate accumulation and washing out of sediment in an eddy half a mile below affected the gage to such an extent as to render worthless the records of gage height. The station has, therefore, been discontinued. It is clearly impossible to construct a curve and rating table from the discharge measurements; but the discharge measurements without reference to gage heights, being well distributed over a period of twelve months, give a fair idea of the flow of the stream. Minimum discharge can not be accurately arrived at, but it can be safely asserted that the discharge has rarely been less than that shown by measurement No. 5. The low velocity in this measurement as compared with measurement No. 3 shows that the gage height of 1.70 was not due to the actual stage of the stream, but to obstructions below.

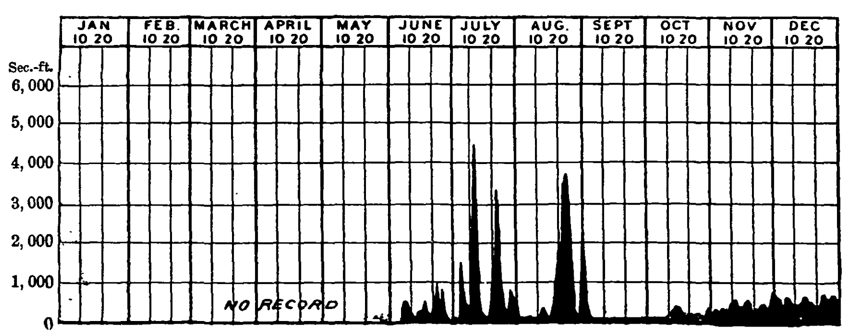


FIG. 59.—Discharge of Flint River at Molina, Georgia, 1897.

CHATTAHOOCHEE RIVER.

A large number of important water-power privileges occur on the tributaries as well as on the main Chattahoochee. The most important fall occurs near Columbus, where the river descends 120 feet in 4 miles. A fall of 362 feet from West Point to Columbus, a distance of 34 miles, occurs in a number of shoals separated by stretches of comparatively quiet water. Bull Sluice, 14 miles from Atlanta, Georgia, has a fall of 50 feet in about 4 miles; and the Vining Shoal, 8 miles from Atlanta, has a fall of 32 feet in about 4 miles. Elaborate surveys of these shoals have been made by companies, with the object of development and electric transmission to Atlanta. Two gaging stations are maintained on Chattahoochee River—one at Oakdale and the other at West Point, Georgia. They are described in Water-Supply and Irrigation Paper No. 15, pp. 46–47.

Rating table for Chattahoochee River at Oakdale, Georgia, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
—0.5	675	2.6	2,702	6.4	7,580	10.2	12,710
—0.4	725	2.8	2,870	6.6	7,850	10.4	12,980
—0.3	775	3.0	3,060	6.8	8,120	10.6	13,250
—0.2	825	3.2	3,275	7.0	8,390	10.8	13,520
—0.1	876	3.4	3,530	7.2	8,660	11.0	13,790
0.0	928	3.6	3,800	7.4	8,930	11.2	14,060
0.1	980	3.8	4,070	7.6	9,200	11.4	14,330
0.2	1,035	4.0	4,340	7.8	9,470	11.6	14,600
0.4	1,148	4.2	4,610	8.0	9,740	11.8	14,870
0.6	1,266	4.4	4,880	8.2	10,010	12.0	15,140
0.8	1,388	4.6	5,150	8.4	10,280	12.5	15,815
1.0	1,515	4.8	5,420	8.6	10,550	13.0	16,490
1.2	1,647	5.0	5,690	8.8	10,820	13.5	17,165
1.4	1,785	5.2	5,960	9.0	11,090	14.0	17,840
1.6	1,927	5.4	6,230	9.2	11,360	14.5	18,515
1.8	2,075	5.6	6,500	9.4	11,630	15.0	19,190
2.0	2,226	5.8	6,770	9.6	11,900	16.0	20,540
2.2	2,380	6.0	7,040	9.8	12,170	17.0	21,890
2.4	2,540	6.2	7,310	10.0	12,440		

Estimated monthly discharge of Chattahoochee River at Oakdale, Georgia.

[Drainage area, 1,560 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	9,065	1,035	2,575	158,330	1.90	1.65
February	6,365	2,150	3,734	207,376	2.49	2.39
March	15,950	2,075	5,658	347,897	4.19	3.63
April	21,890	2,226	5,147	306,270	3.68	3.30
May	4,475	1,515	2,130	130,970	1.58	1.37
June	1,891	1,091	1,438	85,567	1.02	0.92
July	15,545	1,177	3,360	206,598	2.48	2.15
August	2,965	1,007	1,452	89,280	1.07	0.93
September	1,206	725	845	50,280	0.60	0.54
October	1,855	675	979	60,226	0.72	0.63
November	2,113	876	1,078	64,145	0.77	0.69
December	3,013	1,206	1,845	113,445	1.36	1.18
The year	21,890	675	2,520	1,820,384	21.86	1.62

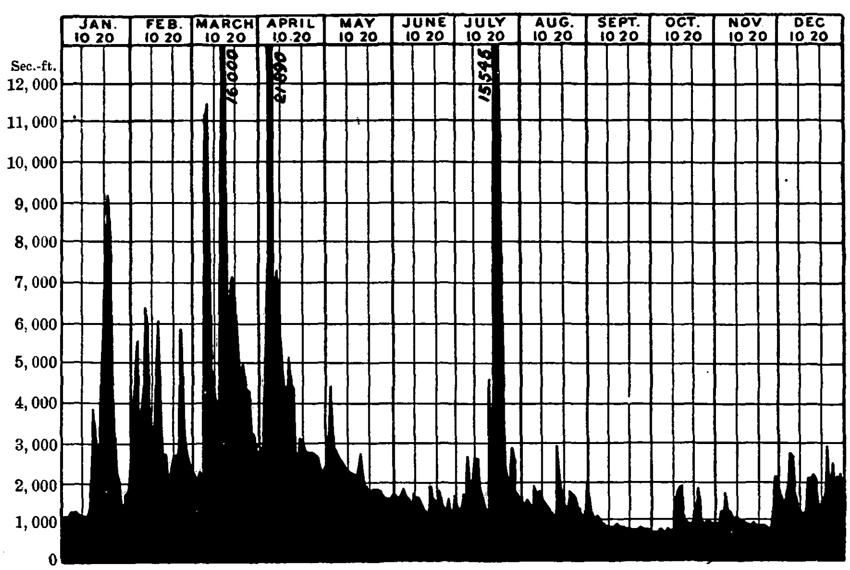


FIG. 60.—Discharge of Chattahoochee River at Oakdale, Georgia, 1897.

The following table gives the list of discharge measurements on Chattahoochee River at West Point, Georgia. The principal facts are also shown in the accompanying figure (fig. 61), in which vertical distances represent the height of water on the gage and horizontal distances the quantity of discharge. The plotted points obtained by measurement are shown by the small circles which are numbered to correspond with the figures in the left-hand column of the table. Near or through these is drawn a smooth curve from which the values for the rating table have been obtained.

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

No.	Date.	Hydrographer.	Meter No.	Gage height.	Area of section.	Mean velocity.	Discharge.
	1896.			*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec. feet.*
1	July 30	Max Hall	16	2.45	3,249	0.748	2,430
2	Aug. 14	.....do	16	1.72	3,077	0.515	1,594
a3	Sept. 5	.....do	11	1.20	2,857	0.352	1,006
4	Sept. 25	.....do	8	1.15	2,792	0.37	1,030
b5	Oct. 28	.....do	11	1.75	2,883	0.57	1,642
	1897.						
6	Jan. 23	B. M. Hall	11	6.66	4,597	2.59	11,921
7	Apr. 26	Max Hall	91	3.70	3,855	1.413	5,448
8	May 4	.....do	11	4.13	4,082	1.526	6,230
9	May 19	.....do	91	3.00	3,556	1.00	3,557
10	June 5	.....do	14	2.90	3,552	0.915	3,253
11	June 19	.....do	91	2.59	3,407	0.861	2,934
12	July 8	.....do	70	3.03	3,562	0.974	3,470
13	July 23	.....do	92	5.01	4,339	1.8+	7,853
14	Aug. 14	.....do	92	2.12	3,269	0.588	1,915
b15	Sept. 4	.....do	92	1.80	3,072	0.55	1,690
c16	Sept. 22	.....do	92	1.20	2,790	0.353	985
17	Nov. 9	A. P. Davis	94	1.71	3,135	0.43	1,345
18	Nov. 23	Max Hall	92	1.60	2,969	0.45	1,322
19	Dec. 17	.....do	92	3.14	3,760	1.06	3,989
	1898.						
20	Jan. 18	.....do	92	2.45	3,353	0.79	2,648

a Too small. b The same as No. 2. c The same as No. 3.

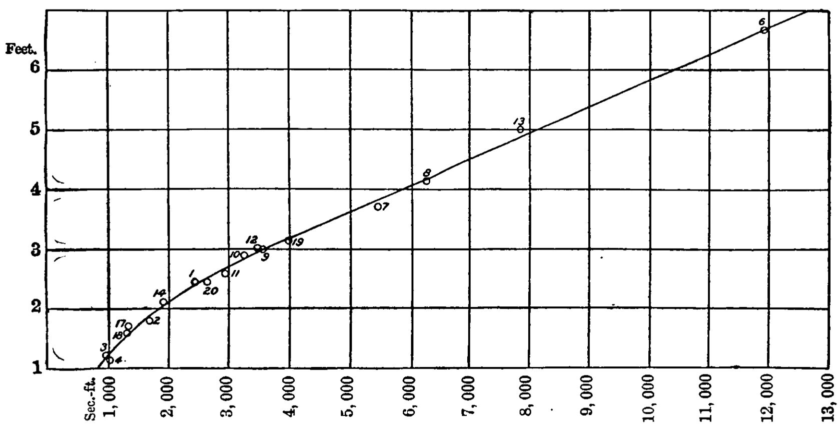


FIG. 61.—Rating curve for West Point station on Chattahoochee River, Georgia.

Rating table for Chattahoochee River at West Point, Georgia, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.0	860	3.6	4,928	6.2	10,856	8.8	16,784
1.2	995	3.8	5,384	6.4	11,312	9.0	17,240
1.4	1,150	4.0	5,840	6.6	11,768	9.5	18,380
1.6	1,325	4.2	6,296	6.8	12,224	10.0	19,520
1.8	1,520	4.4	6,752	7.0	12,680	10.5	20,660
2.0	1,750	4.6	7,208	7.2	13,136	11.0	21,800
2.2	2,020	4.8	7,664	7.4	13,592	11.5	22,940
2.4	2,330	5.0	8,120	7.6	14,048	12.0	24,080
2.6	2,680	5.2	8,576	7.8	14,504	12.5	25,220
2.8	3,105	5.4	9,032	8.0	14,960	13.0	26,360
3.0	3,560	5.6	9,488	8.2	15,416	13.5	27,500
3.2	4,016	5.8	9,944	8.4	15,872	14.0	28,640
3.4	4,472	6.0	10,400	8.6	16,328		

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

[Drainage area, 3,300 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	15,416	1,630	4,246	261,076	1.49	1.29
February	13,592	3,902	8,468	470,290	2.68	2.57
March	28,868	4,700	13,000	799,340	4.55	3.94
April	21,800	4,928	9,241	549,878	3.12	2.80
May	5,840	2,782	4,060	249,640	1.42	1.23
June	3,446	1,630	2,662	158,400	0.90	0.81
July	22,712	1,520	5,038	309,775	1.76	1.53
August	15,188	1,630	4,213	259,050	1.48	1.28
September	1,520	925	1,112	66,170	0.38	0.34
October	3,560	830	1,277	78,520	0.45	0.39
November	2,782	892	1,431	85,150	0.48	0.43
December	6,524	2,330	3,732	229,470	1.30	1.13
The year	28,868	830	4,875	3,516,758	20.01	1.48

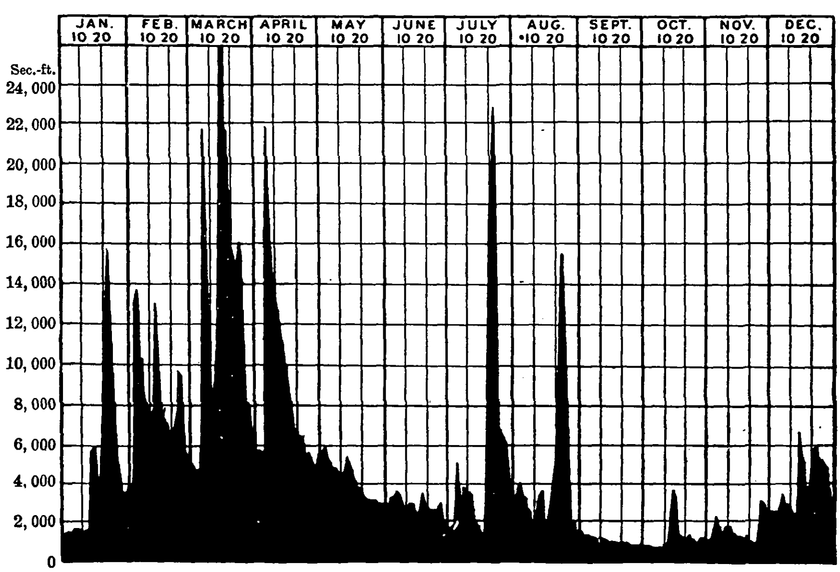


FIG. 62.—Discharge of Chattahoochee River at West Point, Georgia, 1897

List of miscellaneous discharge measurements, Apalachicola Basin.

Date.	Stream.	Locality.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
1897.				*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
May 21	Flint River	Woodbury, Ga	91	1.50	881	0.73	642
May 24	Peachtree Creek	Near Atlanta, Ga	91	0.20	36	1.56	56
May 28	.....do	At mouth	......	....	....	....	36
Do	Procters Creek	.....do	......	....	....	....	6.5
June 11	Flint River	Reynolds, Ga	14	0.95	1,332	1.36	1,810
June 12	Sweetwater Creek	Near Austell, Ga	91	1.00	138	0.67	92
June 23	Red Oak Creek	Near Molina, Ga	91	....	87	1.15	101
June 30	Peachtree Creek	Near Atlanta, Ga	14	0.00	35	1.14	40
July 29	Chestatee River	Near Dahlonega, Ga	92	1.10	225	1.05	236
July 30	Yahoola Ditch	At Dahlonega, Ga	92	....	8.2	1.26	10.3
Do	Cane Creek	Near Dahlonega, Ga	92	....	19.4	0.71	14
July 31	Yahoola Creek	At mouth	92	....	22.7	2.10	48
Do	Chattahoochee River.	Near Gainesville, Ga	92	1.00	275	2.93	810
Sept. 11	Sweetwater Creek	Near Austell, Ga	92	0.43	108	0.29	32
Sept. 22	Peachtree Creek	Near Atlanta, Ga	70	—0.40	13	1.04	13
Sept. 24	Rottonwood Creek	Near Vining, Ga	......	....	2	2.00	4
Sept. 30	Sweetwater Creek	Near Austell, Ga	92	0.43	114	0.31	35
Oct 5	Chattahoochee River.	Columbus, Ga	70	....	756	1.34	1,015
Oct. 6	Warm Spring	Warm Springs, Ga. *a*	70	....	1.9	2.21	4.2
Do	Cold Spring	Bullochville, Ga. *a*	70	....	3.1	1.45	4.5
Nov. 12	Chattahoochee River.	Roswell, Ga	92	0.42	994	0.88	876
Nov. 13	.....do	.....do	92	0.46	1.005	0.96	968
Dec. 8	Peachtree Creek	Near Atlanta, Ga	70	0.43	34	1.28	44

a These springs, as stated by B. M. Hall, are rather remarkable for a crystalline or semicrystalline region. The first is evidently due to a deep fissure in the original gneiss formation. The water comes into the bathing pool at a temperature of 87½° F., but the temperature is supposed to be 90° where the water enters the underground reservoir. The cold spring, which has a temperature of 62° F., is on the opposite side of the ridge and issues from an immense ledge of itocolumite. This spring would be an excellent site for a paper mill or some other manufacturing concern requiring a large supply of clear, pure water and a nigh healthy location.

From these and similar measurements made in 1896, published in the Eighteenth Annual Report, Part IV, p. 92, Prof. B. M. Hall estimates that the following relations hold good at low water: The discharge of the Chattahoochee at Columbus may be approximated by adding 18 per cent to its discharge at West Point. The discharge of Sweetwater Creek at the mouth represents about one-twentieth of the discharge of Chattahoochee River at Oakdale, while that of Peachtree Creek represents about one-thirtieth of that amount. It also appears that the discharge of the Chattahoochee at Shallow Ford near Gainesville is, approximately, one-half of its discharge at Oakdale. The Chestatee contributes 20 per cent of the flow of the Chattahoochee at Oakdale, while 30 per cent of the latter comes from tributaries entering below the mouth of the Chestatee.

COOSA RIVER.

Crossing the northwestern boundary of the Chattahoochee watershed, one enters a country drained by the tributaries of Coosa River, which is formed by the junction at Rome, Georgia, of Etowah and Oostanaula rivers. Wherever the streams cross what is known as the western or Cartersville fall line, falls of considerable magnitude occur. This line marks the boundary between the crystalline rocks on the east and the later rocks of Paleozoic age on the west. It runs southerly through the extreme eastern edge of Murray, Gordon, and Bartow counties, Georgia, crossing Etowah River at Cartersville. From Cartersville this fall line gradually bends southwestward into Polk County, where its course is westward, passing into Alabama. Coosawattee River crosses this fall line at Carters. The gaging stations on this river or its tributaries in the State of Georgia are Canton station on Etowah River, Carters station on Coosawattee River, and Resaca station on Oostanaula River. They are described in Water-Supply and Irrigation Paper No. 15, pp. 48–50, inclusive. The Survey gaging station, on the main Coosa River, is located at Riverside, Alabama, and is described in Water-Supply and Irrigation Paper No. 15, p. 51.

The Engineer Corps of the Army maintained gage readings at Lock No. 4, on Coosa River 3 miles above Riverside.

Although a number of measurements have been made in 1896, 1897, and 1898 which serve to establish a relation between the gages at Riverside and at Lock No. 4, the results have as yet not warranted the construction of a rating table for the latter station.

At Lock No. 5, 20 miles below the station at Riverside, the United States Engineer Corps have maintained gage readings since 1892. Also from their discharge measurements of 1893 a rating curve has been constructed and published in the Eighteenth Annual Report, Part IV, p. 102. It was the intention to test this rating curve in 1897 by a number of discharge measurements, but owing to the rigid enforcement of the Alabama quarantine laws in 1897 this could not be done. The stations at Lock No. 4 and Lock No. 5 are described in Water-Supply and Irrigation Paper No. 15, p. 51.

The shoals at Wetumpka are caused by the river crossing the southern fall line, which is the continuation of the one forming the principal powers of the streams of the Atlantic Coast States above described. The gaging station at this point is described in Water-Supply and Irrigation Paper No. 15, p. 54. The Engineer Corps have gage readings at this point since 1889 and from their discharge measurements made in 1891 a rating table has been made, but it will not be applied until its accuracy can be verified by future discharge measurements. This could not be done in 1897 on account of the Alabama quarantine.

Rating table for Etowah River at Canton, Georgia, for 1897.

Gage height.	Discharge.		Gage height.	Discharge.	
	Jan. 1 to Oct. 10.	Oct. 11 to Dec. 31.		Jan. 1 to Oct. 10.	Oct. 11 to Dec. 31.
Feet.	*Second-feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Second-feet.*
—0.7	244	....	2.0	2,150	1,981
—0.6	284	....	2.2	2,316	2,155
—0.5	344	....	2.4	2,482	2,329
—0.4	405	....	2.6	2,648	2,503
—0.3	467	....	2.8	2,814	2,677
—0.2	530	....	3.0	2,980	2,851
—0.1	593	....	3.5	3,395	....
0.0	657	275	4.0	3,810	....
0.2	788	415	4.5	4,225	....
0.4	922	589	5.0	4,640	....
0.6	1,059	763	6.0	5,470	....
0.8	1,200	937	7.0	6,300	....
1.0	1,347	1,111	8.0	7,130	....
1.2	1,498	1,285	9.0	7,960	....
1.4	1,655	1,459	10.0	8,790	....
1.6	1,818	1,633	11.0	9,620	....
1.8	1,984	1,807			

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.		Depth in inches.	Second-feet per square mile.
1897.						
January	3,478	593	1,194	73,420	2.28	1.98
February	2,316	1,059	1,291	71,700	2.23	2.14
March	6,466	1,059	2,335	143,574	4.45	3.86
April	9,786	1,200	2,238	133,170	4.14	3.71
May	2,150	722	1,036	63,700	1.98	1.72
June	2,980	657	941	55,995	1.74	1.56
July	6,383	657	1,186	72,925	2.26	1.96
August	1,347	405	859	52,817	1.64	1.42
September	1,200	284	355	21,124	0.65	0.59
October	1,285	244	583	35,848	1.12	0.97
November	937	335	563	33,501	1.07	0.96
December	1,981	676	934	57,430	1.79	1.55
The year	9,786	244	1,134	815,204	25.35	1.87

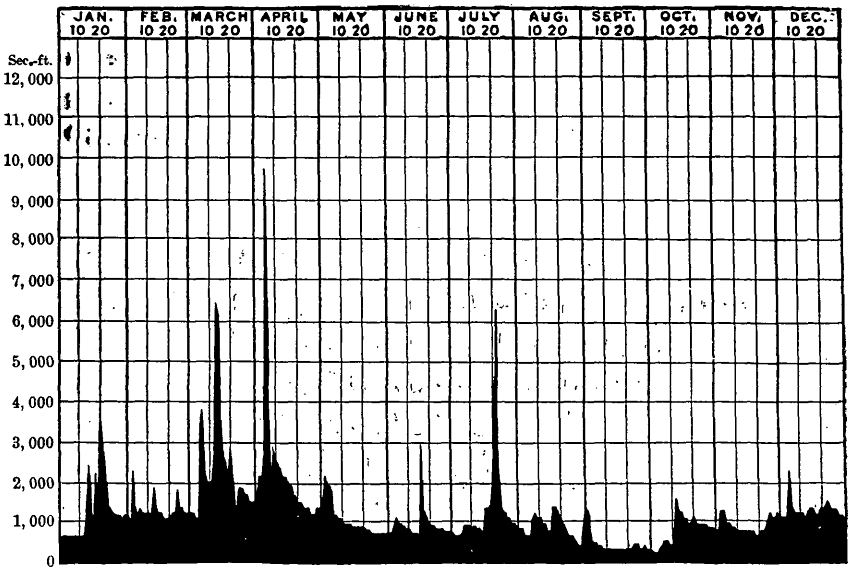


FIG. 63.—Discharge of Etowah River at Canton, Georgia, 1897.

Rating table for Coosawattee River at Carters, Georgia, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.6	219	1.8	674	3.4	1,568	5.0	2,560
0.7	250	2.0	771	3.6	1,692	5.2	2,684
0.8	284	2.2	872	3.8	1,816	5.4	2,808
0.9	318	2.4	977	4.0	1,940	5.6	2,932
1.0	353	2.6	1,086	4.2	2,064	5.8	3,056
1.2	423	2.8	1,201	4.4	2,188	6.0	3,180
1.4	499	3.0	1,320	4.6	2,312	7.0	3,800
1.6	583	3.2	1,444	4.8	2,436	8.0	4,420

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.		Depth in inches.	Second-feet per square mile.
1896.						
August 17-31	337	283	314	9,342	0.33	0.59
September	512	200	262	15,590	0.55	0.49
October	431	215	295	18,138	0.63	0.55
November	3,740	296	598	35,583	1.25	1.12
December	1,031	475	684	42,058	1.49	1.29
1897.						
January	2,033	405	710	43,656	1.53	1.33
February	3,800	499	1,092	60,645	2.14	2.05
March 1-11, 15-31	5,660	698	2,178	120,960	4.27	4.10
April 6-30	2,870	1,320	1,846	91,538	3.22	3.47
May	1,940	674	959	58,965	2.08	1.80
June	1,143	499	633	37,666	1.33	1.19
July	5,600	460	787	48,390	1.71	1.48
August	1,630	284	496	30,498	1.07	0.93
September	353	219	259	15,412	0.55	0.49
October	1,031	205	293	18,015	0.63	0.55
November	540	219	263	15,650	0.55	0.49
December	1,630	265	444	27,300	0.95	0.83

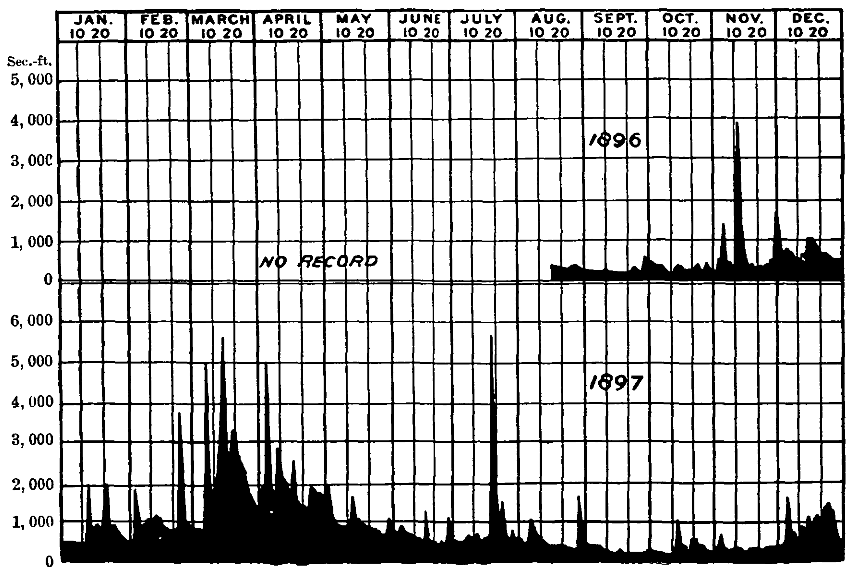


FIG. 64.—Discharge of Coosawattee River at Carters, Georgia, 1896 and 1897.

Rating table for Oostanaula River at Resaca, Georgia.

[This table is applicable from July, 1896, to December 31, 1897.]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.0	350	2.8	1,134	4.6	2,510	6.4	4,040
1.2	408	3.0	1,250	4.8	2,680	6.6	4,210
1.4	475	3.2	1,377	5.0	2,850	6.8	4,380
1.6	552	3.4	1,514	5.2	3,020	7.0	4,550
1.8	637	3.6	1,665	5.4	3,190	7.2	4,720
2.0	727	3.8	1,830	5.6	3,360	7.4	4,890
2.2	822	4.0	2,000	5.8	3,530	7.6	5,060
2.4	921	4.2	2,170	6.0	3,700	7.8	5,230
2.6	1,025	4.4	2,340	6.2	3,870	8.0	5,400

Estimated monthly discharge of Oostanaula River at Resaca, Georgia.

[Drainage area, 1,527 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	6,760	822	2,097	128,940	1.58	1.37
February 5–22	6,930	2,425	4,055	144,900	1.78	2.65
March (*a*)	....	....	....	....	....	....
April 11–30	5,915	2,255	3,552	140,906	1.73	2.32
May	6,040	1,344	2,340	143,880	1.76	1.53
June	2,212	846	1,198	71,285	0.87	0.78
July	8,600	798	2,004	123,220	1.51	1.31
August	2,000	594	969	59,581	0.72	0.63
September	871	350	479	28,503	0.35	0.31
October	1,250	338	506	31,112	0.38	0.33
November	871	475	551	32,786	0.41	0.36
December	6,460	575	2,233	137,300	1.68	1.46

a The discharge through March was beyond the limits of the present rating table, and the flow could not, therefore, be estimated.

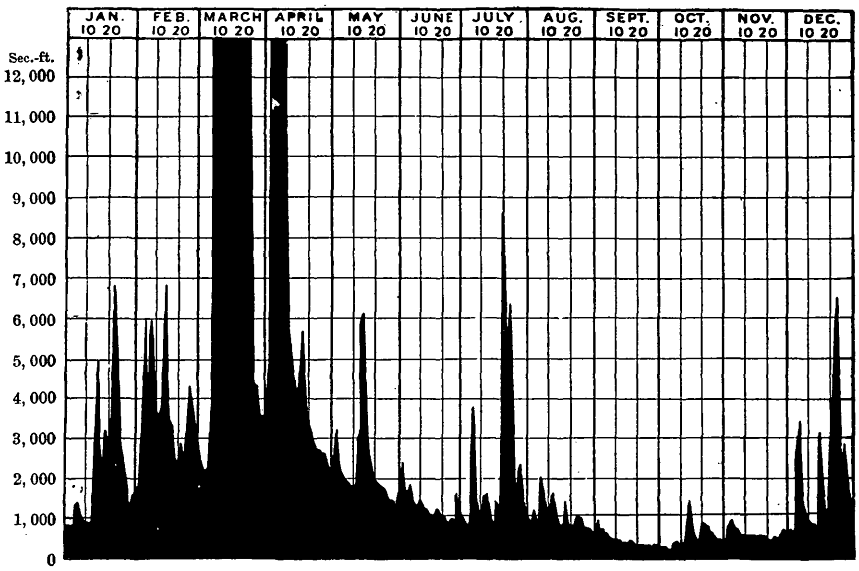


FIG. 65.—Discharge of Oostanaula River at Resaca, Georgia, 1897.

The following table gives the list of discharge measurements made on Coosa River at Riverside, Alabama. The principal facts are also shown in the accompanying figure (fig. 67), in which vertical distances represent the height of water on the gage and horizontal distances the quantity of discharge. The plotted points, obtained by measurement,

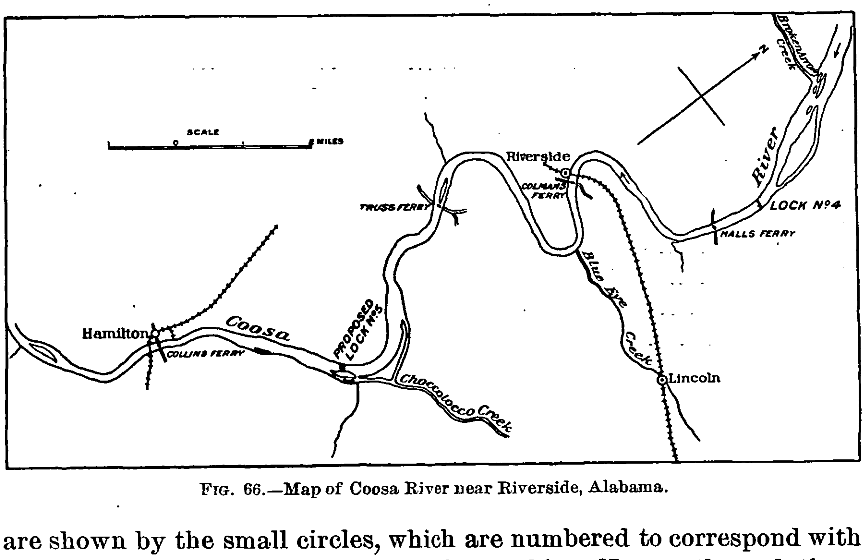


FIG. 66.—Map of Coosa River near Riverside, Alabama.

are shown by the small circles, which are numbered to correspond with the figures in the left-hand column of the table. Near or through these is drawn a smooth curve, from which the values for the rating table have been obtained.

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

No.	Date.	Hydrographer.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
	1896.			*Feet.*	*Sq. feet.*	*Feet per second.*	*Second-feet.*
1	Sept. 8	B. M. Hall.........	8	0.70	2,520	0.65	1,630
*a*2	Sept. 25	Max Hall	11	0.50	2,426	0.58	1,403
3	Oct. 30	B. M. Hall.........	8	0.88	2,605	0.76	1,986
4	Dec. 21	.....do	8	1.57	2,867	1.14	3,272
	1897.						
5	Mar. 31	.....do	91	4.53	4,544	2.53	12,515
6	June 17	Max Hall	11	1.54	2,990	1.25	3,747
7	July 21	.....do	92	5.55	5,351	3.16	16,925
8	Aug. 20	.....do	70	2.58	3,704	1.67	6,174
*b*9	Nov. 29	.....do	92	0.80	2,619	0.71	1,854
	1898.						
10	Jan. 28	.....do	92	10.00	7,378	4.11	30,359

a The same as No. 1. *b* The same as No. 3.

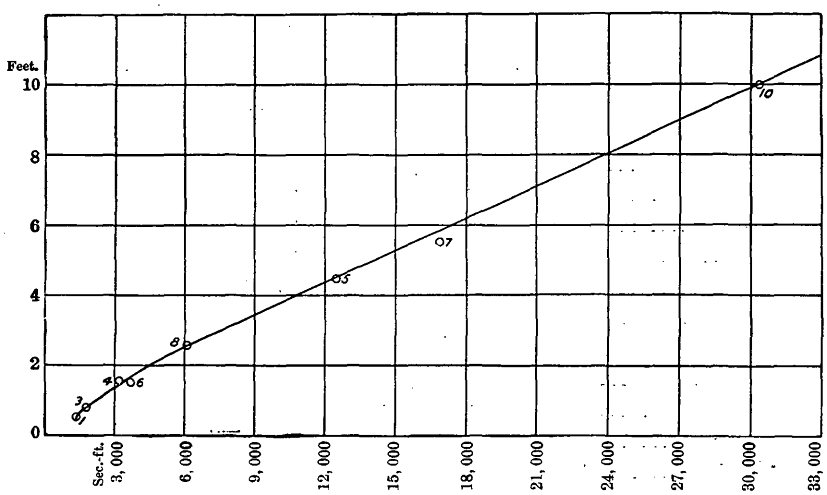


FIG. 67.—Rating curve for Riverside station on Coosa River, Alabama.

Rating table for Coosa River at Riverside, Alabama, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.4	1,350	1.4	3,070	3.0	7,530	7.0	20,566
0.5	1,400	1.6	3,540	3.2	8,178	8.0	23,826
0.6	1,500	1.8	4,020	3.4	8,830	9.0	27,086
0.7	1,650	2.0	4,520	3.6	9,482	10.0	30,346
0.8	1,820	2.2	5,100	3.8	10,134	11.0	33,606
0.9	2,010	2.4	5,700	4.0	10,786	12.0	36,866
1.0	2,210	2.6	6,300	5.0	14,046	13.0	40,126
1.2	2,630	2.8	6,910	6.0	17,306	14.0	43,386

Estimated monthly discharge of Coosa River at Riverside, Alabama.

[Drainage area, 6,850 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	21,707	2,420	8,434	518,590	1.42	1.23
February	27,086	4,520	18,658	1,036,230	2.83	2.72
March	47,624	10,460	32,481	1,997,180	5.47	4.74
April	37,355	5,100	17,698	1,053,105	2.87	2.58
May	10,786	4,270	7,040	432,875	1.19	1.03
June	4,950	3,070	3,915	232,960	0.63	0.57
July	23,826	3,070	7,142	439,145	1.20	1.04
August	6,300	2,850	3,870	237,960	0.64	0.56
September	3,540	1,440	1,976	117,580	0.32	0.29
October	3,660	1,350	1,819	111,845	0.31	0.27
November	2,525	1,570	1,786	106,275	0.29	0.26
December	13,883	1,820	6,566	403,730	1.10	0.96
The year	47,624	1,350	9,282	6,687,475	18.27	1.35

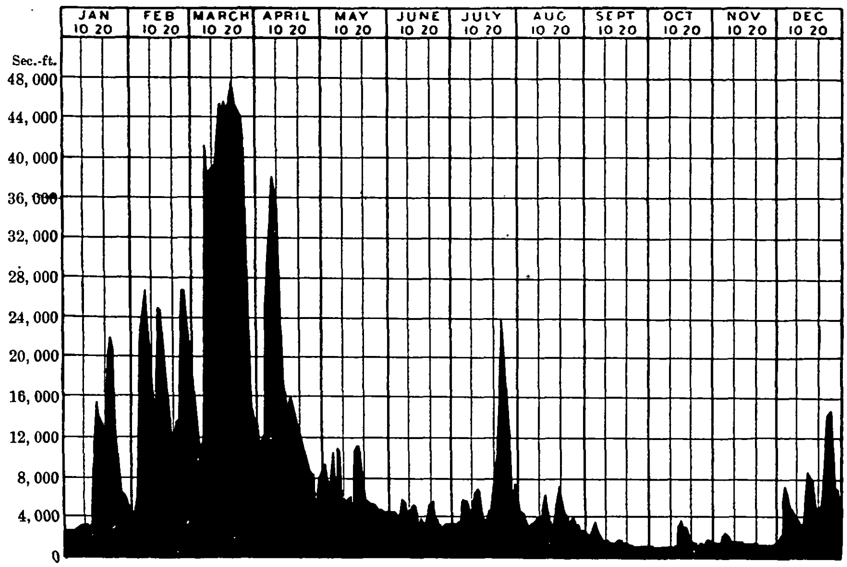


FIG. 68.—Discharge of Coosa River at Riverside, Alabama, 1897.

TALLAPOOSA RIVER.

This river joins the Coosa to form Alabama River at a short distance above Montgomery, Alabama. Its upper tributary drains an area between the Chattahoochee and Coosa basins. At Tallassee, Alabama, where it crosses the southern fall line, shoals occur, forming an obstruction to navigation, and giving a 60-foot head, of the whole river, on the wheels of the new Tallassee cotton mills, now nearing completion. A gaging station was established at Milstead on August 7, 1897, and is described in Water-Supply and Irrigation Paper No. 15, p. 56.

Rating table for Tallapoosa River at Milstead, Alabama, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.5	330	1.5	1,070	3.0	3,129	5.0	5,909
0.6	350	1.6	1,200	3.2	3,407	5.2	6,187
0.7	380	1.7	1,333	3.4	3,685	5.4	6,465
0.8	420	1.8	1,467	3.6	3,963	5.6	6,743
0.9	470	1.9	1,600	3.8	4,241	5.8	7,021
1.0	530	2.0	1,733	4.0	4,519	6.0	7,299
1.1	620	2.2	2,007	4.2	4,797	7.0	8,689
1.2	720	2.4	2,285	4.4	5,075	8.0	10,079
1.3	830	2.6	2,573	4.6	5,353	9.0	11,469
1.4	950	2.8	2,851	4.8	5,631		

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.		Depth in inches.	Second-feet per square mile.
1897.						
August 7-31	12,440	1,070	3,173	157,340	0.77	0.83
September	1,467	420	742	44,155	0.21	0.19
October	470	380	424	26,070	0.12	0.11
November	1,200	470	729	43,379	0.21	0.19
December	6,604	1,070	2,214	136,135	0.67	0.58

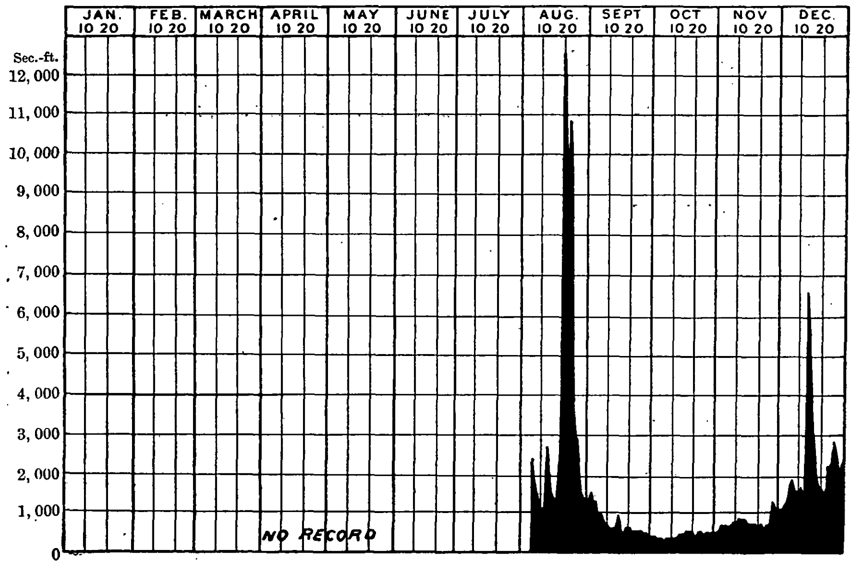


FIG. 69.—Discharge of Tallapoosa River at Milstead, Alabama, 1897.

BLACK WARRIOR RIVER.

This river is a tributary of Tombigbee River, which joins Alabama River to form the Mobile, the name of the stream when it enters the Gulf of Mexico and also the name of the basin. A gaging station is located at Tuscaloosa, Alabama, and described in Water-Supply and Irrigation Paper No. 15, p. 57. The Engineer Corps has a continuous record of gage heights from 1889. During 1895 and 1896 a number of discharge measurements were also made, from which a rating table was obtained. The diagrams of daily discharge from 1889 to 1896 are published in the Eighteenth Annual Report, Part IV, pp. 105–108, inclusive, with the monthly discharges for 1895 and 1896.

Rating table for Black Warrior River at Tuscaloosa, Alabama, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
—2.0	88	1.0	600	20.0	10,880	42.0	69,000
—1.8	92	2.0	1,000	22.0	12,500	44.0	77,000
—1.6	100	3.0	1,470	24.0	14,700	46.0	85,000
—1.4	110	4.0	2,000	26.0	17,600	48.0	93,000
—1.2	120	6.0	3,110	28.0	21,500	50.0	101,000
—1.0	130	8.0	4,220	30.0	26,500	52.0	109,000
—0.8	150	10.0	5,330	32.0	31,700	54.0	117,000
—0.6	175	12.0	6,440	34.0	38,000	55.0	121,000
—0.4	205	14.0	7,550	36.0	45,000		
—0.2	240	16.0	8,660	38.0	53,000		
0.0	280	18.0	9,770	40.0	61,000		

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

[Drainage area, 4,900 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	10,500	385	3,493	214,775	0.82	0.71
February	17,440	1,945	8,409	467,010	1.79	1.72
March	120,080	4,540	52,883	3,251,650	12.44	10.79
April	25,285	2,610	9,657	574,630	2.20	1.97
May	11,195	1,000	3,600	221,355	0.84	0.73
June	1,697	260	715	42,545	0.17	0.15
July	7,810	240	1,809	111,230	0.43	0.37
August	1,595	355	701	43,100	0.16	0.14
September	600	102	295	17,555	0.07	0.06
October	102	90	93	5,718	0.02	0.02
November	125	107	115	6,843	0.03	0.02
December	29,000	115	5,549	341,195	1.30	1.13
The year	120,080	90	7,277	5,297,606	20.27	1.48

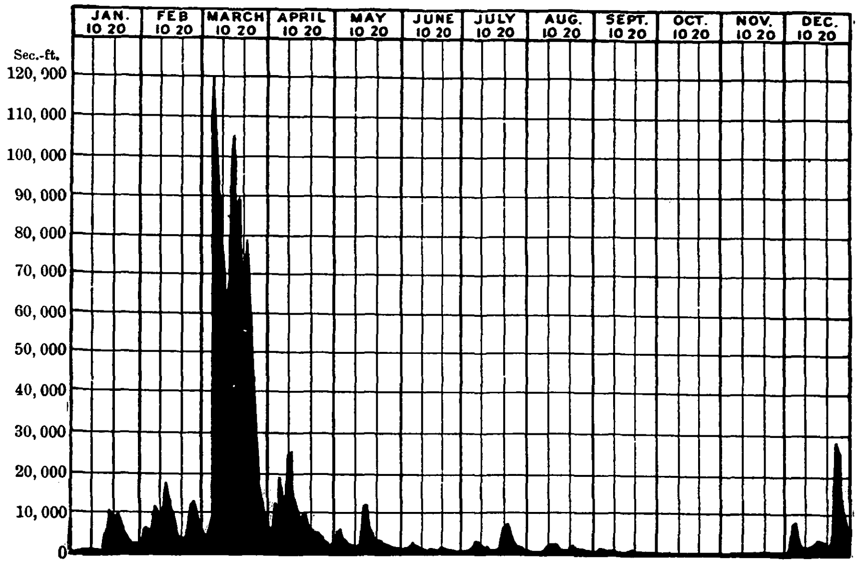


FIG. 70.—Discharge of Black Warrior River at Tuscaloosa, Alabama, 1897.

List of miscellaneous discharge measurements, Mobile Basin.

Date.	Stream.	Locality.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
1897.				*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
May 7	Etowah River	Rome, Georgia (*a*).....	11	2.90	1,055	2.47	2,604
Do...	Oostanaula River..	Rome, Georgia (*b*).....	11	2.75	1,170	1.75	2,042
May 24	Talking Rock Creek	Carters, Georgia......	16	....	75	1.57	117
June 23	Sallacoa Creek.....	Near mouth	16	....	84	0.40	34
June 28	Talking Rock Creek	Near Carters, Georgia	16	....	45	1.25	56
Aug. 20	East Long Swamp Creek.	Marble Hill, Georgia .	92	....	14	1.09	15
Sept. 23	Sallacoa Creek.....	Resaca, Georgia.......	16	....	27	0.81	22
Sept. 27	Talking Rock Creek	Near Carters, Georgia	16	....	14	1.67	23
Oct. 5	Etowah River	Rome, Georgia (*a*).....	92	....	536	0.96	517
Do...	Oostanaula River..	Rome, Georgia (*b*).....	92	—0.15	758	0.65	473
Oct. 15	East Long Swamp Creek.	Marble Hill, Georgia .	92	....	12	0.97	11
1898.							
June 23	Big Long Swamp Creek.	Near Ball Ground, Georgia.	......	....	....	....	50
June 25	Amicalola Creek...	At mouth.............	......	....	....	....	112

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

From the miscellaneous measurements made during 1897 and the preceding year, published in the Eighteenth Annual Report, Part IV, p. 108, the following conclusions have been reached by Prof. B. M. Hall: To find the approximate discharge at low water of the Etowah at Rome, multiply its discharge at Canton by 2.3. Of the discharge at the latter point, about 11 per cent is derived from Long Swamp Creek and 22 per cent from Amicalola Creek. There seems to be no fixed relation between the discharges of Oostanaula River at Resaca and at Rome. At low water the discharge of the river at the former station is composed as follows: 53 per cent of the flow comes from Coosawattee River, 7 per cent from Talking Rock Creek, 28 per cent from Connasauga River, and 12 per cent from Sallacoa Creek and other tributaries entering below Carters.

OHIO BASIN.

Ohio Basin comprises the subbasins of Great Kanawha and Tennessee rivers in which hydrographic work was done in 1897.

GREENBRIER RIVER.

Two gaging stations have been maintained in the Great Kanawha Basin, one on the Greenbrier River at Alderson, West Virginia, described in Water-Supply and Irrigation Paper No. 15, p. 58, and the other some distance below on the main New River at Fayette, West Virginia, described in Water-Supply and Irrigation Paper No. 15, p. 59.

Rating table for Greenbrier River at Alderson, West Virginia, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.3	45	3.0	1,900	5.4	7,740	9.0	19,000
1.4	70	3.2	2,330	5.6	8,300	9.5	20,700
1.5	115	3.4	2,770	5.8	8,900	10.0	22,500
1.6	185	3.6	3,240	6.0	9,500	10.5	24,400
1.7	275	3.8	3,720	6.2	10,100	11.0	26,500
1.8	365	4.0	4,200	6.4	10,700	12.0	31,200
1.9	460	4.2	4,680	6.6	11,300	13.0	36,200
2.0	550	4.4	5,160	6.8	11,900	14.0	41,200
2.2	745	4.6	5,660	7.0	12,500	15.0	46,200
2.4	975	4.8	6,180	7.5	14,000	16.0	51,200
2.6	1,230	5.0	6,700	8.0	15,600	17.0	56,200
2.8	1,540	5.2	7,220	8.5	17,300		

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

[Drainage area, 1,344 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	1,620	505	903	55,520	0.77	0.67
February	55,850	550	7,743	430,024	6.00	5.76
March	11,750	1,460	4,140	254,560	3.56	3.08
April	6,310	745	2,197	130,730	1.82	1.63
May	32,200	745	3,992	245,459	3.43	2.97
June	1,900	550	1,046	62,240	0.87	0.78
July	6,310	595	2,123	130,540	1.82	1.58
August	1,035	230	489	30,068	0.41	0.36
September	185	55	98	5,831	0.08	0.07
October	145	55	92	5,657	0.08	0.07
November	595	70	223	13,269	0.19	0.17
December	4,920	415	1,274	78,335	1.09	0.95
The year	55,850	55	2,027	1,442,233	20.12	1.51

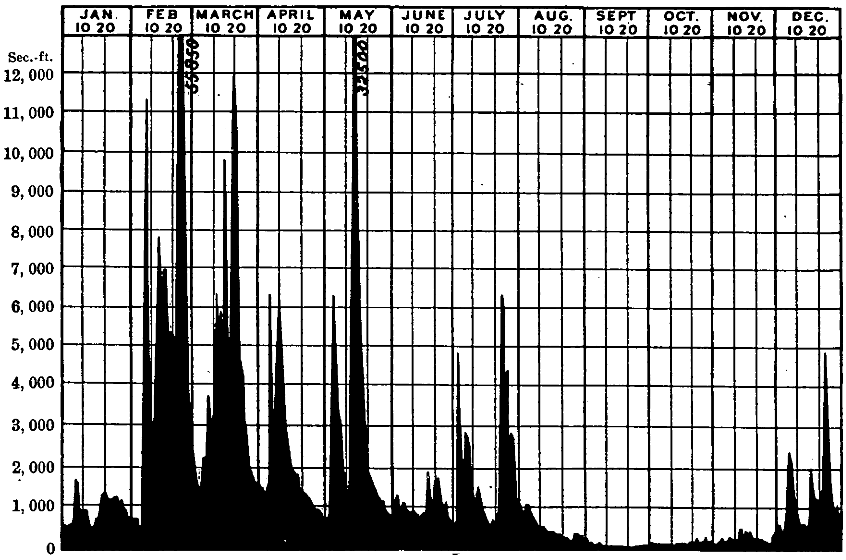


FIG. 71.—Discharge of Greenbrier River at Alderson, West Virginia, 1897.

NEW RIVER.

The principal tributary of Kanawha River is New River, which rises in Watauga, Ashe, and Alleghany counties, North Carolina. The area of the latter two counties is comprised wholly within the drainage basin of New River; their boundaries, being along the mountain ridges, form the divides between the watershed of this river and Yadkin River on the east and of Holston River on the west. The general direction of the river is northwesterly. At first the upper tributaries have a general northeasterly and southwesterly direction, draining narrow valleys of the Greater Appalachian Valley in Virginia. The main river cuts the Alleghany fronts just below Pearisburg, Virginia, and the remainder of the drainage area is confined to the State of West Virginia. For some distance the basin divide follows the State line between Virginia and West Virginia, both north and south of the place the river pierces the Alleghany front. The basin of New River is as beautiful and picturesque a section of country as any in the eastern part of the United States. The river itself is rapid and almost impassable even for canoes. The country on its lower courses, through which the Chesapeake and Ohio Railway passes, is noted for its scenic beauty.

Rating table for New River at Fayette, West Virginia, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
—0.4	1,040	2.4	3,250	5.8	9,578	14.0	35,200
—0.3	1,070	2.6	3,500	6.0	10,026	15.0	38,770
—0.2	1,100	2.8	3,750	6.2	10,474	16.0	42,340
—0.1	1,135	3.0	4,000	6.4	10,922	17.0	45,910
0.0	1,170	3.2	4,300	6.6	11,370	18.0	49,480
0.1	1,210	3.4	4,600	6.8	11,818	19.0	53,050
0.2	1,260	3.6	4,900	7.0	12,266	20.0	56,620
0.4	1,400	3.8	5,210	7.5	13,386	21.0	60,190
0.6	1,550	4.0	5,550	8.0	14,560	22.0	63,760
0.8	1,700	4.2	5,994	8.5	15,890	23.0	67,330
1.0	1,850	4.4	6,442	9.0	17,390	24.0	70,900
1.2	2,010	4.6	6,890	9.5	19,135	25.0	74,470
1.4	2,180	4.8	7,338	10.0	20,920	26.0	78,040
1.6	2,380	5.0	7,786	10.5	22,695	27.0	81,610
1.8	2,580	5.2	8,234	11.0	24,480	28.0	85,180
2.0	2,790	5.4	8,682	12.0	28,050		
2.2	3,000	5.6	9,130	13.0	31,620		

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

[Drainage area, 6,200 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	7,114	2,137	4,078	250,750	0.76	0.66
February	83,574	2,685	27,703	1,538,547	4.65	4.47
March	47,338	10,138	22,014	1,353,590	4.10	3.55
April	24,837	4,750	10,614	631,580	1.91	1.71
May	58,762	4,450	12,331	758,200	2.29	1.99
June	11,258	3,187	6,015	357,920	1.08	0.97
July	26,265	2,685	7,736	475,670	1.44	1.25
August	6,890	2,052	3,205	197,067	0.60	0.52
September	2,010	1,170	1,578	93,895	0.28	0.25
October	9,018	1,170	2,029	124,758	0.38	0.33
November	3,250	1,170	1,791	106,570	0.32	0.29
December	8,346	1,400	3,263	200,634	0.61	0.53
The year	83,574	1,170	8,530	6,089,181	18.42	1.38

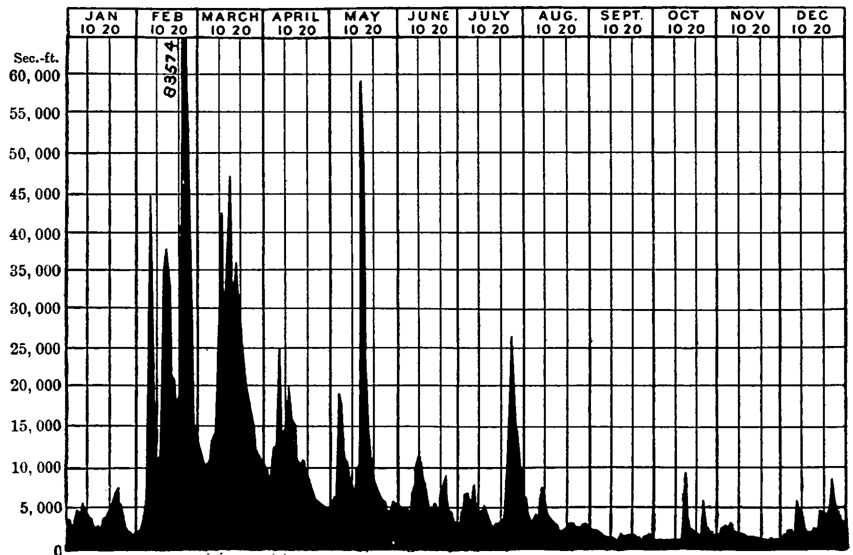


FIG. 72.—Discharge of New River at Fayette, West Virginia, 1897.

FRENCH BROAD RIVER.

The French Broad joins Holston River just above Knoxville, Tennessee, to form Tennessee River. Hydrographic investigations in the Tennessee Basin have been confined to the French Broad, Tuckaseegee, Little Tennessee, and Hiwassee rivers. The gaging stations on these four rivers are located at Asheville, Bryson, Judson, and Murphy, North Carolina, respectively, and are described in Water-Supply and Irrigation Paper No. 15, pp. 60-65, inclusive. On Tuckaseegee and Little Tennessee rivers a sufficient number of measurements were not made on which to base rating tables. The station at Asheville was established in 1895; while a rating table could not be constructed for the station until 1897, the section is practically constant, and monthly estimates are accordingly given since the establishment of the station.

Rating table for French Broad River at Asheville, North Carolina, for 1895 to 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.0	620	3.4	1,330	4.8	2,730	6.5	4,430
2.2	645	3.6	1,530	5.0	2,930	7.0	4,930
2.4	685	3.8	1,730	5.2	3,130	7.5	5,430
2.6	745	4.0	1,930	5.4	3,330	8.0	5,930
2.8	820	4.2	2,130	5.6	3,530		
3.0	930	4.4	2,330	5.8	3,730		
3.2	1,130	4.6	2,530	6.0	3,930		

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.		Depth in inches.	Second-feet per square mile.
1895.						
September 17-30	1,130	745	823	22,854	0.43	0.83
October	780	710	732	45,009	0.85	0.74
November	1,230	745	844	50,221	0.94	0.85
December	3,330	745	1,154	70,956	1.35	1.17
1896.						
January	4,430	800	1,439	88,481	1.68	1.46
February	3,380	1,180	1,733	99,684	1.90	1.76
March 16-31	1,630	1,030	1,227	38,944	0.74	1.24
April	2,130	820	1,092	64,978	1.24	1.11
May	2,530	780	1,063	65,362	1.25	1.08
June	1,330	745	922	54,863	1.03	0.93
July	7,780	727	2,191	134,719	2.56	2.22
August	1,180	710	866	53,248	1.01	0.88
September	1,130	672	772	45,937	0.87	0.78
October	762	685	705	43,348	0.82	0.71
November	4,130	762	1,634	97,230	1.85	1.66
December	3,730	845	1,281	78,765	1.50	1.30

Estimated monthly discharge of French Broad River at Asheville, North Carolina—Cont'd.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	2,380	780	1,164	71,570	1.36	1.18
February	5,830	1,530	2,709	145,450	2.85	2.74
March	5,180	1,630	3,036	186,680	3.56	3.08
April	5,530	1,580	2,607	155,130	2.94	2.64
May	5,030	1,180	1,920	118,056	2.25	1.95
June	2,430	980	1,410	83,900	1.60	1.43
July	1,530	800	1,187	72,985	1.38	1.20
August	1,930	710	908	55,830	1.06	0.92
September	762	672	698	41,535	0.79	0.71
October	1,280	652	792	48,696	0.92	0.80
November	1,780	652	841	50,040	0.94	0.85
December	1,580	697	950	58,412	1.10	0.96
The year	5,830	652	1,518	1,088,284	20.75	1.54

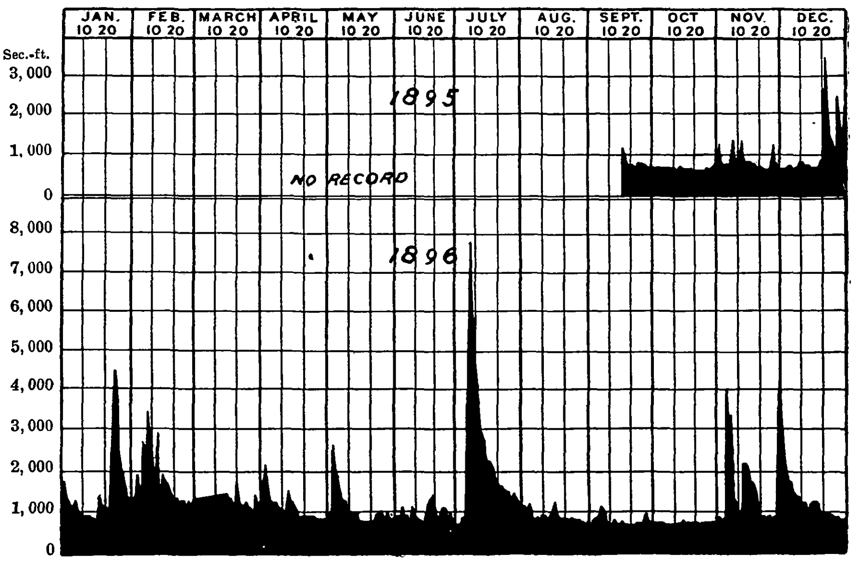


FIG. 73.—Discharge of French Broad River at Asheville, North Carolina, 1895 and 1896.

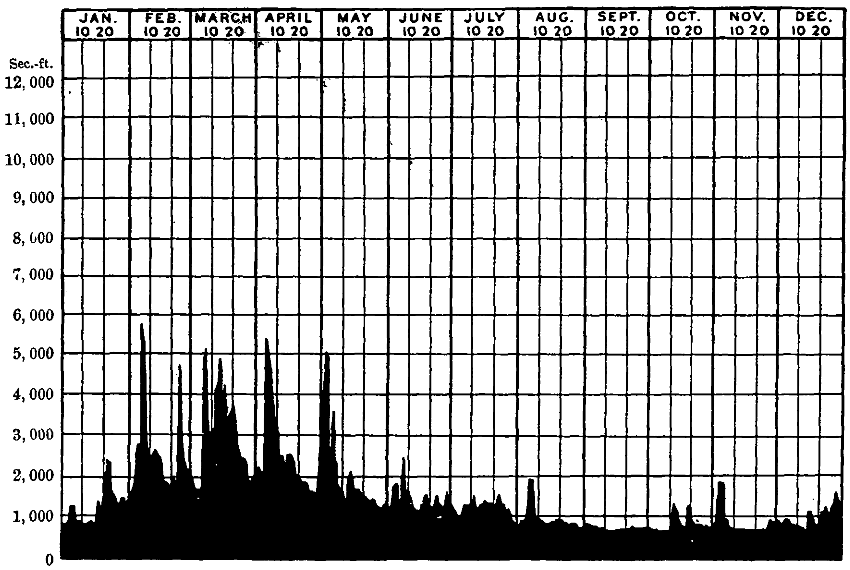


FIG. 74.—Discharge of French Broad River at Asheville, North Carolina, 1897.

HIWASSEE RIVER.

The station on Hiwassee River was established June 26, 1896, but the interpretation of gage heights into daily discharges can only be made from October 20, 1897. The wire gage was twice stolen in 1897 and replaced each time according to the figures for the elevation of the bench mark. On the final replacing, October 20, 1897, it was discovered that there was a difference of about 1 foot between the new and old data. At the time of the establishment of the station a tape was used that was broken at about the 1-foot mark, and it is thought that the allowance of this amount was not made in reporting the elevation of the bench mark. It is not known within 0.2 foot what this correction should be. For this reason, and also because of the fact that no discharge measurements have been made for the higher gage readings, it is considered unwise to compute the daily discharges previous to October 20, 1897.

Rating table for Hiwassee River at Murphy, North Carolina.

[This table is applicable from October 20, 1897, to December 31, 1897.]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
4.6	225	5.4	570	6.2	1,320	7.0	2,120
4.7	250	5.5	640	6.3	1,420	7.1	2,220
4.8	280	5.6	720	6.4	1,520	7.2	2,320
4.9	315	5.7	820	6.5	1,620	7.3	2,420
5.0	350	5.8	920	6.6	1,720	7.4	2,520
5.1	400	5.9	1,020	6.7	1,820	7.5	2,620
5.2	450	6.0	1,120	6.8	1,920		
5.3	510	6.1	1,220	6.9	2,020		

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.		Depth in inches.	Second-feet per square mile.
1897.						
October 20–31	350	237	268	6, 380	0. 29	0. 65
November	570	315	342	20, 350	0. 92	0. 83
December	2, 470	350	737	45, 316	2. 08	1. 80

List of miscellaneous discharge measurements, Tennessee Basin.

Date.	Stream.	Locality.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
1897.				*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
May 14.	Hiwassee River	Reliance, Tenn.	11	4. 04	2, 470	1. 50	3, 705
May 15.	do	do	11	3. 84	2, 376	1. 34	3, 181
Nov. 17.	Holston River.	Knoxville, Tenn	94		1, 832	1. 69	3, 084

TENNESSEE RIVER.

Investigations on the main stream have been continued at Chattanooga. In the Eighteenth Annual Report, Part IV, p. 119, are given by months the discharges of this river from 1890 to 1895. Here similar figures for 1896 and 1897 are given.

Rating table for Tennessee River at Chattanooga, Tennessee, for 1897. (a)

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second feet.*	*Feet.*	*Second feet.*	*Feet.*	*Second feet.*	*Feet.*	*Second feet.*
0. 2	3, 080	1. 4	10, 208	3. 4	22, 088	12. 0	73, 172
0. 3	3, 674	1. 6	11, 396	3. 6	23, 276	13. 0	79, 112
0. 4	4, 268	1. 8	12, 584	3. 8	24, 464	14. 0	85, 052
0. 5	4, 862	2. 0	13, 772	4. 0	25, 652	15. 0	90, 992
0. 6	5, 456	2. 2	14, 960	4. 4	28, 028	16. 0	96, 932
0. 7	6, 050	2. 4	16, 148	4. 8	30, 404	18. 0	108, 812
0. 8	6, 644	2. 6	17, 336	6. 0	37, 532	20. 0	120, 690
0. 9	7, 238	2. 8	18, 524	8. 0	49, 412	22. 0	132, 570
1. 0	7, 832	3. 0	19, 712	10. 0	61, 292	24. 0	144, 450
1. 2	9, 020	3. 2	20, 900	11. 0	67, 232	26. 0	156, 330

a Above 26 feet use table as published in the Eighteenth Ann. Rept., Part IV, p. 120.

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.		Depth in inches.	Second-feet per square mile.
1896.						
January	50, 600	15, 554	26, 169	1, 609, 079	1. 41	1. 22
February	85, 052	26, 840	55, 577	3, 196, 826	2. 79	2. 59
March	95, 150	22, 088	39, 257	2, 413, 834	2. 11	1. 83
April	409, 520	23, 276	87, 649	5, 215, 478	4. 56	4. 09
May	29, 216	14, 366	20, 574	1, 265, 054	1. 10	0. 96
June	43, 472	17, 336	24, 365	1, 449, 815	1. 27	1. 14
July	130, 196	20, 306	55, 390	3, 405, 820	2. 99	2. 59
August	34, 562	14, 960	22, 433	1, 379, 360	1. 21	1. 05
September	18, 524	9, 020	12, 346	734, 636	0. 64	0. 58
October	19, 712	8, 426	11, 588	712, 523	0. 62	0. 54
November	57, 728	9, 020	22, 603	1, 344, 969	1. 18	1. 06
December	45, 254	16, 148	27, 951	1, 718, 651	1. 51	1. 31
The year	409, 520	8, 426	33, 825	24, 446, 045	21. 39	1. 58
1897.						
January	45, 254	16, 148	27, 932	1, 717, 483	1. 50	1. 30
February	308, 060	19, 712	89, 962	4, 996, 236	4. 37	4. 20
March	363, 240	52, 976	165, 448	10, 173, 067	8. 90	7. 72
April	231, 520	36, 344	81, 056	4, 823, 156	4. 22	3. 78
May	134, 948	26, 543	50, 124	3, 082, 025	2. 70	2. 34
June	38, 126	21, 494	29, 107	1, 731, 983	1. 52	1. 36
July	74, 657	21, 791	34, 428	2, 116, 909	1. 86	1. 61
August	34, 562	14, 366	25, 847	1, 589, 280	1. 39	1. 21
September	14, 960	6, 050	8, 951	532, 620	0. 47	0. 42
October	13, 772	4, 268	7, 842	482, 189	0. 43	0. 37
November	9, 614	6, 050	7, 330	436, 164	0. 38	0. 34
December	62, 183	8, 129	24, 627	1, 514, 265	1. 33	1. 15
The year	363, 240	4, 268	46, 055	33, 195, 377	29. 07	2. 15

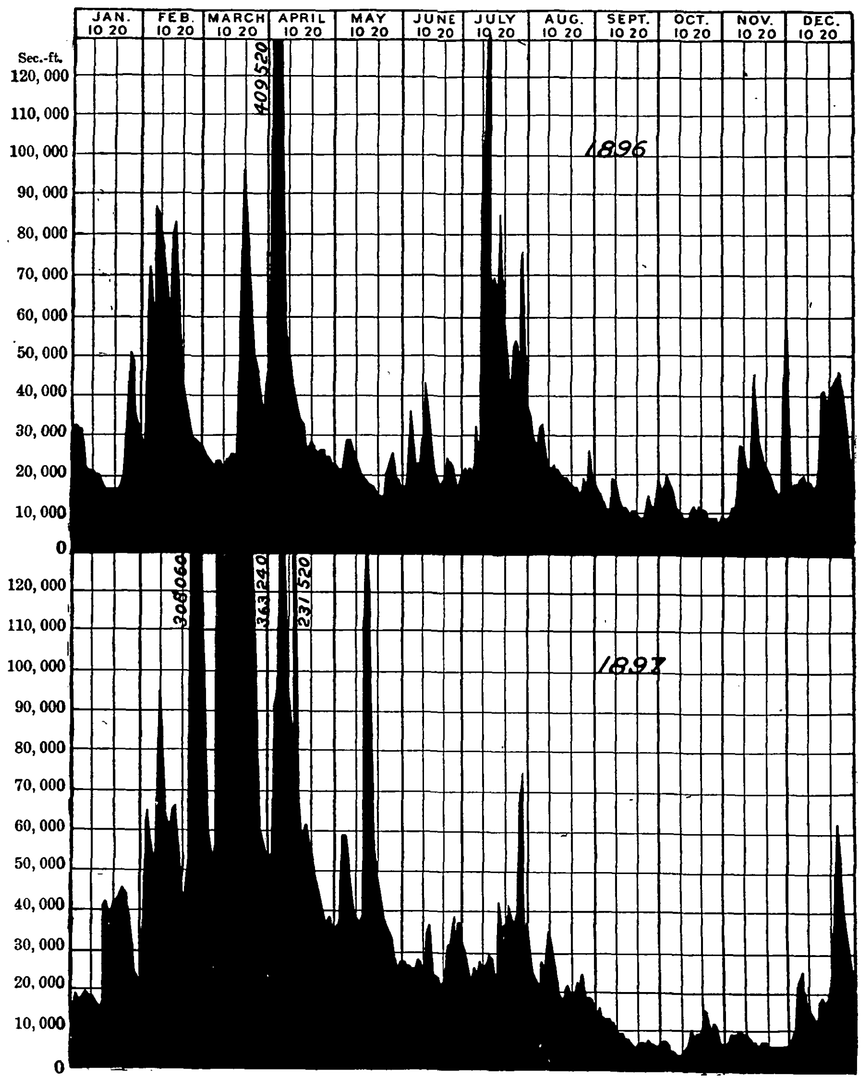


FIG. 75.—Discharge of Tennessee River at Chattanooga, Tennessee, 1896 and 1897.

GREAT LAKES WATERSHED.

GENESEE RIVER.

Surveys of the Genesee River have been made under the direction of the State engineer and surveyor of New York, as shown in various annual reports, for the purpose of ascertaining the possibility of increasing the water supply for Erie Canal. In the last paper on the subject, prepared by Mr. George W. Rafter and printed as Appendix VII of the Annual Report of the State Engineer and Surveyor of New York for the fiscal year ending September 30, 1896, a detailed discussion is given of the flow of the stream and of the influence of deforestation upon the run-off. The first series of measurements as there noted extended from June 17 to December 2, 1890. On August 21, 1893, observations were begun at the dam belonging to the Mount Morris Hydraulic Power Company, and maintained until the dam was

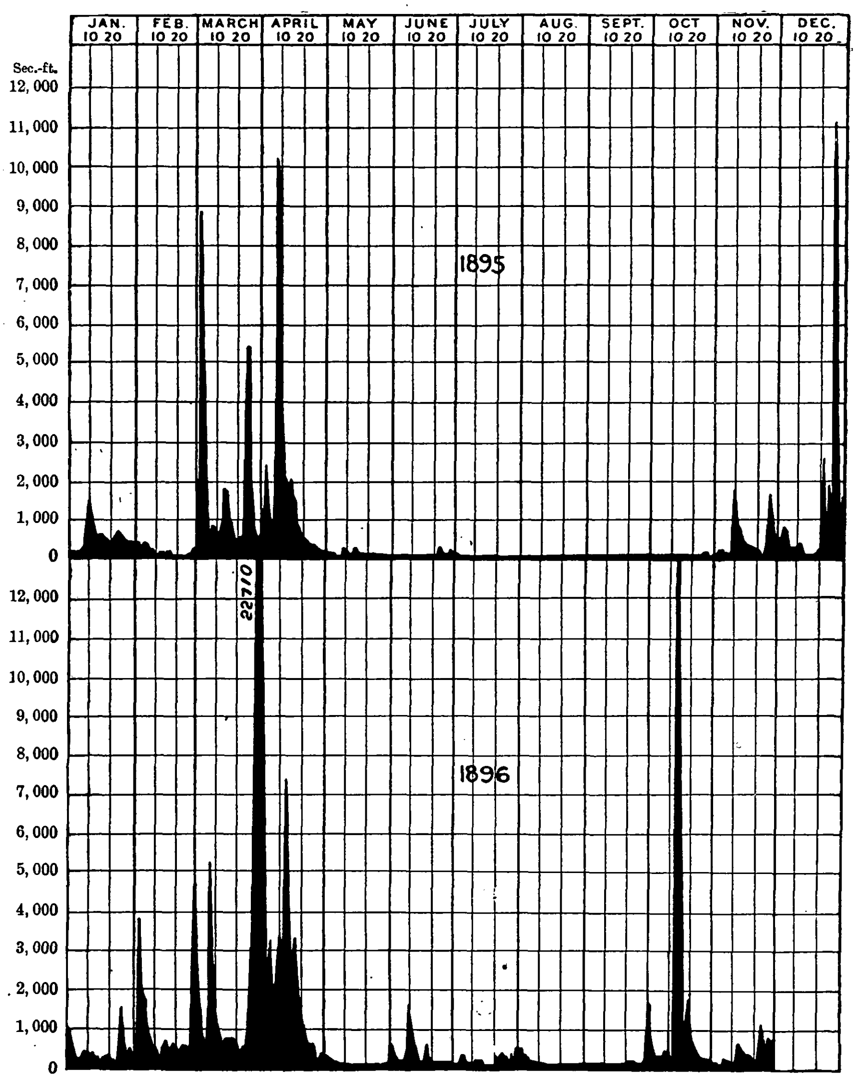


FIG. 76.—Discharge of Genesee River at Mount Morris, New York, 1895 and 1896.

destroyed by flood, early in March, 1897. Readings of the height of the water passing over the dam were taken twice each day during ordinary stages, but in time of high water readings were made at shorter intervals. The dam, which was 337 feet in length, had an irregular crest, and in order to apply weir formulæ an accurate profile was made and the dam divided into a number of approximately level sections. The flow over each section was computed for each tenth of a foot up to 10 feet in height. Allowance was made for leakage, which was assumed to be 100 second-feet.

In order to verify the results obtained by the use of the formula a weir was constructed during the summer of 1896 at a point 2½ miles above the dam. Observations at the two points were correlated and a verification obtained of the results computed for the Hydraulic Power Company's dam. This weir was injured by a severe flood in October, 1896, and owing to lack of funds has not been replaced up to the summer of 1898. The results of the computations of discharge from August 21, 1893, to March 31, 1894, are shown on a diagram facing page 336 of the Report of the State Engineer and Surveyor for 1894, and from February 1, 1895, to November 30, 1896, on Pl. C, facing page 644 of the Annual Report of the State Engineer and Surveyor for 1896. The principal facts concerning stream flow given on this plate are shown in the accompanying figure (fig. 76).

UPPER MISSISSIPPI BASIN.

MISSISSIPPI RIVER.

Measurements of discharge of Mississippi River at St. Paul, Minnesota, below the mouth of Minnesota River, have been made for a number of years by the Engineer Corps of the United States Army. The results up to June 30, 1893, have been compiled and published in a pamphlet issued by the Mississippi River Commission.[1]

The results of measurements since that time are to be found in the annual reports of the Chief of Engineers, United States Army.[2]

The first recorded measurement is that of September 24, 1866. During the succeeding year, 1867, a number of measurements were made during the months from July to November, inclusive. From that time occasional measurements were made during 1868, 1874, 1878, 1879, 1880, 1884, 1885, and 1886. Systematic work was begun under a specific appropriation in 1889, and has been carried on each year since that

[1] Tabulated Results of Discharge Observations, Mississippi River and its Tributaries and Outlets, 1838–1894. Compiled in the office of the secretary Mississippi River Commission. Mississippi River Commission print, 1895.

[2] Results for the year ending June 30, 1894, Annual Report of Chief of Engineers, United States Army, Part III, pp. 1732–1735. Contains rating curve or diagram showing volume of Mississippi River at St. Paul, Minnesota, corresponding to readings of the United States Signal Service (Weather Bureau) gage, being based on the mean of measurements taken during the four years ending June 30, 1894.

Results for the year ending June 30, 1895, Annual Report of Chief of Engineers, United States Army, Part III, pp. 2202–2205. Contains discharge diagram for months of July to November, 1893.

Results for year ending June 30, 1896, Annual Report of Chief of Engineers, United States Army, Part III, pp. 1859-1863. Contains table and discussion of relation of run-off to rainfall on the watershed of Mississippi River above St. Paul, Minnesota, for the years 1894 and 1895.

Results for year ending June 30, 1897, Annual Report of Chief of Engineers, United States Army, Part III, pp. 2164–2170. Contains table and discussion of relation of run-off to rainfall for the years 1894 to 1896, inclusive.

time. The following details have been obtained from Mr. Archibald O. Powell, United States assistant engineer:

The object of the measurements is the determination of the effect of the reservoirs at the head of the Mississippi River in maintaining deep or navigable water during periods of drought. Measurements and computations of the amount of water discharged from the reservoirs at such seasons are made and comparisons had with the behavior of the river at St. Paul and lower places. The measurements are made at a section about halfway between Wabasha street bridge and Robert street bridge in the city of St. Paul. A long, low strip of land, known as Raspberry Island, occupies the middle of the channel, the greater part of the water passing at ordinary stages to the left of this or against the St. Paul shore. To maintain deep water on the St. Paul side the Government has constructed a loose stone dam from the island to the right bank, across the part of the river west of the island. Observations of river height are made at the United States Weather Bureau gage, located on a wharf at the foot of Jackson street. The zero of this gage is at an elevation of 683.334 feet. When the water on this gage stands at a height of 4.65 feet and upward, the stream passes over the dam on the west side of the island. Between stages of 4.65 and 6.70 feet it is impracticable to measure with a meter the volume passing on the west side of the island, as the current is too sluggish. The amount has been approximated, however, by plotting the gage readings and discharges between the heights of 6.70 and 10.50 feet and then extending the curve downward.

The measurements of discharge are made from a boat with Ellis current meters. The meter is held in position by two men, one in the bow and the other in the stern, each grasping a wire rope. Two of these are stretched across the river parallel and at a distance of 13 feet apart. The upper line is tagged every 10 feet, a sounding being taken at each tag and an observation for velocity at alternate tags. The wire ropes are laid before each measurement, and afterwards reeled up. Velocities are obtained by observing at mid-depth in these sections 20 feet apart. The mean velocity has been assumed to be 95 per cent of the measured mid-depth velocity. The results of observations indicate that the river begins to rise at St. Paul within seven or eight days following release of water from the distributing reservoir at Pokegama Falls, and that in about five days the full effect is felt. The rise on the United States Weather Bureau gage, due to the reservoir water, in 1893 was 1 foot; in 1894, 1.3 feet; and in 1895, 1.2 feet.[1]

From the rating curve given in the report of the Chief of Engineers for 1894 a rating table, given on page 267, has been constructed which is assumed to be fairly accurate for average conditions, or at least sufficiently so for computations of mean discharge. The figures given in this table have been applied to the readings of the United States

[1] Report of Lieut. Col. W. A. Jones, in Annual Report of Chief of Engineers, 1896, Part III, p. 1861.

Weather Bureau gage and computations made of mean monthly flow, as shown by the tables on pages 268 to 270. Values have also been plotted on diagrams giving the behavior of the stream for the years 1887 to 1896, inclusive. The rating curve was based on measurements made during the four years ending June 30, 1894, but subsequent observations agree with this so well that the values are assumed to be practically constant.

The accompanying plates illustrate the methods of measurements of the river at St. Paul. The bridges are too high above the surface of the water to be satisfactory, and on account of navigation it is not practicable to stretch a cable permanently across near the surface of the water. Accordingly, temporary wires are used whenever discharge measurements are to be made, and removed immediately after, so that the channel is not impeded.

The first view (Pl. XXX, *A*) shows the wire being put across the river. It is placed on a reel mounted in the stern of a boat and paid out as the boat is rowed across the stream, the ends being cleared and the wire drawn up to clear the water.

The second view (Pl. XXX, *B*) shows the two parallel wires in place, the upper one with tags at uniform intervals, indicating the distance from the shore, or the initial point. A man at each end of the boat holds this in position, while a third man in the bow takes soundings of depths by means of a rod.

The third view (Pl. XXXI, *A*) shows the boat with a timber, suitably arranged, projecting forward over the bow and supporting the current meter, which, in the picture, is drawn up so that the lead weight and tail are partly submerged, the meter being entirely out of the water. When in use the apparatus is lowered by the chain which runs over the end of the timber. The two men, one in the bow and the other in the stern, hold the boat in position, while the third man records the time and revolutions of the meter.

The fourth view (Pl. XXXI, *B*), similar to the first, illustrates the method of taking in the wires after the measurement is completed. Each wire is drawn in over the bow and wound upon the reel, which is mounted on bearings provided for the purpose. The whole operation of putting up the wires, taking velocity measurements, and reeling in the wires can be accomplished in about two hours, or even less when the river is at low stages, everything being kept in readiness for the purpose.

	Square miles.
Drainage area above St. Paul, Mississippi River	19,735
Drainage area above St. Paul, Minnesota River	16,350
Total above St. Paul	36,085

A.

B.

MEASURING VELOCITY OF MISSISSIPPI RIVER AT SAINT PAUL, MINNESOTA.

A, Reeling out the wire; *B*, Sounding the depth.

Elevation of points on Mississippi and Minnesota rivers.

MISSISSIPPI RIVER. (*a*)

Locality.	Elevation above sea.	Distance above St. Paul. (*b*)
	Feet.	*Miles.*
Lake Itasca	Not known.	Not known.
Cass Lake	1,302	Do.
Lake Winnibigoshish	1,290	Do.
Pokegama Falls, above	1,269	354
Pokegama Falls, below	1,255	221
Aitkin	1,189	
Mouth of Sauk River	992	92
St. Anthony Falls, above crest	782	14
St. Anthony Falls, below fall	752	
St. Paul, low water, 1864	683	....
St. Paul, high water, 1881	702	....

MINNESOTA RIVER.

Locality.	Elevation above sea.	Distance above St. Paul.
Mouth of Blue Earth River	756	117.1
Mankato	751	115.3
Le Sueur	715	81.5
Belle Plain	696	51.7
Carver	689	32.7
Shakopee	688	25.9
Mendota (Fort Snelling)	687	7

a Data from letter of December 26, 1893, from Maj. W. A. Jones, Corps of Engineers, United States Army, G. R. 2279.
b Distances not stated may be approximately scaled from Land Office maps.

Rating table for Mississippi River at St. Paul, Minnesota.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.0	1,750	3.0	6,210	6.0	14,160	12.0	40,975
0.5	2,360	3.5	7,100	7.0	17,900	13.0	46,025
1.0	3,060	4.0	8,070	8.0	21,920	14.0	51,075
1.5	3,800	4.5	9,150	9.0	25,980	15.0	56,125
2.0	4,580	5.0	10,650	10.0	30,875	16.0	61,175
2.5	5,380	5.5	12,320	11.0	35,925	17.0	66,225

Estimated monthly discharge of Mississippi River at St. Paul, Minnesota.

[Drainage area, 36,085 square feet.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Depth in inches.	Second-feet per square mile.
1887.					
March 22-31	21,514	17,520	19,863	0.20	0.55
April	28,855	12,320	20,402	0.63	0.57
May	13,430	6,920	9,505	0.30	0.26
June	6,920	5,700	6,078	0.19	0.17
July	6,040	5,060	5,632	0.18	0.16
August	5,380	4,420	4,890	0.16	0.14
September	5,540	4,260	4,804	0.14	0.13
October	4,580	4,100	4,353	0.14	0.12
November 1-27	4,420	2,780	3,716	0.10	0.10
1888.					
April 7-30	53,095	7,670	37,623	0.93	1.04
May	51,580	31,885	40,486	1.29	1.12
June	34,915	20,300	24,639	0.75	0.68
July	21,110	9,650	16,134	0.52	0.45
August	13,050	6,210	9,151	0.29	0.25
September	6,740	5,870	6,387	0.20	0.18
October	7,290	6,040	6,691	0.22	0.19
November	7,480	5,220	6,453	0.20	0.18
December 1-11	5,540	4,580	4,958	0.06	0.14
1889.					
March 12-13, 19-31	8,490	7,100	7,813	0.12	0.22
April	7,670	5,380	6,104	0.19	0.17
May	9,150	6,560	7,597	0.24	0.21
June	7,100	4,900	5,731	0.18	0.16
July	6,040	4,580	5,136	0.16	0.14
August	6,560	5,060	5,710	0.18	0.16
September	6,560	4,420	5,297	0.17	0.15
October	4,580	3,950	4,214	0.14	0.12
November 1-24	4,420	3,200	3,909	0.10	0.12
1890.					
March 25-31	6,210	4,260	5,316	0.04	0.15
April	12,320	3,800	7,983	0.24	0.22
May	7,290	5,700	6,349	0.21	0.18
June	17,900	7,480	12,833	0.40	0.36
July	13,050	5,700	8,725	0.28	0.24
August	5,220	3,500	4,200	0.14	0.12
September	5,060	3,950	4,516	0.14	0.13

A.

B.

MEASURING VELOCITY OF MISSISSIPPI RIVER AT SAINT PAUL, MINNESOTA.

A, Preparing to take meter measurement; *B*, Reeling in the wire.

Estimated monthly discharge of Mississippi River at St. Paul, Minnesota—Continued.

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Depth in inches.	Second-feet per square mile.
1890.					
October	5,540	3,950	4,776	0.15	0.13
November	5,060	3,060	4,263	0.13	0.12
December 1-2	2,640	2,500	2,570	0.05	0.07
1891.					
March 29-31	5,700	4,420	5,007	0.02	0.14
April	15,620	6,560	13,456	0.41	0.37
May	11,290	5,870	7,658	0.24	0.21
June	6,040	5,380	5,710	0.18	0.16
July	6,040	4,420	5,003	0.16	0.14
August	4,900	3,350	4,022	0.13	0.11
September	3,950	3,200	3,540	0.11	0.10
October	4,260	3,350	3,791	0.13	0.11
November 1-28	3,500	1,980	2,692	0.07	0.07
1892.					
March 7-31	10,650	4,580	7,322	0.18	0.20
April	13,050	6,380	9,258	0.29	0.26
May	44,005	8,270	23,835	0.76	0.66
June	38,450	24,380	28,231	0.87	0.78
July	23,560	9,150	13,821	0.44	0.38
August	16,380	6,740	9,966	0.32	0.28
September	8,270	6,040	7,116	0.22	0.20
October	6,380	4,900	5,658	0.18	0.16
November 1-26	4,740	3,060	4,193	0.11	0.12
1893.					
April	42,995	19,100	31,028	0.95	0.86
May	54,610	29,360	41,512	1.33	1.15
June	28,350	8,930	15,885	0.49	0.44
July	8,490	5,060	7,130	0.23	0.20
August	5,540	4,260	4,864	0.15	0.13
September	6,380	5,700	6,118	0.19	0.17
October	6,380	5,700	6,106	0.20	0.17
November	6,210	2,500	4,708	0.14	0.13
December 1-11	4,580	3,950	4,319	0.05	0.12
1894.					
March 8-31	9,150	4,580	7,231	0.18	0.20
April	33,905	6,040	15,413	0.48	0.43
May	39,965	19,500	28,209	0.90	0.78
June	18,280	5,870	9,865	0.30	0.27
July	5,870	1,980	4,140	0.14	0.12
August	4,580	1,980	3,537	0.12	0.10

Estimated monthly discharge of Mississippi River at St. Paul, Minnesota—Continued.

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Depth in inches.	Second-feet per square mile.
1894.					
September	4,420	3,650	4,044	0.12	0.11
October	4,900	3,950	4,395	0.15	0.13
November 1-29	5,540	3,060	4,323	0.12	0.12
1895.					
March 23-31	3,650	2,100	2,964	0.03	0.09
April	3,350	2,100	2,847	0.09	0.08
May	5,380	2,640	4,145	0.14	0.12
June	9,380	4,260	7,168	0.22	0.20
July	7,670	3,800	5,410	0.17	0.15
August	5,060	2,780	3,990	0.13	0.11
September	5,380	3,800	4,507	0.13	0.12
October	5,220	3,350	4,329	0.14	0.12
November 1-27	3,800	2,365	3,356	0.09	0.09
1896.					
January	....	....	a1,782	....	....
February	....	....	a1,600	....	....
March 29-31	2,640	1,860	2,160	0.07	0.06
April	34,410	1,640	15,676	0.49	0.44
May	33,400	21,514	27,350	0.87	0.76
June	26,380	14,160	20,268	0.62	0.56
July	13,050	4,260	7,553	0.24	0.21
August	5,540	4,100	4,719	0.15	0.13
September	5,060	3,500	4,441	0.13	0.12
October	5,380	4,260	4,699	0.15	0.13
November 1-27	7,100	3,800	5,413	0.15	0.15
December	....	....	a4,445	....	....
1897.					
January	....	....	....	....	....
February	....	....	....	....	....
March 20-31	48,550	7,870	24,781	0.30	0.69
April	71,275	32,390	55,654	1.72	1.54
May	30,875	11,630	17,999	0.58	0.50
June	17,140	11,290	14,288	0.45	0.40
July	49,055	16,000	32,864	1.05	0.91
August	25,580	9,150	15,285	0.48	0.42
September	12,320	9,150	10,474	0.32	0.29
October	10,310	7,670	8,524	0.28	0.24
November	7,870	5,060	7,003	0.19	0.19
December	....	....	a7,480	0.24	0.21

a Approximate.

UPPER MISSOURI BASIN.

The basins of the three rivers, Gallatin, Madison, and Jefferson, which unite to form Missouri River near Threeforks, Montana, have been described at various times in the Annual Reports of this Survey, especially in the Thirteenth Annual Report, Part III, beginning on page 41.

SMALLER TRIBUTARIES OF GALLATIN RIVER.

A gaging station was maintained on Middle Creek during 1896 and the data obtained were of considerable value owing to the number of irrigation ditches taken from that creek. The station is located some distance above the canyon and the only available observer moved away in the spring of 1897, so that the station could not be regularly maintained through the year. A number of discharge measurements were made on it, however, and will be found in Water-Supply and Irrigation Paper No. 15, p. 67.

A number of discharge measurements were also made on Bozeman Creek and Rocky Creek, tributaries to the East Gallatin. They are published in Water-Supply and Irrigation Paper No. 15, p. 75.

EAST GALLATIN RIVER SEEPAGE MEASUREMENTS.

During the latter part of September, 1897, a series of discharge measurements were made by Roe Emery on East Gallatin River, in Montana, for a study of the seepage of that river. In fig. 77 is shown the relative location of the points of measurement and the principal streams and towns. The table, pages 273 and 274, gives the measurements of the rivers, of the ditches, and of the creeks entering the river. The next table, pages 274 and 275, shows the computations for the seepage. The points at numbers 1, 2, and 4 are on Bozeman, Rocky, and Bridger creeks, respectively, which form at their junction East Gallatin River. To obtain the total flow in East Gallatin River, the flow in Story Mill ditch, No. 3, which takes water both from Bridger and Rocky creeks, should be added. Between these measurements and that at No. 6, the next lower point on the main river, two ditches, Nos. 5 and 7, are taken out. The sum of these two latter measurements subtracted from the sum of measurements 1 to 4, inclusive, gives 43.6 second-feet. The measurement of East Gallatin, No. 6, at the first bridge is 48.3 second-feet. This shows a gain of 4.7 second-feet.

Between measurements No. 6 and No. 8 on the main river only one ditch, No. 9, is taken out, and at the time of measurement it was carrying no water. The difference, therefore, between measurement No. 6, which is 48.3 second-feet, and measurement No. 8, which is 58.0 second-feet, makes the gain between these two points, 9.7 second-feet. The distance between these two measurements was 1.75 miles.

Between measurements 8 and 19, on the main river, 5 ditches are taken out, numbered respectively 10, 13, 14, 17, and 18. One slough, No. 11, enters between. The sum of measurements at 8 and 11 is 58.5 second-feet. The sum of measurements of ditches taken out and of measurement No. 19 at the third bridge is 36.4 second-feet. This shows a loss in a distance of 4.25 miles of 22.1 second-feet.

Between measurements 19 and 20, on the main river, creeks 12 and 13 enter and ditches 21 and 22 are taken out. The water entering added to the measurement at the third bridge, No. 19, gives 67.1 second-feet. Ditches taken out, added to the gaging at the lower or fourth bridge, sum up to 50.5 second-feet. The apparent loss of 16.6 second-feet occurs in the distance of 2¼ miles.

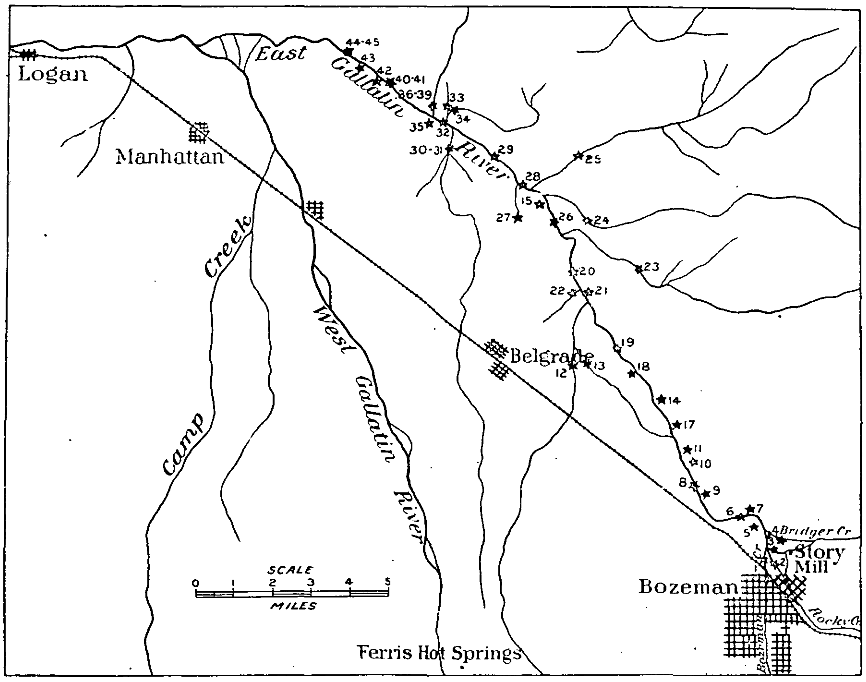


FIG. 77.—Location of points of measurement of seepage waters in East Gallatin River.

In the next estimation for seepage, measurements between No. 20 at the fourth bridge and No. 28 at the sixth bridge are considered. The gaging at the fifth crossing, No. 26, of 16.5 second-feet, is so considerably under measurement 20, although there are no ditches taken out between them, it has not been considered in this discussion. It would seem that there was some mistake in the measurement or that the sections must have been extremely poor. Between the two points under consideration, Nos. 20 and 28, four creeks enter the river, Nos. 23, 24, 25, and 25*a*. No ditches are taken out between these points. The discharge of the creeks, added to measurement 20, at the fourth crossing, equals 78.3 second-feet; this, subtracted from the measurement at the sixth crossing of 92.0 second-feet, shows a gain of 13.7 second-feet occurring in the distance of 2¾ miles.

Between measurements No. 28 at the sixth bridge and No. 32 at the seventh bridge enter sloughs and creeks, Nos. 27, 29, 30, 31, 33, and 34. Their discharge, added to the measurement at No. 28, equals 179.7 second-feet, which, subtracted from the gaging at the seventh crossing of 181.0 second-feet, shows a gain of 1.3 second-feet in 2½ miles.

Adding to measurement 32, at the seventh bridge, the creeks, 35 and 36 to 39, inclusive, that enter between this measurement and that at the eighth crossing, gives a total of 212.2 second-feet. This, subtracted from the measurement at the eighth crossing of 284.1 second-feet, shows a gain of 71.9 second-feet in a distance of 1.75 miles.

Adding to the measurement at the eighth bridge the discharge of creeks 42 and 43 gives a total of 297.4 second-feet. This, subtracted from measurements 44 and 45 at the ninth crossing, 336.8 second-feet, shows a gain of 39.4 second-feet in a distance of 1 mile.

The country north of Belgrade and south of the river under consideration is one vast swamp, due principally to seepage water from West Gallatin River, so that the large gains shown in the last few measurements are not altogether due to water taken from East Gallatin River.

East Gallatin River seepage measurements.

	Second-feet.
1. Bozeman Creek bridge, left bank, runs into Rocky Creek	12.5
2. Rocky Creek	9.1
3. Story Mill ditch, right bank Rocky Creek	22.1
4. Bridger Creek, right bank, forming East Gallatin	2.7
5. Jackson ditch	0.0
6. East Gallatin, first bridge, 1½ miles below Bridger Creek	48.3
7. Ditch on right bank, 300 yards above No. 1	2.8
8. East Gallatin, second bridge, Jackson's ranch	58.0
9. Ditch one-fourth mile above second bridge; no water	0.0
10. Nelson & Arnold ditch, 100 yards below second bridge, right bank	4.7
11. Slough, three-fourths mile from second bridge, right bank	0.5
12. Middle Creek bridge, left bank, empties into East Gallatin below	39.2
13. Branch East Gallatin, runs into Middle Creek	7.7
14. Ditch on right bank, Flannery's taken out, one-half mile above bridge, Arnold's ranch	2.3
17. Ditch taps right bank on J. Beck's ranch (dry), empties into Nelson & Arnold ditch	0.0
18. Touhy's ditch on left bank, three-fourths mile above Flannery's bridge.	1.5
19. East Gallatin, third bridge	20.2
20. East Gallatin, fourth bridge, Davis	50.5
21. Touhy's ditch taps right bank below third bridge, no water	0.0
22. Ditch on west bank, Touhy's ranch, no water	0.0
23. Creek empties in one-half mile below fourth bridge on Henry Davis, right bank Cottonwood Creek	4.9
24. Creek enters slough, then to Gallatin right bank	14.9
25. Reese Creek	7.0
25*a*. Small slough, 200 yards below Penwells	1.0
25*b*. Ditch right bank, 300 yards, dry	0.0
25*c*. Ditch right bank, one-half mile, dry	0.0
25*d*. Ditch right bank, three-fourths mile, dry	0.0

		Second-feet.
26. East Gallatin, fifth crossing		16.5
27. Slough, left bank		16.5
28. East Gallatin, sixth bridge		92.0
29. Slough enters East Gallatin 1¼ miles below sixth bridge on left bank		21.7
30 and 31. Small creek, 100 yards below left bank		1.0
32. East Gallatin, seventh bridge, Dry Creek		181.0
33. Small stream into East Gallatin, 150 yards above seventh bridge	6.4	
34. Large stream, Foster Creek	42.1	
		48.5
35. Stream into left bank, three-fourths mile below seventh bridge		13.3
36. Dry Creek, one-fourth mile below seventh bridge	5.3	
37. Dry Creek ditch empties into East Gallatin	2.1	
38. Branch Dry Creek	4.5	
39. Branch Dry Creek	6.0	
		17.9
40 and 41. East Gallatin, eighth (Kinney's) bridge		284.1
42. Small stream, three-eighths mile below eighth bridge, left bank		4.7
43. Small stream, one-fourth mile below eighth bridge, left bank		8.6
44 and 45. East Gallatin, ninth (Brooks's) bridge		336.8
46. Small creek, left bank, 1 mile below ninth bridge		4.0

East Gallatin River seepage computations.

1. Bozeman Creek	12.5	
2. Rocky Creek	9.1	
3. Mill ditch	22.1	
4. Bridger Creek	2.7	
		46.4
5. Jackson ditch	0.0	
7. Ditch	2.8	
		2.8
Difference		43.6
6. East Gallatin, first bridge		48.3
Gain		4.7
6. East Gallatin, first bridge		48.3
9. Ditch	0.0	
8. East Gallatin, second bridge	58.0	
		58.0
Gain		9.7
8. East Gallatin, second bridge		58.0
11. Slough		0.5
		58.5
10. Nelson & Arnold ditch	4.7	
13. Branch	7.7	
14. Ditch	2.3	
17. Ditch	0.0	
18. Touhy's ditch	1.5	
19. East Gallatin, third bridge	20.2	
		36.4
Loss		22.1

	Second-feet.	
12. Middle Creek	39.2	
13. Branch	7.7	
19. East Gallatin, third bridge	20.2	
		67.1
21. Ditch	0.0	
22. Ditch	0.0	
20. East Gallatin, fourth bridge	50.5	
		50.5
Loss		16.6
20. East Gallatin, fourth bridge	50.5	
23. Cottonwood Creek	4.9	
24. Creek	14.9	
25. Reese Creek	7.0	
25*a*. Small Slough	1.0	
		78.3
28. East Gallatin, sixth bridge		92.0
Gain		13.7
28. East Gallatin, sixth bridge	92.0	
27. Slough	16.5	
29. Slough	21.7	
30 and 31. Small creek	1.0	
33 and 34. Foster Creek	48.5	
		179.7
32. East Gallatin, seventh bridge		181.0
Gain		1.3
32. East Gallatin, seventh bridge	181.0	
35. Creek	13.3	
36 to 39. Dry Creek	17.9	
		212.2
40 and 41. East Gallatin, eighth bridge		284.1
Gain		71.9
40 and 41. East Gallatin, eighth bridge	284.1	
42. Creek	4.7	
43. Creek	8.6	
		297.4
44 and 45. East Gallatin, ninth bridge		336.8
Gain		39.4

WEST GALLATIN RIVER.

The station on this river is one of the most important of the Montana stations, as a number of large irrigation canals are taken therefrom. The Kleinschmidt ditch, carrying about 50 second-feet, diverts water from the river above the station. In the table for monthly discharges the average for January, February, and March, as well as that for November, has been estimated, as the river varies but little during those months. The discharge measurements and table of gage heights were published in Water-Supply and Irrigation Paper No. 15, p. 66.

Rating table for West Gallatin River at Salesville, Montana, for 1897.

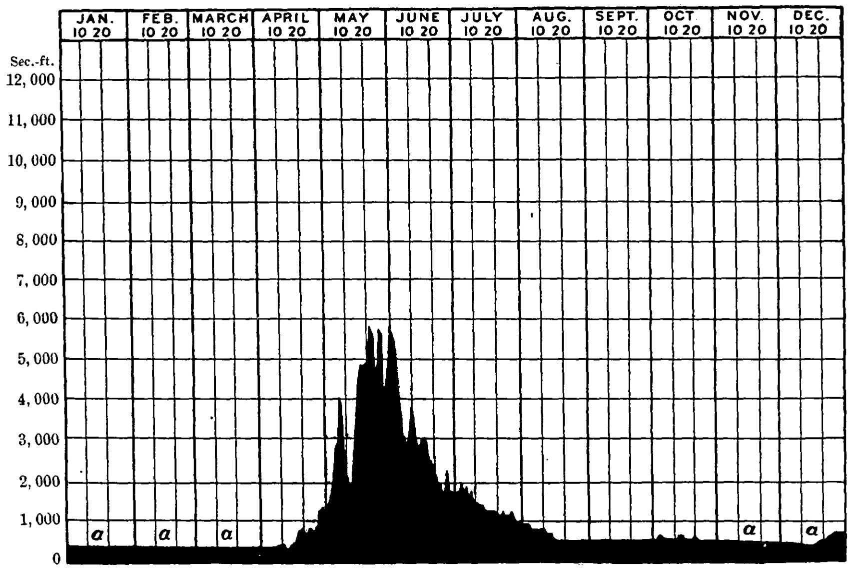
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
3.0	400	3.7	1,000	4.8	2,125	6.0	4,250
3.1	450	3.8	1,100	5.0	2,450	6.2	4,610
3.2	510	3.9	1,200	5.2	2,810	6.4	4,970
3.3	600	4.0	1,300	5.4	3,170	6.6	5,330
3.4	700	4.2	1,500	5.6	3,530	6.8	5,690
3.5	800	4.4	1,700	5.8	3,890	7.0	6,050
3.6	900	4.6	1,900				

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.		Depth in inches.	Second-feet per square mile.
1897.						
January	....	....	*a* 250	15,372	0.33	0.29
February	....	....	*a* 250	13,884	0.30	0.29
March	....	....	*a* 300	18,446	0.40	0.35
April	1,300	350	582	34,630	0.75	0.68
May	5,780	1,450	3,839	236,050	5.15	4.46
June	5,510	1,750	2,803	166,790	3.64	3.26
July	1,950	900	1,316	80,920	1.76	1.53
August	900	510	637	39,168	0.85	0.74
September	510	510	510	30,345	0.65	0.59
October	600	510	526	32,344	0.70	0.61
November	....	....	*a* 450	26,778	0.58	0.52
December	....	....	*a* 450	27,669	0.60	0.52
The year	....	....	993	722,396	15.71	1.15

a Approximate.



a Approximate.

FIG. 78.—Discharge of West Gallatin River at Salesville, Montana, 1897.

GALLATIN RIVER.

The gaging station on this river is located at the railroad bridge at Logan, Montana, 6 miles above the mouth of the river. The data show the amount of water running to waste at this point, and present also the discharge of East Gallatin River. The station was described and the list of discharge measurements and table of gage heights for 1897 given in Water-Supply and Irrigation Paper No. 15, p. 68.

Rating table for Gallatin River at Logan, Montana, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.5	360	1.3	800	2.2	1,710	3.8	4,750
0.6	400	1.4	870	2.4	2,090	4.0	5,130
0.7	450	1.5	940	2.6	2,470	4.2	5,510
0.8	500	1.6	1,020	2.8	2,850	4.4	5,890
0.9	550	1.7	1,120	3.0	3,230	4.6	6,270
1.0	610	1.8	1,220	3.2	3,610	4.8	6,650
1.1	660	1.9	1,330	3.4	3,990	5.0	7,030
1.2	730	2.0	1,450	3.6	4,370		

Estimated monthly discharge of Gallatin River at Logan, Montana.

[Drainage area, 1,620 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January			a 700	43,040	0.49	0.43
February			a 650	36,100	0.42	0.40
March			a 650	39,965	0.46	0.40
April	1,450	635	990	58,910	0.68	0.61
May	6,460	1,390	3,777	232,240	2.69	2.33
June	6,270	1,450	2,900	172,560	2.00	1.79
July	1,330	400	694	42,670	0.49	0.43
August	450	425	448	27,546	0.32	0.28
September	550	450	518	30,823	0.36	0.32
October	695	550	616	37,875	0.44	0.38
November	800	610	674	40,105	0.47	0.42
December	870	600	646	39,720	0.46	0.40
The year			1,105	801,554	9.28	0.68

a Approximate.

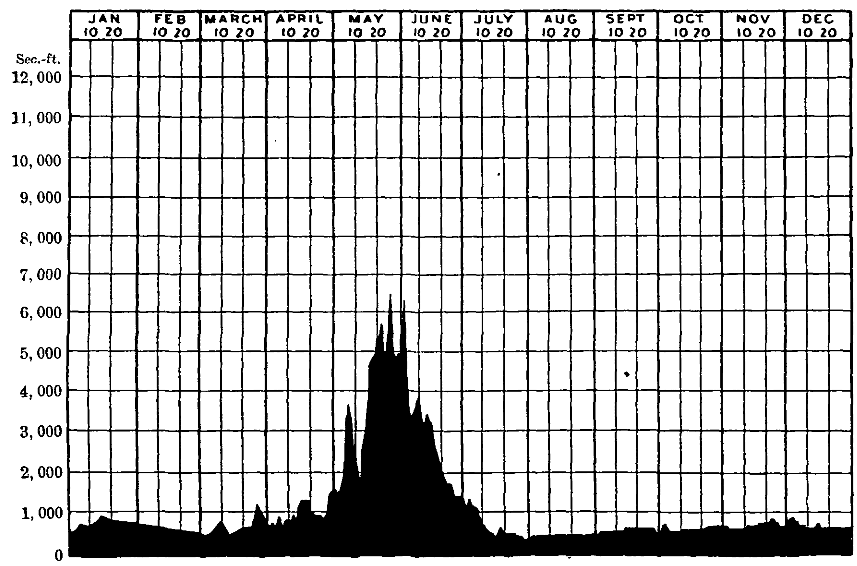


FIG. 79.—Discharge of Gallatin River at Logan, Montana, 1897.

MADISON RIVER.

The source of this river is in the continental divide, in Yellowstone National Park. Its course is northerly, in canyon most of the way, until it is some distance beyond the western boundary of the park. Ennis is at the lower end of an opening of considerable extent, called the 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 out into the lower valley. Little irrigation is practiced along the course of the river, except at its lower end.

For several years previous to 1897 a gaging station on this river was maintained at Threeforks, just above the mouth. It has been a poor section, however, on account of the many sloughs which carry off the flood waters and which were not included in the measurements. This station was maintained on account of the heavier expense of having one farther up in the canyon and because of the limited funds then allotted for the work. May 1, 1897, the station was moved 30 miles up the river and the gage established at Mrs. Black's ranch, just above the mouth of Elk Creek. Discharge measurements were made at the Red Bluff iron highway bridge, about 3 miles above. Cherry Creek enters between the bridge and the gage rod, and it was necessary to measure its discharge whenever a measurement of the main river was made. The old station, as described in Bulletin No. 131, p. 18, was located at what is known as Haywood Bridge, 1 mile below the new iron bridge.

In the table of monthly discharges the figures for the first four months of the year are for the Threeforks station. During the low stage, however, most of the water passed through the main channel at this point, so that the figures will be approximately correct for the Red Bluff station, as the river did not commence to rise until the end of April. From May 18 to May 26, inclusive, the river was slightly over the top of the gage, so that it could not be read. The height probably reached about 4.20 feet, but the overflow was largely quiet water and the main discharge was confined to the old channel. It is not thought that the maximum discharge exceeded 12,000 second-feet.

Rating table for Madison River at Red Bluff, Montana, for 1897.

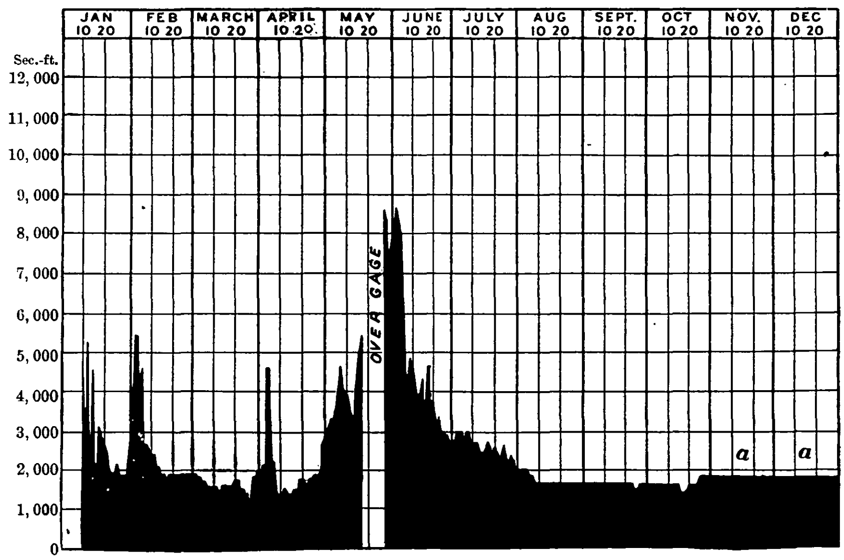
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.0	1,100	1.7	2,200	2.8	5,525	4.2	10,075
1.1	1,200	1.8	2,450	3.0	6,175	4.4	10,725
1.2	1,300	1.9	2,700	3.2	6,825	4.6	11,375
1.3	1,450	2.0	3,000	3.4	7,475	4.8	12,025
1.4	1,600	2.2	3,600	3.6	8,125	5.0	12,675
1.5	1,800	2.4	4,225	3.8	8,775		
1.6	2,000	2.6	4,875	4.0	9,425		

Estimated monthly discharge of Madison River at Red Bluff, Montana.

[Drainage area, 2,085 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January			a 1,600	98,380	0.89	0.77
February			a 1,600	88,859	0.80	0.77
March			a 1,600	98,380	0.89	0.77
April			a 1,900	113,058	1.01	0.91
May 2-17, 27-31	8,613	3,300	4,928	205,264	1.85	2.36
June	8,613	2,700	4,430	263,600	2.36	2.12
July	3,000	2,000	2,553	156,980	1.41	1.22
August	2,000	1,600	1,681	103,360	0.93	0.81
September	1,600	1,525	1,544	91,870	0.82	0.74
October	1,800	1,450	1,634	100,470	0.87	0.78
November			a 1,700	101,157	0.90	0.81
December			a 1,700	104,529	0.93	0.81

a Approximate.



a Approximate.

FIG. 80.—Discharge of Madison River at Red Bluff, Montana, 1897.

JEFFERSON RIVER.

Jefferson River is formed by the union of Big Hole and Beaver Head rivers. The former stream has its source among the high and almost inaccessible ranges of the Rocky Mountains, and forms the continental divide and the State boundary line between Montana and Idaho. The head-water tributary of Beaver Head River is Red Rock Creek, rising in the southwestern part of the State about 20 miles west of the boundary line of Yellowstone National Park.

More or less irrigation is practiced in the valleys of the tributaries of Beaver Head River, but in a somewhat crude way. The principal crop is alfalfa, and the method of applying water by flooding is productive of considerable waste. The country is generally at too high an elevation for any but the more hardy crops.

The most notable enterprise during the past year in this vicinity has been the power-development project on Big Hole River at Divide. A dam has here been placed in the river and the electric power developed is to be transmitted by wire to Butte, a distance of 17 miles, where it is to be used in the lighting of the city and as motive power for the street railways. The Montana Power Company controls the enterprise, and its main object is to furnish power for the hoisting of ores from the mines in the vicinity of Butte. It is estimated that when completed this project will have cost over a million dollars. Mr. M. S. Parker, engineer for the company, states that Big Hole River at the power house had a very uniform flow from the middle of August, 1897, to the end of the year, averaging 350 second-feet.

Within the past year work has been prosecuted on another canal which takes water from Jefferson River, about 15 miles below the junction of Big Hole and Beaver Head rivers, and is to be used for a smelter near Whitehall. The canal is about 10 miles long, but for several miles of its course runs through a limestone much cracked and fissured. The loss of water through this section has been of such considerable extent that the company has been compelled to consider plans for preventing it. It is hardly feasible to close the fissures by silting them up, owing to their considerable extent, and it is probable that it will be necessary to construct a flume across this place.

The gaging station on Jefferson River is located at Sappington, and observations and measurements of discharge were maintained through 1897. The station is described and a list of discharge measurements and the table of gage heights given in Water-Supply and Irrigation Paper No. 15, p. 70. A wire gage is fastened to the guard rail of the Northern Pacific Railway bridge, but measurements of discharge were made from a car and cable erected a short distance above the bridge. During the low-water stage of the river in August the readings on the rod were minus, and on November 1 the rod was lowered 0.8 of a foot by moving it that much nearer to the pulley.

Rating table for Jefferson River at Sappington, Montana, for 1897.

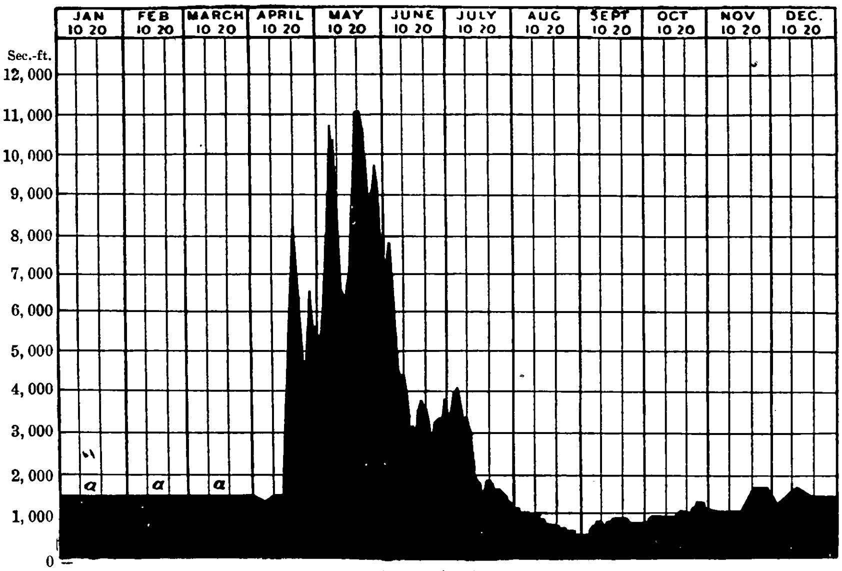
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
—0.5	390	0.4	860	1.6	2,500	3.4	6,600
—0.4	420	0.5	940	1.8	2,900	3.6	7,300
—0.3	460	0.6	1,020	2.0	3,300	3.8	8,100
—0.2	500	0.7	1,100	2.2	3,700	4.0	8,940
—0.1	550	0.8	1,225	2.4	4,100	4.2	9,780
0.0	600	0.9	1,350	2.6	4,500	4.4	10,620
0.1	650	1.0	1,475	2.8	5,000	4.6	11,460
0.2	700	1.2	1,775	3.0	5,500	4.8	12,300
0.3	780	1.4	2,125	3.2	6,000	5.0	13,140

Estimated monthly discharge of Jefferson River at Sappington, Montana.

[Drainage area, 8,984 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January			*a* 1,500	92,230	0.20	0.17
February			*a* 1,500	83,305	0.18	0.17
March			*a* 1,500	92,230	0.20	0.17
April			*a* 3,300	196,364	0.41	0.37
May	11,040	5,375	8,587	528,000	1.10	0.96
June	7,900	2,900	4,274	254,320	0.54	0.48
July	4,100	1,100	2,356	144,870	0.30	0.26
August	1,100	550	794	48,820	0.10	0.09
September	860	550	758	45,105	0.09	0.08
October	1,225	780	1,013	62,290	0.12	0.11
November			*a* 1,300	77,355	0.16	0.14
December			*a* 1,400	92,231	0.18	0.16
The year			2,357	1,717,120	3.58	0.26

a Approximate.



a Approximate.

FIG. 81.—Discharge of Jefferson River at Sappington, Montana, 1897.

MISSOURI RIVER.

Occasional measurements at the gaging station at Townsend were made in 1897. A list of these is given in Water-Supply and Irrigation Paper No. 15, p. 65. Observations of gage heights are maintained by the Missouri River Commission, and although the section is not an ideal one, it still seems desirable to make occasional measurements, as the station is easily accessible and the daily gage observations are taken at no expense to this Survey.

In the fall of 1897 a dam for an electric plant was practically completed on Missouri River a short distance below Canyon Ferry. The power developed is to be transmitted by wire and to be used in the smelters in the vicinity of Helena.

Rating table for Missouri River at Townsend, Montana, for 1897.

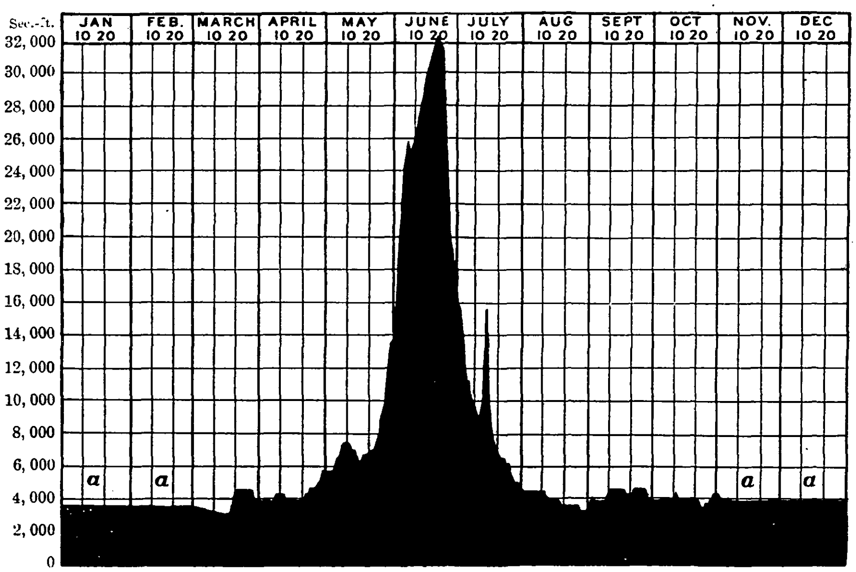
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
88.0	1,800	89.6	6,110	91.2	12,100	92.8	20,200
88.2	2,200	89.8	6,790	91.4	13,000	93.0	21,300
88.4	2,600	90.0	7,480	91.6	13,900	93.2	22,400
88.6	3,040	90.2	8,180	91.8	14,850	93.4	23,500
88.8	3,600	90.4	8,900	92.0	15,850	93.6	24,700
89.0	4,200	90.6	9,700	92.2	16,900	93.8	25,900
89.2	4,810	90.8	10,500	92.4	18,000		
89.4	5,450	91.0	11,300	92.6	19,100		

Estimated monthly discharge of Missouri River at Townsend, Montana, for 1896.

[Drainage area, 14,500 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1896.						
January			a3,600	221,355	0.29	0.25
February			a3,600	207,074	0.27	0.25
March			a3,600	221,355	0.29	0.25
April	5,780	3,900	4,215	250,810	0.33	0.29
May	13,675	5,780	7,494	460,788	0.60	0.52
June	32,500	15,100	25,904	1,541,395	1.99	0.78
July	15,850	4,810	9,199	565,624	0.72	0.63
August	4,500	3,300	3,953	243,061	0.31	0.27
September	4,500	3,900	4,225	251,405	0.32	0.29
October	4,200	3,600	3,895	239,494	0.31	0.27
November			a3,800	226,116	0.29	0.26
December			a3,800	233,653	0.30	0.26
The year			6,440	4,662,130	5.71	0.36

a Approximate.



a Approximate.

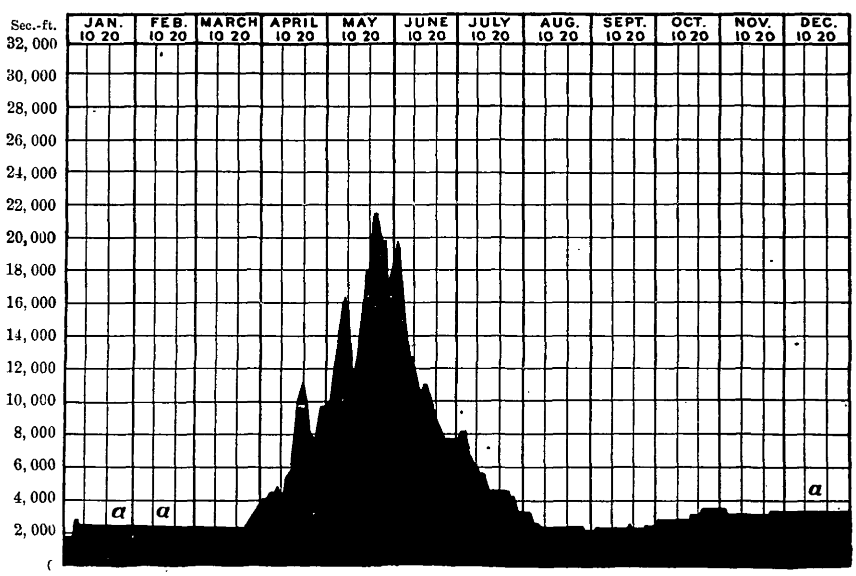
FIG. 82.—Discharge of Missouri River at Townsend, Montana, 1896.

Estimated monthly discharge of Missouri River at Townsend, Montana, for 1897.

[Drainage area, 14,500 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January			a2, 800	172, 170	0. 22	0. 19
February			a2, 800	156, 503	0. 20	0. 19
March			a3, 000	184, 460	0. 24	0. 21
April	11, 300	4, 200	6, 995	416, 230	0. 55	0. 48
May	21, 300	9, 700	15, 811	972, 200	1. 26	1. 09
June	19, 650	7, 830	11, 374	676, 800	0. 87	0. 78
July	8, 180	3, 300	5, 345	328, 650	0. 43	0. 37
August	3, 300	2, 200	2, 642	162, 450	0. 21	0. 18
September	2, 820	2, 200	2, 611	155, 366	0. 20	0. 18
October	3, 600	3, 040	3, 264	200, 700	0. 26	0. 23
November	3, 600	3, 300	3, 410	202, 900	0. 27	0. 24
December			a3, 600	221, 355	0. 29	0. 25
The year			5, 304	3, 849, 784	5. 00	0. 37

a Approximate.



a Approximate.
FIG. 83.—Discharge of Missouri River at Townsend, Montana, 1897.

MILK RIVER.

Milk River rises on the eastern slope of the Rocky Mountains in the extreme northern part of Montana. The tributaries have a general northeasterly direction, crossing the national boundary into British territory, in which there is a large area in the province of Alberta drained by other tributaries of Milk River. The stream reenters the United States at about longitude 110° 30′ W., and flows in a general southeasterly direction to Havre. Thence the course is easterly to where the river enters the Missouri, about 120 miles above the mouth of the Yellowstone.

The valley of this river is fertile and well adapted to agriculture for the hardier grains, such as oats, wheat, barley, and hay. Development in this section has been slow, however, owing to the lack of transportation facilities, the Great Northern Railway having only been built within recent years; and until recently the entire strip of country between the eastern State line and the Rocky Mountain divide, and bounded on the south by the Missouri and Marias rivers, including the basin of Milk River, was an immense Indian reservation. It was thrown open to settlement, however, a few years ago, and development since has been rapid. The area drained by Milk River after it reenters the United States is one vast rolling prairie land, excellent for grazing purposes, still covered with a good growth of grass, in contrast to many of the noted grazing lands in Washington and Oregon and other parts of Montana, which have been nearly destroyed by the amount of stock maintained on them.

A number of canals are now constructed taking water from both sides of Milk River. The most important is that of the Fort Belknap Irrigation Company, which heads on the north side of the river about 10 miles above the gaging station at Chinook, and near old Fort Belknap, and is controlled by a corporation of farmers and stock men irrigating lands in the vicinity of Chinook. A small ditch, the Davey ditch, heads on the south bank of the river just below Toledo and extends from there to Yantic. The next ditch of importance is Harlem canal, owned by a stock company and irrigating lands, between Zurich and Harlem. Paradise Valley canal is an enterprise of considerable magnitude, taking water from the south side of Milk River just below the mouth of the North Fork and about 5 miles east of Chinook. A number of smaller ditches irrigate lands on private ranches from the tributaries of Milk River, the most notable being North Fork ditch. Cook ditch is a recent enterprise from this latter tributary.

The main crops raised here are oats and hay, which find a ready market at the military posts, and on the stock ranches where, on account of the severe winters, the more progressive stockmen have found it necessary to feed their stock during the winter season.

Owing to its great length Milk River, in the lower section, is at such a distance from the high snow fields of the Rocky Mountains that the gradual melting of the snow in the spring does not maintain the constant flow in the river that it otherwise would. The snowfall on the lower basin in some winters is considerable, but, the altitude being relatively low, whenever a warm wind, or "chinook," as it is called, strikes the snow, it melts with exceeding rapidity, finds its way into the creeks, and causes them to rise to considerable heights. Milk River, as a result, is a very flashy stream, rising and falling suddenly and eroding its banks at each rise. On account of the instability of the banks it has been found difficult to maintain canal headworks, and a number have been destroyed from time to time. So variable a stream, as a general rule, has a low discharge in summer, and Milk River is no exception to the rule. The last year or so the Fort Belknap and other ditches have found it difficult to obtain sufficient water during the irrigating season. The basin, as mentioned above, is of a rolling character, intercepted by numerous draws, or coulées, down which water pours during certain seasons of the year. A number of these are known to be excellent reservoir sites, and some of the ranchers are considering the advisability of damming a number of them at their outlets and storing the spring freshets.

One in particular, not very far from Chinook, in Red Rock Canyon, is a fine site, and construction work on a rock and earthen dam was to have been started in the fall of 1897. Owing to the desirability of obtaining an idea of the amount of flood water passing down this stream, especially in connection with reservoir propositions, a gaging station was established at the wagon bridge, 1 mile south of Chinook, May 25, 1897. This station is described in Water-Supply and Irrigation Paper No. 15, p. 73. Only three measurements of discharge were made, the number not being sufficient to construct a rating table. May 25, gage height, 1.40 feet; discharge, 110 second-feet; July 3, gage height, 2.30 feet; discharge, 460 second-feet; November 10, gage height, 0.72 foot; discharge, 34 second-feet. To illustrate the rapid rise of this stream it is only necessary to inspect the table of gage heights. For instance, on June 15 the gage read 0.8 foot; the next day it was 1.4 feet. On June 17 it jumped to 9 feet and then gradually fell.

The station was discontinued at the end of October. It was resumed in the spring of 1898, but will be removed to Havre, about 20 miles above. This places it above the head of Fort Belknap ditch, which takes a considerable amount of water, and the measurements will show the amount available for storage purposes.

YELLOWSTONE BASIN.

YELLOWSTONE RIVER.

This river has its source in Yellowstone Lake in the National Park, and where it crosses the line into Montana has a large flow throughout all seasons of the year. A description of the basin will be found in the Thirteenth Annual Report of this Survey, Part III, beginning on page

63. The old gaging station on this river was located at Horr, about 4 miles below Cinnabar. A new station was established May 2, 1897, at the highway bridge 5 miles south of Livingston, at the mouth of the canyon. The description and list of discharge measurements made in 1897 at this station will be found in Water-Supply and Irrigation Paper No. 15, p. 74. All diversions from this river are made below the station.

The only project of considerable magnitude during 1897, in the line of irrigation developments along this river, was in the vicinity of Billings, and was the result of a desire to take advantage of the grant by the General Government of certain arid lands authorized by the so-called Carey Act. The State has undertaken the construction of a canal heading on the north side of Yellowstone River, a short distance above Laurel, with the idea of irrigating the bench lands in the vicinity of Billings. A number of canals are already taken from the river in this vicinity, but they serve only the bottoms. For a few years these lowlands produced excellent crops, but within the last year or so considerable alkali has developed in the soil. Experiments are now being made at the Agricultural College in Bozeman to devise means to overcome this. The bench lands, which the State ditch, as it is called, is to irrigate, are of better quality than those adjacent to the river. The work on this ditch was interrupted in 1897 owing to a number of lawsuits instituted in order to determine the validity of the State bonds which have been issued for its construction. The State, through a Commission, is building the ditch, paying for the work either in bonds or in land.

Rating table for Yellowstone River at Livingston, Montana, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.7	1,200	2.0	3,300	3.6	7,600	5.2	17,520
0.8	1,300	2.2	3,710	3.8	8,840	5.4	18,760
0.9	1,400	2.4	4,130	4.0	10,080	5.6	20,000
1.0	1,500	2.6	4,550	4.2	11,320	5.8	21,240
1.2	1,800	2.8	4,990	4.4	12,560	6.0	22,480
1.4	2,120	3.0	5,440	4.6	13,800	6.2	23,720
1.6	2,500	3.2	6,000	4.8	15,040	6.4	24,960
1.8	2,900	3.4	6,650	5.0	16,280	6.6	26,200

Estimated monthly discharge of Yellowstone River at Livingston, Montana.

[Drainage area, 3,580 square miles.]

Month.	Discharge in second feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
May	23,100	3,200	13,402	824,057	4.31	3.74
June	26,820	10,080	15,257	907,850	4.75	4.26
July	11,940	5,100	7,231	444,620	2.33	2.02
August	4,990	3,100	4,099	252,040	1.33	1.15
September	3,100	1,950	2,450	145,780	0.75	0.68
October	2,210	1,650	1,915	117,750	0.61	0.53
November	....	....	*a*1,600	95,207	0.50	0.45
December	....	....	*a*1,300	79,934	0.41	0.36

a Approximate.

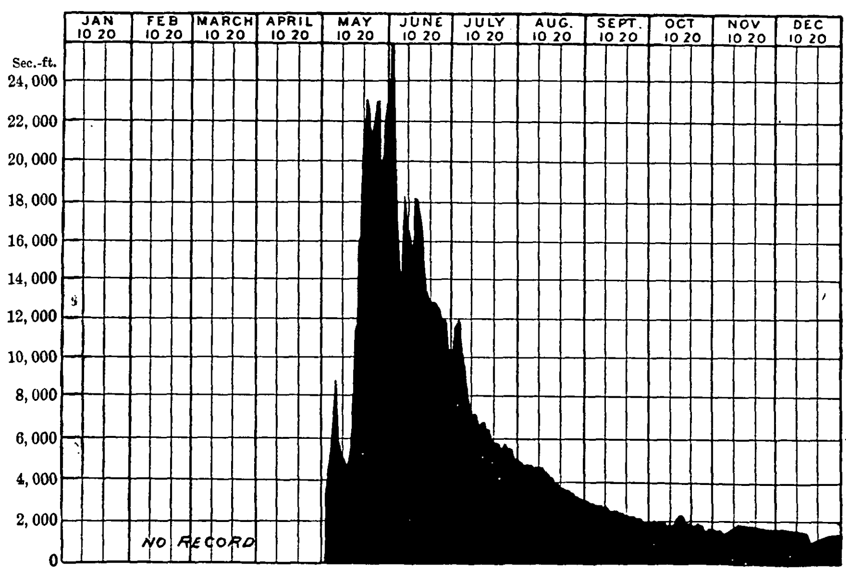


FIG. 84.—Discharge of Yellowstone River at Livingston, Montana, 1897.

List of miscellaneous discharge measurements, Upper Missouri Basin.

Date.	Stream.	Locality.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
1897.				*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
May 9	Spanish Creek.	Gallatin Canyon.	75	....	47	3.49	164
May 26	Missouri River.	Fort Benton, Montana.	75	5.6	5,046	5.68	28,662
July 3	North Fork of Milk River.	Chinook, Montana.	75	....	46	1.55	72
Do..	West Fork of Milk River.	.....do	75	....	97	.95	93
July 5	Giant Springs.	Great Falls, Montana.	75	....	66	3.90	256
Aug. 25	Smith Creek...	15 miles SW. of Augusta, Montana.	.....	....	13	1.18	16

BIGHORN VALLEY.

SHOSHONE RIVER.

Hydrographic work in Bighorn Valley has been confined to measurements on two tributaries, Shoshone River (or Stinking Water, as it was formerly termed) and Grey Bull River. In 1896 two stations were established on Shoshone River, one on the South Fork at Marquette and the other on the main river at Corbett. No measurements of discharge were made, however. A record of gage heights for a period of about a month only at each point was maintained. The gage rod at Corbett was connected with the precise levels of the topographic division of the Survey, and the zero was found to be at an elevation of 4,653.02 feet above sea level.

The North Fork of the Shoshone rises on the eastern edge of Yellowstone National Park and flows in an easterly direction through the Yellowstone Park Timber Land Reservation. Ranches begin to appear on the river in the vicinity of Robie Creek, and from that point occasionally downstream. Water for irrigation is used not so much from the main stream as from the creeks entering it—as, for example, Trout and Rattlesnake creeks, which furnish water to several ranches in their valleys, principally for the irrigation of hay.

Similarly on the South Fork a few ranchers irrigate hay lands on the side creeks. In 1895 a canal called the Cody ditch was taken from the right bank of the South Fork of Shoshone River at Marquette. The idea was to bring the canal in an easterly direction across Sage Creek and irrigate lands on the east side of the latter stream.

The canal was constructed for about 6 miles down to Cedar Mountain, where it encountered some bad land, or gypsum land, as it is called in that vicinity. This formation continues almost to Sage Creek, and on this account the project for continuing the canal was abandoned. This bad-land formation is exceedingly poor for canal construction, as it causes great loss of water and is of such a slippery nature that canal banks will not stand upright. The canal project was modified to the extent of continuing the canal after passing over the stretch of the bad-land formation at Cedar Mountain down to Sho-

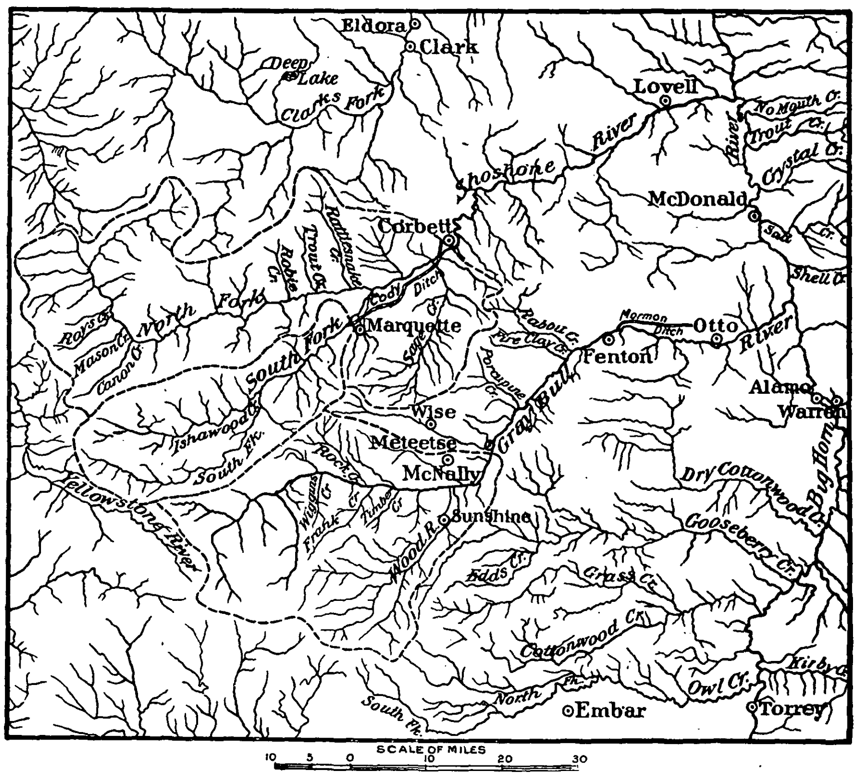


FIG. 85.—Map of Bighorn Basin, Wyoming.

shone River and crossing just above Corbett. The country north of this town and west of the river is susceptible of irrigation. The only irrigated land at present under the canal is a section of about 3,000 acres lying in the triangle bounded by Cedar Mountain on the northeast, the South Fork of the Shoshone on the west, and the canal on the south. The canal is not yet completed to Corbett. At the head it is 40 feet wide on the bottom. The drainage area of the South Fork at Marquette is 500 square miles; of the main river at Corbett, 1,718 square miles.

During the summer of 1897 surveys for a large canal from the main river were started, heading a short distance above Lovell. They were made under the law known as the Carey Act, which allows canal companies to obtain control under State supervision of a certain tract of land. A gaging station was established on this river at Lovell, May 23, 1897. The rod is fastened to the landing pier of the Lovell ferry on the south side of the river. The station is described in Water-Supply and Irrigation Paper No. 15, p. 76, which gives the list of discharge measurements, together with the table of daily gage heights. Following is, first, the rating table for this station, and next, the table of monthly discharges. The station was established during the middle of the flood season, so that the total discharge for this year can not be known.

Rating table for Shoshone River at Lovell, Wyoming, for 1897.

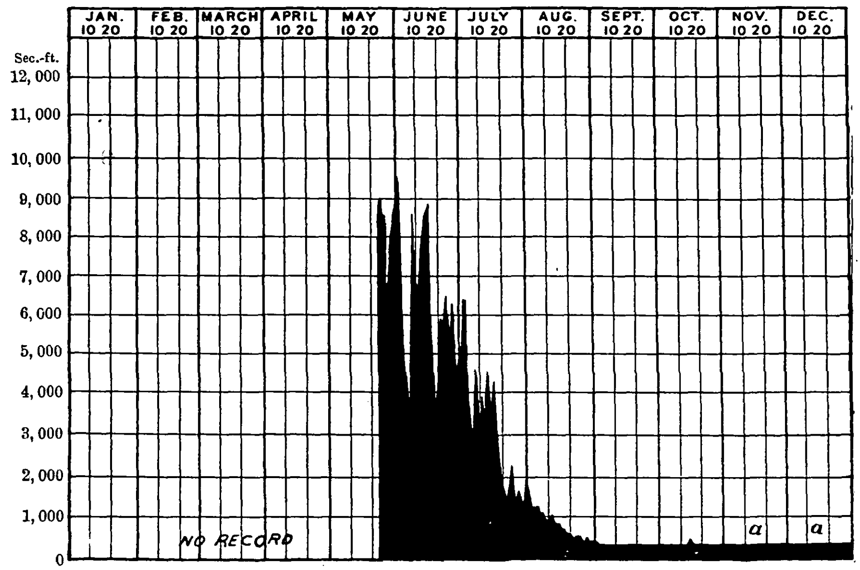
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
—0.8	310	—0.2	800	0.8	3,060	2.0	6,540
—0.7	360	—0.1	920	1.0	3,640	2.2	7,120
—0.6	430	0.0	1,080	1.2	4,220	2.4	7,700
—0.5	500	0.2	1,450	1.4	4,800	2.6	8,280
—0.4	600	0.4	1,900	1.6	5,380	2.8	8,860
—0.3	700	0.6	2,480	1.8	5,690	3.0	9,440

Estimated monthly discharge of Shoshone River at Lovell, Wyoming.

[Drainage area 2,720 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
June	9,440	3,640	6,124	364,400	2.51	2.25
July	6,250	1,250	3,176	195,280	1.35	1.17
August	1,650	430	777	47,780	0.33	0.29
September	360	360	360	21,422	0.14	0.13
October			*a* 350	21,520	0.15	0.13
November			*a* 350	20,826	0.14	0.13
December			*a* 350	21,520	0.15	0.13

a Approximate.



a Approximate.

FIG. 86.—Discharge of Shoshone River at Lovell, Wyoming, in 1897.

BIGHORN AND NO WOOD RIVERS.

A discharge measurement was made on each of these rivers in 1897, by Messrs. Elwood Mead and C. T. Johnston. August 21, No Wood River at Morgan's ranch, 4 miles above its mouth, was found to be discharging 109 second-feet. This point is near Warren, shown on the sketch map, fig. 85 (p. 291). On the same date Bighorn River was carrying 1,804 second-feet at Alamo, Wyoming.

GREY BULL RIVER.

This stream enters Bighorn River about 30 miles south of the mouth of Shoshone River. The irrigation conditions that prevail in this basin are similar to those in the adjoining basin of the Shoshone. A number of ranchers are located at the head waters of the river, and each one takes out small ditches, principally from the small tributaries, to irrigate his land. At the mouth of Wiggins Creek is the upper settlement. Continuing downstream ranches are found on Rock Creek, Frank Creek, and a model stock ranch on Timber Creek. Below Meeteetse the greater portion of the irrigable land is on the north side of the river. The altitude at Meeteetse is given as 5,925 feet. At Fenton is taken out a ditch, from the left bank, known as the Mormon ditch. It is 10 miles long and 12 feet wide on the bottom. It irrigates considerable land between Fenton and Otto, and is controlled by a Mormon settlement. The irrigation possibilities of this basin are among the best in the State of Wyoming, and considerably superior to those in the southern part of the State, as the general elevation of the country is 2,500 feet lower. The great drawback at present is the lack of railroad facilities, which prevents the export of any of the crops, and, as a result, the demand is limited to home consumption. The distance to the nearest railroad line is about 100 miles. The probabilities are that one or two railroads will be built into the country before long, as a number of surveys have been made with this in view. On Pl. XXXII, *A* is shown the bridge at which measurements of Grey Bull River are made, and *B* gives a general view of the town of Meeteetse.

Rating table for Grey Bull River at Meeteetse, Wyoming, for 1897.

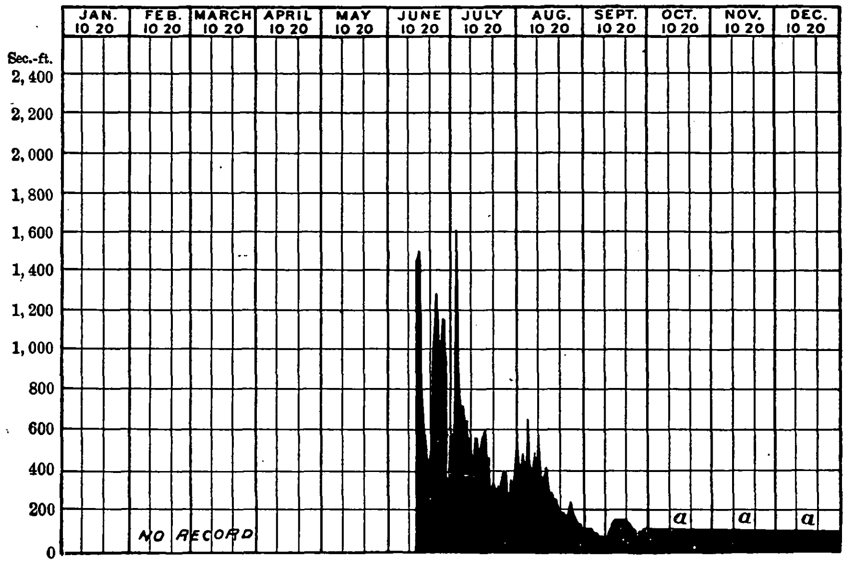
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.9	65	2.7	170	3.5	564	4.3	1,140
2.0	75	2.8	190	3.6	636	4.4	1,212
2.1	85	2.9	220	3.7	708	4.5	1,284
2.2	95	3.0	270	3.8	780	4.6	1,356
2.3	105	3.1	320	3.9	852	4.7	1,428
2.4	120	3.2	370	4.0	924	4.8	1,500
2.5	135	3.3	420	4.1	996		
2.6	150	3.4	492	4.2	1,068		

Estimated monthly discharge of Grey Bull River at Meeteetse, Wyoming.

[Drainage area, 870 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
June 14-30	1,500	320	943	31,795	0.68	1.08
July	1,608	245	513	31,542	0.68	0.59
August	636	105	299	18,385	0.39	0.34
September	135	65	104	6,189	0.13	0.12
October			*a* 100	6,149	0.13	0.11
November			*a* 100	5,950	0.12	0.11
December			*a* 100	6,149	0.13	0.11

a Approximate.



a Approximate.

FIG. 87.—Discharge of Grey Bull River at Meeteetse, Wyoming, 1897.

GOOSE CREEK.

The two stations on Big and Little Goose creeks in the town of Sheridan, Wyoming, were continued during 1897, and the results are given in Water-Supply and Irrigation Paper No. 15, p. 77. Although no measurements of discharge were made, the rating tables constructed from the measurements in 1896 are applicable to the gage-height record for 1897. These rating tables are to be found in the Eighteenth Annual Report, Part IV, pp. 136–137. The conditions prevailing in this drainage basin are similar to those of a number of other streams in Wyoming. Reference is made to the diversion of water from the head waters of one stream into those of another, to be again diverted some distance below for irrigation purposes. In this connection the following is quoted from the biennial report of Elwood Mead, State engineer of Wyoming, for 1895 and 1896, pp. 108–110:

The stations for recording the flow of Big Goose Creek and Little Goose Creek are both within the corporate limits of Sheridan. The two streams unite within the limits of the town, and as the municipal authorities have straightened and improved the channels it is a favorable location for securing observers and for obtaining correct gaging results.

The station on Little Goose Creek is only a few hundred feet above where it empties into Big Goose Creek, hence the record does not show the water supply of the stream, but the volume which runs to waste. The station on Big Goose Creek is also below all important ditches, since beyond the town of Sheridan the valley is narrow and but little land can be irrigated. The records of both these stations give no information of the volume which they supply, but only that which runs to waste. It would be interesting if a record of the entire flow of these streams could be had, since it would furnish some interesting comparisons and a measure of the volume used. This is out of the question at present, for reasons which are worthy of some discussion.

For several years there has been a recognized scarcity of water in Little Goose Creek for late irrigation, only the older priorities being undisturbed throughout the season. The rule is for the water commissioner to begin dividing water in June and to continue until September, which makes the rights of late appropriators exceedingly precarious. Several measures have been devised to relieve this shortage. Some of the later appropriators have constructed ditches to divert water from Big Goose Creek. The Peralto, one of the largest ditches in the valley of Little Goose Creek, receives its entire supply from this source. The taking of water from one stream to the other is made easy by the fact that the head waters of Big Goose Creek drain the summit of the range, while the tributaries of Little Goose Creek begin in the mountains below. The transfer is made far back in the range, the head gates of the diverting ditches being 10 miles above the place where Big Goose Creek emerges from the mountains, and the water enters Little Goose Creek 9 miles away from and 2,000 feet above the head of the first irrigating ditch taking water from that stream.

The transfer of water from one stream to another is a perplexing question under any conditions, because of the local jealousies which it creates and the difficulty of measuring and dealing with the quantity involved. It is especially so in this instance. It requires nearly a week's journey from Sheridan to visit the heads of the three ditches turning water from one stream to the other, to measure their flow, and to return. Frequent examinations are therefore out of the question. It is almost equally difficult and expensive to reach the point where the water turned into Little Goose Creek enters the stream, and the rocky and irregular channel over which it flows makes measurements of even approximate accuracy out of the question. It would be too expensive, therefore, to base the division on actual measurements, and the water commissioner must, as a rule, exercise his best judgment in the disposition of the water so diverted, with but little assistance from the inadequate data which he can secure and with his efforts badly handicapped by opinions and desires of irrigators, which vary with the interests and prejudices of those who hold them.

The appropriators of the normal supply naturally fear that the appropriators of water turned into the stream from other sources divert more than they supply, and this opinion becomes very active when early users from the stream are without water while adjoining ditches, built at a later date, have an abundance, simply because of their superior source of supply.

With the growing use of water on Big Goose Creek and a consequent threatened need to supply the irrigators in its own drainage basin there has come the opposite complaint—that the amount turned into Little Goose Creek is in excess of the appropriators' rights on that stream and that the surplus is being utilized by those having no legal right thereto. Only actual measurements of the flow of both streams above all ditches and of the volume transferred will determine the actual situation and the extent to which these conflicting opinions are founded on facts; but as yet they are not of sufficient practical importance to warrant establishing a station and employing an observer to make daily measurements of the mountain ditches, and without this it is impossible to determine the normal flow of either stream. In fact, it will be difficult to make these measurements when they become indispensable, as they will in time. A station located in the canyon of Little Goose Creek would be above ten of its tributaries. These would have to be measured if the total volume of the stream was to be determined, and the diversion of these begins as soon as they leave the mountains, so that only seepage or waste water reaches the main stream.

The stations established at Sheridan, while they throw no light on the question as to how accurately the commissioner regulates the water turned from one stream to the other, show the period of scarcity on Little Goose Creek and whether or not the diversion of water causes any loss to irrigators on the large stream. They are also of value in connection with the subject of storage. During the past four years surveys have been made which show the existence of a large number of morainal lakes on the head waters of both these streams and late appropriators have

A. GAGING STATION ON GREY BULL RIVER AT MEETEETSE, WYOMING.

B. MEETEETSE, WYOMING.

already begun their utilization. Before making any large outlay parties wish to know the length of the period in which water runs to waste and the volume of the surplus which can be thus impounded, and this feature of the record will be most closely studied and of most value.

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

[Drainage area, 128 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
May 21-31	207	72	129	2,816	0.41	1.01
June	111	8	44	2,618	0.38	0.34
July	16	8	9	553	0.08	0.07

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

[Drainage area, 320 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
May 21-31	595	179	349	7,612	0.45	1.09
June	307	64	132	7,854	0.46	0.41
July	75	17	37	2,275	0.14	0.12

CLEAR CREEK.

The measurements on Clear Creek are made by Fred Bond at a point about 4 miles west of Buffalo, Wyoming. They are made at a flume built in 1889 for the purpose of obtaining accurate figures of discharge. A description of the station and list of heights of water observed during 1897 are given in Water-Supply and Irrigation Paper No. 15, p. 78.

Estimated monthly discharge of Clear Creek at Buffalo, Wyoming.

[Drainage area, 118 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second feet per square mile.
1897.						
May	632	209	345	21,214	3.37	2.92
June	657	189	280	16,662	2.64	2.37
July	246	55	112	6,887	1.09	0.95
August	82	39	54	3,320	0.53	0.46
September			*a* 30	1,785	0.28	0.25
October			*a* 30	1,845	0.29	0.25
November			*a* 30	1,785	0.28	0.25
December			*a* 26	1,599	0.25	0.22

a Approximate.

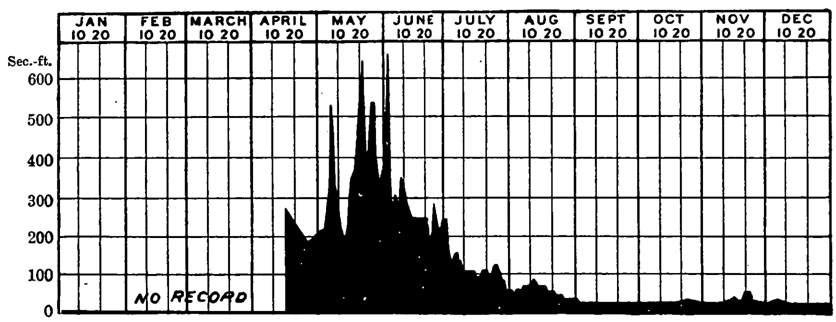


FIG. 88.—Discharge of Clear Creek at Buffalo, Wyoming, 1897.

WHITE RIVER.

White River rises in the northwestern corner of the State of Nebraska, but soon passes the State line and enters South Dakota, where it drains a strip of country in the southern section of the State and finally enters Missouri River. A gaging station is located at Crawford, Nebraska, where the drainage area is only 270 square miles. The gage rod is placed against the stop gate in the canal of the Crawford Water Power and Irrigation Company, about one-eighth of a mile below the head. All of the water of White River is diverted into this canal and only an insignificant amount escapes between the head of the canal and the gage. On June 26, 1897, a measurement was made on White River below Crawford, Nebraska, and a discharge of 13 second-feet ascertained. The station is described in Water-Supply and Irrigation Paper No. 15, p. 79.

Rating table for White River at Crawford, Nebraska, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.3	8.3	0.5	9.7	0.7	12.0	0.9	15.4
0.4	8.9	0.6	10.7	0.8	13.6		

Estimated monthly discharge of White River at Crawford, Nebraska.

[Drainage area, 270 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
July 13-31	18	10	13	490	0.05	0.05
August	14	9	11	676	0.04	0.04
September	12	9	11	655	0.04	0.04
October	16	12	14	861	0.05	0.05
November	....	....	*a* 15	892	0.07	0.06
December	....	....	*a* 15	922	0.07	0.06

a Approximate.

NIOBRARA RIVER.

This river drains an area in the northern part of Nebraska and a small area in South Dakota. The gaging station is located about three-quarters of a mile southwesterly from Fort Niobrara and about 3 miles east of Valentine, Nebraska. A sufficient number of discharge measurements on which to base a rating curve were not made at this point. The station is described in Water-Supply and Irrigation Paper No. 15, p. 80. The area drained at the point is 6,300 square miles.

List of miscellaneous discharge measurements, Niobrara Basin.

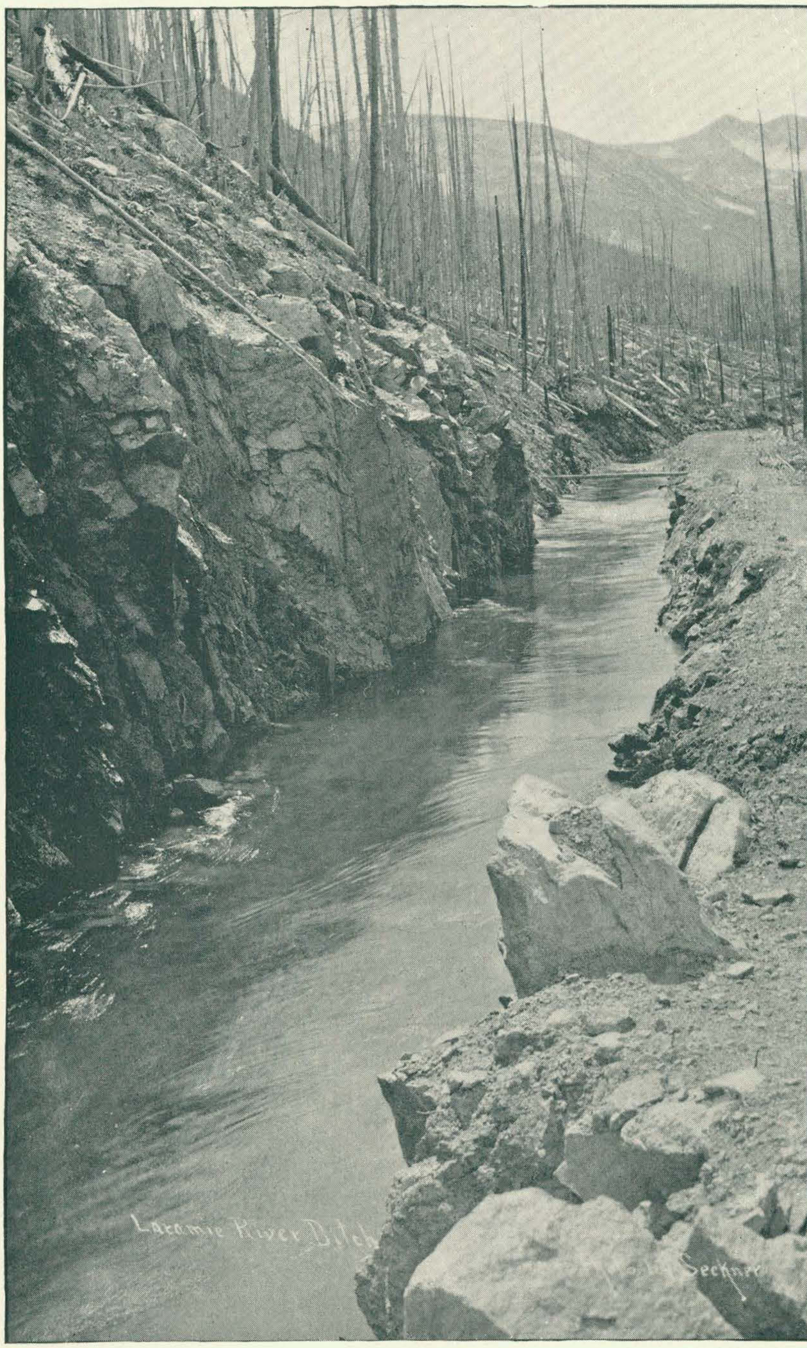
Date.	Stream.	Locality.	Meter.	Area of section.	Mean velocity.	Discharge.
1897.				*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
June 22	Niobrara River	Niobrara, Nebraska.	....	382	1.99	759
June 24	Minnechadusa River.	Valentine, Nebraska	Price .	17	1.25	21
June 25	Niobrara River	Lavaca P. O., Nebraska.	...do ..	46	2.25	105
July 23	Gordon Creek.	Sec. 15, T. 32, R. 29 ..	...do ..	2	1.68	4
Do...	Snake River...	Mouth southwest of Valentine, Nebraska.	...do ..	84	3.33	280
July 24	.....do	Kennedy, Nebraska.	...do ..	1	1.97	215

PLATTE BASIN.

LARAMIE RIVER.

Laramie River, a tributary of North Platte River, rises in Laramie Lake, in the northern part of Colorado, and after flowing northerly for about 30 miles crosses the State line into Wyoming. The valley along this section averages about a mile wide, and more or less irrigation is practiced, principally on hay ranches. The highest point of diversion of the waters is the canal of the Water Supply and Storage Company of Colorado, called the Sky Line Canal, which takes water into Cache la Poudre River. It is at an elevation of about 10,000 feet and is 5 miles long, built principally through solid rock, at a cost of about $90,000. A view of it is shown in Pl. XXXIII. Its maximum capacity is 100 second-feet. On account of its altitude this canal is not practically available until late in June. The taking of this water from Laramie River is a source of loss to irrigators in Wyoming, as none of the water returns to the stream through seepage or percolation. A number of canals from Laramie River in Wyoming have prior appropriations to the Sky Line Canal, but owing to the present existing irrigation laws the Wyoming appropriators appear to have no redress.

The valley of Laramie River, in Colorado, is at a general elevation of 8,000 feet, and is separated from the second diversion of the basin—that of the Laramie Plains—by a canyon 8 miles long. The gaging station at Woods Landing is located near the mouth of this canyon, and the results show the amount of water available for the canal systems below, of which there are quite a number. The systems in operation, with those contemplated, will require more than the available supply, including the diversion by the Sky Line Canal. Little Laramie River is fully appropriated by the canals from it. No meas-



SKY LINE CANAL NEAR GREELEY, COLORADO.

urements have been made of the flood flow of this tributary that would give data of the water available for storage purposes. The general elevation of Laramie Plains is 7,000 feet. When Laramie River bends eastward it enters another canyon and passes through the Laramie Hills to the third plain, which extends from the eastern edge of this range to the mouth of the river.

Rating table for Laramie River at Woods Landing, Wyoming, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.4	45	1.0	125	2.2	940	3.2	2,090
0.5	50	1.2	200	2.4	1,170	3.4	2,320
0.6	60	1.4	290	2.6	1,400	3.6	2,550
0.7	70	1.6	410	2.8	1,630	3.8	2,900
0.8	85	1.8	550	3.0	1,860	4.0	3,300
0.9	100	2.0	710				

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

[Drainage area, 435 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	....	....	*a* 70	4,304	0.18	0.16
February	....	....	*a* 70	3,888	0.17	0.16
March	....	....	*a* 70	4,304	0.18	0.16
April	350	48	128	7,617	0.23	0.29
May	3,425	443	1,964	120,762	5.22	4.52
June	2,700	550	1,564	93,064	4.01	3.60
July	475	125	266	16,356	0.70	0.61
August	183	70	93	5,718	0.24	0.21
September	70	60	65	3,868	0.17	0.15
October	....	....	*a* 60	3,689	0.16	0.14
November	....	....	*a* 65	3,868	0.17	0.15
December	....	....	*a* 70	4,304	0.18	0.16
The year	....	....	374	271,842	11.61	0.86

a Approximate.

Rating table for Laramie River at Uva, Wyoming, for 1897.

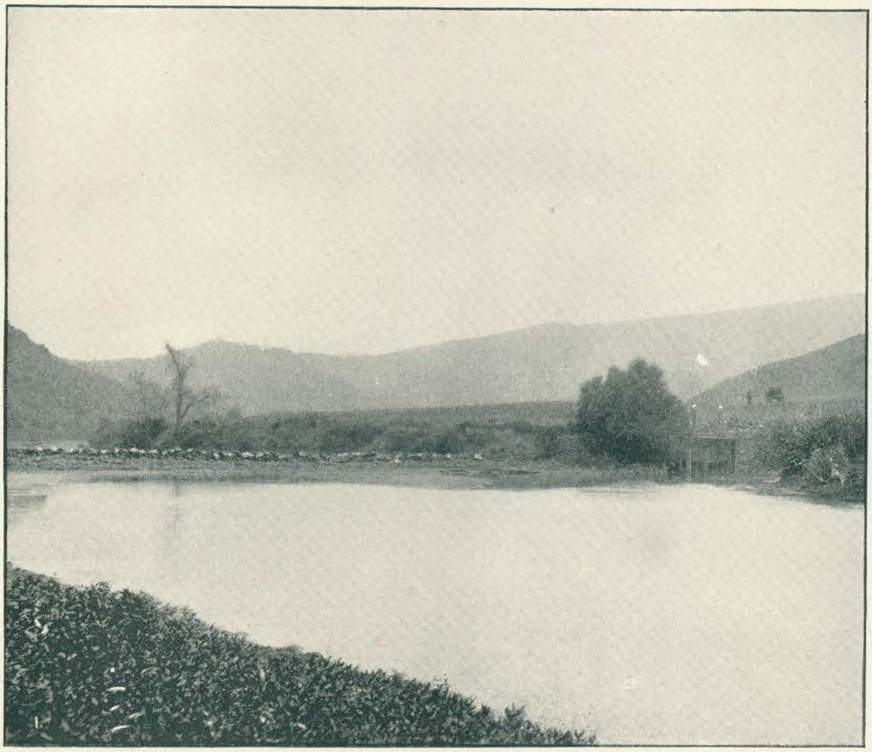
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.5	5	1.4	100	2.8	620	4.2	1,580
0.6	10	1.6	140	3.0	720	4.4	1,760
0.7	15	1.8	190	3.2	820	4.6	1,940
0.8	21	2.0	260	3.4	920	4.8	2,120
0.9	30	2.2	340	3.6	1,040	5.0	2,300
1.0	40	2.4	425	3.8	1,220	5.2	2,480
1.2	62	2.6	520	4.0	1,400	5.4	2,660

Estimated monthly discharge of Laramie River at Uva, Wyoming.

[Drainage area, 3,179 square miles.]

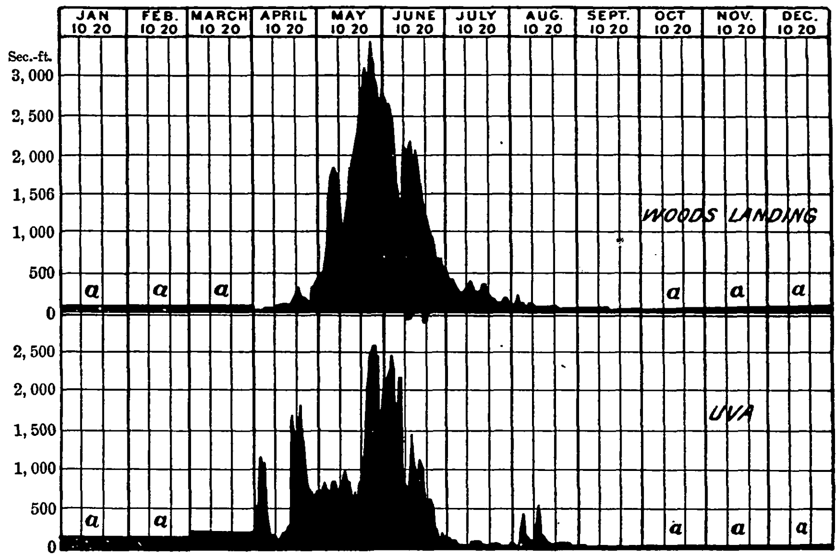
Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January			*a* 100	6,149	0.036	0.031
February			*a* 100	5,554	0.032	0.031
March			*a* 150	9,223	0.054	0.047
April	1,760	120	712	42,367	0.250	0.224
May	2,570	670	1,239	76,185	0.450	0.390
June	2,480	120	1,050	62,479	0.368	0.330
July	120	21	40	2,460	0.015	0.013
August	520	15	109	6,702	0.039	0.034
September	21	8	12	714	0.004	0.004
October			*a* 15	922	0.006	0.005
November			*a* 15	893	0.006	0.005
December			*a* 15	922	0.006	0.005
The year			296	214,570	1.266	0.093

a Approximate.



A. DAM AND HEAD GATES OF WYOMING DEVELOPMENT COMPANY'S CANAL, ON LARAMIE RIVER NEAR WHEATLAND, WYOMING.

B. INTAKE OF 3,100-FOOT TUNNEL OF WYOMING DEVELOPMENT COMPANY, NEAR WHEATLAND, WYOMING.



a Approximate.

FIG. 89.—Discharge of Laramie River at Woods Landing and Uva, Wyoming, 1897

The second considerable diversion from the river, the upper canal of the system of the Wyoming Development Company, takes water from Laramie River about 27 miles southwest of Wheatland. At this point there is a substantial stone dam, with head gates for an open ditch 2,000 feet long. At the end of this open way is the intake of a tunnel 3,100 feet long and 7 by 8 feet cross section, cut through the divide between Blue Grass Creek and Laramie River, as shown in Pl. XXXIV, *B*. From the outlet of the tunnel the water empties into a small tributary of Blue Grass Creek; thence it flows for 13 miles down this stream to its junction with Sybille Creek. One and one-half miles farther down are the head gates of canal No. 1 of the Wyoming Development Company.

The accompanying view (Pl. XXXIV, *A*) shows the dam and head gates of the canal on Laramie River. Pl. XXXIV, *B*, is a view of the intake of the tunnel, and Pl. XXXV, *A*, of the outlet on Blue Grass Creek. The head gates of canal No. 2, on Sybille Creek, shown in Pl. XXXV, *B*, are located about 11 miles below the head of canal No. 1. A third canal, taking water from Sybille Creek between the heads of the two earlier ditches, has been constructed more recently. Canal No. 3 is a supply ditch for a reservoir located about 6 miles below its head, which was completed in 1897. It covers 400 acres, and has an available depth of about 40 feet. Water is taken from it by means of a tunnel in the sand, lined with brick and terra cotta. From the end of the pipe are two branches, one leading to canal No. 2, which it will supply at low stages of Sybille Creek, and the other will irrigate land not covered by the system of laterals from canal No. 1.

There are two gaging stations on this river. The one at Woods

Landing, above mentioned, is described in Water-Supply and Irrigation Paper No. 15, p. 81, which gives the list of discharge measurements made in 1897, together with the table of gage heights. The rating table on page 301 has been constructed, based on those measurements. Next is shown the table of monthly discharges. The area drained at this point is 435 square miles.

The second gaging station is at Uva, below the head of all important irrigating canals, and the results show the amount of water available

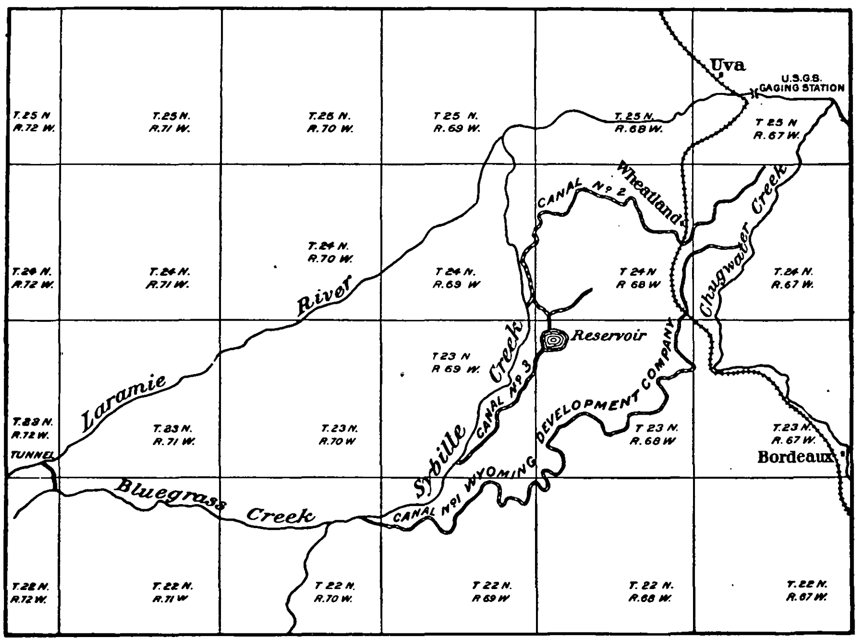


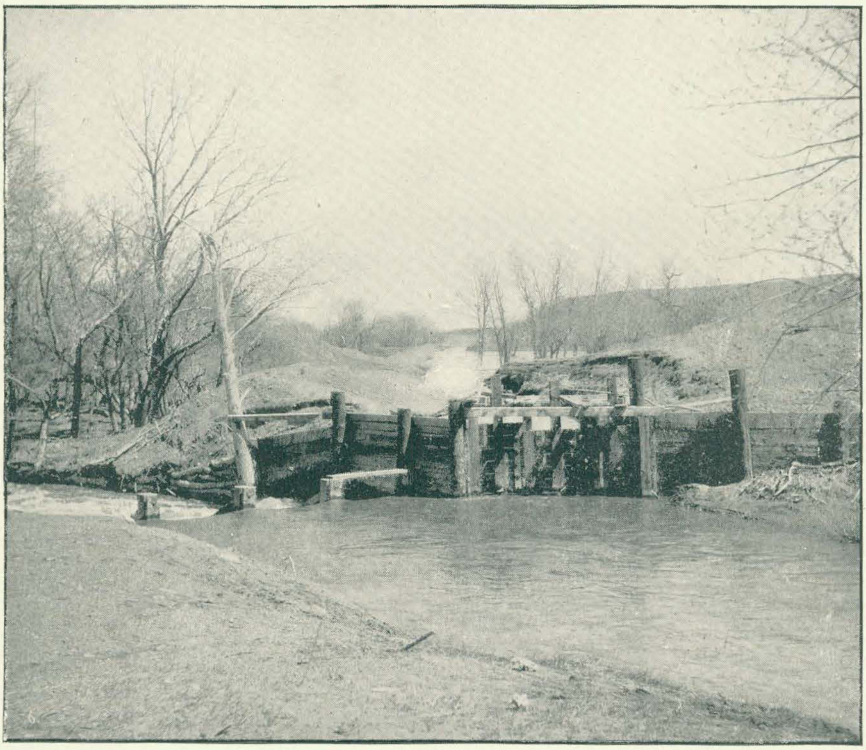
FIG. 90.—Map of canals in the vicinity of Wheatland, Wyoming.

for storage. It is described in Water-Supply and Irrigation Paper No. 15, p. 182. North Laramie River enters the main stream a short distance above the point of measurement. Considerable irrigation on a small scale is practiced in its basin.

NORTH PLATTE RIVER.

North Platte River has its source in the high mountains in northern Colorado, which rise to elevations of 10,000 to 12,000 feet. Numerous tributaries descend into the valley, and, uniting, flow northerly as the North Platte across the State line into Wyoming. This basin is known as the North Park, and the general elevation of the lower lands is about 8,000 feet. Irrigation is practiced to a considerable extent from small ditches, aggregating 150 in number, according to the report of the State engineer of Colorado. They are used almost entirely, however, in flooding native grass lands for forage purposes. A little

A. OUTLET OF 3,100-FOOT TUNNEL OF WYOMING DEVELOPMENT COMPANY, NEAR WHEATLAND, WYOMING.



B. HEAD GATES OF WYOMING DEVELOPMENT COMPANY'S CANAL NO. 2, ON SYBILLE CREEK, NEAR WHEATLAND, WYOMING.

timothy is raised, and also some oats. The elevation is too high and the climate too severe for general agricultural operations. The total area in Colorado drained by the river is 1,696 square miles. At the northern end the Medicine Bow Range closes in from the east and Park Range from the west, through which the river finds its way in a narrow canyon into Wyoming, entering what is known as the Upper Platte Valley and thence extending from the State line down to the Union Pacific Railroad at Fort Steele. This valley is about 40 miles in length, averaging 4 miles wide on the east and from 1 to 2 miles on the west. The main river receives a number of tributaries from the Sierra Madre Mountains, on the west, and from the Snowy Range, on the east. Numerous ditches take water from these tributaries to irrigate small ranches along their valleys. The average elevation of this lower valley is somewhat under 7,000 feet, the elevation at Fort Steele being 6,516 feet. The river continues northward through Carbon County, receiving from the west Sweetwater River, along the tributaries of which considerable irrigation is practiced. Pl. XXXVI contains two views of North Platte River in Wyoming.

The upper gaging station on the North Platte is located at Orin Junction, at which point the area drained is 14,828 square miles. A description of the field work done at this station in 1897 will be found in Water-Supply and Irrigation Paper No. 15, p. 83. The flow as here determined, combined with the discharge at the Uva station, on the Laramie River, shows the amount of water passing out of the State. An irrigation enterprise of considerable importance was planned a year or so ago, taking water from the North Platte River at Fairbanks to irrigate lands in what is known as Goshen Hole, a depression in the general country south of the main river. Its average elevation is 4,300 feet, the lowest considerable area in the southeastern portion of the State.

Mitchell canal heads on the south side of North Platte River, about 2½ miles west of the Nebraska and Wyoming State line. It is about 22 miles long and irrigates land principally in what is known as Mitchell Bottom, northwest of Gering. This opening is about 6 miles long and 2½ miles wide. The canal ends at the bad lands surrounding Scotts Bluff. On the north side of the river, a little above Gering, there should be mentioned in their order downstream the following canals: Farmers canal, 11 miles long, heading just west of the State boundary line; Enterprise canal, heading about 2½ miles below the mouth of Horse Creek and about 20 miles long; and Winter canal, heading about 4 miles above the Gering bridge, at which the first gaging station in Nebraska is located. This station was established May 29, 1897. Owing to the interruption of the gage-height record in June, discharges can be estimated only from July 1. The work done at this station in 1897 is described in Water-Supply and Irrigation Paper No. 15, p. 84.

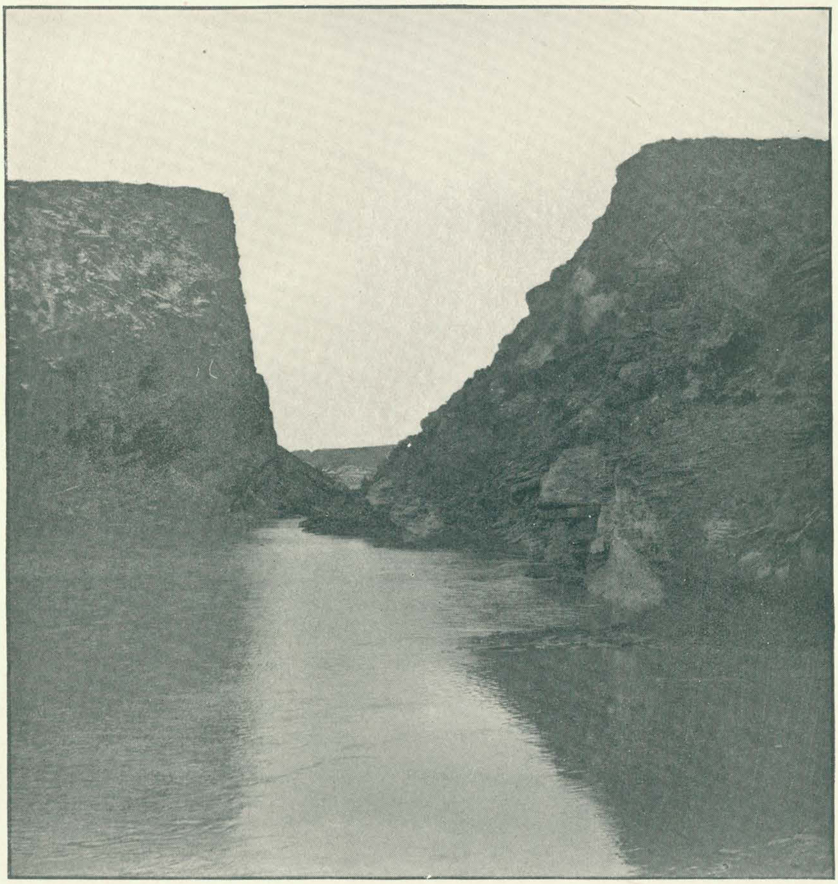
The next gaging station below is at Camp Clarke. A number of large canals take out water on both sides of the river between the two points. From the south side of the river these are as follows: Castle Rock ditch, 13 miles long, heading 4 miles east of Gering; Chimney Rock canal, 10 miles long, heading at the crossing of the boundary line between Cheyenne and Scotts Bluff counties, and Belmont canal, 20 miles long, heading about 3 miles above Camp Clarke. The canals from the north side of the river are: Minatare ditch, Bayard canal, a small ditch heading near Long Island, and the Alliance canal, respectively 6, 13, 3, and 8 miles in length. Browns Creek canal is on the north side of the river and heads about 4½ miles below Camp Clarke. The field work done in 1897 at the Camp Clarke gaging station is described in Water-Supply and Irrigation Paper No. 15, p. 85.

The plateau country south of Camp Clarke, between North Platte River and the Union Pacific Railroad, is on an average about 600 feet above the river. Proceeding eastward this difference of elevation decreases slowly for about 30 or 40 miles, and then more and more rapidly. The section in Deuel and Cheyenne counties has a large number of deep wells located at ranches, varying from 250 to 350 feet in depth. The water is raised by means of windmills and used wholly for stock and domestic purposes. The principal industry is stock raising, the ranchers having from 50 to 300 head of stock each.

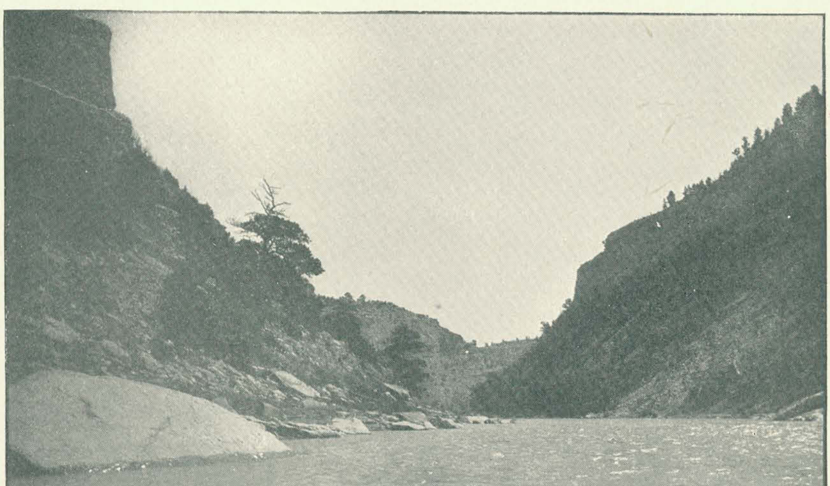
The next station is at North Platte, where a number of discharge measurements were made in 1897 and published in Water-Supply and Irrigation Paper No. 15, p. 86. The bed of the river is here sandy and liable to change at flood stages so that a number of rating curves were made for different parts of the year.

Rating table for North Platte River at Orin Junction, Wyoming, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.0	300	1.2	850	3.4	3,200	5.6	11,640
0.1	335	1.4	950	3.6	3,600	5.8	12,580
0.2	370	1.6	1,050	3.8	4,050	6.0	13,520
0.3	410	1.8	1,150	4.0	4,500	6.2	14,460
0.4	450	2.0	1,300	4.2	5,200	6.4	15,400
0.5	500	2.2	1,450	4.4	6,000	6.6	16,340
0.6	550	2.4	1,650	4.6	6,940	6.8	17,280
0.7	600	2.6	1,900	4.8	7,880	7.0	18,220
0.8	650	2.8	2,150	5.0	8,820		
0.9	700	3.0	2,450	5.2	9,760		
1.0	750	3.2	2,800	5.4	10,700		



A.



B.

NORTH PLATTE RIVER IN WYOMING.

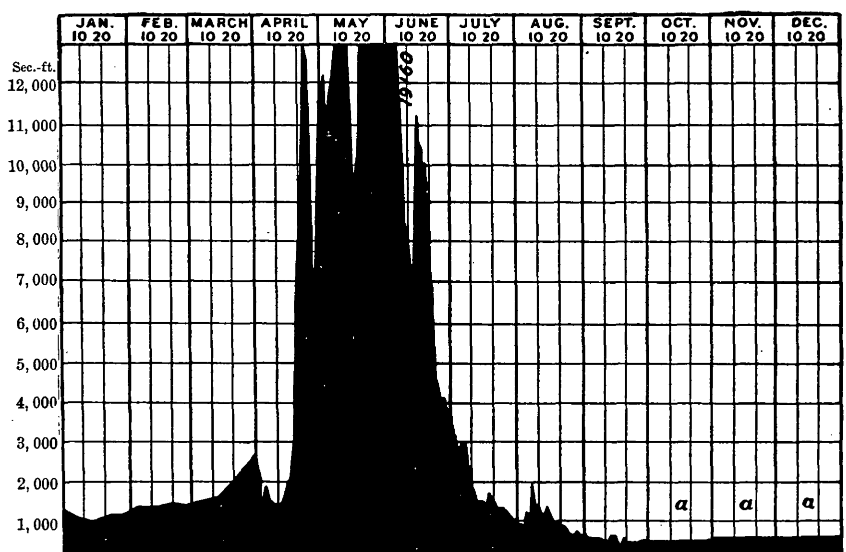
A, 35 miles southwest of Casper; *B*, 10½ miles above mouth of Horseshoe Creek.

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.		Depth in inches.	Second-feet per square mile.
1897.						
January	....	....	*a* 1, 100	67, 637	0. 07	0: 07
February	....	....	*a* 1, 350	74, 975	0. 09	0. 09
March	....	....	*a* 1, 500	92, 232	0. 12	0. 10
April	13, 050	1, 413	5, 037	299, 722	0. 38	0. 34
May	19, 160	9, 525	13, 962	858, 495	1. 08	0. 94
June	18, 220	3, 400	8, 994	535, 180	0. 68	0. 61
July	3, 200	950	1, 828	112, 400	0. 14	0. 12
August	1, 900	650	1, 014	62, 349	0. 08	0. 07
September	650	500	572	34, 036	0. 04	0. 04
October	....	....	*a* 500	30, 744	0. 03	0. 03
November	....	....	*a* 550	32, 727	0. 04	0. 04
December	....	....	*a* 550	33, 818	0. 04	0. 04
The year	....	....	308	2, 234, 315	2. 79	0. 21

a Approximate.



a Approximate.

FIG. 91.—Discharge of North Platte River at Orin Junction, Wyoming, 1897.

Rating table for North Platte River at Gering, Nebraska, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.8	455	1.5	2,340	2.2	7,887	2.9	17,093
0.9	500	1.6	2,909	2.3	8,978	3.0	18,707
1.0	620	1.7	3,552	2.4	10,144	3.1	20,396
1.1	815	1.8	4,269	2.5	11,384	3.2	22,159
1.2	1,084	1.9	5,062	2.6	12,699	3.3	23,997
1.3	1,428	2.0	5,929	2.7	14,089	3.4	25,910
1.4	1,847	2.1	6,870	2.8	15,554	3.5	27,898

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.		Depth in inches.	Second-feet per square mile.
1897.						
July	4,269	1,084	2,140	131,584	0.10	0.09
August	2,340	500	1,071	65,854	0.04	0.04
September	815	455	537	31,954	0.02	0.02
October	620	455	514	31,605	0.02	0.02
November			*a* 520	30,942	0.02	0.02
December			*a* 520	31,974	0.02	0.02

a Approximate.

Rating table for North Platte River at Camp Clarke, Nebraska, for 1897.

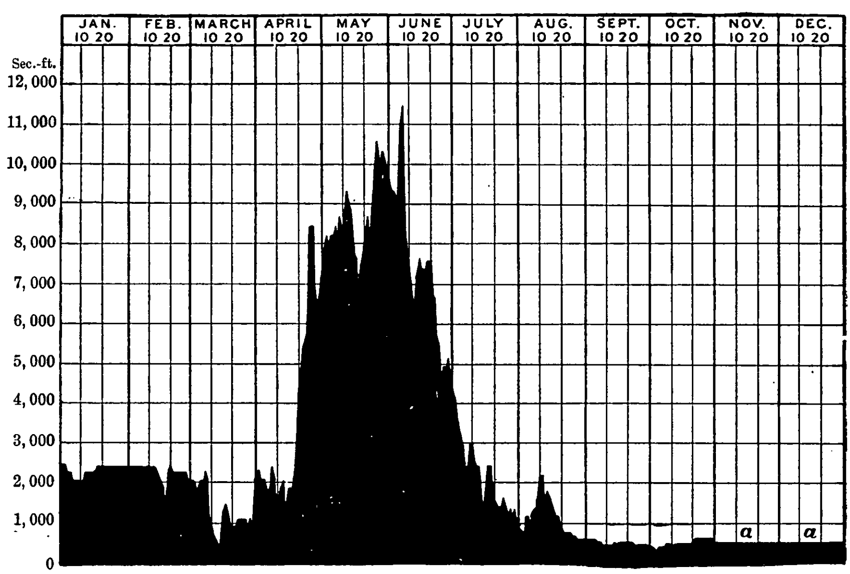
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.0	350	2.8	2,042	3.6	5,380	4.4	8,820
2.1	450	2.9	2,404	3.7	5,810	4.5	9,250
2.2	580	3.0	2,800	3.8	6,240	4.6	9,680
2.3	740	3.1	3,230	3.9	6,670	4.7	10,110
2.4	930	3.2	3,660	4.0	7,100	4.8	10,540
2.5	1,160	3.3	4,090	4.1	7,530		
2.6	1,420	3.4	4,520	4.2	7,960		
2.7	1,714	3.5	4,950	4.3	8,390		

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.		Depth in inches.	Second-feet per square mile.
1897.						
January	2,404	2,042	2,287	140,623	0.106	0.092
February	2,404	1,567	2,253	125,125	0.095	0.091
March	2,223	450	1,299	79,873	0.060	0.052
April	8,390	1,567	3,649	217,130	0.164	0.147
May	10,540	6,885	8,688	534,208	0.400	0.350
June	11,400	4,520	7,491	440,389	0.332	0.298
July	4,305	930	2,147	132,015	0.099	0.086
August	2,042	580	1,066	65,546	0.049	0.043
September	580	400	492	29,276	0.022	0.020
October	580	350	484	29,760	0.022	0.019
November			*a*500	29,752	0.022	0.020
December			*a*500	30,744	0.023	0.020
The year			2,564	1,854,441	1.394	0.103

a Approximate.



a Approximate.

FIG. 92.—Discharge of North Platte River at Camp Clarke, Nebraska, 1897.

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

[Drainage area, 28,517 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	8, 650	4, 876	6, 932	426, 296	0. 280	0. 243
February	9, 489	2, 471	6, 663	370, 044	0. 236	0. 233
March	9, 489	1, 774	3, 921	241, 094	0. 158	0. 138
April	13, 486	2, 471	5, 110	304, 125	0. 200	0. 179
May	21, 527	7, 812	13, 981	859, 664	0. 565	0. 490
June	23, 720	6, 518	13, 920	828, 296	0. 545	0. 488
July	6, 197	1, 090	3, 688	226, 768	0. 149	0. 129
August	4, 754	743	2, 876	176, 839	0. 116	0. 101
September	850	422	609	36, 238	0. 024	0. 021
October	3, 878	486	1, 132	69, 604	0. 046	0. 040
November	4, 112	743	2, 152	128, 053	0. 084	0. 075
December	6, 037	3, 174	5, 116	314, 634	0. 207	0. 180
The year	23, 720	422	5, 509	3, 981, 655	2. 610	0. 193

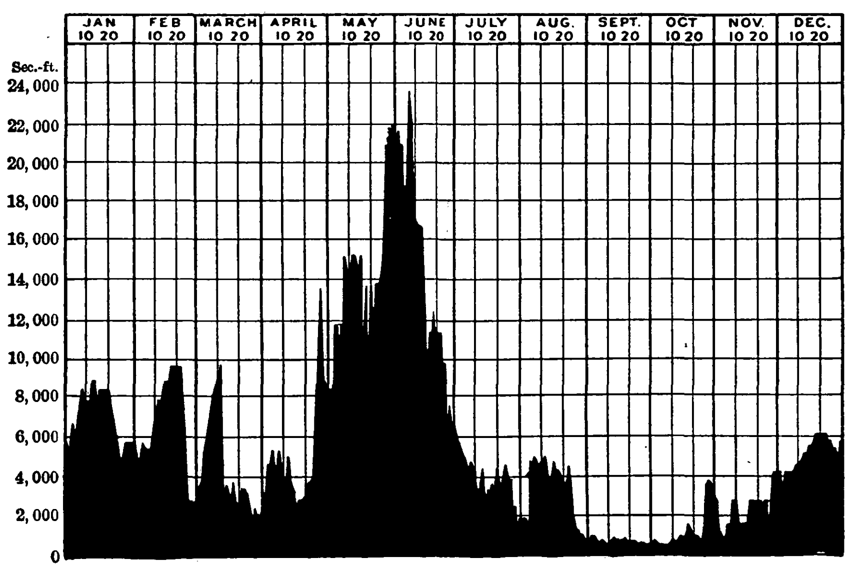


FIG. 93.—Discharge of North Platte River at North Platte, Nebraska, 1897.

SOUTH PLATTE RIVER.

South Platte River rises in the Rocky Mountains southwest of Denver. The mountainous area is similar to the basin drained by the North Platte in Colorado. Mountain peaks rise to elevations of 13,000 feet above the sea, and the average elevation of the valley is 8,000 feet. The basin is known as the South Park. There is considerable irrigation in the district and a large number of canals have been taken from the tributaries, which often produce a shortage in the summer months. On account of the high altitude none but the hardier crops can be raised, of which the principal is native hay for forage purposes.

Several important tributaries of South Platte, from which irrigation is extensively practiced, come from the eastern slope of the mountain range which the main river skirts. Gaging stations were maintained on a number of these, in order downstream as follows: Bear Creek, South Boulder Creek, Boulder Creek, St. Vrain Creek, and Big Thompson Creek. Measurements of the Cache la Poudre are maintained by the State Agricultural College, and the record will be found in the reports of that institution.

The upper gaging station on South Platte River is located at Deansbury at the mouth of the canyon. Below this point a number of large canals are taken out which are among the most successful in the country.

The second gaging station is at Denver. Thence the river flows in a general northeasterly direction, gradually receding from the mountain range until it receives its principal tributary, the Cache la Poudre, when it turns abruptly eastward and continues through the arid section of northeastern Colorado. The lowest station in this State is at Orchard. Continuing eastward, the water supply gradually diminishes until in the summer the river for long stretches is practically dry.

In 1897 the condition of the river at North Platte, Nebraska, where it joins with North Platte River, was as follows: During the months of January and February there were several small channels running, but their combined discharge was very small, and they ceased to flow in the spring. June 3 the river commenced to flow and the discharge increased gradually until June 21, when the river was carrying 4,427 second-feet; it then decreased until July 2, when it ceased to flow. August 9 water appeared in the river again, increasing until August 13, when the discharge was 2,880 second-feet; it then declined gradually until September 1, when there was no flow; the river was entirely dry through September, October, and November; in December there was a small flow through various channels. The mean discharge for the 27 days in June was 2,110 second-feet, and for the 22 days in August, 1,505 second-feet. From these figures the total discharge of the river in 1897 was 178,672 acre-feet.

Rating table for South Platte River at Deansbury, Colorado, for 1897.

Gage height.	Discharge.		Gage height.	Discharge.	
	Jan. 1 to Apr. 7.	Apr. 8 to June 30.		Jan. 1 to Apr. 7.	Apr. 8 to June 30.
Feet.	*Second-feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Second-feet.*
0.7	....	118	3.0	95	650
0.8	....	132	3.2	112	730
0.9	....	146	3.4	138	810
1.0	....	161	3.6	164	890
1.2	....	190	3.8	190	970
1.4	....	221	4.0	217	1,050
1.6	....	254	4.2	244	1,130
1.8	....	291	4.4	270	1,210
2.0	55	330	4.6	....	1,290
2.2	63	370	4.8	....	1,370
2.4	71	420	5.0	....	1,450
2.6	79	490	5.2	....	1,530
2.8	87	570	5.4	....	1,610

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

[Drainage area, 2,600 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	97	67	81	4,981	0.03	0.03
February	164	71	80	4,443	0.03	0.03
March	217	73	101	6,210	0.04	0.04
April	630	190	370	22,016	0.16	0.14
May	1,530	610	984	60,504	0.44	0.38
June	1,550	770	1,046	62,241	0.45	0.40

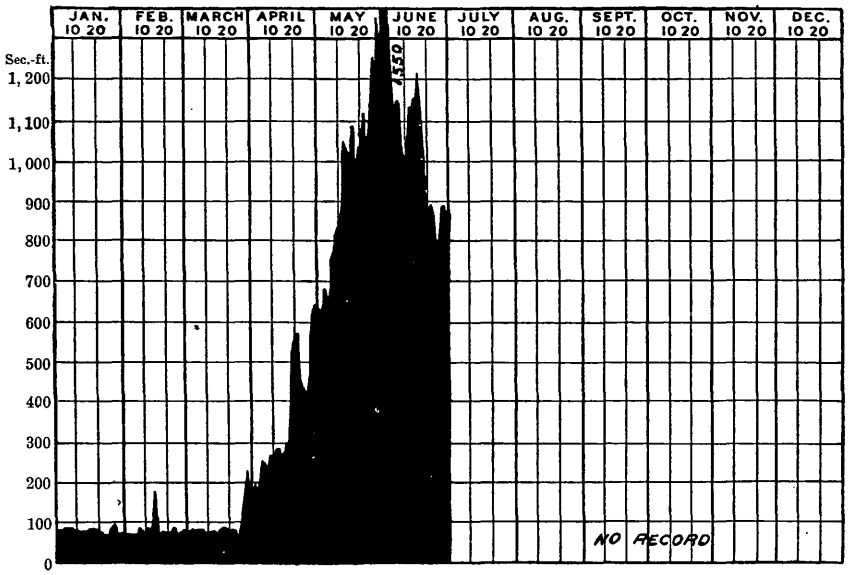


FIG. 94.—Discharge of South Platte River at Deansbury, Colorado, 1897.

Rating table for South Platte River at Denver, Colorado, for 1897. (*a*)

Gage height.	Discharge.		Gage height.	Discharge.	
	Jan. 1 to Sept. 30.	Oct. 1 to Dec. 31.		Jan. 1 to Sept. 30.	Oct. 1 to Dec. 31.
Feet.	*Second-feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Second-feet.*
4.2	50	....	6.4	1,130	....
4.4	70	....	6.6	1,270	....
4.6	90	....	6.8	1,410	....
4.8	110	110	7.0	1,550	....
5.0	160	130	7.2	1,690	....
5.2	290	175	7.4	1,830	....
5.4	430	240	7.6	1,970	....
5.6	570	330	7.8	2,110	....
5.8	710	470	8.0	2,250	....
6.0	850	610	8.2	2,390	....
6.2	990	750			

a The flood of August 4 caused the principal changes in this rating table.

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

[Drainage area, 3,840 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	110	80	95	5,841	0.029	0.025
February	105	55	83	4,610	0.023	0.022
March	430	85	179	11,006	0.054	0.047
April	850	220	470	27,967	0.136	0.122
May	1,410	430	735	45,194	0.220	0.191
June	1,445	535	1,026	61,051	0.297	0.267
July	1,200	85	392	24,103	0.118	0.102
August	2,425	118	687	42,242	0.206	0.179
September	605	100	270	16,066	0.078	0.070
October	575	175	267	16,417	0.081	0.070
November	680	110	406	24,159	0.118	0.106
December	305	150	217	13,343	0.066	0.057
The year	2,425	55	402	291,996	1.426	0.105

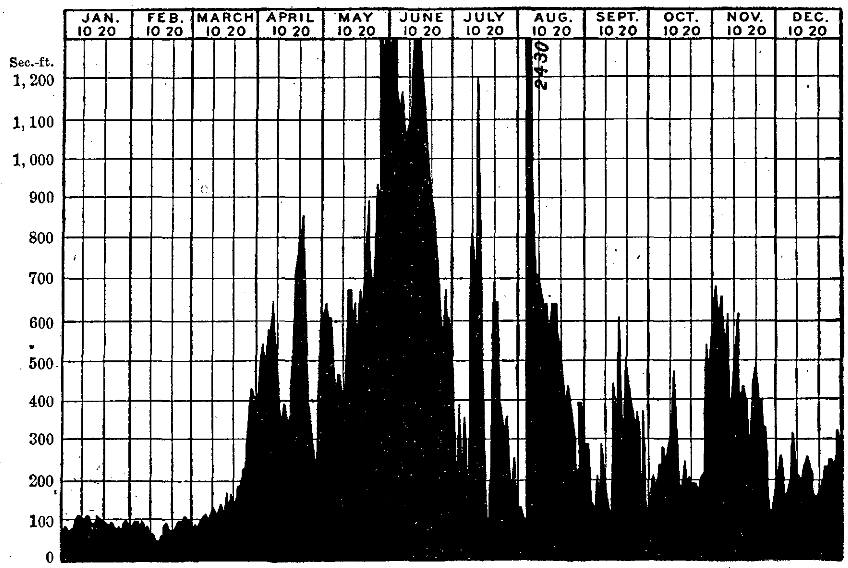


FIG. 95.—Discharge of South Platte River at Denver, Colorado, 1897.

Rating table for South Platte River at Orchard, Colorado, for 1897.

Gage height.	Discharge.		
	Jan. 1 to June 19.	June 20 to July 20.	July 21 to Dec. 31.
Feet.	*Second-feet.*	*Second-feet.*	*Second-feet.*
2.3	....	39	39
2.4	....	61	61
2.5	81	86	86
2.6	89	113	109
2.7	97	146	135
2.8	105	185	160
2.9	115	238	188
3.0	124	330	217
3.2	146	504	282
3.4	170	708	369
3.6	200	912	523
3.8	238	1,116	715
4.0	294	1,320	907
4.2	489	1,524	1,099
4.4	847	1,728	1,294
4.6	1,205	1,930	1,490
4.8	1,563	2,130	1,686
5.0	1,921	2,330	1,882
5.5	2,820	2,830	2,372
6.0	3,720	3,330	2,862
6.5	4,620	....	....
6.8	5,160	....	....

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.		Depth in inches.	Second-feet per square mile.
1895.						
November 22–30	925	790	870	15,530	0.024	0.071
December	925	610	759	46,669	0.071	0.062
1896.						
January	880	610	775	47,652	0.072	0.063
February 16–29.....	700	520	610	16,940	0.026	0.050
March	700	520	581	35,724	0.054	0.047
December	2,280	228	789	48,513	0.074	0.064

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

[Drainage area, 12,260 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	1,116	228	631	38,799	0.059	0.051
February	1,116	228	557	30,933	0.047	0.045
March	262	218	231	14,204	0.013	0.019
April	847	250	529	31,478	0.048	0.043
May	3,720	81	898	55,216	0.084	0.073
June	5,160	555	2,637	156,912	0.240	0.215
July	1,320	39	347	21,736	0.032	0.028
August	2,274	147	803	49,374	0.075	0.065
September	147	61	92	5,474	0.009	0.008
October	1,294	86	303	18,631	0.029	0.025
November	1,392	715	1,109	65,990	0.100	0.090
December	1,931	475	1,232	75,753	0.115	0.100
The year	5,160	39	779	564,500	0.851	0.064

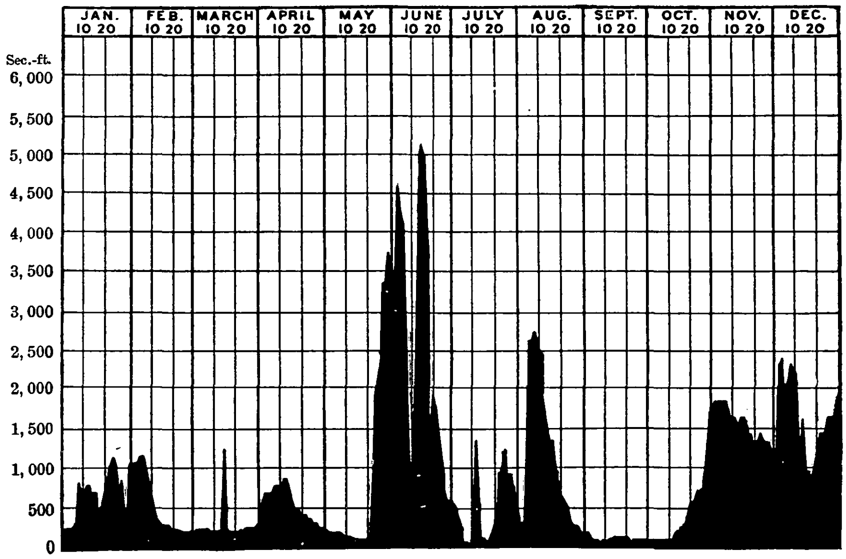


FIG. 96.—Discharge of South Platte River at Orchard, Colorado, 1897.

Rating table for Bear Creek at Morrison, Colorado, for 1897.

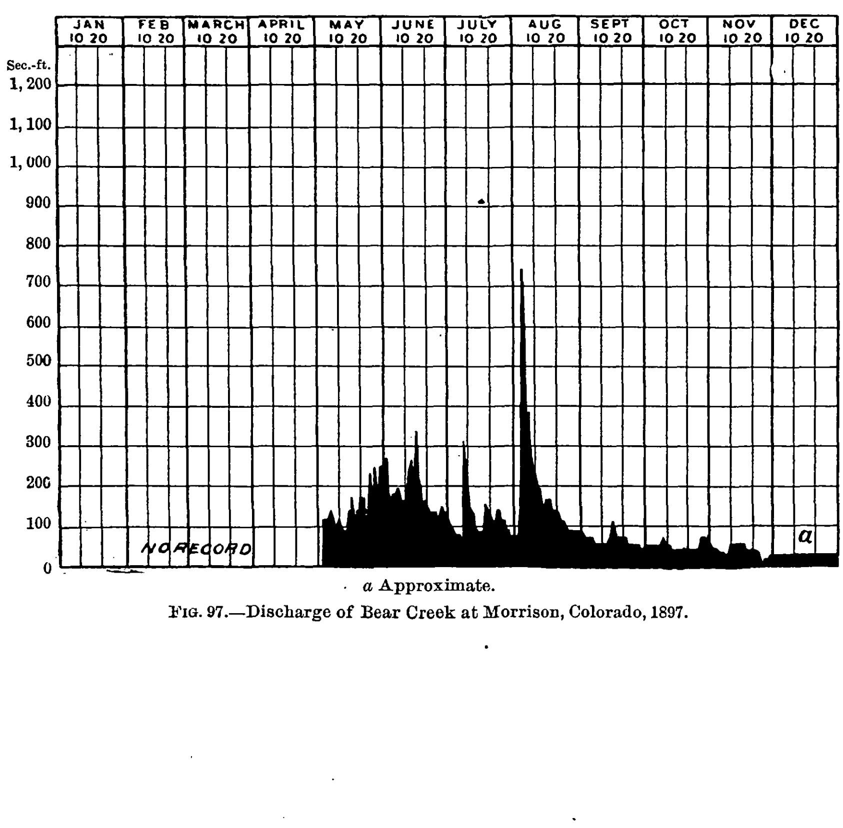
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.5	7	3.2	83	3.9	288	4.6	561
2.6	12	3.3	102	4.0	327	4.7	600
2.7	18	3.4	124	4.1	366	4.8	639
2.8	27	3.5	149	4.2	405	4.9	678
2.9	37	3.6	179	4.3	444	5.0	717
3.0	49	3.7	212	4.4	483		
3.1	65	3.8	250	4.5	522		

Estimated monthly discharge of Bear Creek at Morrison, Colorado.

[Drainage area, 170 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
May	250	92	152	9,346	1.02	0.89
June	327	124	175	10,413	1.15	1.03
July	307	74	115	7,071	0.78	0.68
August	737	83	199	12,236	1.35	1.17
September	113	49	67	3,987	0.44	0.39
October	74	49	55	3,382	0.37	0.32
November	49	5	34	2,023	0.22	0.20
December			*a* 20	1,230	0.14	0.12

a Approximate.



a Approximate.

FIG. 97.—Discharge of Bear Creek at Morrison, Colorado, 1897.

Rating table for South Boulder Creek at Marshall, Colorado, for 1897.

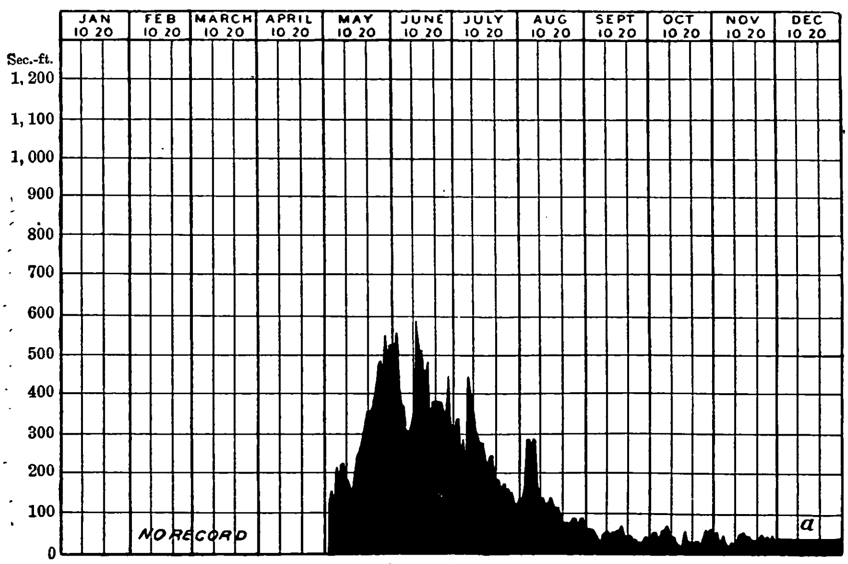
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.8	14	1.5	99	2.2	277	2.9	461
0.9	22	1.6	120	2.3	303	3.0	488
1.0	31	1.7	146	2.4	329	3.1	514
1.1	41	1.8	172	2.5	355	3.2	540
1.2	52	1.9	198	2.6	381	3.3	567
1.3	65	2.0	224	2.7	408	3.4	594
1.4	80	2.1	250	2.8	435		

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

[Drainage area, 125 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
May	554	120	305	18,754	2.82	2.44
June	594	303	401	23,861	3.58	3.21
July	435	120	235	14,450	2.17	1.88
August	290	65	129	7,932	1.19	1.03
September	65	22	43	2,559	0.38	0.34
October	65	18	39	2,398	0.36	0.31
November	52	18	35	2,083	0.31	0.28
December	....	....	*a* 30	1,845	0.28	0.24

a Approximate.



a Approximate.

FIG. 98.—Discharge of South Boulder Creek at Marshall, Colorado, 1897.

Rating table for Boulder Creek at Boulder, Colorado, for 1897.

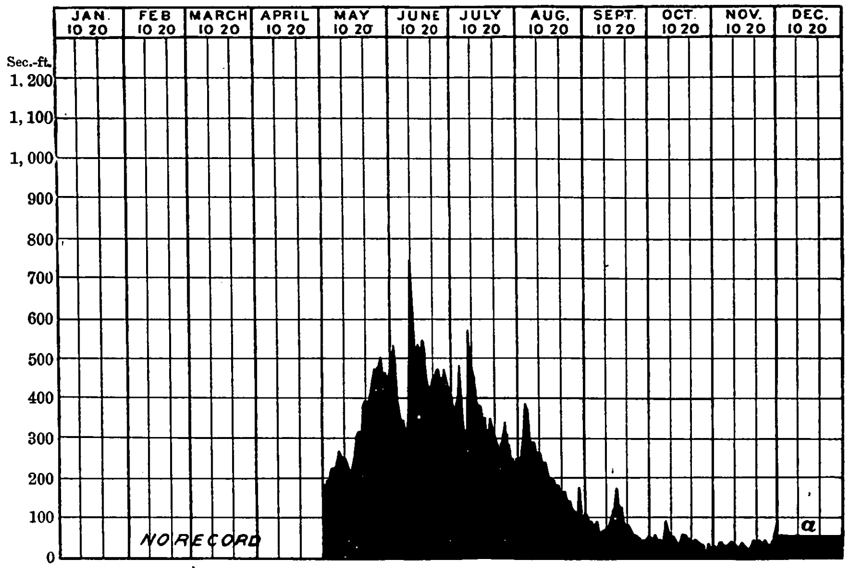
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.3	25	1.2	145	2.1	370	2.9	570
0.4	30	1.3	170	2.2	395	3.0	595
0.5	38	1.4	195	2.3	420	3.1	620
0.6	48	1.5	220	2.4	445	3.2	645
0.7	58	1.6	245	2.5	470	3.3	670
0.8	70	1.7	270	2.6	495	3.4	695
0.9	84	1.8	295	2.7	520	3.5	720
1.0	100	1.9	320	2.8	545	3.6	745
1.1	120	2.0	345				

Estimated monthly discharge of Boulder Creek at Boulder, Colorado.

[Drainage area, 102 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
May	495	182	323	19,861	3.66	3.17
June	745	320	458	27,253	5.01	4.49
July	557	232	339	20,844	3.83	3.32
August	395	100	213	13,097	2.41	2.09
September	170	48	83	4,939	0.90	0.81
October	92	30	47	2,890	0.53	0.46
November	92	23	38	2,261	0.41	0.37
December			*a* 60	3,689	0.68	0.59

a Approximate.



a Approximate.

FIG. 99.—Discharge of Boulder Creek at Boulder, Colorado, 1897.

Rating table for St. Vrain Creek at Lyons, Colorado, for 1897.

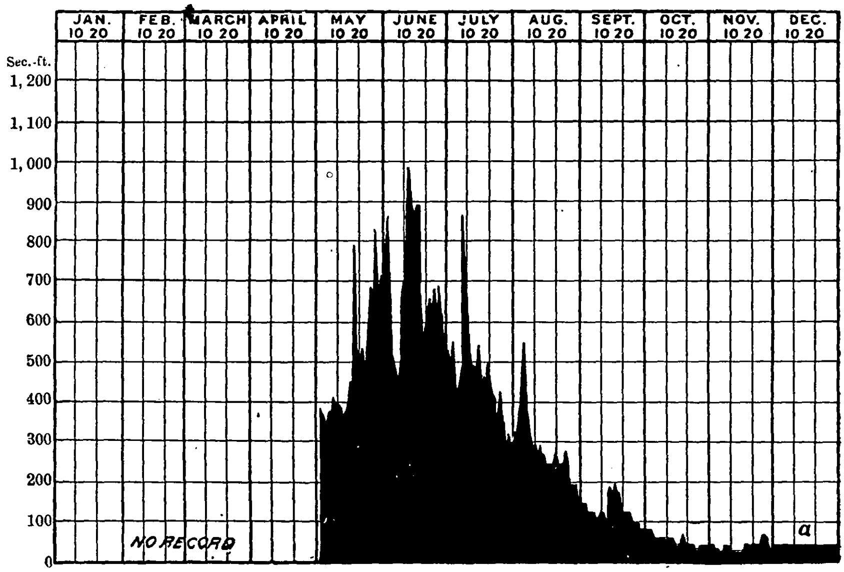
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.5	24	2.2	155	3.4	459	4.6	763
1.6	33	2.4	206	3.6	510	4.8	824
1.7	46	2.6	256	3.8	561	5.0	872
1.8	64	2.8	307	4.0	612	5.2	920
1.9	85	3.0	358	4.2	662	5.4	968
2.0	107	3.2	408	4.4	712	5.6	1,016

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

[Drainage area, 209 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
May	824	345	510	31,359	2.82	2.44
June	980	447	668	39,749	3.56	3.19
July	860	294	457	28,100	2.53	2.19
August	548	143	274	16,848	1.51	1.31
September	180	75	123	7,319	0.65	0.59
October	75	28	47	2,890	0.24	0.22
November	54	28	35	2,083	0.19	0.17
December	....	....	*a* 40	2,460	0.22	9.19

a Approximate.



a Approximate.

FIG. 100.—Discharge of St. Vrain Creek at Lyons, Colorado, 1897.

Rating table for Big Thompson Creek at Arkins, Colorado, for 1897.

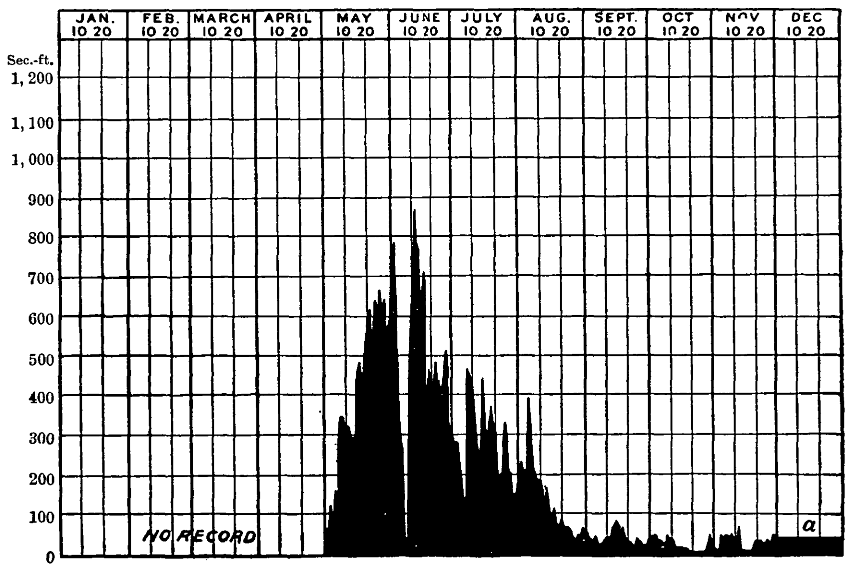
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.0	6	0.7	85	1.4	321	2.0	597
0.1	12	0.8	107	1.5	367	2.1	643
0.2	19	0.9	132	1.6	413	2.2	689
0.3	27	1 0	160	1.7	459	2.3	735
0.4	36	1.1	190	1.8	505	2.4	781
0.5	48	1.2	229	1.9	551	2.5	827
0.6	64	1.3	275				

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.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
May	666	64	417	25,640	1.58	1.37
June	850	36	462	27,491	1.68	1.51
July	459	146	265	16,294	1.00	0.87
August	390	36	132	8,116	0.49	0.43
September	85	19	37	2,202	0.13	0.12
October	48	6	17	1,045	0.07	0.06
November	64	6	27	1,607	0.10	0.09
December	....	....	*a* 40	2,460	0.15	0.13

a Approximate.



a Approximate.

FIG. 101.—Discharge of Big Thompson Creek at Arkins, Colorado, 1897.

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

[Drainage area, 23,294 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
June 4-30	4,427	177	2,110	112,998	0.09	0.09
August 10-31	2,880	151	1,505	65,670	0.05	0.06

LOUP RIVER.

On this tributary of Platte River three stations are maintained, one each on the North and the Middle Loup at St. Paul, Nebraska, just above their respective mouths, and one at Columbus, on the main river, just above the junction with the Platte. A description of the St. Paul stations will be found in Water-Supply and Irrigation Paper No. 15, pp. 95-96, and of the Columbus station on Loup River, p. 97 of the same paper. In computing the daily discharges Prof. O. V. P. Stout

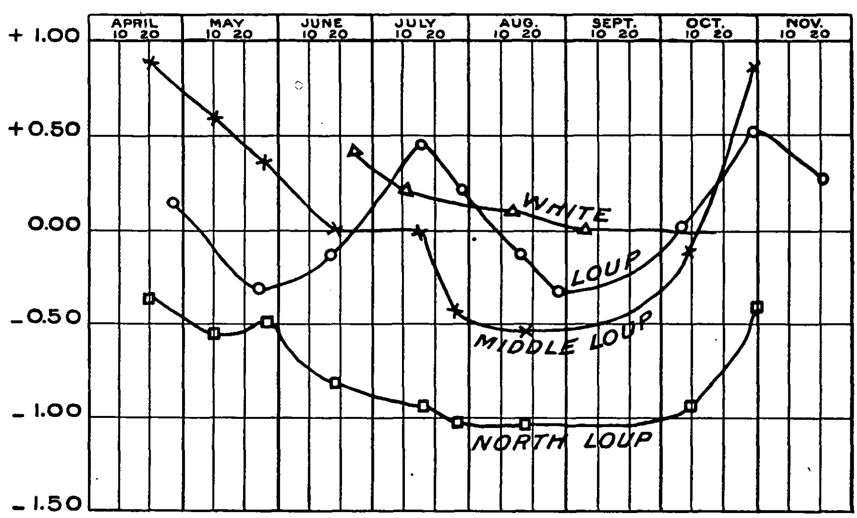


FIG. 102.—Corrections to gage height, 1897.

has employed a method which he describes as follows: A diagram, fig. 102, has been used to facilitate the indirect application of the rating tables. The observed heights are first corrected by use of this diagram, and then the rating table is applied to obtain the estimated discharge. By this means a single rating table is used instead of a number of tables modified at short intervals. For example, take the case of Middle Loup River.

At St. Paul, Nebraska, in 1897, measurements of discharge were made as noted in the following table:

Measurements of discharge of Middle Loup River at St. Paul, Nebraska, in 1897.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
	Feet.	*Second-feet.*		*Feet.*	*Second-feet.*
April 2	1.74	1,792	July 27	1.56	666
May 11	1.77	1,441	August 18	1.65	661
May 27	1.84	1,256	October 9	1.70	814
June 18	1.87	979	October 30	1.68	1,671
July 16	1.58	816			

An examination of the foregoing table fails to reveal any stable relation between gage height and discharge. When the results of the measurements are plotted on cross-section paper the problem of obtaining a rating table for either direct or indirect application seems at first to be one of hopeless difficulty. A rating table, however, has been prepared in the manner indicated by the following paragraph, which is quoted from the report of field work in Nebraska in 1897:

The discharge curve has been made to conform to the gagings of June 18 and July 17 and to the assumption that for the greater discharges it follows the same law as the corresponding portion of the curve for the Platte River at Columbus, due allowance having been made for the difference in the width of the two rivers.

The rating table is as follows:

Rating table for Middle Loup River at St. Paul, Nebraska, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.0	625	1.6	820	2.1	1,155	2.6	1,740
1.1	655	1.7	865	2.2	1,250	2.7	1,890
1.2	685	1.8	925	2.3	1,360	2.8	2,050
1.3	715	1.9	990	2.4	1,480	2.9	2,215
1.4	745	2.0	1,065	2.5	1,605	3.0	2,390
1.5	780						

The following table, to be used in connection with the indirect application of the former rating table to obtain discharge of Middle Loup River at St. Paul, Nebraska, has been prepared:

Correction table for Middle Loup River at St. Paul, Nebraska, for 1897.

Date of discharge measurement.	Gage height.	Corrected gage height.	Correction to gage height.
	Feet.	*Feet.*	*Feet.*
April 2	1.74	2.63	+0.89
May 11	1.77	2.37	+0.60
May 27	1.84	2.20	+0.36
June 18	1.87	1.88	+0.01
July 16	1.58	1.58	0.00
July 27	1.56	1.13	−0.43
August 18	1.65	1.11	−0.54
October 9	1.70	1.59	−0.11
October 30	1.68	2.55	+0.87

The corrected gage height is that which in the rating table corresponds to the measured discharge. The correction to gage height is that which must be applied to the observed gage height to obtain the corrected gage height.

This method has been used in place of the following table, which has been deduced independently by the method commonly employed in the case of streams with shifting cross sections.

Rating table for Middle Loup River at St. Paul, Nebraska, as deduced by usual method.

Gage height.	Discharge.			
	Apr. 1 to May 1, and Oct. 28 to Nov. 30, 1897.	May 2 to 21, 1897.	May 22 to June 1, 1897.	June 2 to Oct. 27, 1897.
Feet.	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Second-feet.*
1.4				483
1.5	1,002	885		598
1.6	1,326	1,095	780	713
1.7	1,650	1,305	980	823
1.8	1,974	1,515	1,180	943
1.9	2,298	1,725	1,380	1,058
2.0	2,622			1,173
2.1	2,946			1,288
2.2	3,270			1,403
2.3	3,594			1,518
2.4	3,918			1,633
2.5				1,748

Rating table for Middle Loup River at St. Paul, Nebraska, as deduced by usual method—Continued.

Gage height.	Discharge.			
	Apr. 1 to May 1, and Oct. 28 to Nov. 30, 1897.	May 2 to 21, 1897.	May 22 to June 1, 1897.	June 2 to Oct. 27, 1897.
Feet.	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Second-feet.*
2.6	....	....	....	1,863
2.7	....	....	....	1,978
2.8	....	....	....	2,093
2.9	....	....	....	2,208
3.0	....	....	....	2,323
3.1	....	....	....	2,438

To construct the diagram, fig. 104 (see p. 331), a number of horizontal lines are ruled at equal distances apart on a sheet which has a vertical ruling for each day of the year. One of the horizontal lines is assumed as the zero or base line, from which the correction to gage height may be laid off to scale on the vertical line corresponding to the date of the discharge measurement. A free-hand curve is drawn through the points thus located, and it is considered that the ordinate intercepted between this curve and the zero line, on the vertical line corresponding to any date, is the correction to gage height for that date. When this correction has been applied to the observed gage height, the rating table is entered with the corrected gage height as an argument, and the mean rate of discharge for that date is found.

It may be said, with show of reason, that this method of rating a gaging station is founded on a rational basis. Except at the lowest stages of a sandy river, when it is divided into several channels, or when it occupies only a portion of the ordinary channel, the main cause of the changes in the relation between gage height and discharge is the elevation and depression of the bed of the river, which are known to take place. This change usually occurs at a gradual rate, and presumably with some regularity. Sudden floods, however, tend to wash the sand from the channel of the river and to deposit it on the sides, so that when the flood subsides it is found that the surface of the water is considerably lower than at times of equal discharge previous to the flood. The curves here given, however, do not show any marked instances of this effect. This fact may be explained by the absence of excessive floods in 1897.

Now, if the river bed be imagined as permanent, and a rating table be deduced, it is apparent that this rating table can be applied indirectly to the station, in spite of changes in the average elevation of the bed of the stream, if the form of the cross section of the stream does not undergo material change.

If such a rating table could be obtained, the curve of corrections to gage height, as here defined, would represent at the same time the changes in the average elevation of the bed of the stream. Throughout a season during which no floods occur we should expect the curve to be one of considerable regularity and smoothness. Those portions of the curve which were adjacent, in point of time, to floods of magnitude, would be expected to present irregularities not in accord with the smoother portions of the curve on each side of them.

Recurring now to the cases in hand, it must be noted that in no one of them is there more than the roughest approximation to the conditions of the ideal case which has been assumed. Soundings have shown that at times of equal discharge the sections at the same point may vary materially in area and in form. Nevertheless, the process which has been described has been founded upon the assumption of the existence of the ideal conditions, and it may be of interest to examine the curves as constructed and see how nearly they approximate in their nature to what would be expected if the ideal conditions actually prevailed. When the direction of curve is upward in the direction of the progress of time it indicates that the river bed is falling, and vice versa.

The curve which represents corrections to gage height on the Middle Loup River at St. Paul is smooth, with the exception of a departure from the normal in the vicinity of the point which corresponds to the gaging of July 16. The maximum flood of the season, which occurred on July 1, might explain this exception, but a flood on August 10, which reached nearly as great a height, seems to have been without effect on the nature of the curve. The curve indicates that the average surface of the bed of the river rose until August 18, from which time it fell until the close of the season.

The curve for North Loup River at St. Paul is of the same general nature as that for the Middle Loup. The bed of the river rose, except as noted, until a period about August 18, during which it seems to have been stationary and after which it fell until the end of the season. The only exception to the general smoothness of the curve occurs in the portion governed by the gaging made on May 28. For a short period at this time it seems that the bed of the river fell, while the general change during the season until August 18 was in the opposite direction. The season from June 22 to July 6, inclusive, was one of floods, the highest stage of water for the year occurring on July 3. The effect of these floods on the curve is not apparent. The rating table for this station was prepared for use in connection with the work of 1896 and is to be found in the Eighteenth Annual Report, Part IV, p. 177.

The curve for the Loup River at Columbus indicates that the bed of the river was subject to several alternations of rise and fall. It seems to have risen rapidly from March 19 to March 23, then to have been stationary until April 27, to have fallen until May 25, to have risen again until July 16, to have fallen until August 29, to have risen until October 30, and thereafter to have fallen. These indications are confirmed by the points representing gagings on the following dates and which lie between the extreme points at which changes in the direction of the curve appear, viz, June 17, July 29, August 17, and October 7. The principal floods of the season reached their maxima on June 27 and July 1, but they do not seem to have interfered with the smoothness of the curve. The rating table used for this station was prepared in 1895, was modified and extended in 1896, and was published in the Eighteenth Annual Report, Part IV, p. 183.

The rating table for the White River at Crawford has been made to conform to the measurements of discharge which were taken on September 6 and 21, October 18, and November 5. The curve of corrections to gage heights therefore coincides with the zero line during the period covered by those dates and indicates no change in the height of the bed of the stream. The other portion of the curve which applies to the period from June 25 to September 6, inclusive, indicates that the bed of the stream rose steadily throughout that period. No floods occurred in this stream during the season of observations.

In the following pages are given the results of the usual method of computation—that is, by the use of a number of rating tables each applicable for a short period:

Rating table for North Loup River at St. Paul, Nebraska, for 1897.

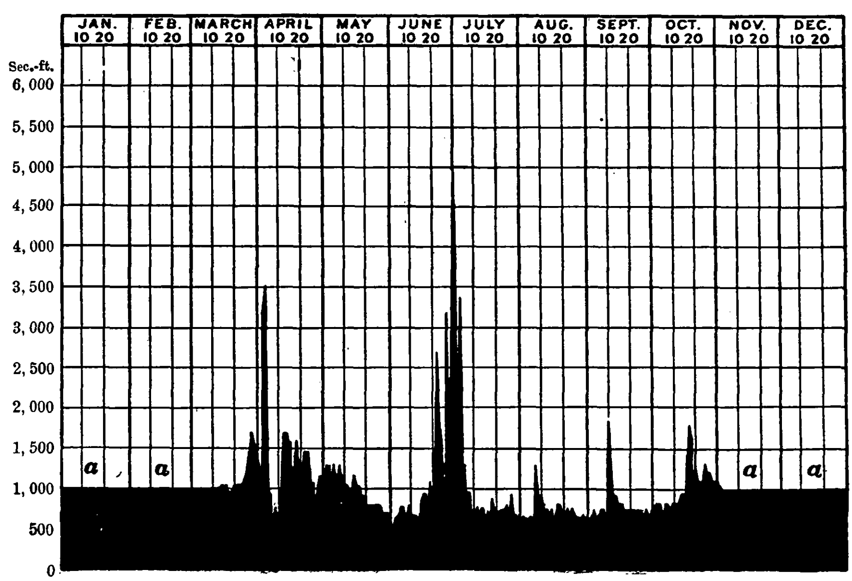
Gage height.	Discharge.		Gage height.	Discharge.	
	Mar. 13 to June 1.	June 2 to Oct. 31.		Mar. 13 to June 1.	June 2 to Oct. 31.
Feet.	*Second-feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Second-feet.*
2.6	460	580	3.4	2,380	1,980
2.7	690	615	3.5	2,610	2,212
2.8	920	660	3.6	2,840	2,444
2.9	1,150	820	3.7	3,070	2,676
3.0	1,460	1,052	3.8	3,300	2,908
3.1	1,690	1,284	3.9	3,530	3,140
3.2	1,920	1,516	4.0	....	3,372
3.3	2,150	1,748			

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.		Depth in inches.	Second-feet per square mile.
1897.						
January			a 1,000	61,488	0.29	0.25
February			a 1,000	55,537	0.26	0.25
March			a 1,000	61,488	0.29	0.25
April	3,530	575	1,329	79,081	0.37	0.33
May	1,265	575	961	59,090	0.28	0.24
June	4,880	575	1,183	70,393	0.32	0.29
July	3,372	635	954	58,660	0.28	0.24
August	1,284	635	728	44,763	0.21	0.18
September	1,864	635	788	46,889	0.22	0.20
October	1,748	740	1,013	62,287	0.29	0.25
November			a 1,000	59,504	0.28	0.25
December			a 1,000	61,488	0.29	0.25
The year			996	720,668	3.38	0.23

a Approximate.



a Approximate.

FIG. 103.—Discharge of North Loup River at St. Paul, Nebraska, 1897.

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.		Depth in inches.	Second-feet per square mile.
1897.						
January			a1,500	92,232	0.25	0.22
February			a1,500	83,306	0.23	0.22
March			a1,600	98,380	0.26	0.23
April			a2,000	119,008	0.32	0.29
May	1,490	1,055	1,274	78,335	0.22	0.19
June	2,600	860	1,037	61,706	0.17	0.15
July	1,800	660	865	53,186	0.15	0.13
August	885	605	673	41,381	0.12	0.10
September	720	585	675	40,166	0.11	0.10
October	2,800	705	1,169	71,879	0.20	0.17
November			a1,100	65,454	0.18	0.16
December			a1,100	67,636	0.18	0.16
The year			1,208	872,669	2.39	0.18

a Approximate

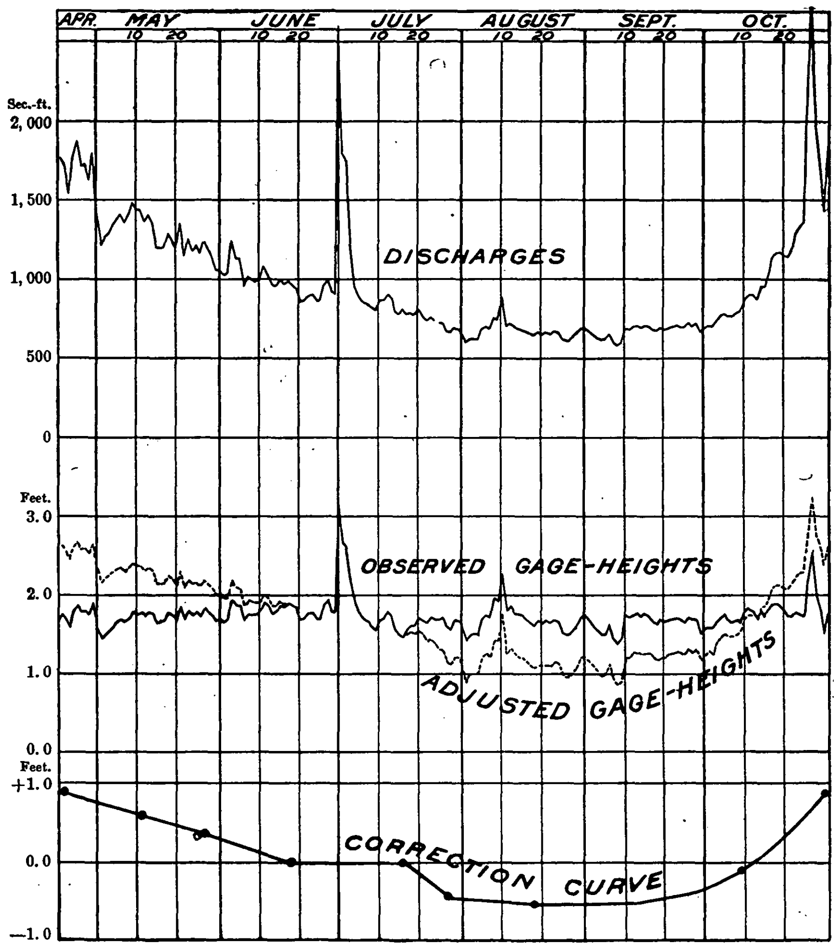


FIG. 104.—Correction curve, observed and estimated heights, and discharge of Middle Loup River at St. Paul, Nebraska, 1897.

Rating table for Loup River, Columbus, Nebraska, for 1897.

Gage height.	Discharge. *a*			
	Mar. 15 to Apr. 27.	May 25 to July 1.	July 2 to Aug. 4.	Aug. 5 to Nov. 21.
Feet.	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Second-feet.*
3.7	....	....	560	....
3.8	....	....	1,060	....
3.9	....	....	1,720	....
4.0	....	....	2,380	1,100
4.1	....	....	3,040	1,300
4.2	....	....	3,700	1,650

a Discharges from April 28 to May 24 were interpolated.

Rating table for Loup River, Columbus, Nebraska, for 1897—Continued.

Gage height.	Discharge. *a*			
	Mar. 15 to Apr. 27.	May 25 to July 1.	July 2 to Aug. 4.	Aug. 5 to Nov. 21.
Feet.	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Second-feet.*
4.3	....	1,450	4,360	2,200
4.4	2,780	1,600	5,020	2,920
4.5	2,950	1,800	5,680	3,640
4.6	3,150	2,050	6,340	4,360
4.7	3,400	2,400	7,000	5,080
4.8	3,700	3,200	7,660	5,800
4.9	4,200	4,040	....	6,520
5.0	4,850	4,880	....	7,240
5.1	5,500	....	....	....
5.2	6,150	....	....	....
5.3	6,800	....	....	....
5.4	7,450	....	....	....
5.5	8,100	....	....	....
5.6	8,750	....	....	....
5.7	9,400	....	....	....
5.8	10,050	....	....	....
7.7	....	27,000	....	....

a Discharges from April 28 to May 24 were interpolated.

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.		Depth in inches.	Second-feet per square mile.
1897.						
April	4,525	2,675	3,695	219,867	0.30	0.27
May	2,875	1,750	2,496	153,473	0.21	0.18
June	4,880	1,520	2,498	148,641	0.20	0.18
July	27,000	670	3,490	214,593	0.30	0.26
August	5,870	1,000	2,311	142,099	0.20	0.17
September	2,780	1,160	1,837	109,309	0.16	0.14
October	23,800	1,510	4,401	270,609	0.36	0.33

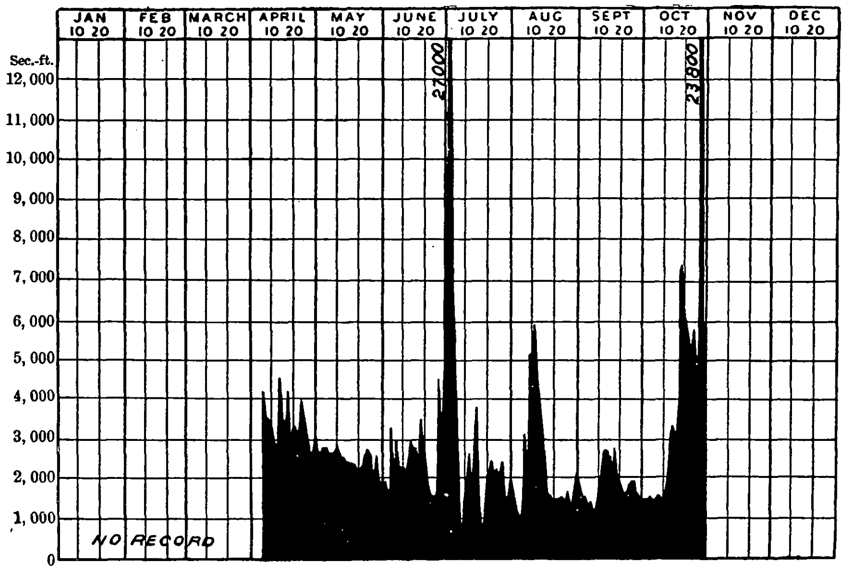


FIG. 105.—Discharge of Loup River at Columbus, Nebraska, 1897.

PLATTE RIVER.

One gaging station is maintained on the main Platte River at Columbus, described in Water-Supply and Irrigation Paper No. 15, p. 98. It is a short distance above the mouth of Middle Loup River.

Rating table for Platte River at Columbus, Nebraska, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.5	1,400	3.3	4,500	4.0	9,200	4.7	18,000
2.6	1,676	3.4	5,000	4.1	10,300	4.8	19,700
2.7	1,984	3.5	5,500	4.2	11,300	4.9	21,600
2.8	2,324	3.6	6,050	4.3	12,300	5.0	23,700
2.9	2,696	3.7	6,700	4.4	13,450	5.1	26,000
3.0	3,100	3.8	7,400	4.5	14,800	5.2	28,400
3.1	3,500	3.9	8,200	4.6	16,400	5.3	31,000
3.2	4,000						

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.		Depth in inches.	Second-feet per square mile.
1897.						
May	21,600	6,700	11,801	725,620	0.24	0.21
June	31,000	8,700	16,904	1,005,856	0.33	0.30
July	8,200	990	2,771	170,383	0.06	0.05

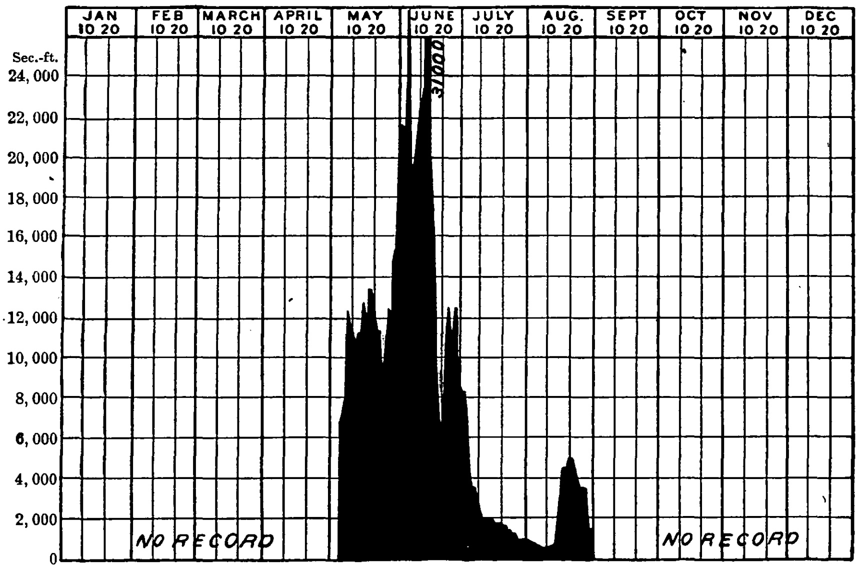


FIG. 106.—Discharge of Platte River at Columbus, Nebraska, 1897.

ELKHORN RIVER.

Elkhorn River drains an area in northeastern Nebraska adjoining the basins of Niobrara and Loup rivers. This river is the last important tributary of the Platte before the latter stream enters Missouri River.

A gaging station is located about 2 miles south of Norfolk, Nebraska, and above the mouth of the North Fork. The results of the field work at this station are given in Water-Supply and Irrigation Paper No. 15, p. 99.

Four measurements of the North Fork near Norfolk were made, as follows: March 24, discharge 701 second-feet; May 6, discharge 166 second-feet; May 24, discharge 77 second-feet; July 30, discharge 70 second-feet.

Rating table for Elkhorn River at Norfolk, Nebraska, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.5	115	1.0	256	1.5	435	2.0	660
0.6	140	1.1	289	1.6	477	2.1	740
0.7	166	1.2	323	1.7	519	2.2	820
0.8	194	1.3	359	1.8	562	2.3	915
0.9	224	1.4	396	1.9	607	2.4	1,010

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.		Depth in inches.	Second-feet per square mile.
1897.						
January			*a* 1,000	61,488	0.46	0.40
February			*a* 900	49,983	0.37	0.36
March			*a* 800	49,190	0.37	0.32
May	1,020	320	539	33,142	0.25	0.22
June	370	255	302	17,970	0.14	0.12
July	380	180	244	15,003	0.12	0.10
August	275	150	206	12,667	0.09	0.08
September	190	115	158	9,402	0.07	0.06
October	295	140	209	12,851	0.09	0.08
November			*a* 200	11,901	0.09	0.08
December			*a* 200	12,298	0.09	0.08

a Approximate.

List of miscellaneous discharge measurements, Platte Basin.

Date.	Stream.	Locality.	Meter number.	Area of section.	Mean velocity.	Discharge.
				Sq. feet.	*Feet per second.*	*Sec.-feet.*
Feb. 5	Salt Creek	Lincoln, Nebraska	105			38
Mar. 28	Blue Creek	NE. ¼ sec. 30, T. 16 N., R. 42 W.	Float	37	3.15	115
May 14	South Platte River	North Platte, Nebraska	Price	1,141	1.71	1,949
May 28	Middle Loup River	Boelus, Nebraska	Price	383	2.17	837
Do	South Loup River	St. Michael, Nebraska	Price	147	1.48	220
June 14	South Platte River	North Platte, Nebraska	1	1,141	1.71	1,949
June 21	do	do	1	1,792	2.47	4,427
June 23	Elkhorn River	O'Neill, Nebraska	Price	19	1.08	21
July 24	North Loup River	T. P. John's ranch, mouth of Waumeduzu Creek.	Price	69	1.88	130
Aug. 13	South Platte River	North Platte, Nebraska	Price	1,348	2.13	2,880

EVAPORATION AND SEEPAGE NEAR KEARNEY, NEBRASKA.

Observations of evaporation were made, under the direction of Prof. O. V. P. Stout, on a small pond on the grounds of the Nebraska State Industrial School at Kearney by Maj. H. C. McArthur. A hook gage was placed August 12, 1895, fastened vertically and reading to one-hundredths of an inch. This pond is 320 feet long in a north and south direction and about 90 feet wide east and west. When full the depth is nearly 7 feet, and is usually from 5 to 5.5 feet. The water supply, with the exception of that which falls in the form of rain and snow upon the surface of the pond and the inner slopes of the embankment, is under complete control, being admitted from the Kearney Canal through a cast-iron pipe with a gate valve. The results of the work in 1895 will be found in Bulletin No. 140, p. 349. The results for 1896 are given below; in 1897 readings were taken only through October, November, and December.

Daily mean evaporation and seepage, near Kearney, Nebraska, for 1896.

Day.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1	......	1.06	(*a*)	1.60	......	(*a*)	1.17	2.55
2	......	1.10	......	1.33	3.25	(*b*)	1.16	2.15
3	......	0.91	2.10	1.21	2.90	......	1.17	1.95
4	......	1.13	1.90	1.00	2.40	2.69	(*a*)	1.80
5	......	(*c*)	1.55	1.00	(*b*)	2.36	(*a*)	1.65
6	......	1.11	1.40	(*b*)	1.88	2.03	2.59	1.25
7	......	1.12	0.70	1.10	1.67	1.75	2.10	1.25
8	......	1.11	0.83	1.05	1.70	1.56	2.08	1.11
9	......	1.09	0.78	(*b*)	1.52	1.81	1.93	0.93
10	......	(*a*)	0.94	0.80	1.51	(*b*)	1.63	0.94
11	......	(*a*)	(*b*)	0.98	1.57	......	1.42	0.92
12	......	(*a*)	0.86	0.90	1.31	1.79	1.35	0.90
13	......	2.73	1.12	0.99	(*a*)	1.69	1.28	0.90
14	......	2.68	1.08	1.03	......	(*b*)	1.27	0.80
15	......	(*b*)	1.14	1.04	2.37	......	1.23	(*a*)
16	......	(*b*)	0.98	(*a*)	2.29	3.04	1.20	......
17	......	1.38	0.92	(*a*)	(*b*)	3.02	1.19	*d*1.61
18	......	1.97	1.04	......	......	(*b*)	(*a*)	*d*1.64
19	0.95	(*b*)	1.06	3.05	3.28	......	1.65	*d*1.58
20	1.70	1.31	1.10	1.93	2.72	1.88	1.57	1.35
21	1.40	0.98	1.00	2.82	(*b*)	1.80	(*a*)	1.20
22	1.25	0.62	1.05	2.65	(*b*)	1.75	(*a*)	1.10
23	1.25	0.97	(*b*)	(*b*)	......	1.67	1.43	1.00
24	1.22	0.85	0.76	(*b*)	2.95	1.60	1.35	0.90

a Pond full. *b* Rain. *c* Gage moved. *d* Ice in pond.

Daily mean evaporation and seepage, near Kearney, Nebraska, for 1896—Continued.

Day.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
25	1.27	1.09	(*a*)	....	2.80	1.55	1.40	0.85
26	1.17	1.10	(*a*)	3.72	2.28	(*b*)	1.08	(*c*)
27	1.25	1.15	....	(*b*)	2.08	1.38	1.05	(*c*)
28	(*b*)	1.12	1.85	....	1.74	1.16	1.02	(*c*)
29	1.25	1.11	(*b*)	3.65	1.63	1.19	(*b*)	(*c*)
30	1.03	1.05	(*b*)	3.05	3.39	1.18	(*b*)	(*c*)
31	....	(*a*)	....	(*b*)	(*a*)	....	(*b*)	....
Mean	1.25	1.25	1.15	1.75	2.25	1.85	1.45	1.32
Total, estimated	*d*15.00	38.75	34.50	54.25	69.75	55.50	44.95	39.60

a Pond full. *b* Rain. *c* Frozen. *d* April 19 to 30.

Estimated monthly evaporation and seepage near Kearney, Nebraska.

Month.	Inches per 24 hours.			Total inches.
	Maximum.	Minimum.	Mean.	
1896.				
April 19 to 30	1.70	0.95	1.25	15.00
May	2.73	0.62	1.25	38.75
June	2.10	0.70	1.15	34.50
July	3.72	0.80	1.75	54.25
August	3.39	1.31	2.25	69.75
September	3.04	1.16	1.85	55.50
October	2.59	1.02	1.45	44.95
November	2.55	0.80	1.32	39.60

KANSAS BASIN.

The basin of Kansas River is located between that of the Platte on the north and the Arkansas on the south. It differs from these two watersheds in that it is wholly a plains basin and none of the tributaries drain mountainous areas. It is also different from the ordinary river system in that rainfall is least at its head, averaging about 10 inches in eastern Colorado and then gradually increasing toward the east, where the average is about 40 inches. The head-water streams rise in an arid country, passing through what is known as the subhumid region, and then below the course of the main stream is in the humid belt. The larger tributaries of Kansas River carry considerable water, but they are not utilized for irrigation to any great extent.

Kansas River proper is formed by the junction of Republican and Smoky Hill rivers at Junction City, Kansas; these two rivers drain at their mouths 25,837 and 20,428 square miles, respectively.

REPUBLICAN RIVER.

On Republican River two gaging stations have been maintained—one at Superior, Nebraska, and the other at Junction City, Kansas. They are described in Water-Supply and Irrigation Paper No. 16, pp. 107 and 109, respectively. The results of the work at Superior, the upper station, are not so satisfactory as they might be on account of the occurrence of a milldam directly below the gage and to the fact that the water when running in the mill race is not included in the measurements. The error is greatest at low water when the discharge of the canal is a larger percentage of the flow of the river than during high water. Also at extreme low stages the storage in the mill pond is drawn upon and no water then passes over the crest of the dam. The data in the accompanying tables show the amount of water passing over the crest of the dam. It is reported that the water was used by the mill at a nearly constant rate, about 85 second-feet. This amount, therefore, should be added to the figures in the tables. The conditions prevailing at this gaging station are more fully described in the Eighteenth Annual Report, Part IV, p. 201. The area drained at this point is 22,347 square miles.

The Junction City station is located at the mouth of the river where it joins Smoky Hill River. The figures show the total run-off for the basin.

Rating table for Republican River at Superior, Nebraska, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.0	60	0.5	341	1.0	880	1.5	2,360
0.1	101	0.6	420	1.1	1,130	1.6	2,660
0.2	150	0.7	506	1.2	1,460	1.7	2,960
0.3	206	0.8	600	1.3	1,760		
0.4	270	0.9	710	1.4	2,060		

Estimated monthly discharge of Republican River at Superior, Nebraska.

[Drainage area, 22,347 square miles.]

Month.	Discharge in second-feet. *a*			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	900	555	710	43,655	0.037	0.032
February	1,520	420	906	50,316	0.043	0.041
March	650	385	510	31,359	0.026	0.023
April	2,870	620	1,244	74,023	0.062	0.056
May	1,130	180	420	25,825	0.022	0.019
June 1–25	750	180	359	17,802	0.018	0.016
July	4,310	119	922	56,690	0.047	0.041
August	1,460	94	259	15,924	0.014	0.012
September	241	0	71	4,225	0.003	0.003

a Discharges represent amount going over dam only; the mill race carries on an average 85 second-feet.

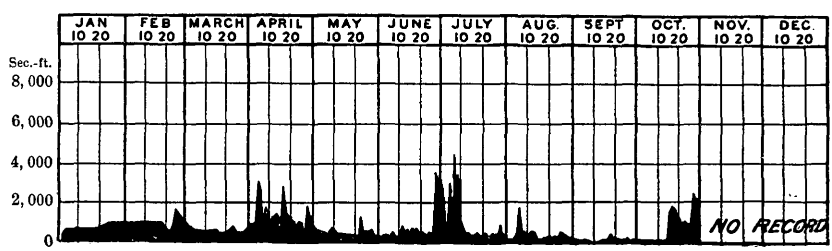


FIG. 107.—Discharge of Republican River at Superior, Nebraska, 1897.

Rating table for Republican River at Junction City, Kansas, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.1	85	3.2	515	4.3	1,240	5.8	2,975
2.2	102	3.3	560	4.4	1,325	6.0	3,300
2.3	125	3.4	625	4.5	1,415	6.2	3,600
2.4	154	3.5	690	4.6	1,505	6.4	3,925
2.5	210	3.6	750	4.7	1,605	6.6	4,280
2.6	254	3.7	810	4.8	1,710	6.8	4,700
2.7	290	3.8	870	4.9	1,820	7.0	5,140
2.8	325	3.9	930	5.0	1,925	7.2	5,580
2.9	365	4.0	1,000	5.2	2,150	7.4	6,053
3.0	415	4.1	1,080	5.4	2,420		
3.1	465	4.2	1,160	5.6	2,675		

Estimated monthly discharge of Republican River at Junction City, Kansas.

[Drainage area, 25,837 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	1,160	560	740	45,507	0.033	0.029
February	3,055	625	1,343	74,563	0.054	0.052
March	1,160	750	898	55,228	0.040	0.035
April	8,250	1,000	2,032	120,895	0.087	0.078
May	2,550	325	833	51,213	0.037	0.032
June	6,053	290	1,592	94,713	0.068	0.062
July	6,360	440	1,824	112,147	0.082	0.071
August	2,210	254	619	38,042	0.028	0.024
September	537	125	204	12,156	0.009	0.008
October	415	85	205	12,605	0.009	0.008
November	1,120	290	632	37,577	0.027	0.024
December	930	290	668	41,070	0.030	0.026
The year	6,360	85	966	695,716	0.504	0.037

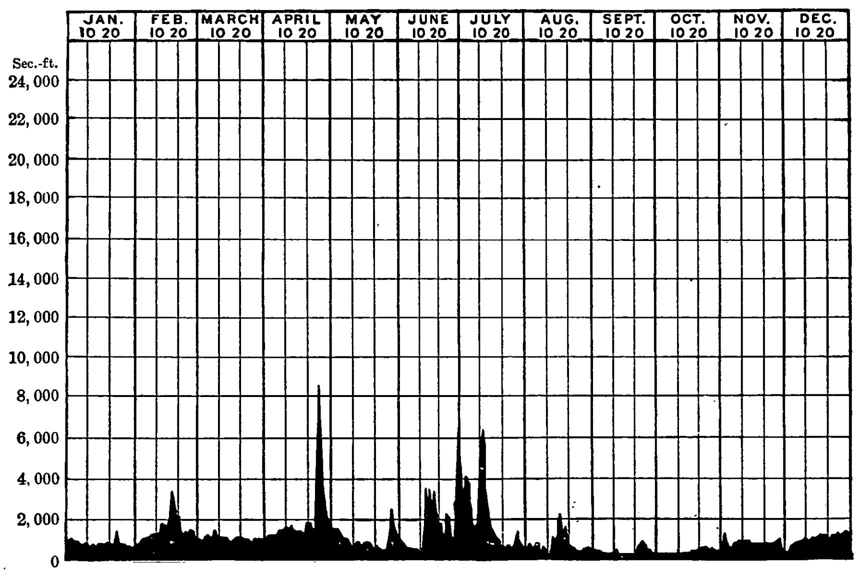


FIG. 108.—Discharge of Republican River at Junction City, Kansas, 1897.

SOLOMON RIVER.

The principal tributaries of Smoky Hill River are Solomon and Saline rivers. Gaging stations have been maintained on each of these streams. On the former the old station at Beloit, described in Water-Supply and Irrigation Paper No. 16, p. 110, was discontinued June 30, 1897, because of its poor section. Another station has been established, however, lower down the river at Niles, near the mouth, May 6, 1897, and from that date the record is continuous. This station is described in Water-Supply and Irrigation Paper No. 16, p. 111.

Rating table for Solomon River at Beloit, Kansas, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.4	16	3.8	350	5.2	975	6.6	1,740
2.6	20	4.0	425	5.4	1,075	6.8	1,865
2.8	25	4.2	508	5.6	1,180	7.0	1,990
3.0	75	4.4	590	5.8	1,295	7.2	2,125
3.2	150	4.6	680	6.0	1,400	7.4	2,265
3.4	210	4.8	775	6.2	1,515	7.6	2,415
3.6	275	5.0	875	6.4	1,625	7.8	2,565

Estimated monthly discharge of Solomon River at Beloit, Kansas.

[Drainage area, 5,539 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	225	16	130	8,024	0.027	0.023
February	387	20	193	10,724	0.036	0.035
March	312	92	227	13,933	0.047	0.041
April	7,470	180	663	39,463	0.133	0.120
May	368	18	150	9,254	0.031	0.027
June	6,400	19	1,377	81,913	0.278	0.249

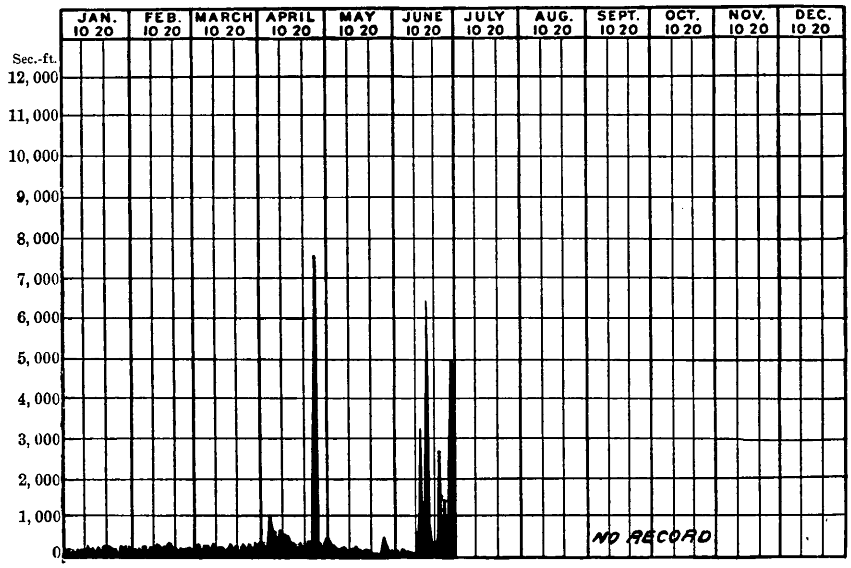


FIG. 109.—Discharge of Solomon River at Beloit, Kansas, 1897.

Rating table for Solomon River at Niles, Kansas, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
4.2	60	6.8	380	9.4	974	15.0	2,450
4.4	65	7.0	412	9.6	1,000	15.5	2,610
4.6	86	7.2	447	9.8	1,040	16.0	2,775
4.8	103	7.4	482	10.0	1,080	16.5	2,960
5.0	124	7.6	518	10.5	1,200	17.0	3,145
5.2	148	7.8	560	11.0	1,325	17.5	3,358
5.4	174	8.0	600	11.5	1,455	18.0	3,575
5.6	200	8.2	642	12.0	1,585	18.5	3,795
5.8	230	8.4	696	12.5	1,725	19.0	4,030
6.0	260	8.6	750	13.0	1,850	19.5	4,257
6.2	290	8.8	800	13.5	2,000	20.0	4,500
6.4	320	9.0	853	14.0	2,150	20.5	4,757
6.6	350	9.2	913	14.5	2,300		

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.		Depth in inches.	Second-feet per square mile.
1897.						
May	669	161	267	16,411	0.045	0.039
June	4,500	103	1,083	64,433	0.177	0.159
July	5,380	215	838	51,551	0.142	0.123
August	320	108	193	11,892	0.033	0.028
September	200	65	106	6,319	0.017	0.016
October	142	62	97	5,976	0.016	0.014
November	154	86	114	6,784	0.019	0.017
December	161	60	100	6,124	0.017	0.015

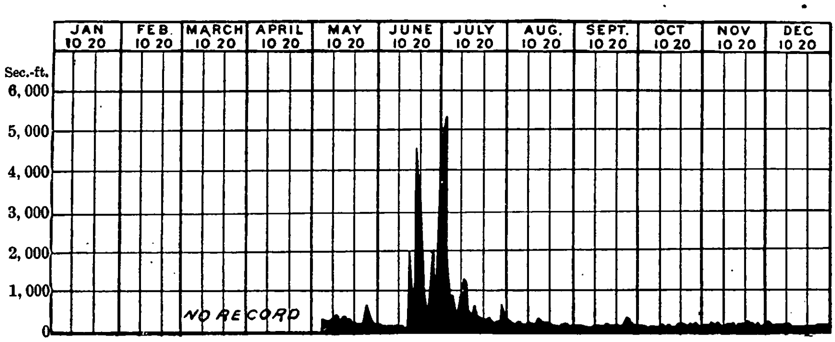


FIG. 110.—Discharge of Solomon River at Niles, Kansas, 1897.

SALINE RIVER.

The old gaging station at Beverly, on the Saline River, described in Water-Supply and Irrigation Paper No. 16, p. 112, was also discontinued June 30, 1897, on account of the poor section. A station at Salina was established May 4, 1897, just above the mouth of the river, which takes the place of the Beverly station. A description of this station will be found in Water-Supply and Irrigation Paper No. 16, p. 113.

Rating table for Saline River at Beverly, Kansas, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
3.7	12	4.5	45	5.3	138	6.2	250
3.8	14	4.6	53	5.4	150	6.4	276
3.9	17	4.7	67	5.5	162	6.6	302
4.0	20	4.8	79	5.6	174	6.8	326
4.1	23	4.9	90	5.7	186	7.0	350
4.2	27	5.0	102	5.8	198		
4.3	32	5.1	114	5.9	211		
4.4	38	5.2	126	6.0	224		

Estimated monthly discharge of Saline River at Beverly, Kansas.

[Drainage area, 2,730 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	108	17	48	2,927	0.020	0.017
February	243	27	73	4,054	0.027	0.026
March	67	32	46	2,835	0.019	0.017
April	626	49	192	11,424	0.078	0.070
May	357	53	146	8,953	0.061	0.053
June	*a*11,000	38	452	26,920	0.185	0.166

a Approximate.

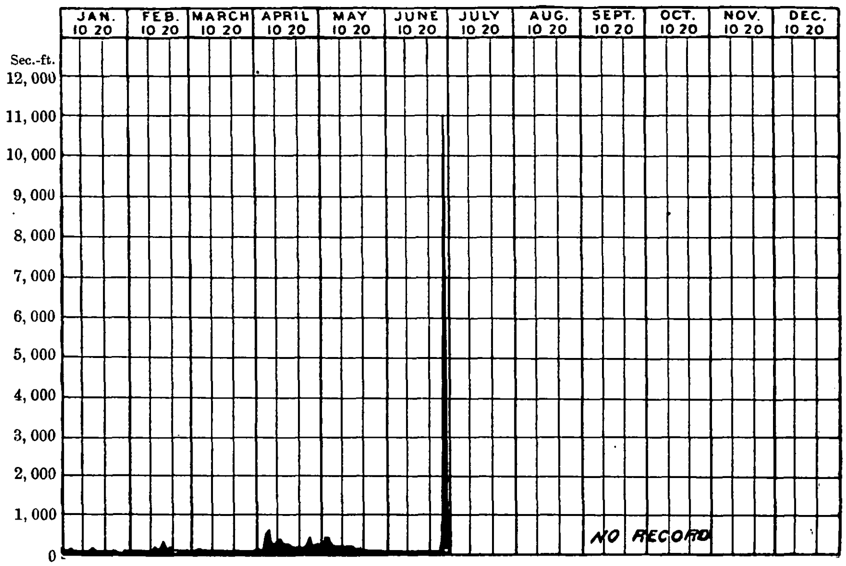


FIG. 111.—Discharge of Saline River at Beverly, Kansas, 1897.

Rating table for Saline River at Salina, Kansas, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.8	26	3.8	76	4.8	139	5.8	215
2.9	31	3.9	82	4.9	146	5.9	224
3.0	36	4.0	88	5.0	153	6.0	233
3.1	41	4.1	94	5.1	160	6.2	251
3.2	46	4.2	99	5.2	167	6.4	270
3.3	51	4.3	105	5.3	175	6.6	292
3.4	55	4.4	111	5.4	183	6.8	314
3.5	59	4.5	118	5.5	191	7.0	335
3.6	65	4.6	125	5.6	198		
3.7	70	4.7	132	5.7	206		

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.		Depth in inches.	Second-feet per square mile.
1897.						
May	335	79	147	9,039	0.051	0.044
June	a4,400	51	256	15,203	0.085	0.077
July	a685	36	83	5,104	0.028	0.025
August	381	28	74	4,532	0.025	0.022
September	57	20	30	1,803	0.010	0.009
October	70	16	32	1,955	0.011	0.010
November	48	26	38	2,279	0.013	0.012
December	46	28	41	2,521	0.014	0.012

a Approximate.

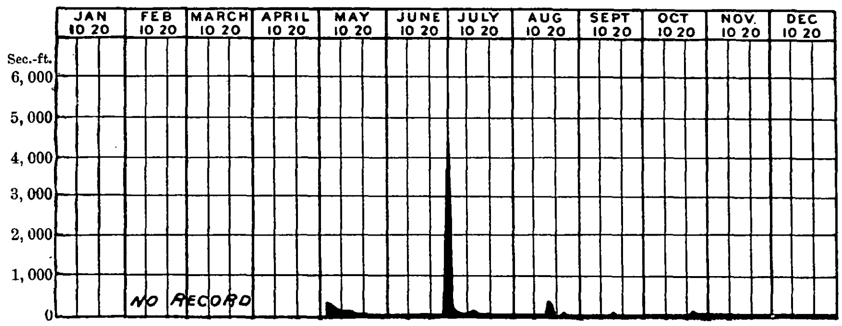


FIG. 112.—Discharge of Saline River at Salina, Kansas, 1897.

SMOKY HILL RIVER.

The only gaging station on Smoky Hill River itself is located at Ellsworth, Kansas, and observations were continued through 1897 at that point. The station is described in Water-Supply and Irrigation Paper No. 16, p. 114.

Rating table for Smoky Hill River at Ellsworth, Kansas, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.9	10	1.4	77	1.9	190	2.4	324
1.0	15	1.5	97	2.0	213	2.5	353
1.1	22	1.6	118	2.1	240	2.6	385
1.2	35	1.7	142	2.2	267		
1.3	58	1.8	164	2.3	295		

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

[Drainage area, 7,980 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	153	22	68	4, 198	0. 010	0. 008
February	213	35	122	6, 798	0. 016	0. 015
March	77	22	35	2, 164	0. 005	0. 004
April	385	35	158	9, 401	0. 022	0. 020
May	385	87	173	10, 624	0. 025	0. 022
June	240	35	87	5, 153	0. 012	0. 011
July	97	19	38	2, 336	0. 006	0. 005
August	295	15	95	5, 854	0. 014	0. 012
September	130	15	40	2, 386	0. 006	0. 005
October	97	10	32	1, 949	0. 005	0. 004
November	77	15	38	2, 285	0. 005	0. 005
December	107	19	38	2, 337	0. 006	0. 005
The year	385	10	77	55, 485	0. 132	0. 010

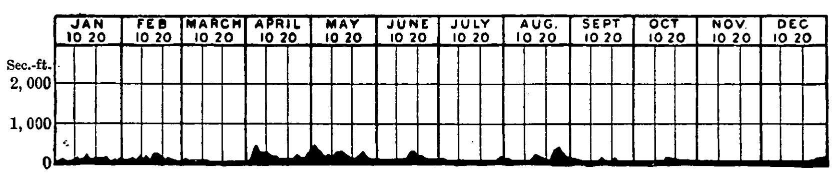


FIG. 113.—Discharge of Smoky Hill River at Ellsworth, Kansas, 1897.

BLUE RIVER.

This stream is one of the principal tributaries of Kansas River and drains part of southeastern Nebraska and northeastern Kansas. Its northern tributaries extend almost to Platte River. The drainage basin receives copious rainfall, and therefore the run-off from the basin is larger than from the watersheds of the more western tributaries of the main river. The gaging station, located at Manhattan, on this river, is described in Water-Supply and Irrigation Paper No. 16, p. 115.

Rating table for Blue River at Manhattan, Kansas, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.0	180	4.8	930	7.6	2,480	14.0	10,448
2.2	200	5.0	1,010	7.8	2,620	14.5	11,388
2.4	220	5.2	1,100	8.0	2,760	15.0	12,328
2.6	250	5.4	1,200	8.5	3,125	16.0	14,208
2.8	280	5.6	1,300	9.0	3,520	17.0	16,088
3.0	320	5.8	1,400	9.5	4,000	18.0	17,968
3.2	360	6.0	1,500	10.0	4,500	19.0	19,848
3.4	410	6.2	1,600	10.5	5,030	20.0	21,728
3.6	470	6.4	1,700	11.0	5,610	21.0	23,608
3.8	540	6.6	1,810	11.5	6,280	22.0	25,488
4.0	610	6.8	1,930	12.0	7,000	23.0	27,368
4.2	690	7.0	2,060	12.5	7,755	24.0	29,248
4.4	770	7.2	2,200	13.0	8,580	25.0	31,128
4.6	850	7.4	2,340	13.5	9,508	26.0	33,008

Estimated monthly discharge of Blue River at Manhattan, Kansas.

[Drainage area, 9,490 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	1,300	610	965	59,335	0.12	0.10
February	2,200	610	1,228	68,200	0.14	0.13
March	2,165	870	1,434	88,174	0.17	0.15
April	32,256	1,200	7,935	472,166	0.93	0.84
May	4,815	1,375	2,232	137,240	0.28	0.24
June	20,694	810	2,966	176,490	0.35	0.31
July	8,158	1,010	2,555	157,100	0.31	0.27
August	3,392	890	1,698	104,405	0.21	0.18
September	970	210	578	34,395	0.07	0.06
October	770	320	561	34,494	0.07	0.06
November	810	505	681	40,523	0.08	0.07
December	850	610	730	44,886	0.09	0.08
The year	32,256	210	1,964	1,417,408	2.82	0.21

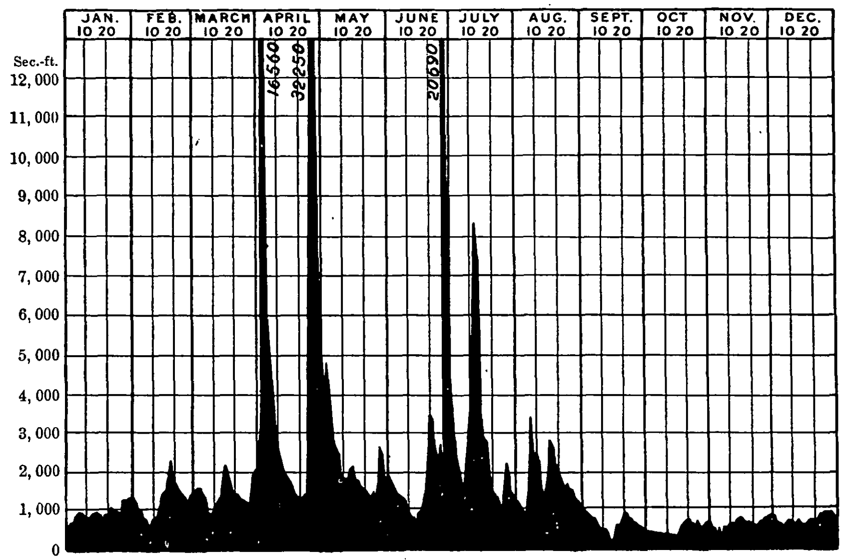


FIG. 114.—Discharge of Blue River at Manhattan, Kansas, 1897.

KANSAS RIVER.

A gaging station on the main Kansas River is located at Lawrence, Kansas, at which the measurements have been continued throughout the year, as shown in the accompanying tables. The field work here during 1897 will be found described in Water-Supply and Irrigation Paper No. 16, p. 116.

Rating table for Kansas River at Lawrence, Kansas, for 1897. (a)

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.0	787	—0.5	682	—1.0	632	—1.5	582
—0.1	737	—0.6	672	—1.1	622	—1.6	572
—0.2	712	—0.7	662	—1.2	612	—1.7	562
—0.3	702	—0.8	652	—1.3	602	—1.8	552
—0.4	692	—0.9	642	—1.4	592	—1.9	542

a For gage readings above zero use rating table for 1896, published in Eighteenth Annual Report, Part IV, p. 221.

Estimated monthly discharge of Kansas River at Lawrence, Kansas.

[Drainage area, 59,841 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	2,687	967	2,137	131,399	0.040	0.035
February	11,440	1,643	4,720	262,136	0.082	0.079
March	5,837	2,687	3,515	216,130	0.068	0.059
April	58,000	4,035	13,782	820,085	0.256	0.230
May	14,890	3,327	5,907	363,200	0.114	0.099
June	32,290	2,395	7,321	435,630	0.136	0.122
July	39,000	2,998	10,420	640,700	0.201	0.174
August	5,623	897	2,904	178,560	0.056	0.049
September	1,255	715	969	57,660	0.018	0.016
October	1,872	787	1,156	71,080	0.022	0,019
November	2,687	662	1,927	114,664	0.036	0.032
December	1,255	562	775	47,652	0.015	0.013
The year	58,000	562	4,628	3,338,896	1.044	0.077

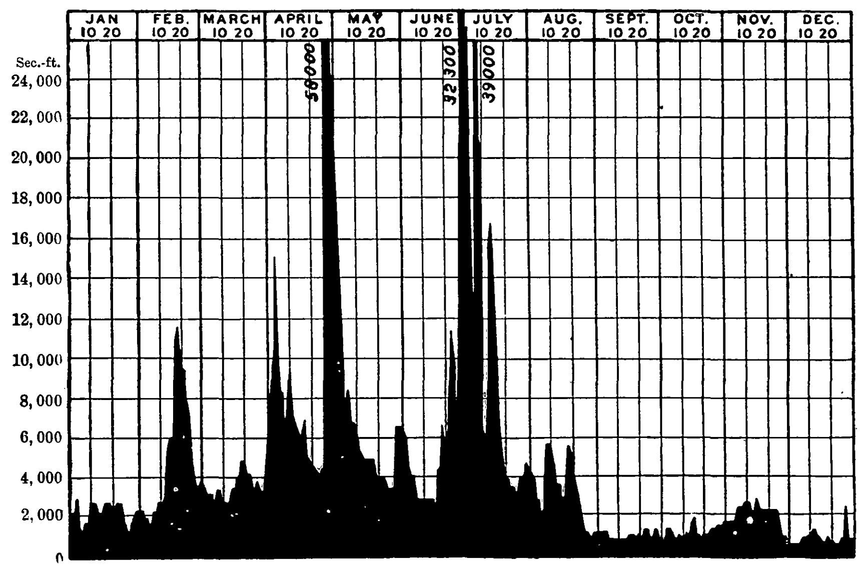


FIG. 115.—Discharge of Kansas River at Lawrence, Kansas, 1897.

List of miscellaneous discharge measurements, Kansas Basin.

Date.	Stream.	Locality.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
1897.				*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
Apr. 12	Mill Race	Superior, Nebraska.	Price..	....	57	1.03	59
Apr. 13	Republican River.	McCook, Nebraska.	...do ..	....	284	2.62	745
Apr. 14	Frenchman River.	Wauneta, Nebraska.	...do ..	2.31	37	3.43	128
May 19	.....do	.....do	...do ..	2.00	41	1.61	65
July 2	.....do	Palisade, Nebraska.	...do ..	....	65	0.95	63
Aug. 14	Saline River..	Russell, Kansas.	55	....	37	2.80	103

ARKANSAS BASIN.

ARKANSAS RIVER.

Arkansas River is a typical stream of the arid region, having a mountainous catchment area and traversing a high plain area adapted to irrigation and through which the river decreases gradually in discharge until, during the low season, it finally disappears altogether in places. It is an interesting basin to study on account of the many hydrographic problems that are presented. The mountainous section may be said to extend from the upper limit at Tennessee Pass down to the city of Canyon, where the river emerges from its canyon to enter upon the plains. The area drained above this point is 3,060 square miles. This section is in reality a long narrow valley located in the central part of Colorado, surrounded by high mountains rising from 12,000 to 14,000 feet in elevation. The river itself makes a descent from 10,000 feet at Leadville to 5,300 feet at Canyon in 120 miles. Its character in this division of its course is torrential. Farther eastward this grade is gradually lessened until finally the river wanders back and forth in long, sinuous curves. Little irrigation is practiced above Canyon, but at the mouth of the canyon several canals are taken out, and at short intervals down the river through Colorado other canals divert the flowing water. On account of the shortage of water in the river when it is most needed, recourse must be had in the near future to artificial storage. The mountainous drainage area offers many facilities for this purpose, a number of excellent reservoir sites having been found and reported by the topographers and engineers of the Geological Survey. On the upper tributaries of Arkansas River above Leadville a number of fine sites were found, but their development will not be necessary on account of the superior site at Twin Lakes. This reservoir site was surveyed in 1889, and the results were published in the Thirteenth Annual Report of the United States Geological Survey, Part III, p. 365. The elevation of the surface of the lower lake is 9,194 feet and of the upper lake 9,200 feet. The levels of the lakes do not vary more than 2 feet during the year. A dam placed at the lower outlet at a maximum height of 73 feet would impound 103,500 acre-feet. The drainage area is 102 square miles. The flow into the reservoir could be supplemented by a short canal, not more than 4 miles long, diverting water from Arkansas River at what is known as Hayden station, 6 miles above Granite; the area drained above this point is 285 square miles. Within the last year or so private parties have been considering this proposition.

The plains region east of the mountains is a large artesian basin, very thoroughly described by Mr. G. K. Gilbert.[1] The source of water supply is in a series of beds of Dakota sandstone, often separated by thin beds of shale, which underlie the region. The collecting area is where these sandstones appear at the surface or are covered by superficial sands. This area is in two portions. First, a line of hogbacks which are in a general parallel direction to the Rocky Mountains and extend from about Colorado Springs down to the canyon of Turkey Creek, thence eastward through Glendale to a point a little northeast of Canyon, where the ridge bends to the southeast, continues down nearly to Beulah, and from there to the Three R ranch. The second collecting area consists of a number of detached areas of Dakota sandstone in the outlying plain. The line of ridges known as the hogbacks are separated from the main ridge of the Rockies by a series of narrow valleys, sufficient, however, to cut off from the Dakota sandstone the drainage from the mountains, so that the rainfall on the area is the only water that these beds receive. The number of artesian wells sunk shows the existence of such a basin. Eastward from the source of supply these wells increase in depth. The contour of 1,000 feet depth is in the southwestern end of the city of Pueblo, and extends thence northeasterly. In the opposite direction the line continues southerly from Pueblo until it reaches St. Charles River, and then bears more to the southeast. In the Pueblo folio, above referred to, one of the sheets shows by shaded sections areas that will yield flowing wells, areas that will probably yield pumping wells, areas that will probably not yield water freely, and areas not containing artesian water. On the same map is shown by contour lines the depth from the surface down to water.

A number of gaging stations have been maintained on the river; the longest record is that at Canyon, dating from 1889. The upper

[1] Underground waters of the Arkansas Valley in eastern Colorado, by G. K. Gilbert: Seventeenth Ann. Rept. U. S. Geol. Survey, Part II, 1896, p. 551. Geologic Atlas U. S., folio 36, Pueblo, Colo., 1897.

station at which measurements were made during the last year was at Granite, immediately below the outlet of Twin Lakes. Observations of gage heights at this point, as well as at Salida, were maintained by the Denver and Rio Grande Railway Company at the request of this office. Canyon station is an important one, as it is located at the mouth of the canyon above most of the canals. In fact, only two canals are taken out above the station, and as they are easily accessible they can be measured whenever the station is visited. For the field work in 1897 at the stations Granite, Salida, and Canyon, reference may be made to Water-Supply and Irrigation Paper No. 16, pp. 117–119.

The next lower gaging station is located in the city of Pueblo, and results show the amount of water available for the canals below. A description of this station, list of discharge measurements, and table of gage heights are found in Water-Supply and Irrigation Paper No. 16, p. 120.

A short record was kept of the height of the river at Nepesta and at Rocky Ford. At the former station the record is from September 19 to October 16. A rating table has been made from the discharge measurements and published. Owing to the shortness of the gage record, the monthly averages are omitted. The station is described in Water-Supply and Irrigation Paper No. 16, p. 121.

At Rocky Ford the only discharge measurement was on September 29: gage height, 0.37 foot; discharge, 140 second-feet. The station is described in Water-Supply and Irrigation Paper No. 16, p. 122.

Rating table for Arkansas River at Granite, Colorado, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
3.0	114	3.9	615	4.8	1,233	5.7	1,852
3.1	154	4.0	683	4.9	1,302	5.8	1,920
3.2	198	4.1	752	5.0	1,370	5.9	1,989
3.3	244	4.2	820	5.1	1,438	6.0	2,058
3.4	294	4.3	889	5.2	1,507	6.1	2,127
3.5	350	4.4	957	5.3	1,576	6.2	2,196
3.6	412	4.5	1,026	5.4	1,645		
3.7	478	4.6	1,096	5.5	1,714		
3.8	546	4.7	1,164	5.6	1,783		

Estimated monthly discharge of Arkansas River at Granite, Colorado.

[Drainage area, 425 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
May	2,058	268	1,109	68,190	3.01	2.61
June	2,162	923	1,459	86,817	3.83	3.43
July	1,096	444	719	44,209	1.95	1.69
August	546	176	350	21,520	0.94	0.82
September	350	114	169	10,057	0.45	0.40
October	114	114	114	7,009	0.31	0.27
November	....	....	*a* 115	6,843	0.30	0.27
December	....	....	*a* 115	7,071	0.31	0.27

a Approximate.

Rating table for Arkansas River at Salida, Colorado, for 1897.

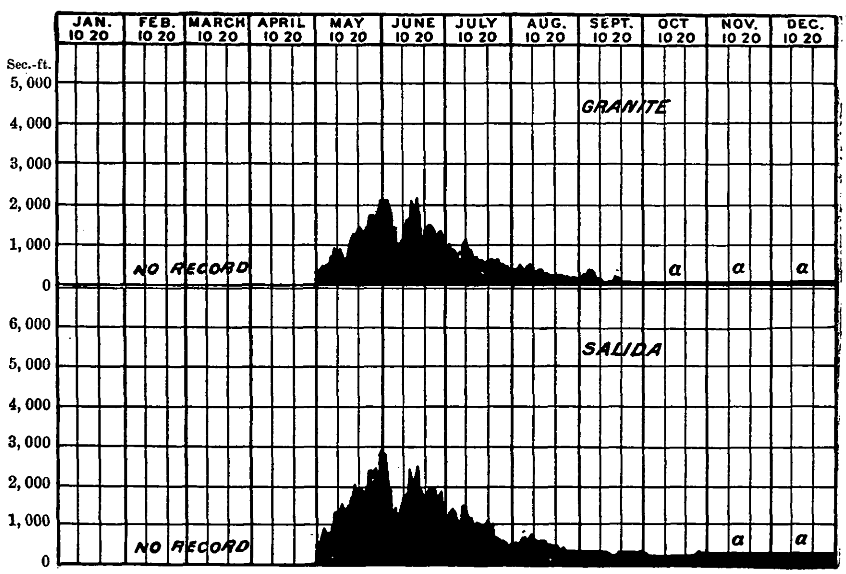
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.6	275	1.4	620	2.4	1,420	3.4	2,270
0.7	300	1.6	750	2.6	1,590	3.6	2,440
0.8	325	1.8	910	2.8	1,760	3.8	2,610
0.9	360	2.0	1,080	3.0	1,930	4.0	2,780
1.0	400	2.2	1,250	3.2	2,100	4.2	2,950
1.2	500						

Estimated monthly discharge of Arkansas River at Salida, Colorado.

[Drainage area, 1,160 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
May	2,907	500	1,646	101,210	1.64	1.42
June	2,865	1,165	1,839	109,430	1.77	1.59
July	1,462	530	985	60,565	0.98	0.85
August	715	400	518	31,850	0.52	0.45
September	425	360	397	23,625	0.38	0.34
October	342	287	289	17,770	0.29	0.25
November	....	....	a300	17,851	0.29	0.26
December	....	....	a300	18,446	0.30	0.26

a Approximate.



a Approximate.

FIG. 116.—Discharge of Arkansas River at Granite and Salida, Colorado, 1897.

Rating table for Arkansas River at Canyon, Colorado, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.0	210	3.0	620	4.0	1,628	5.0	2,768
2.2	265	3.2	790	4.2	1,856	5.2	2,996
2.4	335	3.4	980	4.4	2,084	5.4	3,224
2.6	410	3.6	1,180	4.6	2,312	5.6	3,452
2.8	500	3.8	1,400	4.8	2,540		

Estimated monthly discharge of Arkansas River at Canyon, Colorado.

[Drainage area, 3,060 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square inch.
1897.						
January			*a* 380	23, 365	0. 14	0. 12
February			*a* 380	21, 105	0. 12	0. 12
March			*a* 380	23, 365	0. 14	0. 12
April	530	230	320	19, 041	0. 11	0. 10
May	3, 281	500	1, 741	107, 050	0. 66	0. 57
June	3, 395	1, 628	2, 464	146, 618	0. 90	0. 81
July	1, 799	500	1, 115	68, 560	0. 41	0. 36
August	1, 180	335	553	34, 002	0. 21	0. 18
September	410	335	366	21, 778	0. 13	0. 12
October	620	370	471	28, 960	0. 17	0. 15
November	620	370	519	30, 883	0. 19	0. 17
December			*a* 400	24, 595	0. 15	0. 13
The year			757	549, 322	3. 33	0. 25

a Approximate.

Rating table for Arkansas River at Pueblo, Colorado, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0. 0	146	0. 7	580	1. 8	1, 506	3. 2	3, 330
0. 1	180	0. 8	654	2. 0	1, 728	3. 4	3, 610
0. 2	230	0. 9	730	2. 2	1, 970	3. 6	3, 890
0. 3	295	1. 0	806	2. 4	2, 218	3. 8	4, 170
0. 4	365	1. 2	964	2. 6	2, 490		
0. 5	436	1. 4	1, 126	2. 8	2, 770		
0. 6	508	1. 6	1, 309	3. 0	3, 050		

Estimated monthly discharge of Arkansas River at Pueblo, Colorado.

[Drainage area, 4,600 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	544	230	328	20,168	0.08	0.07
February	544	202	335	18,605	0.07	0.07
March	365	146	213	13,096	0.06	0.05
April	616	146	241	14,341	0.06	0.05
May	3,470	580	1,674	102,930	0.41	0.36
June	3,750	1,216	2,213	131,683	0.54	0.48
July	1,848	472	1,041	64,010	0.26	0.23
August	1,170	180	467	28,715	0.12	0.10
September	436	146	272	16,185	0.07	0.06
October	580	230	413	25,395	0.10	0.09
November	580	365	484	28,800	0.12	0.10
December	436	230	356	21,890	0.09	0.08
The year	3,750	146	670	485,818	1.98	0.14

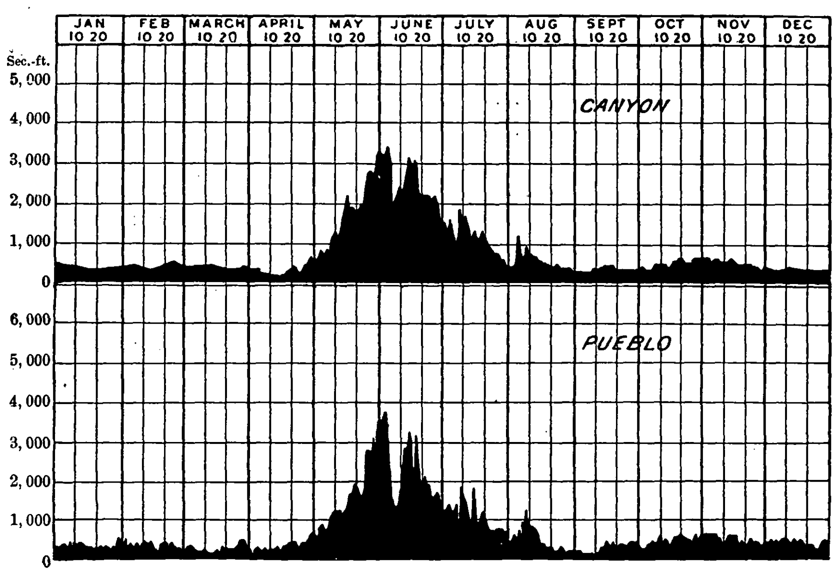


FIG. 117.—Discharge of Arkansas River at Canyon and Pueblo, Colorado, 1897.

Rating table for Arkansas River at Nepesta, Colorado, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.5	20	1.8	102	2.1	200	2.3	266
1.6	40	1.9	134	2.2	233	2.4	299
1.7	69	2.0	167				

PURGATORY RIVER.

Trinidad gaging station is located on Purgatory River, a tributary of Arkansas River, which enters at Las Animas. This station is described in Water-Supply and Irrigation Paper No. 16, p. 123. A station is maintained on the lower Arkansas River at Hutchinson, Kansas, described in Water-Supply and Irrigation Paper No. 16, p. 124.

Rating table for Purgatory River at Trinidad, Colorado.

Gage height.	Discharge.			Gage height.	Discharge.		
	1896—May 1 to July 23.	1896—July 24 to Nov. 30.	1897.		1896—May 1 to July 23.	1896—July 24 to Nov. 30.	1897.
Feet.	*Sec.-feet.*	*Second-feet.*	*Second-feet.*	*Feet.*	*Sec.-feet.*	*Second-feet.*	*Second-feet.*
2.7	0	....	....	3.9	780	189	189
2.8	15	....	....	4.0	....	273	273
2.9	30	....	....	4.1	....	386	386
3.0	45	....	....	4.2	....	554	554
3.1	60	....	....	4.3	....	799	799
3.2	75	....	....	4.4	....	1,044	1,044
3.3	95	....	10	4.5	....	1,289	1,289
3.4	130	....	15	4.6	....	....	1,534
3.5	200	0	30	4.7	....	....	1,779
3.6	300	25	54	4.8	....	....	2,023
3.7	420	60	85	5.0	....	2,513	....
3.8	600	120	127				

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.		Depth in inches.	Second-feet per square mile.
1896.						
May	113	45	67	4,120	0.10	0.09
June	780	0	60	3,570	0.09	0.08
July	4,600	8	342	21,029	0.53	0.46
August	1,657	0	76	4,673	0.12	0.10
September	554	0	73	4,344	0.11	0.10
October	189	18	71	4,366	0.12	0.10
November	60	25	35	2,083	0.06	0.05
December			*a* 40	2,460	0.06	0.05
1897.						
January			*a* 40	2,459	0.06	0.05
February			*a* 50	2,777	0.07	0.07
March			*a* 50	3,074	0.08	0.07
April	327	68	165	9,818	0.24	0.22
May	1,412	327	731	44,947	1.14	0.99
June	1,534	189	403	23,980	0.60	0.54
July	1,657	30	250	15,372	0.39	0.34
August	2,023	10	282	17,339	0.44	0.38
September	386	30	97	5,772	0.14	0.13
October	104	54	60	3,689	0.09	0.08
November	54	30	42	2,499	0.07	0.06
December			*a* 35	2,152	0.06	0.05
The year			184	133,878	3.38	0.25

a Approximate.

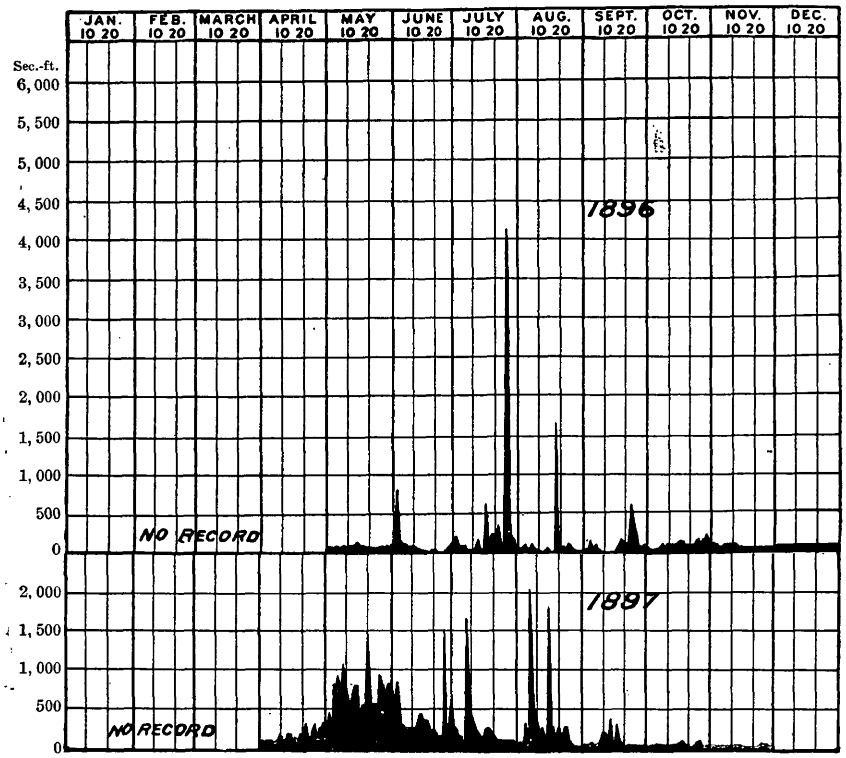


FIG. 118.—Discharge of Purgatory River at Trinidad, Colorado, 1896 and 1897.

ARKANSAS RIVER IN KANSAS.

Rating table for Arkansas River at Hutchinson, Kansas, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.1	4	1.5	52	1.9	177	2.3	505
1.2	11	1.6	73	2.0	225	2.4	700
1.3	22	1.7	103	2.1	300	2.5	1,000
1.4	35	1.8	136	2.2	390		

Estimated monthly discharge of Arkansas River at Hutchinson, Kansas.

[Drainage area, 34,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	201	73	130	7,994	0.004	0.004
February	2,270	73	506	28,085	0.016	0.015
March	505	103	221	13,607	0.008	0.006
April	390	103	235	14,001	0.008	0.007
May	700	73	244	14,978	0.008	0.007
June	505	62	280	16,661	0.009	0.008
July	201	4	51	3,160	0.002	0.002
August	1,400	0	294	18,078	0.010	0.009
September	225	4	60	3,594	0.002	0.002
October	43	0	15	910	0.001	0.000
November	35	11	19	1,154	0.001	0.001
December	103	35	44	2,723	0.001	0.001
The year	2,270	0	175	124,945	0.070	0.005

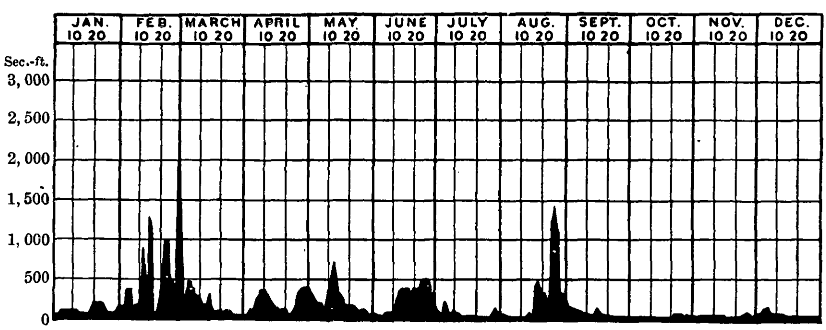


FIG. 119.—Discharge of Arkansas River at Hutchinson, Kansas, 1897.

NEOSHO RIVER.

Neosho River drains a long, narrow strip in southeastern Kansas, extending down into Indian Territory. The upper part of the basin has a general east and west direction, draining an area immediately north of the tributaries of Verdigris River and south of Kansas River. The general direction of the basin bends gradually southward between Emporia and Iola; that direction is maintained the rest of the course. The mouths of Neosho and Verdigris rivers, where they empty into the Arkansas in Indian Territory, are only about half a mile apart. The gaging station is located at Iola and is described in Water-Supply and Irrigation Paper No. 16, p. 126.

Rating table for Neosho River at Iola, Kansas, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.8	1	3.4	745	5.2	2,800	11.0	17,350
1.9	25	3.6	920	5.4	3,100	12.0	20,450
2.0	50	3.8	1,115	5.6	3,400	13.0	23,550
2.2	105	4.0	1,330	5.8	3,710	14.0	26,650
2.4	170	4.2	1,565	6.0	4,150	15.0	29,750
2.6	245	4.4	1,715	7.0	6,200	16.0	32,850
2.8	340	4.6	1,980	8.0	8,500	17.0	35,950
3.0	455	4.8	2,250	9.0	11,200	18.0	39,050
3.2	590	5.0	2,520	10.0	14,250	19.0	42,150

Estimated monthly discharge of Neosho River at Iola, Kansas.

[Drainage area, 3,670 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	920	105	531	32,650	0.167	0.145
February	3,970	395	1,689	93,802	0.479	0.460
March	4,840	340	960	59,030	0.302	0.262
April	2,183	395	894	53,197	0.272	0.244
May	665	170	379	23,305	0.119	0.103
June	1,445	75	363	21,600	0.110	0.099
July	422	87	163	10,023	0.051	0.044
August	87	50	72	4,427	0.023	0.020
September	62	1	9	536	0.002	0.002
October	1	0	1	62	0.000	0.000
November	1	1	1	60	0.000	0.000
December	1	1	1	62	0.000	0.000
The year	4,840	0	422	298,754	1.525	0.115

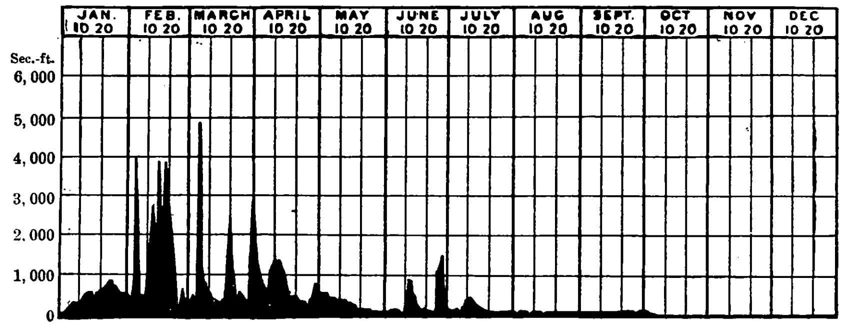


FIG. 120.—Discharge of Neosho River at Iola, Kansas, 1897.

VERDIGRIS RIVER.

The following description of the basin of Verdigris River has been compiled from data furnished by Prof. E. C. Murphy.

The Verdigris River, as shown in fig. 121, rises in the southeastern corner of Chase County, Kansas, and flows in a southerly direction through Kansas and part of Indian Territory, emptying into Arkansas River. Its length, as found by measurement on the best available maps, is 290 miles. It falls from an elevation of 1,400 feet at its head to 700 feet at a point about 11 miles north of the Kansas and Indian Territory line, in a distance of 141 miles. From here to the mouth, a distance of 148 miles, it falls about 100 feet. Throughout its length the river flows in a well-defined channel, and the banks are from 20 to 40 feet high. The width at the ordinary stage of water at the State line is 140 feet and at the mouth 250 feet. It is essentially a surface run-off stream; its water is muddy, the flood flow large, the summer flow small, and the fluctuations in height rapid.

The principal tributaries of Verdigris River are Fall River, Elk River, Caney River, and Bird Creek. These all enter the river from the west and take a southeasterly direction. The first three rise in the Flint Hills, Butler County, Kansas, and the last in Indian Territory. Caney River, the largest of the four, drains an area of 2,440 square miles, has a length of 140 miles, and falls from an elevation of 1,500 feet at its head to 750 feet near the State line, a distance of 48 miles. Fall River is 96 miles long and has a fall from 1,500 feet to 750 feet in 43 miles. It drains an area of 875 square miles. Its water is less muddy and its flow more steady than that of Verdigris River. The width near the mouth at ordinary low water is 75 feet. Elk River drains an area of 687 square miles. Its length is 70 miles, and its width near the mouth at ordinary low water is 75 feet. It falls from 1,500 feet to 750 feet in 43 miles. It is less steady in its discharge than Fall River, resembling the main stream in this respect. Bird Creek has a length of 85 miles and drains an area of 1,340 square miles.

The watershed of the Verdigris has an area of 8,610 square miles. Its total length is 180 miles, and its greatest width 72 miles. The

Flint Hills, in the highest (the northwestern) part of its boundary, have an elevation of something over 1,600 feet. The northern boundary varies in height from 1,200 to 1,400 feet. The eastern boundary falls from 1,400 to 650 feet,' and the western from 1,600 to 650 feet, decreasing toward the south. The upper part is comparatively rough,

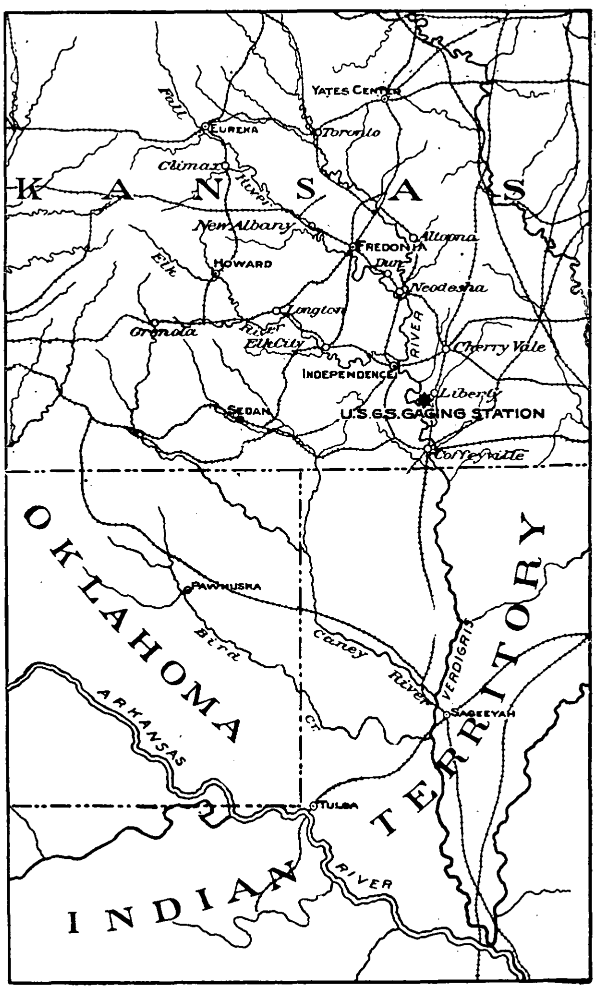


FIG. 121.—Map of drainage basin of Verdigris River.

the general fall toward the river is 25 feet to the mile, and the land is used for grazing purposes. The rest of the basin contains some of the best farming land in the Mississippi Valley. In some parts the general surface is broken by mounds having an elevation of 100 to 250 feet above the general level. Such is Table Mound, 6 miles northwest of Independence, and the mounds near Fredonia and Cherryvale, in Kansas, and near Sageeyah, Indian Territory.

The following table gives the distance in miles between 50-foot contours along Verdigris, Fall, and Elk rivers:

Distance betweeen 50-foot contours along Verdigris, Fall, and Elk rivers.

Elevation.	Verdigris River.	Fall River.	Elk River.
Feet.	*Miles.*	*Miles.*	*Miles.*
1,300 to 1,250	3	2	1
1,250 to 1,200	2	2	2
1,200 to 1,150	7	3	2
1,150 to 1,100	4	3	4
1,100 to 1,050	3	3	3
1,050 to 1,000	7	6	3
1,000 to 950	6	13	4
950 to 900	12	22	6
900 to 850	30	19	6
850 to 800	32	16	16
800 to 750	8	....	12
750 to 700	26	....	....
700 to 600	148	....	....

Fall River is subject to more rapid rise than the Verdigris. Mr. F. E. Morgan, a miller living near Fall River, reports that on one evening in September, 1895, probably September 8, there was scarcely enough water to run his mill. Early in the morning he was awakened by the noise of the water and found that the river had risen 20 feet in five or six hours. During the same flood the river at Neodesha was 25 feet higher than when the measurement on July 22 was made (see p. 369). A dam on this river, near Fredonia, Kansas, is shown in Pl. XXXVII, *B*. Elk River is also subject to sudden and extreme fluctuation in height.

The mean annual rainfall over this area varies along the eastern border from 35 inches in the northern part to about 44 inches in the middle, in Montgomery County, Kansas, and then decreases to 36 inches at the southern end. Along the western border it is about 33 inches. The greatest variation is in the central part, where there is a decrease from 44 inches on the eastern border to 33 inches on the western. The monthly rainfall at six places in or near this watershed since August, 1895, when a gaging station on the river was established, is given in the following table. The greatest monthly precipitation is seen to be 12.5 inches, at Emporia in August, 1895; the least monthly precipitation, 0, at Tulsa, in August, 1896, and September, 1897:

Monthly rainfall on watershed of Verdigris River, in inches.

AT EMPORIA, KANSAS.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1895..	.....	.....	.....	.....	.....	.....	2.60	12.45	8.25	0.15	2.65	4.25
1896..	0.30	0.40	0.65	6.05	6.20	3.20	3.75	3.50	1.90	3.55	1.50	0.04
1897..	1.25	1.70	1.15	3.10	1.50	3.00	0.70	3.50	2.50	1.80	T.	0.75

AT GRENOLA, KANSAS.

1895..	.....	.....	.....	.....	.....	.....	4.20	5.85	1.60	0.30	1.70	3.35
1896..	0.35	T.	0.90	1.65	1.75	5.30	5.50	0.10	3.10	4.45	2.25	0.35
1897..	0.95	0.90	3.53	5.77	1.56	2.98	4.62	3.30	1.09	1.42	0.21	1.15

AT INDEPENDENCE, KANSAS.

1895..	.....	.....	.....	.....	.....	.....	3.51	5.53	6.04	0.29	2.34	8.20
1896..	0.43	0.57	1.84	2.41	7.20	3.46	6.47	0.57	3.47	4.35	1.35	0.63
1897..	2.46	1.31	3.44	3.79	1.23	3.97	7.03	3.52	0.89	0.99	0.66	1.51

AT TORONTO, KANSAS.

1895..	.....	.....	.....	.....	.....	.....	1.86	7.19	7.76	0.32	2.56	3.65
1896..	0.57	0.51	1.04	2.55	8.05	2.21	5.71	1.56	3.96	4.17	1.71	0.65
1897..	1.51	1.06	2.69	4.06	1.31	3.38	3.17	3.01	1.90	1.15	0.35	1.06

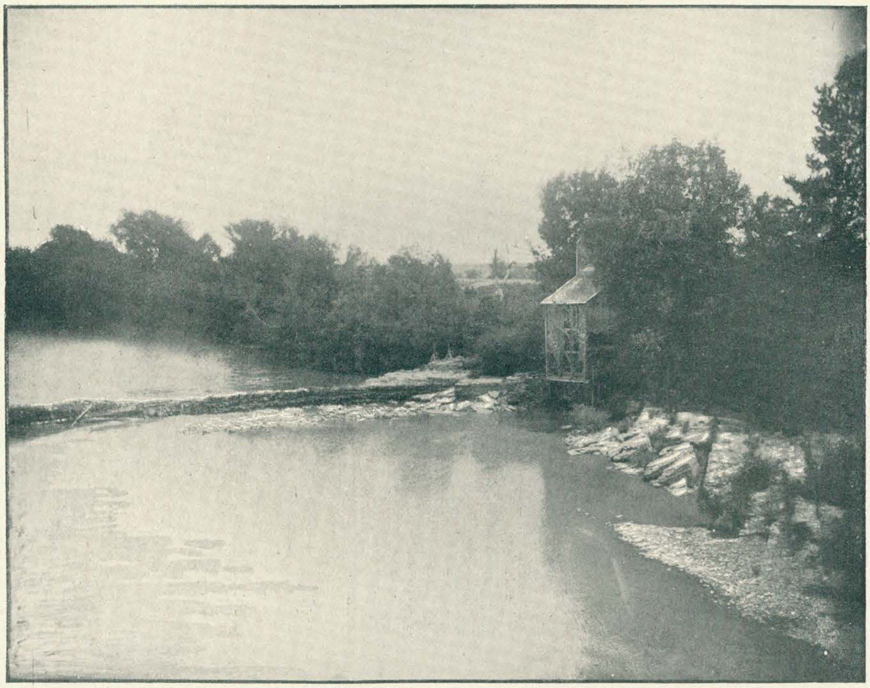
AT SEDAN, KANSAS.

1895..	.....	.....	.....	.....	.....	.....	6.15	5.33	1.65	0.41	2.86	5.41
1896..	0.54	0.25	1.55	1.98	5.51	5.84	4.54	0.72	3.48	3.67	2.12	0.68
1897..	2.10	1.07	4.07	5.15	1.84	3.79	4.06	3.43	1.52	1.97	0.19	0.94

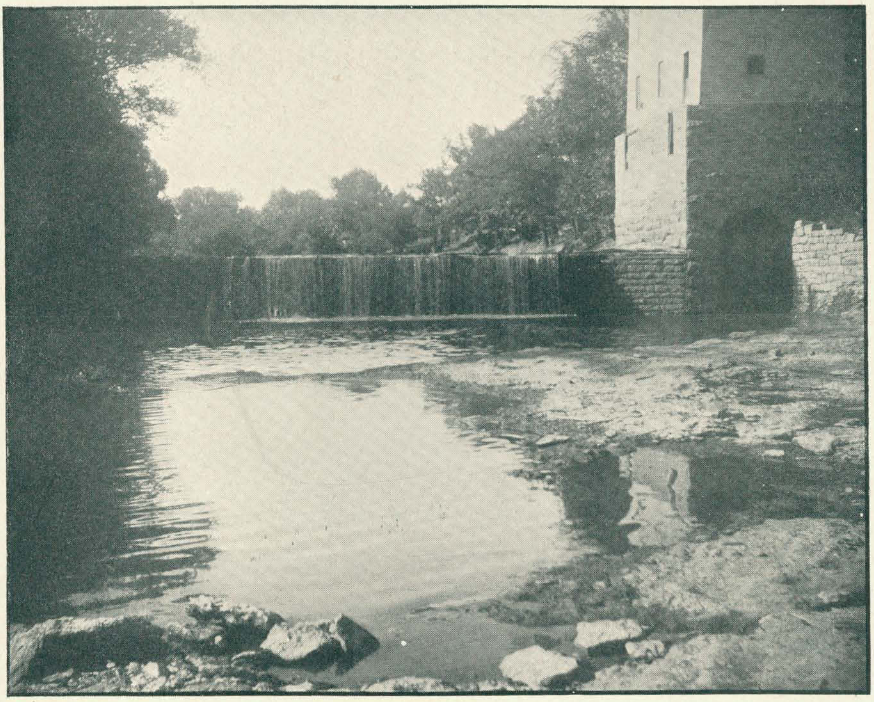
AT TULSA, INDIAN TERRITORY.

1895..	.....	.....	.....	.....	.....	.....	10.30	2.20	1.90	1.60	5.80	7.90
1896..	0.50	0.30	1.30	1.60	5.90	4.10	0.60	0.00	1.50	4.60	2.50	0.90
1897..	0.97	2.40	6.70	5.60	0.80	2.20	3.72	4.24	0.00	1.22	1.29	1.08

The rainfall on the watershed above the gaging station is shown in the accompanying table. It represents the mean of the rainfall at Toronto, Grenola, and Independence. The greatest mean monthly rainfall for this part of the watershed was 6.19 inches, in August, 1895; the least, .30 inch, in October, 1895.



A. POINT OF MEASUREMENT ON VERDIGRIS RIVER NEAR LIBERTY, KANSAS.



B. DAM ON FALL RIVER NEAR FREDONIA, KANSAS.

Average rainfall and run-off on drainage basin of Verdigris River.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
MEAN RAINFALL, IN INCHES, AT TORONTO, GRENOLA, AND INDEPENDENCE.												
1895..	.....	.....	.....	.....	.....	.....	3.19	6.19	5.13	0.30	2.20	5.07
1896..	0.45	0.36	1.26	2.20	5.67	3.66	5.89	0.74	3.51	4.32	1.77	0.54
1897..	1.64	1.09	3.22	4.54	1.33	3.44	4.98	3.28	1.29	1.19	0.41	1.24
RUN-OFF, IN INCHES, ABOVE THE GAGING STATION.												
1895..	.....	.....	.....	.....	.....	.....	.....	0.29	2.15	0.03	0.03	1.57
1896..	0.25	0.15	0.09	0.24	1.56	0.79	0.63	0.02	0.03	0.22	0.36	0.17
1897..	0.32	0.53	0.81	1.02	0.47	0.19	0.15	0.01	0.01	0	0	0
RATIO OF RUN-OFF TO RAINFALL, IN PER CENT.												
1895..	.....	.....	.....	.....	.....	.....	.....	5	42	10	1	31
1896..	56	42	7	11	28	22	10	3	1	5	20	32
1897..	20	50	25	22	35	6	3	$\frac{1}{8}$	$\frac{1}{8}$	0	0	0
Mean	38	46	16	17	32	14	6	3	14	5	7	21

The place at which systematic measurements of discharge of Verdigris River have been made is McTaggart's mill, shown on Pl. XXXVII, *A*, about 6 miles southeast of Independence and 3.5 miles southwest of Liberty. The locality is more particularly described in Water-Supply and Irrigation Paper No. 16, on page 125, where is given also the record of daily heights during 1897 and a partial list of discharge measurements.

The accompanying list gives the results of discharge measurements in 1895, 1896, and 1897. There have also been added the results of measurements on Elk and Fall rivers. The measurement of the latter stream near Sageeyah was at a point about 50 miles south of Coffeyville. In the case of all these measurements the gage height given is that at the regular station near Liberty, Kansas. Comparing the two measurements, that on July 20, near Liberty, of 312 second-feet, and that on July 22, near Sageeyah, 55 miles below by rail, where the discharge was 1,540 second-feet, an enormous increase in flow appears. This is due to the fact that on July 21 a rain covering the country below Liberty caused the river to rise until it was from 2.5 to 3 feet higher than a few days before. The effect of this storm is also seen in the measurement of July 22 on Fall River. The discharge of Elk River is nearly three times that of Fall River, although the watershed of the latter is larger. It is difficult to find a time when the condition of the ground in all parts of the watershed, or even of two or more tributary watersheds, is such that the drainage per square mile is proportional to the mean annual rainfall.

During the period of two and a half years, since August 1, 1895, when the station was established, the highest gage reading was 35.5 feet, on September 11, 1895, when the discharge was about 37,000 second-feet. The lowest gage reading was 1.7 feet, in November, 1897, when the discharge was about 5 second-feet. It is said that during the flood of May, 1895, the river was several feet higher than in September, 1895. The river rises and falls rapidly. For example, from September 8-9, 1895, the river rose from 4.1 to 27 feet—nearly 23 feet in twenty-four hours. Again, March 4, 1897, it rose from 5 to 20 feet in twenty-four hours. The observer has reported a rate of rise of 1 foot per hour. During the five months of 1895 the lowest gage reading was 2.2, and this stage of water continued for sixteen consecutive days. During the year 1896 the lowest gage reading was 1.7, or a discharge of 5 second-feet; this stage of water lasted for one week. For thirty-two days, during parts of August and September, the discharge was from 5 to 20 second-feet. During 1897 there were four months when the discharge was at no time more than 20 second-feet, and for one month it was only 2 or 3 second-feet. At Sageeyah, in the flood of May, 1895, the water was 31.5 feet higher than when measurement No. 16 was made, or about 34 feet above ordinary stage of water.

In the Eighteenth Annual Report, Part IV, p. 237, there is published a table of the estimated monthly discharge of Verdigris River at the gaging station. The measurements during 1897 gave a more accurate rating curve than the one for the preceding year, and a new rating table was applied from the establishment of the station, August 1, 1895, to December 31, 1897; the estimated monthly discharge for this period is herewith published. The results for 1897 are considered more accurate than those for the previous year.

List of miscellaneous discharge measurements.

Date.	Stream.	Locality.	Gage height.	Area of section.	Mean velocity.	Discharge.
1895.			*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
Aug. 2	Verdigris River..	Liberty	2.4	130	0.88	107
Sept. 7	.....do	.....do	3.4	278	1.59	443
Nov. 15	.....do	.....do	2.7	188	1.16	218
1896.						
Apr. 15	.....do	.....do	3.4	250	1.47	368
May 26	.....do	.....do	20.0	3,516	4.14	14,574
May 27	.....do	.....do	19.5	3,465	3.97	13,756
July 8	.....do	.....do	3.7	304	2.25	684
Sept. 25	.....do	.....do	2.6	132	1.29	170
Sept. 26	.....do	.....do	2.7	150	1.52	229

List of miscellaneous discharge measurements—Continued.

Date.	Stream.	Locality.	Gage height.	Area of section.	Mean velocity.	Discharge.
1897.			*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
Apr. 2	Verdigris River..	Liberty	6.6	691	3.70	2,558
Apr. 3	.....do	.....do	5.9	584	3.43	2,003
Apr. 30	.....do	.....do	17.0	2,917	3.55	10,367
May 1	.....do	.....do	7.4	851	3.97	3,384
June 29	.....do	.....do	2.4	111	0.63	70
July 20	.....do	.....do	3.0	205	1.47	312
Do	Elk River	Independence ...	3.0	181	....	147
July 21	Verdigris River..	Sageeyah	3.0	1,835	0.84	1,540
July 22	Fall River	Neodesha	2.8	171	....	51
Sept. 8	Verdigris River..	Independence ...	2.0	13	1.09	14
Nov. 28	Fall River	Fall River	1.6	....	1.2	1

Rating table for Verdigris River at Liberty, Kansas.

[This table is applicable from August 1, 1895, to December 31, 1897.]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.5	0	3.0	256	5.0	1,400	15.0	9,540
1.6	2	3.2	351	6.0	2,160	16.0	10,360
1.7	5	3.4	450	7.0	2,980	17.0	11,120
1.8	9	3.6	553	8.0	3,800	18.0	12,150
1.9	14	3.8	660	9.0	4,620	19.0	13,250
2.0	20	4.0	770	10.0	5,440	20.0	14,470
2.2	39	4.2	890	11.0	6,260	21.0	15,890
2.4	68	4.4	1,010	12.0	7,080	22.0	17,370
2.6	110	4.6	1,136	13.0	7,900	23.0	18,850
2.8	171	4.8	1,268	14.0	8,720	24.0	20,330

Estimated monthly discharge of Verdigris River at Liberty, Kansas, for 1895 and 1896.

[Drainage area, 3,067 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1895.						
August	7,121	20	783	48,144	0.294	0.255
September	37,000	87	5,985	356,132	2.179	1.953
October	155	39	69	4,243	0.025	0.022
November	171	39	82	4,879	0.030	0.027
December	28,000	68	4,226	259,847	1.589	1.378
1896.						
January	1,136	450	661	40,643	0.249	0.216
February	770	256	426	24,503	0.145	0.139
March	351	171	242	14,880	0.091	0.079
April	3,882	171	677	40,285	0.246	0.221
May	19,900	171	4,181	257,080	1.572	1.363
June	16,620	303	2,200	130,909	0.800	0.717
July	10,770	138	1,699	104,467	0.639	0.554
August	210	14	46	2,828	0.017	0.015
September	424	5	71	4,225	0.026	0.023
October	8,720	9	600	36,893	0.226	0.196
November	9,130	110	1,017	60,516	0.369	0.331
December	1,010	171	448	27,547	0.168	0.146
The year	19,900	5	1,022	744,776	4.548	0.333

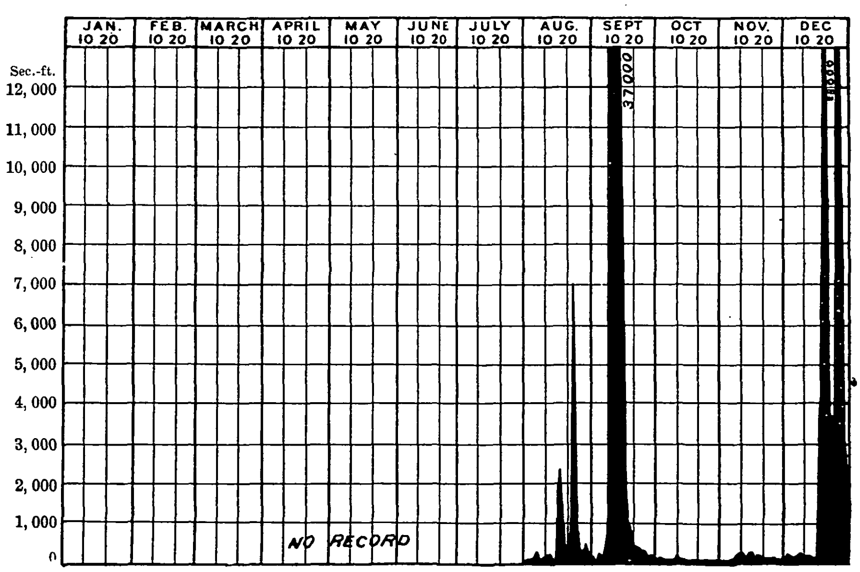


FIG. 122.—Discharge of Verdigris River at Liberty, Kansas, 1895.

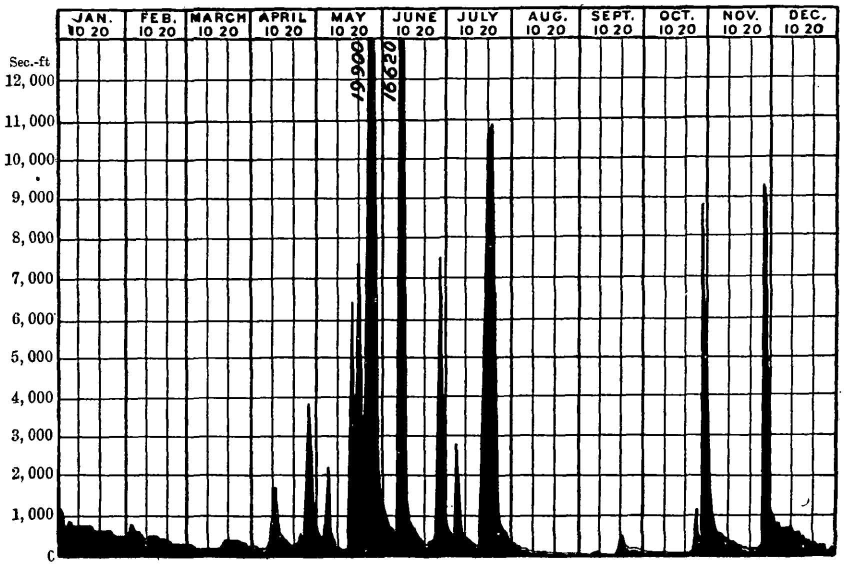


FIG. 123.—Discharge of Verdigris River at Liberty, Kansas, 1896.

Estimated monthly discharge of Verdigris River at Liberty, Kansas, for 1897.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	1,616	351	887	54,540	0.333	0.289
February	5,276	450	1,591	88,360	0.532	0.518
March	14,470	553	2,201	135,333	0.838	0.718
April	26,100	450	2,829	168,338	1.030	0.923
May	8,105	256	1,260	77,474	0.474	0.411
June	4,005	52	505	30,050	0.184	0.165
July	4,989	39	408	25,088	0.153	0.133
August	39	20	28	1,722	0.011	0.009
September	20	20	20	1,190	0.008	0.007
October	20	5	8	492	0.003	0.003
November	5	2	2	119	0.001	0.001
December	39	2	12	738	0.004	0.004
The year	26,100	2	813	583,444	3.571	0.267

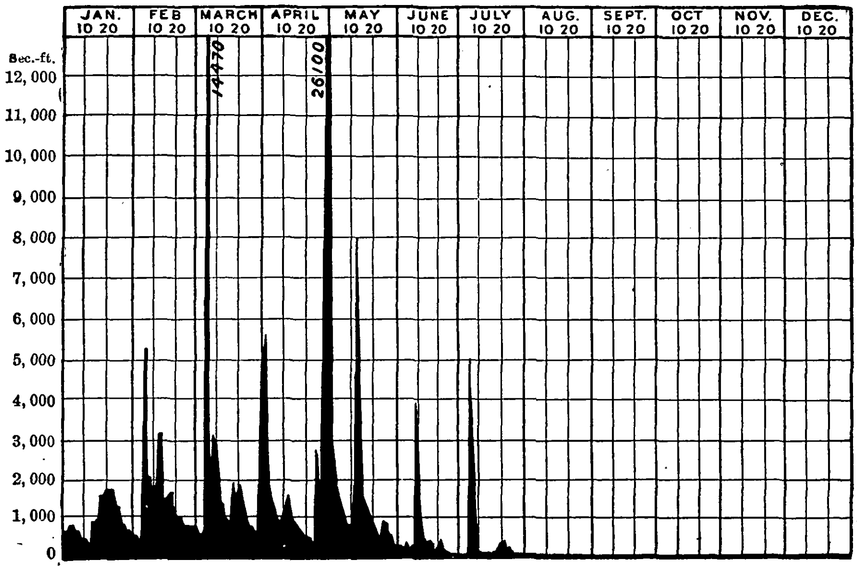


FIG. 124.—Discharge of Verdigris River at Liberty, Kansas, 1897.

List of miscellaneous discharge measurements, Arkansas Basin.

Date.	Stream.	Locality.	Meter number.	Area of section.	Mean velocity.	Discharge.
1897.				*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
July 20	Elk River...	3 miles north of Independence, Kansas.	19	181	0.81	147
July 21	Verdigris ...	1½ miles north of Sageeyah, Indian Territory.	19	1,835	0.84	1,540
July 22	Fall River...	1 mile south of Neodesha, Kansas.	19	171	0.29	51
Dec. 7	.....do	Fall River, Kansas...	.....	1	(*a*)	(*a*)

a Less than 1.

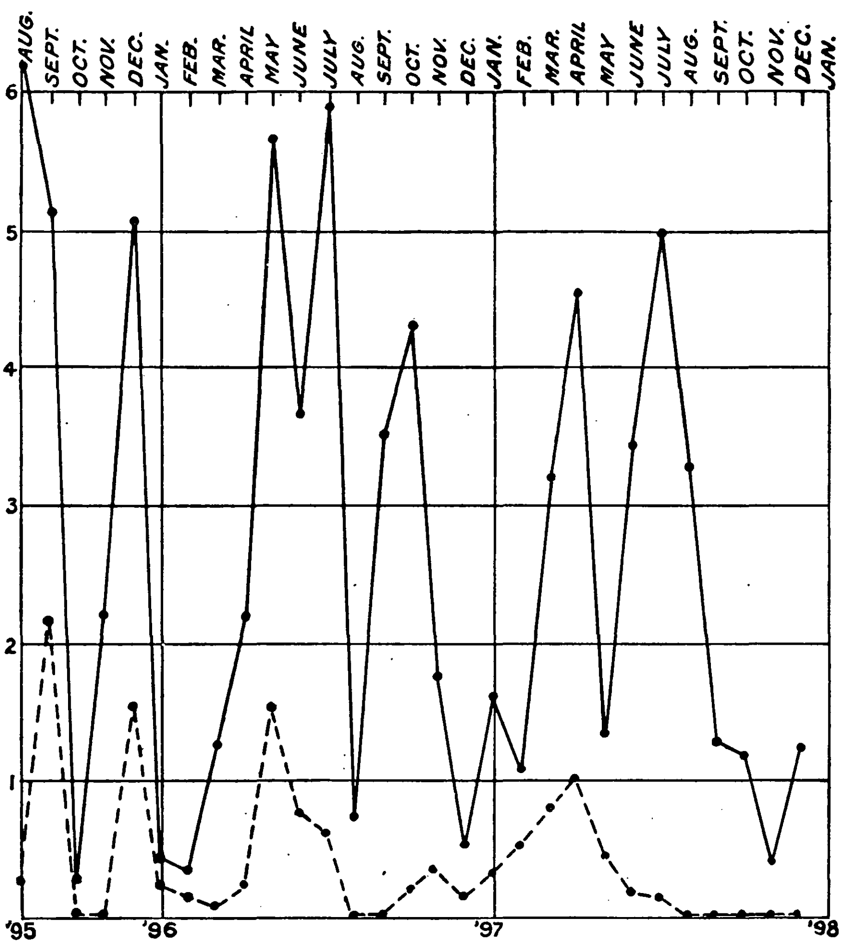


FIG. 125.—Depth in inches of rainfall in and run-off from Verdigris Basin from August, 1895, to December, 1897. Full line, rainfall; broken line, run-off.

CURVE OF MEAN VELOCITY OF FLOW.

One characteristic of the Verdigris at the gaging station, which early attracted attention, is that after the depth reaches 7 or 8 feet the mean velocity of the water does not increase so rapidly as the depth. This was especially noted on April 30, 1897. The gage read 16 feet in the evening about 7 o'clock. The next morning, about 8 o'clock, when the station was again visited, the gage read 7.4 feet and the surface velocity appeared to be greater than on the previous evening, when the water was 8.6 feet higher. The curve in the following figure (fig. 126) shows how the mean velocity varies with the height of gage reading. Gage readings are plotted as ordinates, and mean velocity in feet per second as abscissas. The mean velocity is found by dividing the discharge in second-feet by the area of the section. The mean velocity is seen to increase rapidly as the height increases until $7\frac{1}{2}$ feet is reached, with a mean velocity of 4 feet per second; the velocity then remains constant to a gage reading of 20 feet.

The curve of mean velocities for the gaging station on Neosho River, near Iola, Kansas, is a nearly straight line, starting with a velocity of 5 feet per second for a gage reading of 2.7 feet, and having a velocity of about 11 feet per second for a gage reading of 16.7 feet. The curve

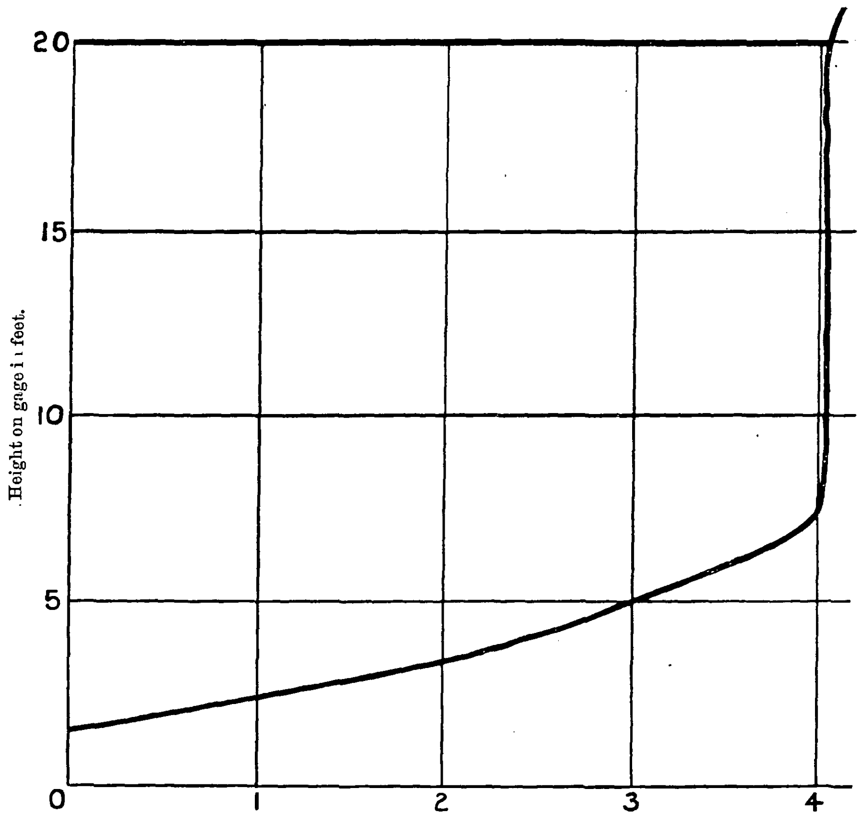


FIG. 126.—Variation of mean velocity with height of water on gage, on Verdigris River, at Liberty, Kansas.

of mean velocities of Kansas River at Lawrence is also a nearly straight line, starting with zero velocity for zero gage reading and having a velocity of 7 feet for gage reading of 9 feet.

With the view of ascertaining the cause of this peculiarity of Verdigris River, in July, 1897, another gage was placed at Independence and referred to the same datum as the rod at the gaging station. Arrangements were made to have both read hourly when the water is rising or falling. These readings will give the fall in the surface of the river between the gages for different depths of water. The discharge since the erection of the gage has been too small to yield definite results.

WATER POWER.

The water power of this river is not utilized to so great an extent now as fifteen or twenty years ago. In the years 1880 to 1890 it is said that there were eleven dams on the Verdigris in Kansas, but at the present time not more than three are in use. Three dams were located in the vicinity of Coffeyville; two were in the vicinity of Liberty, of which the one remaining, McTaggart's, is shown on Pl. XXXVII, *A*; one was at Independence and one 7 miles above Independence, both gone; two were in the vicinity of Neodesha, both gone; one near Altoona, and one at Guilford. The dam at the gaging station was built in 1874–75 of brush and stones. Its length is 175 feet, its height is 5 feet, and it gives a head of 5 feet when in good repair. The flume is 10 by 12 feet. There are four wheels, one 48 inches and three 33 inches. The horsepower utilized is said to be 40. The dam backs the water about 7 miles. The dam at Altoona is built of timber and stone and the lower courses are bolted to the rock bottom. Its length is 140 feet and its height 13 feet. The mill runs by steam when there is not enough water to work the wheels. The dam at Guilford is built of timber and stone. It is 9 feet high and supplies water to a 48-inch wheel, which yields 39 horsepower.

The power of Fall River, at the present time, is utilized to a larger extent than that of the Verdigris. There are at least six dams on it in use. The first one, starting from the mouth, is located 1 mile west of Neodesha. It is 8 feet high, built of stone and timber, and backs the water 2½ miles. There is one 40-inch wheel. It is said that the water is sufficient to work the wheel about nine months in the year.

The next dam is at Dun station. It is built of stone, and gives a head of about 5 feet, runs a 52-inch wheel, and gives 25 horsepower. The next in order up the river, shown in Pl. XXXVII, *B*, is located 1½ miles south of Fredonia, and is the best on the river. It is built of masonry, 90 feet long, 7 feet wide on top, and gives a head of 8 feet. There is one 44-inch wheel, built fifteen years ago, which gives 40 horsepower. The water will run it on the average eleven months in the year.

The dam at New Albany is 100 feet long, is built of timber and stone, and gives an 8-foot head. It runs a 40-inch wheel and gives 30 horsepower. The dam at Fall River is 200 feet long, 2 feet high, and built on a curve. With the fall it gives a head of 9 feet. It runs one 42-inch wheel from seven to ten months in the year.

Six years ago there was a dam 4 feet high at Climax, which gave a head of 8 feet. It ran a 40-inch wheel and gave about 30 horsepower.

The dam 1 mile northwest of Eureka is 150 feet long, built of stone, and gives a head of 3.5 feet.

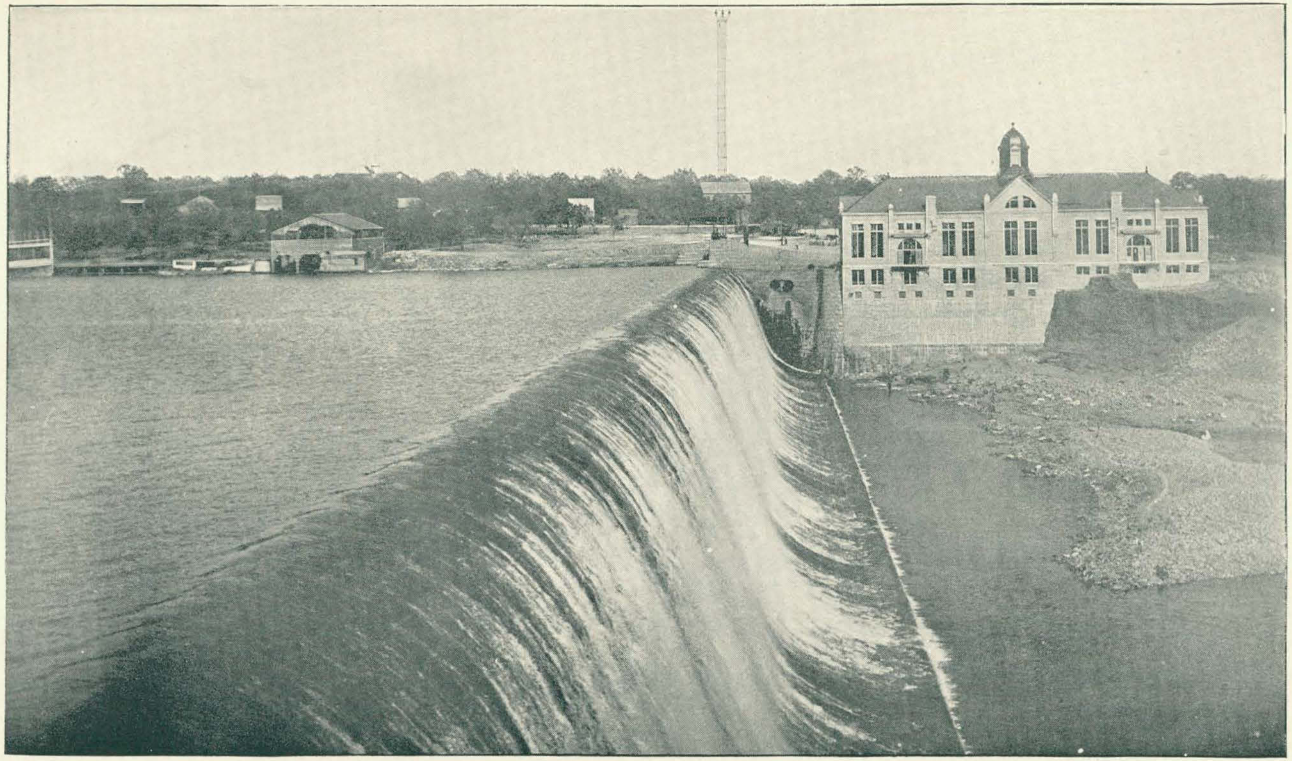
There are three dams on Elk River. One at Elk City, 154 feet long and 6 feet high, is built of timber and stone. A 50-inch wheel has a head of 9 feet and is said to furnish 45 horsepower. The river stopped flowing the latter part of September, 1897, and remained dry until after January 1, 1898. The mill has a steam plant to furnish power when there is not sufficient water power. There is another dam 4 miles southeast of Longton and one 4 miles northwest of Howard.

The reason the power of this river is now utilized to a less extent than formerly is because of the smallness and uncertainty of the discharge and the cheapness of steam power. The river is close to the coal mines and in the center of a natural-gas belt. In Coffeyville it is said that gas fuel does not cost more than one-fourth as much as coal.

TEXAS STREAMS.

Prof. Thomas U. Taylor, of the University of Texas, at Austin, has begun a series of measurements on a few of the more important rivers of Texas. In May, 1897, he took up the question of deposit of sediment in Lake McDonald, which is formed by the construction of the large dam across the Colorado River above Austin. The dam was completed in May, 1893, and as the soundings were made in May, 1897, the results yielded bear upon the rate of sedimentation during four years. He first examined the notes of surveys made prior to the construction of the dam and obtained cross sections of the Colorado River, made before the dam was built, and covering about 23 miles of the length of the river, at about 15 points between the dam and Lakeside, where there is no backwater. Later in the year he took up the establishment of river stations and, after a reconnaissance, selected points on the Brazos, Colorado, Guadalupe, and Pecos rivers. The point on the Brazos is about 1¼ miles southwest of the town of Lewis, at the railroad bridge; that on the Colorado is one-half mile southwest of the city of Austin; that on the Guadalupe is 1 mile east of New Braunfels; and that on the Pecos at the high railroad bridge of the Southern Pacific. He has also made measurements at different points along Colorado River above and below Austin on the Comal, San Marcos, San Antonio, San Felipe, Del Rio, and Devils rivers, and other streams accessible by rail from Austin.

The description of the results of measurements of silting of Lake McDonald are taken from the manuscript report of Professor Taylor. The shape of Lake McDonald, formed by damming the Colorado River, and the relative position of the lines of soundings are shown on the accompanying illustration, fig. 127. The dam is about 2½ miles northwest of the city. The black lines crossing the river above this indicate the position of the lines of soundings and the figures opposite give the distance in miles above the dam, which is marked 0.00. These correspond to the figures given on the right-hand side of fig. 128. On the left-hand side of the illustration are the names of the localities. In Pl. XXXVIII is given a view of the dam looking across from the west side toward the power house.



AUSTIN DAM AND POWER HOUSE, TEXAS.

The city of Austin, Texas, by a vote of its people, on May 5, 1890, authorized the issue of bonds to the extent of $1,400,000, for the construction of a dam across Colorado River and the erection of a power house and an electric-light plant. The estimate of the probable cost of these operations, made by Mr. J. P. Frizell, of Boston, was as follows:

Engineering	$59,000
Dam proper	463,000
Power house	32,000
Electric-light plant	46,000
Water mains, etc	154,000
Distribution	295,000
Reservoir	104,000
Canal	50,000
Contingencies	119,000
Total	1,322,000

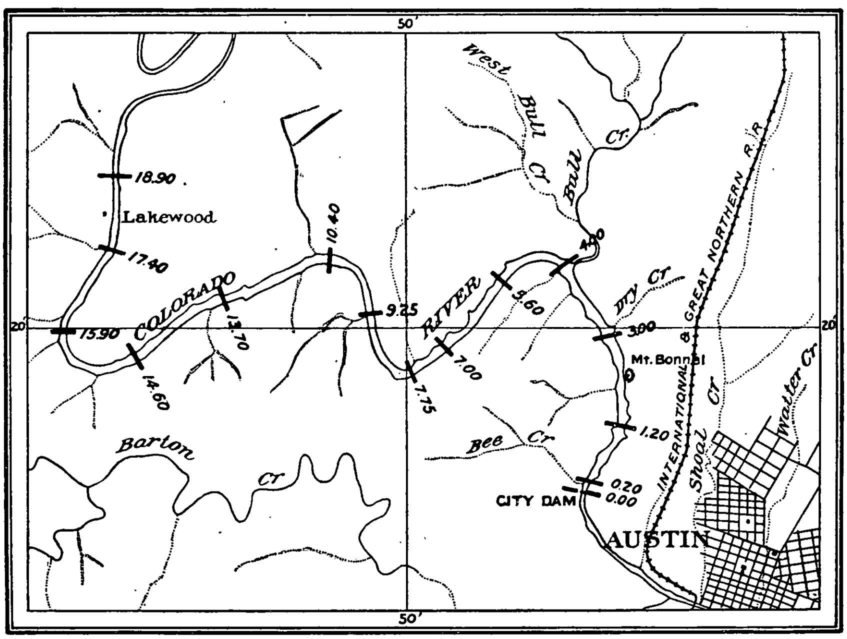


FIG. 127.—Index map of lines of soundings across Lake McDonald above Austin, Texas.

Mr. Frizell was employed as engineer after the bonds had been authorized, and designed the general outline of the dam and its accessories. He resigned in 1891 and was succeeded by Mr. J. T. Fanning.

The dam proper is 1,091 feet long between bulkheads and 68 feet high. The upstream face is vertical, while the downstream face is inclined at a batter of 3 in 8 at the upper part and terminates in a circle of 31 feet radius, permitting the overflow water to leave the dam in a horizontal direction. The original design contemplated a flat top about 18 feet wide, but this was finally rounded on both upstream and downstream edges. The cave of the dam was made of Portland cement and compact limestone, while the faces and top were made of an excellent grade of Burnet County (Texas) granite, laid in the best Portland cement. The dam was completed in May, 1893.

The Colorado River at Austin drains an area of 40,000 square miles, and was supposed to have a minimum flow of 1,000 second-feet and a maximum or flood discharge of 200,000 to 250,000 second-feet. A serious error was made in estimating the minimum flow. The flow has been measured at the tailrace of the dam and at the head of the lake at different times when the water was below the top of the dam, and these measurements gave an average flow through the power house (at tailrace) of 231 second-feet. The minimum flow is certainly less than this amount, for, during the summer of 1896, while there was less than 231 second-feet going through the power house, the water level in the lake continued to sink from May 27 to July 1, when it attained its lowest record since the power was turned on—5.7 feet below the crest of the dam. The average daily fall was 2 inches, the greatest fall being 3½ inches and the smallest being 1¼ inches. The average width of the lake is about 800 feet and the length of backwater varies from 23 to 19 miles. The loss of water is about 163 second-feet a day. No measurements of inflow and outflow were made, but it is obvious that the average inflow was 163 second-feet less than the amount used up either by the city plant or by evaporation and leakage. One source of leakage is the so-called spring which is discharged from the side of the power house, in a horizontal direction, from a 10-inch pipe. Several measurements were made on this. For two or three years it had a discharge of about 3,000,000 gallons per day (4.6 second-feet), but in May, 1897, its flow suddenly increased to 10 second-feet. This rate has been maintained with slight variations up to the present time.

The original volume of water in the lake was about 2,330,000,000 cubic feet—that is, an amount that would be represented by a solid whose base is 1 mile square and whose height is 83 feet.

Cross sections of the river were taken in September, 1890, at seventeen different places. The dam was completed in May, 1893, and the water first flowed over the completed dam May 16, 1893. Accurate soundings were made at the cross sections in May, 1897, and a comparison was instituted with former cross sections. The lake had been silting up about four years. In May, 1897, there was in the lake, level with the top of the dam, about 1,362,000,000 cubic feet of water, leaving 968,000,000 cubic feet of silt. In 1893 there was 83 feet of water on a square-mile base; and in 1897 there was about 50 feet of water and 33 feet of silt. This is an average filling up of 8¼ feet per year on a square-mile base. The following table presents the other data obtained. On account of the many bends in the river, the depth of deposit was found to obey no general law. The maximum and average depths at each section are indicated in the table, but these do not always correspond in position. While the maximum depths at Santa Monica Springs were 29.4 feet in 1893 and 11 feet in 1897, the maximum depth of deposit was 21 feet. The channel has shifted from the south to the north side of the river at this place.

Results of soundings at Lake McDonald, in 1893 and 1897.

Section.	Maximum depth.		Maximum depth of silt.	Average depth.		Average depth of silt.	Amount of filling up.	Distance of section from dam.	Remarks.
	1893.	1897.		1893.	1897.				
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Per ct.*	*Miles.*	
Dam	68.0	45.0	23.0	......	......	......	......	......	Mud bottom.
Bee Creek	67.0	42.0	23.0	37.6	31.0	6.6	18	0.2	Do.
Mormons Spring.	63.8	42.5	21.3	30.6	26.2	4.4	11	1.2	Do.
Williams	56.0	39.5	16.5	33.4	24.4	7.0	21	3.0	Do.
Bull Creek	47.8	36.0	11.8	38.0	28.0	10.0	26	4.0	Do.
Ennis farm	47.5	32.5	15.0	36.7	24.9	11.8	32	5.6	Do.
Devils Hollow.	47.0	27.0	20.0	36.3	21.5	15.8	43	7.0	Do.
Ogarita	44.8	25.0	19.8	30.7	19.4	11.3	36	7.8	Do.
McNeill's lane.	40.4	19.0	21.4	30.8	15.4	15.4	50	9.3	Do.
Scotts Tower	40.9	19.0	21.9	27.2	14.3	12.9	47	10.4	Do.
Santa Monica	29.4	11.0	18.4	20.3	6.6	13.7	68	13.7	Do.
Hughes farm	24.0	8.7	15.3	17.2	6.9	10.5	61	14.6	Do.
Honey Creek	16.6	10.0	6.6	13.2	7.0	5.2	40	15.9	Do.
Harrison Branch.	13.2	6.8	6.4	11.2	5.0	7.2	64	17.4	Part sand.
Clifton farm.	7.6	5.0	2.6	5.6	3.9	1.7	30	18.9	Sandy bottom.
Sulphur Hollow.	3.7	2.2	1.5	2.8	2.0	0.8	29	20.0	Sandy bottom.

The total amount of silt in the lake is 968,000,000 cubic feet. This would cover 1 square mile to a depth of 33 feet. The total amount of water in the lake would cover 1 square mile to a depth of 50 feet.

The facts shown in the above table are graphically exhibited in fig. 128, which gives the sections at various points at and above the dam. The vertical scale is twice the horizontal. On the left-hand side are given the names of the localities and on the right-hand side the distance in miles above the dam. The amount of sediment accumulated from May, 1893, to May, 1897, is shown by the cross-hatched areas, the lower line being the contour of the ground before the dam was built, and the upper line the shape of the bottom of the lake four years later. The figures above each section indicate the original width in feet.

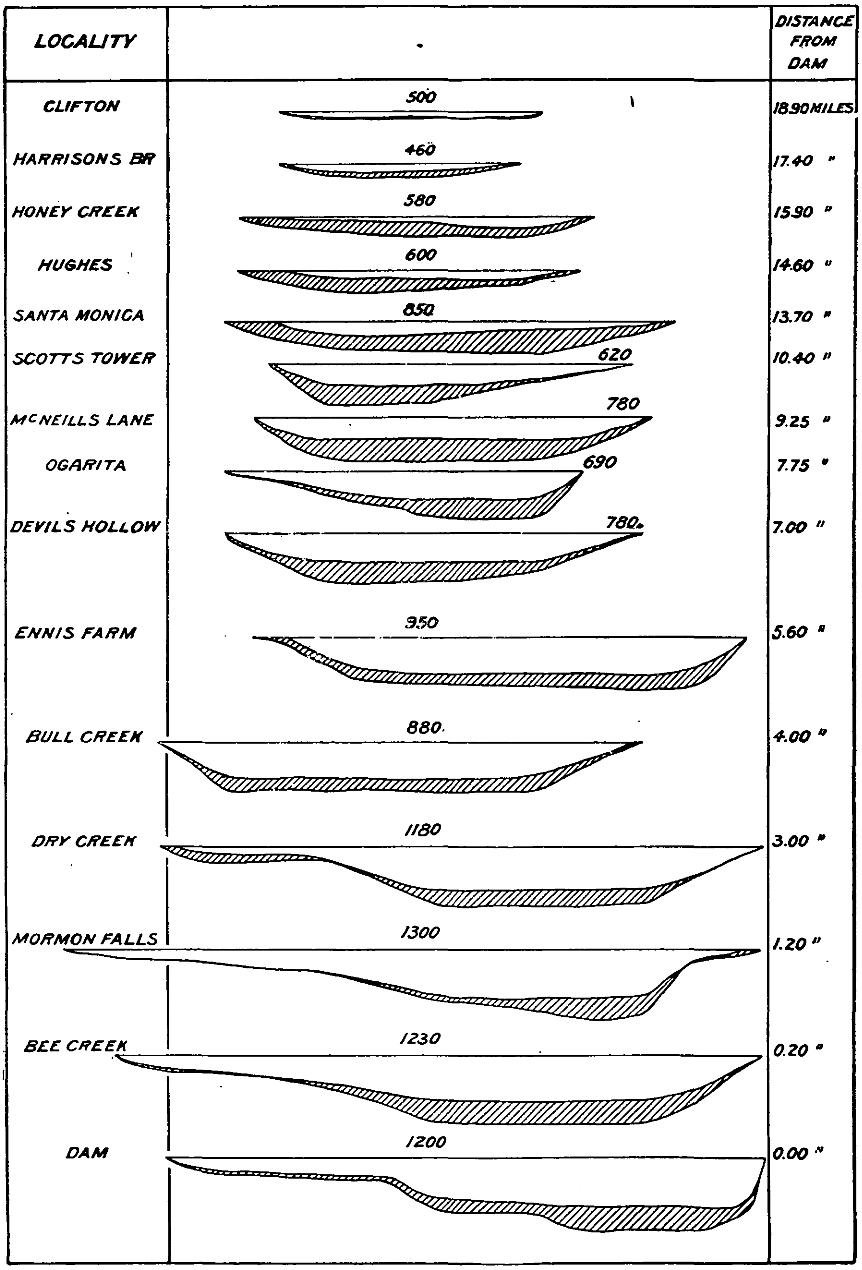


FIG. 128.—Cross section of Lake McDonald, illustrating accumulation of silt.

RIO GRANDE BASIN.

This basin is described in detail in the Twelfth Annual Report of this Survey, Part II, on pages 240 to 290, all of the data at that time available as to rainfall and run-off being discussed. Since that time (1890-91) measurements of the discharge of the Rio Grande have been made at short intervals at several important points and the volume of the stream has been made known.

RIO GRANDE.

This river, as described in the above-mentioned report, has its source in the Rocky Mountains in southern Colorado and flows in a general easterly direction until it leaves its mountainous basin to enter San Luis Park. Its course is thence southeasterly to the end of the park, where it turns due south. San Luis Park is the valley of greatest area along the Rio Grande, its dimensions being 70 by 40 miles. A large number of canals take water to irrigate what appears by eye to be level stretches of land many miles in extent.

A gaging station is located about 3 miles above the town of Del Norte and above the head of most of the important canals. The field work at this station in 1897 is described in Water-Supply and Irrigation Paper No. 16, p. 127.

For a year or more a gaging station was maintained at Alamosa, near the lower end of the park, and the measurements show the amount of seepage water at this point, for during dry seasons all the water in the river is diverted above. Owing to the considerable quantities of water used in this valley and to the slight fall of the country, areas in the lower sections are tending to become swampy and alkaline. It has been thought that the slope of the country was not sufficient for drainage canals, but a level line run during 1897 demonstrated the fallacy of this idea.

Some miles above the Colorado and New Mexico State boundary line the Rio Grande enters a canyon locally known as Rio Grande Canyon, and continues in it to below Embudo, New Mexico. This gorge is from 300 to 500 feet in depth. During its course through this section the stream receives a number of small tributaries both from the east and the west. Although the river has been reported as being dry at the lower end of San Luis Park, a constant discharge is found at Embudo, as shown by the records at the gaging station there.

Results obtained in 1897 at the Embudo station will be found in Water-Supply and Irrigation Paper No. 16, p. 128. The rating tables and the table of monthly discharges are given on pages 384 and 385.

Three miles below Embudo the river enters Espanola Valley, and at the lower end White Rock Canyon, through which it flows for 30 miles. It then enters the Albuquerque Valley, which averages in width from 1 to 3 miles and continues down to about Socorro. Numerous canals are taken out from each side of the river both above and below Albuquerque, and considerable areas are irrigated on a small scale. Most of the ditches are owned by Mexicans and are poorly constructed and wasteful of water. Flooding is the principal method of application. A survey was made in 1897 for a large irrigation enterprise taking water from the Rio Grande from above Albuquerque, to be used in the vicinity of that city.

The Rio Grande gaging station, located at the upper end of White River Canyon, is described in Water-Supply and Irrigation Paper No. 16, p. 130.

The San Marcial gaging station is the fourth on this river at which work was prosecuted during 1897 and is described in Water-Supply and Irrigation Paper No. 16, p. 131. Immediately below San Marcial the railroad leaves the river and continues southward on a level plain many miles in extent. If water could be brought to it, undoubtedly it would produce rich crops. Two years ago an enterprise having as its object the irrigation of this land contemplated the building of a dam at what is known as Elephant Buttes and carrying the water by means of a long canal to this east side plain. It is in the hands of an English corporation. The proposition was agitated at the time active surveys were being made for the international dam and reservoir at El Paso, and the National Government sought to enjoin the company from building the dam, as it would be likely to interfere with the supply at El Paso.

Mesilla Valley, extending from Fort Selden, New Mexico, to within 3 miles of the city of El Paso, Texas, is a noted section, and contains a number of important irrigation enterprises. The method of irrigation in this valley is described in Water-Supply and Irrigation Paper No. 10.[1]

A gaging station has been maintained at El Paso for several years. The work accomplished at this station during 1897 is described in Water-Supply and Irrigation Paper No. 16, p. 132. The bottom of the river here for a number of miles above and below El Paso is unstable, scouring on a rise and filling on a fall of the river. The only method of accurately estimating the daily discharge is that practiced at a number of other gaging stations where the beds of the rivers are similarly unstable (the method, for instance, followed at the McDowell stations on Salt and Verde rivers and the Butte station on Gila River), and consists in taking a large number of discharge measurements at intervals of only one or two days. May 1, 1897, this station was placed under charge of Mr. W. W. Follett, consulting engineer of the International (Water) Boundary Commission. Ninety-one discharge measurements were made at this point in 1897.

[1] Irrigation in Mesilla Valley, New Mexico, by F. C. Barker.

Rating table for Rio Grande at Del Norte, Colorado, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.4	305	2.2	756	3.6	2,336	5.0	4,292
1.5	354	2.4	896	3.8	2,638	5.2	4,561
1.6	406	2.6	1,052	4.0	2,939	5.4	4,830
1.7	460	2.8	1,232	4.2	3,216	5.6	5,100
1.8	516	3.0	1,456	4.4	3,485	5.8	5,367
1.9	570	3.2	1,734	4.6	3,754		
2.0	626	3.4	2,035	4.8	4,023		

Estimated monthly discharge of Rio Grande at Del Norte, Colorado.

[Drainage area, 1,400 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January			a 1,000	61,488	0.82	0.71
February			a 1,000	55,537	0.74	0.71
March			a 1,000	61,488	0.82	0.71
April	2,111	598	1,067	63,491	0.84	0.76
May	5,234	1,660	3,537	217,483	2.92	2.53
June	4,830	1,660	3,391	201,778	2.70	2.42
July	2,261	570	1,108	68,129	0.91	0.79
August	598	354	475	29,207	0.39	0.34
September	972	354	631	37,547	0.50	0.45
October	2,261	756	1,472	90,510	1.21	1.05
November	860	542	665	39,570	0.54	0.48
December			a 800	49,190	0.66	0.57
The year			1,346	975,418	13.05	0.96

a Approximate.

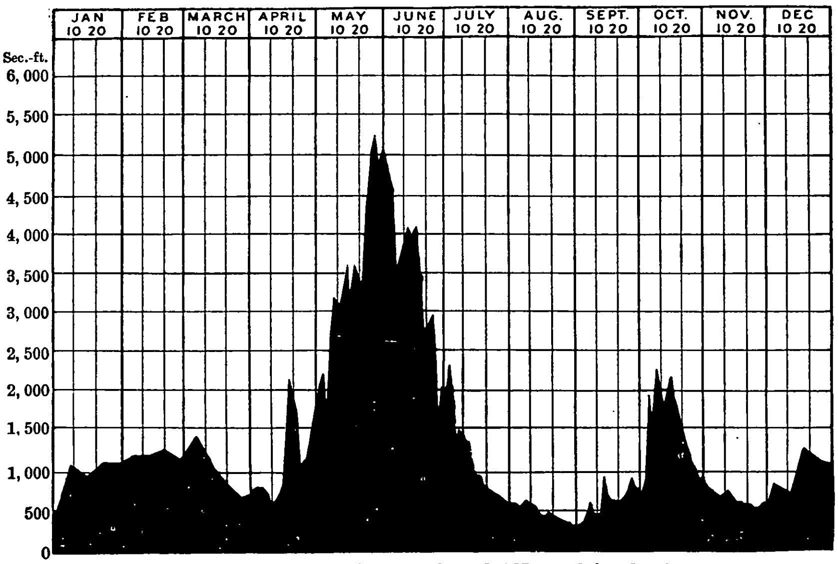


FIG. 129.—Discharge of Rio Grande at Del Norte, Colorado, 1897.

Rating table for Rio Grande at Embudo, New Mexico, for 1897.

Gage height.	Discharge.			Gage height.	Discharge.		
	Jan. 1 to Apr. 18.	Apr. 19 to Aug. 21.	Aug. 22 to Dec. 31.		Jan. 1 to Apr. 18.	Apr. 19 to Aug. 21.	Aug. 22 to Dec. 31.
Feet.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*
7.3	....	285	....	9.4	1,150	1,435	1,260
7.4	....	305	....	9.6	1,320	1,625	1,435
7.5	....	330	285	9.8	1,500	1,820	1,625
7.6	....	360	305	10.0	1,680	2,035	1,820
7.7	375	390	330	10.2	....	2,270	2,035
7.8	390	425	360	10.4	....	2,530	....
7.9	410	460	390	10.6	....	2,815	....
8.0	435	495	425	10.8	....	3,105	....
8.2	495	580	495	11.0	....	3,395	....
8.4	565	685	580	11.5	....	4,120	....
8.6	650	805	685	12.0	....	4,845	....
8.8	750	940	805	12.5	....	5,570	....
9.0	865	1,090	940	13.0	....	6,295	....
9.2	1,000	1,260	1,090	14.0	....	8,745	....

Estimated monthly discharge of Rio Grande at Embudo, New Mexico.

[Drainage area, 7,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	435	375	394	24,226	0.07	0.06
February	480	375	408	22,659	0.06	0.06
March	865	410	561	34,495	0.09	0.08
April	3,177	700	1,698	101,038	0.27	0.24
May	8,745	3,177	5,443	334,679	0.90	0.78
June	7,600	2,270	4,621	274,968	0.73	0.66
July	2,465	375	1,274	78,336	0.21	0.18
August	1,015	285	338	20,783	0.06	0.05
September	460	285	344	20,469	0.06	0.05
October	2,150	495	1,538	94,569	0.25	0.22
November	1,435	745	1,138	67,716	0.18	0.16
December	745	460	551	33,880	0.09	0.08
The year	8,745	285	1,497	1,107,818	2.97	0.22

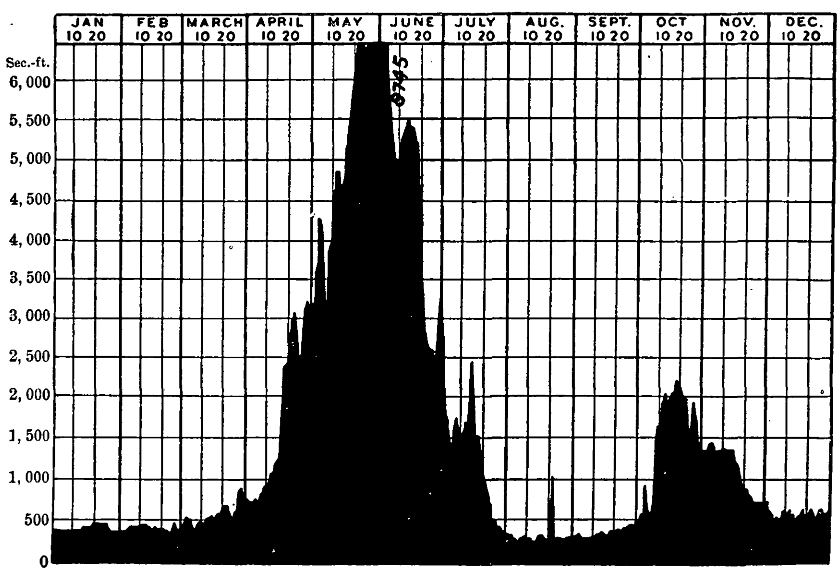


FIG. 130.—Discharge of Rio Grande at Embudo, New Mexico, 1897.

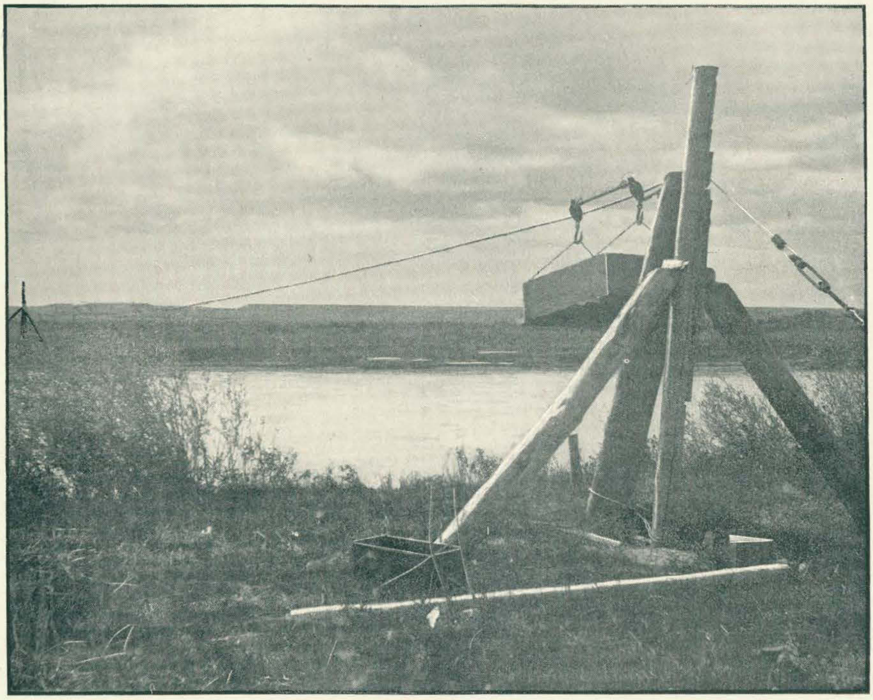
Rating table for Rio Grande at Rio Grande, New Mexico, for 1897.

Gage height.	Discharge.			Gage height.	Discharge.		
	Jan. 1 to June 19.	June 20 to Aug. 16.	Aug. 17 to Dec. 31.		Jan. 1 to June 19.	June 20 to Aug. 16.	Aug. 17 to Dec. 31.
Feet.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*
4.0	....	100	200	6.6	1,980	2,620	2,230
4.2	250	165	260	6.8	2,380	2,900	2,490
4.4	310	240	320	7.0	2,800	3,190	2,750
4.6	390	320	380	7.2	3,220	3,500	3,010
4.8	470	420	460	7.4	3,640	3,820	3,270
5.0	550	660	550	7.6	4,060	4,180	....
5.2	630	900	650	7.8	4,480	4,540	....
5.4	710	1,140	780	8.0	4,900	....	....
5.6	820	1,380	950	9.0	7,300	....	....
5.8	1,000	1,620	1,190	10.0	9,700	....	....
6.0	1,200	1,860	1,450	11.0	12,100	....	....
6.2	1,410	2,100	1,710	12.0	14,500	....	....
6.4	1,690	2,340	1,970				

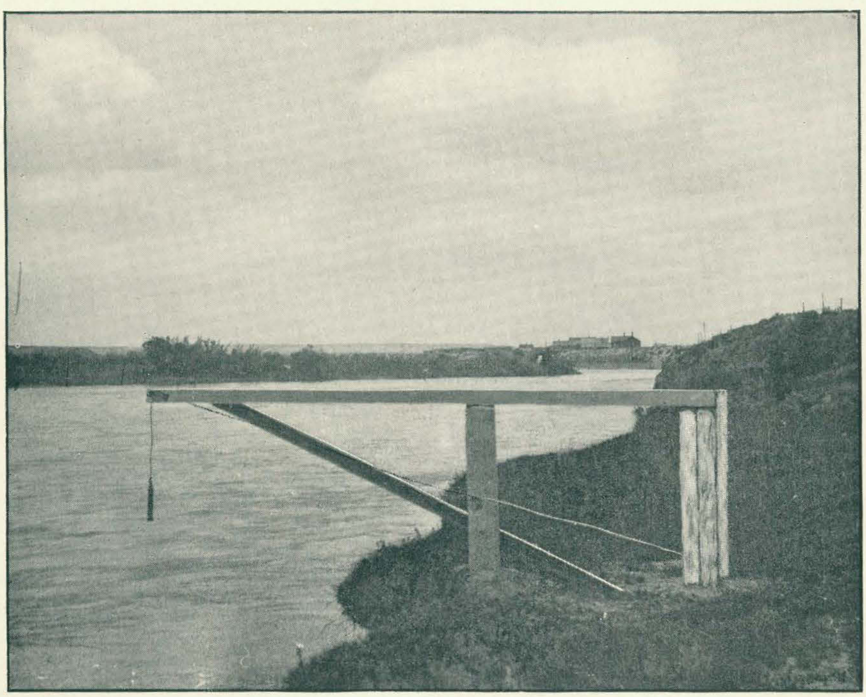
Estimated monthly discharge of Rio Grande at Rio Grande, New Mexico.

[Drainage area, 11,250 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	570	290	467	28,715	0.04	0.04
February	590	470	542	30,101	0.05	0.05
March	2,485	610	988	60,750	0.10	0.09
April	9,220	1,200	5,094	303,113	0.50	0.45
May	15,340	8,500	11,421	702,254	1.18	1.02
June	10,900	2,480	6,153	366,128	0.61	0.55
July	3,190	200	1,582	97,274	0.16	0.14
August	1,255	200	446	27,423	0.04	0.04
September	2,360	260	680	40,463	0.07	0.06
October	3,465	550	2,215	136,196	0.23	0.20
November	1,710	680	1,208	71,881	0.12	0.11
December	745	215	524	32,220	0.06	0.05
The year	15,340	200	2,610	1,896,518	3.00	0.23



A.



B.

GAGING APPARATUS ON BLACK FORK NEAR GRANGER, WYOMING.

A, Cable and car; *B*, Wire gage.

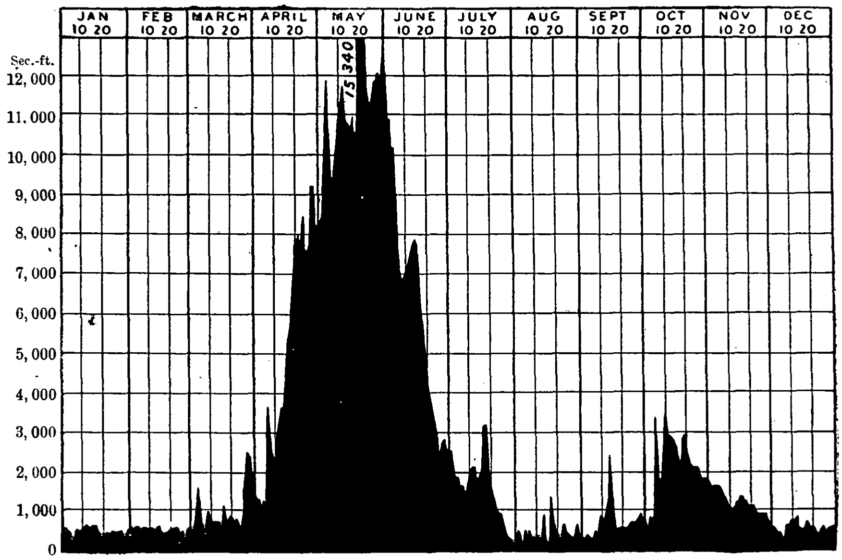


FIG. 131.—Discharge of Rio Grande at Rio Grande, New Mexico, 1897.

Rating table for Rio Grande at San Marcial, New Mexico, for 1897.

Gage height.	Discharge.					
	Jan. 1 to Mar. 31.	Apr. 1 to May 7.	May 8 to May 23.	May 24 to Sept. 4.	Sept. 5 to Oct. 4.	Oct. 5 to Dec. 31.
Feet.	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Second-feet.*
5.0	....	....	....	5	....	....
5.2	....	....	....	21	....	....
5.4	....	....	....	37	....	....
5.6	....	....	....	53	....	....
5.8	....	....	....	69	....	....
6.0	....	....	....	85	....	....
6.2	....	....	....	101	....	....
6.4	....	....	....	120	290	....
6.6	....	....	....	170	390	....
6.8	....	....	....	270	520	....
7.0	200	....	....	400	800	....
7.2	276	....	....	580	1,500	....
7.4	350	....	....	850	2,200	....
7.6	850	900	....	1,200	2,900	2,100
7.8	1,350	1,400	....	1,650	3,600	2,700
8.0	1,850	1,900	....	2,150	4,300	3,500
8.2	2,360	2,400	....	2,800	5,000	4,300
8.4	2,880	2,900	....	3,600	5,700	5,100
8.6	....	3,400	....	4,450	....	5,900
8.8	....	3,900	....	5,350	....	6,700

Rating table for Rio Grande at San Marcial, New Mexico, for 1897—Continued.

Gage height.	Discharge.					
	Jan. 1 to Mar. 31.	Apr. 1 to May 7.	May 8 to May 23.	May 24 to Sept. 4.	Sept. 5 to Oct. 4.	Oct. 5 to Dec. 31.
Feet.	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Second-feet.*
9.0	....	4,500	....	6,250	....	7,500
9.2	....	5,100	....	7,150	....	8,300
9.4	....	5,800	....	8,050	....	9,100
9.6	....	6,500	....	8,950	....	9,900
9.8	....	7,200	....	9,850	....	10,700
10.0	....	7,900	10,400	10,750	....	11,500
10.2	....	8,600	11,200	11,200	....	12,300
10.4	....	9,300	12,000	11,650	....	13,100
10.6	....	10,000	13,000	12,100	....	13,900
10.8	....	10,700	14,000	12,550	....	14,700
11.0	....	11,400	15,000	....	....	15,500
11.2	....	12,100	16,000	....	....	....
11.4	....	....	17,000	....	....	....
11.6	....	....	18,000	....	....	....
11.8	....	....	19,000	....	....	....
12.0	....	....	20,000	....	....	....
12.2	....	....	21,000	....	....	....
12.4	....	....	22,000	....	....	....

Estimated monthly discharge of Rio Grande at San Marcial, New Mexico.

[Drainage area. 28,067 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	600	200	318	19,553	0.013	0.011
February	600	350	438	24,325	0.017	0.016
March	1,350	350	663	40,767	0.028	0.024
April	7,025	900	3,572	212,548	0.142	0.127
May	21,750	6,150	12,282	755,196	0.505	0.438
June	11,088	1,775	6,158	366,426	0.244	0.219
July	2,025	270	1,073	65,977	0.044	0.038
August	365	5	100	6,149	0.004	0.004
September	6,050	5	1,919	114,188	0.075	0.068
October	15,500	650	4,581	281,677	0.188	0.163
November	3,500	2,100	2,953	175,715	0.117	0.105
December	3,100	2,400	2,484	152,736	0.102	0.089
The year	21,750	5	3,045	2,215,257	1.479	0.109

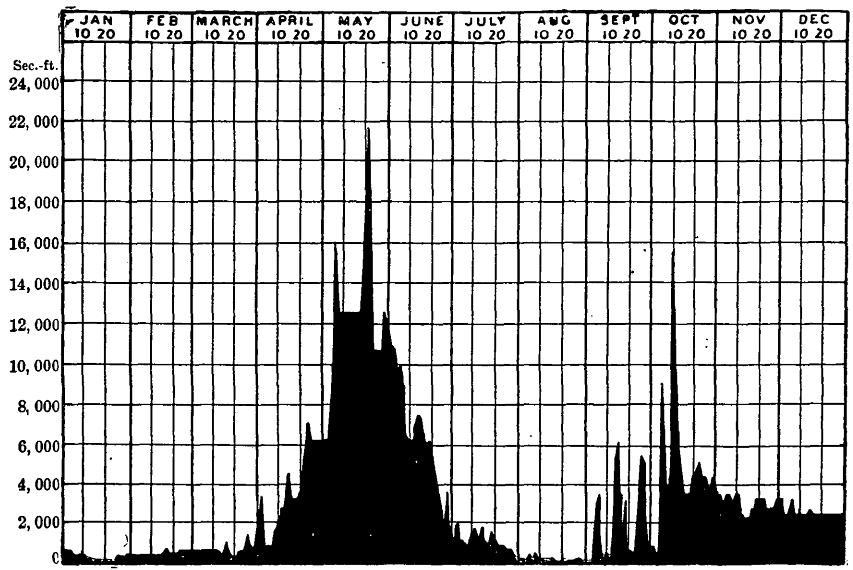


FIG. 132.—Discharge of Rio Grande at San Marcial, New Mexico, 1897.

Rating table for Rio Grande at El Paso, Texas, for 1897. (*a*)

Gage height.	Discharge.		Gage height.	Discharge.	
	Jan. 1 to Apr. 30.	Nov. 1 to Dec. 31.		Jan. 1 to Apr. 30.	Nov. 1 to Dec. 31.
Feet.	*Second-feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Second-feet.*
5.6	30	....	8.4	1,440	1,270
5.8	42	....	8.6	1,680	1,440
6.0	60	....	8.8	1,940	1,610
6.2	90	....	9.0	2,200	1,780
6.4	130	....	9.2	2,470	....
6.6	170	....	9.4	2,740	....
6.8	210	....	9.6	3,010	....
7.0	250	460	9.8	3,280	....
7.2	350	500	10.0	3,550	....
7.4	500	570	10.2	3,820	....
7.6	660	650	10.4	4,090	....
7.8	830	770	10.6	4,360	....
8.0	1,000	930	10.8	4,630	....
8.2	1,200	1,100			

a Discharges from May 1 to October 31 were interpolated.

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.		Depth in inches.	Second-feet per square mile.
1897.						
January	1,260	90	305	18,754	0.011	0.010
February	230	125	194	10,774	0.006	0.006
March	120	30	72	4,427	0.002	0.002
April	4,225	40	1,740	103,537	0.064	0.058
May	17,000	5,000	8,312	511,088	0.320	0.277
June	11,000	2,000	6,095	362,677	0.226	0.203
July	5,300	300	1,330	81,770	0.051	0.044
August	600	0	132	8,116	0.005	0.004
September	2,880	0	705	41,950	0.025	0.023
October	5,000	230	1,758	108,096	0.068	0.059
November	1,695	810	1,132	67,359	0.043	0.038
December	1,015	460	680	41,812	0.026	0.023
The year	17,000	0	1,871	1,360,360	0.847	0.062

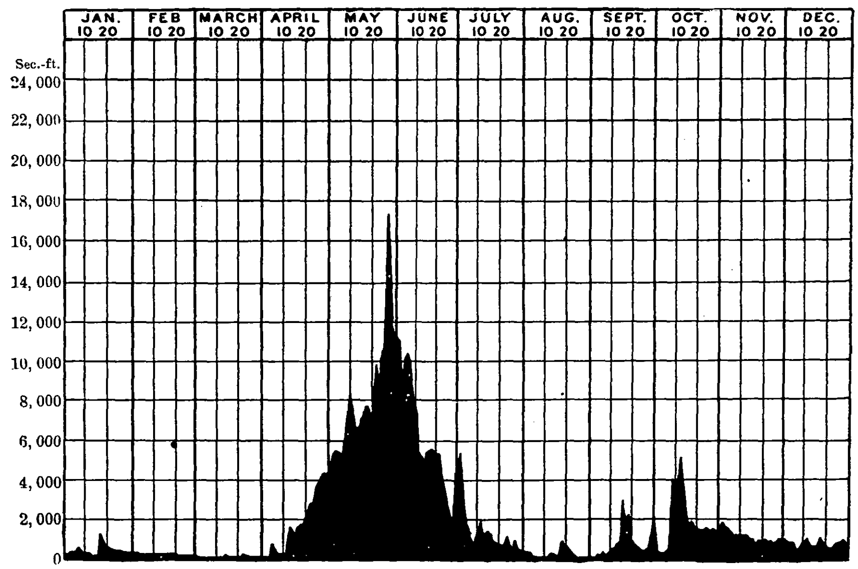


FIG. 133.—Discharge of Rio Grande at El Paso, Texas, 1897.

COLORADO BASIN.

A general description of this basin is given in the Twelfth Annual Report of the Survey, Part II, beginning on page 290. Colorado River is formed by the junction of Green and Grand rivers, about 60 miles south of the gaging station at Blake, Utah, where the Rio Grande

Western Railway crosses the former stream. On October 22, 1897, a sample of water was taken by Prof. J. A. Holmes from the Colorado River at the point where it is reached by Hance's trail from Flagstaff, Arizona. This, upon examination, gave a neutral reaction and contained suspended matter to the amount of 749.65 grains per gallon and dissolved matter 43.38 grains per gallon. At that time the stream was not considered to be unusually muddy.

BLACK FORK.

The station on this tributary is located in the southwest corner of Wyoming, adjoining the Bear River drainage, and it empties into Green River about 20 miles below Greenriver. Irrigation is practiced on the head-water creeks; and around Fort Bridger wheat, oats, and vegetables are raised under the Black Fork canal, the elevation being over 6,500 feet. The stream has a rapid fall and the banks are low, resulting, during high water, in the formation of many sloughs along the bottoms of the creek. This is rather a drawback to the irrigator, for if he constructs a ditch from a slough during one year after the high water of next season his head gates may be left high and dry in an abandoned channel, the water having found a new course through another slough.

Hams Fork is the largest tributary of Black Fork and enters it from the north about 1 mile above Granger. Irrigation is practiced along its length, the water being used for hay ranches. A number of ditches have been abandoned along the lower course of the stream on account of the appropriation of water above. The method of using the water in this basin is very wasteful, the settlers thinking it necessary to flood their lands at the beginning of the irrigating season and to keep them in a partially submerged state until a short time before the cutting. There have been complaints by the settlers on the lower stretches on this account. Hay is the principal crop raised, the climate being too severe for the growing of vegetables and garden truck except along the lower valley. The principal industry for this entire section of country is stock raising, the cattle being ranged on the heights during the summer and driven to the valleys during the winter, when the hay raised in summer is used to feed them. Within recent years bands of sheep have been encroaching on the ranges, compelling many of the cattlemen to seek new country, for sheep, as is well known, almost totally destroy a range for several years.

The gaging station is located at Granger, below all of the principal ditches, it being impossible to locate a station above on account of the distribution of the ditches among the head-water tributaries. The results obtained show the amount of water going to waste that could be utilized for storage purposes. The old station was located 2 miles west of Granger, at the Union Pacific Railroad bridge, and above Hams Fork, so that the results did not include the flow of this latter stream.

On April 28, 1897, the location was abandoned and the station was removed to a point below Hams Fork, and about one-fourth of a mile below Granger. The upper station was at a poor section and inconvenient of access. The new station is equipped with a cable and car, shown in Pl. XXXIX, *A*. The gage rod, as shown in Pl. XXXIX, *B*, is different from the ordinary type. It consists of two vertical 6 by 6 inch posts set firmly into the ground at the edge of the river, and 5 feet apart. A horizontal timber, 4 by 5 inches by 12 feet, is placed on top of the vertical posts with one end projecting out over the water, and braced by a 2 by 4 inch diagonal. To this timber is attached a wire gage with the graduations marked along the top. The advantage of this style of gage is that it is not disturbed by ice and is not liable to be carried out by high water unless a section of the bank is carried away.

The station at Granger is described in Water-Supply and Irrigation Paper No. 16, p. 134, together with the list of discharge measurements and the table of gage heights. Two tables of monthly discharges are given: From January 1 to April 27, 1897, inclusive, which is for the old station above Hams Fork, the rating table, as derived from 1896 measurements, and given in the Eighteenth Annual Report, p. 271, was used; from April 28 to the end of the year the new rating table, herewith published, based on measurements made in 1897, was used. The table of monthly discharges is computed from the latter.

Rating table for Black Fork at Granger, Wyoming.

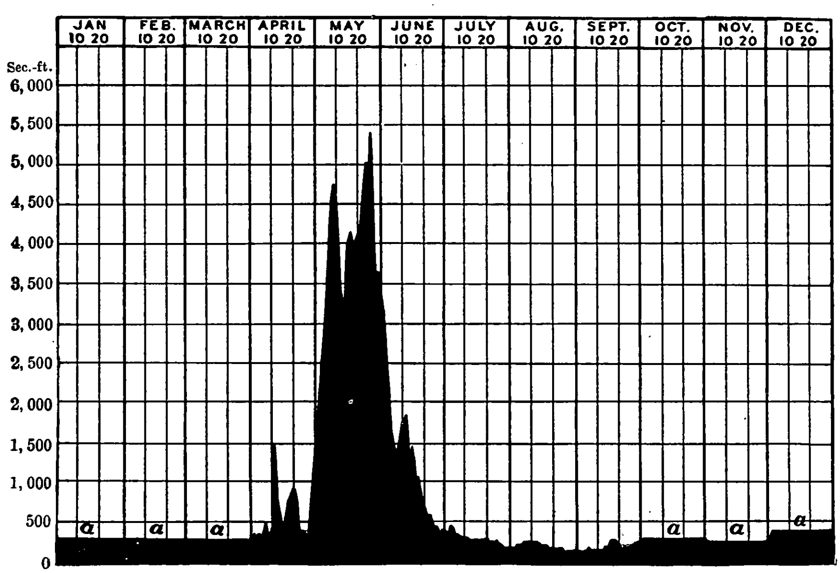
Gage height.	Discharge.		Gage height.	Discharge.	
	Apr. 1, 1896, to Apr. 27, 1897.	Apr. 28 to Dec. 31, 1897.		Apr. 1, 1896, to Apr. 27, 1897.	Apr. 28 to Dec. 31, 1897.
Feet.	*Second-feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Second-feet.*
—0.1	....	150	2.4	....	1,380
0.0	....	155	2.6	215	1,625
0.1	....	170	2.8	260	1,875
0.2	....	190	3.0	315	2,125
0.3	....	210	3.2	365	2,375
0.4	....	230	3.4	425	2,625
0.5	....	250	3.6	500	2,875
0.6	....	270	3.8	570	3,125
0.7	....	290	4.0	650	3,375
0.8	....	320	4.2	745	3,625
0.9	....	350	4.4	830	3,875
1.0	....	390	4.6	930	4,125
1.2	....	470	4.8	1,040	4,375
1.4	....	550	5.0	1,155	4,625
1.6	....	670	5.2	1,300	4,875
1.8	....	830	5.4	1,430	5,125
2.0	....	1,000	5.6	....	5,375
2.2	....	1,180	5.8	....	5,625

Estimated monthly discharge of Black Fork at Granger, Wyoming.

[Drainage area, 1,747 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January			a 285	17,524	0.14	0.12
February			a 285	15,828	0.12	0.12
March			a 285	17,524	0.14	0.12
April	1,500	285	645	38,380	0.30	0.27
May	5,375	1,875	3,881	238,635	1.87	1.62
June	3,375	410	1,274	75,808	0.59	0.53
July	470	190	294	18,077	0.14	0.12
August	230	155	190	11,683	0.09	0.08
September	250	150	182	10,830	0.08	0.08
October			a 300	18,446	0.15	0.13
November			a 260	15,471	0.12	0.11
December			a 400	24,595	0.20	0.17
The year			690	502,801	3.94	0.29

a Approximate.



a Approximate.

FIG. 134.—Discharge of Black Fork at Granger, Wyoming, 1897.

GREEN RIVER.

Green River has its source in the Wind River and Gros Ventre Mountains, in western Wyoming, and flows southward, draining a large area of mountainous country. The principal industry of this section is stock raising, the little irrigation practiced being confined to hay ranches along the bottom of the creeks. In the southwestern corner of Fremont County and the northwestern corner of Sweetwater County is a large plateau bounded by Green River on the west and Big Sandy Creek on the south, averaging 7,000 feet in elevation. If this land could be irrigated it could be well utilized for forage crops and for the cereals, but as it lies high above the bed of the river the cost of bringing water would be considerable.

The upper gaging station on this river is located at Greenriver, Wyoming, at the crossing of the Union Pacific Railroad, and is described in Water-Supply and Irrigation Paper No. 16, p. 136. As the river below here in this State runs through a bad-lands section not suitable for cultivation, measurements at the gaging station represent the amount of water flowing out of the State.

The next important tributary of Green River below Black Fork is Yampa River. The drainage area is almost entirely included in the northwestern corner of the State of Colorado, a small area being drained outside—that of Little Snake River, in Wyoming. The drainage basin of Yampa River is very sparsely settled and little irrigation is practiced in its limits.

The next two important tributaries of Green River below the Yampa are Duchesne River, entering from the west, and White River, entering from the east. The mouths of these two streams are only a few miles apart. The northern tributaries of Duchesne River have their source in the Uinta Mountains. The entire drainage basin of the main river is comprised within the Uinta Indian Reservation and includes some very fine irrigable lands, but at the present time only a small area is under cultivation. This Indian reservation has already been subdivided, and land has been allotted to the Indians residing within its borders, but it has not as yet been thrown open to settlement. During the last year, however, a commission, appointed by the General Government, has been trying to draw up a treaty with the Indians, the main object of which is to purchase the greater portion of the reservation, leaving to the Indians the land that has already been allotted to them. When this area is thrown open some fine land with a good water supply will be available.

Price River is a large tributary of Green River draining a section of central Utah, and entering the main river about 15 miles above Blake. Little irrigation is practiced within its drainage basin.

A gaging station has been maintained at Blake, or Greenriver postoffice, Utah, at the crossing of the Rio Grande Western Railway, and is described in detail in Water-Supply and Irrigation Paper No. 16, p. 136.

The area drained by Green River, distributed by States, is as follows: Wyoming, 20,977 square miles; Colorado, 10,332 square miles; Utah, 15,916 square miles; total at its mouth, 47,225 square miles.

Rating table for Green River at Greenriver, Wyoming, for 1897.

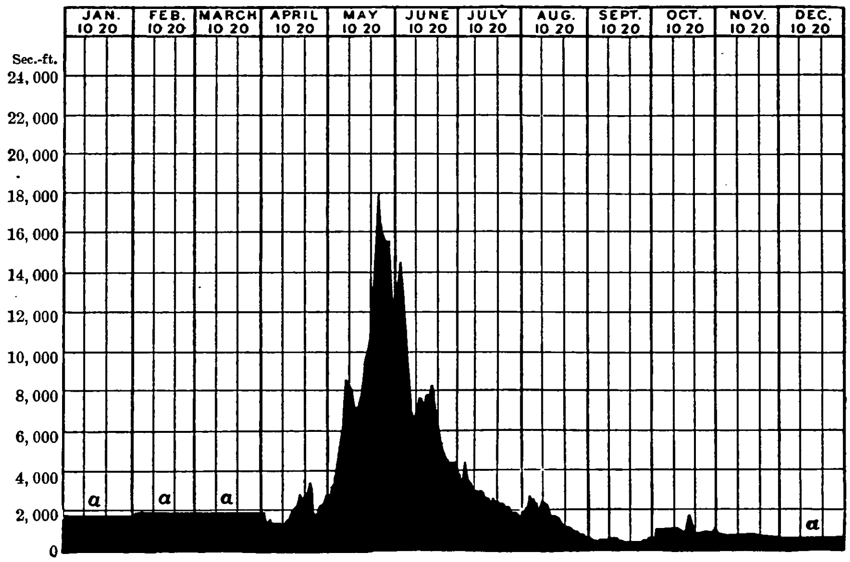
Gage height.	Discharge.		Gage height.	Discharge.	
	Jan. 1 to May 31.	June 1 to Dec. 31.		Jan. 1 to May 31.	June 1 to Dec. 31.
Feet.	*Second-feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Second-feet.*
0.9	400	400	3.4	7,080	6,240
1.0	500	500	3.6	7,960	7,200
1.2	800	800	3.8	8,840	8,160
1.4	1,120	1,120	4.0	9,720	9,120
1.6	1,440	1,440	4.2	10,600	10,080
1.8	1,760	1,760	4.4	11,480	11,040
2.0	2,080	2,080	4.6	12,360	12,000
2.2	2,400	2,400	4.8	13,240	12,960
2.4	2,850	2,800	5.0	14,120	13,920
2.6	3,600	3,200	5.2	15,000	....
2.8	4,440	3,650	5.4	15,880	....
3.0	5,320	4,400	5.6	16,760	....
3.2	6,200	5,280	5.8	17,640	....

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.		Depth in inches.	Second-feet per square mile.
1897.						
January	....	....	*a* 1,800	110,678	0.28	0.24
February	....	....	*a* 1,900	105,520	0.27	0.26
March	....	....	*a* 1,900	116,827	0.30	0.26
April	3,200	1,200	1,958	116,509	0.29	0.26
May	17,860	2,725	9,769	600,676	1.51	1.31
June	14,400	4,400	7,548	449,136	1.13	1.01
July	4,400	1,760	2,794	171,797	0.43	0.37
August	2,500	640	1,603	98,565	0.25	0.22
September	640	400	462	27,491	0.07	0.06
October	1,760	500	1,013	62,287	0.16	0.14
November	880	600	760	45,223	0.11	0.10
December	....	....	*a* 600	36,893	0.09	0.08
The year	....	....	2,676	1,941,602	4.89	0.36

a Approximate.



a Approximate.

FIG. 135.—Discharge of Green River at Greenriver, Wyoming, 1897.

The following table gives the list of discharge measurements made on Green River at Blake, Utah. The principal facts are also shown in the accompanying figure (fig. 136), in which vertical distances represent height of water on the gage and horizontal distances the quantity of discharge. The plotted points obtained by measurement are shown by the small circles, which are numbered to correspond with the figures in the left-hand column of the table. Near or through these is drawn a smooth curve, from which the values for the rating table have been obtained.

List of discharge measurements made on Green River at Blake, Utah.

No.	Date.	Hydrographer.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
				Feet.	*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
1	Oct. 21, 1894	A. P. Davis	22	2.48	1,660	1.83	3,035
2	June 30, 1895	.....do	55	5.80	3,397	4.43	15,065
3	Sept. 29, 1895	.....do	55	2.00	1,423	1.40	1,938
4	Nov. 9, 1896	C. C. Babb	63	2.33	1,416	1.37	1,940
5	Apr. 21, 1897	.....do	70	4.88	2,556	3.20	8,175
6	May 22, 1897	W. B. Dougall	7	10.10	5,456	10.24	55,886
7	Nov. 22, 1897	C. C. Babb	74	2.80	1,870	1.80	3,373

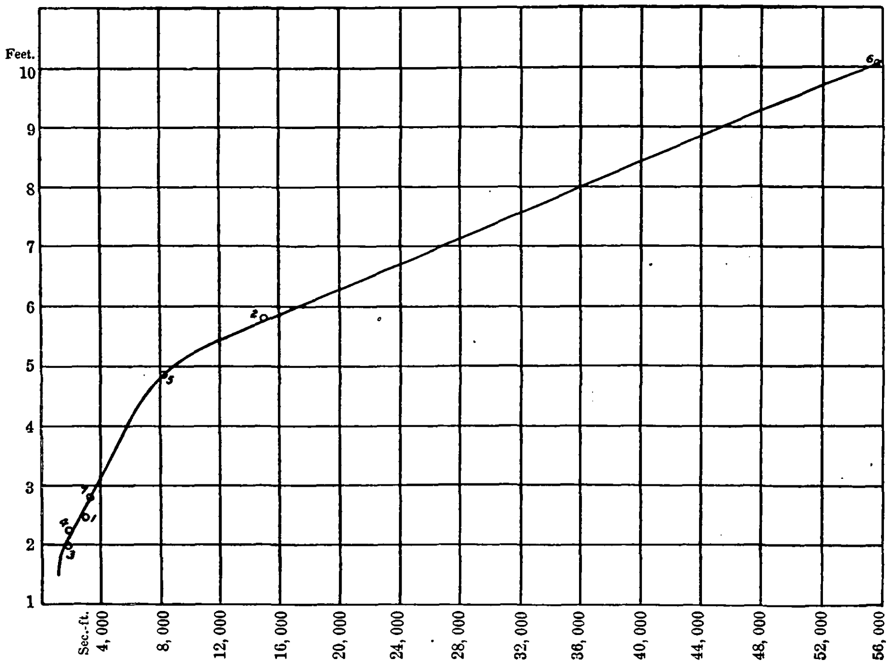


FIG. 136.—Rating curve for Blake station on Green River, Utah.

Rating table for Green River at Blake, Utah, for 1897.

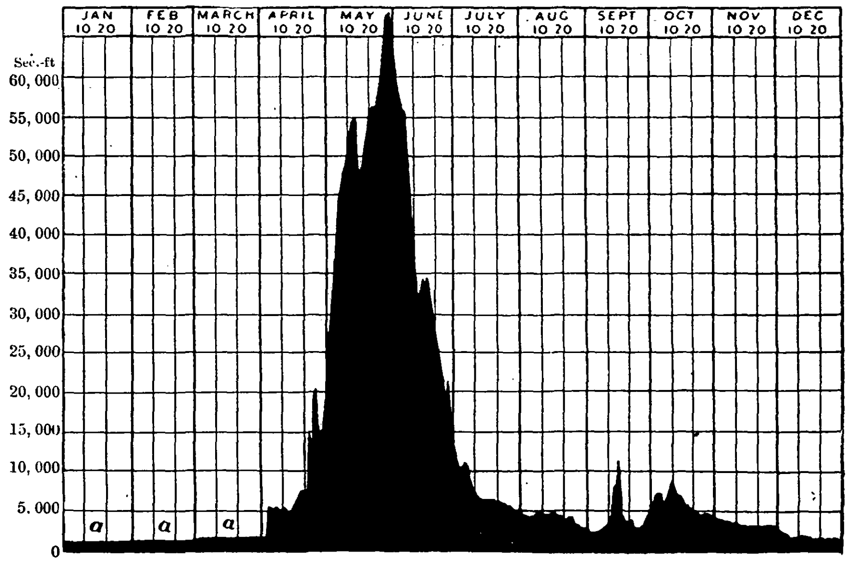
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.0	1,000	3.0	3,700	5.0	9,000	7.0	27,000
1.2	1,080	3.2	4,120	5.2	10,200	7.5	31,750
1.4	1,160	3.4	4,540	5.4	11,800	8.0	36,500
1.6	1,250	3.6	4,960	5.6	13,700	8.5	41,250
1.8	1,400	3.8	5,380	5.8	15,600	9.0	46,000
2.0	1,600	4.0	5,800	6.0	17,500	9.5	50,750
2.2	2,020	4.2	6,220	6.2	19,400	10.0	55,500
2.4	2,440	4.4	6,640	6.4	21,300	10.5	60,250
2.6	2,860	4.6	7,300	6.6	23,200	11.0	65,000
2.8	3,280	4.8	8,100	6.8	25,100		

Estimated monthly discharge of Green River at Blake, Utah.

[Drainage area, 38,200 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January			a1,300	79,934	0.03	0.03
February			a1,500	83,306	0.04	0.04
March			a1,700	104,530	0.04	0.04
April	20,350	4,750	9,133	543,452	0.27	0.24
May	68,800	24,625	51,531	3,168,517	1.56	1.35
June	60,725	15,125	34,838	2,073,000	1.01	0.91
July	13,225	4,540	7,047	433,306	0.21	0.18
August	4,750	2,440	3,788	232,917	0.12	0.10
September	11,000	2,020	3,682	219,094	0.11	0.10
October	8,300	4,120	5,768	354,663	0.17	0.15
November	4,120	3,070	3,459	205,824	0.10	0.09
December	2,860	1,040	1,456	89,527	0.04	0.04
The year			10,434	7,588,070	3.70	0.27

a Approximate.



a Approximate.

FIG. 137.—Discharge of Green River at Blake, Utah, 1897.

GRAND RIVER.

This tributary of Colorado River drains an area of 22,294 square miles in Colorado, being 21 per cent of the total area of the State. It rises north of the central portion of the State, adjoining the head waters of the North and South Platte and the Arkansas rivers. It receives its water supply from a long stretch of the western slope of the Rocky Mountains forming the continental divide. A record of the gage heights of Grand River was kept for a short period in 1897 by the Denver and Rio Grande Railroad Company at Shoshone, 10 miles east of Glenwood Springs and a short distance below the mouth of Eagle River. No discharge measurements were made at the point however. This station is described in Water-Supply and Irrigation Paper No. 16, p. 137.

The gaging station at Grand Junction has been maintained throughout the year, with results as shown in the accompanying tables. This station is also described in Water-Supply and Irrigation Paper No. 16, p. 137.

The river at the gaging station discharges through two channels, and it has been found necessary to rate these two channels separately in order to get an accurate record of daily discharge. Two sets of rod readings were maintained, known as records for rod No. 1 for the right channel, and for rod No. 2 for the left channel. To obtain the total discharge of the river the discharge for the two channels have been added.

The bluffs on Grand River, as well as those on the Gunnison, are from 80 to 90 feet above the river. The section included between the two streams in the vicinity of Grand Junction is fairly level, and a portion of it is under cultivation. The water supply is furnished by a number of pumping plants, and those in successful operation at the present time are operated by water power. Several plants which depended on steam power have been abandoned, as it was found that the cost of operating them was greater than the returns from the products. The most successful style of pump seems to be the rotary type, when built solidly and fitted to the need of an irrigation plant. It will lift water to any height if the power is sufficient, in distinction from the ordinary centrifugal pump. The efficiency of the latter style rapidly decreases for lifts above 35 or 40 feet. Mr. Charles N. Cox has successfully irrigated a considerable area with water pumped from Grand River. He has constructed a canal one-half mile long, giving him at the lower end a head of from 9 to 12 feet, according to the stage of water in the river. The capacity of the canal is 1,000 second-feet. The power is supplied by a 44-inch Victor turbine wheel, generating 109 horsepower. Two pumps are in use, one a Smith-Vaile 16 by 18 inch piston pump and the other a 14-inch Root's modified rotary pump. The capacity of each is 2,000 gallons per minute. The lift is 84 feet, and 400 acres of orchard land were irrigated in 1896. The machinery for such a plant as is here described costs about $5,000 outside of the expense of the construction of a canal. The labor of one man, and sometimes two men, is required to operate the plant. The annual cost under this system is from $1.25 to $1.75 per acre.

Another plant near by uses two centrifugal pumps in tandem, with a total lift of 80 feet, so that each pump lifts water 40 feet. They are 8-inch centrifugals, with a discharge pipe of the same size. On account of the friction, it would have been better to have used a 12-inch discharge pipe with an 8-inch pump. The canal for furnishing the power is two-thirds of a mile long and cost about $6,000. The machinery, consisting of two pumps, turbine wheels, connections, and piping, cost about $3,000. The discharge is 1,400 gallons per minute, sufficient to irrigate 240 acres.

Rating table for Grand River at Grand Junction, Colorado, for 1897.

Gage height.	Discharge.		Gage height.	Discharge.	
	Right channel.	Left channel.		Right channel.	Left channel.
Feet.	*Second-feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Second-feet.*
0.0	0	....	4.2	9,008	1,940
0.1	15	....	4.4	9,649	2,200
0.2	32	....	4.6	10,290	2,500
0.3	50	....	4.8	10,931	2,800
0.4	70	....	5.0	11,571	3,200
0.5	92	....	5.2	12,211	3,600
0.6	114	....	5.4	12,852	4,050
0.7	137	....	5.6	13,492	4,550
0.8	164	....	5.8	14,132	5,150
0.9	200	....	6.0	....	5,820
1.0	250	....	6.2	....	6,628
1.2	370	....	6.4	....	7,456
1.4	520	....	6.6	....	8,284
1.6	790	....	6.8	....	9,112
1.8	1,317	....	7.0	....	9,940
2.0	1,957	....	7.2	....	10,768
2.2	2,598	....	7.4	....	11,596
2.4	3,239	....	7.6	....	12,424
2.6	3,880	....	7.8	....	13,252
2.8	4,521	900	8.0	....	14,080
3.0	5,162	1,020	8.5	....	16,150
3.2	5,803	1,150	9.0	....	18,220
3.4	6,444	1,280	9.5	....	20,290
3.6	7,085	1,420	10.0	....	22,360
3.8	7,726	1,560	10.5	....	24,430
4.0	8,367	1,720	11.0	....	26,500

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.		Depth in inches.	Second-feet per square mile.
1897.						
January			a 1,000	61,488	0.14	0.12
February			a 1,050	58,314	0.12	0.12
March			a 1,100	67,637	0.15	0.13
April	11,476	1,280	3,723	221,534	0.48	0.43
May	37,950	12,785	29,436	1,809,948	3.93	3.41
June	37,008	15,618	25,350	1,508,429	3.27	2.93
July	15,606	3,400	8,830	542,935	1.18	1.02
August	5,470	1,720	3,000	184,463	0.40	0.35
September	2,650	1,640	1,803	107,286	0.23	0.21
October	2,350	1,560	1,813	111,478	0.24	0.21
November	1,820	1,455	1,663	98,955	0.21	0.19
December			a 1,550	95,306	0.21	0.18
The year			6,693	4,867,773	10.56	0.78

a Approximate.

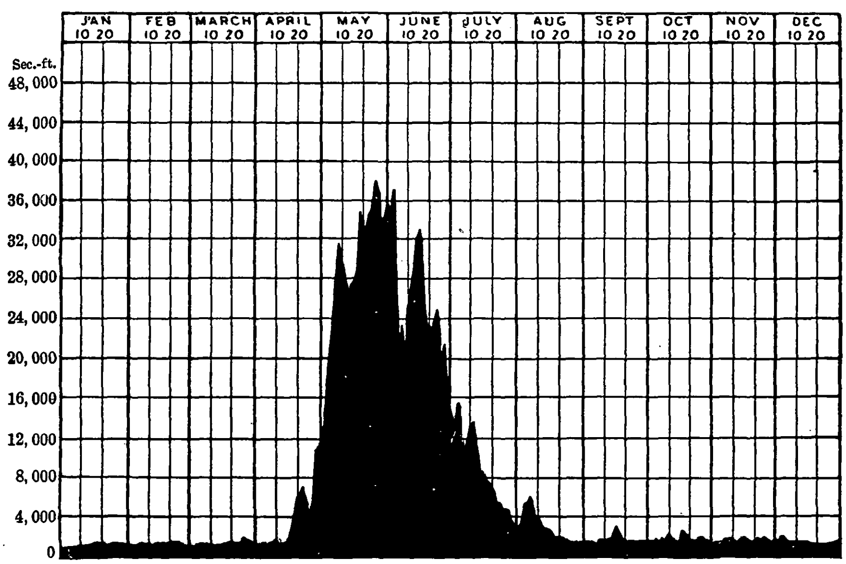


FIG. 138.—Discharge of Grand River at Grand Junction, Colorado, 1897.

UNCOMPAHGRE RIVER.

In the following list are given the results of measurements of discharge of Uncompahgre River at Fort Crawford, most of these being shown graphically in fig. 139, in which vertical distances represent height of water and horizontal distances the discharge in cubic feet per second. The points obtained by the discharge measurements do not lie along the path of any one curve, and indicate that the relation between gage height and discharge has not been permanent. Two curves have, therefore, been sketched, the lower being applicable from April 1 to June 8, the upper for the remainder of the year.

List of discharge measurements made on Uncompahgre River at Fort Crawford, Colorado.

No.	Date.	Hydrographer.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
	1895.			*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec. feet.*
1	June 24	F. Cogswell	55	4.00	104	4.90	512
2	Aug. 27	do	14	3.20	66	3.08	205
3	Oct. 8	do	14	2.65	36	2.24	81
	1896.						
4	May 12	do	14	3.75	97	3.70	360
5	June 16	do	14	3.45	78	3.72	290
6	July 20	do	14	3.15	62	2.82	175
7	Aug. 23	do	14	2.60	36	1.72	62
8	Sept. 22	do	14	2.75	41	2.07	85
a 9	Oct. 20	do	14	2.60	35	1.80	63
	1897.						
10	Apr. 18	do	63	3.90	103	4.73	487
11	May 10	do	63	4.55	156	5.67	884
12	June 21	do	63	5.05	189	5.72	1,081
13	July 19	do	63	4.50	119	3.97	473
14	Aug. 23	do	63	3.45	47	1.49	70
15	Sept. 20	do	63	3.85	48	3.19	153
16	Oct. 18	do	63	4.00	54	3.61	195

a Same as No. 7.

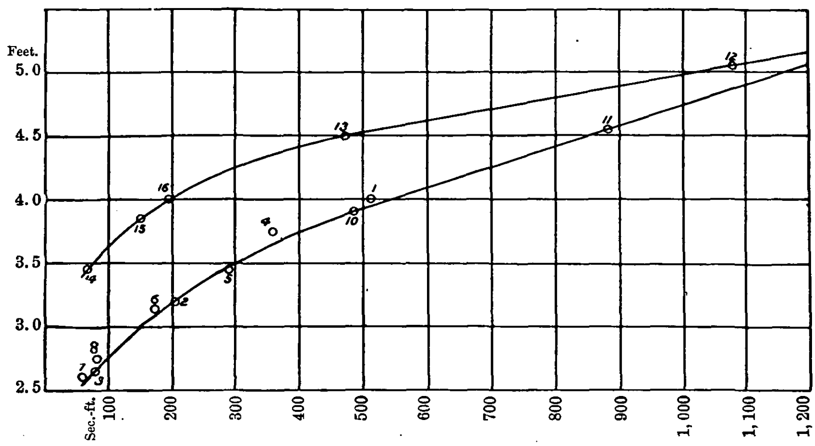


FIG. 139.—Rating curve for Fort Crawford station, on Uncompahgre River, Colorado.

Rating table for Uncompahgre River at Fort Crawford, Colorado, for 1897.

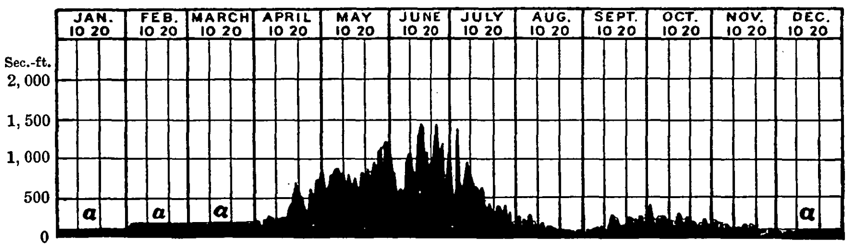
Gage height.	Discharge.		Gage height.	Discharge.	
	Apr. 1 to June 8.	June 9 to Nov. 27.		Apr. 1 to June 8.	June 9 to Nov. 27.
Feet.	*Second-feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Second-feet.*
3.0	151	....	4.4	790	396
3.2	200	....	4.6	913	583
3.4	264	62	4.8	1,035	804
3.6	344	95	5.0	1,158	1,025
3.8	435	138	5.2	1,281	1,246
4.0	545	195	5.4	1,403	1,467
4.2	667	274			

Estimated monthly discharge of Uncompahgre River at Fort Crawford, Colorado.

[Drainage area, 497 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January			a 100	6,149	0.23	0.20
February			a 150	8,314	0.31	0.30
March			a 150	9,223	0.35	0.30
April	790	141	391	23,267	0.88	0.79
May	1,158	575	823	50,604	1.91	1.66
June	1,467	514	974	57,957	2.19	1.96
July	1,412	151	529	32,527	1.22	1.06
August	274	55	137	8,424	0.32	0.28
September	274	55	146	8,688	0.32	0.29
October	360	138	204	12,544	0.47	0.41
November	179	95	126	7,498	0.28	0.25
December			a 100	6,149	0.23	0.20
The year			319	231,344	8.71	0.64

a Approximate.



a Approximate.

FIG. 140.—Discharge of Uncompahgre River at Fort Crawford, Colorado, 1897.

GUNNISON RIVER.

This is the largest tributary of the Grand, and drains a section of country adjoining it on the south. The sources of the eastern tributaries are also on the western slope of the continental divide.

A record of heights of Gunnison River for a short period in 1897 was kept by the Denver and Rio Grande Railroad Company at two points: First, at Roubideau station, at the railroad bridge 6 miles west of Delta, Colorado; second, at Whitewater station, 13 miles southeast of Grand Junction. Measurements of discharge were not made at either of these points. The regular Survey gaging station is located at the highway bridge, 1 mile above its mouth, at Grand Junction, Colorado, and is described in Water-Supply and Irrigation Paper No. 16, p. 137.

Rating table for Gunnison River at Grand Junction, Colorado, 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.5	160	2.8	1,850	4.6	6,000	6.2	12,248
1.6	230	3.0	2,210	4.8	6,640	6.4	13,056
1.7	330	3.2	2,600	5.0	7,400	6.6	13,864
1.8	440	3.4	3,000	5.2	8,208	6.8	14,672
1.9	550	3.6	3,420	5.4	9,016	7.0	15,480
2.0	670	3.8	3,860	5.6	9,824	7.5	17,500
2.2	930	4.0	4,320	5.8	10,632	8.0	19,520
2.4	1,200	4.2	4,880	6.0	11,440	8.5	21,540
2.6	1,510	4.4	5,370				

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.		Depth in inches.	Second-feet per square mile.
1897.						
May	20,732	11,844	16,921	1,040,438	2.46	2.13
June	19,116	5,370	11,161	664,124	1.57	1.41
July	5,370	1,510	3,231	198,668	0.47	0.41
August	1,850	160	975	59,951	0.14	0.12
September	1,510	160	628	37,369	0.09	0.08
October	2,020	1,060	1,472	90,510	0.22	0.19
November	1,200	230	933	55,517	0.13	0.12

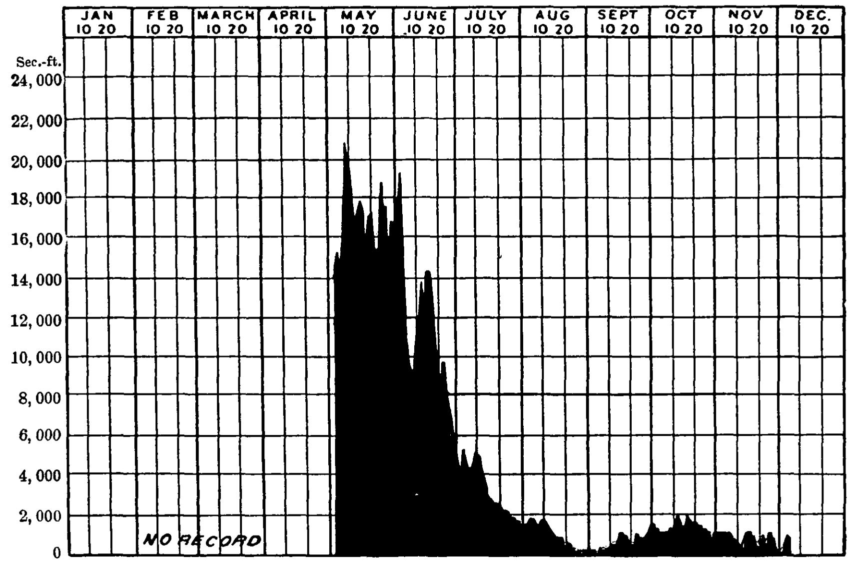


FIG. 141.—Discharge of Gunnison River at Grand Junction, Colorado, 1897.

SAN MIGUEL RIVER.

In the basin of the San Miguel irrigation is practiced to a considerable extent, but mainly by small private ditches. A gaging station has been maintained on the San Miguel at Fall Creek, near Sawpit. This is described in Water-Supply and Irrigation Paper No. 16, p. 142.

Rating table for San Miguel River at Fall Creek, Colorado, 1897.

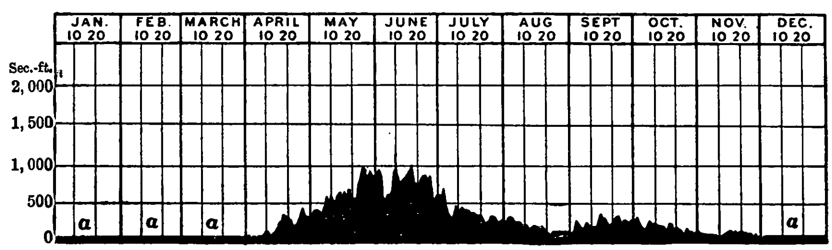
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.3	57	3.0	177	3.7	388	4.4	792
2.4	68	3.1	201	3.8	433	4.5	860
2.5	81	3.2	228	3.9	480	4.6	928
2.6	95	3.3	258	4.0	531	4.7	997
2.7	113	3.4	288	4.1	587		
2.8	132	3.5	319	4.2	655		
2.9	154	3.6	352	4.3	723		

Estimated monthly discharge of San Miguel River at Fall Creek, Colorado.

[Drainage area, 327 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	....	....	a 60	3, 689	0.21	0.18
February	....	....	a 60	3, 332	0.19	0.18
March	....	....	a 60	3, 689	0.21	0.18
April	433	52	213	12, 674	0.72	0.65
May	962	369	626	38, 491	2.20	1.91
June	997	504	774	46, 056	2.64	2.37
July	621	243	375	23, 058	1.33	1.15
August	288	122	183	11, 252	0.64	0.56
September	304	132	215	12, 793	0.73	0.66
October	273	122	184	11, 314	0.64	0.56
November	132	62	96	5, 712	0.32	0.29
December	....	....	a 75	4, 612	0.26	0.23
The year	....	....	243	176, 672	10.09	0.74

a Approximate.



a Approximate.

FIG. 142.—Discharge of San Miguel River at Fall Creek, Colorado, 1897.

DOLORES RIVER.

Dolores River is the last important tributary of Grand River. It has its source in the La Plata and San Miguel Mountains and flows in a northwest direction, crossing the State line into Utah, where it shortly enters the Grand. Two gaging stations have been maintained within the basin, one near Sawpit at Fall Creek, on the San Miguel, already mentioned, and the other on the Dolores, at the town of Dolores. The station on the Dolores is described in Water-Supply and Irrigation Paper No. 16, p. 143. From Dolores River, besides the smaller ditches for irrigating purposes, there are also taken out one or two of larger dimensions, especially in the vicinity of Dolores. One system takes water from the left side of the river in two directions, the lower branch irrigating lands to the northwest. The canal from the left bank shortly enters the ridge forming the divide between the Dolores and the head waters of certain tributaries of the San Juan and irrigates lands in the vicinity of Cortez, in the drainage basin of the latter stream.

Rating table for Dolores River at Dolores, Colorado, 1897.

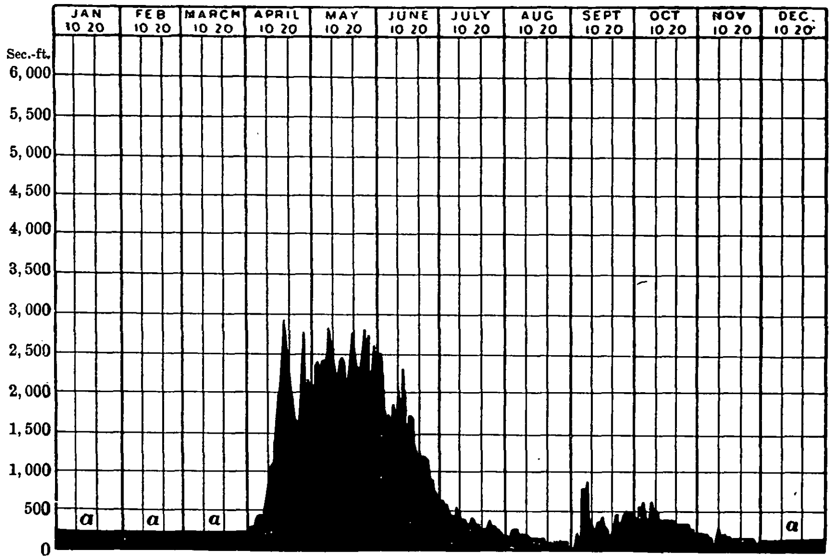
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.6	76	3.4	462	4.1	1,026	4.8	1,726
2.7	108	3.5	534	4.2	1,120	4.9	1,832
2.8	145	3.6	608	4.3	1,216	5.0	1,938
2.9	186	3.7	688	4.4	1,312	5.2	2,150
3.0	235	3.8	768	4.5	1,408	5.4	2,362
3.1	286	3.9	852	4.6	1,514	5.6	2,574
3.2	338	4.0	938	4.7	1,620	5.8	2,785
3.3	396						

Estimated monthly discharge of Dolores River at Dolores, Colorado.

[Drainage area, 562 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January			*a* 200	12,298	0.42	0.36
February			*a* 200	11,107	0.37	0.36
March			*a* 200	12,298	0.42	0.36
April	2,944	235	1,483	88,244	2.94	2.64
May	2,838	1,991	2,436	149,785	5.00	4.33
June	2,521	570	1,465	87,173	2.91	2.61
July	608	186	368	22,628	0.75	0.65
August	235	76	148	9,100	0.30	0.26
September	852	76	394	23,445	0.78	0.70
October	570	235	391	24,042	0.81	0.70
November	235	108	172	10,235	0.35	0.31
December			*a* 120	7,379	0.24	0.21
The year			631	457,734	15.29	1.12

a Approximate.



a Approximate.

FIG. 143.—Discharge of Dolores River at Dolores, Colorado, 1897.

SAN JUAN RIVER.

The tributaries of San Juan River drain the southwestern corner of Colorado and have a general southerly course, crossing the State line into New Mexico, where they join the main river, which thence has a westerly course through New Mexico and into Utah, where the river enters the Colorado in the Grand Canyon region. The gaging stations maintained in this basin are as follows: Arboles station, on the San Juan River, a short distance above the mouth of Piedra River; Arboles station, on Piedra River, a short distance above its mouth; and Durango station, on Animas River. The field work at these stations in 1897 is described in Water-Supply and Irrigation Paper No. 16, pp. 144, 145, and 146, respectively.

Rating table for San Juan River at Arboles, Colorado, 1897.

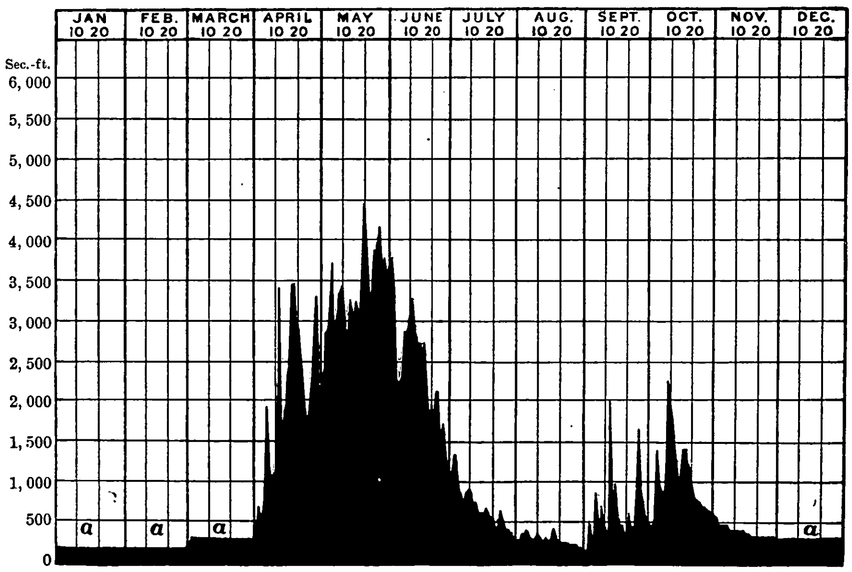
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
5.7	182	6.5	478	7.3	1,135	8.2	2,431
5.8	208	6.6	534	7.4	1,260	8.4	2,726
5.9	234	6.7	596	7.5	1,400	8.6	3,022
6.0	263	6.8	664	7.6	1,546	8.8	3,316
6.1	300	6.9	738	7.7	1,693	9.0	3,612
6.2	340	7.0	820	7.8	1,841	9.5	4,349
6.3	382	7.1	915	7.9	1,998		
6.4	428	7.2	1,020	8.0	2,136		

Estimated monthly discharge of San Juan River at Arboles, Colorado.

[Drainage area, 1,394 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January			*a* 200	12, 298	0.16	0.14
February			*a* 200	11, 107	0.15	0.14
March			*a* 300	18, 446	0.24	0.21
April	3, 464	478	1, 987	118, 234	1.58	1.42
May	4, 423	2, 431	3, 393	208, 629	2.80	2.43
June	3, 759	1, 020	2, 311	137, 513	1.85	1.66
July	1, 328	340	685	42, 119	0.56	0.49
August	404	182	303	18, 631	0.25	0.22
September	1, 998	182	607	36, 119	0.49	0.44
October	2, 210	478	1, 019	62, 656	0.84	0.73
November	534	300	396	23, 564	0.31	0.28
December			*a* 300	18, 446	0.24	0.21
The year			975	707, 762	9.47	0.70

a Approximate.



a Approximate.

FIG. 144.—Discharge of San Juan River at Arboles, Colorado, 1897.

PIEDRA RIVER.

The following table gives the list of discharge measurements made on Piedra River at Arboles, Colorado. The principal facts are also shown in the accompanying figure (fig. 145), in which vertical distances represent height of water on the gage and horizontal distances the quantity of discharge. The plotted points obtained by measurement are shown by the small circles, which are numbered to correspond with the figures in the left-hand column of the table. Near or through these is drawn a smooth curve, from which the values for the rating table have been obtained.

List of discharge measurements made on Piedra River at Arboles, Colorado.

No.	Date.	Hydrographer.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
	1896.			*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
1	May 18	F. Cogswell........	14	3.90	182	2.99	544
2	June 20	.....do	14	2.90	90	1.21	109
3	July 24	.....do	14	3.05	107	1.77	189
4	Sept. 27	.....do	14	3.70	161	2.51	405
5	Oct. 25	.....do	14	3.00	104	1.72	179
	1897.						
6	Apr. 24	.....do	63	5.20	317	4.51	1,429
7	May 15	.....do	63	5.65	352	4.63	1,629
8	June 26	.....do	63	4.20	212	3.19	677
9	July 24	.....do	63	3.10	104	2.21	230
10	Aug. 28	.....do	63	2.60	62	1.05	65
11	Sept. 25	.....do	63	4.15	202	3.34	675
12	Oct. 23	.....do	63	4.00	181	3.24	586

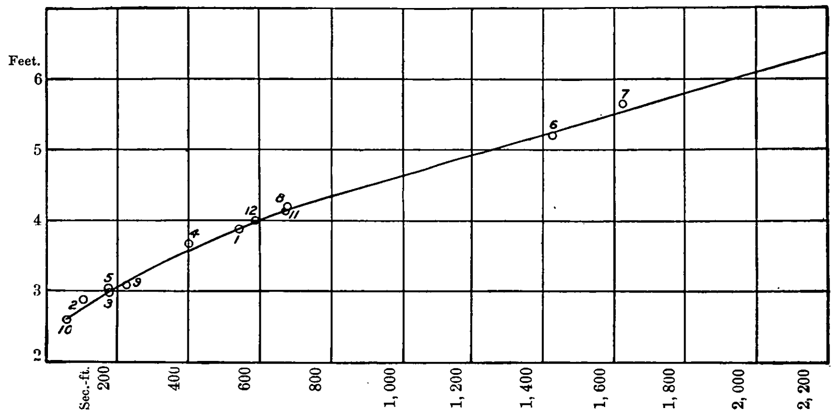


FIG. 145.—Rating curve for Arboles station on Piedra River, Colorado.

Rating table for Piedra River at Arboles, Colorado, for 1897.

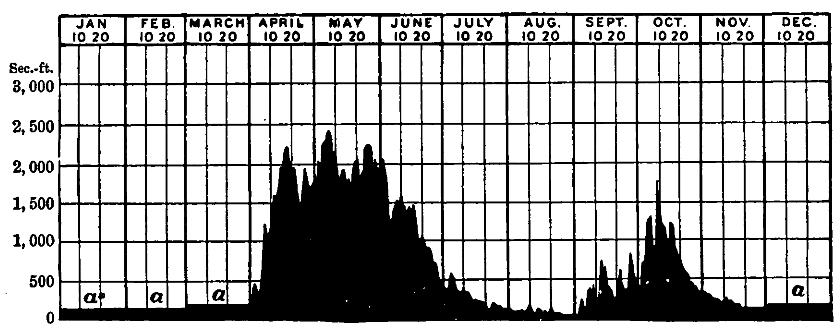
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.6	68	3.4	324	4.2	694	5.0	1,251
2.7	96	3.5	364	4.3	764	5.2	1,390
2.8	124	3.6	404	4.4	833	5.4	1,529
2.9	152	3.7	445	4.5	903	5.6	1,668
3.0	183	3.8	487	4.6	972	5.8	1,807
3.1	215	3.9	534	4.7	1,042	6.0	1,946
3.2	249	4.0	585	4.8	1,112	6.5	2,294
3.3	286	4.1	637	4.9	1,181		

Estimated monthly discharge of Piedra River at Arboles, Colorado.

[Drainage area, 650 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January			*a* 150	9,223	0.26	0.23
February			*a* 150	8,331	0.24	0.23
March			*a* 200	12,298	0.36	0.31
April	2,190	344	1,460	86,876	2.51	2.25
May	2,398	1,703	2,025	124,513	3.60	3.12
June	2,051	487	1,189	70,750	2.04	1.83
July	585	152	296	18,200	0.53	0.46
August	168	68	106	6,518	0.18	0.16
September	799	68	399	23,742	0.68	0.61
October	1,772	364	840	51,650	1.49	1.29
November	364	183	241	14,340	0.41	0.37
December			*a* 200	12,298	0.36	0.31
The year			605	468,999	12.66	0.93

a Approximate.



a Approximate.

FIG. 146.—Discharge of Piedra River at Arboles, Colorado, 1897.

ANIMAS RIVER.

Rating table for Animas River at Durango, Colorado, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
4.9	230	5.9	780	6.9	1,500	7.9	2,500
5.0	275	6.0	840	7.0	1,580	8.0	2,620
5.1	325	6.1	900	7.1	1,670	8.2	2,900
5.2	375	6.2	970	7.2	1,760	8.4	3,225
5.3	425	6.3	1,040	7.3	1,850	8.6	3,580
5.4	480	6.4	1,110	7.4	1,950	8.8	3,970
5.5	540	6.5	1,180	7.5	2,050	9.0	4,370
5.6	600	6.6	1,260	7.6	2,150	9.5	5,370
5.7	660	6.7	1,340	7.7	2,260	10.0	6,370
5.8	720	6.8	1,420	7.8	2,380		

Estimated monthly discharge of Animas River at Durango, Colorado.

[Drainage area, 812 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January			*a* 310	19,061	0.44	0.38
February			*a* 284	15,773	0.36	0.35
March			*a* 374	22,997	0.53	0.46
April	4,770	690	2,608	155,186	3.58	3.21
May	5,870	3,400	4,498	276,573	6.40	5.54
June	5,170	1,715	3,218	191,484	4.42	3.96
July	1,715	660	1,120	68,867	1.59	1.38
August	780	325	534	32,835	0.76	0.66
September	1,340	275	875	52,066	1.20	1.08
October	2,205	780	1,385	85,160	1.97	1.71
November	720	375	553	32,905	0.75	0.68
December			*a* 430	26,440	0.61	0.53
The year			1,349	979,347	22.61	1.66

a Approximate.

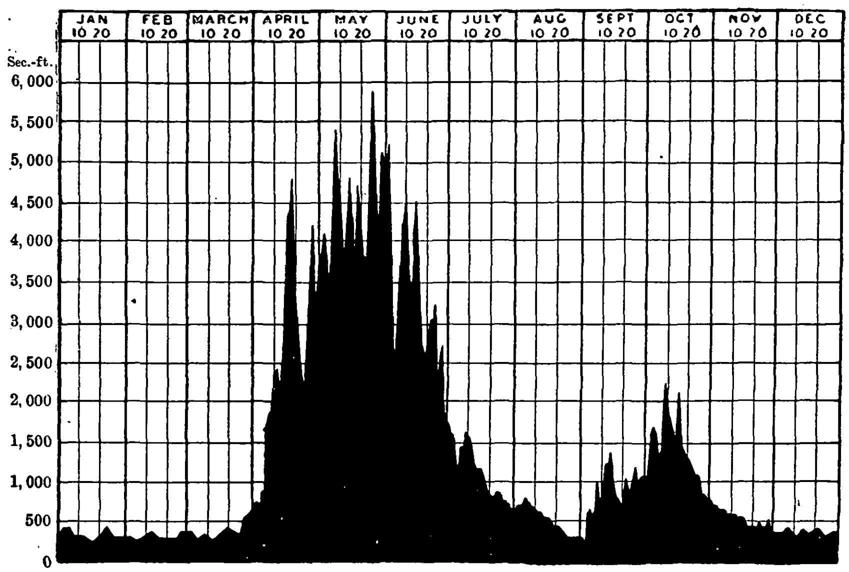


FIG. 147.—Discharge of Animas River at Durango, Colorado, 1897.

GILA RIVER.

The gaging station on this river is located at the Buttes, 16 miles above Florence, Arizona, at the mouth of the canyon. The river above here flows through a mountainous country, the valley widening in places to bottoms of considerable width. On leaving the Buttes, Gila River debouches upon a broad valley or desert, and thence continues its course westerly to its junction with the Colorado at Yuma.

The section at the gaging station is sandy and liable to change at every high water. On this account the ordinary method of rating the river by taking a few discharge measurements at various gage heights and from these constructing a curve is not applicable. A large number of discharge measurements should be made at intervals of one, two, or three days apart. When these are plotted, it appears as though it would be impossible to construct a rating curve from them on account of their great variation. If the gage heights are studied, however, in connection with the discharge measurements, a number of curves can be constructed in which the discharges generally fall into line.

The first measurement of the year at the gaging station was made on January 1, and from then until September 7 the river shows no decided change in the bed. The rating curve applicable from January 1 to September 7, 1897, inclusive, is based on 42 discharge measurements. September 8 the river rose to a gage height of 7 feet. The measurement on that day and on September 13 shows a modification of the channel, and a separate curve for this period of six days has been made. On September 15 a discharge measurement was made showing another modification. The measurements during the rest of the season, that is, those on September 23 and 28, and on October 10 and 24, give a fairly regular curve, from which a table has been constructed, applicable from September 14 to October 24, when observations of gage height were discontinued.

The description of this station, together with a list of discharge measurements and table of gage heights, is given in Water-Supply and Irrigation Paper No. 16, p. 147. Forty-nine discharge measurements were made in all. The bench mark consists of a cross with the letters "B.M. U.S.G.S." chiseled in a rock 4 feet above ground and 90 feet south of cable support and in line with the two supports. Its elevation above sea level is 1,605.6 feet. The gage rod is N. 34° 45′ W., 418 feet from the bench mark, and on the opposite side of the river. The elevation of zero is 1,583.0 feet or 22.6 feet below the bench mark.

Rating table for Gila River at Buttes, Arizona, for 1897.

Gage height.	Discharge.		Gage height.	Discharge.	
	Jan. 1 to Sept. 7.	Sept. 14 to Oct. 24.		Jan. 1 to Sept. 7.	Sept. 14 to Oct. 24.
Feet.	*Second-feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Second-feet.*
1.2	0	....	3.2	1,190	1,360
1.4	41	....	3.4	1,450	1,600
1.6	83	....	3.6	1,710	1,850
1.8	130	....	3.8	1,970	2,240
2.0	215	520	4.0	2,230	2,600
2.2	360	630	4.5	2,880	3,500
2.4	520	740	5.0	3,530	4,400
2.6	680	850	5.5	4,180	5,300
2.8	840	960	6.0	4,830	....
3.0	1,000	1,120			

Estimated monthly discharge of Gila River at Buttes, Arizona.

[Drainage area 13,750 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	4,310	400	1,286	79,074	0.108	0.094
February	1,580	560	883	49,039	0.066	0.064
March	920	520	702	43,165	0.059	0.051
April	800	520	694	41,296	0.056	0.050
May	440	94	224	13,773	0.018	0.016
June	83	20	52	3,094	0.004	0.004
July	2,360	0	565	34,741	0.047	0.041
August	3,270	160	799	49,129	0.067	0.058
September	5,590	106	2,371	141,084	0.192	0.172
October	....	....	*a* 800	49,190	0.067	0.058

a Approximate.

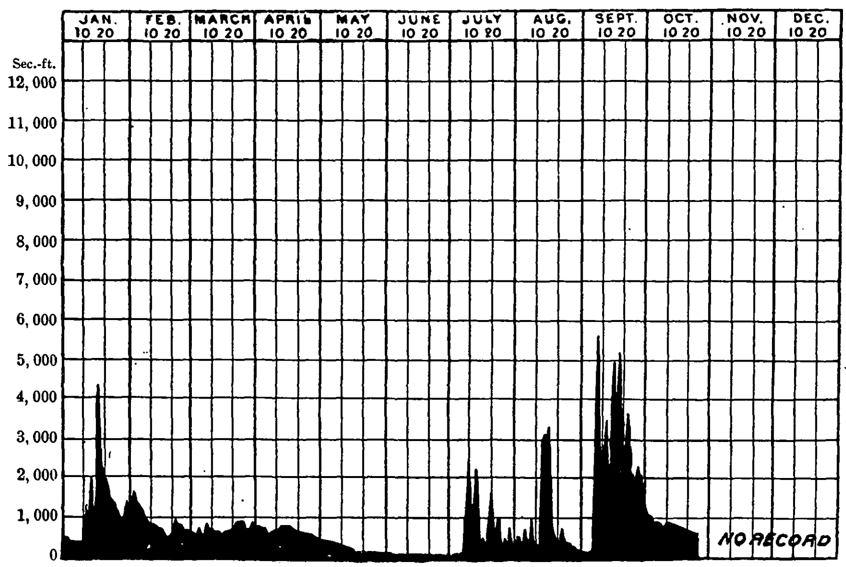


FIG. 148.—Discharge of Gila River at Buttes, Arizona, 1897.

QUEEN CREEK.

This creek is a small tributary of Gila River, rising in the mountains to the east of Silver King mining camp, 40 miles north of Florence, Arizona. After leaving the mountains a short distance below Whitlow's ranch the creek ordinarily loses itself in the desert north of the Gila Reservation. In times of extremely high and protracted floods the waters of this creek reach Gila River below the range known as Sacaton Hills. A detailed study of the discharge of this creek was made in connection with the surveys for the water supply for Gila River Indian Reservation, made by this Survey in 1896. Discharge measurements were made in 1897 during the months of January, February, and March, as shown by the accompanying list. The station was discontinued in April, 1897.

List of discharge measurements made on Queen Creek, at Whitlow's, Arizona.

Date.	Hydrographer.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
1897.			*Feet.*	*Square feet.*	*Feet per second.*	*Second-feet.*
Jan. 2	W. Richins	(*a*)	0.30	0.96	1.12	1.1
Jan. 9	.....do	(*a*)	0.30	0.96	1.00	0.9
Jan. 11	.....do	(*a*)	3.80	354	10.00	3,536
Jan. 12	.....do	69	0.10	3.1	1.18	3.7
Jan. 13	.....do	69	1.95	177	7.36	1,300
Do	.....do	69	0.70	58	4.48	260

a Floats.

List of discharge measurements made on Queen Creek, at Whitlow's, Arizona—Continued.

Date.	Hydrographer.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
1897.			*Feet.*	*Square feet.*	*Feet per second.*	*Second-feet.*
Jan. 14	W. Richins	69	....	2.35	1.20	2.8
Jan. 15	.....do	69	2.40	2.24	7.91	1,779
Jan. 19	.....do	69	....	4.35	1.66	7.2
Jan. 23	.....do	69	....	3.98	1.32	5.2
Jan. 30	.....do	69	0.80	0.48	3.84	185
Do	.....do	69	0.40	29	3.81	109
Jan. 31	.....do	69	0.10	16	1.23	29
Do	.....do	69	0.05	11	2.45	26
Feb. 2	.....do	69	0.10	4.42	1.65	7.3
Feb. 6	.....do	69	0.10	3.61	1.73	6.3
Feb. 13	.....do	69	0.15	3.41	1.64	5.6
Feb. 20	.....do	69	−0.15	3.47	1.63	5.7
Feb. 21	.....do	69	0.70	41	3.00	123
Do	.....do	69	0.60	33	2.38	79
Feb. 22	.....do	69	0.50	23	2.29	52
Do	.....do	69	0.40	10	1.80	18
Feb. 25	.....do	69	0.20	6.32	1.37	8.7
Feb. 27	.....do	69	0.15	4.56	1.43	6.5
Mar. 4	.....do	69	0.70	49	3.41	167
Do	.....do	69	0.70	40	3.34	134
Mar. 5	.....do	69	0.40	19.8	2.63	52
Do	.....do	69	0.33	16	2.46	38
Mar. 6	.....do	69	0.25	14.1	1.88	26
Mar. 8	.....do	69	0.10	7.1	1.57	11
Mar. 13	.....do	69	0.07	5.06	1.44	7.3
Mar. 20	.....do	69	0.07	5.58	1.35	7.5
Mar. 27	.....do	69	0.07	5.1	1.40	7.2
Apr. 3	.....do	69	0.07	5.5	1.30	7.2
Apr. 6	.....do	69	0.07	5.2	1.19	6.2

SALT RIVER.

Salt River is the principal tributary of the Gila. Two stations were established in its basin in 1897. The field work at these stations is published in Water-Supply and Irrigation Paper No. 16, pp. 148–150, inclusive. McDowell station, on Salt River, located half a mile above the mouth of the Verde and 30 miles northeast of Phœnix, was established April 20, 1897. The first discharge measurement on Salt River was made April 21 at a gage height of 13.30 feet. The river steadily fell from this date, with a few minor fluctuations, until August 12.

Twenty-nine discharge measurements were made during this period, and the figures in the first column of discharges, applicable from April 20 to August 11, 1897, inclusive, are based on these measurements and give a very good curve. August 12 the river rose slightly, and measurement No. 30, on August 15, shows a change in the channel, the measured discharge being less than in the first column of discharges. Measurement No. 31 is comparable with the last measurement. September 11 the river rose to a height of 12.73 feet. September 13 a discharge measurement, No. 32, was made, showing a decided change in the channel. The river then fell until September 21, and the second column of discharges, based on measurements Nos. 30–32, inclusive, is applicable from August 12 to September 21, inclusive. September 22 the river rose, and measurement No. 33 shows a scouring of the channel. The third column of discharges is based on measurements Nos. 33 and 34, and is applicable from September 22 to October 30, 1897, inclusive. Five discharge measurements were made during the remainder of the year at practically the same gage height. They show, however, a gradual diminution in amount, proving a filling in of the channel. The daily discharges for November and December were not taken from the table, but were averaged between the five discharge measurements on October 31, November 21 and 28, and December 19 and 27. The measurements at this point and on the Verde were made by Mr. W. A. Farish.

Rating table for Salt River at McDowell, Arizona, for 1897.

Gage height.	Discharge.			Gage height.	Discharge.		
	Apr. 20 to Aug. 11.	Aug. 12 to Sept. 21.	Sept. 22 to Oct. 30.		Apr. 20 to Aug. 11.	Aug. 12 to Sept. 21.	Sept. 22 to Oct. 30.
Feet.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*
9.2	....	....	....	10.9	1,110	630	800
9.3	55	....	....	11.0	1,200	660	850
9.4	110	....	....	11.2	1,380	720	950
9.5	165	....	....	11.4	1,560	780	1,050
9.6	220	....	....	11.6	1,740	840	1,150
9.7	275	....	....	11.8	1,920	900	1,250
9.8	330	300	....	12.0	2,100	960	1,350
9.9	385	330	300	12.2	2,410	1,020	....
10.0	440	360	350	12.4	2,720	1,080	....
10.1	495	390	400	12.6	3,030	1,140	....
10.2	550	420	450	12.8	3,340	1,200	....
10.3	605	450	500	13.0	3,650	....	....
10.4	675	480	550	13.2	3,960	....	....
10.5	750	510	600	13.4	4,270	....	....
10.6	840	540	650	13.6	4,580	....	....
10.7	930	570	700	13.8	4,890	....	....
10.8	1,020	600	750	14.0	5,200	....	....

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.		Depth in inches.	Second-feet per square mile.
1897.						
April 20-30	4,580	2,100	3,051	66,566	0.20	0.49
May	2,010	640	1,172	72,064	0.22	0.19
June	640	193	385	22,909	0.07	0.06
July	303	83	176	10,822	0.03	0.03
August	795	165	431	26,501	0.08	0.07
September	1,350	360	716	42,605	0.12	0.11
October	1,075	300	584	35,909	0.10	0.09
November	305	270	287	17,078	0.06	0.05
December	307	264	284	17,463	0.06	0.05

VERDE RIVER.

McDowell station, on Verde River, located half a mile above its mouth and 30 miles northeast of Phœnix, was established April 20, 1897. The station is equipped with cable, car, and tagged wire. This section, as well as that on Salt River at McDowell station, is similar to the one on Gila River—sandy and liable to change during a slight rise—and a similar method is employed in estimating the daily discharge; that is, a large number of measurements are taken and studied in connection with the gage heights. The first discharge measurement on Verde River was made April 21. From that date the river steadily fell, and the first column of discharges is based on measurements Nos. 1-28, inclusive, and is applicable from April 20 to August 12. August 11 the gage read 7.72 feet. On August 12 the river rose to 9 feet, presumably in its original channel. The next measurement, No. 29, is so large as to fall outside the rating curve. The bed of the river evidently changed during the last freshet, scouring out, and therefore the same gage height indicates a larger discharge. The second column of discharges is based on the discharge at 9 feet in the first column and discharge measurement No. 29. The river fluctuated in this channel until August 23, when it was at a gage height of 7.9 feet. The next day it rose, and the next measurement, No. 30, was on August 29. This shows a decided change in the channel. The discharge, 440 second-feet, is much smaller than that given in the table, the latter being 965 second-feet. The third column of discharges is therefore based on this measurement and on the discharge at gage height 7.90 feet in the second column of discharges.

Presumably the river fluctuated in this last channel until September 8, when it rose again, reaching a height on September 11 of 12 feet. A discharge measurement was not made, however, until September 13, at gage height 9.35 and discharge 1,949 second-feet. This measurement, No. 31, is the controlling point for the third column of discharges, which is applicable from September 8 to 14. This flood also modified the channel as shown by measurement No. 32 on September 26, and the new rating table, or the fifth column of discharges, is based on measurements Nos. 31–38, inclusive, the bed showing no decided change for the rest of the year. Therefore the fifth column is applicable from September 15 to December 31, 1897, inclusive.

It is to be regretted that this station and the one on Salt River were not established earlier in the year, as by the middle of April a large portion of the flood flow had already passed.

By having two stations at McDowell the results are of more value than if one only were maintained at the Arizona dam, which is located not more than a mile below the junction. The combined discharge at the two points shows the amount of water available for the Arizona canal and the canals taken out on both sides of the river below. In having separate stations the data obtained at each can be utilized in studying the run-off of each basin and the amount of water available for the several irrigation projects under consideration on the two rivers.

For Salt River the proposition of greatest magnitude is the storage reservoir of the Hudson Reservoir and Canal Company. This company contemplates building a dam in a rock gorge below the mouth of Tonto Creek to the height of 205 feet, to be 610 feet long on the top, and to impound over 800,000 acre-feet of water. Such a reservoir would be of great benefit to irrigators in Salt River Valley, as during the summer months there is a shortage in the supply of water, and as a result many crops fail.

For the last two years work has been continued on the storage proposition of Verde River. A dam is being constructed in T. 8 N., R. 6 E., with an estimated reservoir capacity of 205,000 acre-feet. The water stored will be let down into the river again to be diverted 25 miles below through a tunnel, and thence into a canal, which continues for 65 miles parallel to and some distance above Arizona canal. A more detailed description of these two enterprises will be found in Bulletin No. 140, p. 204.

Rating table for Verde River at McDowell, Arizona, for 1897.

Gage height.	Discharge.				
	Apr. 20 to Aug. 12.	Aug. 13 to Aug. 23.	Aug. 24 to Sept. 7.	Sept. 8 to Sept. 14.	Sept. 15 to Dec. 31.
Feet.	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Second-feet.*
6.5	...	...	...	...	250
6.6	...	...	...	...	260
6.7	...	...	...	...	270
6.8	...	...	...	...	280
6.9	...	...	...	...	295
7.0	...	...	...	...	310
7.1	...	...	...	...	325
7.2	...	...	...	...	340
7.3	...	...	...	...	360
7.4	90	...	...	...	380
7.5	110	...	240	...	400
7.6	130	...	260	...	440
7.7	155	...	280	...	480
7.8	185	...	300	...	570
7.9	230	300	320	...	660
8.0	280	340	340	...	750
8.2	380	590	380	...	930
8.4	620	840	420	860	1,110
8.6	940	1,090	460	1,090	1,290
8.8	1,260	...	...	1,320	1,470
9.0	1,580	...	...	1,550	1,650
9.2	...	...	...	1,780	1,830
9.4	...	...	...	2,010	2,010
9.6	...	...	...	2,240	2,190
9.8	...	...	...	2,470	2,370
10.0	...	...	...	2,700	2,550
10.2	...	...	...	2,930	...
10.4	...	...	...	3,160	...
10.6	...	...	...	3,390	...
10.8	...	...	...	3,620	...
11.0	...	...	...	3,850	...
11.5	...	...	...	4,425	...
12.0	...	...	...	5,000	...

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.		Depth in inches.	Second-feet per square mile.
1897.						
April 20–30	1,580	460	860	18,764	0.058	0.143
May	460	170	269	16,540	0.052	0.045
June	185	120	150	8,920	0.028	0.025
July	230	90	130	7,993	0.025	0.022
August	1,590	110	439	26,993	0.084	0.073
September	5,000	240	992	59,028	0.184	0.165
October	390	260	309	19,000	0.059	0.051
November	265	260	262	15,590	0.049	0.044
December	280	260	267	16,417	0.052	0.045

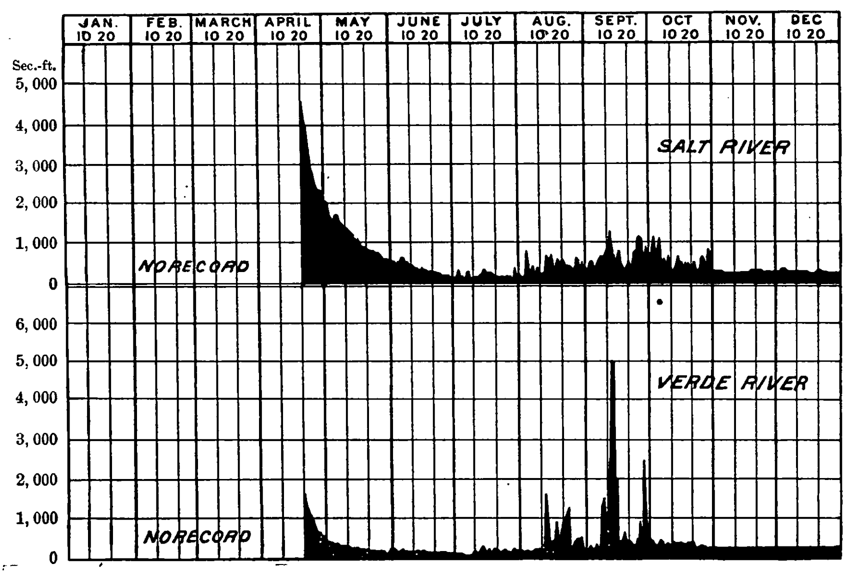


FIG. 149.—Discharge of Salt and Verde rivers at McDowell, Arizona, 1897.

The Southern Pacific Company has maintained gage readings on the main Colorado River at Yuma, Arizona. No measurements of dis charge were made at that point in 1897. The station is described in Water-Supply and Irrigation Paper No. 16, p. 151.

INTERIOR BASIN IN NEVADA.

HUMBOLDT RIVER.

The drainage basin of the Humboldt River occupies the northern portion of the State of Nevada. The river rises in the northeastern corner of the State and flows in a southwesterly direction beyond Palisade station, on the Central Pacific Railway. It then seeks a northwesterly direction until it receives the drainage of Little Humboldt River, when it bends southwesterly, finally discharging its waters into Humboldt Sink. A number of gaging stations have been maintained on the river, as follows, downstream: Elko, Battle Mountain, Golconda, and Oreana stations. These are described in Water-Supply and Irrigation Paper No. 16, pp. 152–155, inclusive. A gaging station was also maintained on the south fork of Humboldt River at Mason's ranch, described in the same paper, p. 156.

Rating table for Humboldt River at Elko, Nevada, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.7	3	3.4	268	5.4	926	7.4	1,861
1.8	7	3.6	319	5.6	1,009	7.6	1,963
1.9	15	3.8	374	5.8	1,094	7.8	2,065
2.0	24	4.0	431	6.0	1,182	8.0	2,167
2.2	46	4.2	492	6.2	1,273	8.2	2,269
2.4	73	4.4	557	6.4	1,366	8.4	2,371
2.6	104	4.6	624	6.6	1,462	8.6	2,473
2.8	139	4.8	695	6.8	1,560	8.8	2,575
3.0	178	5.0	769	7.0	1,660	9.0	2,670
3.2	221	5.2	846	7.2	1,760		

Estimated monthly discharge of Humboldt River at Elko, Nevada.

[Drainage area, 2,840 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	96	59	77	4,735	0.031	0.027
February	178	73	116	6,442	0.042	0.041
March	1,810	113	330	20,291	0.134	0.116
April	2,269	524	1,450	89,256	0.589	0.528
May	2,396	1,560	1,945	119,594	0.790	0.685
June	1,963	477	1,069	63,610	0.420	0.376
July	477	46	205	12,605	0.083	0.072
August	46	11	20	1,261	0.008	0.007
September	11	5	8	476	0.003	0.003
October	34	5	22	1,353	0.009	0.008
November	73	34	54	3,213	0.021	0.019
December	139	46	89	5,472	0.036	0.031
The year	2,396	5	449	328,308	2.166	0.159

Rating table for Humboldt River at Battle Mountain, Nevada, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.4	4	2.0	133	4.2	545	6.4	1,245
0.5	6	2.2	161	4.4	593	6.6	1,341
0.6	9	2.4	191	4.6	643	6.8	1,445
0.7	13	2.6	223	4.8	695	7.0	1,558
0.8	18	2.8	257	5.0	749	7.2	1,683
0.9	24	3.0	293	5.2	806	7.4	1,820
1.0	30	3.2	331	5.4	867	7.6	1,970
1.2	45	3.4	371	5.6	932	7.8	2,133
1.4	63	3.6	412	5.8	1,001	8.0	2,310
1.6	84	3.8	455	6.0	1,076	8.5	2,804
1.8	107	4.0	499	6.2	1,157	9.0	3,359

Estimated monthly discharge of Humboldt River at Battle Mountain, Nevada.

[Drainage area, 7,800 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	169	133	155	9,531	0.023	0.020
February	207	168	183	10,163	0.024	0.023
March	749	176	265	16,294	0.039	0.034
April	3,053	1,001	2,287	136,086	0.327	0.293
May	3,053	2,752	2,876	176,839	0.425	0.369
June	3,131	867	2,070	123,173	0.296	0.265
July	821	95	400	24,595	0.059	0.051
August	84	9	34	2,091	0.005	0.004
September	9	5	6	357	0.001	0.001
October	73	7	36	2,214	0.005	0.005
November	126	78	99	5,890	0.014	0.013
December	275	133	201	12,359	0.029	0.026
The year	3,131	5	718	519,592	1.247	0.092

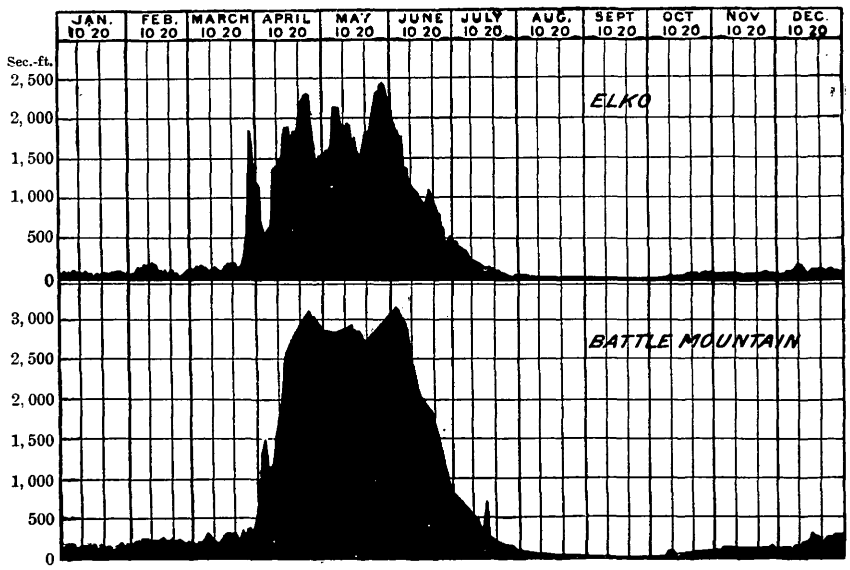


FIG. 150.—Discharge of Humboldt River at Elko and Battle Mountain, Nevada, 1897.

Rating table for Humboldt River at Golconda, Nevada, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.5	5	2.4	162	4.6	516	6.8	1,194
0.6	9	2.6	186	4.8	561	7.0	1,290
0.7	13	2.8	210	5.0	608	7.2	1,394
0.8	18	3.0	236	5.2	657	7.4	1,504
0.9	23	3.2	264	5.4	709	7.6	1,619
1.0	29	3.4	294	5.6	764	7.8	1,738
1.2	43	3.6	326	5.8	823	8.0	1,860
1.4	59	3.8	360	6.0	886	8.5	2,165
1.6	77	4.0	396	6.2	953	9.0	2,475
1.8	97	4.2	434	6.4	1,026	9.5	2,785
2.0	118	4.4	474	6.6	1,106	10.0	3,100
2.2	140						

Estimated monthly discharge of Humboldt River at Golconda, Nevada.

[Drainage area, 10,780 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	210	129	148	9,100	0.016	0.014
February	236	162	200	11,107	0.019	0.018
March	310	117	234	14,388	0.025	0.022
April	2,974	360	1,264	75,213	0.131	0.117
May	3,100	2,537	2,860	175,917	0.306	0.265
June	2,942	1,026	2,197	130,730	0.227	0.204
July	953	210	499	30,683	0.053	0.046
August	198	43	95	5,841	0.010	0.009
September	36	7	17	1,012	0.002	0.002
October	97	5	26	1,599	0.003	0.002
November	112	36	80	4,760	0.008	0.007
December	204	118	170	10,453	0.018	0.016
The year	3,100	5	649	470,803	0.818	0.060

Rating table for Humboldt River at Oreana, Nevada, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.0	23	4.0	312	6.0	860	8.0	1,540
2.2	37	4.2	357	6.2	924	8.5	1,720
2.4	56	4.4	405	6.4	990	9.0	1,902
2.6	78	4.6	455	6.6	1,056	9.5	2,087
2.8	103	4.8	507	6.8	1,124	10.0	2,275
3.0	131	5.0	561	7.0	1,192	10.5	2,465
3.2	162	5.2	617	7.2	1,260	11.0	2,657
3.4	195	5.4	675	7.4	1,329	11.5	2,852
3.6	230	5.6	735	7.6	1,399	12.0	3,047
3.8	269	5.8	797	7.8	1,469		

Estimated monthly discharge of Humboldt River at Oreana, Nevada.

[Drainage area, 14,967 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	195	103	140	8,608	0.012	0.010
February	269	162	216	11,996	0.016	0.016
March	417	269	287	17,647	0.024	0.021
April	2,087	430	958	57,005	0.078	0.069
May	3,047	2,199	2,691	165,464	0.225	0.195
June	2,503	1,612	2,114	125,791	0.171	0.153
July	1,576	357	842	51,773	0.070	0.061
August	357	78	191	11,744	0.016	0.014
September	78	46	61	3,630	0.005	0.004
October	67	26	40	2,460	0.003	0.003
November	62	26	40	2,380	0.003	0.003
December	146	62	110	6,764	0.009	0.008
The year	3,047	26	641	465,262	0.632	0.046

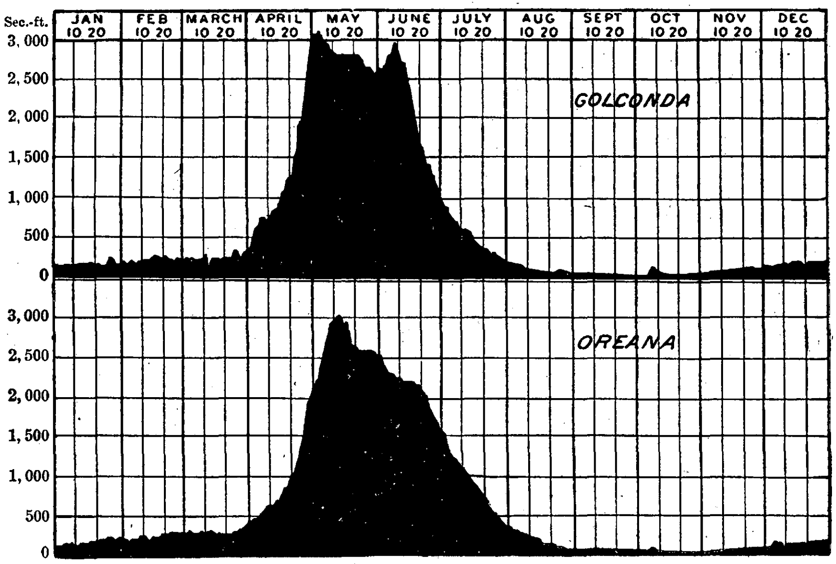


FIG. 151.—Discharge of Humboldt River at Golconda and Oreana, Nevada, 1897.

Rating table for South Fork of Humboldt River at Mason's ranch, Nevada.

Gage height.	Discharge.		Gage height.	Discharge.	
	Aug. 29, 1896, to Apr. 19, 1897.	Apr. 20 to Dec. 31, 1897.		Aug. 29, 1896, to Apr. 19, 1897.	Apr. 20 to Dec. 31, 1897.
Feet.	*Second-feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Second-feet.*
0.3	....	3	2.8	386	501
0.4	....	8	3.0	457	562
0.5	....	15	3.2	530	623
0.6	....	23	3.4	604	684
0.7	1	32	3.6	679	745
0.8	2	42	3.8	755	807
0.9	5	53	4.0	831	868
1.0	11	65	4.2	907	929
1.2	28	94	4.4	983	980
1.4	51	129	4.6	....	1,052
1.6	79	170	4.8	....	1,113
1.8	113	215	5.0	....	1,174
2.0	153	265	5.2	....	1,235
2.2	201	320	5.4	....	1,296
2.4	257	379	5.6	....	1,358
2.6	319	440	5.8	....	1,419

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.		Depth in inches.	Second-feet per square mile.
1896.						
September	11	2	5	298	0.004	0.004
October	15	8	10	605	0.010	0.009
November	28	11	22	1,279	0.021	0.019
December	79	11	36	2,190	0.036	0.031
1897.						
January	39	2	21	1,291	0.021	0.018
February	71	28	48	2,666	0.043	0.042
March	641	28	119	7,317	0.119	0.104
April	1,021	113	535	31,835	0.520	0.466
May	1,327	852	1,064	65,423	1.067	0.926
June	945	252	553	32,906	0.537	0.481
July	334	59	164	10,084	0.164	0.142
August	120	3	28	1,722	0.028	0.024
September	8	3	5	298	0.004	0.004
October	53	8	31	1,906	0.031	0.027
November	170	42	59	3,511	0.058	0.052
December	102	19	65	3,997	0.065	0.056
The year	1,327	2	224	162,956	2.657	0.195

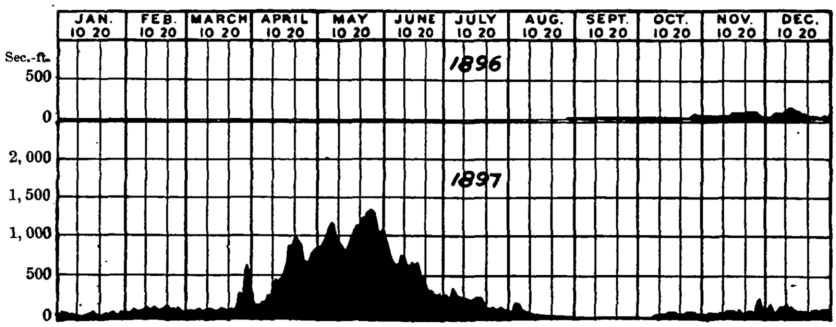


FIG. 152.—Discharge of South Fork of Humboldt River at Mason's ranch, Nevada, 1896 and 1897.

WATERSHED OF GREAT SALT LAKE.

This watershed is in the extreme eastern portion of the great interior basin of the United States. It receives principally the drainage of the Wasatch Mountains, the range extending in a north and south direction through the central portion of Utah. The area to the east is drained by the tributaries of Colorado River, which flows into the Gulf of California. Gaging stations have been maintained on the following rivers tributary to Great Salt Lake: Battle Creek and Collinston, on Bear River; Logan station, on Logan River; Ogden station, on Ogden River; Uinta station, on Weber River; and Provo station, on Provo River. There is also a station at Geneva, where a record of the fluctuations of Utah Lake is kept. The field work in 1897 at the above-named stations is described in Water-Supply and Irrigation Paper No. 16, pp. 157–163, inclusive.

BEAR RIVER.

Bear River rises in Summit County, Utah, and flows in a general northerly direction, swinging back and forth, first into Wyoming and then into Utah. It then enters Idaho, receives the drainage of Bear Lake, and finally returns to Utah again, entering it through Cache Valley. This valley is level and fertile, well adapted to irrigation, and much of the land is under cultivation. Many canals take water from the tributaries of Bear River, as Cub Creek, Logan River, Blacksmith Fork, and Little Bear River, which drain the western slope of the Wasatch Range.

About 39,000 acres are at present irrigated in Cache Valley, 13,000 acres of this being under the canals from Logan River. Comparing this latter acreage with the amount of water used upon it during the four months from June to September, inclusive, it is found that the duty of water is 80 acres to the second-foot. The aggregate maximum capacity of the canals from Logan River is 200 second-feet. They do not carry this amount, however, throughout the irrigating season. For a more detailed account of irrigation in this valley see a recent paper on Seepage Waters of Northern Utah, by Samuel Fortier.[1]

Bear River leaves Cache Valley through a long canyon and enters Boxelder County, through which it flows in a southerly direction to Great Salt Lake. Battle Creek gaging station is located at the head of Cache Valley.

[1] Seepage waters of northern Utah, by Samuel Fortier: Water-Supply and Irrigation Paper No. 7, U. S. Geol. Survey, 1897.

Rating table for Bear River at Battle Creek, Idaho, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.0	400	2.2	1,434	3.4	2,850	4.6	4,700
1.2	505	2.4	1,670	3.6	3,086	4.8	5,100
1.4	625	2.6	1,906	3.8	3,322	5.0	5,500
1.6	780	2.8	2,142	4.0	3,570	5.2	5,900
1.8	970	3.0	2,378	4.2	3,910	5.4	6,300
2.0	1,198	3.2	2,614	4.4	4,300		

Estimated monthly discharge of Bear River at Battle Creek, Idaho.

[Drainage area, 4,500 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	....	....	*a* 950	58,414	0.24	0.21
February	....	....	*a* 870	48,317	0.20	0.19
March	....	....	*a* 900	55,339	0.23	0.20
April	4,300	1,198	2,923	173,930	0.72	0.65
May	6,100	3,570	5,062	311,252	1.29	1.12
June	5,500	1,847	3,593	213,798	0.89	0.80
July	1,788	970	1,335	82,086	0.35	0.30
August	870	780	838	51,527	0.22	0.19
September	970	780	789	46,949	0.20	0.18
October	1,434	780	1,115	68,559	0.29	0.25
November	1,316	1,080	1,127	67,061	0.28	0.25
December	1,080	780	979	60,197	0.25	0.22
The year	....	....	1,707	1,237,429	5.16	0.38

a Approximate.

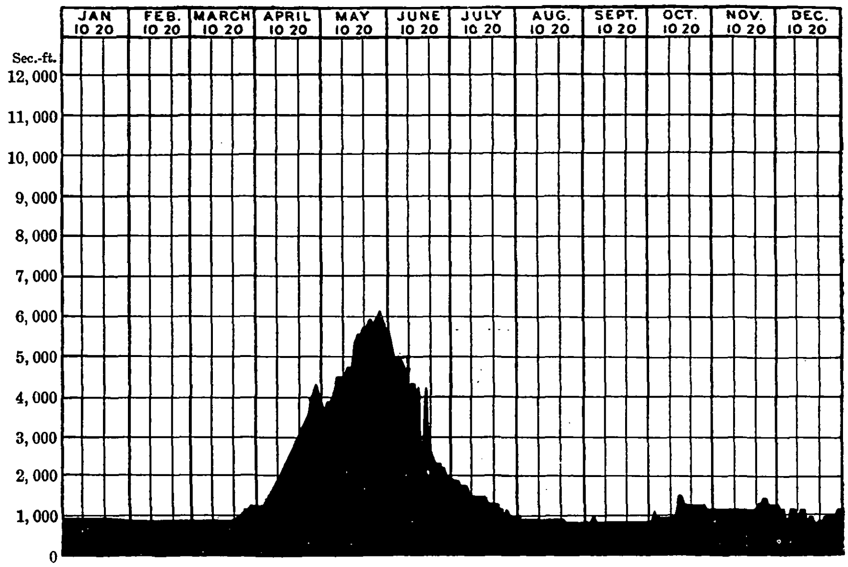


FIG. 153.—Discharge of Bear River at Battle Creek, Idaho, 1897.

LOGAN RIVER.

The station on Logan River is located at the mouth of the canyon, 3 miles east of the city of Logan, and is above the head of all canals taking water from it except the Logan, Hyde Park, and Smithfield canal.

Rating table for Logan River at Logan, Utah, for 1897.

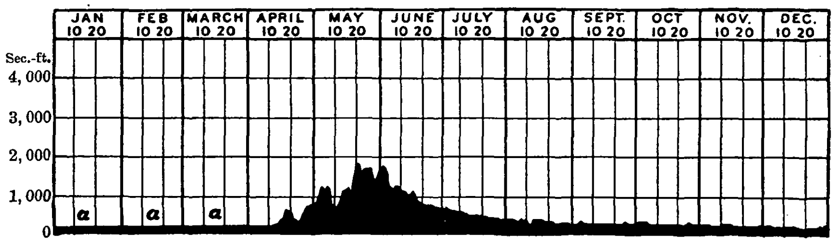
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.4	135	3.1	415	3.8	800	4.5	1,451
2.5	165	3.2	460	3.9	895	4.6	1,544
2.6	205	3.3	505	4.0	986	4.7	1,637
2.7	245	3.4	555	4.1	1,079	4.8	1,730
2.8	285	3.5	610	4.2	1,172	4.9	1,823
2.9	325	3.6	665	4.3	1,265	5.0	1,916
3.0	370	3.7	725	4.4	1,358		

Estimated monthly discharge of Logan River at Logan, Utah.

[Drainage area, 218 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January			a150	9,223	0.79	0.69
February			a150	8,331	0.72	0.69
March			a150	9,223	0.79	0.69
April	760	150	317	18,863	1.67	1.45
May	1,823	760	1,264	77,721	6.69	5.80
June	1,684	637	990	58,909	5.07	4.54
July	665	392	493	30,314	2.61	2.26
August	392	265	330	20,291	1.74	1.51
September	325	265	270	16,066	1.38	1.24
October	285	245	264	16,233	1.39	1.21
November	245	225	232	13,805	1.18	1.06
December	225	150	188	11,560	0.99	0.86
The year			400	290,539	25.02	1.83

a Approximate, on account of interference of ice.



a Approximate.

FIG. 154.—Discharge of Logan River at Logan, Utah, 1897.

BEAR RIVER BELOW LOGAN RIVER.

The station on Bear River at Collinston, Utah, is located in the canyon of the river about 2 miles below the diversion dam of Bear River canal.

Rating table for Bear River at Collinston, Utah, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.0	770	2.4	1,910	3.8	3,800	5.2	6,910
1.2	840	2.6	2,170	4.0	4,180	5.4	7,370
1.4	930	2.8	2,430	4.2	4,610	5.6	7,830
1.6	1,050	3.0	2,690	4.4	5,070	5.8	8,290
1.8	1,230	3.2	2,950	4.6	5,530	6.0	8,750
2.0	1,440	3.4	3,210	4.8	5,990	6.5	9,900
2.2	1,670	3.6	3,490	5.0	6,450	7.0	11,050

Estimated monthly discharge of Bear River at Collinston, Utah.

[Drainage area, 6,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	1,670	1,050	1,429	87,866	0.28	0.24
February	1,670	1,440	1,466	81,418	0.25	0.24
March	2,690	1,440	1,582	97,274	0.30	0.26
April	8,980	1,790	5,822	346,432	1.08	0.97
May	10,590	8,520	9,566	588,194	1.83	1.59
June	9,440	2,690	5,637	335,424	1.04	0.94
July	2,690	1,130	1,807	111,109	0.35	0.30
August	1,130	990	1,082	66,530	0.21	0.18
September	1,330	1,050	1,224	72,833	0.22	0.20
October	2,040	1,280	1,769	108,772	0.33	0.29
November	1,670	1,230	1,351	80,390	0.26	0.23
December	2,235	1,280	1,626	99,979	0.31	0.27
The year	10,590	990	2,863	2,076,221	6.46	0.48

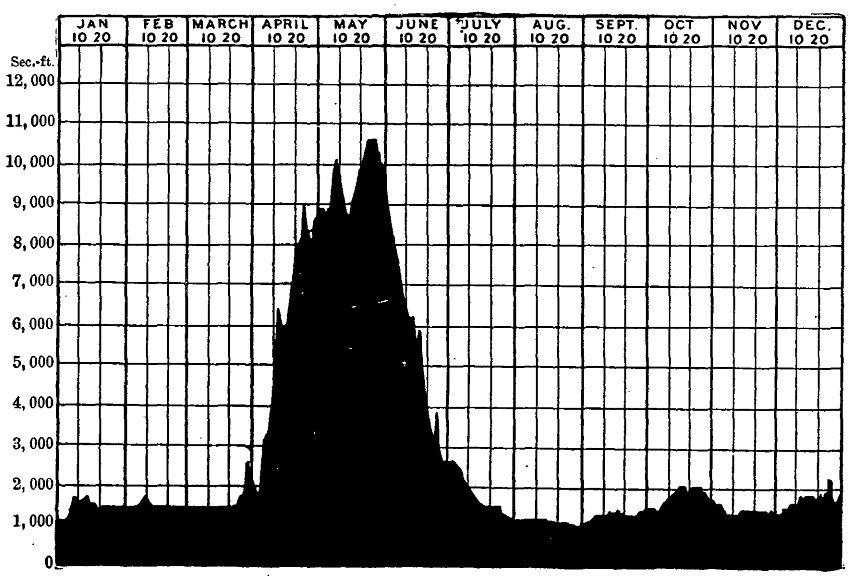


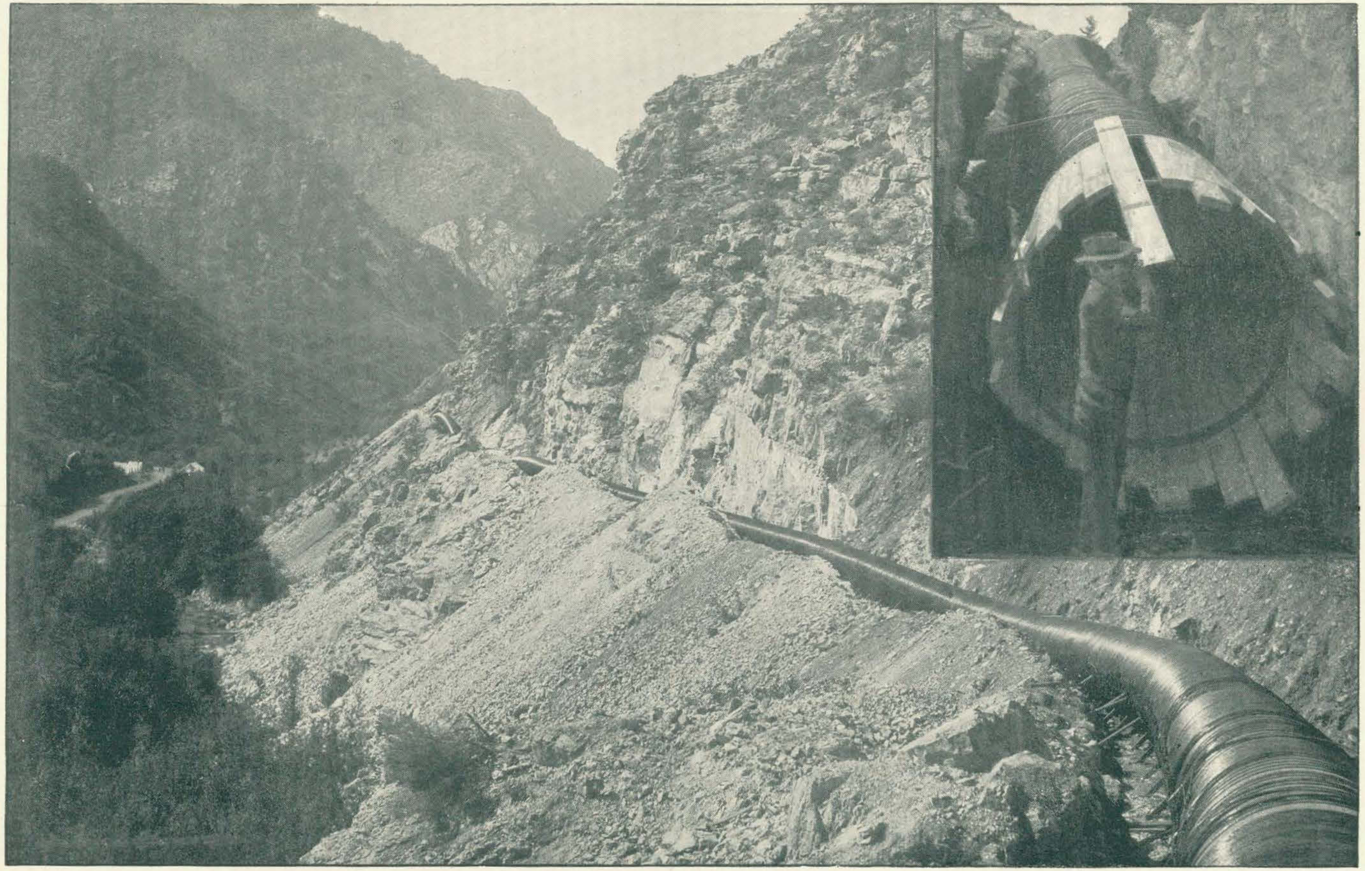
FIG. 155.—Discharge of Bear River at Collinston, Utah, 1897.

OGDEN RIVER.

Measurements of this stream were formerly made at the head of the canyon below the mouth of the North Fork. During the latter part of 1896, however, the dam of the Pioneer Electric Power Company, located about 1 mile below this point, was completed, backing up the water and necessitating the abandonment of the station. A new one was therefore established in the canyon about 4 miles below, near the site of an old powder mill. The water diverted by the power company, the amount of which is not included in the following tables, enters a 6-foot wooden pressure pipe and is conducted down to the electric works of the company at the mouth of the canyon. The energy here developed is distributed to Ogden and Salt Lake City. A full description of this power plant is given in Transactions of the American Society of Civil Engineers, Vol. XXXVIII, pp. 246-314. From this publication the following facts have been obtained:

It is proposed to erect a concrete dam, the foundations of which, to reach bed rock, will be placed to a depth of 40 feet beneath the surface of the ground, while the top will be 60 feet above the present surface, making a total height of 100 feet, and the length on the crest will be 400 feet. This will back up water for several miles into the valley above the canyon, forming a storage reservoir of 2,000 acres. A waste weir will be provided by excavating the rock on the north wall of the canyon, and water will be taken out through the tunnel already driven in the south wall. Pending the erection of this large storage dam a temporary dam has been built by which water is diverted into the tunnel.

From this tunnel a wooden stave pipe, 6 feet in internal diameter, has been completed through the canyon for a length of 27,000 feet. A view of this pipe is given and the method of its construction illustrated in Pl. XL. This pipe is laid along the wall of the canyon, and is supported in a trench cut in the wall or by short bridges or trestles when crossing ravines. The hydraulic grade is 2 feet per thousand, a slope which is estimated to correspond to the friction in the pipe. The pipe is built of Douglas fir, in this respect differing from most of the other wooden pipes used in the West, these being made of California redwood. It terminates in a riveted steel pipe, which descends a steep incline for a distance of 4,600 feet to the power house. The maximum hydrostatic head on the wooden pipe will be 170 feet, giving a pressure of 50 pounds per square inch, while on the steel pipe it is upward of 200 pounds per square inch at the lower end. The pipe is provided with air valves and also with suitable valves for emptying the pipe and removing accumulations of sand or other material. The capacity is estimated to be 250 cubic feet per second with a full reservoir, which corresponds to a velocity of 9 feet per second in the 6-foot pipe. The hydrostatic head from the flow line of the reservoir when full to the



WOODEN PIPE IN OGDEN CANYON, UTAH.

Illustration in corner shows construction.

center of the receivers in the power house will be 516 feet. Taking the effective head at 440 feet, the gross available horsepower will be about 12,500. The water is delivered against wheels of the Knight pattern, 58 inches in diameter, with a capacity of 1,200 horsepower each at 300 revolutions per minute. The dynamos are three-phase alternating current generators. They give an output of 750 kilowatts at 300 revolutions per minute. The voltage is raised by step-up transformers from 2,300 to 16,100, and is thus transmitted by lines 38 miles in length to Salt Lake City, where the voltage at 13,800 is by step-down transformers reduced to 2,300, which is also the current of the local line at Ogden. The water passing from the power house returns to the stream, from which it may be diverted to irrigate lands below.

The following table gives the list of discharge measurements made on Ogden River at Ogden, Utah. The principal facts are also shown in fig. 156 on page 438, in which vertical distances represent height of water on the gage, and horizontal distances show the quantity of discharge. The plotted points obtained by measurement are shown by the small circles, which are numbered to correspond with the figures in the left-hand column of the table. Near, or through these, is drawn a smooth curve from which the values for the rating table have been obtained.

List of discharge measurements made on Ogden River, at Ogden, Utah.

No.	Date.	Hydrographer.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
	1897.			*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
1	May 11	W. B. Dougall	106	6.69	357	5.29	1,890
2	May 26	.....do	7	5.79	264	5.39	1,423
3	June 2	.....do	7	4.79	176	3.88	682
4	June 26	.....do	106	3.25	116	1.47	170
5	July 30	S. Fortier	10	2.80	96	0.71	74
6	Sept. 15	.....do	10	2.61	93	0.55	51
7	Oct. 15	T. H. Humphreys....	......	2.68	100	0.78	78

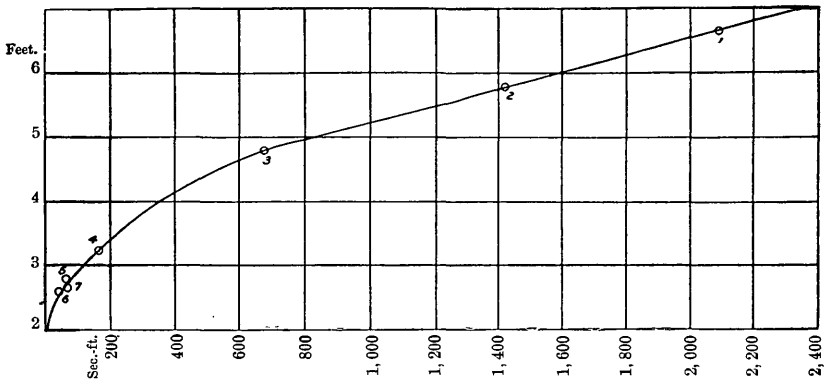


FIG. 156.—Rating curve for Ogden station on Ogden River, Utah.

Rating table for Ogden River at Ogden, Utah, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.0	15	3.4	203	4.8	690	6.2	1,749
2.2	25	3.6	250	5.0	837	6.4	1,901
2.4	35	3.8	300	5.2	989	6.6	2,053
2.6	55	4.0	360	5.4	1,141	6.8	2,205
2.8	85	4.2	420	5.6	1,293	7.0	2,357
3.0	120	4.4	490	5.8	1,445		
3.2	160	4.6	575	6.0	1,597		

Estimated monthly discharge of Ogden River at Ogden, Utah.

[Drainage area, 360 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
May 10-31	2,433	837	1,766	77,066	4.02	4.91
June	761	203	379	22,552	1.17	1.05
July	250	70	90	5,534	0.29	0.25
August	70	55	56	3,443	0.18	0.16
September	70	55	57	3,392	0.18	0.16
October	85	55	72	4,427	0.23	0.20
November	85	55	70	4,165	0.21	0.19
December	70	30	52	3,197	0.16	0.14

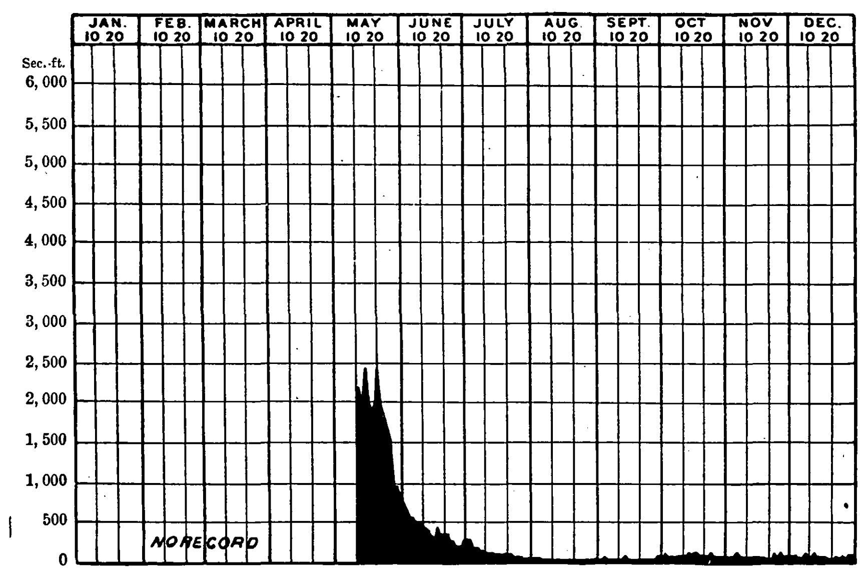


FIG. 157.—Discharge of Ogden River at Ogden, Utah, 1897.

WEBER RIVER.

The gaging station on Weber River is located in the canyon immediately above the narrows known as Devils Gate.

Rating table for Weber River at Uinta, Utah, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.0	130	2.6	1,070	4.2	2,534	5.8	4,198
1.2	190	2.8	1,220	4.4	2,742	6.0	4,406
1.4	260	3.0	1,380	4.6	2,950	6.2	4,614
1.6	355	3.2	1,540	4.8	3,158	6.4	4,822
1.8	475	3.4	1,720	5.0	3,366	6.6	5,030
2.0	620	3.6	1,910	5.2	3,574	6.8	5,238
2.2	770	3.8	2,118	5.4	3,782	7.0	5,446
2.4	920	4.0	2,326	5.6	3,990		

Estimated monthly discharge of Weber River at Uinta, Utah.

[Drainage area, 1,600 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	305	260	290	17,832	0.21	0.18
February	305	260	294	16,328	0.19	0.18
March	1,182	260	462	28,469	0.33	0.29
April	4,094	695	2,255	134,182	1.57	1.41
May	5,342	2,586	4,012	246,690	2.90	2.51
June	2,742	282	1,223	72,773	0.84	0.76
July	190	160	175	10,760	0.13	0.11
August	160	160	160	9,838	0.12	0.10
September	355	160	209	12,436	0.14	0.13
October	475	355	462	28,407	0.33	0.29
November	415	355	395	23,504	0.28	0.25
December	355	282	339	20,844	0.24	0.21
The year	5,342	160	856	622,064	7.28	0.54

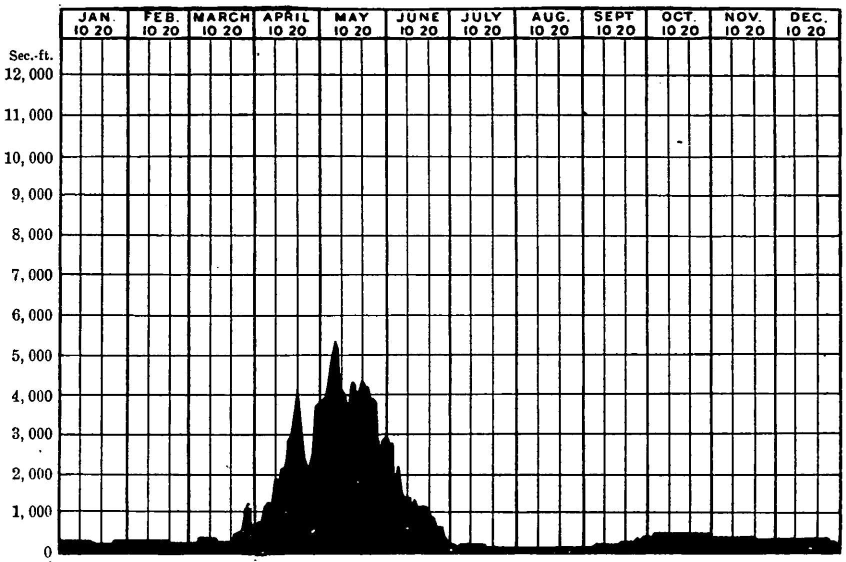


FIG. 158.—Discharge of Weber River at Uinta, Utah, 1897.

PROVO RIVER.

A second power project in Utah has recently been completed on Provo River. Water is diverted about 10 miles above in the canyon and is brought down, not in a pipe, as on Ogden River, but in a flume of semielliptical form, patented by Mr. Guy Sterling, similar to the Santa Ana flume, in southern California. A number of improvements have been introduced in this later construction, especially in the iron braces and methods of tightening them. At the mouth of the canyon where the power works are located a head of something over 300 feet is attained. The object of this plant is the development of electric power to be used in the mines southwest of Provo.

Rating table for Provo River at Provo Canyon, Utah, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
4.0	225	4.7	636	5.4	1,168	6.1	1,720
4.1	265	4.8	712	5.5	1,244	6.2	1,820
4.2	310	4.9	788	5.6	1,320	6.3	1,940
4.3	360	5.0	864	5.7	1,396	6.4	2,120
4.4	415	5.1	940	5.8	1,472	6.5	2,350
4.5	485	5.2	1,016	5.9	1,548	6.6	2,600
4.6	560	5.3	1,092	6.0	1,625		

Estimated monthly discharge of Provo River at Provo Canyon, Utah.

[Drainage area, 640 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January			a 400	24,595	0.71	0.62
February			a 500	27,769	0.81	0.78
March			a 415	25,518	0.75	0.65
April	1,320	712	856	50,935	1.50	1.34
May	2,600	1,320	1,856	114,122	3.35	2.90
June	1,472	360	796	47,365	1.38	1.24
July	360	265	295	18,139	0.53	0.46
August	225	225	225	13,835	0.40	0.35
September	415	225	260	15,471	0.46	0.41
October	485	415	449	27,608	0.81	0.70
November	485	360	433	25,765	0.75	0.68
December	415	360	372	22,874	0.67	0.58
The year			571	413,996	12.12	0.89

a Approximate.

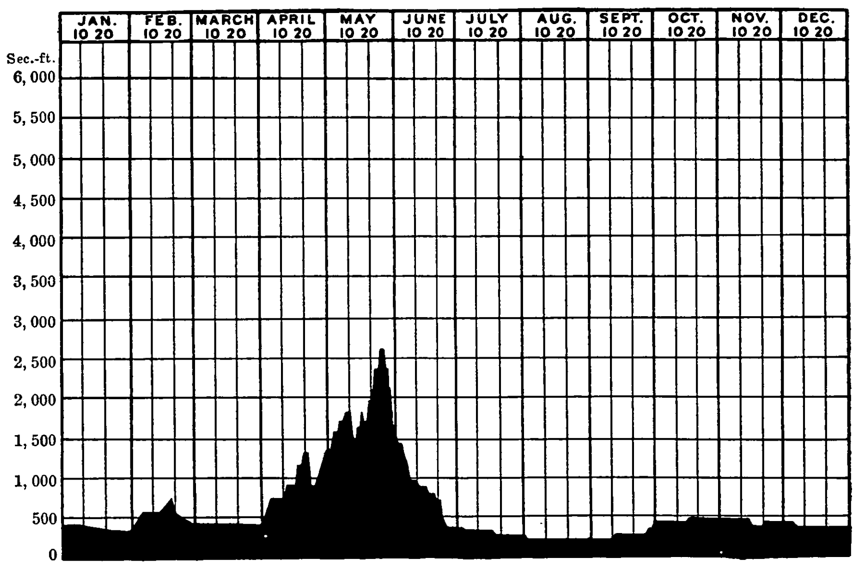


FIG. 159.—Discharge of Provo River at Provo Canyon, Utah, 1897.

UTAH LAKE.

Utah Lake receives the surplus waters and seepage from Provo and neighboring rivers flowing from the Wasatch Mountains. The peculiar conditions existing there have been described in a general way in the Twelfth Annual Report, Part II, on pages 334 to 339, and also in the Eighteenth Annual Report, Part IV, on pages 327 to 330. In the latter volume are given the results of fragmentary observations made by Mr. James Aitken, from February, 1889, to August, 1896. On November 6 of the latter year a station was established at Geneva, Utah, 3 miles south of American Fork. The results of the observations at this point for 1897 are given in Water-Supply and Irrigation Paper No. 16, on page 163.

In the early part of 1896 the Mount Nebo Irrigation Company completed a reservoir and canal to irrigate lands in the vicinity of Goshen, Utah, south of Utah Lake. A dam 30 feet in height has been placed on Currant Creek, forming a reservoir 5 miles long, with the following capacities:

Area and capacity of Currant Creek reservoir.

Elevation above sea level.	Area.	Capacity.
Feet.	*Acres.*	*Acre-feet.*
4,888 (proposed)	2,413	29,890
4,883 (present)	1,847	19,250
4,875	1,062	7,850
4,867	496	2,000
4,859 (bottom of reservoir)		

The regulating works, where water is diverted into the canal, are located 2 miles below the dam. For the first mile down the creek bottom the construction combines canal, flume, and wooden pipe, but after that it leaves the river, and then the main canal is 10 feet wide on the bottom. It passes around the head of Kimball Creek Valley, irrigating lands within that area. It crosses the dry channel of Kimball Creek and one or two other channels by means of flumes. The total length of the main canal is 13 miles. The East Side canal is taken out 1¼ miles below the head of the main canal. This canal crosses Currant Creek and, passing around a high sand ridge immediately south of Goshen, irrigates land southeast of this town. Its total length is 6½ miles. Goshen is 4½ miles south of the southern end of Utah Lake. The elevation of the bottom of the reservoir is 4,859 feet above sea level. The elevation of the crest of the dam is 4,888 feet.

This company is compelled to allow a certain amount of water to pass its head gates down the creek in order to satisfy prior appropriators.

This includes an amount for Draper's mill, for small ditches below, and an amount sufficient to fill Goshen reservoir, a small reservoir 2 miles west of the town of Goshen. After satisfying these prior claims, the company has water and storage capacity sufficient to supply its lands.

The following facts are taken from Engineering News:[1] The dam is 210 feet long at the top, 130 feet at the bottom, and 30 feet high. Its width at the base is 110 feet and at the top 8 feet. The body of the dam is of selected clay. The back and face are lined with loose rock and heavy gravel, hand placed. The outlet tunnel is a cut through the solid rock of the west abutment of the dam. It is 140 feet long and 6 by 4.5 feet in cross section. The wasteway is a cut through the solid rock ridge of the east abutment. The dam and all appurtenances except the wasteway cost about $12,000. The inlet tunnel cost $7.85 per linear foot.

The fluming used is a new and unusual type, being of the Sterling patented semielliptical style shown in Pl. XLI. At the junction of the main canal and the East Side canal the former has a capacity of 120 second-feet and the latter a capacity of 30 second-feet.

COLUMBIA BASIN.

SNAKE RIVER.

Snake River is one of the most important streams in the West, both for its water supply and for the area of irrigable land adjacent to it. It has its source in the Yellowstone National Park, and flows southward through Jackson Lake, receiving many large tributaries from each side, which drain almost inaccessible mountain ranges in western Wyoming. A measurement of Snake River was made by Messrs. Elwood Mead and C. T. Johnston, September 5, 1897, at the outlet of Jackson Lake, and the discharge was found to be 745 second-feet. A number of very fine reservoir sites are located in this section of the drainage basin, but it will be some time before it is necessary to utilize them, on account of the abundant water supply in the river. The North Fork has its source in Henry Lake, a few miles west of the western boundary line of Yellowstone National Park. It flows southward, receiving as its principal tributaries Fall and Teton rivers, which drain the western slope of the Teton Range of mountains, and joins the main river near Market Lake, Idaho.

The largest body of irrigated land in the State is located near the junction of the North Fork and the main river. Little irrigation is practiced north of Fall River, but south of that place many canals are taken out. The largest systems, however, are from the main Snake River, irrigating land lying near and north of Idaho Falls. Willow Creek is a small tributary, but is important both for its natural flow, which is all appropriated, and for its use as a distributary for a number of canals which

[1] Engineering News, Vol. XXXVI, No. 23, December 3, 1896.

FLUME OF MOUNT NEBO RESERVOIR AND CANAL COMPANY, UTAH.

take water from the main river. Two of the principal irrigation systems from the Snake above the North Fork are the Eagle Rock and Willow Creek canal and the Farmers Friend canal. The largest canals from the main river below the North Fork head near Bear Island on either side, the Great Western taking water from the west side and the Idaho canal taking water from the east side. This latter company also has headworks on Snake River, above the mouth of North Fork, and is one of the companies that use Willow Creek for a part of its length as a distributary. During the last two years this company has had the contract from the Government for the construction of an irrigation system for the Fort Hall Indian Reservation. The project includes the construction of two canals on the reservation and the furnishing of water to the same from Snake River. This is accomplished by turning the water into the Blackfoot River and diverting it again about 10 miles below by means of two diversion dams. The upper one supplies water to the High Line canal, used in the vicinity of Ross Fork, with a possible extension to Pocatello. The second one, 2 miles below, supplies water to an old Indian ditch, from which has been taken a lateral constructed by the Indians themselves. By contract the company was to furnish 200 second-feet to the lower canal, and it fulfilled its contract in the fall of 1897. The upper system is to furnish 100 second-feet.

At the request of the State engineer and of the engineers of the Idaho Canal Company and the Fort Hall Indian Reservation, Mr. Cyrus C. Babb, assistant hydrographer, made a measurement of the discharge of the canal at three different stages, the results to be considered authoritative by the two interested parties. The discharge was regulated at the lower head gates, and the measurements were made about three-fourths of a mile below, in the main lateral, as it is called, about 200 feet below its head. The measurements were made October 27, 1897. With the water at a low stage, giving a gage height of 1.0 foot on the rod at the foot of the drop, the discharge was 137 second-feet. The medium stage, at a gage height of 1.5 feet, gave a discharge of 207 second-feet. The maximum capacity, at an estimated gage height of 1.9 feet, was 298 second-feet. Immediately at the head of this lateral is located a drop of 2 feet, at the lower end of the apron of which has been constructed a so-called weir. It is valueless for estimating the discharge on account of the velocity of the water which passes through it. The edge of the weir is only 16 feet below the drop. During the high stage of the canal, when the last discharge measurement was made, the water overtopped the vertical sides of the weir.

The method of irrigation in the vicinity of Idaho Falls is very wasteful of water, but owing to the abundant supply there are few difficulties on this account at present. The low-water flow of Snake River at Idaho Falls is about 3,500 second-feet.

Portneuf River is an important tributary of Snake River, entering it about 15 miles west of Pocatello. The gaging station maintained for the last year is located at Pocatello. The stream is an important one for irrigation purposes, one or two irrigation enterprises having been planned from it.

Idaho is one of the few States which have sought to take advantage of the act of Congress known as the Carey Act, through which a large body of irrigable public land may be obtained by a State. The main object of this act is to provide for the reclamation and settlement of the desert public land, and to secure ultimately to the settlers the absolute ownership of the works constructed for irrigation. None but actual settlers or water users can file on the land.

In order to obtain possession of the lands in Idaho the State passed laws made necessary by the national act. As a result, a number of enterprises have been projected, the majority of them planning systems taking water from Snake River. In this connection, the State made a survey of a canal system heading at a point on Snake River near and south of Minidoka. At the point of diversion the river flows through a relatively narrow gorge, and the plan contemplates building a dam at that point and taking water from both sides.

The gaging station at Montgomery Ferry, on Snake River, is located a few miles below the proposed point of diversion. It is described in Water-Supply and Irrigation Paper No. 16, p. 165. The low-water flow is about 4,500 second-feet, an excess for all requirements of the above-mentioned enterprise. The high-water measurements are of value as giving the flood discharges used in computations for the wasteways of the dam.

A large area of irrigable land is located in the vicinities of Mountain Home and Orchard. It is too high to be easily served from Snake River, and the water supply for it will have to come from smaller creeks in the vicinity or from the tributaries of Boise River. The Mountain Home Canal and Land Company has a reservoir on Rattlesnake Creek, 3 miles from Mountain Home. Water is also supplied to it from Canyon Creek by means of a feeder canal. More than 1,000 acres were irrigated during the last year, but if a larger water supply could be obtained a much greater area could be brought under cultivation.

A fine reservoir site is located on Long Tom Creek above the point of diversion of the feeder canal from Canyon Creek, so that to utilize it water will have to be brought from some other basin. Boise River is only 2 miles north of the central portion of the reservoir, but is separated from it by a high ridge. The river is also 850 feet lower than the site, so that a feeder canal from the Boise would have to be taken out a long distance above. Preliminary examinations have been made with the idea of diverting water over the divide to Long Tom Creek from the following tributaries of the Boise: Camas, Cat, Wood, Louse, and Lime creeks. An inspection of the topographic maps of the region tends to show that the diversion can be accomplished. An accurate survey, however, should be made to determine positively its practicability.

A gaging station was maintained on Camas Creek in 1896, and the measurements show that during the flood discharge 23,500 acre-feet are available for storage. It is difficult to say whether this quantity is the average of a series of years or not, on account of the shortness of the record. It is thought, however, that it is somewhat above the average, judging from the flow of Boise River and adjoining basins.

The Orchard Irrigation Company has a reservoir located on Indian Creek, the outlet of which is closed by means of a well-constructed earthen dam with a cement core wall. The surplus water of Tenmile Creek is conducted to this reservoir by means of a feeder canal. Its capacity, as determined by the survey of the State engineer's office, is 1,500 acre-feet. Water rights, as shown by the records of the county office, have been sold for over 8,000 acres.

Rating table for Snake River at Montgomery Ferry, Idaho, for 1897.

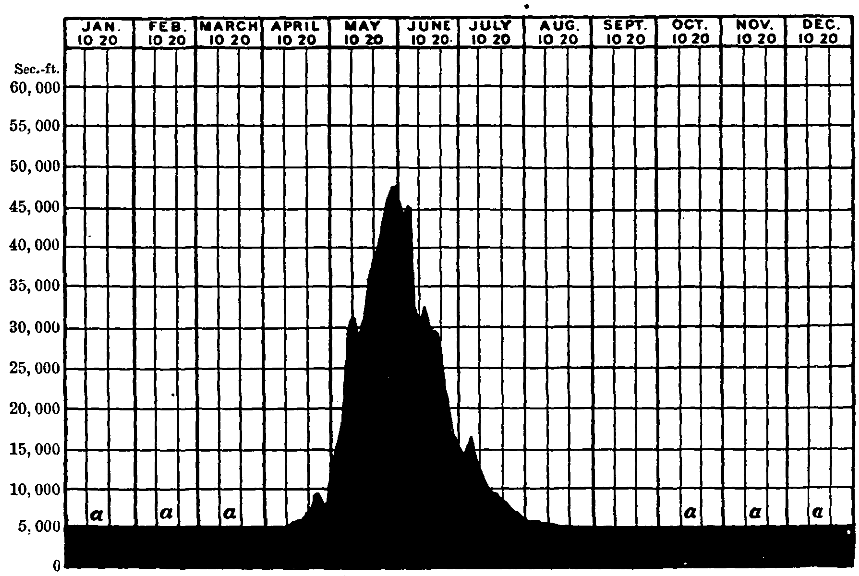
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.0	4,400	4.2	8,000	6.2	16,760	8.5	27,800
2.4	4,700	4.4	8,600	6.4	17,720	9.0	30,200
2.6	4,900	4.6	9,200	6.6	18,680	9.5	32,600
2.8	5,100	4.8	10,100	6.8	19,640	10.0	35,000
3.0	5,400	5.0	11,000	7.0	20,600	10.5	37,400
3.2	5,800	5.2	11,960	7.2	21,560	11.0	39,800
3.4	6,200	5.4	12,920	7.4	22,520	11.5	42,200
3.6	6,600	5.6	13,880	7.6	23,480	12.0	44,600
3.8	7,000	5.8	14,840	7.8	24,440	12.5	47,000
4.0	7,400	6.0	15,800	8.0	25,400	13.0	49,400

Estimated monthly discharge of Snake River at Montgomery Ferry, Idaho.

[Drainage area, 22,600 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	....	....	a5,000	307,440	0.25	0.22
February	....	....	a5,000	277,686	0.23	0.22
March	....	....	a5,000	307,440	0.25	0.22
April	10,775	5,000	6,569	390,882	0.33	0.30
May	47,480	11,720	33,034	2,031,195	1.68	1.46
June	45,320	16,280	30,248	1,799,877	1.50	1.34
July	16,520	6,200	10,711	658,598	0.54	0.47
August	5,900	4,900	5,223	321,152	0.26	0.23
September	5,100	4,800	4,982	296,449	0.24	0.22
October	....	....	a5,000	307,440	0.25	0.22
November	....	....	a5,000	297,520	0.24	0.22
December	....	....	a5,000	307,440	0.25	0.22
The year	....	....	10,064	9,334,314	6.02	0.44

a Approximate.



a Approximate.

FIG. 160.—Discharge of Snake River at Montgomery Ferry, Idaho, 1897.

MALADE AND LITTLE WOOD RIVERS.

Malade and Little Wood rivers are important tributaries of Snake River on account of irrigation possibilities within their valleys. More or less water for irrigation on a small scale is diverted from them. If the flood flows of these two rivers could be stored a considerable tract of irrigable land could be brought under cultivation. Gaging stations on these rivers are located at Toponis, described in Water-Supply and Irrigation Paper No. 16, p. 165.

Rating table for Malade River at Toponis, Idaho, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.0	0	3.4	320	4.8	1,490	6.2	3,020
2.2	10	3.6	460	5.0	1,700	6.4	3,240
2.4	20	3.8	600	5.2	1,920	6.6	3,460
2.6	45	4.0	740	5.4	2,140	6.8	3,680
2.8	80	4.2	910	5.6	2,360	7.0	3,900
3.0	130	4.4	1,090	5.8	2,580		
3.2	210	4.6	1,290	6.0	2,800		

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.		Depth in inches.	Second-feet per square mile.
1897.						
June 6–19	2,360	390	1,455	40,404	0.346	0.664
July	1,000	80	355	21,828	0.187	0.162
August	80	0	36	2,214	0.018	0.016
September	30	0	8	476	0.004	0.004

Rating table for Little Wood River at Toponis, Idaho, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.0	1	2.4	60	3.8	161	5.2	325
1.2	7	2.6	72	4.0	181	5.4	349
1.4	15	2.8	84	4.2	205	5.6	373
1.6	23	3.0	98	4.4	229	5.8	397
1.8	31	3.2	112	4.6	253	6.0	421
2.0	40	3.4	127	4.8	277	6.5	481
2.2	50	3.6	143	5.0	301		

Estimated monthly discharge of Little Wood River at Toponis, Idaho.

[Drainage area, 1,270 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
June	481	66	207	12,317	0.182	0.163
July	60	1	17	1,045	0.015	0.013
August	91	1	19	1,168	0.017	0.015
September	143	50	91	5,415	0.080	0.072

BRUNEAU RIVER.

This river is a tributary of the Snake, entering it from the south, 30 miles west of Glenns Ferry. A number of small canals irrigate lands in the head waters of the stream, but the largest enterprise is the one recently completed, that of the Owyhee Land and Irrigation Company, diverting water from the lower course to be used for irrigation as well as for mining purposes. The capacity of the system is 540 second-feet. The gaging station is located below the headworks near Grandview, Idaho, and shows the amount of water running to waste. The station is described in Water-Supply and Irrigation Paper No. 16, p. 167.

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.		Depth in inches.	Second-feet per square mile.
1897.						
January	120	80	96	5,903	0.06	0.05
February	540	100	146	8,108	0.08	0.08
March	3,840	85	460	28,284	0.30	0.26
April	3,060	290	1,641	97,646	1.01	0.91
May	2,800	1,810	2,269	139,516	1.45	1.26
June	1,880	410	908	54,030	0.57	0.51
July	360	75	196	12,052	0.13	0.11
August	80	30	51	3,136	0.03	0.03
September	55	40	48	2,856	0.03	0.03
October	110	55	90	5,534	0.06	0.05
November	150	100	120	7,140	0.08	0.07
December	150	110	128	7,870	0.08	0.07
The year	3,840	30	513	372,075	3.88	0.29

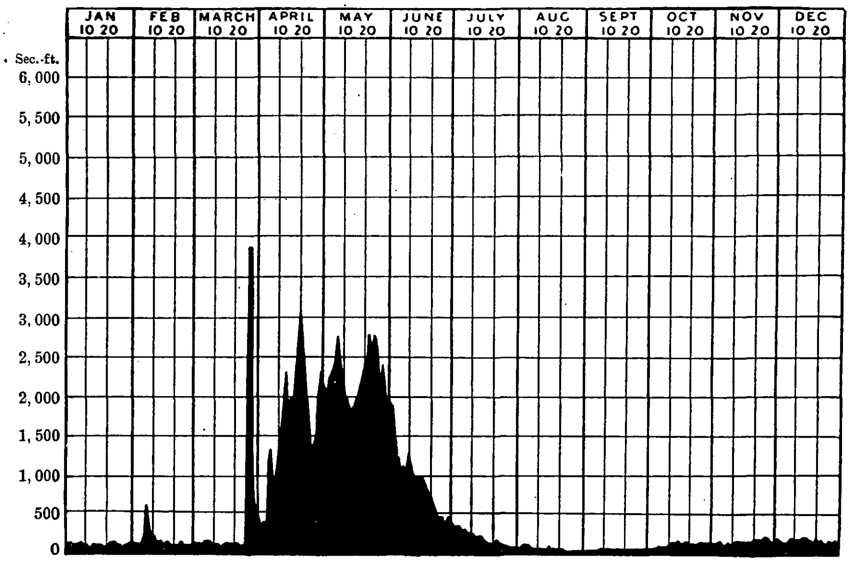


FIG. 161.—Discharge of Bruneau River at Grandview, Idaho, 1897.

BOISE RIVER.

Boise River drains an area above its canyon of 2,450 square miles, mountainous and well wooded. The effect of the latter characteristic is seen in the high summer flow which the river maintains. Below the gaging station, besides various small ditches on both sides of the river, thirteen good-sized canals are taken out. Their aggregate maximum capacity as determined by the State engineer is 1,060 second-feet. During the irrigating season they do not run with full banks, the total probably not amounting to more than 800 to 900 second-feet. From Boise River 32,000 acres are irrigated. This would give a duty of water of about 40 acres to the second-foot. During the fall of 1896 the State engineer made a series of measurements in Phyllis canal to obtain an idea of the loss of water by seepage and evaporation. The length of the canal is 35.5 miles. The daily loss was 1.83 inches over the water surface, or 30 per cent of the water entering the head. The soil is a decomposed lava underlain by hardpan. During the entire season a daily record was kept by the management of Phyllis canal, by means of weirs, of the water entering at the head, of the amount diverted by the different laterals, and of the amount wasting at the lower end. The record shows for the four months from June to September, inclusive, an average daily loss of 6.4 second-feet, or of 2.76 inches from the water surface.

From these daily measurements the percentage of the total amount of water for the season used during the different periods is found to be as follows:[1]

Percentages of total amount of water for the season used during different periods.

	Per cent.
April 10–30	1.7
May 1–31	4.9
June 1–15	6.8
June 16–30	12.7
July 1–15	12.1
July 16–31	12.5
August 1–15	11.4
August 16–31	12.7
September 1–15	8.7
September 16–30	9.1
October 1–15	7.4
Total	100.0

The manager of Ridenbaugh canal has also furnished an estimate of quantities carried in that canal for five months, from which the following percentages are compiled:

Monthly percentages of water carried in Ridenbaugh canal from May to September, inclusive.

	Per cent.
May	13.2
June	26.3
July	26.3
August	21.0
September	13.2
Total	100.0

The accompanying tables show the amount of water in Boise River, as determined at the gaging station in the canyon 10 miles above Boise. A description of the station will be found in Water-Supply and Irrigation Paper No. 16, p. 168.

On April 18 the river cut into the right bank of the station, carrying out the cable and leaving the gage on a small island, so that the record after that date is unreliable. A temporary gage was placed May 12 at the Broadway bridge at Boise and a record was kept by it until June 17, when a new gage was placed in the canyon 1 mile above the old location. The rating table for 1896 as published in the Eighteenth Annual Report, Part IV, p. 342, has been applied to gage heights for 1897 from January 1 to April 19. There is then a blank in the estimates from April 20 to May 11 owing to the unreliability of the record. From May 12 to June 16 the rating table as herewith published for the Broadway bridge has been applied. After that date the table for the new canyon station is used.

The amount of water flowing in Boise River, Idaho, was measured on

[1]First Biennial Report of the State Engineer to the Governor of Idaho, page 64.

August 17, 1885, by the engineers of the New York Mining and Irrigation Company. The point of measurement was in the canyon about 8 miles above the city of Boise. The velocity was ascertained by means of tin tubes 20 inches in depth. The width of the river was found to be 170 feet and the floats were placed at distances of 30 feet. The results give a flow of 960 cubic feet per second.

During the summer of 1885 the same engineers measured various ditches. The results of these measurements, in second-feet, are as follows:

Flow in various ditches in summer of 1885.

	Second-feet.
Central Park ditch, measured just above Middleton	1
McDowell ditch	1.5
Middle Mill ditch	47
Middle Canal Company	36
Cassady, Moore & Davis canal (since changed and enlarged)	7.5
Dry Creek ditch	8
Walling ditch, October, 1883	73.5
Ridenbaugh canal, October 30, 1888	49
Mill ditch	50

Rating table for Boise River at Boise, Idaho, for 1897.

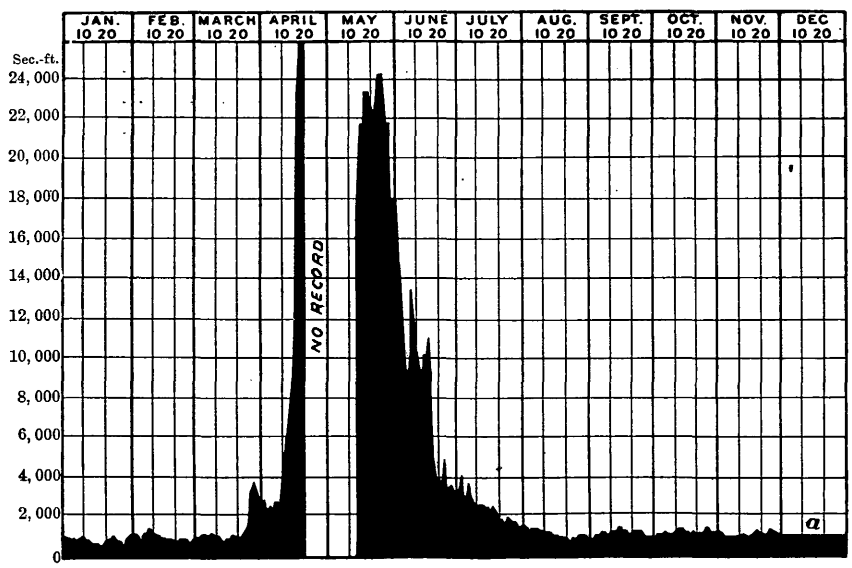
Gage height.	Discharge.			Gage height.	Discharge.		
	Jan. 1 to Apr. 19.	May 12 to June 16.	June 17 to Dec. 31.		Jan. 1 to Apr. 19.	May 12 to June 16.	June 17 to Dec. 31.
Feet.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*
1.0	520	....	600	4.5	3,930	24,875	....
1.2	620	....	860	5.0	4,855	....	....
1.4	720	....	1,120	5.5	5,905	....	....
1.6	830	....	1,380	6.0	7,095	....	....
1.8	950	....	1,640	6.5	8,465	....	....
2.0	1,070	5,500	1,900	7.0	10,110	....	....
2.2	1,210	7,050	2,160	7.5	12,345	....	....
2.4	1,350	8,600	2,420	8.0	15,325	....	....
2.6	1,510	10,150	2,680	8.5	19,342	....	....
2.8	1,680	11,700	2,940	9.0	24,652	....	....
3.0	1,870	13,250	3,200	9.5	31,522	....	....
3.5	2,430	17,125	3,900	10.0	40,132	....	....
4.0	3,120	21,000	5,100				

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.		Depth in inches.	Second-feet per square mile.
1897.						
January	1,070	570	818	50,297	0.38	0.33
February	1,350	770	954	52,983	0.41	0.39
March	3,430	770	1,419	87,251	0.67	0.58
April 1–19	28,572	2,080	8,102	305,330	2.34	3.31
May 12–31	24,100	17,125	21,058	835,360	6.40	8.60
June	14,800	3,460	7,600	452,230	3.46	3.10
July	4,100	1,380	2,309	141,976	1.08	0.94
August	1,380	795	1,089	66,960	0.51	0.44
September	1,250	860	1,042	62,003	0.48	0.43
October	1,250	860	1,020	62,718	0.48	0.42
November	1,250	990	1,077	64,086	0.49	0.44
December	....	....	a1,000	61,488	0.47	0.41

a Approximate.



a Approximate.
FIG. 162.—Discharge of Boise River at Boise, Idaho, 1897.

PAYETTE RIVER.

This river drains a well-wooded, mountainous area similar to that of the Boise. The effect of the forest is shown in the well-sustained summer flow. There is a surplus of water in this river at all seasons for lands tributary to it, and it will be many years before recourse must be had to storage, although a number of fine sites are located in the basin, especially at the Payette lakes. A number of canals take water from both sides of Payette River, the principal ones from the north side being the Lower Payette and Pence ditches. On the south side Last Chance, Enterprise, and Noble ditches irrigate lands from about 3 miles above Emmett to below Falks Store. One of the largest irrigation enterprises of the State is the Payette Valley Irrigation and Water Power Company's system. The main canal heads about 1 mile above Emmett and irrigates lands almost to Snake River. No water is used from the upper 20 miles, the lands being served by the above-described canals. A gaging station is located at the town of Payette, near the mouth of the river, and shows the amount of water wasted. The station is described in Water-Supply and Irrigation Paper No. 16, p. 170. The rating table for 1896, published in the Eighteenth Annual Report, Part IV, p. 351, has been applied to the 1897 heights.

Estimated monthly discharge of Payette River at Payette, Idaho.

[Drainage area, 3,565 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
May 14-31	25,570	19,925	23,139	826,128	4.35	6.49
June	20,350	7,060	11,115	661,387	3.48	3.12
July	7,330	2,080	4,241	260,771	1.37	1.19

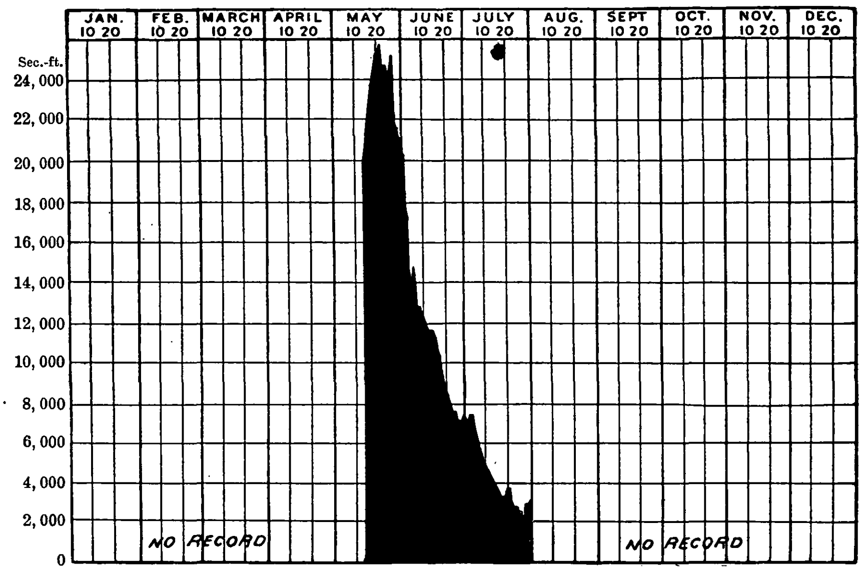


FIG. 163.—Discharge of Payette River at Payette, Idaho, 1897.

WEISER RIVER.

The drainage basin of this stream is mountainous and rocky in contrast to the wooded areas drained by the Payette and Boise rivers, and the effect is shown in the quick spring floods and the extreme low-water discharge. A number of small ditches irrigate lands on either side of the river below the canyon, but the principal canal is the Galloway, serving lands in the vicinity of Weiser. The maximum capacity of the canal is 50 second-feet. The annual rental for water that is used from it is $1.50 per miner's inch, it being almost the only system in the State in which the annual charge is by quantity of water instead of acreage of land. North of the town of Weiser and above the Galloway canal is a stretch of bench land which would produce abundant crops if water could be brought to it. A number of small creeks flow through it having spring discharges but running dry in summer. If this water, which is now wasted, could be stored in the several natural reservoirs which are said to exist in the area it could be well used. Utilization of these reservoir sites in the near future is contemplated. A gaging station on this stream is located in the canyon 10 miles above the town of Weiser and above all irrigation canals. The following tables show the discharge by months. The station is described in Water-Supply and Irrigation Paper No. 16, p. 171.

Rating table for Weiser River near Weiser, Idaho, for 1897.

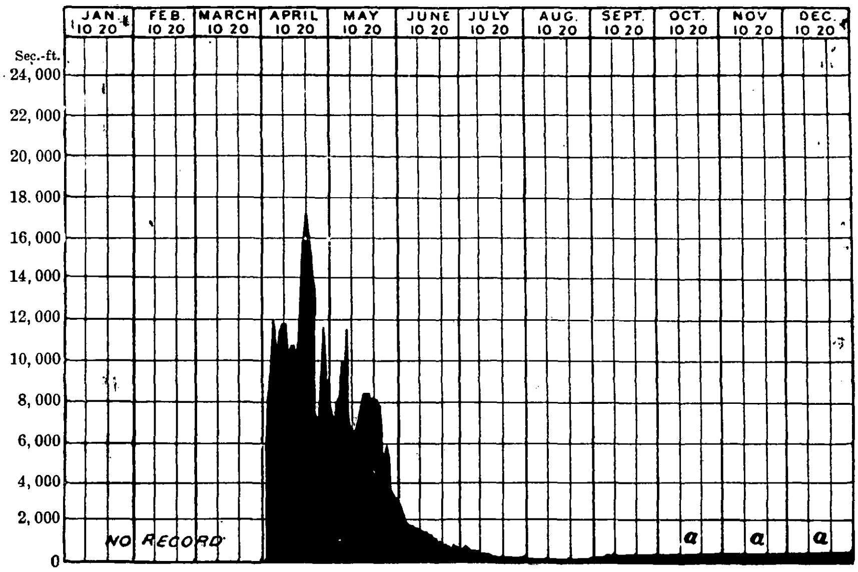
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.6	80	1.8	650	3.4	2,250	5.0	5,285
0.7	100	2.0	800	3.6	2,525	5.5	6,735
0.8	120	2.2	970	3.8	2,820	6.0	8,400
0.9	150	2.4	1,150	4.0	3,135	6.5	10,155
1.0	190	2.6	1,340	4.2	3,485	7.0	11,950
1.2	280	2.8	1,540	4.4	3,875	7.5	13,785
1.4	390	3.0	1,760	4.6	4,305	8.0	15,640
1.6	510	3.2	1,995	4.8	4,775		

Estimated monthly discharge of Weiser River at Weiser, Idaho.

[Drainage area, 1,670 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
April	17,175	5,555	10,878	647,285	7.26	6.51
May	11,590	3,135	7,022	431,769	4.84	4.20
June	2,670	650	1,260	74,975	0.83	0.75
July	800	150	385	23,673	0.26	0.23
August	120	80	86	5,288	0.06	0.05
September	150	100	114	6,783	0.08	0.07
October			*a* 150	9,223	0.10	0.09
November			*a* 150	8,926	0.10	0.09
December			*a* 150	9,223	0.10	0.09

a Approximate.



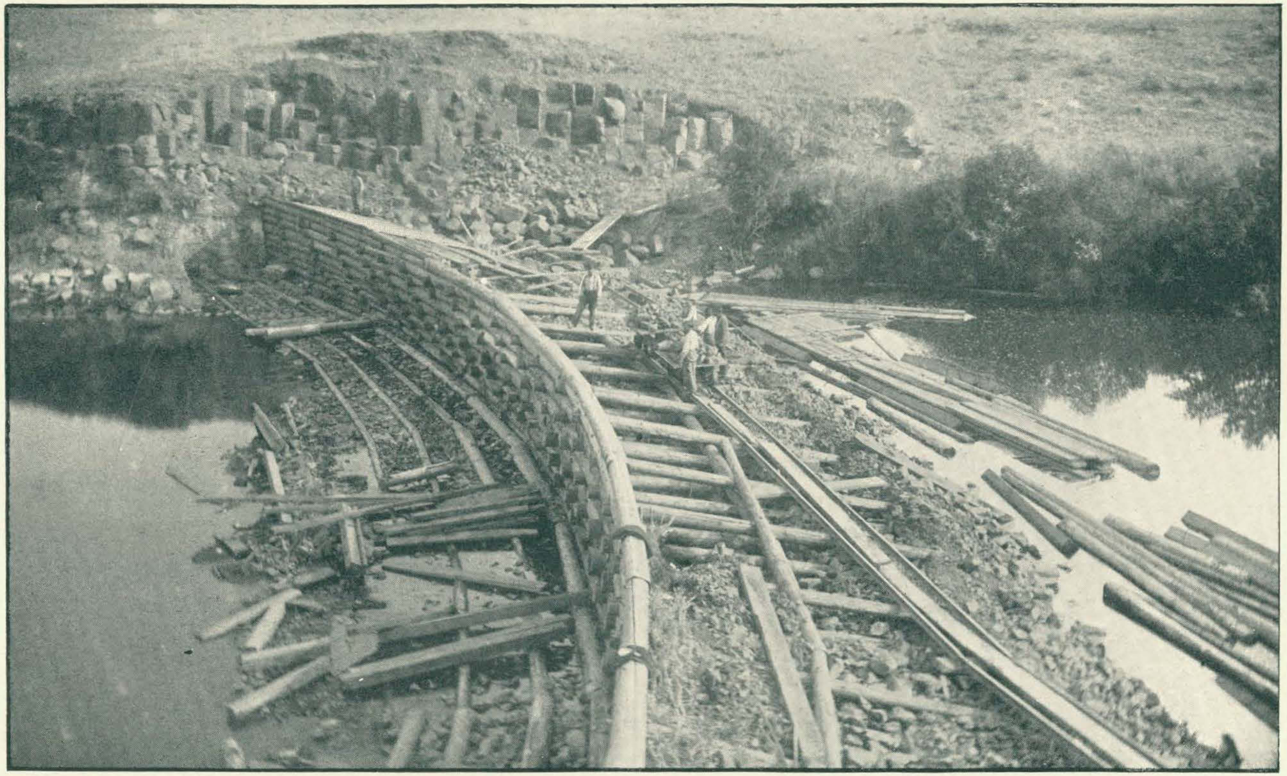
a Approximate.

FIG. 164.—Discharge of Weiser River at Weiser, Idaho, 1897.

PALOUSE RIVER.

Near the tributaries of Potlatch River, a tributary of Clearwater River in Idaho, are a number of streams which flow in a westerly direction across the State line into Washington and there unite, forming Palouse River. Along the lower stretches this river is a peculiar stream, with a fall of not over 10 feet to the mile. For a number of miles above and below Hooper it is a succession of deep holes 10 to 15 feet deep, connected by short riffles. Its valley is about one-half mile wide, bordered with basaltic cliffs approximately 300 feet high. At the point where the river makes a sudden bend to the south and enters its narrow basaltic canyon there is a fine dam site. A dam here, possibly 400 or 500 feet long and 100 feet high, would impound a large body of water extending probably 10 miles up the river. A canal or flume could probably be taken from Palouse River below, perhaps at the falls of the Palouse (said to be 130 feet high), and 10 miles below the dam site, and brought to irrigate lands north of Snake River in the region north of Pasco, Washington.

Another proposition for irrigating lands in the vicinity of Pasco contemplates a widening of the canal of the Palouse River Irrigation Company, heading near Hooper, bringing it across the divide between the Palouse and Washtucna valleys and thence down to a reservoir site below Washtucna. The lower end of this valley can be dammed and the outlet controlled. The feasibility of the project depends on the water supply of Palouse River, which is a very flashy stream, rising and falling suddenly, and a large canal would be necessary in order to obtain sufficient water to fill the reservoir.



DAM ON PALOUSE RIVER NEAR HOOPER, WASHINGTON.

In 1893 a canal was constructed by the Palouse River Irrigation Company, taking water from the left bank of Palouse River, near Hooper, Washington, to irrigate lands in the vicinity of Washtucna, 11 miles below. A dam was constructed at the head of the canal, but it was carried out by a flood two days after it was finished. During the summer of 1897 the company rebuilt the dam, as shown on Pl. XLII, and extended it. The dam is a crib 176 feet long, constructed on the arc of a circle with the middle ordinate 18 feet. It is to be 16 feet high. The abutments are basalt rock. The bottom width of the dam is 40 feet. A part of the old dam, 10 feet wide, is used as an apron for the new dam. The water at this point is 9 feet deep at low stages. The canal is 10 feet wide on the bottom, with a grade of 1.5 feet to the mile—too light a grade for a canal of this size. Three miles below the head it crosses the Palouse in an inverted siphon, 4 feet in diameter, of the Hawkes dovetail pattern. The difference in elevation is about 40 feet from the bottom of the ditch to the lowest point of the pipe line. The length of the pipe is about 1,000 feet. It crosses the river proper on a well-constructed wooden bridge 500 feet below the railroad bridge. Eight miles from the dam the canal crosses the divide between the Palouse drainage and Washtucna Valley. At this point, called "The Summit," the cut is 16 feet through a partly cemented coarse gravel. It is thought that Palouse River originally extended down to Washtucna Valley and emptied into Columbia River near the mouth of Snake River. The topography of the valley of the Palouse is similar to that of the Washtucna.

There are two flumes along the length of the canal, one 300 and the other 400 feet long. They are 8 feet wide on the bottom and 3 feet high. The sides and bottom are of 2 by 12 inch plank, with 4 by 4 inch side pieces. At the time of inspection, in September, 1897, the flumes were in very bad condition, with cracks fully one-half inch wide between the planks. They may possibly swell up and close, however, when water is let down the canal. The canal is designed to irrigate 4,000 acres, and its computed capacity is 30 second-feet. The old canal was constructed to within 2 miles of Washtucna. It is, however, to be extended, but with a bottom width reduced to 5 feet.

April 1, 1897, the Northern Pacific Railway Company established a gaging station on this river near Hooper. September 9, 1897, this Survey took charge of the station, placing the gage rod 1 mile below the former location and opposite the water tank of the railroad company. It is located about 3 miles above the mouth of Cow Creek and 2 miles below the head of the ditch of the Palouse Irrigation Company, which carries, when full, 25 second-feet. The station is located here above Cow Creek because of the desirability of having information on the available flow for the Washtucna reservoir proposition. A sufficient number of discharge measurements were not made in 1897 on which to base the construction of a rating table. The two following measurements of discharge were made this year: September 9, gage height, 2.10 feet; discharge, 73 second-feet. October 1, gage height, 1.90 feet; discharge, 50 second-feet. This latter figure is probably the minimum flow of the river.

CLEARWATER AND ADJACENT RIVERS.

During the course of the survey of the Bitterroot Forest Reserve, in 1897, Mr. J. B. Lippincott, topographer, made a number of measurements of discharge of streams in Idaho and Montana, chiefly within the reserve. They are as follows:

Discharge of streams in Bitterroot Forest Reserve.

Date.	Locality.	Area of basin.	Volume.
1897.		*Sq. miles.*	*Second-feet.*
July 31	Moose Creek above junction of Cedar Creek	83	100
Do	Cedar Creek at mouth	39	25
Aug. 8	Laksha at Jerry Johnson's, below the junction Hot Springs Creek	592	841
Aug. 21	Lolo Creek at Kamiah and Weippe trail crossing	....	120
Aug. 22	Clearwater River at Kamiah	4,300	2,527
Do	South Clearwater at Stewart's	900	300
Sept. 9	Selway crossing, Elk Summit trail	108	140
(*a*)	Snake River at Texas Rapids, Washington	....	26,000
Aug. 27	Spokane River, Spokane	....	2,937
Sept. 30	Bitterroot River, Como P. O.	....	*b* 800
Do	Como Creek below Lake Montana	....	4

a Summer stage. *b* Approximate.

The above measurements are for the low summer stage of the streams. While the measured volume of the Laksha at Johnson's is but 841 second-feet, it is much larger at its junction with the main or longer stream near Stewart's, and it is probable that its volume at its mouth is greater than either of the other large streams of the reserve, the main Clearwater or the South Clearwater.

The striking hydraulic feature of this country is its lakes. They are numerous, but are small, averaging perhaps 5 acres in area. The northeast sides of the peaks in the higher mountains are usually cliffs of 1,000 feet or more, and at the foot of each a lake is generally found. These lakes are not sufficiently large to be a factor in the storage of water for any extensive purpose. The most important is Como Lake, in Montana, which could be made to hold 30,000 acre-feet of water at very slight cost, and there is sufficient drainage back of it to fill it each year. The reserve contains very few reservoir sites. The only others of importance are on the South Clearwater. The Little Elk and Ryan meadows would be worthy of survey in this connection. There is said to be a reservoir site 5 miles northeast of the Newsome House, on Newsome Creek, and one 12 miles southeast from Buffalo Hump, on the Salmon drainage. The trouble with these alpine meadows for reservoir sites is that they have too little drainage back of them. These reservoirs would be valuable to hold flood water for summer placer mining around Elk City, and it is possible that this water might afterwards be conveyed to the prairie lands about Grangeville, Idaho. This plain is known as the Camas Prairie. It is 30 miles long and 20 miles wide, and its mean elevation is about 3,000 feet. It is bounded on the north by Clearwater River, on the south by Salmon River, and on the east by South Clearwater River. It is a gently rolling prairie. The bed rock is basalt, with a deep, rich soil covering. The rainfall is slightly over 20 inches, occurring chiefly in winter. The largest local stream is Cottonwood Creek. Little irrigation is practiced, but it is needed.

There is a hot spring at Johnson's, on the Laksha, of 1 second-foot capacity and a temperature of 100° F. There is also one on Horse Creek, on the north side of Mineral Hill, of 0.5 second-foot capacity and temperature 80° F. A third hot spring of large volume is approximately 10 miles southeast of Elk Summit Peak, on the north bank of a deep canyon.

YAKIMA RIVER.

Yakima River, as shown in fig. 165, has its source in Keechelus Lake, on the eastern slope of the Cascade Mountains, in Kittitas County, Washington. At Easton it receives Kachess River, which is only 3 miles long, being the outlet of the lake of the same name. Two and one-half miles above Clealum it receives the last of the three large head-water tributaries, the outlet of Clealum Lake. The valley of Yakima River is comparatively narrow until it widens out into Kittitas Valley, in which Ellensburg is located. The town has an elevation of 1,550 feet above sea level. The vicinity is devoted to agricultural interests, the cereals and alfalfa being the chief products. It has been found to be rather too cold for orchard products, which do better at North Yakima, 36 miles below, and 500 feet lower in elevation.

The Northern Pacific Land Department, in 1892, had extensive plans for irrigating the Kittitas and North Yakima valleys and the country southward, and made extensive surveys for reservoir sites of the three lakes named above and also of Bumping Lake, on Bumping River, a tributary of Naches River. The outlets of all the lakes are through glacial deposits. They can be easily dammed by structures 30 feet in height, and it was the original plan of the Northern Pacific, Yakima and Kittitas Irrigation Company to construct crib dams of this height at all the lake outlets. This plan was not carried out. The final outcome was the construction of Sunnyside canal, below North Yakima.

The surveys of this company showed that the proposed reservoir at Keechelus Lake, with a dam 30 feet in height, would have a capacity of 50,800 acre-feet.

Irrigation is practiced to a considerable extent in the vicinity of Ellensburg. The largest ditch is the Town ditch, as it is called, which takes water from the left bank of the Yakima at Thorp, 6 miles above Ellensburg. Just below the town this canal passes through a ridge, by means of a tunnel, and then irrigates lands for 10 miles below. The canal is 16 feet wide at the head. Another canal takes water from Tanum Creek and continues southward, ending about opposite Ellens-

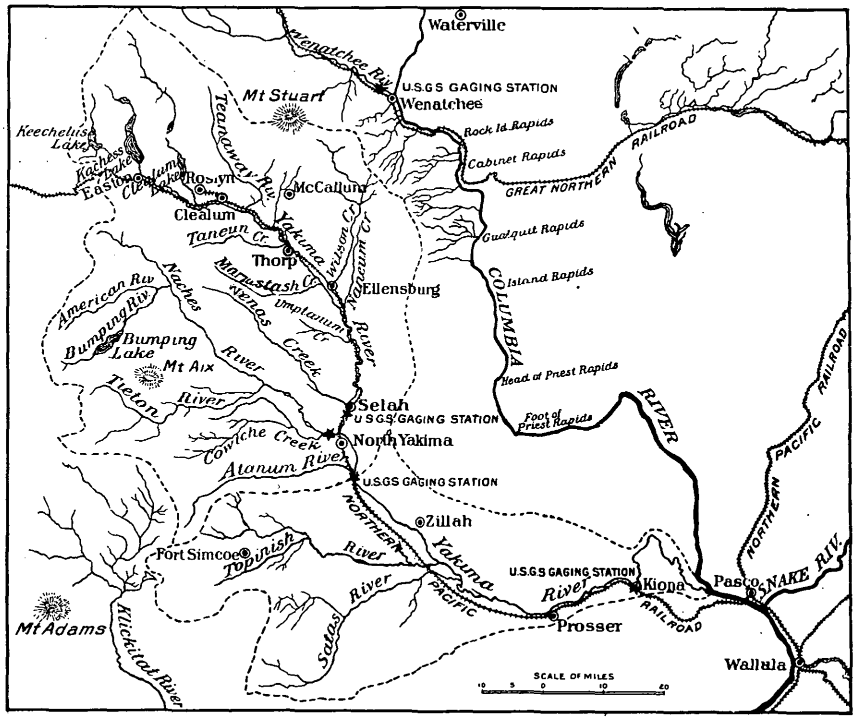
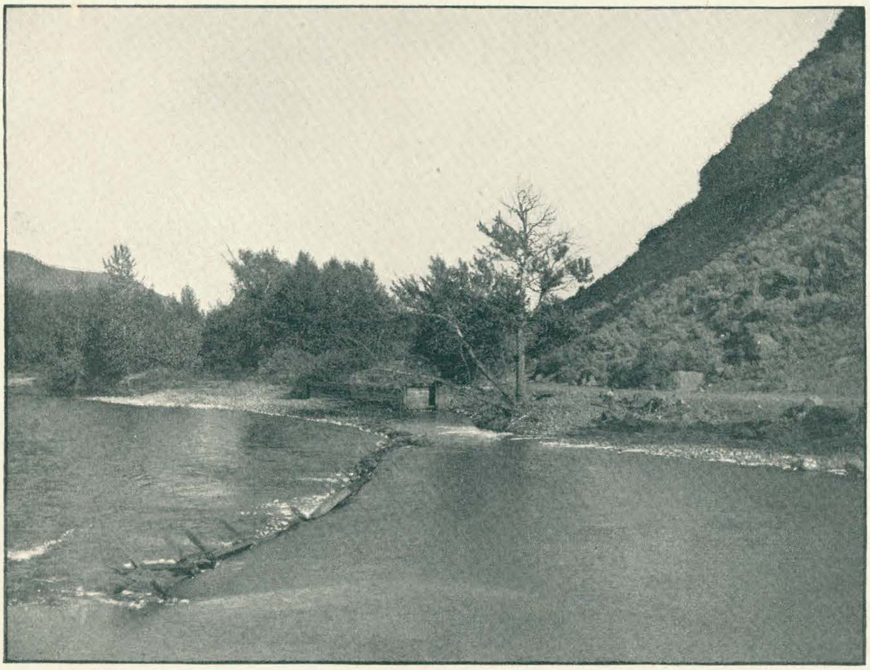
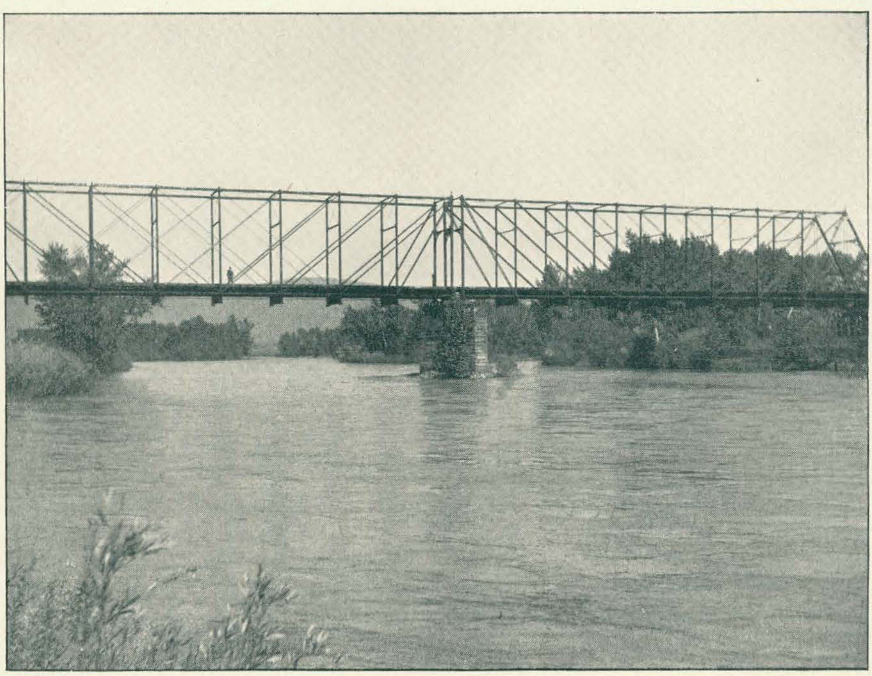


FIG. 165.—Map of drainage basin of Yakima River, Washington.

burg. A number of small local ditches use water from Manastash Creek, as well as from Reeser, Nanum, and Cherry creeks. A small diversion is made from one of the tributaries of Swaak Creek, east of McCallum, bringing water through Green Canyon and into the head of Reeser Creek to be used below. Four years ago a canal taking water from the right bank of Yakima River at Easton was started. Continuing southward, it crossed the river, just above Dudley, to the eastern side. It was then to be extended below Ellensburg, emptying into the river at the line of foothills. This canal was constructed in stretches to a point below Dudley. Such works as flumes, crossing gulches, etc., were not undertaken. Nothing has been done with this



A. WING DAM AND HEAD GATES OF NACHES AND COWICHE CANAL, ABOVE NORTH YAKIMA, WASHINGTON.



B POINT OF MEASUREMENT OF YAKIMA RIVER AT SELAH, WASHINGTON.

canal for the last two or three years. It was known as the Kittitas Valley irrigation canal, or Middle canal. It was to be 20 feet wide at the head, and at about the point where construction stopped it was 350 feet in elevation above Ellensburg.

At the lower end of Kittitas Valley Yakima River enters the canyon, through which it flows for about 20 miles. At Selah the valley broadens out into what is known as Selah Valley, which is about 4 miles long and 3 miles wide. At the lower end of this valley the river passes through another ridge, or the "Upper Gap," as it is called, and enters the North Yakima Valley.

The region near North Yakima, shown on fig. 166, is more extensively irrigated than any other area in the State and contains the largest systems of canals. The following are the principal canals taking water from Naches River:

The Selah Valley irrigation canal is on the north side of the river, heading just above the mouth of Tieton River, about 20 miles from North Yakima. It irrigates land in Selah Valley and has about 1,000 acres in cultivation under its 30 miles of length. Below head the Wapatuck and Naches canals, each about 7 miles long. They irrigate the bottom lands of Naches Valley.

On the south side, the Yakima Valley canal heads about 12 miles from North Yakima and for the first 10 miles of its course is in a flume. At the point known as "Painted Rocks" it is carried around on a trestle about 70 feet high, and thence enters immediately an inverted siphon, which carries the water across the Cowiche Canyon. It continues for about 2 miles, again in flume, and then enters its canal. The siphon is the ordinary type of wooden stave pipe bound by iron bands. A view of it is shown in Part IV of the Eighteenth Annual Report, Pl. XXX, on page 356. The entire length of this canal is 16 miles.

The Naches and Cowiche, or Hubbard, ditch, heads at "Painted Rocks," 5 miles northwest of North Yakima and just below the Nelson bridge over Naches River. (See Pl. XLIII, *A*.)

The canal of the Yakima Water, Light and Power Company, and the Shanno, Broadgauge, Union, and Town ditches head between Hubbard ditch and the lower highway bridge, in the order named, downstream. Their combined length is about 25 miles, and they serve principally the lands lying in the immediate vicinity as well as the town of North Yakima. A drop of 20 feet is obtained in the waterworks canal, developing sufficient power for an electric-light service for the town and for a pumping plant for a water-pressure service.

Three canals take water from the east side of Yakima River, just below the mouth of the Naches, supplying water for Moxee Valley. They are known as the Moxee, Hubbard, and Fowler ditches.

The canal of the Yakima Investment Company, or Sunnyside canal, heads on the east side of Yakima River 9 miles south of North Yakima and 3 miles below the gaging station of the United States Geological

Survey at Union Gap. It is 42 miles long and has a large acreage in cultivation under it. On September 21 the discharge of this canal 3 miles below its head, before much water had been diverted for irrigation, was 88 second-feet. Land under this canal was at first held from $50 to $80 an acre. In the autumn of 1897 the company was reorganized and the land was placed on the market at $30 an acre.

In 1895 the survey of a large canal, called the Naches and Columbia River irrigation canal, was made under the direction of the State arid land commission, an office formed after the passage of the Carey Act. The canal was to head on the north side of Naches River, 3 miles below the head of Selah Valley canal. It was to cross Yakima River a short distance above the mouth of the Naches by means of

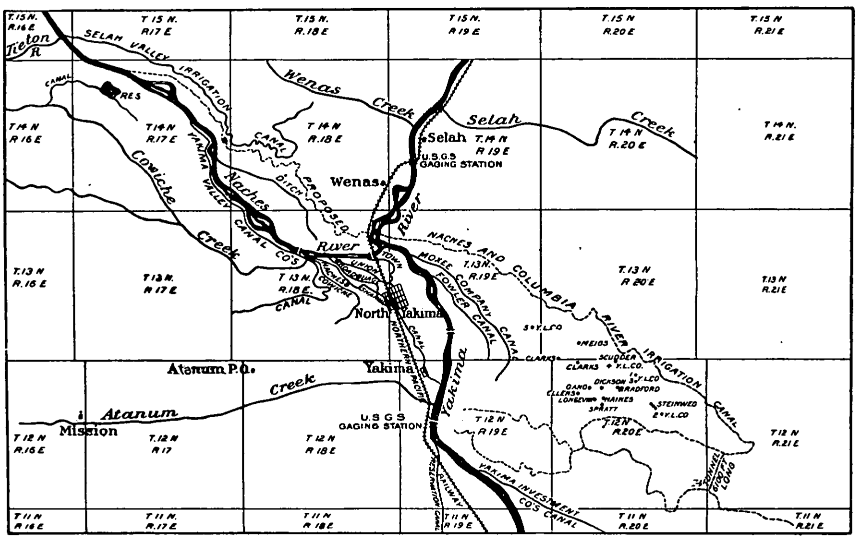


FIG. 166.—Map of canals in vicinity of North Yakima, Washington.

an immense inverted siphon, circle Moxee Valley, pass through the Union Gap Ridge by means of a tunnel 6,100 feet long, and continue down Yakima Valley to the Rattlesnake Range, around which it was to pass to lands overlooking Columbia River. It was to be 140 miles long and to carry at its head 2,000 second-feet of water. The intention was to use as a storage reservoir, in connection with this proposition, Bumping Lake, on Bumping River, a tributary of the Naches, by placing a dam 25 or 30 feet high at the outlet of the lake. A survey of this reservoir site was made in September, 1894, by the Northern Pacific, Yakima and Kittitas Irrigation Company, in connection with extensive plans for the irrigation of the Kittitas and Yakima valleys, which culminated in the construction of the Sunnyside Canal. This company and its successor, the Yakima Investment Company, have endeavored to segregate the site, but have failed, probably because it was on unsurveyed land and the surveys did not connect it with a Government corner, and other parties claimed the site before the survey above mentioned was made.

The following description of the Yakima Indian Reservation canal is furnished by Mr. Sydney Arnold, civil engineer, of North Yakima:

The canal heads about 1 mile below the United States Geological Survey gaging station at Union Gap, or 7 miles below the town of North Yakima, Washington, and was completed during the summer of 1897. It heads on the right bank of the river. The first half mile follows a natural slough, or channel, having a total fall of 7 feet. Then comes the constructed main ditch of the following dimensions: Bottom width, 12 feet; side slopes 2 to 1; maximum depth of water, 2.5 feet; grade, 2.5 feet for the first mile. The discharge by Kutter's formula is 85 second-feet. This is the maximum capacity of the present canal, and not 314 second-feet, as currently reported. The total length of the main ditch is 15.47 miles, with 13.66 miles of laterals. The ditch was constructed from an appropriation allowed by the Indian Bureau, under the direction of the agent of the reservation. The work was done by the Indians, and the water is to be used by them.

During the summer of 1897 a commission composed of three members was endeavoring to treat with the Indians to allot a certain number of acres to each Indian and then to purchase the rest of the reservation with the idea of opening it to white settlement.

At Prosser there is a turbine power and pumping plant in operation capable of irrigating about 3,000 acres, besides furnishing water for factories and other purposes. The pump raises water to an elevation of 100 feet, with a power-producing fall of 20 feet. There are two turbines, 48 inches in diameter, each capable of developing 135 horsepower under a 12-foot head. The pump engines have a 25-inch cylinder and 24-inch stroke, each with a capacity of 4,000 gallons per minute. About 600 acres are now irrigated from this plant. Below Prosser another canal is taken out of the left bank of Yakima River, about 5 miles above Kiona, irrigating land in this vicinity. There is one flume about 2,000 feet long. The water supply is, however, insufficient for the needs of the orchards around Kiona. The canal of the Yakima Irrigation and Improvement Company, or the Leadbetter ditch, taking water from Yakima River near its mouth, was intended to irrigate lands in the vicinity of Kenniwick, but it was never completed. Near the mouth of Yakima River is a large irrigation wheel 50 feet in diameter, which lifts water from the river and irrigates the land of a private ranch.

Several years ago there was considerable discussion of the possibilities of irrigation at Pasco. This section is level and well adapted to irrigation, although the soil is light and blows about considerably under the strong winds that prevail there at times. There have been a number of propositions for irrigating this section, both by gravity ditch and by pumping from Columbia and Snake rivers. Another proposition is to use as a reservoir Washtucna Valley, taking water from Palouse River by means of a canal heading near Hooper, as noted on pages 458 and 459.

Mr. Sydney Arnold, hydrographer in charge of the Washington stations, made two measurements of considerable interest in the fall of 1897. One was of the Columbia River at Pasco, measured from the railroad bridge, and is as follows: October 8, water surface, 39.8 feet below the railroad ties; maximum depth, 23.5 feet; width, 2,041 feet; area, 23,979 square feet; discharge, 69,134 second-feet. The other was of Snake River at the railroad bridge, just above its mouth, 3 miles from Pasco, as follows: October 9, width, 801 feet; area, 10,099 square feet; discharge, 20,081 second-feet.

COWICHE RESERVOIR AND CANAL COMPANY.

In November, 1896, construction work on a reservoir for irrigation purposes was started in the basin of Cowiche Creek, 25 miles northwest of North Yakima. The following description is furnished by Mr. Sydney Arnold, of North Yakima, the engineer of the enterprise:

The reservoir is situated in sec. 8, T. 14 N., R. 17 E., Willamette meridian, on the summit of the dividing ridge between the Naches and Cowiche valleys, and comprises the eastern half only of a compartively shallow natural basin or depression, having no outlet and receiving no drainage. The extreme dimensions of this basin are, approximately, 1.5 miles in length and three-fourths of a mile in width. The portion of the basin appropriated as a reservoir is about one-half mile square and is separated from the remainder by an earthen dam about 15 feet in height and 1,300 feet in length.

In addition to this dam some unimportant dikes will be built across short gaps or low places on the rim of the depression, in order to admit of a total depth of water of about 13 feet.

The dam, as proposed, will be 10 feet wide on top; inside slope, 2 to 1; outside slope, 1.5 to 1. The outlet consists of an 8-inch diameter, wrought-iron pipe, 60 feet in length, laid in a trench cut through the hillside, for the most part in solid rock. The trench will be refilled above the pipe only, the remaining portion being left open. Near this point also will be located the waste weir, this and the outlet pipe discharging into the irrigating ditch. The gate is constructed in the manner described by F. H. Newell on page 189 of the Yearbook of the Department of Agriculture for 1896.

The water supply for the reservoir is obtained from the north fork of Cowiche Creek by means of a canal about 3 miles in length, which discharges into the reservoir near the south end of the dam. The minimum grade of the canal is 5 feet to the mile and the maximum about 20 feet to the mile. Dimensions are 6 feet wide on bottom; side slopes, 1 to 1; depth of water, 2 feet. The surface soil averages about 3 feet deep. The bottom of the canal is for the most part on rock or cement and gravel, water-tight, and admitting of high velocity. The entire canal is in earthwork and there are no flumes. The reservoir covers 165.42 acres. The maximum depth of water on completion of the dam will be 13 feet and the capacity 409,305,600 gallons, or 1,256 acre-feet.

The reservoir will be filled annually during the flood season, in February and March, at which time an abundant supply of water can be obtained from Cowiche Creek.

At the commencement of the irrigation season, in April, the head gates of the canal will be shut down for the year, as the ordinary supply of the creek is already fully appropriated for irrigation purposes by the settlers in Cowiche Valley.

This enterprise was undertaken by a number of settlers in the upper Cowiche Valley who desired to avail themselves of the provisions of the act of Congress approved March 3, 1891, sections 18, 19, 20, and 21 (26 Stat. L., 1095), which provides for the building of reservoirs for irrigation purposes and allows the right of way of canals through the public lands.

In 1898 irrigation will first be practiced by putting in cultivation a small tract of land adjoining the reservoir on the south. This reservoir, although small, is believed to be the first of its kind in the State; that is, where the water supply is dependent solely on the reservoir.

ARTESIAN WELLS.

Southeast of North Yakima, in the upper part of Moxee Valley, a number of artesian wells have been sunk. The first two or three that were drilled in 1892 by the Yakima Land Company were not very successful, owing to one cause or another. Some of them were probably too high; others were choked by stones and gravel and failed to flow. Within the last year or so others have been sunk at a lower level and most of them are successfully flowing. The accompanying table gives the main facts regarding them. The wells penetrate alternate beds of clay, sand, gravel, shale, and sandstone of the John Day system, and interstratified beds of basalt.

A detailed description of the geology of this vicinity will be found in Bulletin No. 108 of this Survey, entitled A Geological Reconnaissance in Central Washington, by I. C. Russell.

Artesian wells in Moxee Valley, near North Yakima, Washington, September 1, 1897.

No.	Well.	Location.			Completed.	Cost of well.	Diameter.	Elevation.	Depth	Depth to water.	Yield per minute.
		Sec.	T.	R.							
							Inches.	*Feet.*	*Feet.*	*Feet.*	*Cu. ft.*
1	Clarke's No. 1.	6	12	20	1893.....	$2,000	6-4.5	1,043	940	700	144
2	Clarke's Nos. 2 and 3.	31	13	20	1892.....	2,500	5-3.5	1,060	1,050	800	84
3	Meig's	32	13	20	....	....	6	1,140	623	120	18
4	Yakima Land Co. No. 4.	4	12	20	1892.....	....	......	1,258	500	......	0
5	Yakima Land Co. No. 1.	3	12	20	1892.....	....	......	b1,151	314	......	......
6	Yakima Land Co. No. 3.	3	12	20	Feb. 25, 1892.	....	6	1,141	340	......	30
7	Bradford	9	12	20	Mar. 25, 1897.	600	4.5	1,090	386	......	36
8	Dickson	8	12	20	(a)	200	4.25	......	294	......	......
9	Gano	8	12	20	Apr. 17, 1897.	400	3	1,005	649	......	30
10	Ellens	7	12	20	(a)	....	6	1,000	550	......	......
11	Longwin	8	12	20	Sept., 1893	....	3	1,005	637	......	28
12	Haines	8	12	20	Mar. 24, 1896.	....	6	1,080	702	......	22
13	Spratt	8	12	20	Feb., 1897	800	6-3	......	835	......	30
14	Steinweg No. 1	10	12	20	May 29, 1894.	....	6	1,120	280	......	45
15	Steinweg No. 2	10	12	20	Sept. 15, 1894.	....	6	1,124	404	......	30
16	Steinweg No. 3	10	12	20	June 12, 1895.	....	6	1,124	534	......	70
17	Yakima Land Co. No. 2.	4	12	20	Jan., 1892	....	8	1,195	617	60	0

a Not finished. b Approximate.

The wells are referred to sea level. No. 1 of the Yakima Land Company was found by aneroid to be 151 feet above the Northern Pacific Railway elevation of 1,000 feet at North Yakima. The elevations of the other wells were found by spirit level from this one.

These logs show little conformity. This is partly due to errors in describing the formations, as well as to the variations in the formations themselves. The Dickson and the Ellens wells were in course of drilling when visited in September, 1897.

SEEPAGE MEASUREMENTS.

The valley of Atanum Creek, southwest of North Yakima, was one of the earliest sections irrigated in this vicinity. For several years all the available summer flow of this stream has been utilized for irrigation, and a number of cases have been tried in the courts as a consequence. During the season of unusually low water in 1892 an action was instituted in the superior court of Yakima County by certain riparian proprietors on Atanum Creek "to restrain certain appropriators from diverting the water of said stream from above and conducting the same to and upon their land, situated at a distance therefrom, for the purposes of irrigation." The injunction was granted and the case was appealed to the State supreme court, where it was upheld by decision rendered July 2, 1897.

A large body of land is under cultivation on the benches north of the river, and it would seem that under this decision irrigation will have to be discontinued unless water can be obtained from other sources. On July 26 the discharge of Atanum Creek, just below the junction of the north and south forks, was 40.1 second-feet. This is above the heads of most of the important canals.

It has been suggested that the canal of Yakima Valley Canal Company be extended to serve lands in Atanum Valley. This is hardly expedient, for two reasons: First, the canal is not high enough to cover much of the valley; second, it carries hardly sufficient water for the land now under it and for which water rights have been sold. A survey was made a few years ago of a canal, called the Burlingame Canal, which headed on the south side of Naches River, just below the mouth of Tieton River. It was carried some distance up Atanum Valley, around the ridge on the south side of the creek, and on to the bench lands above Toppenish Creek on the Yakima Indian Reservation. About 3 miles of construction work in the shape of excavation was accomplished near the head.

The canal down to Painted Rocks would be expensive to construct, on account of the hard basaltic formation through which it passes.

July 25, 26, and 27, 1897, a series of measurements of Atanum Creek and of the canals taking water therefrom was made by Cyrus C. Babb, for the purpose of determining the seepage, or the amount of water returning to the creek. Some difficulty was encountered in making these measurements, on account of a thick underbrush which borders the creek for nearly its entire length and is almost impenetrable in places. Difficulty was also experienced on account of the hostility of a number of ranchers who thought that the hydrographer was a person sent by the supreme court to turn off the water from their canals, as the measurements were made immediately after the decision above referred to was rendered. For this reason the results are not altogether satisfactory. The following list, numbered consecutively downstream, shows the discharge measurements made:

Discharge measurements made on Atanum Creek and canals taking water therefrom.

No.	Locality.	Discharge.
		Second-feet.
1	North Fork, Atanum, above Anderson's ranch, sec. 12, T. 12 N., R. 15 E	50.1
2	Cox ditch at Charles Anderson's, sec 12	6.9
3	Two small ditches below Cox ditch, sec. 12	1.0
4	Slough at Dan Kinney's house, sec. 7, T. 12 N., R. 16 E	4.5
5	North Fork road bridge near Tampico, sec. 18	25.2
6	Waste water near Allen's house (into creek)	2.2
7	Atanum Creek below forks, sec. 17	40.1
8	Dan Lesh ditch, sec. 16	0.6
9	Atanum Creek at Narrows, or Rocky Cliff	49.8
10	Herke's ditch (upper), sec. 14	0.5
11	Herke's ditch (lower), sec. 14	0.5
12	Morris ditch, above North slough	2.5
13	Small Catholic Mission ditch	0.3
14	North slough, above mission, sec. 13	23.4
15	Atanum Creek, 100 feet below Middle slough	9.0
16	Middle or Second slough, 75 feet below head, sec. 18, T. 12 N., R. 17 E	9.8
17	Lynch ditch, sec. 17	0.3
18	Yallup Indian ditch, sec. 16	0.3
19	Atanum Creek, below Indian ditch	8.4
20	Simpson's ranch ditch	3.0
21	Woodhouse ditch	0.6
22	Atanum Creek at Woodhouse ranch, sec. 14	0.7
23	Atanum Creek at Tanner bridge, sec. 8, T. 12 N., R. 18 E	0.8
24	Indian ditch, sec. 8	1.0
25	Atanum Creek, line between secs. 11 and 12	0.9
26	Waste slough, sec. 1	2.5
27	Wide Hollow waste slough, sec. 1	14.9
28	Atanum Creek, Union Gap bridge, sec. 8, T. 12 N., R. 19 E	12.5

The first measurement was made on the North Fork at Anderson's ranch in sec. 12, T. 12 N., R. 15 E., about 2 miles above Tampico post-office, or 3 miles above the junction with the South Fork. The discharge was 50.1 second-feet. Then came measurements Nos. 2, 3, and 4, of the small ditches or sloughs from the left bank of the creek. Their combined flow was 12.4 second-feet. This, subtracted from the first measurement, leaves a difference of 37.7 second-feet. Subtracting from this amount 25.2 second-feet, measurement No. 5 of the North Fork at the bridge at Tampico, leaves a difference of 12.5 second-feet, which shows a loss between these two points. It is almost impossible to get down to the creek along here, and there may be one or two small ditches from the right bank. Measurement No. 6 was of waste water returning to the creek, amounting to 2.2 second-feet. Adding this to measurement No. 5, 25.2 second-feet, gives 27.4 second-feet. This, subtracted from measurement No. 7 of Atanum Creek, one-half mile below the junction of North Fork and South Fork, which was 40.1 second-feet, leaves a difference of 12.7 second-feet for the discharge of the South Fork. Measurement No. 8, of the Lesh ditch which takes water from the left bank of the creek in sec. 17, T. 12 N., R. 16 E., or three-fourths of a mile below the junction of the two forks, is 0.06 second-foot. Measurement No. 9, of the creek at "The Narrows," about the center of section 15, is 49.8 second-feet. Subtracting from this the sum of measurements Nos. 7 and 8, the result shows a gain of 10.3 second-feet in a distance of 2¼ miles. Measurements Nos. 10 to 13, inclusive, are of three small ditches, taking water from the left bank of the creek above the Catholic mission. Their total discharge is 3.8 second-feet. This sum, subtracted from the discharge at "The Narrows," leaves 46.0 second-feet. In the vicinity of the Catholic mission two natural sloughs take a large part of the flow of the creek, and a large number of small canals take water from them lower down. In this series of measurements the sloughs were considered simply as canals or channels from the main creek and were not measured below the head. Measurement No. 14 is of the north slough just above the mission. Measurement No. 16 is of the middle slough, which diverts water a quarter of a mile below the mission. Measurement No. 15 is of the main creek, 100 feet below the mouth of the middle slough. The sum of measurements Nos. 14 to 16, inclusive, is 42.2 second-feet. This, subtracted from 46 second-feet, found above, shows a loss of 3.8 second-feet.

Measurement No. 15 of Atanum Creek below the middle slough is 9 second-feet. The sum of the two small ditches, measurements Nos. 17 and 18, taken out between this point and the next measurement of the creek, is 0.6 second-foot, which, subtracted from measurement No. 15, leaves 8.4 second-feet. Measurement No. 19 is 8.4 second-feet, which shows neither loss nor gain in the distance of 2.5 miles. The sum of measurements Nos. 20 and 21, of two ditches from the left bank, is 3.6 second-feet, which, subtracted from measurement No. 19, leaves 4.8 second-feet. Atanum Creek measurement No. 22, at Woodhouse ranch, gives 0.7 second-foot. This shows a loss of 4.1 second-feet between measurements Nos. 19 and 22, in a distance of 1¾ miles. The sum of measurement No. 23, of the creek at Tanner bridge, in sec. 8, T. 12 N., R. 18 E., and of measurement No. 24, of Indian ditch, gives a result of 1.8 second-feet. This shows a gain of 1.1 second-feet between measurements Nos. 22 and 23, in a distance of 3 miles. The difference between measurements Nos. 23 and 25, taken out of the creek, shows a gain of 0.1 second-foot in a distance of 3¼ miles. Measurement No. 28, at the highway bridge, just above the mouth of the creek, shows a discharge of 12.5 second-feet. This amount comes chiefly from the waste of Wide Hollow slough.

The following table gives a summary of the above measurements:

Summary of measurements on Atanum Creek and canals taking water therefrom.

			Second-feet.
1. North Fork above Anderson's			50.1
2. John Cox ditch		6.9	
3. Two small ditches		1.0	
4. Slough at Kinney's		4.5	
			12.4
Difference			37.7
5. North Fork at bridge			25.2
Loss			12.5
5. North Fork at bridge		25.2	
6. Waste water		2.2	
			27.4
7. Atanum Creek, below junction of North and South forks			40.1
South Fork			12.7
7. Atanum Creek, below junction		40.1	
8. Lesh ditch		0.6	
			39.5
9. Atanum Creek at Narrows			49.8
Gain			10.3
9. Atanum Creek at Narrows		49.8	
10 and 11. Herkes ditches	1.0		
12. Morris ditch	2.5		
13. Small Mission ditch	0.3		
		3.8	
			46.0
14. North slough		23.4	
16. Middle slough		9.8	
15. Atanum Creek		9.0	
			42.2
Loss			3.8
15. Atanum Creek, below Middle slough			9.0
17. Lynch ditch		0.3	
18. Yallup Indian ditch		0.3	
			0.6
Difference			8.4
19. Atanum Creek, below Yallup ditch			8.4
Loss or gain			0.0
19. Atanum Creek, below Yallup ditch			8.4
20. Simpson ditch		3.0	
21. Woodhouse ditch		0.6	
			3.6
Difference			4.8
22. Atanum Creek at Woodhouse ranch			0.7
Loss			4.1

		Second-feet.
22. Atanum Creek at Woodhouse ranch		0.7
23. Atanum Creek at Tanner bridge	0.8	
24. Indian ditch	1.0	
		1.8
Gain		1.1
23. Atanum Creek, Tanner bridge		0.8
25. Atanum Creek, section lines 11 and 12		0.9
Gain		0.1
26. Waste slough		2.5
27. Waste slough, Wide Hollow		14.9
		17.4
28. Atanum Creek, Union Gap Bridge		12.5

List of miscellaneous discharge measurements of Atanum Creek (a).

Date.	Stream.	Locality.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
1897.				*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
May 10	Atanum	Union Gap, Washington.	70		84	3.14	264
June 9	....do	....do			40	3.55	142
July 2	....do	....do	74		37	1.16	43
July 15	....do	....do	74		34	0.91	31
July 27	....do	....do	74				13

a Made at the highway bridge just above the mouth of Atanum Creek at Union Gap.

BUMPING LAKE RESERVOIR SITE.

Naches River is probably the most important stream for irrigation purposes in the State of Washington. The volume of water in the stream is discussed on page 477. It seemed desirable, on account of the number of irrigation systems taking water from this river, as well as on account of several new projects, to investigate its storage possibilities. Bumping Lake reservoir site is especially noted, and in the summer of 1897 it was decided to make a survey of this site. The lake being located at some distance from any surveyed land, it was necessary to connect with a government corner by running a meander line with stadia and transit and then to survey the reservoir site with plane table. A party was formed, consisting of Mr. Cyrus C. Babb and two assistants, one as front flagman and stadia man and the other as rear flagman, with a third man to act as packer and cook.

At the time of the commencement of this survey a party was just completing the survey of two townships for the General Land Office, Ts. 14 and 15 N., R. 15 E. On August 9, 1897, the two assistants started up Naches River with the pack train, with instructions to find these surveyors and obtain from them the description of the most convenient section corner from which to start the meander line to connect with Bumping Lake. This was found to be the north corner on the township line between secs. 3 and 4, T. 15 N., R. 15 E., Willamette meridian. It is marked by a pine post, 4 inches square, set in a mound of rock, located about 5 miles west of Scott Stevens's ranch, in Dry Creek gorge, and 1,000 feet west of the Nile schoolhouse. The survey was started from this point August 12, running in a northwesterly direction up Naches River to the mouth of Bumping River, and thence, in a southwesterly direction, up this latter stream to Bumping Lake. The line was run with stadia and transit, reading horizontal angles, and checking with the magnetic needle bearings. It took from August 12 to 26, inclusive, to run this meander of 32.7 miles. The distances from the Nile schoolhouse to various well-known points along Naches and Bumping River trails are as follows:

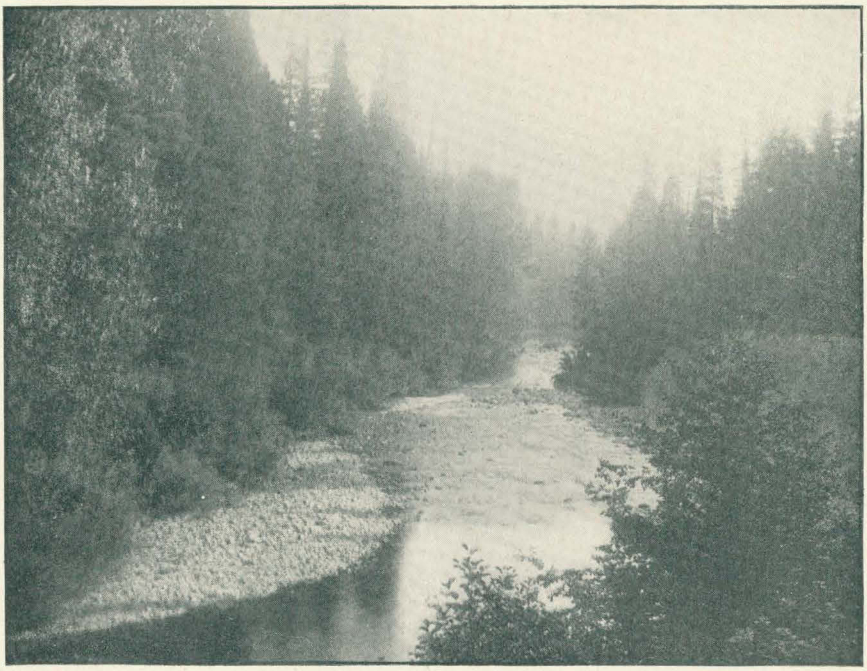
	Miles.
North Yakima to Nile schoolhouse	31.0
Nile schoolhouse to—	
Hanging Rock	5.8
Edgar Rock	10.2
Mouth of Bumping River	15.0
Ford on American River	18.9
Soda Springs	24.6
Goose Prairie	29.0
Outlet Bumping Lake	32.7
Total distance from North Yakima to Bumping Lake	63.7

The return trip was made over the Clover Springs pass and down the Dry Creek trail to the Nile schoolhouse again, shortening the above distance by about 8 miles.

The Naches Valley, from North Yakima to about Nile schoolhouse, is practically timberless. A scrub evergreen growth starts there and gradually increases in size. Large bull pines are encountered near Edgar Rock, the trail often passing through open groves of these trees.

The meander line followed the trail to the crossing of American River, where, the forest growth becoming too dense, it was carried over to Bumping River and thence directly up the river, sighting from one bank to the other, and fording forwards and backwards on horseback. The bed of the river, as shown on Pl. XLIV, *A*, was full of bowlders of all sizes, and it took only a day or so to lame the horses, so that for two days most of the party forded the river on foot.

Bumping Lake, shown on Pl. XLIV, *B*, is in the mountains, surrounded by high peaks, and only 12 miles in a direct line nearly due east from Mount Rainier. The mountainous slopes are covered mainly with a dense forest of pine, tamarack, and fir. The lake is located in the Mount Rainier forest reserve. On August 26 a measurement of the discharge at the outlet was made, giving 83 second-feet. At the time of measurement the water surface was 115 feet wide. The water marks around the lake show an annual fluctuation of about 3 feet. This height may



A. BUMPING RIVER, WASHINGTON, 2 MILES BELOW LAKE.

B. BUMPING LAKE.

reach 7 feet during exceptionally wet seasons or after a winter of heavy snowfall. At a height of 10 feet the water surface would be about 150 feet wide. Above that the ground slopes rapidly from the river. The

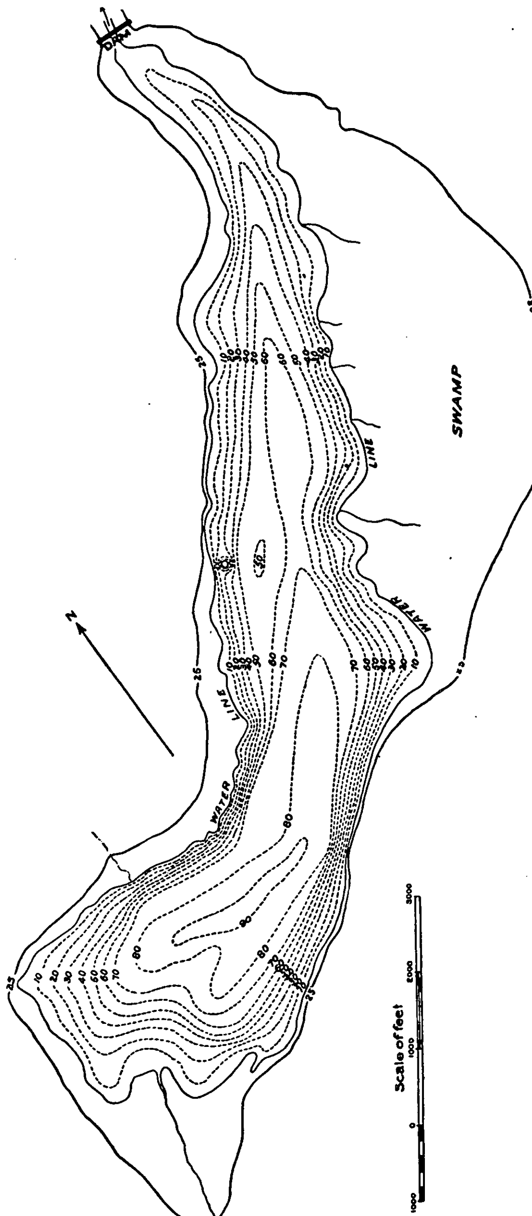


FIG. 167.—Bumping Lake reservoir site as surveyed, August, 1897.

length of the proposed dam, at a height of 25 feet above the bed of the river, at which height the survey was made, would be 480 feet.

The lake was evidently formed by the deposit of glacial drift in the valley, as this is the formation at the outlet. No rock was found in place in that immediate vicinity. If one follows the main trail to the head of the lake on the west side rock is encountered within one-half mile. About opposite the second line of sounding from the lake outlet the trail passes on to a steep shelving rock, sloping rapidly to the lake edge. Beyond the island this slope is more gentle.

When the lake was first reached it was seen that on account of the dense timber growth it would take a long time to apply the usual methods of surveying reservoir sites; that is, to follow a certain contour with the plane table. It was therefore decided to triangulate the lake, to assume the surface as level, and then from a number of stations on the edge of the lake to level up to the contour, sketching in between these points, and thus to locate the contour.

Bordering the lower half and eastern side of the lake is an extensive swamp, impenetrable on account of the dense undergrowth. It is also extremely hazardous to enter it, because of the swampy nature of the ground.

A series of soundings were made of the lake. There were two men in a canoe, one to manage it and the other to make the soundings. A third man was on shore to line in the canoe between signals, and each sounding was finally located with plane table set up at another station. In all, twenty-three soundings were made, distributed along five lines. The greatest depth measured was only 90 feet—a surprise to every one, as the depth had been variously estimated from 200 to 700 feet. The results of the survey are shown concisely in fig. 167.

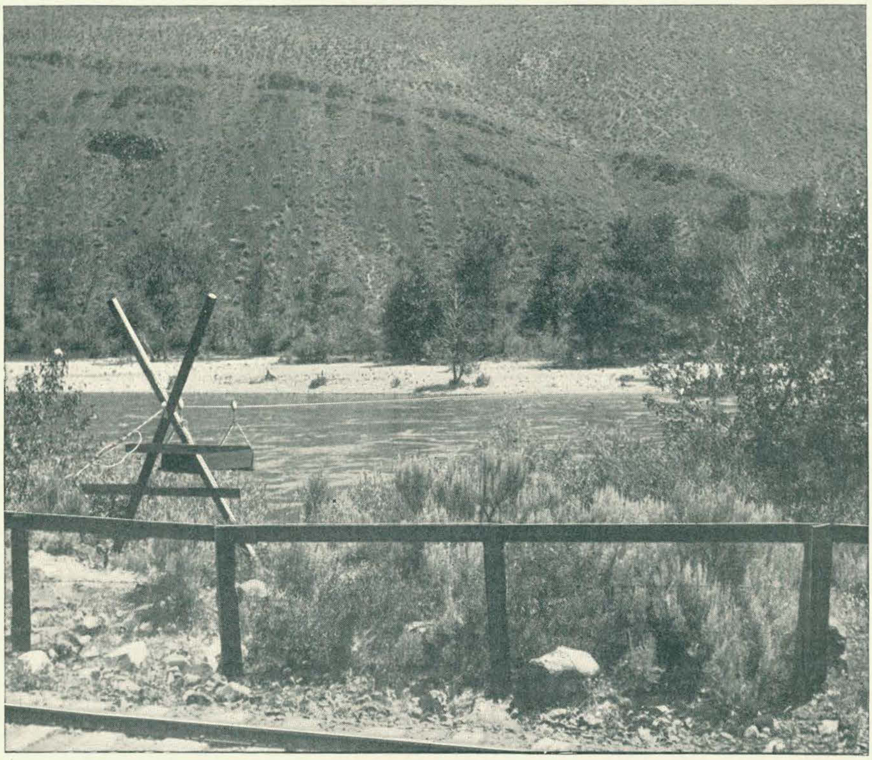
The area of the lake is 631 acres. The area of the 25-foot contour, the height of the proposed dam, is 1,153 acres, giving a reservoir capacity of 22,300 acre-feet. The length of dam would be 480 feet.

Following is a list of lands segregated for the Bumping Lake reservoir site:

Bumping Lake reservoir site segregation, Yakima County, Washington.

	Acres.
T. 16 N., R. 12 E. (unsurveyed).	
E. ½ and E. ½ of SW. ¼, sec. 22	400
W. ½ of NW. ¼ and W. ½ of SW. ¼, sec. 23	160
W. ½ of NW. ¼ and NW. ¼ of SW. ¼, sec. 26	120
N. ½ and SW. ¼ and N. ½ of SE. ¼ and SW. ¼ of SE. ¼, sec. 27	600
E. ½ of NE. ¼ and S. ½ of sec. 28	400
N. ½ of NE. ¼ and SW. ¼ of NE. ¼ and NW. ¼ and N. ½ of SW. ¼, sec. 33	360
NW. ¼ of NW. ¼, sec. 34	80
Total	2,120

As stated above, the Northern Pacific, Yakima and Kittitas Irrigation Company surveyed this site in September, 1894. They also hewed, in the immediate vicinity, tamarack timbers for the dam, and these are now piled up at the outlet of the lake.



A.

B.

POINTS OF MEASUREMENT OF YAKIMA RIVER, WASHINGTON.

A. At Union Gap; *B*, At Kiona.

MEASUREMENTS OF DISCHARGE.

Three gaging stations on Yakima River were maintained during 1897, at Selah, Union Gap, and Kiona, views of which are given in Pl. XLIII, *B*, and Pl. XLV, *A* and *B*. On account of the importance of Naches River it was desirable to maintain a station on that river if possible, but it was not found practicable to do so on account of poor cross sections and the liability of change in channel during every flood. This river during flood brings down immense quantities of débris of sand and gravel. A number of discharge measurements were made of Naches River from the highway bridge at its mouth and below all canals, showing the amount of water going to waste, which is, however, available for the Sunnyside canal below. To the following amounts should be added 150 second-feet, which is approximately the combined flow of the Naches ditches: June 10, 3,178 second-feet; June 18, 1,993 second-feet; July 29, 781 second-feet; September 22, 385 second-feet; November 15, 1,500 second-feet. The maximum discharge of the Naches for 1897 was in May, and was about 7,000 second-feet, as shown by the difference in discharge at the Selah and Union Gap gaging stations on Yakima River. The minimum discharge in 1897 was probably 385 second-feet. This station is described in Water-Supply and Irrigation Paper No. 16, p. 174.

May 19, 1897, a station was established on Yakima River at the bridge of the Northern Pacific Railway at Selah, 7 miles above North Yakima and above the mouth of Naches River, with the idea that the difference in discharge between this station and the one at Union Gap would give approximately the discharge of the Naches. Two ditches, those of the Moxee Company, are taken out between these points, but their amount is about counterbalanced by that received from Atanum Creek and the wastage at Oldtown.

In Water-Supply and Irrigation Paper No. 16, p. 173, is given a description of the Selah station, together with the discharge measurements made in 1897 and the table of gage heights for 1897. The accompanying tables comprise the rating table for this station and the table of monthly discharge. A view of the gaging station is shown in Pl. XLIII, *B*.

Rating table for Yakima River at Selah, Washington, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
4.5	460	6.0	1,900	8.0	5,425	10.0	11,060
4.6	552	6.2	2,150	8.2	5,898	10.5	12,769
4.7	644	6.4	2,422	8.4	6,391	11.0	14,590
4.8	736	6.6	2,718	8.6	6,905	11.5	16,515
4.9	828	6.8	3,038	8.8	7,440	12.0	18,545
5.0	920	7.0	3,380	9.0	7,995	12.5	20,673
5.2	1,104	7.2	3,745	9.2	8,570	13.0	22,895
5.4	1,288	7.4	4,132	9.4	9,165		
5.6	1,472	7.6	4,541	9.6	9,778		
5.8	1,674	7.8	4,972	9.8	10,409		

Estimated monthly discharge of Yakima River at Selah, Washington.

[Drainage area, 1,960 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
May 19-31	13,848	6,142	9,318	240,266	1.97	4.75
June	6,391	2,875	4,021	239,266	2.29	2.05
July	3,745	1,012	2,057	126,481	1.21	1.05
August 1-21	1,015	644	811	33,798	0.32	0.41
September	....	....	a 700	41,653	0.40	0.36
October 20-31	828	828	828	19,704	0.17	0.42
November	19,811	828	3,979	236,766	2.26	2.03
December	8,570	1,472	2,702	166,140	1.59	1.38

a Approximate.

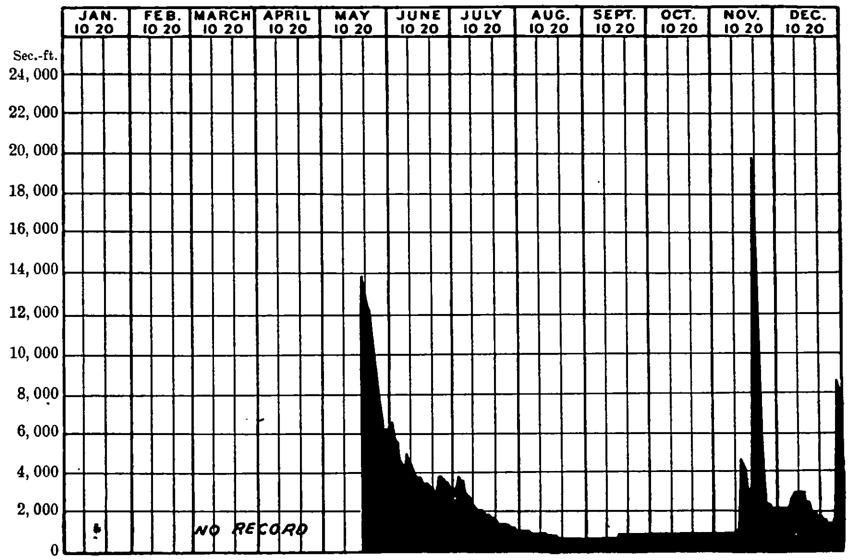


FIG. 168.—Discharge of Yakima River at Selah, Washington, 1897.

The station located at Union Gap, 6 miles below North Yakima, is described in Water-Supply and Irrigation Paper No. 16, p. 175, together with the list of discharge measurements and the table of gage heights for 1897. This station is an important one and is fitted with cable and car, shown on Pl. XLV, *A*, for use in the measurements. The cable was carried away during the high water of November, 1896, but was replaced in the spring of 1897. It is about 2 miles above the head of the Sunnyside canal, and the results show the amount of water available for this canal and the lands below. Following is the rating table and table of monthly discharges:

Rating table for Yakima River at Union Gap, Washington.

[This table is applicable from November 15, 1896, to December 31, 1897.]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
4.0	500	5.6	2,320	7.2	5,793	8.8	11,220
4.2	705	5.8	2,644	7.4	6,365	9.0	12,030
4.4	915	6.0	3,000	7.6	6,969	9.5	14,180
4.6	1,125	6.2	3,388	7.8	7,605	10.0	16,510
4.8	1,335	6.4	3,808	8.0	8,270	10.5	19,015
5.0	1,545	6.6	4,258	8.2	8,964	11.0	21,690
5.2	1,768	6.8	4,738	8.4	9,687	11.5	24,536
5.4	2,028	7.0	5,250	8.6	10,439	12.0	27,550

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.		Depth in inches.	Second-feet per square mile.
1896.						
August	2,600	1,170	1,650	101,454	0.58	0.50
September	1,170	910	1,071	63,729	0.36	0.32
October	910	840	860	52,879	0.30	0.26
November	45,550	910	7,652	455,325	2.58	2.32
December	10,439	2,320	5,162	317,399	1.80	1.56
1897.						
January			*a* 2,100	129,125	0.74	0.64
February			*a* 3,000	166,612	0.95	0.91
March	4,738	1,650	2,472	151,998	0.86	0.75
April	27,550	4,738	15,004	892,798	5.07	4.55
May	23,954	11,621	15,685	964,439	5.47	4.75
June	10,826	4,738	7,109	423,014	2.40	2.15
July	6,365	1,650	3,291	202,357	1.15	1.00
August	1,440	915	1,168	71,818	0.40	0.35
September	915	705	817	48,615	0.27	0.24
October	1,020	705	810	49,805	0.28	0.24
November	25,135	915	5,274	313,824	1.79	1.60
December	11,220	2,320	3,969	244,046	1.38	1.20
The year			5,058	3,658,451	20.76	1.53

a Approximate.

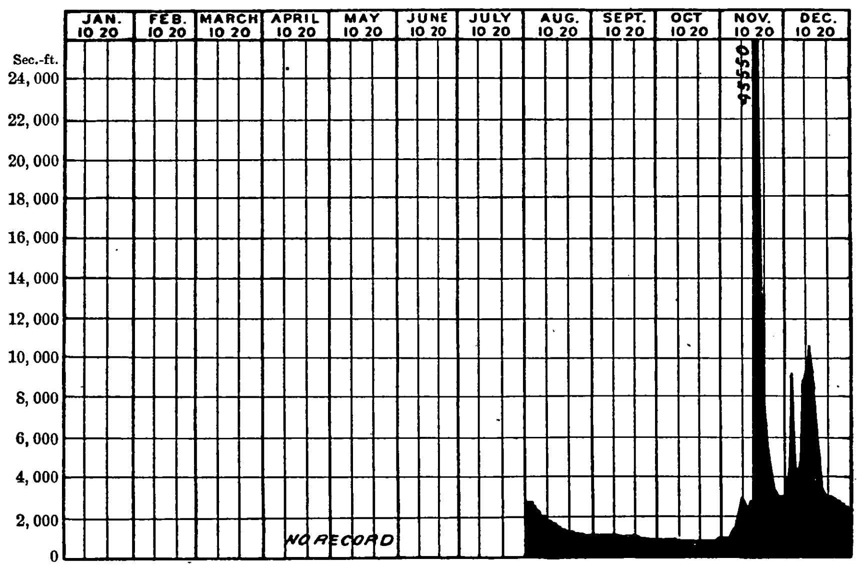


FIG. 169.—Discharge of Yakima River at Union Gap, Washington, 1896.

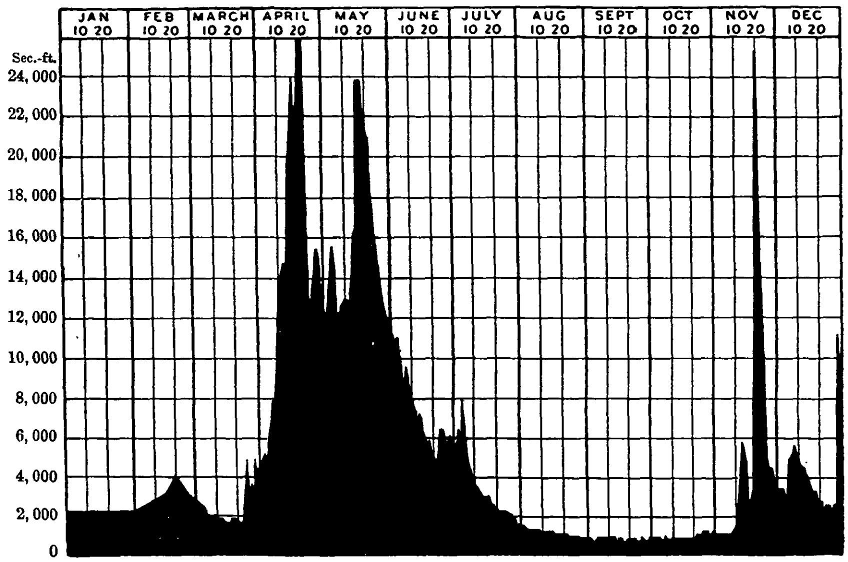


FIG. 170.—Discharge of Yakima River at Union Gap, Washington, 1897.

The section at Kiona is an ideal one. The highway bridge crosses the river on one span. The section is gravelly and does not change at flood stages. It is described in Water Supply and Irrigation Paper No. 16, p. 176. The ordinary method of gaging to obtain the mean velocity of a vertical section is to average the top and bottom velocities, which are measured. The accompanying table gives the percentages of the mean velocity so obtained to the maximum velocity for that section. May 5 and May 24 were for measurements at Kiona; May 15 and May 19 for measurements at Union Gap and Selah, respectively. The first column gives the distance across the section from the initial point. There are four sets of columns, a set for each date. The first column of each set gives the depth of water, and the second the percentage of mean to maximum velocity. These last figures are averaged again in the last line, and the grand average is 85 per cent.

The measurements on the above dates were taken during the large floods of Yakima River, where, if the maximum velocity only had been measured, 90 per cent, or even more, would have been taken for the mean velocity. It is thought that 85 per cent is the figure that should be used.

Percentage of mean to maximum velocity.

Distance.	Kiona. May 5, 1897. (Gage height, 11.50.)		Kiona. May 24, 1897. (Gage height, 11.52.)		Union Gap, May 15, 1897. (Gage height, 10.90.)		Selah, May 19, 1897. (Gage height, 10.77.)	
	Depth.	Per cent.	Depth.	Per cent.	Depth.	Per cent.	Depth.	Per cent.
Feet.	*Feet.*		*Feet.*		*Feet.*		*Feet.*	
40	....	....	....	....	12.7	76	....	....
60	....	....	....	....	14.4	92	8.2	77
80	....	....	....	....	13.9	93	9.2	81
100	....	....	....	....	12.9	84	10.7	84
120	8.9	83	8.5	82	11.6	89	11.0	82
140	9.9	78	10.0	78	10.9	77	6.2	89
160	11.2	89	11.2	81	10.4	76	....	....
180	11.6	80	11.2	87	10.2	83	2.4	92
200	11.8	87	11.7	78	9.9	90	12.5	79
220	11.8	88	11.5	77	9.6	84	10.9	92
240	11.4	91	12.6	79	....	....	9.0	83
260	11.9	96	12.2	81	....	....	9.6	92
280	11.3	88	11.7	88	....	....	7.8	94
300	11.2	95	11.3	84	....	....	....	....
320	9.9	85	9.3	85	....	....	....	....
340	7.1	85	6.0	84	....	....	....	....
360	5.8	90	6.0	84	....	....	....	....
Average	....	87	....	82	....	84	....	86

Average percentage of mean to maximum velocity.

	Per cent.
May 5, Kiona	87
May 15, Union Gap	84
May 19, Selah	86
May 24, Kiona	82
Average	85

Pl. XLV, *B*, shows the gaging station at Kiona, with a water wheel in the foreground, which is used for irrigation purposes.

The following table gives the list of discharge measurements made on Yakima River at Kiona, Washington. The principal facts are also shown in fig. 171, on page 484, in which vertical distances represent height of water on the gage and horizontal distances the quantity of discharge. The plotted points obtained by measurement are shown by the small circles, which are numbered to correspond with the figures in the left-hand column of the table. Near or through these is drawn a smooth curve, from which the values for the rating table have been obtained.

List of discharge measurements made on Yakima River at Kiona, Washington.

Number.	Date.	Hydrographer.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
	1895.			*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
*a*1	Aug. 20	A. P. Davis	55	3.30	753	1.27	954
	1896.						
2	July 30	C. C. Babb	63	6.40	1,240	2.63	3,265
3	Aug. 28	....do	63	4.70	849	1.18	987
4	Oct. 20	....do	63	3.93	732	1.09	796
	1897.						
5	May 8	....do	70	11.5	2,869	5.77	16,557
6	May 24	....do	74	11.5	2,853	5.74	16,344
7	May 29	....do	74	9.7	2,405	4.71	11,338
8	June 8	....do	74	8.75	2,147	4.13	8,868
9	June 15	....do	74	8.05	1,920	3.60	6,908
10	July 7	....do	74	7.15	1,609	3.18	5,118
11	July 13	....do	74	6.30	1,292	2.69	3,475
12	July 21	....do	......	5.55	1,093	2.12	2,318
13	Aug. 5	Sydney Arnold	64	4.61	903	1.34	1,217
14	Aug. 30	....do	64	4.1	760	0.98	742
*b*15	....do	....do	64	4.1	790	0.97	762
16	Nov. 6	....do	64	4.08	779	1.07	839
17	Dec. 29	....do	64	8.54	1,920	3.88	7,459

a Not plotted. *b* The same as No. 14.

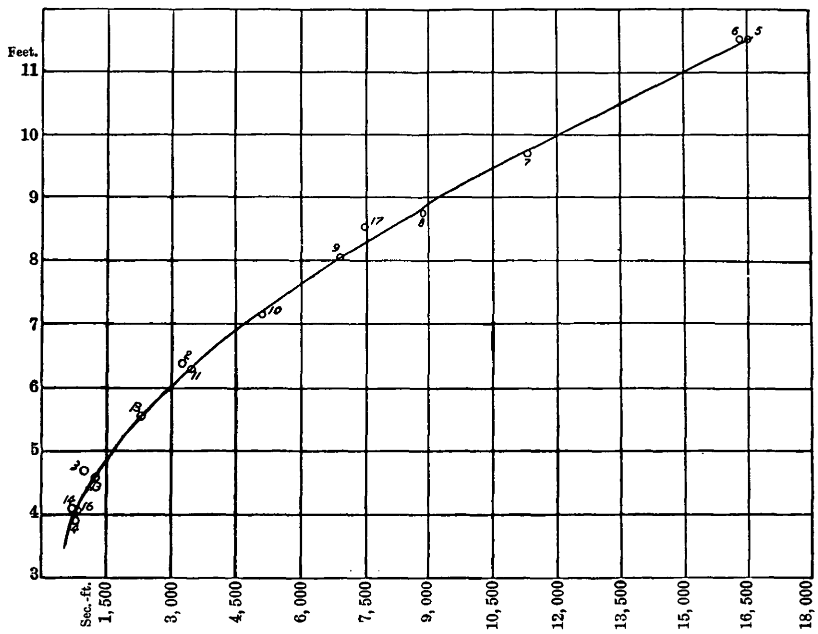


FIG. 171.—Rating curve for Kiona Station on Yakima River, Washington.

Rating table for Yakima River at Kiona, Washington.

[This table is applicable from November 15, 1896, to December 31, 1897.]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
3.5	525	5.4	2,122	7.4	5,498	10.0	12,045
3.6	566	5.6	2,383	7.6	5,921	10.5	13,536
3.8	663	5.8	2,663	7.8	6,358	11.0	15,036
4.0	780	6.0	2,965	8.0	6,810	11.5	16,536
4.2	916	6.2	3,279	8.2	7,275	12.0	18,036
4.4	1,071	6.4	3,609	8.4	7,753	12.5	19,536
4.6	1,245	6.6	3,955	8.6	8,246	13.0	21,036
4.8	1,438	6.8	4,317	8.8	8,751	13.5	22,536
5.0	1,650	7.0	4,695	9.0	9,270	14.0	24,036
5.2	1,878	7.2	5,089	9.5	10,620	14.5	25,536

Estimated monthly discharge of Yakima River at Kiona, Washington.

[Drainage area, 5,230 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1896.						
August	2,780	990	1,511	92,907	0.33	0.29
September	1,010	830	917	54,566	0.20	0.18
October	820	780	799	49,128	0.17	0.15
November	30,000	850	6,555	390,050	1.39	1.25
December	16,685	2,885	9,102	559,660	2.01	1.74
1897.						
January	8,803	2,965	4,617	283,890	1.01	0.88
February	4,990	2,965	3,989	221,538	0.79	0.76
March	6,292	2,330	3,297	202,726	0.72	0.63
April	25,266	4,098	12,997	773,373	2.78	2.49
May	21,936	11,324	15,689	964,685	3.46	3.00
June	14,046	4,890	7,415	441,222	1.58	1.42
July	6,358	1,438	3,377	207,650	0.75	0.65
August	1,438	780	1,033	63,517	0.23	0.20
September	902	680	771	45,878	0.17	0.15
October	902	643	740	45,501	0.16	0.14
November	19,536	833	5,243	311,979	1.11	1.00
December	13,686	2,809	5,170	317,893	1.14	0.99
The year	25,266	643	5,361	3,879,852	13.90	1.03

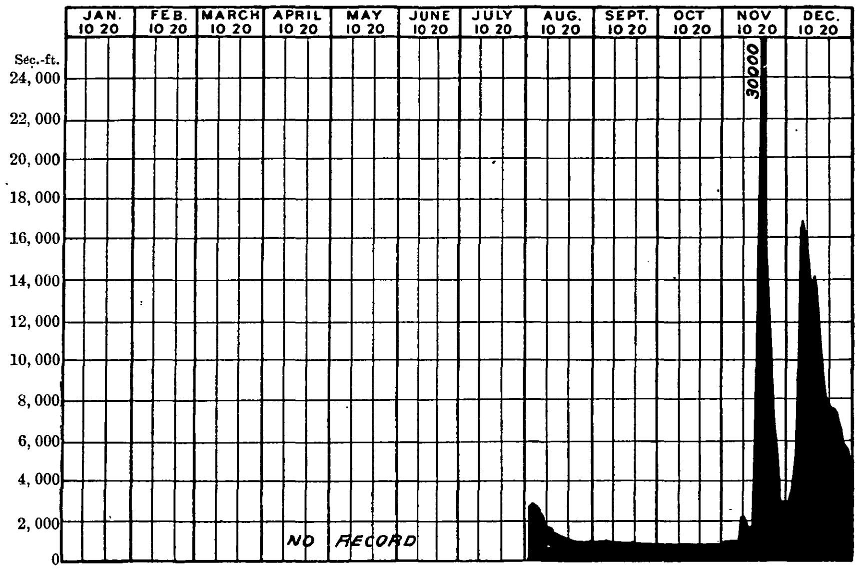


FIG. 172.—Discharge of Yakima River at Kiona, Washington, 1896.

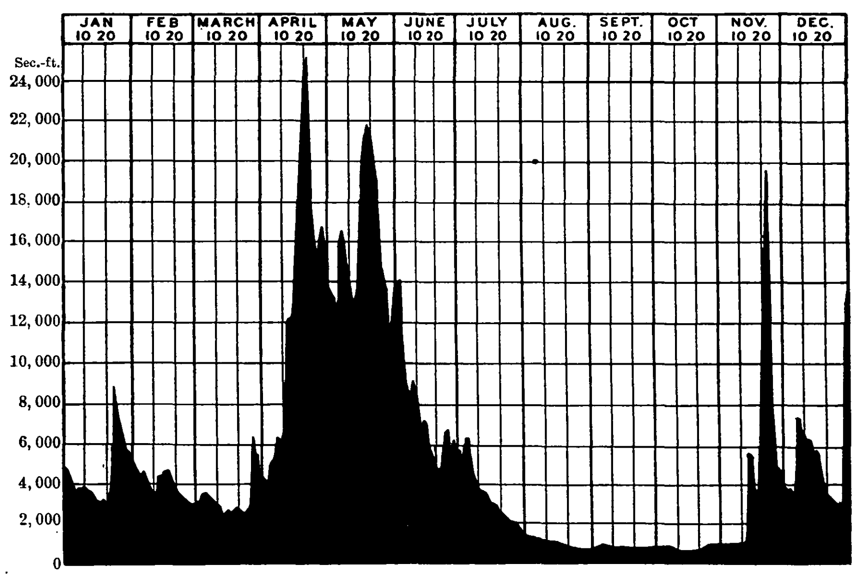


FIG. 173.—Discharge of Yakima River at Kiona, Washington 1897.

SPOKANE RIVER.

Spokane River rises in the beautiful Cœur d'Alene Lake, in the State of Idaho. The two principal feeders of the lake are the Cœur d'Alene and St. Joseph rivers. The latter rises in the Bitterroot Mountains, on the western slope of the continental divide, and flows in a general northwesterly direction, emptying into the lake at its upper or southern end. Spokane River, from the outlet of the lake, flows in a general westerly direction for 30 miles until it reaches Spokane. Throughout this distance it receives no important tributaries. At Spokane it receives the drainage of Hangmans Creek, and a little way below, Little Spokane River empties into it. From that point to its mouth at Columbia River, a distance of 60 miles, no other important stream enters. Above Spokane the river is a surface stream, but at this city a fall of 145 feet occurs, making a valuable water power, which has been utilized to a large extent by flour mills and by a power plant of the Washington Water Power Company, which furnishes electricity for the street-car service and for the electric lighting of the city. The dam for the water supply of Spokane is located 4 miles above the city.

No canals take water from Spokane River for irrigation purposes, although irrigation would be of great benefit to this section of country, as the rainfall is deficient. A gaging station was established on this river October 17, 1896, at the bridge of the Oregon Railway and Navigation Company. The station is described in Water-Supply and Irrigation Paper No. 16, p. 177. A sufficient number of discharge measurements were not made in 1896 to allow the construction of a rating table, but one has been constructed from measurements made in 1897, and has been applied to the 1896 record. The record of gage heights maintained at the dam of the Washington Water Power Company since March, 1891, and published in Water-Supply and Irrigation Paper No. 11, pp. 85–88, can not be utilized for conversion into daily discharges on account of the occurrence of two waste gates in the northern abutment, which are open during high stages, and the flumes of the power company in the south abutment. No record of the amount of flow is kept through either of these outlets.

Several companies utilize the water-power privilege at Spokane, and there is apparent conflict of interests. A point of considerable importance in the use of this stream for power purposes is the fact that the water is exceptionally clear, the stream carrying very little silt of any description that would be likely to clog the pipe lines or the water wheels of the power companies.

Rating table for Spokane River at Spokane, Washington, 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.0	1,341	3.0	4,749	5.0	9,565	8.5	20,577
1.2	1,611	3.2	5,172	5.2	10,114	9.0	22,351
1.4	1,897	3.4	5,609	5.4	10,673	9.5	24,165
1.6	2,199	3.6	6,059	5.6	11,243	10.0	26,012
1.8	2,517	3.8	6,523	5.8	11,824	10.5	27,887
2.0	2,851	4.0	7,000	6.0	12,416	11.0	29,787
2.2	3,201	4.2	7,489	6.5	13,941	11.5	31,712
2.4	3,566	4.4	7,990	7.0	15,525	12.0	33,653
2.6	3,946	4.6	8,503	7.5	17,160		
2.8	4,340	4.8	9,028	8.0	18,845		

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.		Depth in inches.	Second-feet per square mile.
1896.						
October 25–31	1,970	1,897	1,928	26,768	0.12	0.48
November	13,474	1,897	6,684	397,725	1.86	1.67
December	17,493	8,503	13,331	819,691	3.84	3.33
1897.						
January	10,957	6,523	8,014	492,765	2.31	2.00
February	7,000	5,172	6,104	338,999	1.58	1.52
March	8,633	4,441	5,265	323,734	1.51	1.31
April	32,875	8,896	20,101	1,196,090	5.60	5.02
May	30,554	21,636	27,620	1,698,299	7.94	6.89
June	20,928	9,838	12,842	764,150	3.57	3.20
July	9,565	5,389	7,967	489,875	2.29	1.99
August	5,172	2,682	3,693	227,075	1.06	0.92
September	2,766	2,356	2,554	151,973	0.71	0.64
October	2,356	1,972	2,086	128,264	0.60	0.52
November	11,532	1,972	5,648	336,079	1.57	1.41
December	12,416	8,245	10,237	629,453	2.94	2.55
The year	32,875	1,972	9,344	6,776,756	31.68	2.33

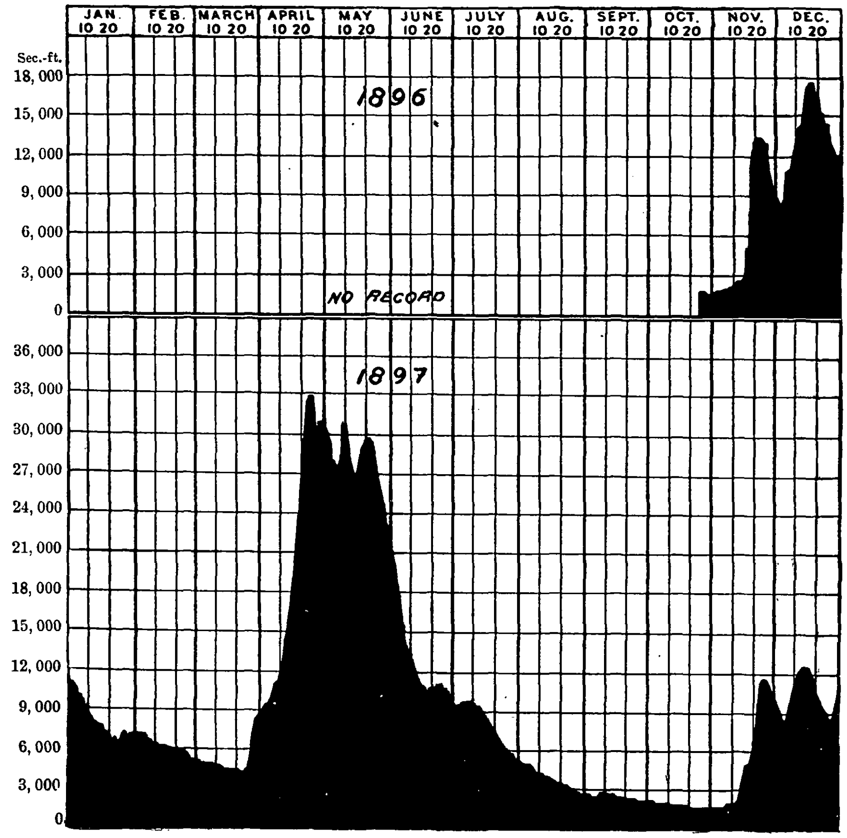


FIG. 174.—Discharge of Spokane River at Spokane, Washington, 1896 and 1897.

WENACHE RIVER.

Wenache River drains a section of the eastern slope of the Cascade Mountains. It has a general southeasterly direction, entering Columbia River at the town of Wenache, Washington. The basin adjoins Yakima River drainage basin immediately on the north, and the areas drained by the two streams are similar. Both are densely wooded, and the winter precipitation in the form of snow is considerable, amounting to 30 feet during some seasons, according to the reports of settlers. On account of the altitude of the mountains the maximum discharge does not generally occur until the latter part of May or in June. The summer flow is also regulated to a certain extent by the occurrence of a number of lakes in the basin.

November 1, 1897, a gaging station was established on this river 6 miles above its mouth and 7 miles from the town of Wenache. It is described in Water-Supply and Irrigation Paper No. 16, p. 178. Observations of heights were taken at the bridge site of the Wenache Water Power Company, 5 miles below the station, and reduced to the station gage by simultaneous readings at both points. A number of discharge measurements were made, sufficient for the construction of a rating table, as published herewith. The following are the average discharges for the three low-water months of 1897: August, 2,100 second-feet; September, 1,000 second-feet; October, 755 second-feet. The area drained at the gaging station is 1,527 square miles. These average discharges for the three months, August, September, and October, would give a run-off of 1.38, 0.65, and 0.49 second feet per square mile, respectively. The minimum discharge for 1897 was 700 second-feet, giving a run-off of 0.46 second-feet per square mile. The discharge of Yakima River for 1897 was about the average, so that 700 second-feet is probably about the average minimum discharge of Wenache River.

During 1897 work was pushed on the canal of the Wenache Water Power Company, heading on the left bank of the river about 1 mile above the gaging station. The canal was practically completed during the year, as well as the bridge over the river about 1 mile above the mouth. A plant is to be located at this bridge for the development of electric power. The bridge is to support a flume to conduct surplus waters to irrigate lands in the vicinity of Wenache. This is a narrow strip of country, comprising about 5,000 acres between the Wenache and Columbia rivers and the foothills. It is at present partially served by a few small spring creeks, but this supply is insufficient and the water furnished by the Wenache Water Power Company can be advantageously used.

Rating table for Wenache River at Wenache, Washington, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.0	700	0.6	1,250	1.2	2,650	1.8	4,300
0.1	770	0.7	1,450	1.3	2,925	1.9	4,575
0.2	840	0.8	1,650	1.4	3,200	2.0	4,850
0.3	910	0.9	1,850	1.5	3,475	3.0	7,600
0.4	1,000	1.0	2,100	1.6	3,750	4.0	10,350
0.5	1,100	1.1	2,375	1.7	4,025	5.0	13,100

WALLAWALLA RIVER.

Wallawalla River rises in the Blue Mountains, in the southeastern corner of the State of Washington and northeastern corner of the State of Oregon. This range of mountains, having an elevation of about 2,000 feet above the surrounding country, is dissected with canyons cut by the head waters of the tributaries of Wallawalla River on the west and Grande Ronde River on the east. The upper portion of the former river flows in a general westerly direction until it is diverted northward by the plateau north of Pendleton, Oregon. In the vicinity of Whitman, Washington, a number of tributaries enter, and thence to its mouth at Wallula, where it empties into the Columbia River, the course of the Wallawalla River is nearly due westward. The head waters of Touchet River have a northerly course until they unite at Dayton and Waitesburg. The course is thence westerly for 15 miles, when the river is diverted southward and a short distance below enters the main stream. Wallawalla River is a surface stream from the time it leaves the mountains until a short distance below Whitman. It then gradually sinks below the general level until, for the lower 5 to 7 miles of its course, it is 70 to 80 feet below that level. The fall from Wallawalla to Wallula, a distance of 30 miles, is 625 feet.

Mill Creek, on which the city of Wallawalla is situated, is a peculiar stream. It emerges from the foothills onto the plain about 8 miles above the city. Three miles farther down the creek divides, part of the

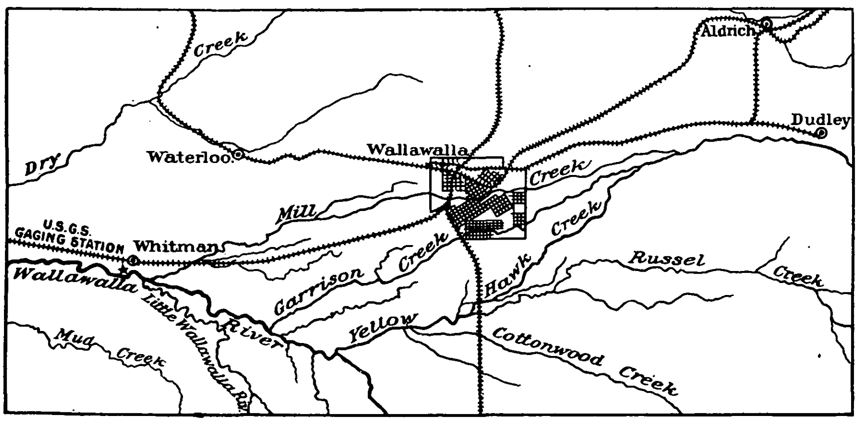


FIG. 175.—Map of streams in the vicinity of Wallawalla, Washington.

water continuing down Mill Creek and a part down Yellow Hawk. One and one-half miles farther down another bifurcation occurs in the Yellow Hawk, forming a new stream, Garrison Creek. These three creeks do not come together, but separately enter Wallawalla River. This delta formation, in a country that has such a slope, 60 feet to the mile, is peculiar, and it has given rise to more or less legal difficulties.

The water of Garrison and Yellow Hawk creeks is used to a certain extent for irrigation purposes. Mill Creek water is not thus employed until after passing through Wallawalla, because it is used in that city for power purposes in a number of mills. Owing to difficulties between the mill owners here and the irrigators on Yellow Hawk and Garrison creeks, the courts decreed a few years ago that 60 per cent of the water should pass down Mill Creek and 40 per cent down Yellow Hawk. At the lower division 50 per cent was to pass down each stream. Weirs were placed at each point, but they have been difficult to maintain, especially the upper one, owing to the torrential character of Mill Creek and to the immense amount of débris brought down in floods.

At the time of inspection, in May, 1897, the weir partitions at the upper point had been destroyed. The wooden abutments and floor were in good condition, however. The channel of the creek had also undergone a change, so that the main channel was on the southern or Yellow Hawk side, and about 60 per cent of the flow, as estimated by eye, was passing down this creek instead of Mill Creek, as the decision called for.

The following table gives the monthly precipitation at Wallawalla, Washington, from 1890 to 1897, inclusive, the yearly amount varying from a minimum of 11.80 inches in 1890 to a maximum of 23.07 inches in 1893. The mean for this period of eight years is 18.05 inches.

Rainfall at Wallawalla, Washington.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*Inches.*
1890....	2.53	1.35	2.45	0.38	1.36	1.42	0.07	0.14	0.38	0.77	0.01	0.94	11.80
1891....	1.18	2.70	1.16	0.73	0.88	3.61	1.33	0.24	0.41	0.47	1.57	1.83	16.11
1892....	3.84	0.80	1.73	2.06	1.25	1.04	0.39	0.21	0.71	0.92	1.73	2.26	16.94
1893....	0.79	1.75	2.33	3.88	3.04	0.37	0.22	T.	2.60	4.02	2.87	1.20	23.07
1894....	4.99	1.74	3.75	2.19	1.85	0.83	0.03	0.03	1.05	2.48	0.75	0.80	20.49
1895....	2.52	0.55	1.17	1.23	2.31	0.04	0.50	0.23	2.13	0.00	1.67	2.54	14.89
1896....	1.88	1.20	1.15	3.85	1.68	0.88	0.15	1.24	0.17	1.57	3.09	2.55	19.41
1897....	1.85	2.61	2.38	1.75	1.05	1.51	0.84	0.42	1.44	0.23	5.15	2.44	21.67

The vicinity of Wallawalla was one of the first settled in the Northwest, and it is now a richly producing agricultural district. The foothills to the east and the plateaus, Eureka on the north, and Athena on the south, produce immense crops of the cereals, without irrigation. In fact, the southern area is so rolling that it would be difficult to irrigate, even if water could be brought to it. The yield of these crops fluctuates to a certain extent; during dry seasons they are almost a failure, but with a plentiful rainfall the yield is abundant. The valley is also noted for its fruit production.

Below or west of Wallawalla recourse must be had to irrigation along the valley. A number of ditches are taken from Wallawalla River below Whitman, as well as from the lower 10 miles of the Touchet. In order to find the amount of water available for these canals, a gaging station was established July 19, 1897, on Wallawalla River, at Whitman, about one-half mile below the mouth of Little Wallawalla River. Only one discharge measurement was made in 1897. This was on August 26: Gage height, 0.86 foot; discharge, 78 second-feet. The area drained at this point is 310 square miles. The station is described in Water-Supply and Irrigation Paper No. 16, p. 179.

UMATILLA RIVER.

The drainage basin of this river and the irrigation enterprises projected from it a few years ago were described in Bulletin No. 131, p. 69. The river above Gibbon, where the gaging station is maintained, has a drainage area of 353 square miles, and is rather heavily wooded. The principal irrigation enterprise in operation on the river is in the vicinity of Echo, where a canal is taken out from the left bank. A canal was completed during 1897, at Pendleton, to be utilized for power purposes. It is understood, however, that the company controlling it could not make satisfactory arrangements with the city of Pendleton for the utilization of the electric power developed. A large body of irrigable land lies north of Umatilla River, and between it and the Columbia, and it could be easily irrigated by means of a canal taken out a short distance below Gibbon.

A sufficient number of discharge measurements were not made at the gaging station on this river in 1896 for the construction of a rating table, but one has been constructed for that year from the 1897 measurements. This is given below together with the table for 1897, and on the next page the resulting figures of monthly discharges from the time of the establishment of the station, July 22, 1896, to December 31, 1897. A description of this station, the list of discharge measurements, and the table of gage heights are given in Water-Supply and Irrigation Paper No. 16, p. 180.

Rating table for Umatilla River at Gibbon, Oregon, for 1896 and 1897.

Gage height.	Discharge.		Gage height.	Discharge.	
	1896.	1897.		1896.	1897.
Feet.	*Second-feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Second-feet.*
0.0	....	40	2.6	984	984
0.1	....	49	2.8	1,114	1,114
0.2	....	61	3.0	1,252	1,252
0.3	....	75	3.2	1,398	1,398
0.4	....	91	3.4	1,552	1,552
0.5	....	109	3.6	1,714	1,714
0.6	....	129	3.8	1,884	1,884
0.7	70	152	4.0	2,061	2,061
0.8	80	177	4.2	....	2,245
0.9	95	204	4.4	....	2,435
1.0	125	233	4.6	....	2,633
1.2	205	298	4.8	....	2,809
1.4	300	372	5.0	....	3,052
1.6	400	454	5.2	....	3,272
1.8	500	544	5.4	....	3,498
2.0	620	642	5.6	....	3,730
2.2	740	748	5.8	....	3,970
2.4	860	862	6.0	....	4,217

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.		Depth in inches.	Second-feet per square mile.
1896.						
July 22-31	95	80	86	1,706	0.09	0.24
August	95	75	83	5,104	0.28	0.24
September	95	80	82	4,879	0.26	0.23
October	145	80	86	5,288	0.28	0.24
November	2,150	125	779	46,354	2.46	2.21
December	1,972	400	785	48,267	2.57	2.23
1897.						
January	544	412	465	28,592	1.52	1.32
February	1,324	412	862	47,873	2.54	2.44
March	4,217	412	933	57,368	3.05	2.64
April	4,093	1,252	2,272	135,193	7.18	6.44
May	2,339	298	1,088	66,899	3.59	3.08
June	316	177	225	13,388	0.71	0.64
July	334	100	165	10,146	0.54	0.47
August	109	75	92	5,657	0.30	0.26
September	109	75	84	4,998	0.27	0.24
October	100	83	88	5,411	0.29	0.25
November	642	91	299	17,792	0.94	0.85
December	1,798	316	772	47,469	2.53	2.19
The year	4,217	75	612	440,786	23.46	1.74

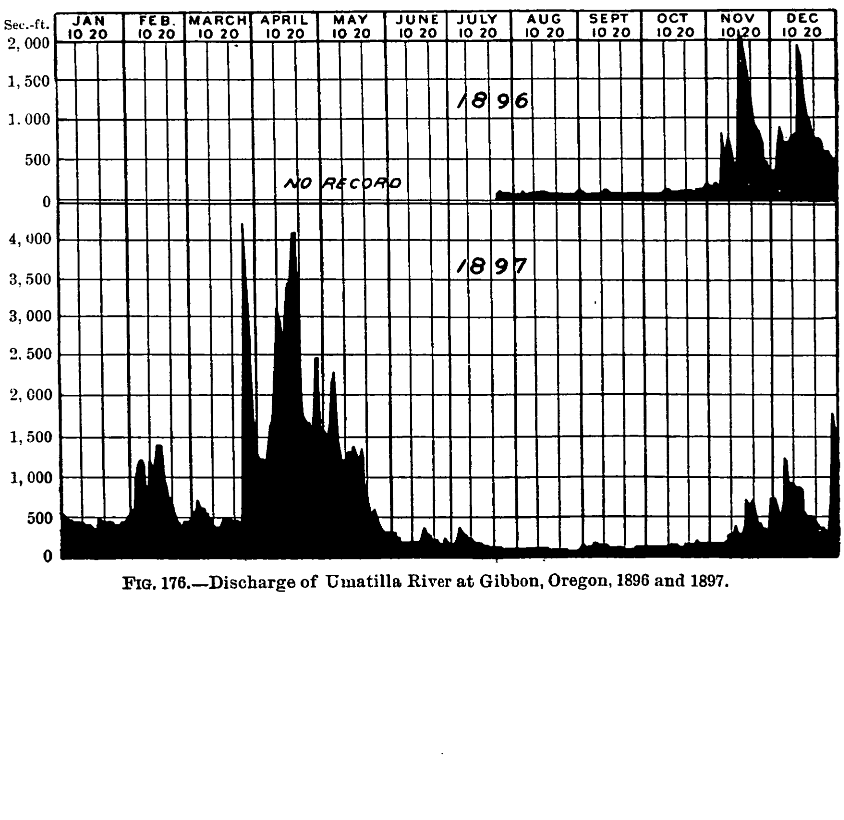


FIG. 176.—Discharge of Umatilla River at Gibbon, Oregon, 1896 and 1897.

DESCHUTES RIVER.

During the first half of October, 1897, Mr. Cyrus C. Babb, assistant hydrographer, made a reconnaissance trip through this basin. From his report the following details have been taken:

Immediately on leaving The Dalles for a trip southward through Deschutes Basin one finds an ascent of 300 or 400 feet to be made of Columbia River bluffs. For the next 25 miles the road is through a heavily rolling country that is hardly susceptible of irrigation on account of this characteristic. The ascent is gradual until the top of Tygh Ridge is reached, at an elevation of about 2,500 feet, and this point may be considered the southern boundary of the rolling section. The area is principally given up to range purposes and to wheat growing. A fair crop of this cereal is generally raised every year, and in a season of plentiful rainfall, as that of 1897, an abundant harvest is gathered.

Deschutes River, the eastern boundary of this section, flows in a canyon 1,100 feet deep at the Free Bridge, 7 miles above its mouth. A measurement on September 27 at this point gave a discharge of 5,962 second-feet. The river was then probably at its lowest stage for the season. In exceptionally dry seasons it drops a foot lower.

From the top of Tygh Ridge a sharp descent of 1,500 feet is made to the valley of Tygh Creek and White River. On October 6 the former stream was discharging 24 second-feet and the latter 192 second-feet. In the head-water country of White River, in the vicinity of Wamic, irrigation is practiced in a small way. Four ditches are taken out: One from Badger Creek, two from Threemile Creek, and one from Rock Creek. The first mentioned is the largest, 5 miles long, 2½ feet wide, and 1 foot deep. The water is used on a number of small orchards and garden patches. Below the mouth of Tygh Creek water is used on a few alfalfa areas.

Crossing White River Valley at Tygh, where it is about 1 mile wide, the road leads over the rim-rock, as it is called, making an ascent of about 300 feet, onto Juniper Flat. This is an approximately level tract of land, extending for 15 miles from White River southward to Mutton Mountains and 15 miles westward from the Deschutes to low ranges of hills. The area is occupied by a number of ranches, and wheat is the principal crop. The rainfall is scanty, and good crops are not made every year. Four years ago a canal was projected to take water from Clear Creek, about 15 miles west of Wapanitia, to be used on this tract, but only about 4 miles of ditch was constructed at the head, and the project was abandoned two years ago. The canal, which is 8 feet wide on the bottom, heads 2 miles below Clear Lake, said to be a good reservoir site. The lake can be easily dammed, and is 2½ miles long and three-fourths of a mile wide.

Continuing southward one soon enters the Warm Springs Indian

Reservation, a mountainous tract of country, but containing a number of large, isolated valleys, where wheat could probably be raised without irrigation. In fact, a number of apparently good Indian ranches were seen, and within the last year or so the Indians of this reservation, a very industrious tribe, have supplied the agency with most of the grain that was required on the reservation.

There is a large level tract several miles wide on each side of Warm Springs River that would produce abundant crops from its fine lava soil if water could be brought on it. Unfortunately the river flows through it in a canyon 700 or 800 feet deep. On October 7 a measurement from the bridge over the river on the agency road gave a discharge of 284 second-feet.

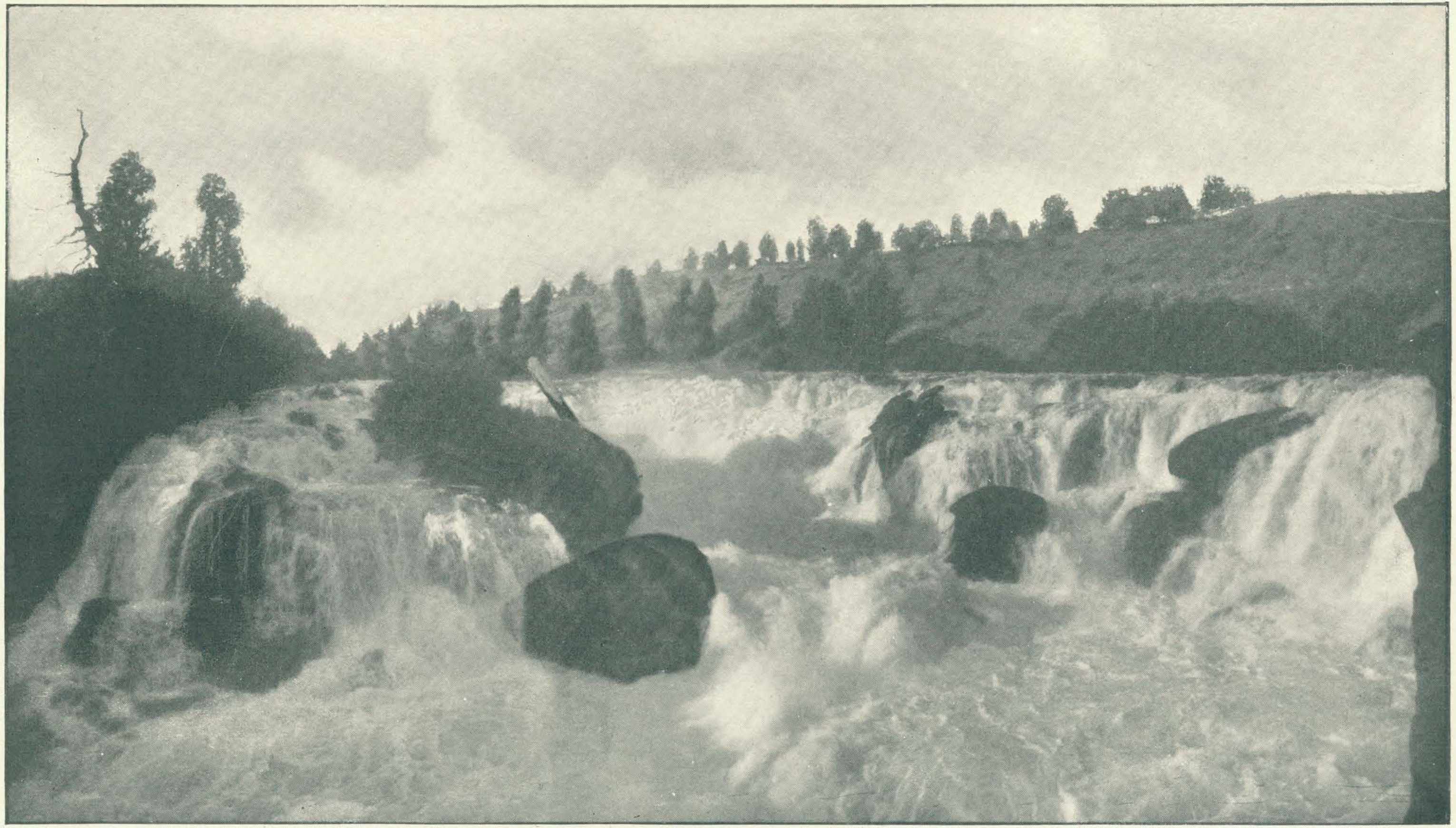
Shitike Creek, 2 miles above its mouth, at the Warm Springs Indian Agency, was discharging 46 second-feet on October 8, and the Deschutes River at the cable ferry above the mouth of this creek was carrying on the same date 4,452 second-feet.

Southwestward, beyond the ferry toward Prineville, it takes over an hour's steady climbing to pull out of Deschutes Canyon. Once on top a drive of 20 miles is made over a nearly perfectly level tract of sage-brush country until, near Haystack post-office, the character of the surface changes, becoming more rolling, and so continues until the edge of the hills overlooking Prineville and Crooked River Valley is reached. At Haystack are a number of prosperous ranches, where hay and some grain is raised by dry farming. On October 9 the combined flow of the new and old channels of Crooked River at Prineville was 57 second-feet and of the Prineville irrigation canal 3.8 second-feet. Ochoco Creek was carrying 12 second-feet on the same date.

The only large irrigation enterprise of the vicinity is the one mentioned above. This canal heads 2 miles above Prineville, is 15 miles long, and has a bottom width of 8 feet. It was finished four years ago, and cost about $25,000, but very little water is used from it, although there are a number of ranches under it. The principal reason for this has been that for the last two years the rainfall has been sufficient to mature crops. A number of ranchers on Ochoco Creek take out water for alfalfa, which they feed to their stock in winter. Crooked River Valley above Prineville is narrow and contains little irrigable land.

The Deschutes River at Tetherow's bridge, 20 miles due west of Prineville, was discharging 1,722 second-feet on October 10. The canyon of the river here is only about 300 feet deep, and it gradually decreases in depth upstream. In fact, it can hardly now be called a canyon, as there is a succession of meadow lands from here up. Pl. XLVI gives a view of falls 30 feet in height, 6 miles south of Tetherow's bridge and about 30 miles west of Prineville.

A characteristic of the river banks is now noticed, not before perceived. At points below, the flood marks have been from 3 to 7 feet above the present low stage. At Tetherow's, and from there up to



DESCHUTES RIVER AT THE FALLS, 30 MILES WEST OF PRINEVILLE, OREGON.

The fall is about 30 feet.

Lava post-office, grassy banks only a foot or so high come directly to the water's edge. Upon inquiry it is discovered that this river, large for an arid region, has a yearly variation in height of less than 16 inches, in some places only 10 inches. Twenty-five miles above Tetherow's, at Sizemore's bridge, at Farewell Bend on the river, as it is called, the discharge on October 11 was 1,921 second-feet. The distance from Sizemore's to Lava post-office is 16 miles. At a point about two-thirds of the way, in an open pine forest growing in the ordinary fine lava soil, a mass of rock is encountered, 15 feet high, a comparatively recent lava flow. For about a mile the road swerves slightly eastward and follows around this wall, lying within a hundred feet of it. In the center of this rough barren lava rises a rounded hill about a quarter of a mile off, and possibly 400 feet high. The area covered by this lava flow is from 7 to 10 square miles. Deschutes River skirts its western edge for 3 miles or so.

It is the accepted idea of the people of the vicinity that as the river rises in the spring the water encounters this porous mass of lava and flows off into it. If this were the case, a more typical mountain river, with flood marks 5 feet or so high, would be found above. But instead, we find the same grassy banks, with a yearly variation in height of water of about 18 inches. The measurement at the Lava post-office bridge gave on October 12, 1,780 second-feet, less by 141 second-feet than the discharge at Sizemore's, below the lava. While making the former measurement large springs were discovered at the west end of the bridge, at the edge of the river. In fact, many of these springs occur on the West Fork, or Big River, and this tributary has the same characteristic of varying not more than about 1 foot in height during the year.

The supply for this stream is evidently the winter snow in the Cascades, melting in the spring, percolating into the ground, and later finding its way into the river through springs. A rancher stated that he had seen large banks of snow melting in the spring, and that 200 feet below the snow the soil was dusty, the water having at once percolated into the ground.

East Fork, or Little River, 2 miles above Lava post-office, was discharging 174 second-feet, October 12.

The country between Lava and Prineville is a level desert from 300 to 600 feet above the Deschutes, and apparently could be easily irrigated from that river. Its general elevation is 4,000 feet above sea level. The climate is rather cold, and frosts occur throughout the whole year.

In returning from Prineville to The Dalles a rolling country is traversed and several small streams are crossed, as Hay, Willow, and Trout creeks. The water of these streams is used on a number of hay ranches.

Falls occur in the river at Sherar's, 30 miles south of The Dalles. This volume of water immediately below flows through a cleft in the lava 30 feet wide and 80 feet deep. A gaging station on Deschutes River was established October 19, 1897, at a ranch 3 miles above what is known as the "Free Bridge," and 16 miles east of The Dalles. It is described in Water-Supply and Irrigation Paper No. 16, p. 181. A sufficient number of discharge measurements have not yet been made here on which to base a rating table.

List of miscellaneous discharge measurements, Deschutes River Basin.

Date.	Stream.	Locality.	Meter number.	Area of section.	Mean velocity.	Discharge.
1897.				*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
Oct. 6 ..	White River........	Tygh, Oregon	74	98	1.95	192
Do...	Tygh Creek.........	.....do	74	16	1.50	24
Oct. 7 ..	Warm Springs	Road-bridge, Oregon.	74	356	0.80	284
Oct. 8 ..	Deschutes River...	Ferry, Warm Springs Agency.	74	1,527	2.92	4,452
Do...	Shitike Creek	Warm Springs Agency.	74	28	1.65	46
Oct. 9 ..	Crooked River.....	Prineville, Oregon .	74	32	0.72	23
Do...	Irrigation ditch...	.....do	74	5	0.73	4
Oct. 10 .	Deschutes River...	Tetherow's bridge.	74	527	3.28	1,722
Oct. 11 .	.....do.............	Sizemore's bridge..	74	856	2.25	1,921
Oct. 12 .	.....do.............	Lava, Oregon......	74	688	2.59	1,780
Do...	Little or East Fork.	.....do	74	254	0.69	174

HOOD RIVER.

Hood River, as shown in fig. 177, rises at the base of Mount Hood, which has an elevation of 11,225 feet above the sea and is covered with snow throughout the year. The river in falling this height to its mouth in the short distance of about 30 miles necessarily has a steep slope and the current is swift.

The valleys proper of Hood River are very narrow. In fact, the stream runs through canyons and gorges throughout most of its course. The so-called Hood River Valley is a plateau extending from Columbia River southward for 7 or 9 miles, and is about 6 miles wide. It is a level tract of land, the northern edge ending abruptly in the terrace overlooking Columbia River and at an elevation of about 250 feet above the river. It thence slopes gently upward and southward. Six or seven years ago this region was largely covered with a growth of fir and juniper. Since then large tracts have been cleared and numerous farms are to be found. The chief products are berries and fruits, especially the smaller kinds. Hood River has made its reputation within the last two years through its superior crops of strawberries, which are noted throughout the Northwest.

The summer rainfall is hardly sufficient to mature the crops and recourse has been had to irrigation. A small ditch from Dry Point Creek has been in use for a number of years, but on account of the

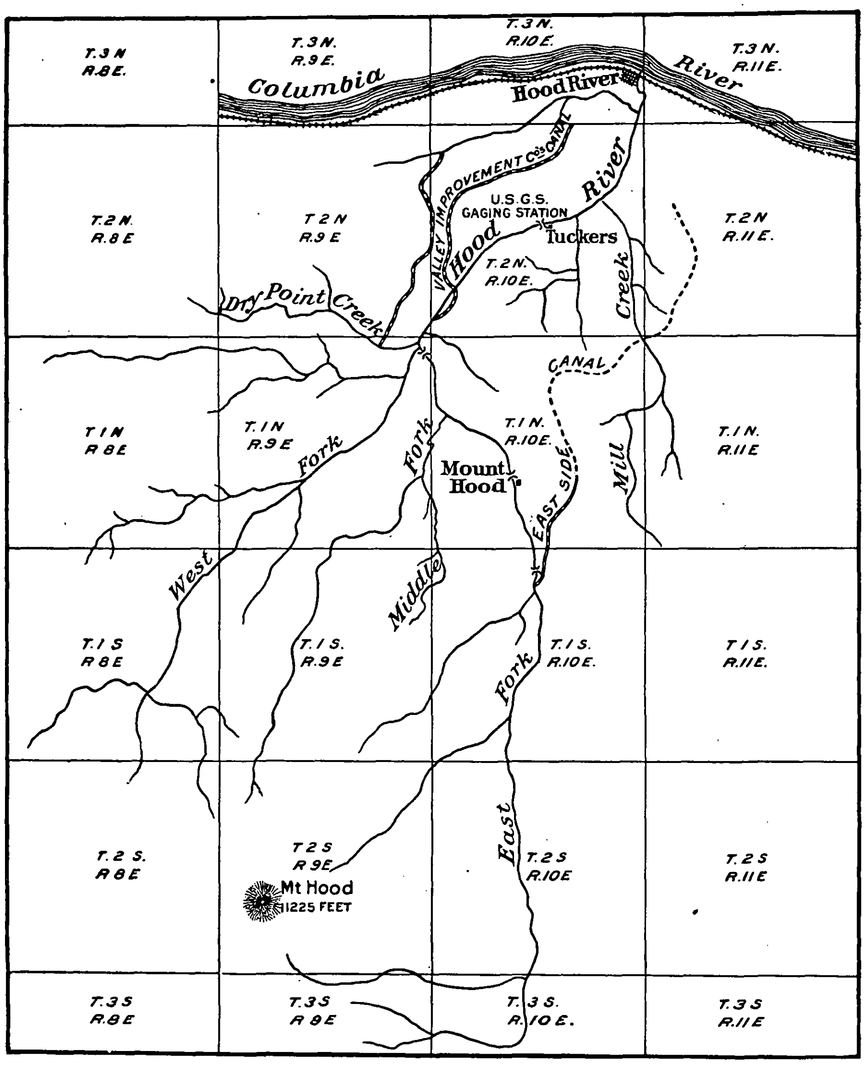


FIG. 177.—Map of drainage basin of Hood River, Oregon.

demand for water, another canal, that of the Valley Improvement Company, was built and completed in July, 1897. Water is sold at $5 an inch at a 6-inch pressure. This is a high rate compared to that generally prevailing throughout the arid region, but the consumers do not complain, the value of their products allowing the tax.

The canal heads about 10 miles south of the town of Hood River and about 1 mile below the junction of the East and West forks, and on the east bank of the river. One mile below its head the canal crosses Hood River on a trestle bridge over to the west side, where the water is used. The canal is 12 miles long, 4 feet wide, and is to carry 3 feet of water. During the summer after its completion, 400 inches of water under a 6-inch pressure were used.

Land adapted to farming purposes is found on the east side of the river as well as on the west side, and to serve the former a ditch was started in 1897, called the East Side or Bone ditch. It heads on the East Fork about 18 miles south of the town of Hood River and only a short distance above the so-called Free Bridge on the stage road to Mount Hood. Three miles only were constructed in 1897, but the idea is to push the canal to completion as soon as possible.

As a suitable location for a gaging station could not be found above the head of the ditches on this river, one was established, October 20, 1897, at Tucker, 5 miles south of the town of Hood River. A measurement on this date showed a discharge of 459 second-feet. A previous measurement on September 28 gave a discharge of 541 second-feet. Probably 400 second-feet is about the minimum flow of this river. The station is described in Water-Supply and Irrigation Paper No. 16, p. 181.

The accompanying table shows the amount of precipitation as recorded at the Weather Bureau station at the town of Hood River, Oregon:

Rainfall at Hood River, Oregon.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
1890....	6.98	8.10	3.14	0.93	0.19	0.47	0.16	0.08	0.00	2.43	0.06	3.09	25.63
1891....	2.45	6.70	2.80	1.10	1.00	1.20	0.35	0.05	1.18	2.45	4.55	12.85	36.68
1892....	4.45	1.50	1.80	4.02	0.75	0.54	0.27	0.12	0.48	2.12	5.83	10.94	32.82
1893....	3.25	8.03	4.23	5.76	2.58	0.50	0.33	0.00	3.26	9.81	9.56	6.86	54.17
1894....	11.72	5.03	12.67	1.68	1.56	1.79	T.	0.00	2.00	3.93	3.78	4.13	48.29
1895....	10.85	1.16	3.68	1.90	3.33	0.25	0.64	0.15	2.91	0.01	3.82	12.83	41.53
1896....	7.61	4.53	5.00	3.17	3.78	0.54	0.00	0.22	0.98	1.81	16.55	9.00	53.19
1897....	2.85	7.45	6.78	1.84	0.81	0.95	0.18	0.30	1.29	1.24	10.64	12.54	46.87

NORTHERN PACIFIC WATERSHED.

CEDAR RIVER.

Measurements of Cedar River, Washington, were begun in August, 1895, by Mr. T. A. Noble,[1] for the Seattle Power Company. The point of measurement is at Clifford's bridge, in sec. 19, T. 22 N., R. 7 E., Willamette meridian. A continuous record of the flow since that time has been kept by Mr. Noble. The drainage area is estimated to be about 143 square miles. The total depth of water coming from this drainage area was 80.73 inches during the year ending August, 1896; 99.83 inches during the year ending December 31, 1896; and 102.35 inches during the year ending December 31, 1897. The nearest official record of precipitation has been kept at Northbend. During 1897 the measurements show that the precipitation was 90 inches, excluding August, September, and October, during which no record was kept. Probably not more than 2 or 3 inches and possibly less than 1 inch fell during these three months. Thus the run-off of over 102 inches, when compared with the probable precipitation of something over 90 inches at Northbend, indicates that there must be a considerable increase of precipitation on the mountain slopes. Mr. Noble thinks that the precipitation near the summit of the mountain must be as much as 150 inches a year. The diagram in fig. 178 gives the record of fluctuations during the year 1897.

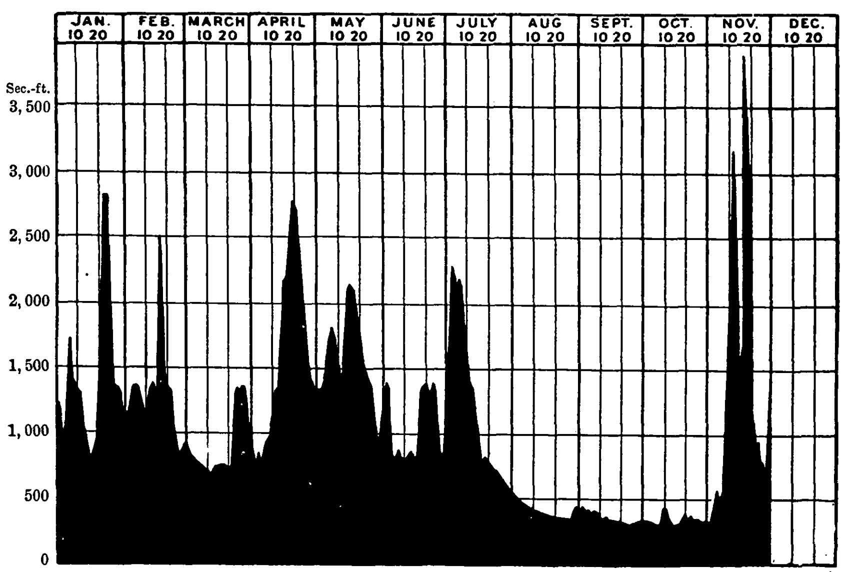


FIG. 178.—Discharge of Cedar River, near Seattle, Washington, 1897.

[1] Gaging of Cedar River, Washington, by Theron A. Noble: Proc. Am. Soc. Civ. Eng., Vol. XXIV, pp. 662–675.

Estimated monthly discharge of Cedar River, near Seattle, Washington.

[Drainage area, 143 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1895.	*Second-feet.*	*Second-feet.*	*Sec.-feet.*	*Acre-feet.*	*Inches.*	*Second-feet.*
September 13-30	433	174	252	9,000	1.17	1.76
October	253	138	181	9,285	1.46	1.27
November	241	94	151	8,985	1.18	1.06
December 13-30	2,176	669	160	41,400	5.40	8.11
1896.						
January	2,932	727	1,273	78,272	10.28	8.90
February	2,469	743	1,334	76,732	10.06	9.33
March	2,034	608	1,012	62,226	8.18	7.08
April	1,316	628	877	52,186	6.83	6.13
May	2,029	864	1,208	74,276	9.75	8.44
June	2,361	1,363	1,650	98,182	12.86	11.53
July	1,901	320	784	48,206	6.33	5.48
August	347	197	260	15,987	2.10	1.82
September	205	157	179	10,652	1.39	1.25
October	221	150	172	10,576	1.38	1.20
November	4,695	721	1,595	94,909	12.43	11.15
December	4,189	757	2,217	136,318	17.90	15.50
The year	4,695	150	1,047	758,522	99.49	7.32
1897.						
January	2,812	815	1,430	87,928	11.55	10.00
February	2,415	823	1,303	72,365	9.49	9.11
March	1,366	723	901	55,400	7.28	6.30
April	2,752	790	1,599	95,147	12.47	11.18
May	2,143	939	1,562	96,043	12.61	10.92
June	1,410	780	1,060	63,074	8.26	7.41
July	2,284	572	1,135	69,788	9.15	7.93
August	561	342	427	26,255	3.44	2.98
September	418	311	350	20,827	2.72	2.44
October	433	294	339	20,844	2.74	2.37
November	3,155	323	1,318	78,426	10.28	9.22
December	3,601	674	1,639	100,778	13.23	11.46
The year	3,601	294	1,089	786,875	103.22	7.61

OLYMPIC PENINSULA.

The section of country known as the Olympic Peninsula, shown in fig. 179, is located in the northwestern part of the State of Washington, between Puget Sound and the Pacific Ocean, and comprises Clallam and Jefferson counties and the northern half of Chehalis County. It is occupied by the mass of the Olympic Mountains, the highest peak being Mount Olympus, with an elevation of 8,138 feet above sea level.

This district is as little known as any in the United States. The mountains are rugged and extremely precipitous, and the forest growth is so dense as to be almost impenetrable. No exploring expeditions have penetrated the heart of the range, and only one or two have been through the western portion of it. The settlements are along the shores or extend for only a few miles up the valleys of some of the rivers.

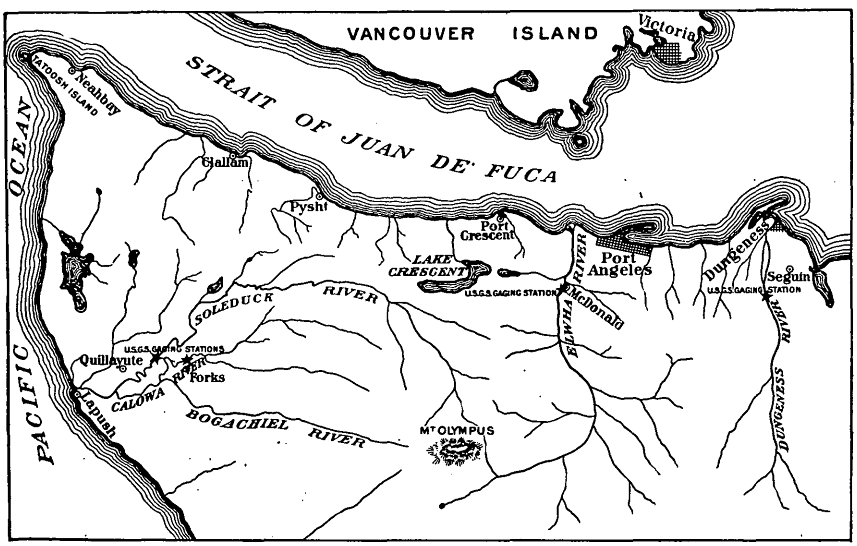


FIG. 179.—Map of river stations in Olympic Peninsula.

The accompanying view, Pl. XLVII, *A*, was taken in the forest 10 miles south of Port Angeles, Washington. The precipitation in this region is greater than that in any other part of the United States. The rainfall at a number of stations here is shown in the table on page 508. The greatest annual amount was at Neah, in 1894, when 131.52 inches fell. Probably a greater amount falls on the mountain summits. As may be seen from the tables, the rainfall increases from east to west. In the vicinity of Dungeness and Port Angeles the least rainfall occurs in the summer months at the time when it is most needed for the growing crops. On this account the farmers are beginning to realize the advantages of irrigation, and already two ditches have been taken from Dungeness River.

During the summer of 1897 a gaging station was established on this river, as well as one each on the Elwha, Solduck, and Calowa rivers, the last two in the southwestern corner of Clallam County. Pl. XLVII, *B*, is a view of the gaging station on Dungeness River, established July 5, 1897, at the county bridge, 9 miles above the mouth and above the head of the two ditches. Sufficient discharge measurements have not yet been made to permit the construction of rating tables for these stations and therefore the daily discharges can not be computed.

The following measurements were made: On Dungeness River, July 5, the discharge was 546 second-feet; August 17, 357 second-feet; and December 4, 165 second-feet. On Elwha River, the discharge on October 8 was 406 second-feet; December 28, 4,623 second-feet. On Calowa River, September 6, the discharge was 469 second-feet; November 12, 1,494 second-feet. On Solduck River, September 7, the discharge was 858 second-feet; November 13, 1,898 second-feet. These stations are described in Water-Supply and Irrigation Paper No. 16, pp. 182–184.

The following descriptions of the basins of Dungeness and Elwha rivers are prepared by Mr. A. Judson Adams, civil engineer of Port Angeles and hydrographer in charge of the stations.

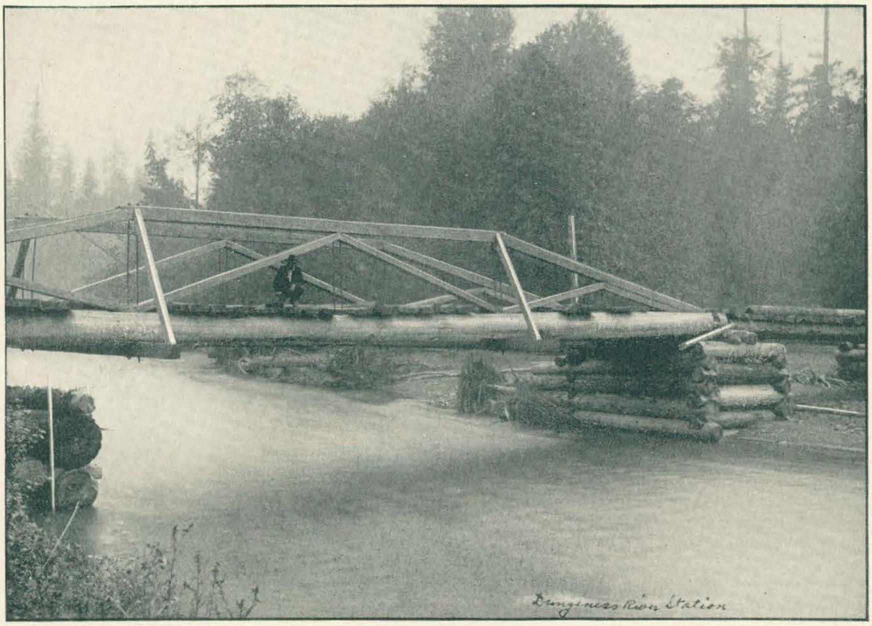
DUNGENESS RIVER.

This river rises in the Olympic Mountains, which have a general easterly and westerly trend and rise to an elevation of 8,000 feet. They are perpetually covered with snow at their summits. The source of the river is in a number of small lakes lying in latitude 47° 37′ and longitude 123° 5′, and at an elevation of 3,000 feet above sea level. Numerous small streams, from 2 to 6 miles long, flowing through deep canyons and along narrow valleys from both the east and west, unite to form the river, which then takes a gener l northerly course to the sea, entering it at New Dungeness, Washington.

The temperature of the waters of the Dungeness, which come directly from melting snow in summer and from cold rains in winter, varies but little during the year from a few degrees above freezing point. The country at the head and on both sides of the river for about 25 miles down is very rough and broken, there being but few narrow valleys suitable for agricultural and grazing purposes. About 15 miles above its mouth the river leaves the rough mountainous country and enters a comparatively level section. Here the lands are very fertile, and although the greater portion of them are in the virgin state, being heavily timbered with fir, cedar, spruce, and hemlock, they are still mainly owned by bona fide settlers, who are gradually clearing them for farming purposes. A few miles farther down is the head of Seguin prairie, containing about 3,000 acres of land, the greater portion of which is under cultivation. This prairie is of very regular contour, lying between the elevations of 110 and 220 feet, and is easily irrigated. The soil is alluvial and very fertile.

The total annual precipitation in this section is from 20 to 30 inches,

A. FOREST NEAR PORT ANGELES, WASHINGTON.



B. DUNGENESS RIVER, WASHINGTON.

At gaging station about 9 miles from mouth.

only a small percentage of which, however, falls during the spring and summer months. The subsoil is of gravel and sand, not suited to retain the moisture, and, as a consequence, the ground becomes dry and vegetation dies. The bulk of the rainfall occurs during a well-defined wet season, from November to April. During the months of June, July, and August there is often little more than a trace of rain.

The Seguin Irrigation Company, composed of a number of farmers having land on Seguin prairie, built a ditch in 1896, taking water from Dungeness River in sec. 26, T. 30 N., R. 4 W., and running to the prairie. For the past two seasons there has been a limited supply of water for irrigation. Although irrigation is something new to most of the farmers of this region and they have not yet learned approved methods of applying the water to the land to obtain the best results, yet they readily see by the experience of the last two years the benefits of irrigation. Several farmers who used water state that they obtained more than double the yield of various crops that was obtained by their neighbors who did not irrigate, and that their products were of better quality. The following statement, giving the ratio of yield in crops per acre with and without irrigation, shows the experience of a prominent farmer of Seguin prairie.

With water: Wheat, 35 to 40 bushels; oats, 55 to 60 bushels; potatoes, 250 to 300 bushels.

Without water: Wheat, 12 to 18 bushels; oats, uncertain; potatoes, 100 bushels. The yield of other products was in about the same proportion.

The Eureka Irrigating and Milling Company, also composed of farmers, is constructing another ditch much larger than the first, and tapping the river about 1 mile above. This latter ditch will be able to reach higher lands on the prairie.

This river has been measured at the bridge shown on Pl. XLVII, *B*, situated about 9 miles above the mouth of the river and 18 miles southeast of Port Angeles, Washington, as described in Water-Supply and Irrigation Paper No. 16, p. 182.

ELWHA RIVER.

This river rises on the southeastern slope of Mount Olympus, and is the largest stream flowing into the strait of Juan de Fuca, or Puget Sound, from the Olympic Mountains. Its waters are clear at all ordinary stages, and run over a gravel and bowlder bottom. It is a tortuous and turbulent stream, winding between high and precipitous mountains, cutting its way through rocky ridges, and forming deep and narrow canyons. It passes through narrow valleys from a quarter of a mile to a mile in width and of various lengths, and finally discharges into the strait of Juan de Fuca about 3 miles west of Port Angeles Harbor, Washington.

At the head of Elwha River are a number of large open plateaus containing thousands of acres of land covered with a luxuriant growth of grass, affording an excellent range and abundant grazing for sheep and cattle for about eight months of the year. During the winter, stock may be driven to the lower lands, where it can be kept at a comparatively small cost. These upper grass lands have never as yet been utilized for stock raising, and only deer, elk, and other wild animals in vast numbers inhabit the country. There are no settlements along Elwha River above Geyser Valley, which is about 18 miles from the mouth of the river.

The bed of Elwha River is from 50 to 200 feet wide and is covered with bowlders and large rocks which have rolled down from the mountain sides. The banks are high and the channel of the river is not liable to change at any place except on the lowlands near the mouth,

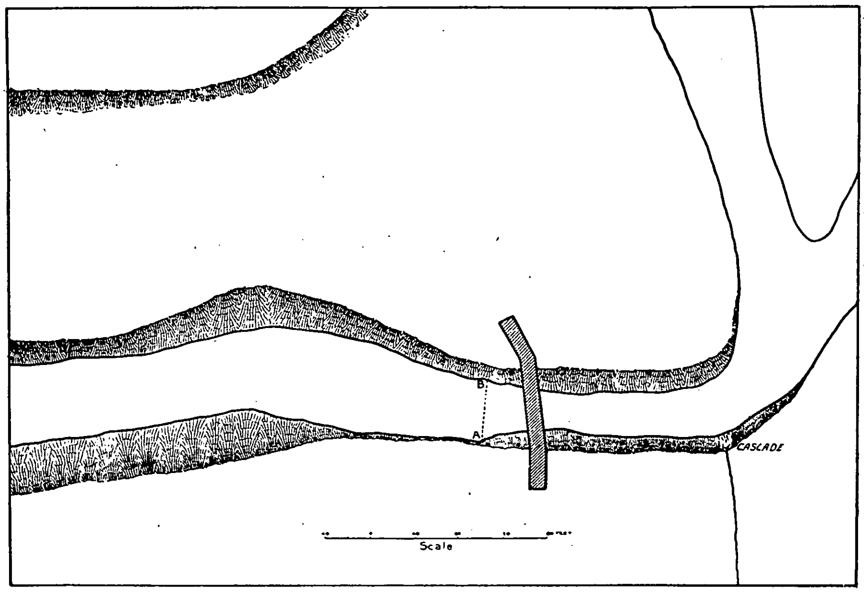
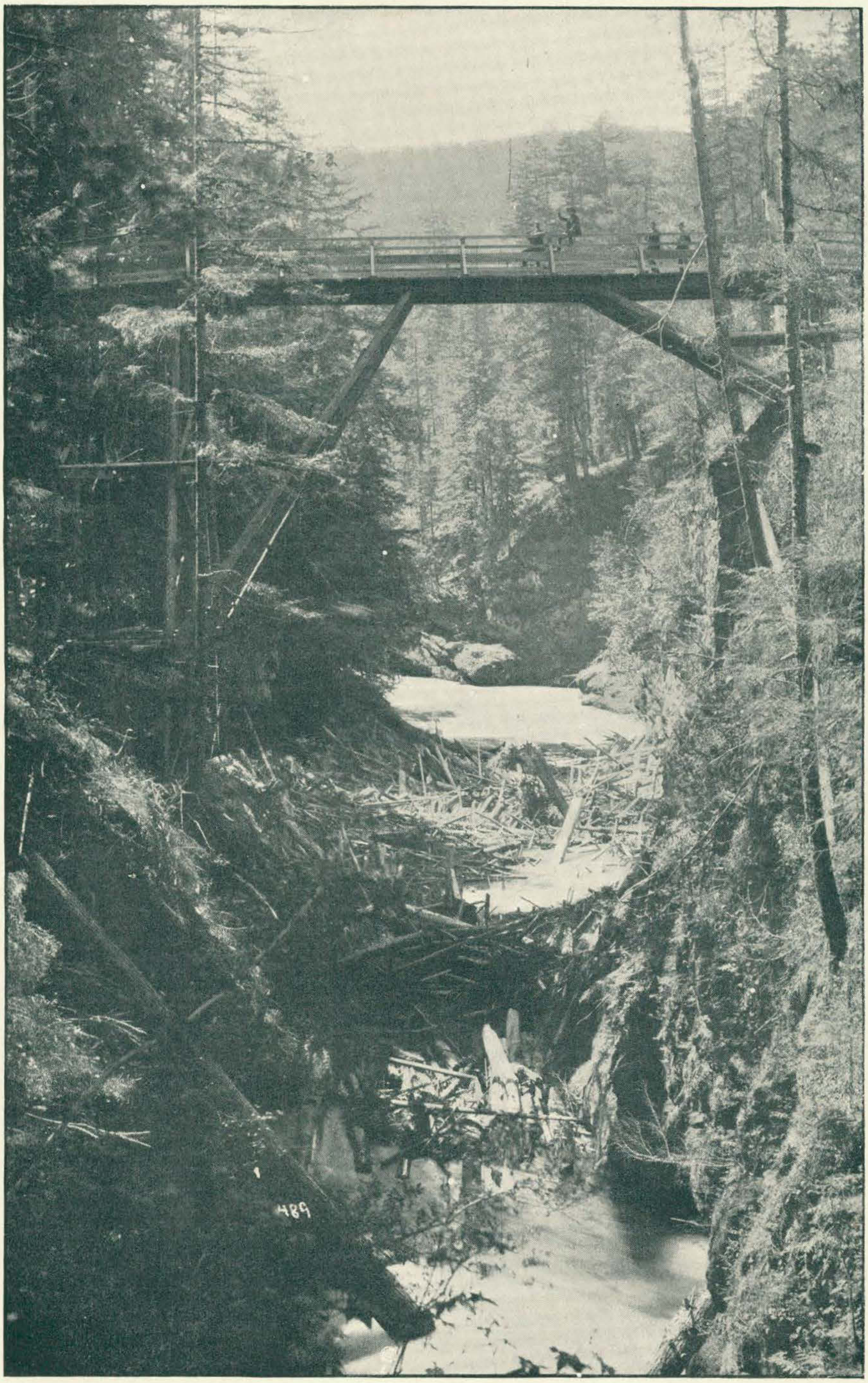


FIG. 180.—Map of dam site on Elwha River, Washington.

where it has been known to shift its course several times, doing a great amount of damage to the farmers in the vicinity. The change of the channel is caused by log jams, which form in the river and back up the water, causing it to seek another outlet.

The land of the river valleys is a very fertile alluvial loam. Owing to the recent settlement of the country, much of this land is still uncultivated, being covered with vine maple, alder, cedar, and salal brush, but the settlers are rapidly clearing it and bringing it under cultivation. Little has yet been done in the way of irrigation, although a number of the farmers realize that they would increase the yield and improve the quality of their crops if they should water their lands during the dry season, which generally sets in before the crops are matured.



CANYON OF ELWHA RIVER, WASHINGTON.

Looking upstream from point near the cascade.

While there is a marked increase in the volume of water in Elwha River at certain seasons of the year, yet the difference is not so great as in many streams in other sections of the country. The reason for this is that during the rainy season or winter months, while rain is falling along the coast and lowlands, snow is being stored in the mountains. During the dry summer seasons the snow gradually melts, so that there is a more regular supply of water to the streams here than to those in regions which do not have this inexhaustible snow supply.

On Elwha River are a number of water powers which are as yet undeveloped. The one of most value is at Aldwells Canyon, shown

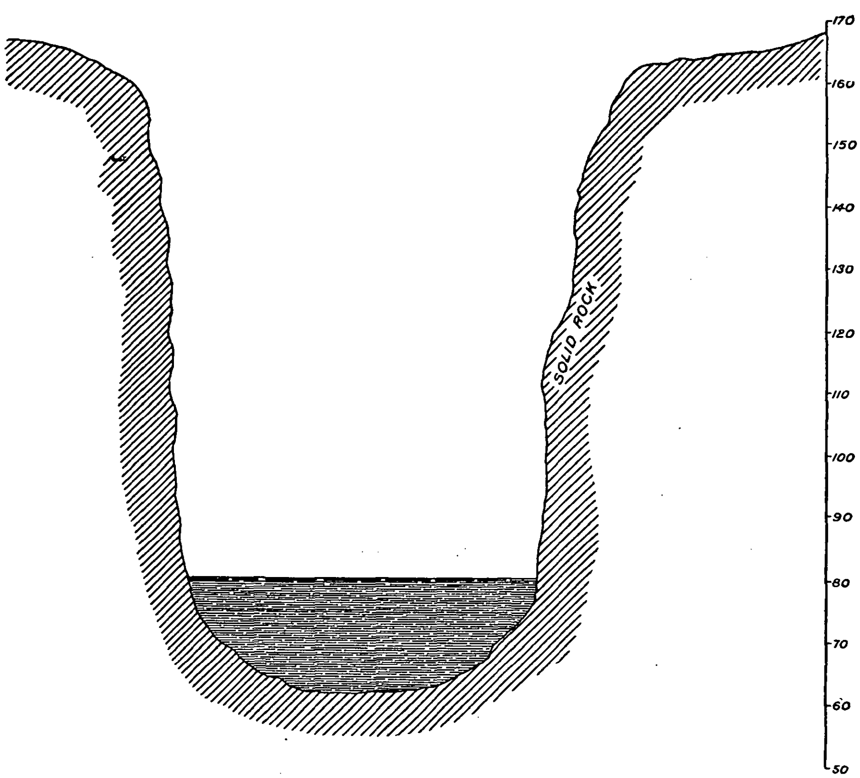


FIG. 181.—Vertical section at dam site on Elwha River, Washington.

in Pl. XLVIII, about 3 miles from the Strait of Juan de Fuca and 5 miles from Port Angeles Harbor. The conditions here are illustrated by figs. 180 and 181, the former being a map of the locality and the latter a section on the line A B shown in fig. 180. The water level in fig. 181 is that of March 29, 1898, when it stood at 80.2 feet. Fully 10,000 horsepower can be developed at this point at comparatively small cost by building a dam across the canyon, which is from 30 to 60 feet wide, 100 feet deep, and one-quarter of a mile long. The walls are of solid lime and slate rock and are nearly perpendicular. The natural formation of the bank on the west side of the canyon is such as to permit the overflow of surplus water during freshets, and avoid the possibility of damage to the power works. The proposition that contemplates developing this power, if consummated, will flood the river bottom for 2½ miles above the canyon.

There are now three bridges across Elwha River; one at Aldwells Canyon, another at McDonald, and a third at Geyser Valley. The bridge at McDonald was selected as the most suitable place for taking discharge measurements.

Annual rainfall at Washington stations.

Stations.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Port Townsend	......	15.00	19.95	24.90	23.50	27.94	27.62	......	......	......
Port Angeles	28.17	27.58	......	......	27.70	36.40	30.42	24.07	30.40	29.12
Port Crescent	......	......	......	......	......	48.79	47.15	40.50	......	......
Pysht	......	......	......	......	......	73.47	66.13	67.58	......	68.31
East Clallam	......	......	......	......	......	91.83	101.15	90.35	......	......
Neah	102.95	......	......	122.11	109.67	118.88	131.52	107.07	......	......
Tatoosh Island	83.72	67.95	87.53	105.47	91.38	104.19	114.34	92.95	100.85	95.21
Lapush	......	......	......	78.22	......	......	92.81	......	......	......

SAN FRANCISCO BAY WATERSHED.

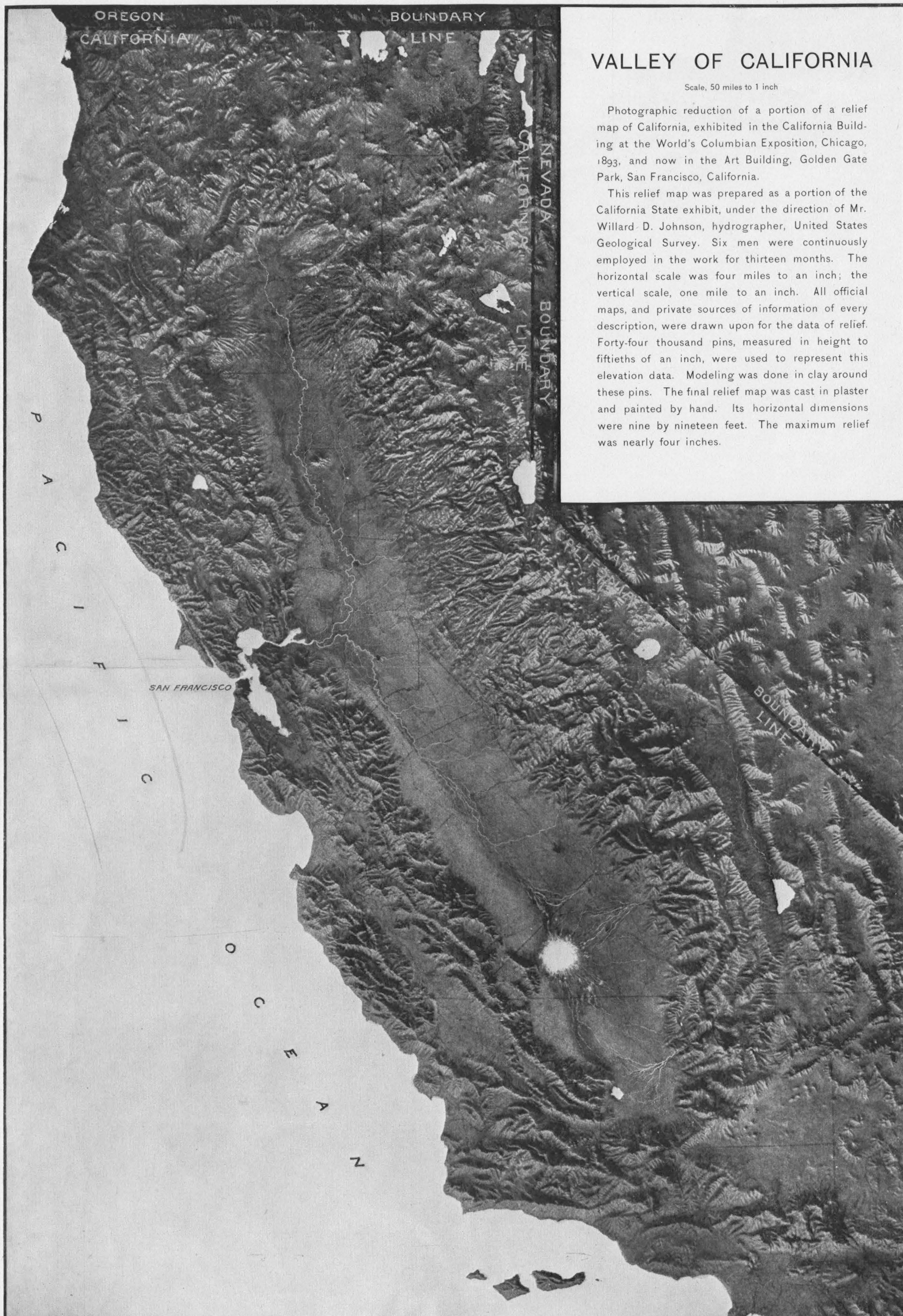
The great valley of California, shown on Pl. XLIX, comprising 39 per cent of the area of California, drains into San Francisco Bay. Of this total area 17 per cent is comprised in the Sacramento Basin, 20 per cent in the San Joaquin Basin, and the remaining 2 per cent is the smaller area immediately adjacent and tributary to the bay.

SACRAMENTO RIVER.

Sacramento River rises in the extreme northeastern corner of the State, and its drainage basin is confined wholly to California. Formerly Goose Lake had an outlet to the Sacramento, but of late years this lake has not overflowed. The area tributary to Goose Lake is about 1,000 square miles, including 650 square miles in Oregon.

The gaging station on Sacramento River is located at Jellys Ferry, 12 miles above the town of Red Bluff, California, and above Iron Canyon. It is described in Water-Supply and Irrigation Paper No. 16, p. 185. A record of the gage heights of the river is also kept by the United States Weather Bureau at Red Bluff, as described in the same paper, on page 185.

The rainfall measured in 1897 at Red Bluff and Sissons is shown in the table, page 539.



VALLEY OF CALIFORNIA

Scale, 50 miles to 1 inch

Photographic reduction of a portion of a relief map of California, exhibited in the California Building at the World's Columbian Exposition, Chicago, 1893, and now in the Art Building, Golden Gate Park, San Francisco, California.

This relief map was prepared as a portion of the California State exhibit, under the direction of Mr. Willard D. Johnson, hydrographer, United States Geological Survey. Six men were continuously employed in the work for thirteen months. The horizontal scale was four miles to an inch; the vertical scale, one mile to an inch. All official maps, and private sources of information of every description, were drawn upon for the data of relief. Forty-four thousand pins, measured in height to fiftieths of an inch, were used to represent this elevation data. Modeling was done in clay around these pins. The final relief map was cast in plaster and painted by hand. Its horizontal dimensions were nine by nineteen feet. The maximum relief was nearly four inches.

Rating table for Sacramento River at Jellys Ferry, California, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
5.0	3,300	7.6	10,400	10.5	19,450	17.0	47,200
5.2	3,820	7.8	11,000	11.0	21,000	17.5	50,050
5.4	4,340	8.0	11,600	11.5	22,750	18.0	52,900
5.6	4,860	8.2	12,200	12.0	24,500	18.5	55,850
5.8	5,380	8.4	12,800	12.5	26,500	19.0	58,800
6.0	5,900	8.6	13,420	13.0	28,500	19.5	61,800
6.2	6,420	8.8	14,060	13.5	30,600	20.0	64,800
6.4	6,940	9.0	14,700	14.0	32,700	21.0	71,000
6.6	7,480	9.2	15,340	14.5	34,850	22.0	77,400
6.8	8,040	9.4	15,980	15.0	37,000	23.0	84,000
7.0	8,600	9.6	16,620	15.5	39,500	24.0	90,800
7.2	9,200	9.8	17,260	16.0	42,000		
7.4	9,800	10.0	17,900	16.5	44,600		

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.		Depth in inches.	Second-feet per square mile.
1897.						
January	49,765	8,320	14,280	878,050	1.80	1.56
February	89,100	17,420	36,108	2,005,335	4.11	3.95
March	44,340	13,100	21,790	1,339,825	2.76	2.39
April	28,710	18,830	22,807	1,357,108	2.79	2.50
May	18,520	9,200	13,737	844,660	1.73	1.50
June	9,200	6,680	7,620	453,420	0.92	0.83
July	6,550	5,120	5,699	350,420	0.71	0.62
August	5,120	4,600	4,776	293,667	0.60	0.52
September	4,600	4,600	4,600	273,718	0.56	0.50
October	6,680	4,600	4,955	304,673	0.62	0.54
November	8,600	5,120	5,590	332,627	0.68	0.61
December	16,940	5,380	7,792	479,114	0 98	0.85
The year	89,100	4,600	12,480	8,912,617	18.26	1.36

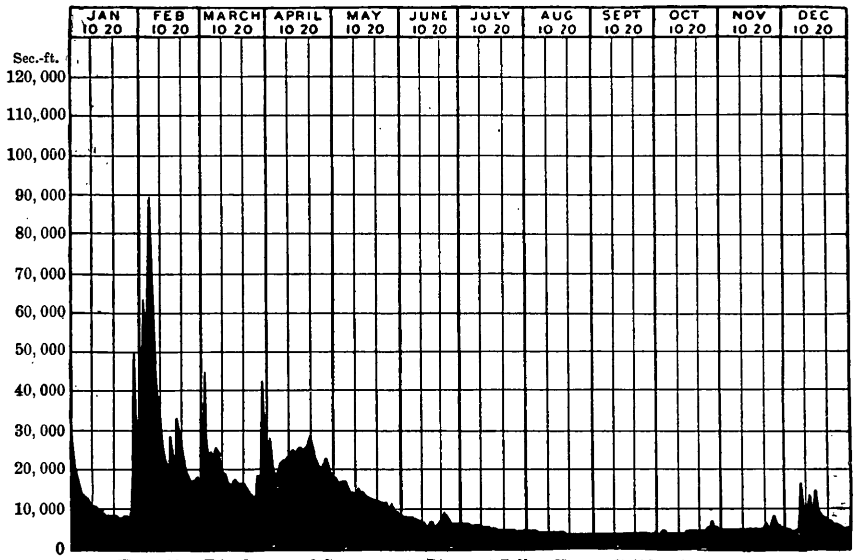


FIG. 182.—Discharge of Sacramento River at Jellys Ferry, California, 1897.

STANISLAUS RIVER.

The gaging station on this river is located at Oakdale, California, and is described in Water-Supply and Irrigation Paper No. 16, p. 187. The diversion from the Stanislaus which occurs through the Stanislaus and San Joaquin canal above Knights Ferry was measured a number of times during 1897. This canal divides at Knights Ferry, the smaller portion of the water being diverted into the Little John canal. The canal measurements made below the diversion of the Little John canal are as follows:

Measurements of flow in Stanislaus and San Joaquin Valley canal.

	Second-feet.
February 16	26
May 30	54
July 13	36
September 6	52
October 29	34
December 19	17

Measurements of flow in Little John canal.

February 16	13
May 30	12
July 13	15
September 6	1.3
October 29	0.7
December 19	3.6

The rainfall, as measured at Sonora in 1897, is shown in the rainfall table, on page 539.

Rating table of Stanislaus River at Oakdale, California, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.5	100	3.0	450	4.5	1,600	7.0	4,510
1.6	110	3.1	516	4.6	1,696	7.2	4,786
1.7	120	3.2	582	4.7	1,792	7.4	5,062
1.8	130	3.3	648	4.8	1,888	7.6	5,340
1.9	140	3.4	714	4.9	1,984	7.8	5,620
2.0	150	3.5	780	5.0	2,080	8.0	5,900
2.1	170	3.6	860	5.2	2,308	8.2	6,184
2.2	190	3.7	940	5.4	2,536	8.4	6,468
2.3	210	3.8	1,020	5.6	2,768	8.6	6,754
2.4	230	3.9	1,100	5.8	3,004	8.8	7,042
2.5	250	4.0	1,180	6.0	3,240	9.0	7,330
2.6	290	4.1	1,264	6.2	3,480	9.5	8,060
2.7	330	4.2	1,348	6.4	3,720	10.0	8,790
2.8	370	4.3	1,432	6.6	3,974	10.5	9,530
2.9	410	4.4	1,516	6.8	4,242	11.0	10,280

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.		Depth in inches.	Second-feet per square mile.
1897.						
January	2,251	410	609	37,446	0.67	0.58
February	10,580	1,264	3,252	180,607	3.23	3.10
March	5,062	1,264	1,915	117,750	2.10	1.82
April	9,234	1,880	5,064	301,328	5.37	4.81
May	9,980	5,480	7,324	450,338	8.04	6.97
June	3,974	860	2,077	123,590	2.21	1.98
July	1,180	250	582	35,786	0.63	0.55
August	230	170	198	12,175	0.22	0.19
September	190	140	152	9 045	0.16	0.14
October	250	140	176	10,822	0.20	0.17
November	780	170	255	15,174	0.27	0.24
December	1,516	210	411	25,272	0.45	0.39
The year	10,580	140	1,835	1,319,333	23.55	1.74

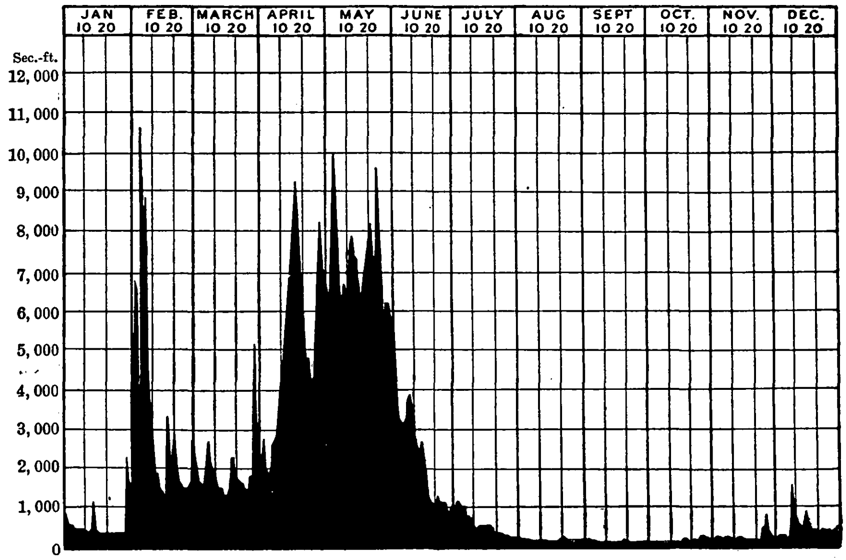


FIG. 183.—Discharge of Stanislaus River at Oakdale, 1897.

TUOLUMNE RIVER.

The upper gaging station on this river is located at the wagon bridge in the town of Lagrange, California, and is described in Water-Supply and Irrigation Paper No. 16, p. 188. The mining company's flume which diverts water from Tuolumne River, 7 miles above the station, was measured three times during the year. Its water returns to the river in part above the bridge and in part below the bridge, depending on the personal convenience of the miners. On May 29 this flume was carrying 22 second-feet; October 30, 6 second-feet; December 20, 34 second-feet. The rainfall was measured at Second Garotte and Crockers during 1897, as shown in rainfall table, page 539.

Discharge measurements were not made at the lower station at Modesto during 1897, on account of the poor character of the cross section. The bed of the river is shifting and the changing elevation of San Joaquin River, into which the Tuolumne discharges 16 miles below, changes the conditions of its grade and therefore modifies the discharge. A record of gage heights, however, was maintained by the Southern Pacific Company. The station is described in Water-Supply and Irrigation Paper No. 16, p. 189.

Rating table for Tuolumne River at Lagrange, California, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
3.5	40	4.6	390	5.7	1,840	7.6	6,680
3.6	52	4.7	480	5.8	2,060	7.8	7,240
3.7	64	4.8	570	5.9	2,280	8.0	7,800
3.8	76	4.9	660	6.0	2,500	8.2	8,400
3.9	88	5.0	750	6.2	3,020	8.4	9,000
4.0	100	5.1	880	6.4	3,540	8.6	9,600
4.1	140	5.2	1,010	6.6	4,060	8.8	10,200
4.2	180	5.3	1,140	6.8	4,580	9.0	10,800
4.3	220	5.4	1,270	7.0	5,100	9.5	12,300
4.4	260	5.5	1,400	7.2	5,620	10.0	13,800
4.5	300	5.6	1,620	7.4	6,140	10.5	15,300

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.		Depth in inches.	Second-feet per square mile.
1897.						
January	3,930	660	1,231	75,692	0.94	0.82
February	13,200	1,840	5,172	287,238	3.59	3.45
March	10,800	2,500	4,032	247,920	3.10	2.69
April	13,500	3,280	7,735	460,263	5.75	5.15
May	14,700	9,600	11,923	733,121	9.15	7.94
June	9,300	2,500	5,673	337,566	4.22	3.78
July	4,840	480	2,181	134,105	1.67	1.45
August	570	76	237	14,573	0.18	0.16
September	140	28	86	5,117	0.07	0.06
October	750	76	222	13,650	0.17	0.15
November	3,540	260	768	45,699	0.57	0.51
December	4,060	570	1,104	67,883	0.85	0.74
The year	14,700	28	3,364	2,422,827	30.26	2.24

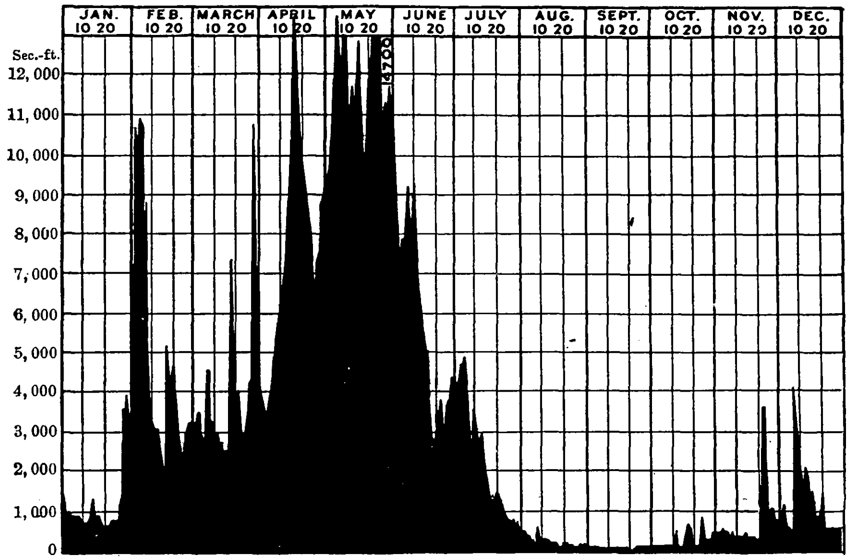


FIG. 184.—Discharge of Tuolumne River at Lagrange, California, 1897.

SAN JOAQUIN RIVER.

The main river basin comprises a considerable area that contributes little, if any, water to the river proper. This includes the greater portion of the eastern slope of the Coast Range; the area at the southern end of the valley; the drainage from the Tejon Mountains; and within recent years, since the development of irrigation, little water is contributed even from the large basins of Kern, Tule, Kaweah, and Kings rivers. The Herndon station is located above the point where the river joins the trunk stream in the central drainage line of the valley.

The irrigation development of the valley is thoroughly discussed by Mr. C. E. Grunsky in the papers, Irrigation near Bakersfield, California, Irrigation near Fresno, California, and Irrigation near Merced, California, published as Water-Supply and Irrigation Papers Nos. 17, 18, and 19.

A number of gaging stations were maintained during 1897 in the basin, as described in Water-Supply and Irrigation Paper No. 16, pp. 187–192, inclusive.

The gaging station on San Joaquin River is located at Herndon, 12 miles north of Fresno, California, on the line of the Southern Pacific, and is described in Water-Supply and Irrigation Paper No. 16, p. 190. The silt in the river affects paint in a rather unusual way, it being necessary to paint the rod twice a year. For this reason a float gage has been arranged with the indicator and painted rod entirely above the water line.

Rating table for San Joaquin River at Herndon, California, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.3	90	3.5	1,300	5.4	4,600	7.8	10,624
2.4	120	3.6	1,450	5.6	5,012	8.0	11,240
2.5	150	3.7	1,600	5.8	5,436	8.2	11,864
2.6	260	3.8	1,750	6.0	5,860	8.4	12,488
2.7	370	3.9	1,900	6.2	6,316	8.6	13,120
2.8	480	4.0	2,050	6.4	6,772	8.8	13,760
2.9	590	4.2	2,390	6.6	7,270	9.0	14,400
3.0	700	4.4	2,730	6.8	7,810	9.5	16,200
3.1	820	4.6	3,080	7.0	8,350	10.0	18,000
3.2	940	4.8	3,440	7.2	8,890	10.5	20,000
3.3	1,060	5.0	3,800	7.4	9,430	11.0	22,000
3.4	1,180	5.2	4,200	7.6	10,008		

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.		Depth in inches.	Second-feet per square mile.
1897.						
January	1,180	535	655	40,275	0.46	0.40
February	15,660	1,180	2,598	144,286	1.66	1.59
March	4,600	1,675	2,325	142,960	1.64	1.42
April	11,708	2,305	6,541	389,216	4.46	4.00
May	18,600	9,565	13,545	832,855	9.54	8.27
June	12,332	2,390	5,862	348,812	3.98	3.57
July	4,300	1,300	2,493	153,290	1.75	1.52
August	1,300	590	898	55,216	0.63	0.55
September	535	105	227	13,507	0.16	0.14
October	820	105	279	17,155	0.20	0.17
November	4,300	120	872	51,887	0.59	0.53
December	4,000	60	968	59,520	0.68	0.59
The year	18,600	60	3,105	2,248,979	25.75	1.90

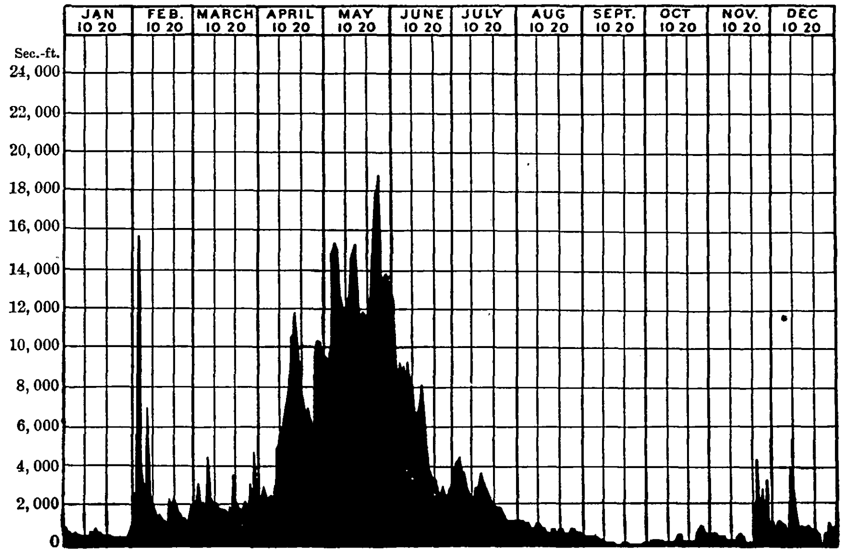


FIG. 185.—Discharge of San Joaquin River at Herndon, California, 1897.

ELECTRIC-POWER TRANSMISSION AT FRESNO, CALIFORNIA.

Three conditions in California urge the development of its latent water power and the long distance electric transmission of this force: First, the absence of local coal deposits and the consequent high price of that needed commodity; second, the average low relative humidity of the atmosphere, which permits a high order of insulation of the line and consequently high voltage or pressure in the current; third, the presence of high mountain ranges passing longitudinally through the State, resulting in numerous streams with very heavy gradients, which flow toward the fertile valleys of the State. The streams rising on the Sierra Nevada are supplied from banks of perpetual snow and furnish ideal power for the operation of electric machinery.

The coal used in southern California comes from Alaska, British Columbia, New Mexico, and even Australia, and the soft coals sell for from $6 to $10 per ton. This of course makes power very expensive and has greatly retarded the manufacturing progress of the State. For these reasons California has been for the past ten years the pioneer in the development and transmission of power and still retains this position.

One of the most interesting plants in the State is that of the San Joaquin Electric Company, which has located its power plant on the North Fork of San Joaquin River (Pl. L). The water is diverted without any weir directly into the flume, and this is fastened to the bed rock of the stream bed by leaded driftbolts. The conduit is 7 miles in length, 4,000 feet being flume and the remainder canal in earth and rock. The capacity is 70 second-feet, the flume having a grade of 3 feet in 1,000 and the canal 1 foot in 1,000. Waste gates are provided every 4,000 feet in the canal, and numerous sand boxes are used to catch the silt, which is very injurious to the wheels and nozzles. A reservoir site 800 feet from the canal line has been made tributary to the plant. Its capacity, with an earth dam 10 feet high by 500 feet long, is about 700 acre-feet, which is sufficient to run the canal for five days and is important in connection with headwork repairs.

The length of pressure pipe from the receiver to the wheels is 4,020 linear feet and the head is 1,411 feet. The pipe is in three sections: The first section, 1,820 feet long, is of riveted steel 24 inches in diameter; the second section, 400 feet long, is of converse lock-joint, lap-welded pipe, 20 inches in diameter, with leaded joints; the third section, 1,880 feet long, 20 inches in diameter, is lap-welded with flange joints bolted and made tight with rubber gaskets. The pipe in some cases is buried from 5 to 8 feet in the soil; in others it is anchored to bed rock, holes being drilled 5 feet into the rock and bolts set and sulphured therein. Semicircular yokes 2½ feet by five-eighths of an inch are placed over the top of the pipe and are screwed fast to the bolts. The pipe was laid in two sections, the closure being between the riveted and welded pipe. The opening between the ends varied between night and day from 7 feet to 7 feet 8 inches. The connection was made at night at the 7-foot opening and the pipe was then filled with water. The normal flow of water in the pipe is, with the present installation of wheels, at the velocity of 1.5 feet per second, but the nozzle velocity is 153 feet per second. It has been a serious matter to control this jet when it is deflected from the wheel. It tears to pieces any masonry put in its path, and when a water cushion is substituted it does not give satisfaction, as the water is thrown out of it in every direction. Covering the pit did not prevent the exit of the water from its top and sides. The final method adopted to check the jet when it is deflected from the wheel is to place before it a chilled iron plate 3½ inches thick. When this is destroyed it is renewed. Because of the great head the ordinary valves and pressure regulator used were found to be inefficient, and the devices finally adopted consisted rather of arrangements to prevent the sudden opening and closing of valves. At one time a pipe valve was opened at the power house when the wheel nozzle was off, the engineer having forgotten that he had removed it. The pipe was emptied faster than it could be filled, and a vacuum was produced, resulting in the collapse of several hundred feet of the pipe, which was flattened as if it had been rolled out.

The wheel used is a 60-inch Pelton water wheel of the "impulse" type, coupled directly to the shaft of the dynamo. On the same shaft is a fly wheel weighing 6,000 pounds. The cups resemble a W in section, the jet striking the central apex, upon which it splits, expending its force on the back of the cups, and theoretically falling as "dead water" on each side of the wheel. The backs of the cups are not angular, but rounded. The efficiency of wheels of this type is from 80 to 90 per cent. Pl. LI shows the water wheels and fly wheels mounted on their shafts. The receiver of the pipe line was not in position when this photograph was taken. It is located above the wheels, and the nozzles are attached to its bottom. One of the detached nozzles is shown on the upper right-hand side. As already stated, the dynamos (shown in Pl. L, *B*) and the water wheels are attached to the same shaft. There are three General Electric multi-polar, three-phase generators, delivering a current at 700 volts to the low-potential switch board, whence it is carried to nine 125-kilowatt transformers which step up the current to 11,200 volts for the line. The poles are 12 by 12 inches at the butt and 6 by 6 inches at the top, set 120 feet apart in the valley and 100 feet apart on the mountain side. They vary from 35 to 40 feet in length. The transmission circuits consist of two triplex, three-wire sets, which may be used independently or together. All wires are of No. 3 Browne & Sharp soft-drawn copper. Triple petticoat porcelain insulators are used. The line is 35 miles long. The company charges the city of Fresno $6.45 per month for each 2,000-candlepower lamp burning all night every night in the month. Power is sold at $64 per horsepower per annum, twenty-four hours a day. Meter service is 15 cents per kilowatt, with discounts up to 25 per cent for large consumers. Power and light are sold for all general purposes.

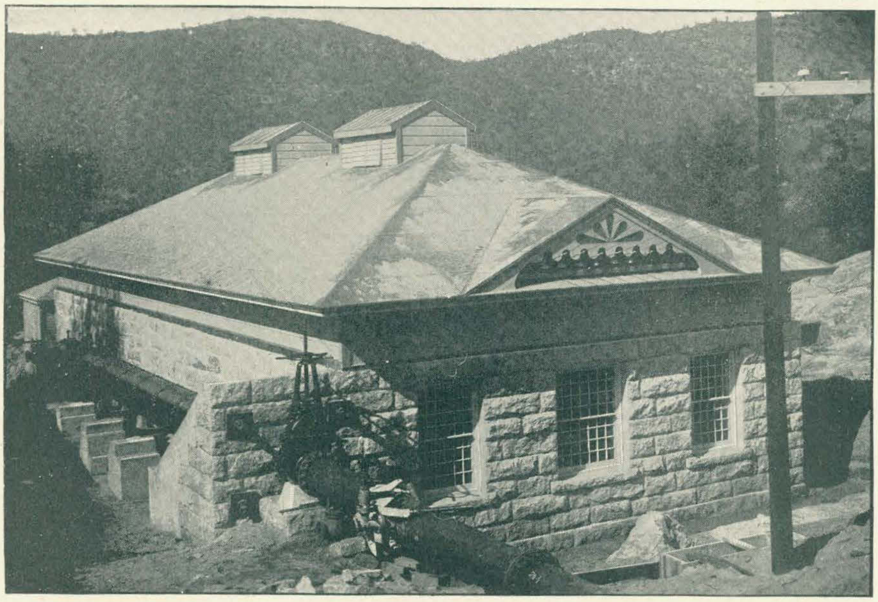
The line has been continued to Hanford, which makes a total length of 69 miles. Power will be transmitted to this point at 19,500 volts, and the loss by line transmission, it is said, will be from 5 to 8 per cent. Over 150 horsepower will be transmitted.

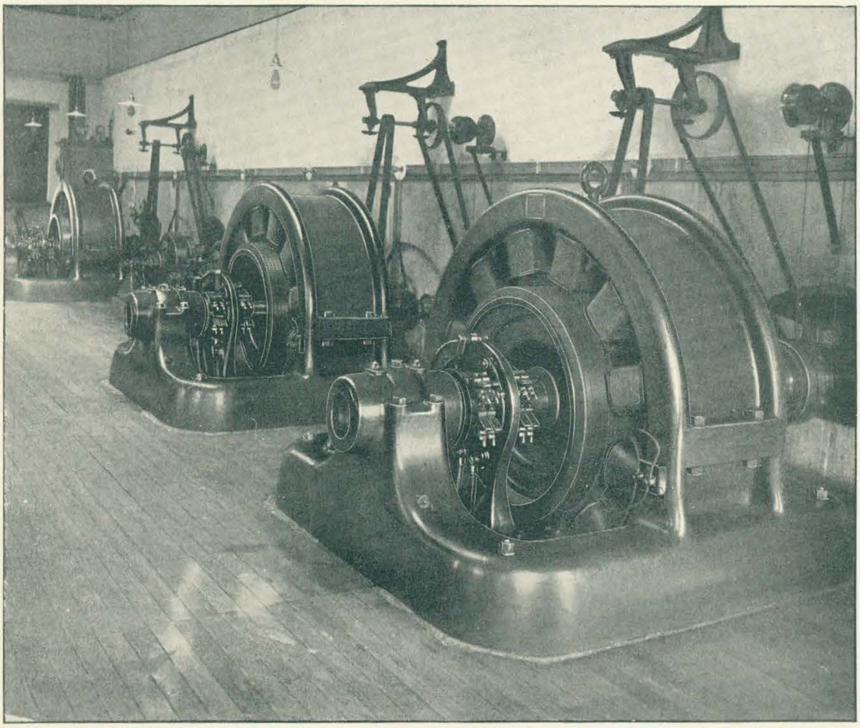
KINGS RIVER.

Two stations have been maintained on this river during 1897. The upper station is located 15 miles east of Sanger, California, and southwest of Red Mountain, above all canal diversions, and is described in Water-Supply and Irrigation Paper No. 16, p. 191.

Rating table for Kings River at Red Mountain, California, 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
4.0	320	5.1	844	7.2	2,808	9.4	7,136
4.1	360	5.2	908	7.4	3,096	9.6	7,716
4.2	400	5.4	1,036	7.6	3,400	9.8	8,348
4.3	440	5.6	1,170	7.8	3,720	10.0	8,980
4.4	480	5.8	1,310	8.0	4,040	10.5	10,980
4.5	520	6.0	1,450	8.2	4,408	11.0	13,520
4.6	572	6.2	1,642	8.4	4,776	11.5	16,720
4.7	624	6.4	1,834	8.6	5,184	12.0	20,060
4.8	676	6.6	2,048	8.8	5,632	12.5	23,400
4.9	728	6.8	2,284	9.0	6,080		
5.0	780	7.0	2,520	9.2	6,608		





POWER HOUSE AND DYNAMOS OF SAN JOAQUIN ELECTRIC COMPANY, CALIFORNIA.

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.		Depth in inches.	Second-feet per square mile.
1897.						
January	624	360	437	26,870	0.29	0.25
February	6,344	1,100	1,631	90,581	0.96	0.92
March	4,408	1,240	1,884	115,843	1.22	1.06
April	9,380	1,930	5,318	316,442	3.33	2.99
May	22,732	6,344	14,470	889,731	9.40	8.15
June	10,580	2,520	6,145	365,652	3.87	3.45
July	4,040	1,036	2,177	133,859	1.41	1.22
August	1,100	440	739	45,440	0.47	0.42
September	480	250	329	19,577	0.20	0.18
October	572	270	394	24,226	0.25	0.22
November	2,520	360	692	41,177	0.44	0.39
December	8,348	572	985	60,566	0.63	0.55
The year	22,732	250	2,933	2,129,964	22.47	1.65

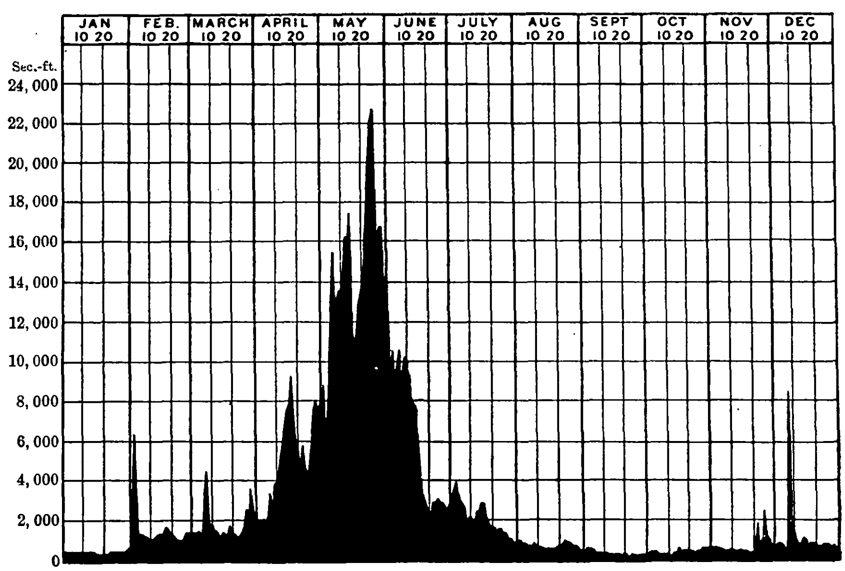
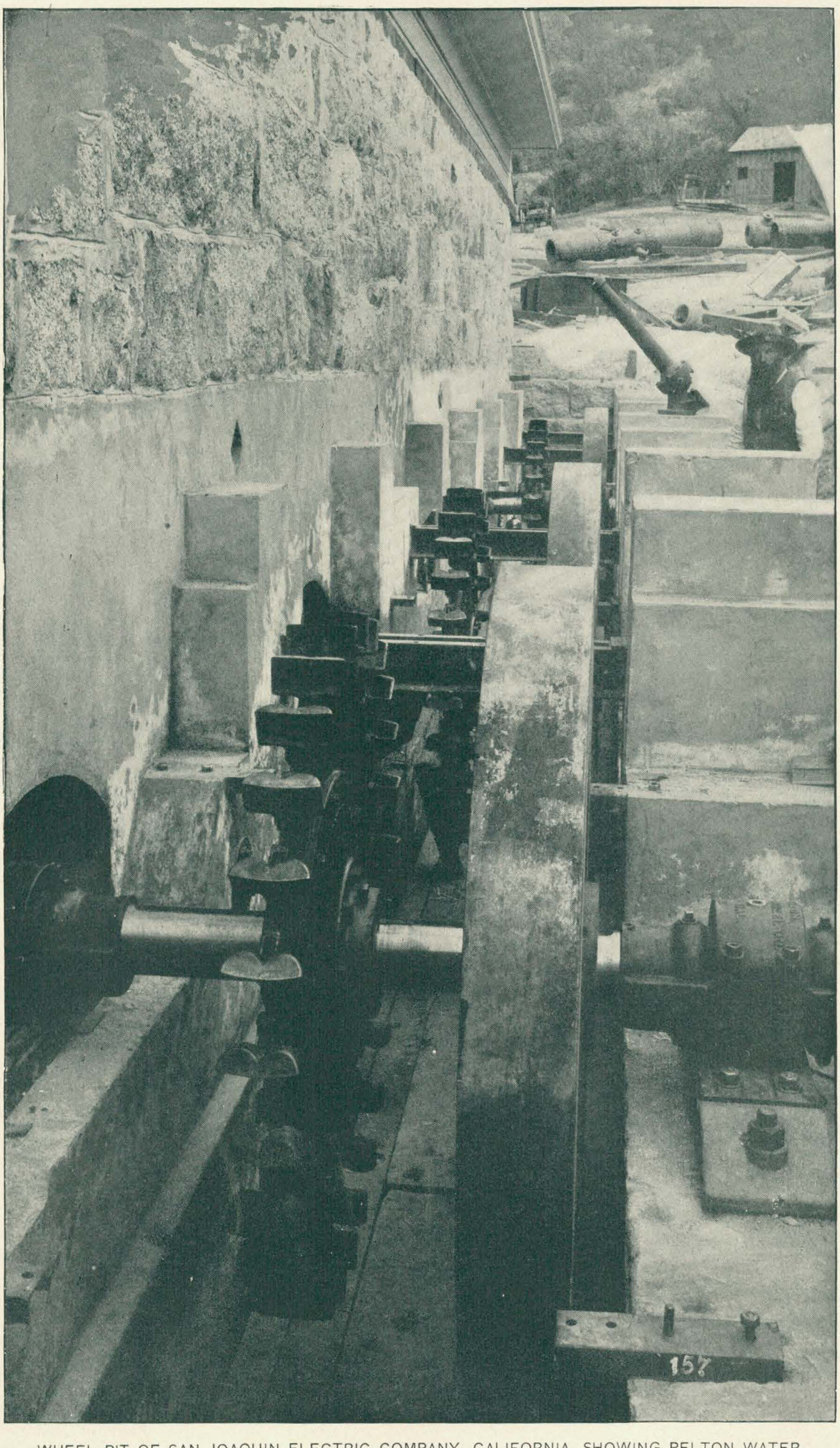


FIG. 186.—Discharge of Kings River at Red Mountain, California, 1897.

The lower station on Kings River is located at Kingsburg and is described in Water-Supply and Irrigation Paper No. 16, p. 192. The channel at the railroad bridge, where discharge measurements were first made, is sandy and shifting, and it has been found necessary to employ a somewhat different method in estimating the daily discharges. Measurements subsequent to April 7, 1897, were made 2 miles above the railroad bridge, at Clarke's bridge, which crosses the river in one span.

It was found that no consistent relation could be established between volumes discharged and rod heights because of the shifting nature of the river channel. Soundings have been taken every two weeks at the railroad bridge to determine the areas of cross section, the height of water on the gage rod being noted at the time of sounding. From these records it has been determined whether the bed of the stream has risen or fallen during the two weeks, and to what extent. For instance, if between June 1 and June 15 the stream bed has lowered 140 square feet, it is assumed that the section increased in area at the rate of 10 square feet a day, irrespective of river heights on the gage rod. The rise and fall of the river surface is then considered, and from these two factors a table of daily areas of cross section is obtained. The area of section at Kingsburg is noted for each measurement that has been taken either at Clarke's bridge or at Kingsburg, and curves have been plotted in terms of areas of cross section and volumes discharged, as shown in fig. 187. These curves are much more satisfactory than the curve showing the relation of river heights and discharge. The rating table is in terms of areas of cross section and discharges instead of the ordinary table of gage heights and discharges.

It was discovered during the summer of 1898 that a diversion dam 2 miles below the Kingsburg gage rod was affecting the grade of the river at the gage, and consequently the corresponding volume, by means of the opening and closing of the head gates. It is therefore obviously impossible to compute a record that is accurate for this station. The individual meter measurements should be correct, but the table of monthly discharge must be considered only as approximate and as the best obtainable under the circumstances.



WHEEL PIT OF SAN JOAQUIN ELECTRIC COMPANY, CALIFORNIA, SHOWING PELTON WATER WHEELS AND FLY WHEELS.

List of discharge measurements made on Kings River at Kingsburg, California.

No.	Date.	Hydrographer.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
	1895.			*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
1	Jan. 10	A. P. Davis	24	6.00	1,985	0.92	1,830
2	Mar. 23	J. B. Lippincott	24	4.10	1,273	0.39	500
3	Dec. 12	.....do	63	3.3	1,027	0.40	366
	1896.						
4	Apr. 11	J. A. Vogleson	63	5.70	2,047	0.92	1,883
	1897.						
5	Feb. 11	J. B. Lippincott	67	5.58	1,903	0.47	905
6	Apr. 6	.....do	67	5.20	1,649	0.61	825
7	June 3	.....do	67	8.6	*a* 3,347	2.70	*a* 5,959
8	July 17	A. Q. Campbell	67	5.02	1,737	0.34	503
9	Sept. 10	.....do	67	3.2	961	0.177	221
10	Nov. 3	.....do	67	4.84	1,557	0.34	465
11	Dec. 23	J. B. Lippincott	67	4.8	1,666	0.38	522

a Estimated.

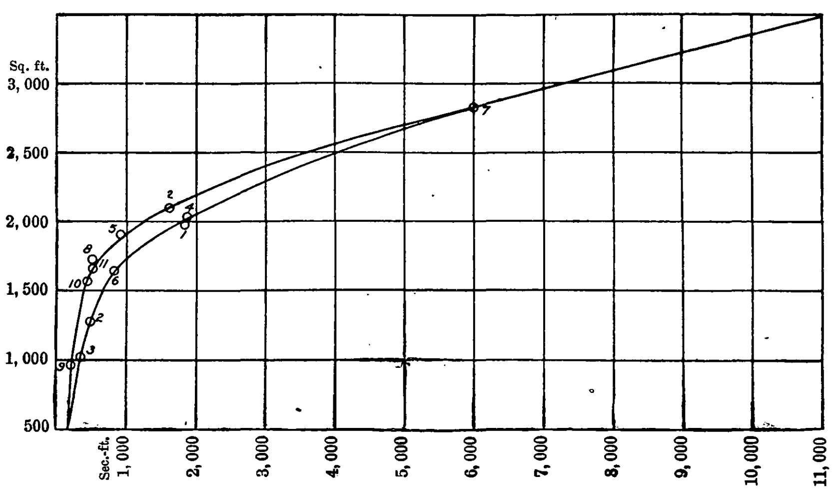


FIG. 187.—Rating curve for Kingsburg station on Kings River, California.

Rating table for Kings River at Kingsburg, California.

Applicable from May 1, 1896, to April 30, 1897.		Applicable from May 1 to December 31, 1897.	
Area.	Discharge.	Area.	Discharge.
Square feet.	*Second-feet.*	*Square feet.*	*Second-feet.*
500	200	500	180
1,000	340	1,000	220
1,500	660	1,500	410
2,000	1,800	2,000	1,280
2,500	4,080	2,500	3,550
3,000	7,290	3,000	7,300
3,500	11,160	3,500	11,150
4,000	15,040	4,000	15,010
4,500	18,900	4,500	18,860
....	....	5,000	22,710

Estimated monthly discharge of Kings River at Kingsburg, California.

[Drainage area, 1,742 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1896.						
May	20,147	408	3,945	242,569	2.61	2.26
June	19,670	3,225	11,652	693,342	7.46	6.69
July	4,239	452	1,942	119,408	1.28	1.11
August	549	400	465	28,567	0.31	0.27
September	641	420	476	28,294	0.30	0.27
October	815	385	628	38,590	0.42	0.36
November	1,450	415	625	37,202	0.40	0.36
December	830	385	581	35,730	0.38	0.33
1897.						
January	805	350	520	31,974	0.35	0.30
February	8,420	690	1,841	102,244	1.10	1.06
March	12,000	580	1,569	96,475	1.04	0.90
April	7,050	665	3,043	181,072	1.95	1.75
May	18,900	4,910	11,360	698,504	7.52	6.52
June	10,690	644	4,354	259,080	2.79	2.50
July	775	230	460	28,284	0.30	0.26
August	305	208	228	14,019	0.15	0.13
September	222	210	216	12,853	0.13	0.12
October	615	215	350	21,520	0.23	0.20
November	2,850	278	676	40,225	0.44	0.39
December	3,440	433	765	47,038	0.50	0.44
The year	18,900	208	2,115	1,533,288	16.50	1.21

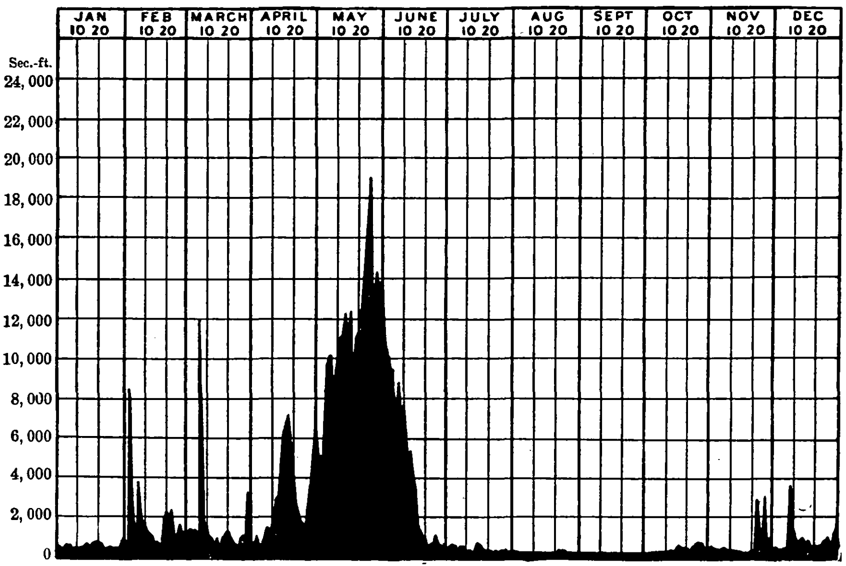


FIG. 188.—Discharge of Kings River at Kingsburg, California, 1897.

KERN RIVER.

Kern River during 1897 has been measured at a point 7 miles northeast of the town of Bakersfield and 12 miles below the mouth of the canyon, the drainage area being 2,345 square miles. This station was originally established in 1893 by the Kern County Land and Water Company, Walter James being chief engineer and A. K. Warren hydrographer. The results are given by the land company for publication. The method of procedure is described in the Eighteenth Annual Report, Part IV, p. 395. The river is measured with meters once a week or oftener. A clock-registering gage gives continuous river heights. The relation of velocity to hydraulic mean radii is determined by the meter observations, and from this base the discharge is figured. The work has been carried on with care and skill. The records of rainfall for Kernville and Mount Breckenridge are given in the table on page 539.

Estimated monthly discharge of Kern River at Bakersfield, California.

[Drainage area, 2,345 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1896.						
January	3,101	377	747	45,931	0.37	0.32
February	798	559	617	35,489	0.28	0.26
March	2,089	652	951	58,475	0.47	0.41
April	1,263	766	972	57,838	0.46	0.41
May	3,370	934	1,401	86,144	0.69	0.60
June	3,611	1,244	2,456	146,142	1.17	1.05
July	2,210	741	1,316	82,762	0.66	0.57
August	741	353	486	29,883	0.24	0.21
September	473	234	304	18,089	0.14	0.13
October	425	223	267	16,417	0.13	0.11
November	416	288	355	21,124	0.17	0.15
December	426	313	347	21,336	0.17	0.15
The year	3,611	223	854	619,630	4.95	0.36
1897.						
January	832	305	373	22,935	0.18	0.16
February	2,306	516	809	44,930	0.36	0.35
March	2,044	688	923	56,753	0.45	0.39
April	4,410	1,094	2,914	173,395	1.38	1.24
May	5,342	4,054	4,580	281,613	2.25	1.95
June	4,352	1,289	2,309	137,395	1.09	0.98
July	1,536	644	1,006	61,857	0.49	0.43
August	671	338	469	28,838	0.23	0.20
September	363	260	295	17,554	0.14	0.13
October	441	278	340	20,906	0.17	0.15
November	477	289	355	21,124	0.17	0.15
December	1,023	327	422	25,948	0.21	0.18
The year	5,342	260	1,234	893,248	7.12	0.53

POWER PLANTS ON KERN RIVER.

One of the interesting features of the development of water power in the southwest is the number of times the same water is used. As an example, Kern River, rising from the crest of the Sierras at Mount Whitney, is to be made to serve a double purpose. The Kern River and Los Angeles Electric Power Company, of Los Angeles, proposes to harness the North Fork of this river near its mouth and to convey the power thus generated a distance of 108 miles to the city of Los Angeles. Similar plans are prepared for the South Fork of this river. Below the junction of these two branches the main river passes through a narrow canyon on its journey to San Joaquin Valley, falling 2,000 feet in a distance of 40 miles. Near the mouth of this canyon the Kern Valley Power Development Company, as noted in the Eighteenth Annual Report, Part IV, p. 396, diverts a portion of this water into a flume having a capacity of 170 second-feet, and obtains a head of 193 feet, which, with the present installment, is used in generating about 1,500 horsepower. The water is then all diverted into San Joaquin Valley for irrigation near Bakersfield, a portion being lost by surface evaporation in the fields, but the remaining portion percolating into the ground. In the lower elevations this has caused the water plane to rise uncomfortably near the surface. Pumping plants are now being put in, to be operated by electric power, to raise this water and again distribute it for irrigation purposes as desired.

The midsummer flow of Kern River seldom falls below 200 second-feet at the mouth of the canyon, so that this company is assured of a permanent supply of water sufficient to fill its flume of 170 second-feet capacity. The diversion is without a weir, directly from the bed of the river, the flume projecting into the bed of the canyon and anchored there. It appears that this vital point is subject to attack from the stream when in flood, especially when bowlders are being rolled down its bed. The diversion conduit is all flume and is 8,500 feet in length. The flume is 5 feet 10½ inches by 8 feet in the clear, and laid on a 1 per cent grade. It is intended to carry water to a depth of 5 feet. It is remarkable for the small amount of lumber used in its construction. (See Pl. LII, *A*.) The cost per linear foot exclusive of excavation was about $3.50. From the illustration (Pl. LII, *B*) it will be seen that the construction was on a very rough hillside. The bench on which the flume rests is from 5 to 8 feet in width. Material for construction was lifted by cable to the bench at the lower end of the line near the power house and from there the structure was built progressively. At first the material was drawn on cars through the bottom of the flume. This tramway was abandoned in favor of a track on a deck of 2-inch plank, placed on the top of the flume. A curve of 25 feet radius is the only one used on the flume. The sides and bottom are constructed of 1-inch redwood boards lined with asphalt-coated building paper, the ends of which are lapped and set with liquid asphalt. This is again lined with ½-inch boards. The floor, which was cut by templets at the mill to fit the curves of the line, was first placed on the sills. The lower side boards were next nailed to the sides of the floor boards. The posts were erected by spiking them to the sides of the 4 by 6 inch sills. The asphalt paper is folded to fit the corners. The inner board of the post covers all vertical joints of the sides. The side boards are all sprung to curve, thus making the flume free from angles.

In order to avoid excavation on the steep hillsides, the bench being narrow, side braces were not put on the posts, but one-half inch iron rods were substituted. They pass directly through the flume 16 inches above the floor.

The flume is impervious except where these rods pass through. The flowing water sets them in vibration and starts leaks where they pass through the sides. Débris of all sorts collects on the rods and interferes with the flow. The character of the sides of the canyon is shown in Pl. LII, *A*. Rains cause the rocks on the side hill to roll or slide down upon the flume, causing serious wrecks. The flume has been cut a number of times in this way, though the 2-inch plank platform top is sufficient to break the force of many of the smaller stones. The interruption of a power plant is most undesirable, and probably it will be found necessary to tunnel through the points of the hills to escape these slides.

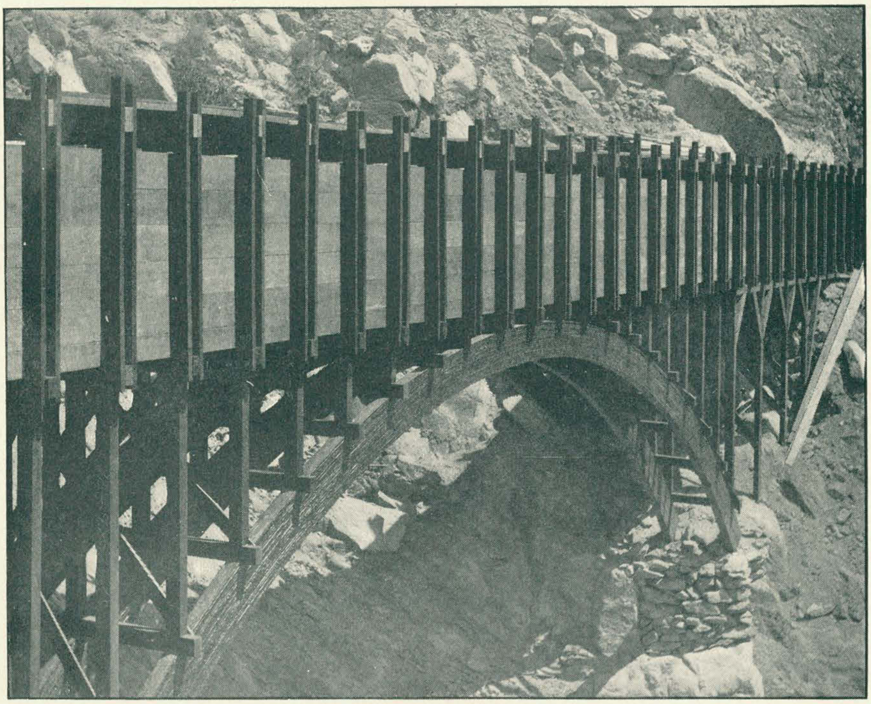
The pressure pipe is shown on Pl. LII, *B*. It is of the double-riveted type generally used in the Southwest. It is 66 inches in diameter and ranges in thickness from 0.203 to 0.375 inch. It provides a head of 193 feet. The pipe is banked upon the sides with a dry rock wall and is anchored with cables to bed rock to stop the daily travel of the pipe from side to side, toward the passing sun. It was found that the water falling into the penstock produced a vibration in the pipe, and this was obviated by covering the first 50 feet with masonry.

Girard water wheels were installed at first. Two wheels were placed on one shaft, and the water entering between them is divided and delivered by impulse against cups set on the inside of the circumference of the wheel. The stream, therefore, near the nozzle is not only split but made to turn two 90-degree angles before its delivery. Eighty-five per cent efficiency of the wheels was guaranteed and about 50 per cent obtained.. One of the Girard wheels was taken out and a Tuttle put in, which is also said to have proved unsatisfactory. An S. N. Knight wheel was then tried and gave an efficiency of from 75 to 80 per cent. The other Girard wheels will be replaced with Knight wheels.

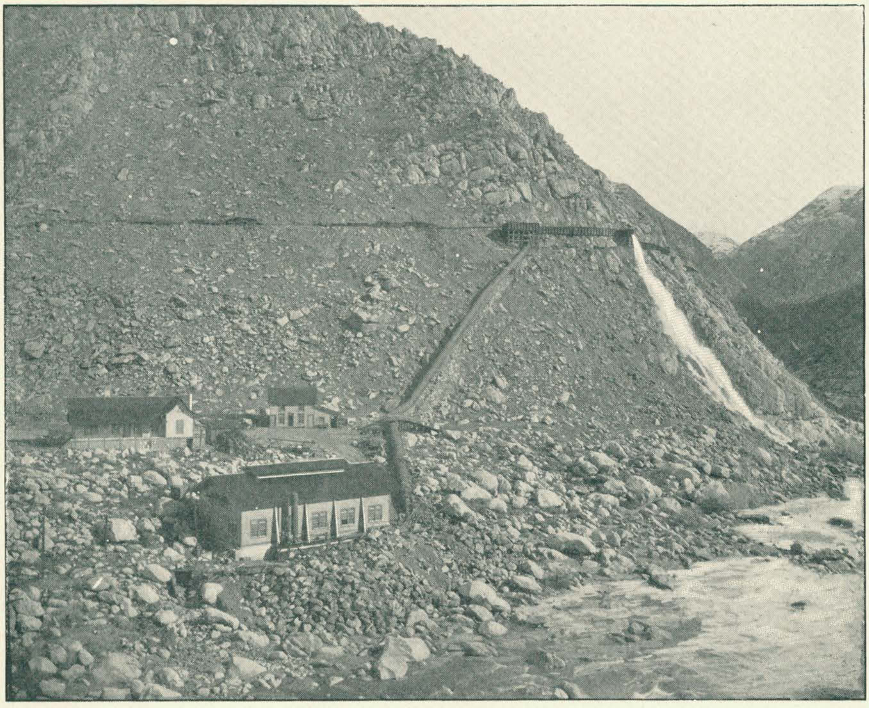
General Electric 450-kilowatt three-phase generators are attached to the wheel shaft. The current is developed at 500 volts and stepped up to 10,000 volts and so conveyed to the town of Bakersfield, where it is stepped down and distributed for power and light. The line is 12 miles long, and 7.5 per cent is lost in transmission.

LITTLE ROCK CREEK.

The drainage basin of this stream lies north of that of the San Gabriel and on the opposite side of the range, the waters discharging northerly into Mohave Desert, east of the Southern Pacific and about 35 miles west of Mohave River. The point of measurement



A. FLUME OF KERN VALLEY POWER DEVELOPMENT WORKS, CALIFORNIA.



B. POWER HOUSE ON KERN RIVER, CALIFORNIA.

is described in the Eighteenth Annual Report, Part IV, p. 402. The following rating table has been applied to the record of daily height given in Water-Supply and Irrigation Paper No. 16, p. 193. From these data the monthly discharges have been estimated.

Rating table for Little Rock Creek at Palmdale, California, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.0	0	0.8	19	1.6	54	2.4	96
0.1	0.5	0.9	23	1.7	59	2.5	102
0.2	2	1.0	27	1.8	64	2.6	108
0.3	4	1.1	31	1.9	70	2.7	114
0.4	6	1.2	35	2.0	75	2.8	120
0.5	9	1.3	39	2.1	80	2.9	126
0.6	12	1.4	44	2.2	86	3.0	132
0.7	15	1.5	49	2.3	91		

Estimated monthly discharge of Little Rock Creek at Palmdale, California.

[Drainage area, 78 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	144.0	4.0	14.0	879.0	0.211	0.183
February	308.0	15.0	52.0	2,894.0	0.696	0.668
March	120.0	41.0	68.0	4,187.0	1.007	0.873
April	120.0	75.0	106.0	6,284.0	1.511	1.354
May	77.0	8.0	36.0	2,189.0	0.526	0.456
June	7.0	3.0	6.7	399.0	0.095	0.086
July	1.0	0.2	0.4	22.1	0.005	0.005
August	0.2	0.2	0.2	12.3	0.003	0.003
September	0.2	0.2	0.2	11.9	0.003	0.003
October	7.0	0.2	5.5	338.0	0.082	0.071
November	8.0	6.0	6.9	411.0	0.098	0.088
December	6.0	5.0	5.7	350.0	0.084	0.073
The year	308.0	0.2	25.0	17,977.0	4.311	0.322

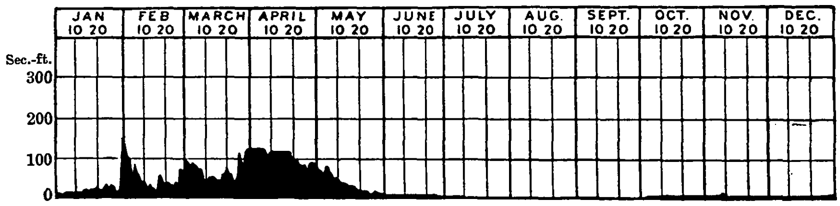


FIG. 189.—Discharge of Little Rock Creek at Palmdale, California, 1897.

SAN GABRIEL RIVER.

The drainage basin of this stream lies on the south side of the Sierra Madre Range, northwest of San Bernardino and northeast of Los Angeles, but slightly nearer the latter city. The tributary streams converge to a central point within the mountains and the stream flowing southwesterly escapes through a narrow canyon to the low valley, in which is situated a number of important towns, each depending largely upon the supply of water derived from the river. The locality at which measurements have been made is described fully in the Eighteenth Annual Report, Part IV, on pages 405 to 411, and later details are given in Water-Supply and Irrigation Paper No. 16, on page 194. The results of computations for 1897 are given in the following tables:[1]

Rating table for San Gabriel River at Azusa, California, for 1897.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.6	0.0	1.6	16.0	2.6	155	4.2	890
0.7	0.1	1.7	21.2	2.7	185	4.4	1,040
0.8	0.3	1.8	27.5	2.8	214	4.6	1,210
0.9	0.6	1.9	36	2.9	243	4.8	1,395
1.0	1.3	2.0	46	3.0	275	5.0	1,600
1.1	2.3	2.1	59	3.2	345	5.2	1,820
1.2	4.0	2.2	73	3.4	420	5.4	2,080
1.3	6.0	2.3	90	3.6	520	5.6	2,340
1.4	8.8	2.4	108	3.8	625		
1.5	12.0	2.5	130	4.0	750		

[1] A flood occurred on the night of October 14, 1897, which rapidly subsided. The water marks and drift indicate that the water stood at a height of 5 feet, corresponding to a discharge of 1,600 second-feet.

Estimated monthly discharge of San Gabriel River at Azusa, California.

[Drainage area, 222 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	130	5	40	2,484	0.201	0.181
February	1,710	46	332	18,420	1.555	1.494
March	1,765	275	448	27,572	2.329	2.020
April	345	141	259	15,417	1.301	1.166
May	141	28	82	5,042	0.420	0.369
June	28	0.2	5	274	0.024	0.021
July	0	0	0	0	0.000	0.000
August	0	0	0	0	0.000	0.000
September	0	0	0	0	0.000	0.000
October	1,600	0	72	4,458	0.372	0.322
November	15	0.4	8	475	0.040	0.036
December	5	3.0	4	221	0.018	0.016
The year	1,765	0	104	74,302	6.260	0.469

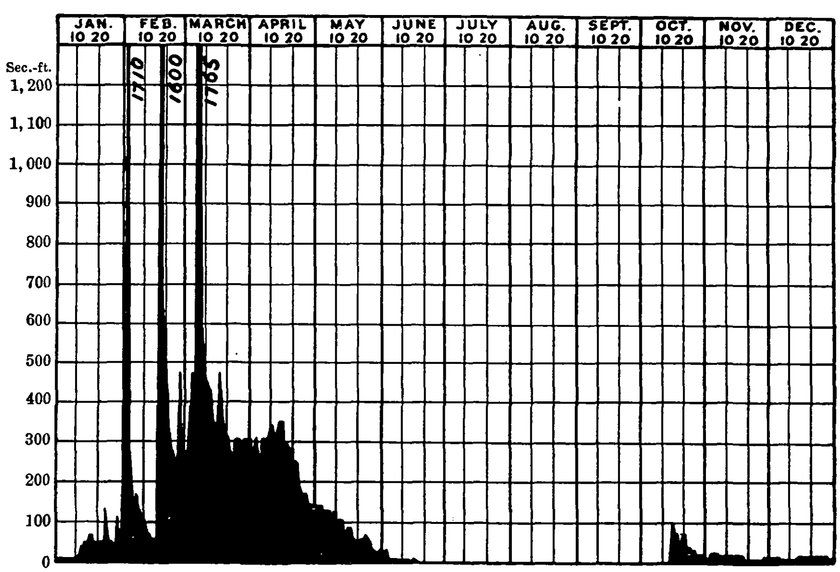


FIG. 190.—Discharge of San Gabriel River at Azusa, California, 1897.

Rating table for San Gabriel canals at division box.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
2.00	14.8	2.45	37.4	2.90	62.4
2.05	17.2	2.50	40.1	2.95	65.2
2.10	19.6	2.55	42.8	3.00	68.0
2.15	22.0	2.60	45.6	3.05	70.8
2.20	24.4	2.65	48.4	3.10	73.6
2.25	26.8	2.70	51.2	3.15	76.4
2.30	29.3	2.75	54.0	3.20	79.2
2.35	32.0	2.80	56.8		
2.40	34.7	2.85	59.6		

Rating table for Azusa canal at Slaughter House tunnel.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
.0	0.0	1.1	10.5	2.2	32.6
.1	0.6	1.2	12.0	2.3	35.3
.2	1.3	1.3	13.6	2.4	38.2
.3	2.0	1.4	15.2	2.5	41.3
.4	2.8	1.5	17.0	2.6	44.4
.5	3.7	1.6	19.0	2.7	47.6
.6	4.6	1.7	21.0	2.8	51.0
.7	5.5	1.8	23.0	2.9	54.5
.8	6.5	1.9	25.2	3.0	58.0
.9	7.7	2.0	27.5		
1.0	9.0	2.1	30.0		

Estimated monthly discharge of San Gabriel canals at Azusa, California.

Month.	Maximum.	Minimum.	Mean.	Total for month.	Run-off.	
					Depth.	Per square mile.
1897.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Inches.*	*Sec.-feet.*
January	22	13	17.56	1,072	.091	.079
February	20	3	13.10	726	.061	.059
March	21	0	17.14	1,051	.089	.077
April	60	15	35.30	2,102	.177	.159
May	68	55	62.97	3,810	.328	.284
June	71	54	63.20	3,759	.317	.285
July	52	27	38.13	2,343	.197	.171
August	34	22	26.45	1,613	.136	.118
September	23	18	20.66	1,226	.098	.088
October	26	10	18.03	1,106	.093	.081
November	29	16	23.30	1,385	.109	.105
December	29	25	26.84	1,648	.139	.121
The year	71	0	30.20	21,831	1.835	.136

Estimated monthly discharge of San Gabriel River and canals at Azusa, California.

[Drainage area, 222 square miles.]

Month.	Maximum.	Minimum.	Mean.	Total for month.	Run-off.	
					Depth.	Per square mile.
1897.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Inches.*	*Sec.-feet.*
January	147	25	57.9	3,617	.292	.260
February	1,713	64	344.8	19,146	1.579	1.553
March	1,765	294	465.6	28,623	2.418	2.097
April	370	201	294.4	17,519	1.478	1.325
May	196	94	145.0	8,851	.748	.653
June	91	54	67.8	4,033	.341	.306
July	52	27	38.1	2,343	.197	.171
August	34	22	26.4	1,613	.136	.118
September	23	18	20.7	1,226	.098	.088
October	1,640	22	90.5	5,564	.465	.403
November	34	31	33.3	1,860	.149	.141
December	34	28	30.5	1,875	.158	.137
The year	1,765	18	134.6	96,270	8.059	.604

SAN LUIS REY RIVER.

The drainage basin of this stream is in the northern part of San Diego County, California, on the west side of the Coast Range. The main stream flows west, descends rapidly, and passes out through a gap in the main range, at which point the greater part of the stream is diverted for purposes of irrigation. Measurements have been made at this point by Mr. E. F. Tabor, of Escondido, California, estimates for 1894 and 1895 having been published in Bulletin of the United States Geological Survey, No. 140, on page 321. This point of measurement is in sec. 23, T. 10 S., R. 1 E. From this point the river continues westerly and empties into the Pacific Ocean at a point about 35 miles north of the city of San Diego.

The area of the basin above the point of diversion, as measured on the county map, is 229 square miles. The total area of the watershed is 566 square miles. Of this, 250 square miles is at an elevation of 3,000 feet and over; 200 square miles, at from 1,000 to 3,000 feet; and the remainder is below the altitude of 1,000 feet.[1]

Water is diverted from the river through the flume of the Escondido irrigation district to a reservoir which is used to store and regulate the flow of the water. The capacity of this conduit is 28 second-feet. The water is ultimately used on the lands of the district. An excellent reservoir site is situated on the stream a few miles above the point of diversion, but its use has been prevented by difficulties as to land title.

The results given in the following table are based on weir readings, supplemented by a few measurements made at various times. The gaps in the record impair its value somewhat, but the figures indicate in a general way the character of the stream. The relatively low run-off is due largely to the fact that a considerable portion of the basin lies behind the main portion of the mountain range.

Estimates of discharge of San Luis Rey River, and depth of rainfall.

[Measurements made on weir in flume, except as noted.]

Date.	Flow.	Rainfall.	Date.	Flow.	Rainfall.
1896.	*Second-feet.*	*Inches.*	1896.	*Second-feet.*	*Inches.*
October 1 to 26	0.5 to 2	....	November 6 to 9	3	....
October 27	7	2.50	November 10	4	.25
October 28	10	....	November 11 to 12	5	....
October 29	8	....	November 13	4	....
October 30	4	....	November 14	3	....
November 1 to 2	3	....	November 15	2	....
November 3 to 5	2	....	November 16	3	....

[1] Irrigation in Southern California, by Wm. Ham. Hall, Sacramento, 1888, p. 38.

Estimates of discharge of San Luis Rey River, and depth of rainfall—Continued.

Date.	Flow.	Rainfall.	Date.	Flow.	Rainfall.
1896.	*Second-feet.*	*Inches.*	1897.	*Second-feet.*	*Inches.*
November 17 to 19	2	....	January 27	21	....
November 20 to 23	3	....	January 28	19	....
November 24	7	.92	January 29	24	.25
November 25	17	....	January 30	30	....
November 27 to 29	7	....	January 31	33	....
November 30	5	....	February 1	*e* 28	.85
December 1 to 8	5	....	February 2 to 9	*e* 33 to 35	....
December 9 to 10	4	....	February 10	*f* 24	....
December 11 to 14	5	....	February 11 to 14	21	....
December 15	*a* 40	1.30	February 15 to 16	19	....
December 16	13	....	February 17	21	.90
December 17	9	....	February 18	29	1.30
December 18	8	....	February 19	(*d*)	.90
December 19	7	....	February 20	(*d*)	2.00
December 20	6	....	February 21	(*d*)	.45
December 21 to 24	5	....	February 24	*g* 300	....
December 25 to 27	4	....	Feb. 24 to Mar. 30	20 to 40	....
December 28	13	.80	March 1	....	.85
December 29	*b* 19	....	March 3	....	.55
December 30	10	....	March 6	....	1.30
December 31	7	....	March 7	....	.70
1897.			March 17	....	.50
January 1 to 2	7	....	March 19	....	.35
January 3 to 6	6	....	March 28	....	.30
January 7 to 9	5	....	April 1 to 10	(*h*)	....
January 10	10	.35	April 3	*i* 79	....
January 11	18	.30	April 10	31	....
January 12	*c* 18	.35	April 11	26	....
January 13	21	1.20	April 12	31	....
January 14 to 18	(*d*)	1.55	April 13	35	....
January 19 to 20	*e* 22	....	April 14	33	....
January 21	*f* 24	....	April 15	28	....
January 22	21	....	April 16	27	....
January 23 to 26	19	....	April 17	24	....

a Estimate in river.
b Plus 19 second-feet in river. Total, 38 second-feet.
c Plus 19 second-feet in river. Total, 37 second-feet.
d No record on account of high water.
e Part only of river.
f All of river.
g Estimated discharge at a point some miles below. Ditch takes only a portion of flow from February 18 to April 10.
h There was no record of full flow at section 33.
i Measured discharge at a point several miles below.

Estimates of discharge of San Luis Rey River, and depth of rainfall—Continued.

Date.	Flow.	Rainfall.	Date.	Flow.	Rainfall.
1897.	*Second-feet.*	*Inches.*	1898.	*Second-feet.*	*Inches.*
April 18	24	....	January 29	22	....
April 19 to 20	22	....	January 30	19	....
April 21	*a* 21	....	January 31	16	....
May 17	*b* 11	....	February 1 to 3	16	....
December 2 to 5	4	....	February 4 to 5	15	....
December 6 to 8	3	....	February 6	13	....
December 9 to 15	2½	.20	February 7	15	.35
December 16	7	....	February 8	*f* 40	.20
December 17	6	....	February 9	*d* 22	....
December 18	10	1.05	February 10	19	....
December 20 to 21	10	....	February 11	17	....
December 25 to 27	9	....	February 12	15	....
December 28 to 30	8	....	February 13	12	....
December 31	6	....	February 14 to 16	10	....
1898.			February 17	13	.10
January 1 to 2	5	....	February 18	22	.05
January 3	9	.25	February 19	17	....
January 4	....	.20	February 20	13	....
January 5	6	....	February 21	12	....
January 6 to 7	8	.15	February 22 to 23	10	....
January 8	50	20.00	February 24 to 28	9	....
January 8 to 13	(*c*)	....	March 1 to 9	8	....
January 14	*d* 19	....	March 10	27	1.40
January 15	19	....	March 11	33	....
January 16	21	....	March 12	21	....
January 17	26	10.00	March 13	17	....
January 18	*e* 38	.05	March 14	18	.30
January 19	19	....	March 15	24	....
January 20	18	....	March 16	17	....
January 21	14	....	March 17	22	.10
January 22	13	....	March 18	21	....
January 23	40	.25	March 19	26	.25
January 24	35	....	March 20	28	....
January 25	26	....	March 21	20	....
January 26	20	....	March 22	17	....
January 27	14	....	March 23	18	.02
January 28	19	.15	March 24	15	....

a From this date to May 21 no full record of flow
b Measured 8 miles lower on stream.
c No record on account of high water.
d All of river.
e Rise probably caused by melting snow.
f Part only of river.

Estimates of discharge of San Luis Rey River, and depth of rainfall—Continued.

Date.	Flow.	Rainfall.	Date.	Flow.	Rainfall.
1898.	*Second-feet.*	*Inches.*	1898.	*Second-feet.*	*Inches.*
March 25	13	....	April 3 to 4	10	....
March 26	28	.35	April 5 to 12	9	....
March 27	24	....	April 13 to 14	7	....
March 28	21	....	April 15 to 16	6	....
March 29	18	....	April 17	*a* 9	.10
March 30	15	....	May 2 to 8	*b* 12	1
March 31	13	....	May 16 to 23	*b* 14	1
April 1 to 2	11	....			

a No daily record since this date. *b* Approxmate.

List of miscellaneous discharge measurements, State of California.

Date.	Stream.	Locality.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
1897.				*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
Jan. 4	Pallett Creek, tributary of Big Rock Creek.	Measured below Cienega.	.....	....	0.52	1.50	0.78
Do..	Big Rock Creek.	Above development at Alberger's dam.	.....	....	6.6	0.92	5.3
Do..	Development tunnel.	Tunnel approach 5,000 feet long in gravel of Big Rock Creek bed.	.....	....	1.09	1.22	1.33
Do..	Diversion into above tunnel.	....	.....	....	1.56	0.82	1.27
Do..	Little Rock above tunnel.	In South Antelope Valley Irrigation Company flume.	.....	0.35	2	1.21	3
Jan. 8	Santa Ana River.	At Warmsprings.	67	1.00	14.2	1.80	26
Do..	Santa Ana canal.	Not included in river measurements at headworks.	Weir	....	....	....	8.72

List of miscellaneous discharge measurements, State of California—Continued.

Date.	Stream.	Locality.	Meter number.	Gage height.	Area of section.	Mean velocity	Discharge.
1897.				*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec.-feet.*
Jan. 8	Green Spot pipe.	At headworks.	Weir	0.30	....	....	0.38
Do..	Redlands canal.	In flume at intake to wooden pipe.	67	....	3.97	5.37	21.32
Do..	Highlands canal.	At intake	Weir	0.500	....	....	11.9
Do..	Waste from Santa Ana canal.	Returned to river below gage at Warm Springs weir.	.....	....	....	....	2.86
Feb. 10	Caloway canal.	Second point of measurement.	67	2.81	185	1.70	314
Do..	.....do	First point of measurement.	67	2.54	....	....	322
May 29	Mining Company ditch.	Lagrange Dam.	67	1.70	10	2.18	22
May 30	Stanislaus and San Joaquin Valley flume.	Knights Ferry, California.	67	5.40	35	1.53	54
Do..	Little John canal.	.....do	67	....	10	1.18	12
July 13	......do	.....do	67	....	14	1.08	15
Do..	Stanislaus and San Joaquin canal.	.....do	67	....	54	0.67	36
Sept. 6	.....do	.....do	67	....	25	2.05	52
Do..	Little John canal.	.....do	67	....	3	0.43	1
Oct. 29	Stanislaus and San Joaquin canal.	.....do	67	....	29	1.19	34
Do..	Little John canal.	.....do	67	....	3	0.26	1

RAINFALL DATA.

In order to obtain precipitation data bearing upon river discharge, a number of rain gages have been placed by Mr. J. B. Lippincott at various important points. The following tables give the location of these and the results of the observations made together with data obtained from persons who have made similar observations with especial reference to problems of water storage or control:

Location of rainfall stations.

Station.	Observer.	Post-office.	County.	Latitude.	Longitude.	Elevation.
				° ′	° ′	*Feet.*
Sisson	Southern Pacific Co		Siskiyou	41 27	122 25	3,555
Red Bluff	U. S. Weather Bureau		Tehama	40 12	122 20	324
Sonora	John Shaw	Sonora	Tuolumne	38 00	120 16	1,824
Second Garotte	J. P. Chamberlain	Groveland	do	37 49	120 12	2,900
Crockers	George Crocker	Sequoia	do	37 48	119 53	4,453
Yosemite	Galon Clark	Yosemite	Mariposa	37 45	119 35	4,063
Mount Home mill	Fred Noller	Daunt	Tulare	36 10	118 48	6,680
Kernville	Stephen Barton	Isabella	Kern	35 45	118 25	2,600
Mount Breckenridge	G. Otterman	Bakersfield	do	35 25	118 35	6,750
Tejon ranch	R. M. Pogson	do	do	35 01	118 45	1,450
Fort Tejon	J. G. Stitt	Lebec	do	34 53	118 53	3,245
Frazier mine	H. Porter	Gorman	Ventura	34 49	118 58	8,000
Manzana	E. A. Silvey	Manzana	Los Angeles	34 47	118 32	2,850
La Liebre	J. W. Forbes	Neenach	do	34 46	118 40	3,170
Sneddens	Burt Snedden	Gorman	Ventura	34 41	119 03	4,900
Smith's ranch	William Smith	do	do	34 40	118 55	3,900
Mutah Flat	Burt Snedden	do	do	34 38	119 03	4,850
Palmdale	Burt Cole	West Palmdale	Los Angeles	34 25	118 03	3,299
Upper Holcomb	Arrowhead Reservoir Co	San Bernardino	San Bernardino	34 18	116 50	7,200
Mount Lowe	Lewis Swift	Echo Mountain	Los Angeles	34 15	118 07	3,200
Follows Camp	R. M. Follows	Azusa	do	34 14	117 49	1,800
Mount Home View	E. W. Hurlburd	Descanso	San Diego	32 50	116 40	3,500
Sweetwater dam	G. N. Savage	National City	do	32 43	117 00	250
Cuyamaca	San Diego Flume	San Diego	do			4,800

Results of observation of rainfall for 1897.

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.	Mean.
Sisson	2.59	4.86	20.43	.83	.00	.15	.00	.00	.00	2.31	2.62	3.72	37.51	....
Red Bluff	3.22	6.26	1.99	1.22	.06	1.25	.00	.00	.03	2.70	1.49	1.86	20.08	23.79
Sonora	3.31	11.89	8.37	.29	.25	.31	.00	.00	.10	3.35	2.15	2.53	32.55	37.13
Second Garotte	4.00	10.75	9.01	.53	T	T	.00	.00	T	2.75	1.00	2.50	30.54	38.98
Crockers	6.56	15.97	21.80	1.33	.00	.75	.00	.00	.45	6.09	2.70	3.80	59.45	....
Yosemite	6.62	11.53	16.32	.40	.62	.16	....	....	....	....	....	....	....	....
Mount Home mill	5.70	7.45	6.07	.40	1.85	.20	.35	.00	.10	2.45	.75	3.37	28.69	....
Kernville	3.40	3.60	2.57	.10	.00	.00	.00	.00	.15	.38	.00	1.28	11.48	....
Mount Breckenridge	2.00	4.67	7.72	.00	.40	.10	.00	.00	.00	.00	....	....	....	....
Tejon ranch	2.90	4.88	3.34	.26	.00	.17	.00	.00	.36	1.33	.29	1.25	14.78	11.62
Fort Tejon	3.52	5.14	3.63	.95	.00	.00	.00	.00	.00	1.39	.00	1.72	16.35	17.99
Frazier Mine	7.37	6.43	4.05	.15	.28	.00	.02	.48	.33	1.00	T	1.33	21.44	....
Manzana	2.70	3.04	1.71	.04	.01	T	T	.28	.00	.21	.00	.10	8.09	....
La Liebre	3.67	4.01	2.30	.10	.00	.00	.00	.00	.00	.50	.00	.40	10.98	....
Sneddens	8.30	2.92	2.71	.02	.53	.00	.25	.20	.14	.70	.00	.04	15.81	20.00
Mutah Flat	9.10	3.50	3.59	.00	.00	.00	.30	.00	.00	1.75	.00	.15	18.39	20.00
Palmdale	3.78	3.71	1.31	.04	.32	.00	.03	1.57	T	.86	.00	.14	11.72	....
Upper Holcomb	3.30	3.70	1.30	.00	.20	....	....	....	....	....	....	....	....	14.08
Mount Lowe	6.42	7.47	6.67	.19	.87	.10	.15	.00	.00	2.57	.40	.22	25.06	26.65
Follows Camp	5.43	10.39	8.25	.15	.28	T	.00	.07	.45	7.85	.20	.36	33.43	....
Sweetwater dam	3.11	2.95	2.05	.00	.02	.00	.00	.00	.00	1.40	.06	.45	10.04	12.27
Cuyamaca	6.32	8.14	8.56	.22	.38	.00	.00	.00	.36	5.09	1.07	2.46	32.60	44.46
Covina	4.78	7.28	3.18	.00	.00	.00	.00	.00	.00	2.75	.00	.62	24.61	....

WATER SUPPLY OF SAN BERNARDINO VALLEY.

By J. B. LIPPINCOTT.

GENERAL STATEMENT.

The area discusssed in this report is in southern California, lying for the most part easterly from the city of San Bernardino (see fig. 191) and consisting of the upper or higher part of the valley in which is situated the town of Redlands. It is about 50 miles distant from the ocean and has an elevation of from 1,000 to 1,500 feet in the vicinity of San Bernardino and Redlands. Northerly and easterly from the valley the mountains rise abruptly, reaching altitudes of from 6,000 to 7,000 feet, a few of the peaks rising to 10,000 or even 11,000 feet. The abrupt slopes by which the valley is bounded aid in producing a rainfall relatively heavy for the arid region. The waters, uniting into streams, descend rapidly through narrow gorges, issuing finally upon accumulations of bowlders and smaller débris which stretch in fan-shaped masses away from the mouth of each canyon. The region, though dry, has thus a notable water supply, and the exceptional climate and soil have resulted in an extraordinary development of agriculture by irrigation. Lands and crops have reached high values in San Bernardino Valley and expensive irrigation works have been built. A denser population is supported than in any other farming region of the West. This has been accomplished in spite of the fact that the cost of constructing works and of reclaiming the lands has been very great.

The topographic conditions of this locality favor the production of high-grade fruits. The ranges of mountains to the north and east shut out the cold desert winds, leaving the southwestern exposure tempered by breezes from the sea. The distance inland is sufficient to admit of the high summer temperatures necessary to the successful ripening of citrus fruits. The success of this industry has rendered it possible to secure capital for the construction of the works for water storage and distribution, and has resulted in a correspondingly great economy in the quantity of water employed. In this valley water is made to do more work and earn greater returns, probably, than in any other portion of the arid region of the United States.

The discussion of the water resources given in the following pages relates particularly to the systems taking water from Santa Ana River and its tributaries and supplying Crafton, Highlands, Redlands, and

VIEW IN SAN BERNARDINO MOUNTAINS, CALIFORNIA.

Old San Bernardino. There has also been included a discussion of Mohave River, which rises on the northern slopes of the mountains and flows northerly into the desert, for it is probable that by means of certain storage works now under construction much of this water will be caught and turned southward by diverting lines or tunnels to supply portions of San Bernardino Valley. The drainage area of Santa Ana River is shown by the index map, fig. 191, which exhibits the relative position of the principal towns and systems of irrigation. As shown by a glance at this map, the Santa Ana, rising in the high mountains, flows southeasterly through San Bernardino Valley. Be-

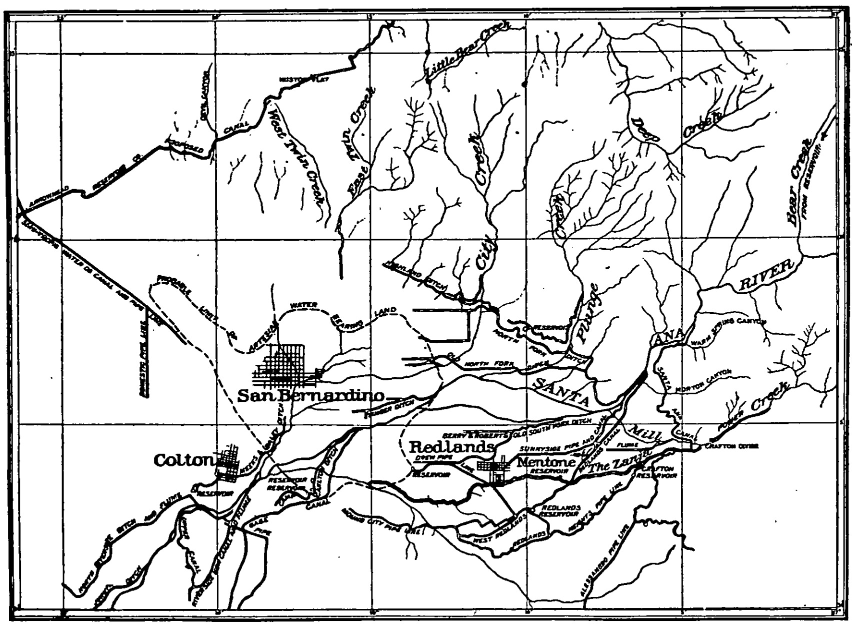


FIG. 191.—Index map of principal irrigation systems.

yond this it passes through low ranges of hills, and finally escapes crossing the coastal plain to the ocean. At present we are concerned only with the head waters of this river above San Bernardino. South of the main stream, and tributary to it, is Mill Creek, and on the north Plunge Creek and City Creek. The view on Pl. LIII shows San Gorgonio, or Grayback Peak, in the background and a portion of the country tributary to Mill Creek. In the following discussion each of these will be considered independently, for, although topographically they are part of the same stream, their waters for the most part are caught and utilized before leaving the mountains, so that for all practical purposes they are independent sources of supply.

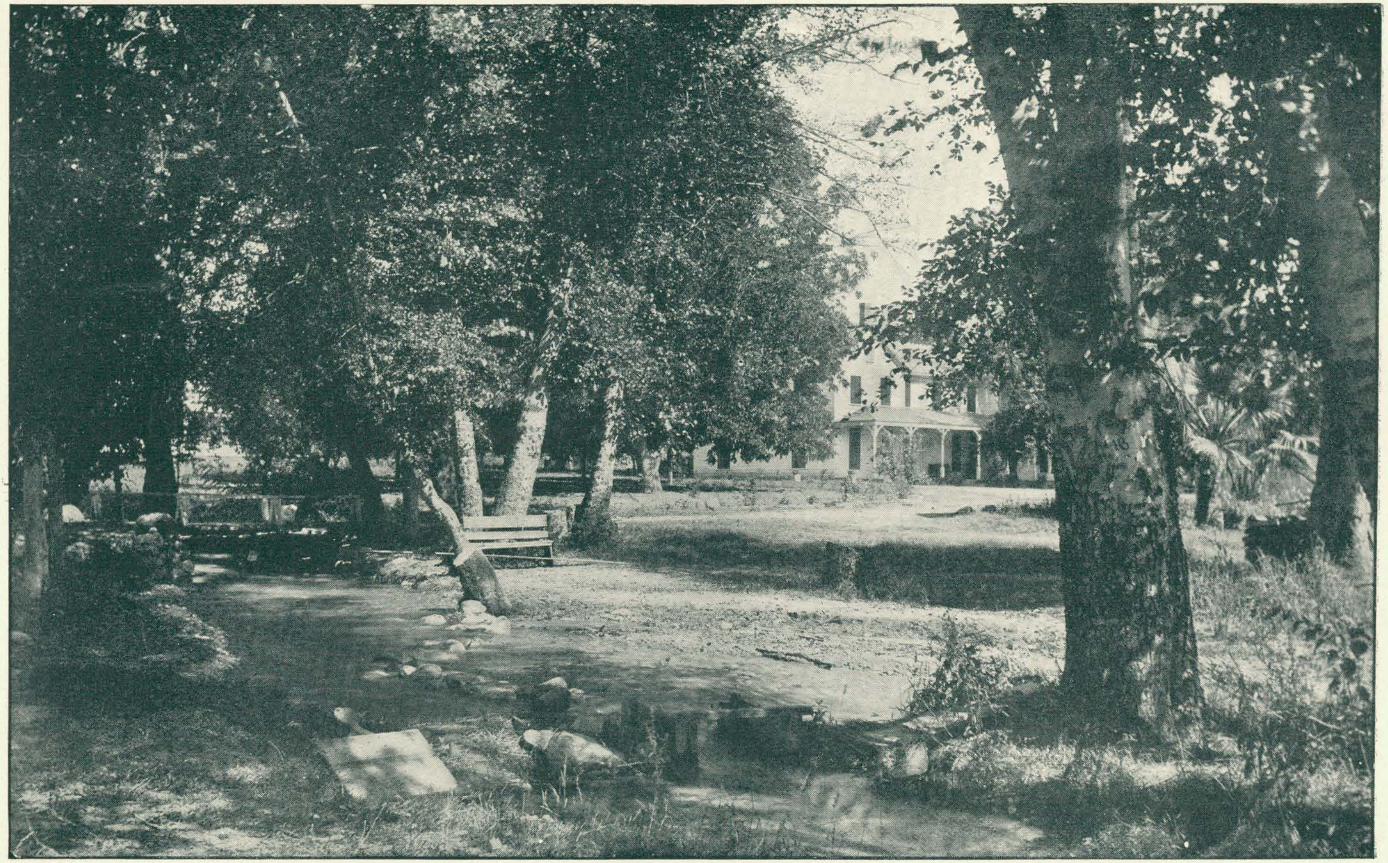
EARLY IRRIGATION HISTORY.

The first settlement in California was by the Spanish padres of the Catholic Church. The task of civilizing the Indians was given them by the Spanish Government, and in order that they should have power to carry out their policy, they received great grants of land upon which they were to care for and instruct the natives in the ways of peace. The great missions were thus founded and developed, the Indians becoming practically the slaves of the church. From the principal missions as a center the work was extended by establishing smaller branches in the interior valleys, such, for example, as San Bernardino Mission, founded in 1820.

In 1821 San Bernardino Mission built the first ditch constructed in this valley, leading from Mill Creek, above Crafton, to the mission church and farm, sometimes called in early days Cottonwood Row, and now known as Old San Bernardino. This canal, shown in Pl. LIV, was built on the natural grade of the valley, which is about 300 feet to the mile, was 12 miles long, and supplied water for 536 acres of grain and vines. Its capacity, approximately 2,000 miner's inches (40 second-feet), commanded the entire summer flow of the creek, and it has maintained this right ever since. It was a crude, wasteful ditch and always lost a large proportion of its water by overflow, percolation, and evaporation. This primitive construction has never been improved, and it remains to-day as a record of the past. The agreement on the part of the church to return the lands to the State when the Indians became civilized was disregarded until the Mexican Government, in 1833, secularized all mission lands.

The Mexican grant of the Rancho San Bernardino to José Maris Lugo and others was made by Governor Alvarado in 1842, and specifically conveyed title to the ditch and the waters of Mill Creek. Subsequently contests followed to determine whether the grant of water was made to cover all of these lands or only the particular portions then irrigated. The decrees of the court and local customs have held that these water rights, as well as others, belong to the actual irrigator, who can sell to other parties or transfer them to other canals, as he may elect.

Mormons from Utah entered the valley in 1851. They were chiefly Josephite members of the Church of the Latter-Day Saints, who did not believe in polygamy, and so left Utah. These people purchased the San Bernardino grant in 1852. By an order of the church many of the Mormons returned to their "Valley of Jordan" in 1857. Later settlers around Crafton and outside of the grant claimed the zanja to be a natural water course, and used it first for domestic purposes, and by a compromise in 1875 were given its entire flow from 3 p. m. to 9 p. m. each day. During that interval Crafton Settlement, being 8 or 10 miles above the old Mormon settlement, could take the water which



OLD MILL CREEK ZANJA, NEAR CRAFTON, CALIFORNIA.

Built in 1821.

would pass the Mormon settlement unused at night. Out of these concessions grew the Crafton system.

It has been said of California that every township has a distinct climate, and to a limited extent this is true. In the lower portions of the valley there may be heavy frosts, while a few hundred feet higher the lands are practically frostless, thus permitting a more tropical variety of fruit to be grown. These "foothill fruits" are also of finer flavor than those of the valley. This has led to a singular irrigation custom in this district. As the farmers have come to appreciate these facts they have seen the desirability of tilling the higher lands and of moving their water rights up from the lower valleys. Hence the custom has grown of holding the water right separate from the land, and thus permitting its transfer from one canal to another or its sale outright. The usual method of operation has been to sell "canal shares," which represented at first runs of the entire ditch for so many hours per month. Gradually this share has developed into a "certificate," which entitles the holder to a certain amount of water, which he may call for, on presentation of his certificate, at any point on the system and at any rate of flow, provided he does not accumulate his water for a period of more than thirty days. For instance, the Bear Valley certificate, Class A, calls for one-seventh of a miner's inch (0.003 second-foot) continuous flow for each acre. This right the company has sold, and the irrigator may either take the one-seventh inch continuous flow, or he may call for a month's water in one day, which would be about 4.3 miner's inches (0.09 second-foot) for that time, and as he will probably irrigate 10 acres at a time his "irrigation head" in that case would be 43 miner's inches (0.9 second-foot).

DUTY OF WATER.

In San Bernardino Valley, as well as in southern California as a whole, not only are the irrigation works as a rule well planned and expensive, but the water is also used with great care. This is expressed by saying that the duty of water is high, or that a large area of ground is cultivated by a given quantity of water. The unit of quantity is taken to be the cubic foot per second, or second-foot, as often abbreviated. The miner's inch is the unit popularly employed, this being handed down from the time when water in California was considered valuable mainly for hydraulic mining. The miner's inch has been found to be an indefinite quantity, varying in different parts of the State, and has, after much controversy, been fixed by law to be the fiftieth part of a second-foot. The duty of water is, for example, sometimes stated to be an inch to 2 acres; or, in other words, a miner's inch flowing continuously through the season will irrigate 2 acres of land; or at this rate a cubic foot per second flowing continuously will irrigate 100 acres.

It is difficult to make a general statement of the duty of water, for it is dependent on so many factors. It varies with the temperature, precipitation, and humidity of the locality in question. Sandy soil, if the subdrainage is good, requires more water than soils that contain much clay or humus. The character of the main canals and of the laterals, whether lined or unlined, in light soils, has much influence. The skill of the irrigator in the application of the water is also of especial importance. It was found during a year of extreme shortage under the Sweetwater system, where the usual duty of water is 1 inch to 10 acres, that with a smaller supply a crop of more than average value was produced by resorting to repeated cultivation. This system, however, is in use on the coast, where the average humidity is about 80 per cent, which is much above the average of the arid region.

In order to convey a broad impression as to the variation in the duty of water, the following table is introduced from the Manual of Irrigation Engineering, by H. M. Wilson, p. 49:

Duty of water.

[Based on supply entering canal head.]

Locality.	Duty per second-foot.
	Acres.
Northern India	60 to 150
Italy	65 to 70
Colorado	80 to 120
Utah	60 to 120
Montana	80 to 100
Wyoming	70 to 90
Idaho	60 to 80
New Mexico	60 to 80
Southern Arizona	100 to 150
San Joaquin Valley, California	100 to 150
Southern California:	
Surface irrigation	150 to 300
Subirrigation	300 to 500

As shown by the table, the duty of water in southern California surpasses the usual practice throughout the arid region. As a matter of fact, however, it is probable that there is used on the land nearly as much water here as elsewhere, except near the coast, where the atmosphere is humid. The difference is largely accounted for by the superior economy in the conveyance of water from its source to the place where used.

Within a mile of the sea, on the sandy bench lands, where moisture is derived from fogs, it is not unusual to raise a good crop of corn without a drop of water apparently falling on it or artificially supplied. But in San Bernardino Valley such conditions are unknown; there irrigation must be continuously practiced. Very little grain is grown by irrigation, but fruits are watered regularly throughout the season. Deciduous fruit trees require only about one-half the amount used by the citrus fruits, as their bearing season is shorter and they are not extensively irrigated after the crop is gathered. The citrus fruits are irrigated from the time the spring rains cease, usually in April, until the frost threatens the tender new growth in November.

In San Bernardino Valley, where a supply for citrus fruits of 1 miner's inch to 4 acres (1 second-foot to 200 acres) is used, the irrigating season lasts from one hundred and eighty to two hundred days. The old water rights at Redlands and Crafton call for this amount of water. At Highlands the duty is greater, being usually 1 inch to 5 acres. As a rule, the duty of water is being increased by better cultivation, but at the same time the trees are growing older and more are coming into bearing, so that it is not desirable to diminish the amount put on the orchards.

There is no question that the continued cultivation of the soil, by breaking up the small capillary evaporating tubes that form in the hard-baked top soils, greatly assists in retaining its moisture. It is not desirable to turn the soil over with a plow, nor simply to go through it with a weed cutter, but rather to stir the top with a cultivator. This practically stops evaporation and permits the soil to retain moisture in a way that is remarkable.

Antelope Valley, in Los Angeles County, has a rainfall during the winter months of about 10 inches, an evaporation from a water surface of 65 inches, and a relative humidity in some large almond orchards of 30 per cent or less. The soil is decomposed granite and clay loam, which has been cultivated about once a month during the growing season. Under these conditions the almond trees for the last five years have grown slowly but surely, and practically without irrigation. There is probably no tree better adapted to this extreme dryness. Where the apple and other trees have failed the almond has continued to grow.

There is no doubt in the minds of experienced irrigators that these trees would have grown with much greater rapidity if they had had water, and that judicious irrigation would insure and increase the crop. Vigorous irrigation in the summer, after the crop has been harvested, assists the tree in its work of preparation for the coming year.

Lemon and orange trees require much water. While continued cultivation of the soil greatly assists the tree in feeding, and reduces the amount of water required for its supply, yet in rather light soils the citrus trees in full bearing, when thus cultivated, do best with a water supply of nearly 2 acre-feet, intelligently applied and distributed through the growing season of two hundred days. There is no economy in saving a few dollars per acre per annum on water when the crop would be increased 50 or 100 per cent by its use. In this locality deciduous fruits do well on one-third or one-half the amount needed for citrus fruits.

Mr. F. S. Beresford, an eminent Indian engineer, states that each cubic foot of water entering a canal at its head is distributed in five ways:

(1) In waste by absorption and evaporation passing from the canal head to the distributing head.

(2) In waste from the same causes between the distributing head and the head of the private channel.

(3) In wastes in passing from the private channel to the field to be watered.

(4) In waste by the cultivator in handling the water, causing loss either by evaporation or by percolation where an unnecessary amount is applied.

(5) In useful irrigation.

Mr. Beresford, to facilitate the computation of the efficiency of the system, puts this loss in the form of an equation:

Let Q be the discharge of the river at the head gate, W the total waste from the head gate to the outlet, L the length of the main canal, Lx some function of the length, as $\frac{5}{8}$ or $\frac{7}{8}$, found by experiment, AP loss in volume by absorption and percolation in an average mile, E the efficacy of the main canal, Ew the efficacy of the distributing canal, Ec the efficacy of the cultivator, Eo the efficacy at the point under consideration on the main canal. The small letters apply to the distributing canal in the same way as the capitals apply to the main canal.

$$Eo = 1 - \frac{AP \times Lx}{Q} \qquad (1)$$

$$Ew = 1 - \frac{ap \times lx}{q} \qquad (2)$$

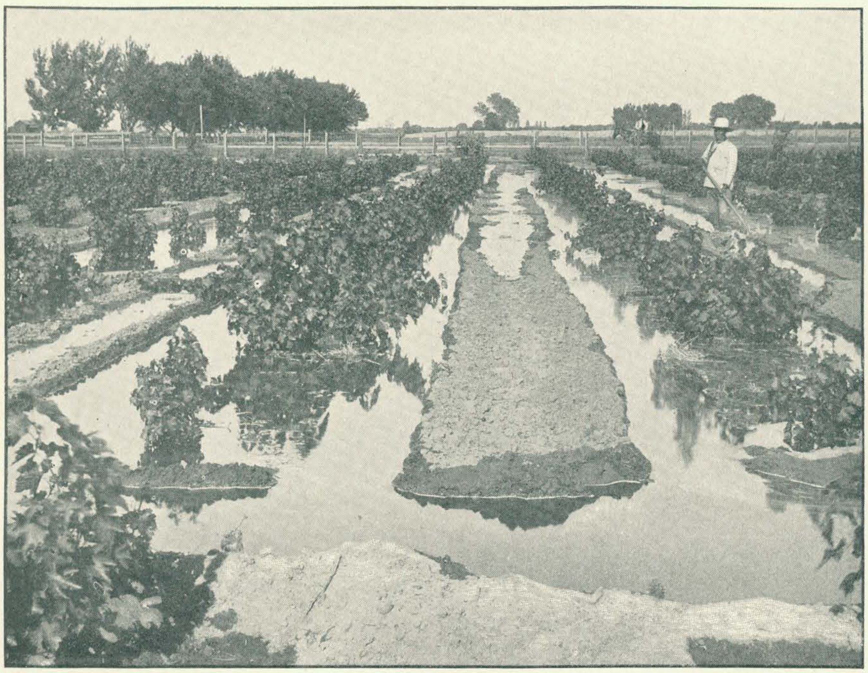
$$E = Eo \times Ew \times Ec \qquad (3)$$

Say, Ec=0.75.

It has been found that in the Indian canals the amount of water efficiently used on the trees is often as low as 40 per cent of the amount entering the headworks. From the equation given above it is evident the longer the canal line the greater the care necessary to prevent loss by absorption and percolation, and the more desirable are high velocities.

In the citrus-growing districts of southern California no such loss is permitted. The water is diverted in lined canals from the river and distributed in flumes, or frequently in pipes, as is customary with a domestic water supply. The conduits are also comparatively short. A loss of 1.5 per cent per mile is considered large in canals having a capacity of 25 second-feet and over. The Santa Ana canal has about 20 second-feet of water (1,000 miner's inches) entering its head gates,

A.



B.

VIEWS IN SAN JOAQUIN VALLEY, CALIFORNIA, SHOWING LOW EFFICIENCY ON THE PART OF THE IRRIGATOR.

A, Orchard irrigation; *B*, Vineyard irrigation.

and loses about 15 per cent in 8 miles. This is considered a heavy loss.

It is stated by the superintendent of the Bear Valley Irrigation Company that of the water diverted from Santa Ana River for the Alessandro and Perris districts there is a loss of 35 per cent between the river and the irrigation districts. This water is carried for the first 8 miles in the Santa Ana canal, where the loss in summer is about 15 per cent. It is then conducted through a steel pipe 9.7 miles, from Mill Creek to the Moreno tunnel, and thence distributed to the lands in question through small reservoirs, pipes, and flumes, the total distance carried being about 22 miles. This loss is so great that the figures are seriously doubted by some engineers.

The duty of water is seldom considered in southern California except as measured at the land where it is to be applied. but even if measured at the headworks the waste in delivery in a good system should not exceed an average of 15 per cent for the year. The users of this water are an intelligent class of people, handling a very high priced water and crop. In many of the orchards, the water being limited and the land areas always in excess of the water supply, every drop is utilized. For these reasons it is safe to say that the cultivator here is as careful as any elsewhere, and that his personal efficiency would be equal to the best, which Mr. Beresford found to be 90 per cent.

Assuming the above to be true, the final efficiency of the water used in San Bernardino Valley may be safely taken to be 70 to 80 per cent of the water entering the head gates, or nearly twice that of India. If in India the duty of water entering the canal is 1 second-foot to 100 acres, with an efficiency of 40 per cent, the duty of the effective water there would be 1 second-foot to 250 acres, which would give a depth of 1.44 feet on the land. This is found to be a common practice for citrus fruits in this valley. In irrigation enterprises there is a constant temptation on the part of the management to sell more land or water for land than the tributary drainage basin can supply, or to underestimate the amount of water required because of the limited supply.

An explanation of the wide range in the duty of water may be had in the illustrations (Pl. LV), giving views in San Joaquin Valley, taken in 1887: *A* is a view in an orchard; *B* in a vineyard; both showing an amount of water applied to the soil so great that a large portion of it is wasted and probably the results in crop yield are not as large as though a smaller amount had been applied at a time. In contrast with these, reference should be made to Pls. LVII and LVIII, showing care and skill in the prevention of waste.

In southern California the first cost of works has often been so great that those companies that looked for profit only from the sale and rental of their water, have, as a rule, failed. Land without water is universally regarded as of little or no value, but with a good water right the same land would be thought cheap by the same people at $100 per acre, yet it would be difficult to induce them to pay from $60 to $90 per acre for a water right. The water company might earn this increased valuation, but the only way in which they could collect it would be by purchasing the land, improving it, and afterwards selling land and water together. It has recently been ruled by Judge Erskine M. Ross, in the United States district court at Los Angeles, that a company can not sell a water right; that they can only charge for the conveyance of the water such rates as may be regulated by the local board of county supervisors, but that these rates must be large enough to bring in to the company a fair return on the value of the water plant. This decision has not been confirmed by appeal to the higher courts. As it stands, it evidently makes it still more desirable for the water company to control the lands under its system. The result of this decision has been that some of the water companies have repudiated the water certificates (acre water rights) that they have previously sold and are endeavoring to increase annual water rentals.

WATER POWER.

Following the development of agriculture by irrigation, and the rapid growth in population and wealth, has come the utilization of water for power purposes. This secondary employment has, as a rule, not interfered with irrigation, because most of the streams, as previously stated, descend with rapid slope from the high mountains, giving enormous available heads for power purposes. The most prominent industrial development has thus been the utilization of the many water powers of this section for the purpose of generating electricity and the transmission of the electric current to the near-by cities for light, heat, and power. The rapid strides made in electric development during the last ten years have rendered feasible many projects that prior to 1887 were impracticable, and the distance over which electric power may be transmitted with favorable commercial results has been increased, it is said, to at least 100 miles.

The area lying along the southern base of the Sierra Madre and San Bernardino mountains in southern California, and extending from the Pacific Ocean to the city of Redlands, a distance of 80 miles, is the locality to which belongs the honor of having installed the first long-distance transmission plant in the United States—that from San Antonio Canyon to the city of San Bernardino, a distance of 28 miles. This valley contains the cities of Los Angeles, Pasadena, Pomona, Ontario, Colton, San Bernardino, Riverside, and Redlands, besides many smaller towns, and is traversed by the Santa Fe and the Southern Pacific railway systems for the entire length.

Beginning on the east, the first stream of importance is Mill Creek, with an approximate average summer flow of 30 second-feet; then Santa Ana River, with an approximate flow of 80 second-feet; Lytle Creek, with about 25 second-feet; San Antonio Creek, with about 10 second-feet; and San Gabriel River, with approximately 35 second-feet. These discharge figures are taken from local records and are not the result of official measurement. In addition to these there are a number of smaller streams which, for various reasons, are not available for power purposes. The largest stream among those named, and the most available for power purposes, is Santa Ana River, and the next in order are Mill Creek and Lytle Creek. San Gabriel River, while having a greater flow of water than either Mill Creek or Lytle Creek, has less available fall per mile. On all of these streams the waters have been appropriated for power purposes, and on San Antonio and Mill creeks the electric plants have been in operation since 1892.

In 1891 work was begun on the plant of the San Antonio Light and Power Company, and in October, 1892, current was delivered over the lines to the cities of Pomona and San Bernardino, distant from the power house 18 and 28 miles, respectively. This was the first long-distance electric-transmission plant in the United States, and is operated at a line voltage of 10,000 volts, something hitherto unknown outside of the laboratory of electric scientists. The plan of hydraulic development of this power was the diversion of water from the creek into a riveted steel pipe 26 inches in diameter, having a pressure head of 400 feet at its lower end, where it entered a heavy riveted steel receiver. From this receiver the water was delivered through small nozzles to Pelton impulse wheels, directly connected to the shafts of the electric generators in the power house, the latter being separated from the wheel pit by a heavy masonry wall.

The operation of this plant has been continuous and successful from its inception, although the transformer apparatus for raising the line voltage is crude and inefficient as compared with the present types of construction. This plant was so constructed that it could deliver electricity for lighting purposes but not for the operation of electric motors.

In 1892 the Redlands Electric Light and Power Company began work on the utilization of the waters of Mill Creek, and put into operation in the summer of 1893 a 1,500-horsepower plant for the electric transmission of light, heat, and power. The working capacity of the pipe line is stated as 30 second-feet. This was the first installation in the United States of the three-phase power-transmission plant, and the details of its operation and construction were much discussed and favorably commented on in the technical journals of the United States and Europe. This plant is now supplying with light, heat, and power for manufacturing purposes the cities of Redlands, Riverside, and Colton, as well as the State Insane Asylum at Highlands and a large ice manufactory, the latter using 200 horsepower for a synchronous motor. The population of these cities and their distance from the power house are as follows: Redlands, population 5,000, distance from power house, 7½ miles; Riverside, population 8,000, distance from power house, 22 miles; Colton, population 3,000, distance from power house, 15 miles.

The line voltage to Redlands is 2,500 volts, and to the asylum, Colton, and Riverside, 11,000 volts. The average cost per horsepower delivered to these towns from Mill Creek is, approximately, $60 per annum for a 10-hour day. When sold to large consumers the price is usually 1 cent per hour per horsepower for 20-hour days. The hydraulic development is of a similar type of construction to that of the San Antonio Company, except that the pressure head is greater, being 510 feet, and the length of the 30-inch steel pipe, 10,250 feet. In the case of the Mill Creek plant the head is developed through a 30-inch steel pipe laid in the bed of the canyon itself, from the headworks to the power house, the pipe having a relatively small loss of head by friction. Difficulty has been experienced in removing all the silt from the water before it enters the pipe line, and the silt deposited in the lower portions, until removed, reduces the efficiency of the line. The operation of this plant has been very successful from the beginning, and the company owning it is preparing to install a similar plant on Mill Creek above the present headworks, having bought the lands necessary for this purpose.

The way pointed out by these pioneers has been industriously traveled, and the later comers have so improved methods of transmission that work has now begun on the development of the power possibilities of Santa Ana River, with the intention of transmitting the power over a line 80 miles long to the city of Los Angeles. This will be the longest distance over which electric power has been delivered under commercial conditions, and its operation will be watched with great interest. The line voltage will be 33,000 volts, and the line will run along the tracks of the Santa Fe Railway the entire distance, being built on the right-of-way lands of this company. The climatic conditions of southern California are peculiarly favorable to the operation of a high-voltage line, the atmosphere being very dry and free from fogs.

The hydraulic plans of the Southern California Power Company, who have the Santa Ana project under construction, provide for a canal 3¼ miles long, following the hills bordering on the river, consisting chiefly of tunnels 5½ feet by 7 feet in section connected by flumes, and gradually increasing in relative elevation above the river bed from the intake to a height of 750 feet. This conduit is designed to leave the river bed at the mouth of Bear Creek. At the lower end of the conduit the water will be delivered into a steel pipe 36 inches in diameter, with a length of 2,200 feet and a fall of 750 feet. With an average available amount of water of 80 second-feet, or 4,000 miner's inches, this will give an electric output at the station of 5,367 horsepower. The conduit is to have a present capacity of 4,000 miner's inches and an ultimate capacity of 7,000 miner's inches.

The same general method of power-machinery construction will be used as in the San Antonio and Mill Creek plants, namely, impulse wheels, with rim buckets keyed to a shaft directly connected with the shaft of the electric generator. There will be five 1,000-horsepower generators installed. The power will be used in Pasadena and Los Angeles for the purpose of operating electric street railways and lighting plants, now using steam as a motive power. The total present use of electric power in Pasadena and Los Angeles amounts to about 8,000 horsepower and is rapidly increasing.

On May 21, 1897, the Southern California Power Company awarded the contract for the construction of flumes and tunnels in Santa Ana Canyon. The bid for the tunnel work, of which there will be about 10,000 feet, was $6 per foot. The price for flume work was $31 per thousand feet of timber, which will make this part of the contract amount to about $90,000. The completion of the work has been somewhat delayed, but it will probably be finished by January 1, 1899.

MILL CREEK.

Mill Creek drains the area south of the head waters of Santa Ana River. The basin is composed of crystalline rocks with a considerable soil covering. It is about 13 miles in length and 3 miles in average width, the total drainage area being 47 square miles, as measured with a planimeter on Beasley's map of San Bernardino County, edition of 1892. It lies above the point where the stream crosses the west line of range 1, the latter being near the headworks of the Redlands Electric Light and Power Company and less than a quarter of a mile east of the junction of the Yucaipe and Mill Creek wagon roads. The area, as given by the California State engineer, is 58 square miles, but the initial point on the stream is not stated.

The drainage basin rises from an elevation of 3,000 feet at the head works of the power company to 12,000 feet on Grayback Mountain, the highest peak south of the Tehachapaies. It has a favorable exposure for rainfall, and the run-off is correspondingly large, probably at least as great per square mile as that from any other basin of similar area in southern California, the flow being well sustained in the summer. The creek consists of a main stream with short lateral tributaries. The valley is seldom more than 2,000 feet wide, being of the nature of a canyon, but it does not narrow into the boxlike form usual in other gorges of this kind. The surface, up to an altitude of about 10,000 feet, is covered with brush and timber. The higher peaks, San Bernardino and Grayback, are almost bare.

As stated on a previous page, the first ditch constructed in this valley took water from Mill Creek, heading above Crafton and receiving the entire summer flow. At a later time, as water rights increased, a division was established at what is known as the Crafton divide, described on a later page. The flow during the summer of 1896 may be considered as relatively very low. On August 16, 1896, a severe storm, locally known as a cloud-burst, caused a temporary rise which could not be measured. The following table gives the data available:

Discharge of Mill Creek, San Bernardino County, California.

[Drainage area, 47 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1895.						
August	27.6	24.0	24.5	1,505	0.60	0.52
September	26.5	19.5	20.0	1,310	0.52	.47
October	24.5	17.0	19.6	1,205	0.48	.42
1896.						
May	21.4	9.4	13.4	825	0.33	.28
June	16.0	5.1	10.3	615	0.25	.22
July	16.0	6.1	11.5	709	0.28	.24
August	13.2	8.7	11.6	716	0.28	.25
September	15.0	7.4	11.5	687	0.27	.24
October	13.1	9.0	10.5	637	0.26	.22

The rainfall for the winter of 1897–98 is very low and is the culmination of a group of five years, the mean of which is much below the general mean for southern California. The streams of this section during the summer of 1898 have in general been lower than recorded heretofore. This condition is indicated by the rainfall table for San Bernardino, shown on page 619. At other rain-gage stations than San Bernardino the rainfall for the season of 1896–97 is either near the mean or slightly below it.

The following measurements of Mill Creek were made during the season of 1898 at the Crafton divide:

Discharge of Mill Creek at division box.

Date.	Area.	Velocity per second.	Volume.
1898.	*Square feet.*	*Feet.*	*Second-feet.*
April 12	(*a*)		15.73
April 29	(*a*)		18.88
June 12	1.92	9.42	18.10
July 23	1.43	8.27	11.82
September 8	1.23	10.62	13.07

a Measured on weir.

Well up in the canyon, at an altitude of about 3,000 feet, the water of Mill Creek is first diverted to the works of the Redlands Electric Light and Power Company by means of a small concrete dam and regulating gate, as described on a preceding page. From the power house the water returns to the original channel, where it flows to the Crafton divide. This consists of a cemented bay 18 feet long, from which two weirs discharge. One weir is permanent and the other is a double adjustable gate. One of these gates is made of heavy plank and rests on the bottom of the bay. This gate can be raised and the bay flushed. The second is supported by and moves on the upstream face of the wooden gate. The wooden gate rests on the sill of the bay, and the iron gate by an independent motion can be set so as to make the proper division of the water. As is the case with most of the weirs of California, this measurement is defective. The Crafton weir, which is permanent, is an iron knife-edge, which projects about 1 inch above and is set 1 foot back in the flat top of a concrete wall. The measuring edge of the other adjustable weir is made of an angle iron, which has a vertical web of 2 inches, and a horizontal web, extending upstream, of 1 inch. These weirs divide the summer flow of Mill Creek, the water of which is worth at least $25,000 per second-foot of continuous flow.

The old Mill Creek zanja has been slower in the transfer of rights from the lower to the higher lands than any of the other canals in the valley, but its water is being used more and more around Crafton, and probably before many years the transfer will be complete.

CRAFTON CANAL.

From the divide described on the preceding page the water for Crafton is led through a lined canal to the Crafton reservoir. By agreement between the owners of water rights in the Mill Creek zanja its waters, as before stated, were divided, so that during certain hours all of the water is given to the Crafton people. Under this arrangement nearly all of the water flowing during the night goes to Crafton. The reservoir was constructed in order to control this supply more conveniently. To form the reservoir a cutting was made in the hillside and an embankment constructed on the lower edge. The reservoir thus made is faced with cement and a rock lining. The usual method of constructing such works at Redlands is to place on the water face cobbles or rock taken from the excavation. These are set on edge to form a wall 8 inches thick, then rammed firmly into position and the spaces filled with spalls and sand, water being freely used. When completed, the reservoir is filled for a week or ten days. The water is then drawn off and the surface of the rock lining is covered with mortar made of one part cement to five of sand, put on by a trowel, the thickness of the coat being about three-fourths of an inch. When the material is furnished at the reservoir, the cost of mixing and putting it in place is about 28 cents per square yard.

The capacity of this reservoir is about 35,000,000 gallons. The supply is increased by water from Santa Ana River, brought by the Green Spot pipe line, which discharges into the head of the Crafton canal. The length of this pipe line is 3½ miles, and its capacity is 9.1 second-feet, or 455 miner's inches. The canal is 4 feet wide on top, 2 feet wide on the bottom, and 2 feet deep, a section being shown in fig. 192.

The following is the most approved method of building canals of this character evolved by local experience: The side walls are laid first. Bowlders which weigh from 50 to 200 pounds are used for this purpose. They are laid flat in a lime-and-cement mortar. The side walls should be

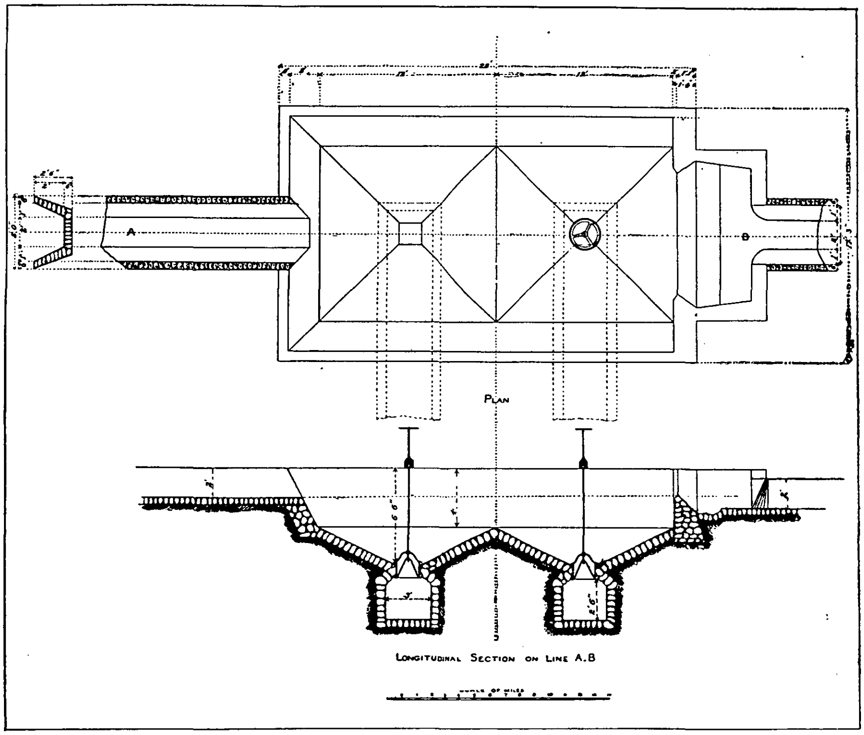


FIG. 192.—Plan and section of canal and masonry sand box of Crafton Water Company.

carried down a foot or more below the proposed floor of the canal. The wall is surfaced with a strong hydraulic-cement mortar. The floor of the canal is made of bowlders of the same size, set on edge and chinked. Sand is then brushed over the floor with brooms and all the spaces are well filled. The water, carrying fine silt, by its own action finishes the work of cementing the floor of the canal. It is found that these canals become water-tight and give good service. The high velocities in this district cut off the cement plaster that may be put on the bottom of the canal. The North Fork or Highlands canal, built in this manner, has been in operation since 1888 and carries 30 second-feet, or 1,500 miner's inches, of water. In places it is built on a grade of 16 per cent and the velocity of the water reaches 20 feet per second.

The Crafton canal is said to lose 75 miner's inches (1.5 second-feet) between Mill Creek and the Crafton reservoir, a distance of 2½ miles. This is doubted, as the weirs are too poor to measure with any such refinement.

Fig. 192 also shows the sand box on the Crafton line of canal. It is located about 200 feet east of the reservoir. The effort has been made to so enlarge the section of the sand box that the water will be reduced to a velocity of 0.7 foot per second over the sills of the sand box. The sand that has been carried in suspension to this point is dropped into sloping hoppers, into which the bay has been divided. The tendency of the sand is to settle toward the center of the bay or hopper. The bell-shaped gate at the vortex of the hopper drops vertically from its position by means of a screw thread on its shaft at the wheel. The weight of the sand and water tends to press the sand down through the opening. The water, in theory, first pushes the sand out before wasting itself, but in practice the slopes should be steeper than they are here to produce this result.

In this case the water has to flush the sand through the opening. An improvement could be made in the lip of the bell. A small gravel or stick may lodge in this curved lip, and it is then extremely difficult to remove the obstacle or to close the gate. It would be better if the lip, instead of being turned up, were made flat, so as to permit the sticks and gravel to slide off the shoulder easily. The ideal location for a sand box is on a trestle passing over some cross-drainage line. In this event a deep box can be located with the sides nearly vertical, which permits the silt to be pushed or flushed out with greater rapidity.

In a sand box of the type on the Santa Ana canal, where the slopes of the floor of the sand hopper are 1 on 4 and the sides 2 on 3, with heads of 20 second-feet, the sand has to be shoveled into the opening, as the water does not acquire enough power to flush quickly the sand through the openings. The openings would have been better adapted to their purpose if they had been 2½ feet, instead of 1½, in diameter.

The Crafton Water Company owns the Crafton canal and reservoir as well as the distributing-pipe systems to the Redlands Heights and Canyon Crest Park. The operation of this company is the outgrowth of local custom and methods, and is in most respects similar to the other local water companies of the valley, such as the North Fork, Redlands Heights, Drew, and others. Its capital stock of $350,000 is divided into 3,500 shares of the par value of $100 per share. Its property consists of water rights, reservoirs, canals, conduits, and system for the development, storage, and distribution of water.

The following condensed extracts from the constitution of the company illustrate the customs referred to above:

The unissued stock of this company may be issued to any person deemed fit by the board of directors to become a stockholder, upon condition that the title to a certain quantity of water and the exclusive use thereof, delivered into the Crafton supply canal or into the Crafton reservoir, be first conveyed to this corporation. That in such transaction stock shall be estimated as follows: For one hour's flow of the Mill Creek zanja once in every seven days and $250 in money, 25 shares of such stock may be issued, and in the same rates for a longer or shorter flow, from whatever source; and for one hour's full flow of said stream once every ten days and $175 in money, 17½ shares of such stock may be issued, and in the same rates for a longer or shorter flow, from whatever source: Provided, That when water be acquired from any other source than Mill Creek, each share of stock shall be estimated to equal at least one-seventh of a miner's inch. And no stock shall be issued for money other than as above provided.

Any stockholder is entitled to have water from the reservoir and water system delivered through hydrants on the highest point of his land by paying to the company the proper proportion of the expense of finishing the distributing canal to a point where the water leaves the canal, and his proportional part of the expense of laying cement or vitrified pipe to his land; also for his hydrant.

Any stockholder owning land that can be more cheaply irrigated from the supply canal may have water from it by paying his proportional expense of making or laying cement or vitrified pipe from the canal. The ratio of the expense of the cement or vitrified pipes shall be divided among stockholders as follows: The land nearest the zanje, canal, or ditch from which the pipe leads shall pay the least, and the land farthest from the same, measured by the route of the pipe conducting the water to the land in question, shall pay the most, and each intermediate lot of land shall pay in proportion to the length of pipe necessary to reach it, no stockholder paying for the pipe beyond his hydrant. In distribution of water to consumers the whole quantity of water which is subject to and may be delivered through the water system of the company at the time of the distribution shall be considered as consisting of as many equal parts as there are shares of capital stock actually issued. The person owning any of these shares, upon proper demand or notice, shall be entitled to have delivered to him such quantity of water as his stock then represents.

After the completion of the pipes running to any of the lots the pipes become the property of the company and are maintained by it, except when injured by the fault of the stockholder.

The board of directors of this company may acquire title to water for the stockholders and consumers by purchase for a money consideration on such terms as may be deemed reasonable. For such purpose they may issue such obligations of this company as may be necessary, provided that the water be delivered into the Crafton supply or distributing canal or reservoir. All the water and water rights controlled by this company are to be used and distributed exclusively to its stockholders, as they may require, and only upon lands under the system.

FLOATING DIVISION WEIR.

The division of the water among irrigators is usually made over weirs. A masonry box of size varying with the requirements in the case is connected with the main canal by means of a pipe. The water stands at a head in the box varying with the height of water in the main canal and the regulation of an intervening gate. From this box the water flows over a weir to the consumer, the quantity varying with the conditions in the main canal. In this connection an apparatus for the delivery of any constant amount of water has been invented and patented by Mr. W. T. Lambie, of Los Angeles. Fig. 193 on page 557 illustrates the workings of this machine, which is adapted to measure water by uniform flow from lakes, reservoirs, rivers, ditches, etc., for irrigation or other purposes, under all conditions of fluctuation of the surface of the supplying body of water.

This machine is simple in form, cheaply constructed, and can be manufactured of wood or metal, or of both in combination. It can be used on ground having but little fall, and can be made for any flow, from a fraction of a miner's inch to 10,000 miner's inches, or more. The machine can be gaged for the flow desired and the top of the cistern or box closed and locked to prevent it from molestation. Machines have been placed with capacities varying from 1 to 1,000 miner's inches and their uniformly satisfactory working for any size has been demonstrated.

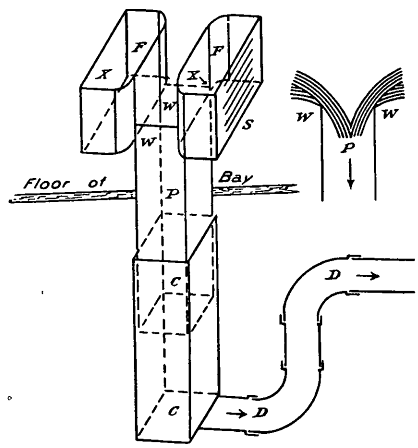


FIG. 193.—Section of floating weir. *F*, floats for supporting movable receiving pipe *P*; *X*, weights placed in floats to submerge same to the necessary depth, as per scale *S* (any heavy substance, such as stone, bricks, or iron, having flat sides, so that they will stay where placed, may be used); *S*, graduated scale on side of floats, showing lines to which the floats should be submerged to measure the quantity of water required over the weirs; *W*, weirs, over which the water falls into the receiving pipe *P*; *P*, the movable pipe down which the water falls after passing over the weirs; *C*, the stationary pipe into which the movable pipe *P* telescopes at the bottom of cistern or box (*P* slides through a close-fitting collar which prevents the escape of any appreciable quantity of water, the joint being such as to work without sufficient friction to interfere with the free movement of *P*); *D*, the discharge pipe (not necessary except to save excavation where outlet is deep owing to length of pipe *P* where fluctuation of water level is great).

The first machine placed was on the water development at Titus ranch, near San Gabriel, Los Angeles County, California, and segregates 6 inches from a 30-inch development, while 6 inches constant flow is set aside to the East San Gabriel Hotel property. It was placed in April, 1894, has been in constant operation since, and has given entire satisfaction.

The largest machine yet built was located on the Laguna rancho, on the south boundary of Los Angeles city, by order from the council of that city, on a large zanja or ditch. Its capacity was 1,000 miner's inches (20 second-feet), and it has the indorsement of the city engineer and other city officials.

The device has the advantages of simplicity, compactness, and accuracy. Its efficiency has been demonstrated by five years' service. Other devices of this nature have been made with a bellows attachment at the bottom of the canal, to avoid the possibility of any catching that there may be in the sliding up and down of the movable pipe. The objection to the bellows lies in the fact that silt deposits in the folds and makes the weighting of the floats uncertain.

ORCHARD LATERALS.

From the Crafton reservoir, shown in Pl. LVI, the distribution is made in cement-lined ditches to the various orchards. These conduits are made of either small or split bowlders. This character of work is carried down to the individual irrigator, where the capacity of the little ditch is not over 25 miner's inches, or one-half of a second-foot. This latter ditch is made of split pieces of bowlder set on edge for the sides, and laid flat for the bottom, in cement mortar, and having small galvanized-iron slides over openings about 1 inch square at intervals of from 2 to 7 feet, the slides being about 1½ inches wide by 3 inches long. The guides for these slides are folded strips of zinc set in cement.

There are several other types of small orchard irrigating flumes. On the flat slopes the square board flume is quite popular. It is made of 1½-inch lumber, and is usually about 8 inches square inside. Two joints in the bottom of the square flume afford twice the opportunity for leaking that there is in the V-shaped flume, which is made of two

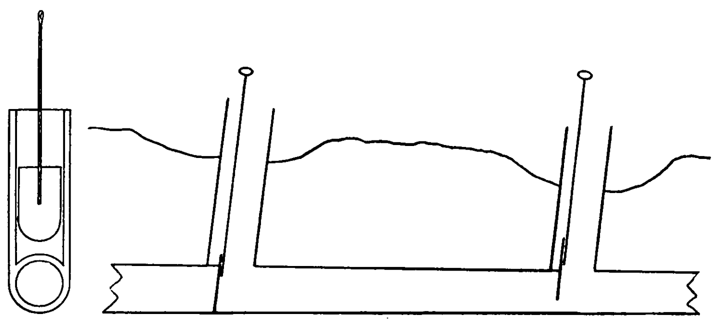
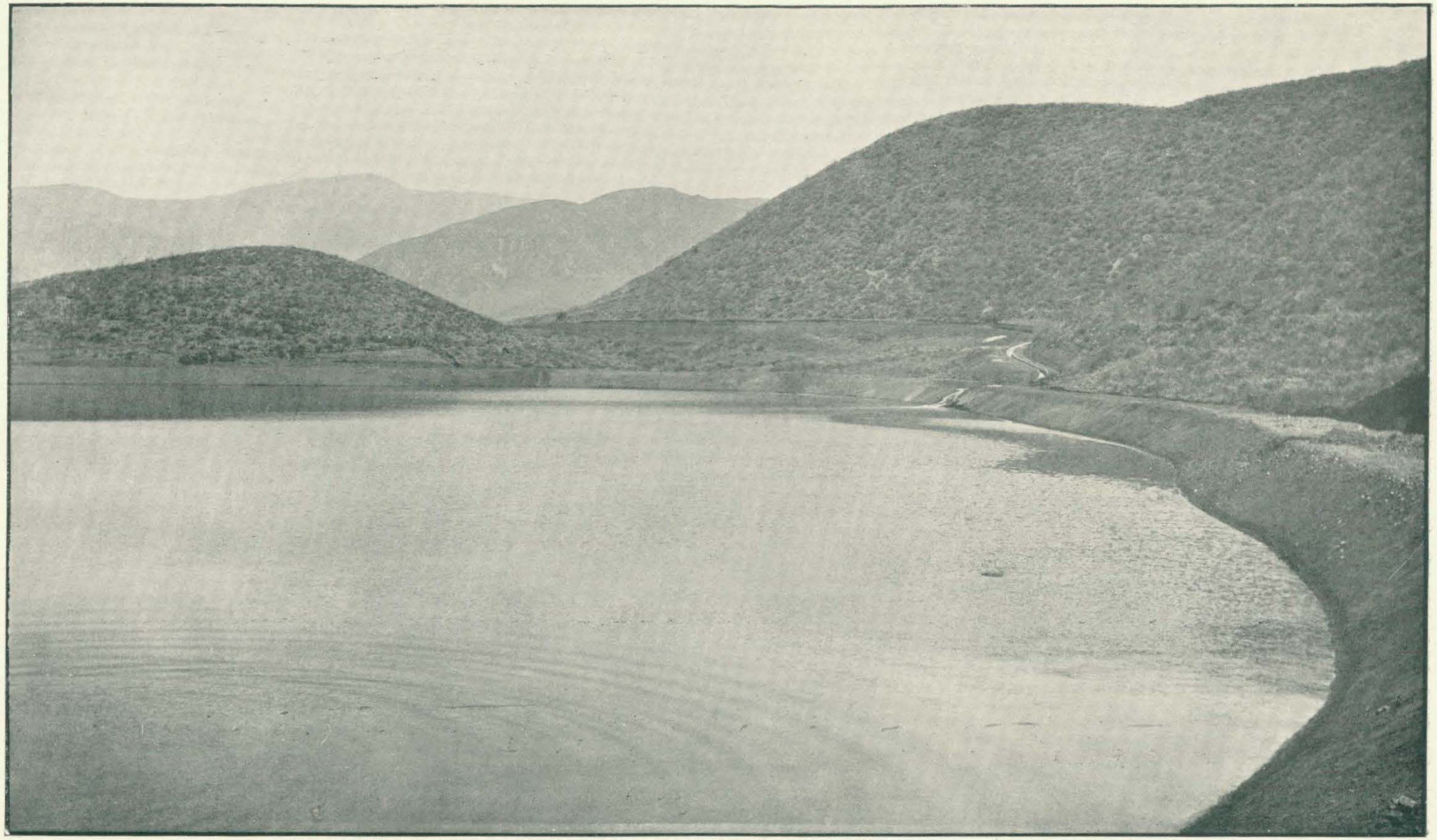


FIG. 194.—Sections of Duarte gate and orchard pipe.

boards with one joint. On hillsides, where the erosion from the leak is great, this is a matter of considerable importance. On steep slopes the flume should be set up a few inches above the ground so that the water from any leak can be controlled.

There is a terra-cotta flume made which possesses some desirable features, but which is not yet generally used. It is about 8 inches square in the clear. The early patterns did not have bell joints, as in the case of sewer pipes, and for this reason did not give satisfaction. Later patterns have remedied this defect. The sections are 2 feet long, and in the center of each section, on one side and next to the bottom, is the regulation opening of 1 square inch, with a terra-cotta spout 5 inches long projecting from it. In the center and opposite this spout, in the top, is a round hole large enough to admit the hand into the flume, so that a small block of wood may be adjusted against a shoulder just below the spout to produce a better flow, and any obstacles may be removed from the spouts.

The form of distribution almost universally used in the Duarte



CRAFTON RESERVOIR, CALIFORNIA.

district is shown in fig. 194. The pipes are made of sand and cement. They are usually 8 inches in diameter. The pipe is so laid as to command the orchard by gravity, and is placed about 2 feet below the surface of the ground. Each of the standpipes shown is in the nature of a safety valve, to relieve the excess of pressure. The top of the standpipe is about 1 foot above the surface of the ground. There is a small gate that works vertically in guides in the standpipe, so adjusted that the desired amount of water is made to flow in artesian style over the top of the vertical pipe. A standpipe is provided for each row of trees, and from it water is led in furrows as desired. The Duarte people claim that they have little or no trouble with roots getting into the pipes.

In the Crafton and Redlands country the cement pipe is held to be very unsatisfactory because the roots fill the pipe and because the small amount of silt carried by the water has often, in their two or three years' use, cut the bottom out of the pipes, leaving the sides and top a shell. Speaking generally, cement pipes, especially of small diameter, are considered a failure.

The system of subirrigation has been entirely abandoned. This consisted of the delivery of water under pressure in iron pipes underground to the root of each tree. The method of delivering water under pressure to each tree on the surface of the ground has also been abandoned, except on terraces, and systems of these types have largely been torn out and replaced by the ordinary surface flume. The objection was that the irrigator desired to see his water and the division of it. The pipes also became clogged and delivered varying amounts of water, and were difficult to clean.

APPLICATION OF WATER.

In this valley, where only orchards and gardens are irrigated, the method of actual distribution of water over the surface of the ground is chiefly by furrows. These furrows are run as the slope of the ground directs, a grade of 0.4 foot to 100 feet, or 0.4 per cent, being satisfactory. They are from 3 to 6 inches deep and are run from 2 to 5 feet apart, the entire orchard being commanded in this way. Each ditch is supplied from one of the small openings in the distributing flume with from 0.1 to 0.25 miner's inch of water. The little stream slowly flows and percolates across the tract, taking in some instances one or two days to cross a 10-acre tract. The fact that the upper side of the tract comes in contact with the more water is compensated largely by the general tendency of the water to move downhill through the soil. Little trouble is experienced from this source. The result of the method is the uniform soaking of the soil.

After the irrigation, as soon as the ground is sufficiently dry, the entire field is plowed, preventing or breaking up the caking or baking of the soil and stopping weed growth. This method in its general result resembles the action of rain, as the distribution is general and slow over the entire surface. The result of the general distribution of the moisture is to draw out the roots of the trees in all directions in their search for water, which gives them an extended feeding area for other purposes. In the case of irrigating in basins around the trees, or with only two furrows next to the trees, the reverse effect on the roots would follow and diminished quantity or quality of fruit would result.

Irrigation by the check method is little practiced here, as the slopes are so steep that the checks would have to be either so large or so numerous as to interfere with the cultivation of the soil. The check method requires the flooding of the ground with water several inches in depth, which shuts off for the time both light and heat. Irrigation by checks is largely practiced with grain and alfalfa in San Joaquin Valley, and is doubtless the cheapest way of irrigating these crops, but they are not so grown in this valley.

Pl. LVII shows one method of irrigation on a sidehill or slope. In this case checks are thrown up, forming basins into which the water is discharged and permitted to settle into the ground. Another method of irrigation on the sidehill is to run furrows with a plow on grade contours, the water then being handled as in the ordinary method of furrow irrigation. The furrow method is the one generally adopted in the San Bernardino Valley as the most satisfactory. Either way gives a high efficiency to the water used.

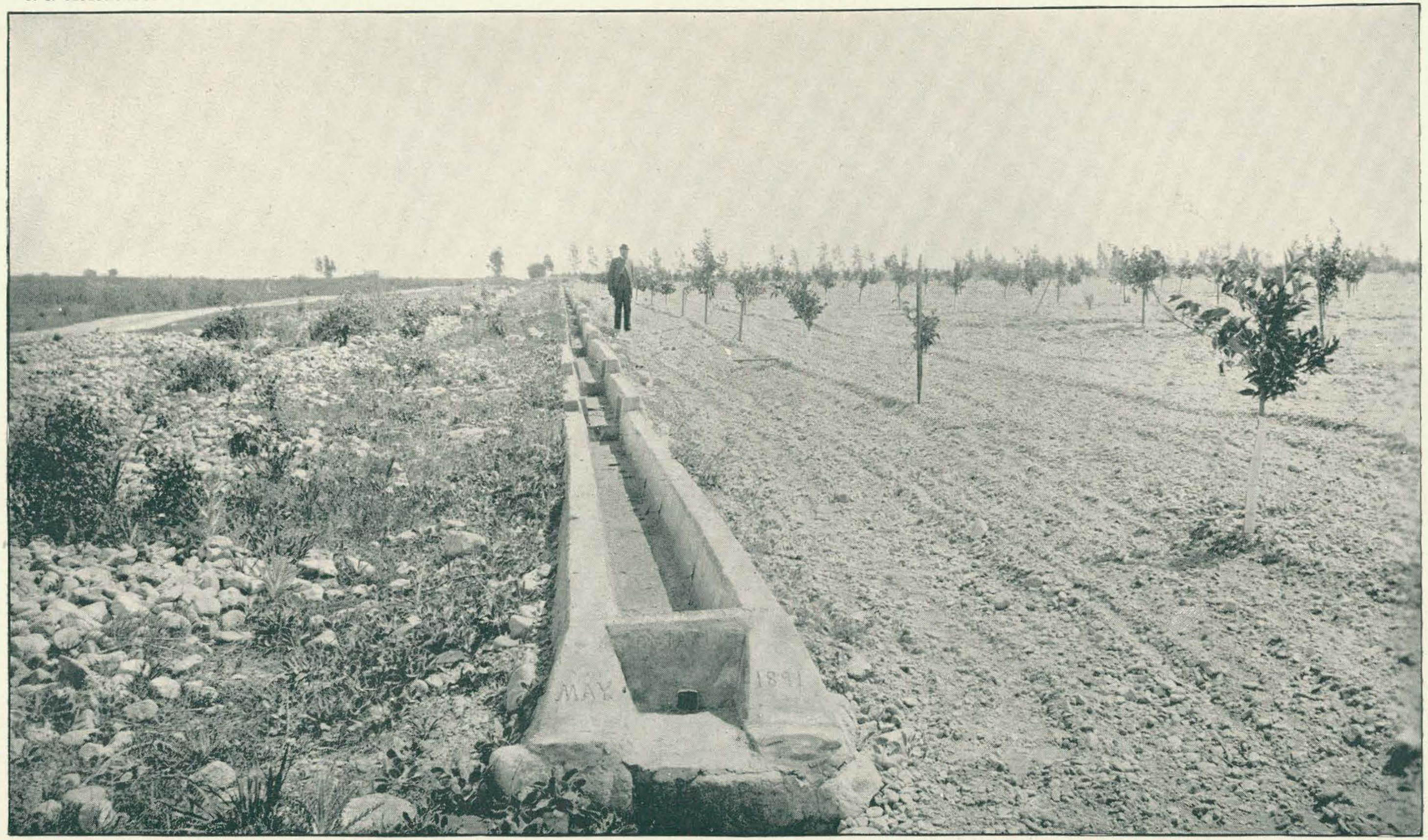
Pl. LVIII shows an orchard lateral, such as is frequently used in southern California in the distribution of water to the orchards, and illustrates the detailed care with which the irrigators handle this valuable and scarce commodity. Small openings may be noticed in the lower right-hand side of the conduit through which the water passes to the furrows. These openings are regulated by means of small zinc slide gates which are worked vertically in small metal grooves. At intervals of about 50 feet checks are put in the canal to still the water and to increase the head over the openings. A comparison with Pl. LV, showing the ordinary method of irrigation by flooding, will illustrate the relative care with which water is used in southern California.

REDLANDS HEIGHTS.

The waters from Mill Creek supply the higher lands of San Bernardino Valley on the southern side. From the end of the Crafton main a 16-inch cement pipe extends 2 miles to Redlands Heights, thence a 6-inch pipe extends 2 miles farther to command Smiley Heights, or Canyon Crest Park. These pipes, with several miles of laterals, constitute the Redlands Heights system, which is owned by the Crafton Water Company.

Two methods of applying water are practiced here. By one the hill is terraced, as shown in Pl. LIX. In this method a slight excess in

ORANGE ORCHARD, SHOWING METHOD OF APPLYING WATER BY BASINS ON TERRACES.



CEMENT DISTRIBUTING DITCH, NORTH POMONA, LOS ANGELES COUNTY, CALIFORNIA, ILLUSTRATING METHOD OF DISTRIBUTING WATER TO ORCHARDS.

elevation is given to the outside bank to prevent washing, and the water is then handled in the furrow manner on the benches. Another and cheaper method is to run the furrows on the grade contours without terracing, using much care to prevent breaks and washes, but this is usually unsatisfactory. The landscape effect of these hillside orchards is very beautiful, and terrace irrigation is practiced by many wealthy fruit growers and gardeners, of whom there are a considerable number in the valley. This feature lends a peculiar charm to Crafton and Redlands.

The soil of the southern slope of the valley is of red-clay loam, mixed somewhat with disintegrated granite crystals. It does not require as much water as the more sandy soils and gravels, but much more skill in the application to the land. The duty of water for citrus fruits ranges from 4 to 7 acres per miner's inch for this locality. One inch to 4 acres is regarded by experienced growers as the best amount for well-developed citrus orchard. It is generally thought that the deciduous fruits require about one-half as much water.

The flow of water is considered as continuous from five to seven months each year, beginning with February or April. The rainy season in California extends generally from November to April, and this limits the duration of the irrigating season.

CANYON CREST PARK.

Canyon Crest Park, having an area of 200 acres, lies on the hills southwest of Redlands, with its slope on the south breaking off to San Timoteo Canyon. Ten years ago Messrs. A. K. and A. H. Smiley bought this land and succeeded in obtaining water from the Crafton Water Company, storing it in reservoirs. There are several miles of pipe line in the park, and the water is delivered under pressure through small hydrants.

The grounds are terraced and planted to orchards of oranges, lemons, and olives. There are one thousand varieties of trees and shrubs. Miles of winding drives are laid out on the hills. The walks, drives, and canyons are planted with rare trees and beautiful flowers. The outlook from these hills commands San Bernardino Valley, with ranges of snow-covered mountains serving as a background.

Where a decade ago sheep could scarcely feed there is now one of the most beautiful parks in the world, the delight of hundreds of tourists and the pride of southern California.

MENTONE WATER DEVELOPMENTS.

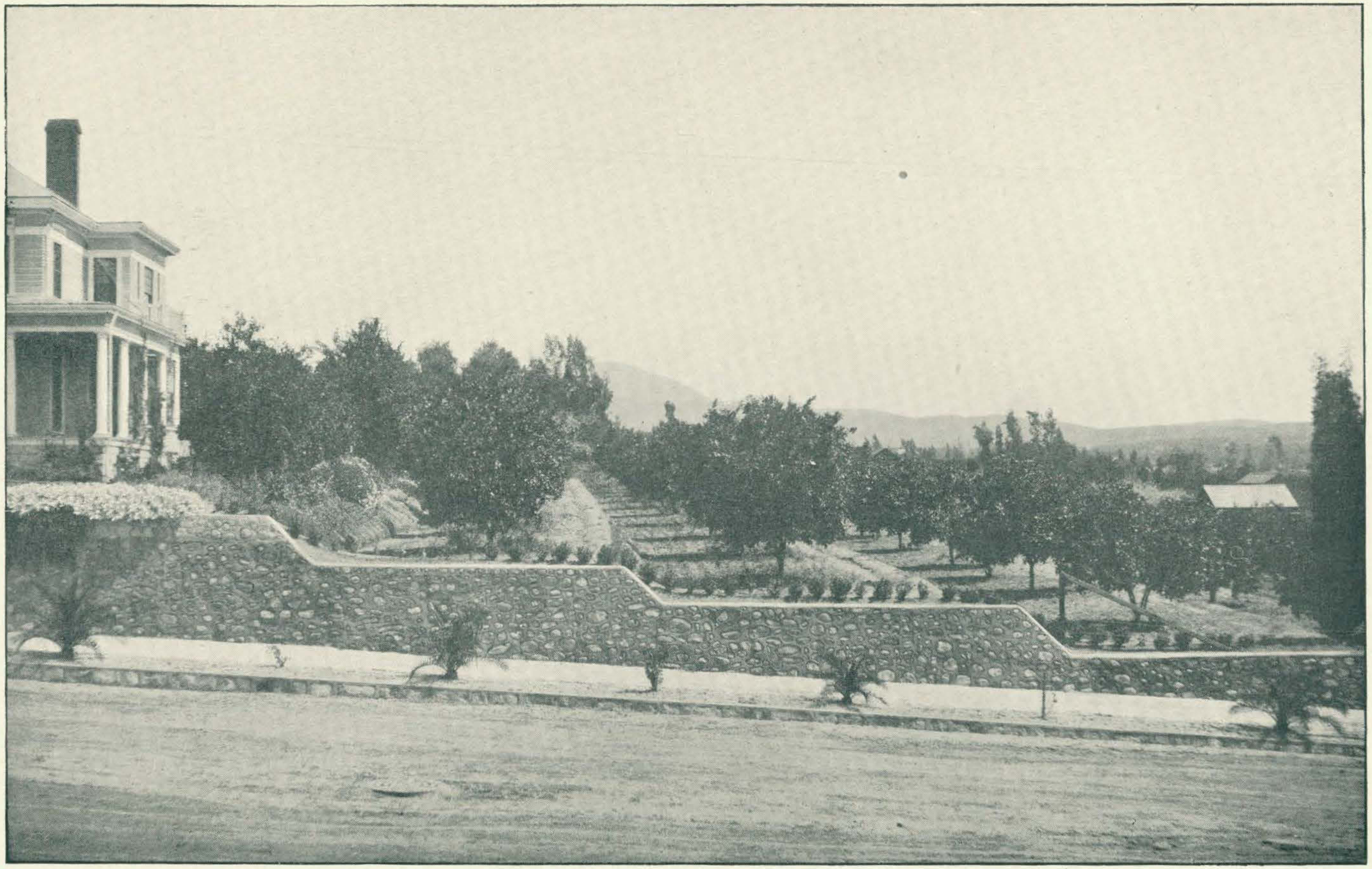
Mentone is situated in the eastern end of the valley, northerly from Crafton and easterly from Redlands. The source of supply is Mill Creek, the rights being secondary to those of the owners of water from the Mill Creek zanja. A description of the works of the Mentone Irrigation Company has been furnished by James D. Schuyler, consulting engineer, permission having been obtained to make this use of his report to the directors of the company.

The lands along Mill Creek consist of a broad gravel dump, or wash, from 500 to 2,000 feet wide, over which the stream meanders at flood time in channels from 15 to 20 feet below the level of the banks. The zanja, built by the mission fathers about the year 1820, has customarily taken the entire surface flow of the stream during the summer stage, but the winter flood flow has always passed down through the main wash, on the lands now owned by the Mentone Irrigation Company, to where it is united to Santa Ana River. This yearly flushing of the gravel beds of the stream replenishes the natural reservoir of the broad, rocky "wash," and the level of the subsurface of the water table, drawn down by slow drainage through the summer, is restored in winter. This underflow is partially thrown to the surface in some places, and at two points some development work has been done in the way of tunneling and open trenching, by which means the present water supply has been obtained.

The points selected for this work were where the living springs appeared on the surface. The upper one of these is on sec. 22, T. 1 S., R. 2 W., adjacent to the lands of Mrs. M. A. Brown. Immediately below these springs there is a bold outcrop of granite on the north side of the creek, forming an abrupt bluff, which seems to force a part of the subsurface water to the top of the ground. Apparently this water comes from the mountain drainage immediately adjoining and finds its way into the gravel beds underlying the bench land (which is parallel with and 15 to 20 feet higher than the stream), as well as in part, no doubt, from the creek itself. Here the work for the development of water was commenced by the Excelsior Company about the year 1884, which company afterwards sold to the Mentone Company.

In 1885 and 1886 Mrs. Brown cut some drain ditches in the cienaga and drove a tunnel that is said to have been 1,100 feet long, in a direction almost parallel to the south line of her property, and but 50 feet distant from it, resulting, it is stated by her son, in a flow of 135 miner's inches from the mouth of the tunnel. At the present time there is nothing to be seen of the tunnel, as its mouth has become choked, the approach wholly or partially filled, and there is practically no water issuing from it. This choking has no doubt been caused by willow roots that have penetrated to the water and formed a mattress in the tunnel and so filled the entire tunnel that no water of any moment can pass.

The predecessor of the Mentone Irrigation Company at the beginning of its operations first constructed a ditch, called Excelsior ditch, with a capacity of 700 miner's inches, and diverted water from various springs on and adjacent to the land owned by Mrs. Brown out across the wash onto the mesa and thence toward Mentone. This was the first appropriation of the water of these springs. This ditch was super-



TERRACE GARDENING AT REDLANDS HEIGHTS, CALIFORNIA.

seded shortly after its construction by a sheet-steel pipe, 10½ inches in diameter, which began a few hundred feet below the head of the ditch, at the mouth of the development tunnel that was started in the gravelly bed of the wash, and was driven in an easterly direction nearly parallel with the north line of the property and about 100 feet south of the line; and the water from the tunnel, as well as that brought from the surface ditch directly from the springs, was taken into the pipe at this point.

This tunnel, starting 1,150 to 1,200 feet west of the mouth of Mrs. Brown's tunnel and about 50 feet lower in elevation, has been driven a total distance of 950 feet, including about 120 feet of open cut. The last 400 feet of the tunnel were driven in the summer of 1894. A crosscut of about 100 feet, which was run over to the north line of the property, encountered bed rock on the way and went into it for some distance, but without material increase in the flow. This is explained by the fact that the principal part of the water comes from the south and east, as is demonstrated at the last shaft, about 100 feet east of the crosscut, where, by looking down the open shaft, which is placed just to the south of the tunnel and not directly over it, a strong stream is plainly to be seen from the surface, flowing across northward into the tunnel. The total amount of water flowing from the mouth of the tunnel October 30 was carefully measured over a weir placed in a sand box at the head of the pipe line, and was found to be 123.15 miner's inches, or 8.5 miner's inches per linear foot of excavation. The 10½-inch pipe before mentioned extends along the wash of Mill Creek to the south bank, a distance of 800 feet, where its highest point is but 7.2 feet lower than its head, which limits its capacity to 120 miner's inches. At 890 feet from the head it is reduced to 6 inches in diameter for 300 feet to the division box, where part of the supply is carried in a 6-inch pipe across the wash again to the "bench" on the north side of Mill Creek, supplying about 135 acres of orchard lands lying from 200 to 250 feet lower than the tunnel. From the division box a flume 12 inches square formerly extended all the way down the slope to Mentone, but a few years ago about one-half mile of this flume was accidentally burned and later replaced by a 6-inch cement pipe. The capacity of the flume on the grade it has, when tight, in good order, and full, is about 325 miner's inches. The north flume, from the lower development at the German Springs, joins the upper flume about a mile below the tunnel. The lower development, at what is known as German Springs, about 3,800 feet below the mouth of the tunnel, has been made in the way of a crosscut, following the bed rock part of the way across the stream channel, which is here about 500 feet wide.

This has been done as an open cut, 10 to 15 feet deep, which has been lined with a flume and partly refilled; but it is evident that willow roots, which have been so disastrous elsewhere, have here filled the cut and flume to such an extent that but little water gets through, and most of that found comes from the surface flow of the springs and from a ditch leading from an independent spring about 300 feet higher up the creek on the north side. This latter source measured 9.13 miner's inches, and the total, including that from the crosscut and the German Springs, was found to be 30 miner's inches. The entire measured supply, on October 30, 1896, may be recapitulated as follows: From the ditch north of the mouth of the tunnel, known as part of Excelsior ditch, 48.27 miner's inches; Mentone Water Company's tunnel, 123.15 miner's inches; Triangle Springs, 9.13 miner's inches; German Springs, north of flume, 20.78 miner's inches; total, 201.33 miner's inches. The discharge is now greatly reduced.

The flume leading from the German Springs to a junction with the main flume, 1,920 feet below, is 24 inches in width for 533 feet and 16 inches the rest of the way, and is 12 inches in depth. At the head, where it has a grade of 1 per cent, it originally had a capacity of about 650 miner's inches. About 400 feet of the 16-inch flume is on a 1 per cent grade and has a capacity of 385 inches; the remainder is on a 2 per cent grade and has a maximum capacity of 550 inches. During the course of his investigations Mr. Schuyler took occasion to measure the Mill Creek zanja. At the crossing of the Bear Valley upper canal the measurement showed a flow of approximately 1,130 inches. Half a mile higher up, at the head of the zanja, the river carried about as much above the foot of the power company's race way as that conduit was delivering, which was found to be 640 miner's inches, as measured over the permanent weir at that point. No exact measurement could be made of this quantity without going to the expense and trouble of putting in a weir in the stream above the junction of the power race way; this was not done, but judging by the eye there was very little difference in the two streams, which would make the total stream flow when united about 1,240 miner's inches.

While this is usually all appropriated and used, one has the right to the underflow of the stream, which is, to be sure, an indefinite quantity, impossible of estimation, but nevertheless a resource whose possibilities and probabilities are great and well worth exploiting. Mill Creek, as before stated, has a watershed area of 58 square miles of such character that the mean run-off may be safely estimated at 50 per cent of 48 inches precipitation, which would be equivalent to 74,000 acre-feet, or sufficient to supply 25,000 acres with a perpetual flow of 1 miner's inch to 5 acres. Unfortunately much of this goes to waste during floods, and as there is no opportunity for impounding it, and no good storage reservoir sites available on the stream, the only portion that can be utilized is that which is naturally stored in the great gravel beds in and below the canyon. The rate of flow through gravel mixed with sand is exceedingly slow, varying from 1 to 10 miles per annum, and for this reason a gravel-bed reservoir, even though it be on a steep grade, only needs to be of sufficient area, depth, and extent to afford large streams of water when tapped at a considerable depth by a tunnel. San Antonio Creek, in the western part of San Bernardino County, affords a very encouraging example of this sort of water-supply development. The various tunnels and artesian wells between Pomona and the mountains north of it are fed directly by the underflow of San Antonio Creek and must amount in aggregate to over 1,500 miner's inches, notwithstanding the fact that the watershed of the creek is 25 square miles, which is less than half that of Mill Creek.

The gravel dump may be very much wider and deeper and of greater area than that of Mill Creek, and it may be restrained from draining away as quickly by special conditions that do not prevail on Mill Creek, but there is enough similarity to permit analogous deductions and to encourage the belief that there is considerable water to be drawn from these gravel beds if properly treated.

The total land for which water rights have been sold is, approximately, 413 acres, exclusive of the 360 acres within the limits of the town site of Mentone. Messrs. McIntosh, Marlette & Dood own 1,300 acres additional, of which 520 acres are in the gravel wash of Mill Creek and will never be irrigated, leaving 780 acres needing water. This, added to the 413 acres already sold and 360 acres of the town site, makes a total of 1,553 acres to be provided. When the lands were first subdivided and the water company was organized it was the general impression among real-estate men and many irrigators that an allowance of 1 miner's inch to 10 acres was enough for all fruit crops. On a basis of 1 inch to 10 acres there would be required about 155 inches to supply the lands already sold and then on sale, which it was intended to serve with water by the Mentone Irrigation Company.

SIMILAR WATER DEVELOPMENTS.

In connection with this water development the following information is of interest: At Tempe, Arizona, a well 6 feet in the clear was sunk through sand and bowlders to a depth of 25 feet, the plane of saturation being about 4 feet below the surface of the ground. A centrifugal pump lifting 4 second-feet made a run of 158 hours, which affected the plane of saturation, as shown by a series of bored wells in line from the main well, as follows: At main well, drop in plane of saturation of 17.7 feet; 56 feet from main well, 6.8 feet; 118 feet from main well, 4.9 feet; 183 feet from main well, 3.4 feet; 360 feet from main well, 1.8 feet.

The location was below a 30-foot mesa in the bottom-wash land of Salt River. The pump discharged into an unlined canal within 20 feet of the shaft. The result indicates the reach or draw from the well into the plane of saturation, which plane is supplied from the river and adjacent canals.

The Azusa and Duarte irrigators own the surface waters of San

Gabriel River in southern California, and at first diverted these waters at the mouth of the canyon. The Vineland irrigation district, desiring a water supply, constructed a tunnel 2,000 feet in length into the sand-and-bowlder wash of the canyon, following its western wall, the head being within 175 feet of the river. Between the tunnel head and the river two wells were sunk by the Azusa people to determine the relation of the water levels. The results obtained much resembled the conditions shown at the Tempe well.

A supply was obtained by the Vineland people of from 1 to 2 second-feet. The original water company, to avoid the drain on the surface flow, built a pipe-and-tunnel line to a point a mile above the Vineland heading and there diverted their water on bed rock. On July 15, 1896, the water was all turned into the new pipe line. The flow of the Vineland tunnel at once began to diminish, and gradually fell from 1.11 second-feet on July 15 to 0.0 on August 7, 1896.

On August 16 a cloud-burst occurred on a clay portion of the basin, washing down much silt and ashes, "slicking" over the channel of the river to the mouth of the canyon. On October 27, 1896, the irrigating season being over, the water of the river was returned by the Azusa people to its old bed, but it did not as before percolate through to the Vineland tunnel. On February 1, 1897, a heavy general storm raised the river so that it flushed out its bed, and in a few days the Vineland tunnel was collecting and discharging 2 second-feet of water.

It would be difficult to show a clearer connection between so-called developed water and surface water. The case at Tempe, showing the reach from a well or tunnel, and that at San Gabriel, demonstrating the source of supply, are interesting, as indicating the effect of development on surface flow in formations of this character. Doubtless the sands and gravels are charged each year by storm waters that may be drawn upon, but the supply is greatly enhanced by a running stream or canal on the surface. The statement given below shows the amount of water obtained by development works in a sand or bowlder wash. In each instance running water is on the surface of the ground within a distance of 100 to 500 feet.

Amount of water obtained by development works in a sand or bowlder wash.

Locality.	Company.	Class of work.	Length of work.	Miner's inches per 100 linear feet.
			Feet.	
German Springs, Mill Creek.	Mentone Irrigation Company.	Open cut..	500	6.0
Upper Spring, Mill Creek.	.....do	Tunnel....	1,050	11.7
Santa Ana tunnel, No. 1.	Redlands Water Company.	....do	600	5
Santa Ana tunnel, No. 2.	.....do	....do	1,800	7
East Twin Creek...	E. A. Phillips	....do	400	5
San Gabriel River..	Vineland irrigation district.	....do	2,000	5
San Fernando Valley.	West Los Angeles Water Company.	Open cut..	3,000	11
Mill Creek wash....	Mrs. M. A. Brown ...	Tunnel....	1,100	*a*12
Arroyo Seco	Pasadena Water Company.	....do	6,000	4

a Has decreased over one-half.

In the case of the West Los Angeles Water Company there was a flow of 60 miner's inches at a spring to start with, which has been deducted from the total flow. This development is in a dry channel of Los Angeles River and consists of an open cut, the maximum depth of which is 30 feet.

SANTA ANA RIVER.

The mountainous area which constitutes the drainage basin of Santa Ana River has steep slopes, but the surface is fairly well covered with soil, except in the canyons, the underlying granitic rocks having been largely disintegrated, leaving an absorbent soil on the surface. The northern slopes are covered with underbrush at elevations of from 2,000 to 6,000 feet. At an elevation of 3,000 feet pines appear, the trees increasing in size and number to an altitude of 6,000 feet and disappearing at about 10,000 feet. The catchment basin is not so well situated as that of Mill Creek, as regards precipitation, being, to a large extent, to the lee of the crest of the range, and Grayback and San Bernardino peaks cut off in part storm winds from the south.

The drainage basin may be divided into four portions, whose areas are as follows: Main river above junction of Bear Creek, 88 square miles; tributary to Bear Valley reservoir, 54 square miles; Bear Creek below dam, 16 square miles; main river below Bear Creek, 31 square miles; total, 188 square miles. These areas have been measured from

Beasley's county map, edition of 1892. The 16 square miles of basin tributary to old Bear Lake are not included in the total given above, as the overflow is toward the desert.

RAINFALL.

Observations have been made at two rain gages, one at the Bear Valley dam and the other near the eastern rim of the basin at Bear Creek. The Bear Valley rain gage, besides being located in a canyon where the precipitation might be expected to be excessive, is situated so as to get the advantage of the crest rains, and its average record of 53.70 inches is probably 20 to 30 inches greater than the mean for the basin. (See remarks on Arrowhead rainfall, page 620). The maximum year given is 176 per cent of the mean, and the minimum 37 per cent of the mean.

Bear Valley rainfall record, September 1 to August 31.

Year.	Inches.	Year.	Inches.
1883-84	94.60	1889-90	93.40
1884-85	28.06	1890-91	78.40
1885-86	65.51	1891-92	38.00
1886-87	24.00	1892-93	44.32
1887-88	62.30	1893-94	19.75
1888-89	46.08	1894-95	50.00

The portion of Bear Valley basin to the east of the gage at the dam not only has much less precipitation, but a very much greater portion of the snowfall is lost by evaporation, owing to its exposure to the dry desert winds. It is found that at the eastern end of the basin the snow reduces to water at the ratio of 10 to 1, while approaching the crest it is nearer 5 to 1.

The Upper Holcomb rain gage is near the northeast edge of the Bear Valley basin and shows this marked decrease in rainfall near the eastern rim. The mean for the years given is 14.09 inches. The rainfall at San Bernardino city during the period 1892-93 and 1897-98 was 84 per cent of the twenty-eight-year mean at that place.

Upper Holcomb rainfall record. (a)

Year.	Inches.	Year.	Inches.
1892-93	11.70	1895-96	7.90
1893-94	15.27	1896-97	13.50
1894-95	21.80	1897-98 *b*	9.30

a NE. ¼ sec. 33, T. 3 N., R. 1 E. Elevation, 7,200 feet.
b Record for 1897-98 is from September 1, 1897, to June 1, 1898.

DISCHARGE MEASUREMENTS.

Estimates of the amount of water available from Santa Ana River have been made by the Bear Valley Company. The results are shown in the progress report for 1895.[1] In June, 1896, the writer established a station for measuring the streams at a point opposite Warmsprings, immediately above the junction of Warmsprings Canyon with Santa Ana River, this being below the point of diversion of the canal. Here the channel is comparatively deep and broad, being straight for a distance of over 100 feet above and 50 feet below. A cable was stretched across the stream and measurements were made from a suspended car. The gage is about 60 feet above the cable on the south or left bank of the stream, and consists of an inclined rod fastened under a group of bowlders at the lower end and by wires to trees at the upper end. The initial point for sounding is on the left bank, at a staple in a cottonwood tree at the cable. The results obtained are shown in the accompanying table. The observer, A. Laird, zanjero for the Bear Valley Irrigation Company, reads the gage daily. At about 75 feet below the cable is a riffle which causes slack water and deposit of silt near the cable. This being occasionally flushed out necessitates frequent revision of the rating curve and prevents a fairly constant relation between area of section and velocity. A more detailed description of this station is given in Water-Supply and Irrigation Paper No. 16, p. 195. The relation of gage height to discharge, and the estimated discharges of the river are given in the following table:

Rating table for Santa Ana River at Warmsprings, California.

Gage height.	Discharge.			Gage height.	Discharge.		
	July 1, 1896, to May 31, 1897.	June 1 to July 31, 1897.	Aug. 1 to Dec. 31, 1897.		July 1, 1896, to May 31, 1897.	June 1 to July 31, 1897.	Aug. 1 to Dec. 31, 1897.
Feet.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*
0.8	....	....	23	2.0	260	....	....
0.9	25	....	24	2.1	300	....	....
1.0	33	55	26	2.2	340	....	....
1.1	41	60	30	2.3	380	....	....
1.2	52	67	38	2.4	420	....	....
1.3	64	78	52	2.5	460	....	....
1.4	81	92	70	2.6	500	....	....
1.5	101	110	90	2.7	540	....	....
1.6	126	129	....	2.8	580	....	....
1.7	153	151	....	2.9	620	....	....
1.8	186	....	....	3.0	660	....	....
1.9	221	....	....				

[1] Report of progress of the Division of Hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge: Bull. U. S. Geol. Survey No. 140, 1896, pp. 318-321.

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.		Depth in inches.	Second-feet per square mile.
1896.						
July	76	48	63	3,891	0.39	0.34
August	83	33	57	3,492	0.35	0.30
September	77	27	55	3,289	0.32	0.29
October	170	38	55	3,387	0.33	0.29
November	52	30	a 33	1,939	0.19	0.17
December	40	33	a 35	2,176	0.22	0.19
1897.						
January	101	27	62	3,836	0.38	0.33
February	580	72	181	10,060	1.00	0.96
March	460	64	119	7,317	0.72	0.63
April	186	101	146	8,675	0.87	0.78
May	101	29	61	3,769	0.38	0.33
June	67	57	63	3,737	0.37	0.33
July	85	57	67	4,119	0.41	0.36
August	80	34	57	3,505	0.35	0.30
September	61	38	47	2,779	0.28	0.25
October	250	25	42	2,582	0.25	0.22
November	52	34	a 38	2,261	0.22	0.20
December	30	22	a 26	1,610	0.16	0.14
The year	580	22	76	54,250	5.39	0.40
1898.						
January	58	33	49	2,987	0.30	0.26
February	76	33	48	2,688	0.27	0.26
March	40	25	40	2,448	0.24	0.21
April	....	28	36	2,134	0.21	0.19
May	149	26	61	3,727	0.37	0.32
June	58	36	48	2,840	0.28	0.25
July	53	33	43	2,625	0.26	0.23
August	58	33	43	2,653	0.26	0.23

a The reduced flow of November and December is due to closing the Bear Valley dam.

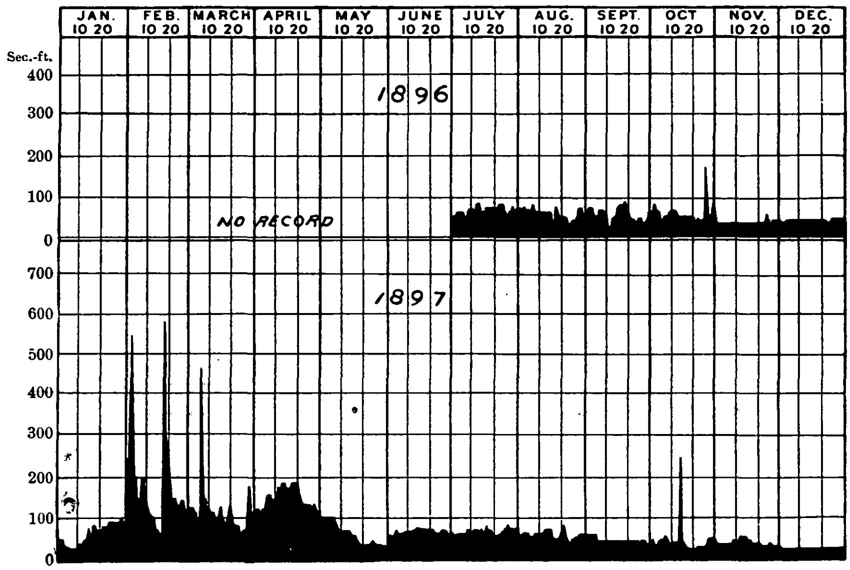


FIG. 195.—Discharge of Santa Ana River at Warmsprings, California, 1896 and 1897.

Estimated monthly discharge of Santa Ana River and Santa Ana canal.

Month.	Discharge in second-feet.					
	Santa Ana River.			Santa Ana canal.		
	Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.
1896.						
July	76	48	63	....	....	14.0
August	83	33	57	....	....	14.0
September	77	27	55	....	....	14.0
October	170	38	55	....	....	16.0
November	52	30	33	....	....	3.5
December	40	33	35	....	....	4.2
1897.						
January	101	27	62	8.5	3.2	5.6
February	580	72	181	6.0	0.0	4.0
March	460	64	19	6.0	0.5	5.2
April	186	101	146	12.0	0.0	3.8
May	101	29	161	20.0	0.0	15.0
June	67	57	63	19.0	0.0	16.6
July	85	57	67	18.5	10.6	15.6
August	80	34	57	20.0	17.4	18.3
September	16	38	47	....	....	20.0
October	250	25	42	....	....	12.4
November	52	34	38	....	....	7.0
December	30	22	26	....	....	7.0
The year	580	22	76	....	....	10.9

Estimated monthly discharge of Santa Ana River and Santa Ana canal—Continued.

Month.	Discharge in second-feet.					
	Santa Ana River.			Santa Ana canal.		
	Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.
1898.						
January	58	33	49	....	....	9.0
February	76	33	48	....	....	10.0
March	40	25	40	....	....	11.0
April	34	28	36	....	....	9.0
May	149	26	61	....	....	8.0
June	58	36	48	....	....	3.9
July	53	33	43	....	....	5.3
August	58	33	43	....	....	3.0

Estimated monthly discharge of Santa Ana River, including Santa Ana canal, at Warmsprings, California.

[Drainage area, 188 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1896.						
July	....	....	77	4,753	0.47	0.41
August	....	....	71	4,353	0.44	0.38
September	....	....	69	4,124	0.41	0.37
October	....	....	71	4,372	0.44	0.38
November	....	....	37	2,148	0.21	0.19
December	....	....	39	2,435	0.24	0.21
1897.						
January	104	35	68	4,179	0.41	0.36
February	585	77	185	10,282	1.02	0.98
March	465	70	124	7,637	0.76	0.66
April	190	113	150	8,899	0.89	0.80
May	113	48	76	4,690	0.47	0.41
June	86	60	80	4,723	0.47	0.42
July	102	70	83	5,077	0.51	0.44
August	100	54	75	4,628	0.46	0.40
September	81	58	67	3,968	0.39	0.35
October	270	45	54	3,347	0.33	0.29
November	59	40	45	2,678	0.27	0.24
December	38	29	33	2,040	0.21	0.18
The year	585	29	87	62,148	6.19	0.46

HIGHLANDS OR NORTH FORK SYSTEM.

Mormons from Salt Lake, who were the first Anglo-Saxon immigrants to enter this valley, founded the town of San Bernardino, and in 1855 built on the south side the first ditch from Santa Ana River. This ditch, known as the Tinney ditch, with some of the underlying lands, was purchased by Judge H. M. Wills, in 1857, from Bishop Tinney. Judge Wills did not make immediate use of his canal, and so lost his right, the water being claimed by a lower ditch on the opposite or north side, known as the North Fork, which, however, must not be confounded with the North Fork of the present day. These ditches were located but a few miles east of San Bernardino.

The second ditch constructed on the Santa Ana was the Timber ditch, which was built in 1857. This canal also was built on the north side of the river. In 1898 this ditch was dry and practically abandoned. Gradually other small ditches were constructed and controversies arose.

As a result of the first water suit brought in San Bernardino County, the Cram-Van Lueven ditch, which was built in 1858 and made its diversion at the mouth of the canyon, was given one-sixth of the entire flow of Santa Ana River at that point. The old North Fork ditch was abandoned and its waters transferred to this Cram-Van Lueven ditch, which was enlarged, and the consolidated canal was known as the North Fork.

The North Fork Water Company was incorporated in July, 1885, and jointly with the Cram-Van Lueven people operated this north-side system. The location of this canal was changed several times, each move putting it on higher ground, until in 1887 or 1888 the present cement-lined ditch was constructed next to the foot of the mountains from the mouth of Santa Ana Canyon, through East Highlands, and along the foothills to Del Rosa. A pipe line to San Bernardino was constructed by the Bear Valley Irrigation Company from this terminus.

By reference to the table in Bulletin No. 140, p. 318, giving the flow of Santa Ana River, it is seen that the North Fork canal, having a right to one-half of the water in the river, obtained only 6 second-feet, or 300 miner's inches, during minimum years. Mr. F. E. Brown, having studied the situation and the possibilities of the Bear Valley reservoir, submitted propositions to the North Fork and the South Fork companies to guarantee them each year the following water: June, 500 miner's inches; July, 600; August, 600; September, 500; October, 450; November, 400; mean, 508. The privilege was further granted them of taking water in such amounts as they pleased, provided they did not use over 2,200 miner's inches in any four consecutive months. In consideration of this the Bear Valley Company was to be permitted to store all available water at the Bear Valley reservoir at all times of the year. It was also permitted to run through this canal an amount of water equal to that run by the North Fork Company, but the Bear Valley Company was to pay one-half of the cost of reconstructing and enlarging the old canal and one-half the cost of maintenance, which was to be under the control of the North Fork people. If the Bear Valley Company failed in the contract it was to forfeit all interest in the plant. This agreement became effective June 1, 1886.

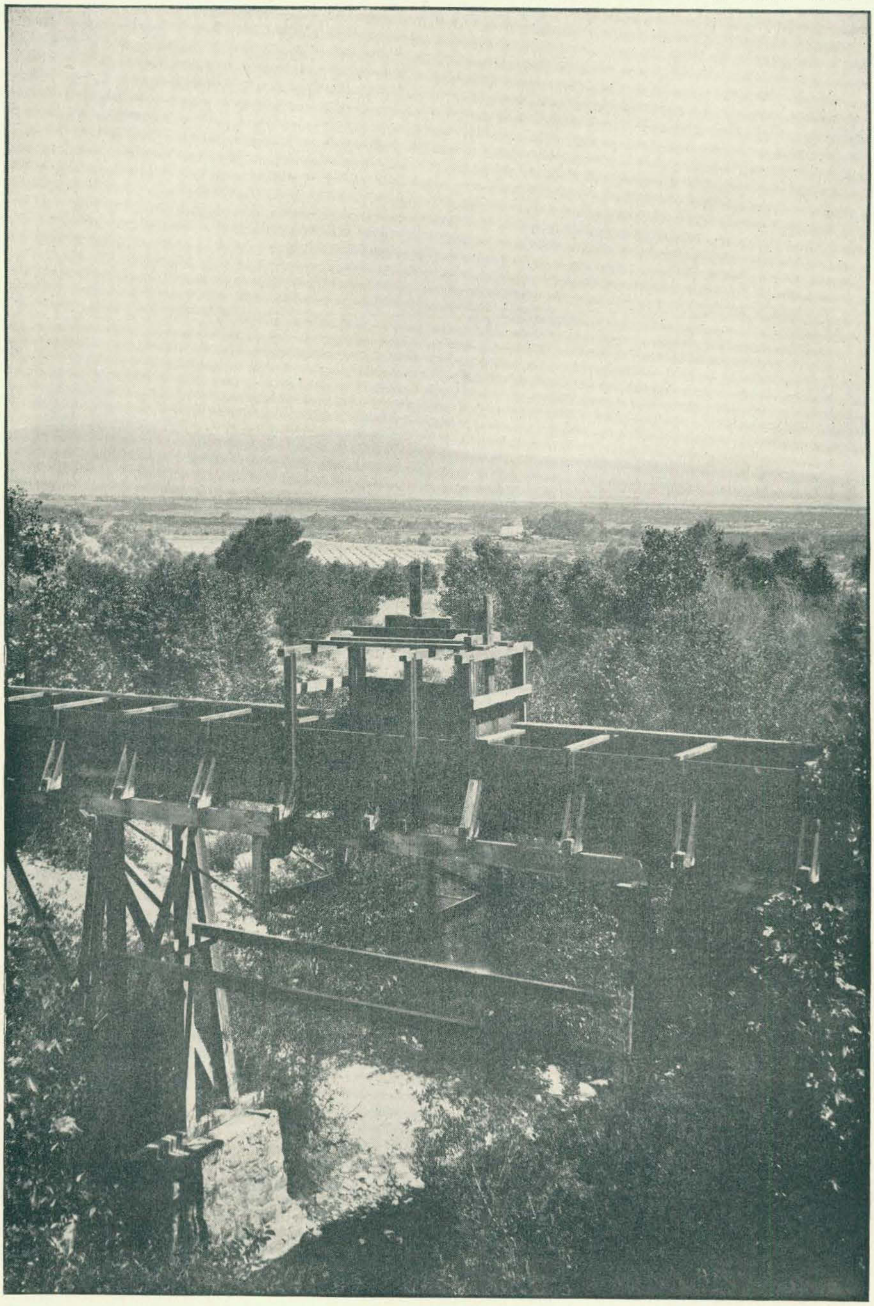
NORTH FORK CANAL.

The diversion of water from Santa Ana River is by means of temporary headworks below the "divide." The canal is the same form of structure as that described on page 554 in the Crafton discussion. This canal in places is on a 16-per-cent grade; the berms are very narrow, permitting the sand to blow into the canal, but it has stood in good condition for ten years and is now quite perfect. Velocities of 20 feet per second have been measured in this canal. (See Pl. LX.)

In places where the Highlands or North Fork canal passes through a conglomerate formation of sand, gravel, and clay, partly indurated, a cement plaster, consisting of 1 part cement and 3 parts sand, is put directly on the natural material and has stood well. The same practice has been followed to advantage in tunnels. Where the line has been built on fills, a year has been given for the earth to settle. The bottom widths vary with the grade from 2½ to 6 feet, the top from 4½ to 8 feet, and the depth from 2½ to 3½ feet. The total cost is estimated at $37,500. Other expenses, such as right of way, legal expenses, etc., will bring the total up to between $45,000 and $48,000 to the North Fork Company, and $77,000 to $80,000 to all concerned.

The North Fork water was valued, in 1888, at $720 a miner's inch. During the summer season of 1896 the Bear Valley Irrigation Company charged and collected 35 cents per 24-hour day per miner's inch (0.2 second-foot) for water. Considering that the season lasts six months, or 180 days, this water would cost the irrigator $63 per miner's inch. With a duty of water of 1 inch to 4 acres and a cost of operation and maintenance of $2 per acre per annum, or $8 per miner's inch per annum, the net value of an inch of water, on the above basis, would be $55, which, capitalized at the legal rate of 7 per cent, would give $786 as the value of an inch of water in the North Fork district during 1896. During the drought of 1898 individual rights to water were sold for $2.50 per miner's inch for twenty-four hours around Redlands, and the Bear Valley Company charged 10 cents additional for toll on the transfer through its canals.

The North Fork water is owned and operated by an association of irrigators. The North Fork ditch was originally divided into hours; that is, one hour's water represented the full flow of the ditch for that length of time. When the company was reorganized the stock was divided into shares, twenty shares representing one hour; so a share now means one-twentieth of an hour's run of the 400 miner's inches.



VIEW ON THE NORTH FORK SYSTEM, NEAR HIGHLANDS, CALIFORNIA.

The irrigated lands of Highlands in the background.

The cost per acre irrigated for maintenance alone has been about $1.50 a year. Each shareholder can call for any part of his water, or sell it at any point along the system. There is an agreement on the part of the company, however, that no shares can be transferred to the South Fork canal. The North Fork and Cram-Van Lueven water shares or stock are all owned by the landowners and used on the land lying under the ditch. There is none of this stock now on the market. A recent sale of "an hour's run of the ditch," which is equal to 1.68 miner's inches perpetual flow, was made for $900. This would be at the rate of $540 per miner's inch.

The Bear Valley Company and the Cram-Van Lueven Company have the right to run water through this ditch, but the operation and maintenance is in the hands of the North Fork Company. The Bear Valley Company has 600 miner's inches, the Cram-Van Lueven Company 200 miner's inches. The cost of maintenance during the year 1896 was $4,975, each company paying its proportion. Of this amount, $2,136 was paid in interest and notes on a construction debt, and also included taxes. If the debt of $14,700 could be wiped out, it is estimated that the maintenance charges would not exceed $5 per annum per inch.

The cost of the water per inch is estimated as follows: Operating expenses and maintenance of ditch, per miner's inch, $5; interest on value of water, say $540 at 6 per cent, $32.40; total annual charge per inch, $37.40.

With a duty of 1 miner's inch to 4 acres, this would be an annual expense to the water owners of $9.35 per acre, or with 1 miner's inch to 5 acres, $7.48 per acre.

During the year 1896 the Bear Valley Company charged $35 for a 24-hour run of 100 miner's inches. With a duty of 1 miner's inch to 4 acres, this costs the irrigator $15.75 per acre, or $8.75 per acre-foot; with a duty of 1 miner's inch to 5 acres, the cost would be $12.60 per acre. In 1897 the rate was fixed at $20 per day for 100 miner's inches. This would cost $9 on a basis of 1 miner's inch to 4 acres, or $7.20 for a duty of 1 miner's inch to 5 acres. On the basis of 1897 the Bear Valley water costs the irrigator no more than the North Fork water.

The Highlands Vineyard Company canal is a continuation of the North Fork canal. It is 2½ feet wide on the bottom, 4½ feet wide on top, 2½ feet deep, and on a 10 per cent grade. It is constructed in the same way as the main canal.

The total area irrigated on the north side for 1896 was, approximately, 5,000 acres.

The soil of Highlands is largely a loam of recent formation, and though in places it is very light, it universally produces a high grade of oranges and lemons. As in other localities, the best citrus lands lie next to the foothills and are very limited in area. A distance of a mile will often make the difference between success and failure in this class of fruit, as frost settles into the lower portions of the valley.

The duty of water in this district for citrus trees ranges from 1 miner's inch for 3 acres to the same for 7 acres, six months' flow, depending largely on the amount of water that the irrigator can command. The other fruits require, approximately, one-half this amount. Little else than citrus fruits is raised on this high-priced foothill land.

Fertilizing is very generally practiced in this and adjoining localities. The Chilean nitrates are said to be the best wood growers, and the guanos are the best for fruit. The method of distribution of water practiced on this land is the same as that of Redlands.

SUMMARY OF NORTH-SIDE SYSTEM.

Below is a synopsis of the north-side system of canals used or owned by the Bear Valley Irrigation Company:

North Fork ditch (capacity, 1,500 miner's inches).—Beginning at a point at or near Santa Ana Canyon, in the SW. ¼ sec. 4, T. 1 S., R. 2 W., it runs in a northwesterly direction along the base of the mountains to a point west of City Creek, on the south line of sec. 28, T. 1 N., R. 3 W., thence to the southeast corner of sec. 29, T. 1 N., R. 3 W., having a total length of 8 miles.

The Bear Valley Irrigation Company owns an undivided half interest in this ditch and the right to run one-half the capacity, viz, 750 miner's inches.

Highlands ditch (capacity, 1,500 miner's inches).—Beginning at a point near the North Fork ditch, in the NW. ¼ sec. 34, T. 1 N., R. 3 W., it runs in a northwesterly direction along the base of the mountains to a point near the west line of sec. 19, T. 1 N., R. 3 W., having a length of 4 miles.

North San Bernardino pipe line (capacity, 1,400 miner's inches).—Beginning at the end of the Highlands ditch, at a point near the west line of sec. 19, T. 1 N., R. 3 W., it runs west to the northeast corner of North and San Bernardino streets, having a length of 2 miles, thence south 1 mile.

REDLANDS OR SOUTH-SIDE WORKS.

As stated in the description of the Highlands or North Fork water rights, on page 573, the first water taken from Santa Ana River was used near old San Bernardino, on the south side of the valley, being diverted by the Tinney ditch, built in 1855. After being abandoned it was opened to take the water claimed under the Berry Roberts filing, made March 10, 1869, on the surplus flood waters of Santa Ana River. A number of irrigators under the Timber ditch, who owned land on the Sunnyside or south side of Santa Ana River, began to transfer their rights there. Direct purchase was made in some instances of Timber ditch water, which was transferred to the Berry Roberts ditch, and this was continued until the Timber ditch was abandoned.

In 1874 parties interested in this Sunnyside or south-side water began the construction of a canal from the mouth of Santa Ana Canyon, opposite the point of diversion of the North Fork and Cram-Van Lueven ditch. This canal was built on a light grade as far as Mill Creek wash, but it was not used until 1878. In February, 1878, the water commissioners granted a permit to relocate the ditch, commencing "four hundred yards above the present diversion of the North and South Fork canals and running about one hundred and fifty yards southeasterly of that point." The water was then discharged through an old river channel and delivered through natural drainage lines to the old head of the Berry Roberts ditch.

In July, 1878, the county water commissioners were asked to locate the South Fork canal on the line which had been in large part constructed in 1877. This was done, and water was first run through this canal in the fall of 1878. This canal line is practically on the location of the Bear Valley Redlands canal of the present day. Thus, as the water became more valuable and the advantage of the higher and warmer valley lands became better understood, the points of diversion were gradually moved upstream to prevent the loss of water and to command these lands.

The owners of the South Fork water constituted an association controlling the main canal. The water was used in the Lugonia, Redlands, and Sunnyside districts, and the local jealousies of these rival settlements for a long time prevented incorporation.

Lugonia is on the east of Redlands, a depression occurring between them. The Lugonia Water Company was incorporated in 1887 with a capital stock of $369,000. The old water owners exchanged their water rights for shares of stock in the new company, 10 stock shares being given for 1 original water share of the old Timber ditch. In 1886 about 170 original shares had been so surrendered to the Lugonia Water Company; 50 were held by the Redlands Water Company, and 33 by the Domestic Water Company, which would not unite with the Lugonia; the remaining 87 shares were held by parties who declined to enter the company. These shares called for 1.3 miner's inches of water, or a supply for 10 acres. The Lugonia Park Water Company is an offspring of the Lugonia Water Company.

AGREEMENTS WITH THE BEAR VALLEY IRRIGATION COMPANY.

South Fork Company, for the same reason as the Highlands or North Fork Company, entered into agreements with the Bear Valley Company. The associations on the south side of San Bernardino Valley, however, did not secure as favorable contracts as those of the north side, because they were not so well organized. The Bear Valley Company lined the earthen canal of the South Fork Company between the canyon and Redlands with bowlders in cement, and has since operated it. Failure on the part of the Bear Valley Company to fulfill contracts with the South Fork Company will cause the forfeiture of all contracts and rights of the Bear Valley Company.

The contract as to the division of the water is that in consideration of the rights of the surplus and winter waters of the Santa Ana, which the South Fork Company surrenders to the Bear Valley Company, this corporation will deliver to the South Fork Company at the Sunnyside divide 466.67 miner's inches (9.33 second-feet) from May to October, inclusive. The South Fork Company, by giving notice on or before April 20 of any year, can accumulate its water in any months, provided no month shall have assigned to it more than 600 miner's inches (12 second-feet).

The South Fork Company, having a right to one-half the summer flow of the Santa Ana, in 1881 was able to obtain but 350 miner's inches (7 second-feet) and in 1883 but 320 miner's inches (6.4 second-feet), so that it gained by this agreement 146 miner's inches (2.93 second-feet) over low or controlling years.

SUNNYSIDE ASSOCIATION.

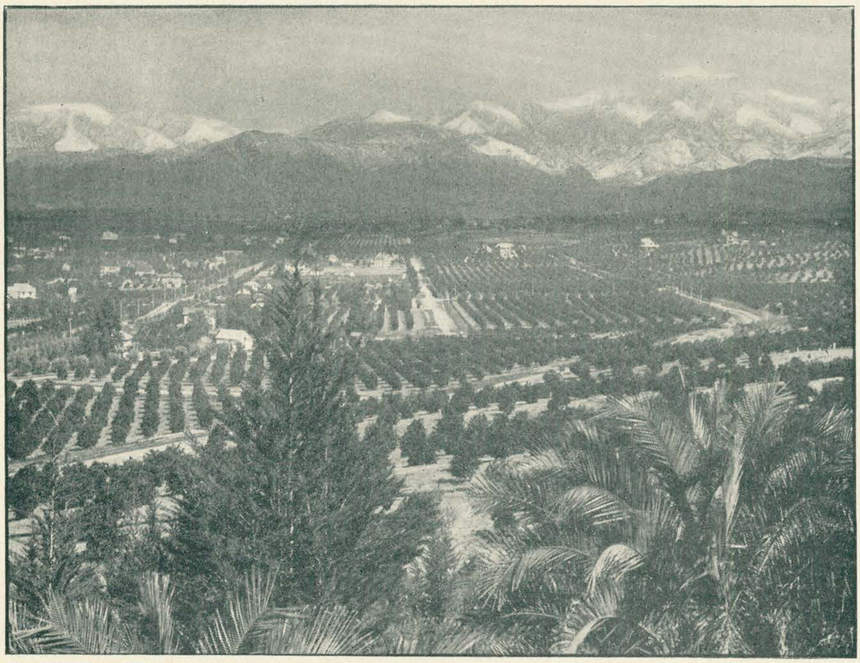
The Sunnyside Association, or South Fork Company, now takes its water from the Redlands canal of the Bear Valley Irrigation Company at a point about one-half a mile east of Mentone. It is then conducted through an earthen canal a distance of 1 mile, with a loss of about 75 miner's inches. There are 10 miles of main-line canals, most of which are paved with cobbles but not cemented. The loss by seepage and evaporation on this system is about 25 per cent of the entire supply.

A majority of the shares (222 out of 369) are now held by the Lugonia Water Company, which purposes to reconstruct this system and put in a pipe-line plant. The annual expense of maintenance of the works has ranged from 20 to 30 cents per acre per annum to the irrigators. The original shares (Timber ditch) represent 1.3 miner's inches, which is considered adequate for 10 acres of land.

The proposition for the incorporation of the Sunnyside or South Fork canal is for the holders of the original Timber ditch shares to surrender them to the new corporation, which will then issue new shares calling for water and give the original shares as security for a mortgage, and the funds raised will be used to build the pipe system. Those shareholders who do not enter the association will be asked for cash to pay their share of the construction expenses. The Lugonia Water Company has voted $30,000 in bonds, secured by their 222 shares; but it is hoped that all of the original holders will soon enter the agreement.

LUGONIA AVENUE PIPE LINE.

The Lugonia Avenue Pipe Line is owned by Mr. H. L. Williams. Its capacity is 1,000 miner's inches, but at present little more than 100 miner's inches are used through it. This water is obtained by Class B, Bear Valley certificates. It is taken from the Bear Valley Redlands



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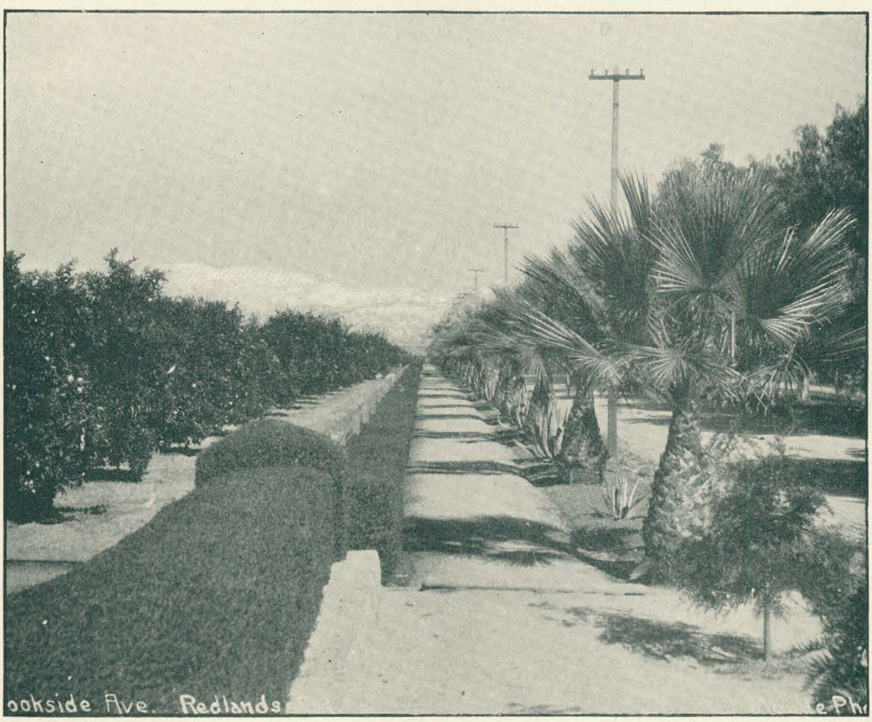

B.

VIEWS OF REDLANDS, CALIFORNIA.

A. General view; *B*, Brookside avenue.

canal at Mentone into a pipe line that is 20 inches in diameter, 25,910 feet long, laid to the west from Mentone along Lugonia avenue to the Williams tract. This was constructed in 1893.

REDLANDS WATER COMPANY.

Irrigation began in the Redlands tract in 1882, and by 1897 it had grown to a community of 5,000 people, its citrus groves being estimated to produce about 1,200 carloads of fruit per annum, worth probably $1,000,000. It is doubtful if this locality can be equaled for beauty, productiveness, progress, or wealth per acre anywhere west of the Mississippi River. Its development is a monument to the physical conditions of the district and to the energy of its people.

Two views of Redlands are shown on Pl. LXI. The first of these, *A*, being a general view and the second, *B*, a view of Brookside avenue. This illustrates a marked feature in irrigation development, in that effort is constantly made to render the homes with surrounding orchards beautiful as well as profitable. The lands are highly cultivated and produce crops of citrus fruits, returning in some instances as high as $500 per acre; 10 acres are ample for the support of a family, thus permitting the horticulturist to enjoy all the convenience of a suburban town, such as electric lights and street cars. The avenue shown is fairly typical of many others, with curbing, a row of palms on the edge of each sidewalk, and a row of pepper trees in the center of the street. The view is taken in midwinter.

The original settlement was made on 1,500 acres of land. This land carried a water right of 0.13 miner's inch per acre. The principal promoters of this district, and the ones to whom its early success was in large part due, were Messrs. E. G. Judson and F. E. Brown of Redlands.

The necessary water was obtained from 50 of the original 369 shares of the Sunnyside or Timber ditch stock, thus providing 54.2 miner's inches. In addition, 133 miner's inches were obtained in large part by a development tunnel at the mouth of Santa Ana Canyon, a description of which will be given later.

The Redlands Water Company was organized to supply the settlement with water, for which it built the Bolen tunnel, and the Judson & Brown ditch. They also ultimately obtained the water of Morton Canyon. This company was organized in 1881 with $1,500,000, divided into 1,500 shares of stock, one for each acre of land.

Enough water could not be delivered from the above sources to supply the requisite 187.5 miner's inches, so 640, Class A, certificates of Bear Valley Company were added to the other waters of the company. The water was afterwards increased by further purchase of Bear Valley certificates, so that the supply was ultimately placed on a basis of 1 inch to 4 acres, controlled by original rights, and 1,032 Bear Valley certificates for .14 miner's inch each.

The total supply of the Redlands Water Company is 375 miner's inches. The holdings of the company are subject to changes caused by sales and purchases. The cost of maintenance has been from $3 to $5 per acre. Each share of company stock entitles the holder to a certain amount of water, which may be called for at any point under the company's system.

The water company originally built a canal from the mouth of Santa Ana Canyon to a reservoir on the Yucaipe road, known as the Redlands reservoir, which commands the district now included in Redlands proper. This ditch was paved and partly cemented. It was afterwards rebuilt and relined under the Bear Valley Company agreement, and is now operated by the Bear Valley Company. A view of Redlands canal is shown on Pl. LXII.

The reservoir is located at the end of the Redlands canal and has a capacity of 25,000,000 gallons. It was constructed for the purpose of regulating the flow and of distributing water to the orchards lying below it. Its construction is similar to that of Crafton reservoir, described on page 553.

JUDSON & BROWN DITCH AND BOLEN TUNNEL.

This ditch derived its water supply from Morton Canyon, which flows from 5 to 10 inches in summer, and from a tunnel development below the North and South Fork divide at the mouth of Santa Ana Canyon, known as the Bolen tunnel. The first tunnel run for this company was near the south wall of the canyon. Bed rock that dipped toward the center of the canyon was found 9 feet below the surface, and 30 miner's inches were developed in a total length of 600 feet, or 1 miner's inch for each 20 linear feet of tunnel. A second tunnel, having a total length of 1,800 feet, with a crosscut to the north wall of the canyon and running under the bed of Santa Ana River, has also been constructed. This tunnel began at the mouth of the canyon and runs up it. One hundred and thirty miner's inches were originally obtained. At present this tunnel is badly choked, and is carrying only 50 miner's inches.

It will be remembered that the waters of the North and South Fork canals are divided at a point near the mouth of the canyon. They are then run over its gravel-and-bowlder bed to its mouth, before their diversion to their respective canals, thus passing over the Bolen tunnel, which is but 30 to 45 feet below the water surface.

From the examples quoted in the discussion of Mill Creek development tunnel for the Mentone Irrigating Company—and other examples could be given—it will be seen that there must be practically a diversion of the surface water of the stream in order to satisfy the draw of 130 miner's inches, which was obtained at first by this tunnel. It is estimated that the tunnel is run to bed rock, but this is probably incorrect. It is lined with bowlders, which were at hand, the sides laid in

CANAL AT REDLANDS, CALIFORNIA.

cement and the top and bottom laid dry. The top of the tunnel is an arch with about 1½ feet inside radius. It has held well. The tunnel is only 3 feet high in the clear, was built without instrumental alignment or grade, and is very crooked. To enter is difficult, if not dangerous. It is now flowing 50 miner's inches.

The cost of the development of this water was at the rate of $156 per miner's inch for the two tunnels for 160 miner's inches. The amount of water obtained in the larger one was at the rate of 1 miner's inch to each 14 linear feet of tunnel.

LUGONIA AND CRAFTON DOMESTIC WATER COMPANY.

This company was organized to furnish domestic water to the districts named. Its water rights were accumulated as it grew by purchases from various water companies. In 1897 they were based on the following contracts: Bear Valley deeded water, 200.1 miner's inches; Class A, Bear Valley certificates, 23.4 miner's inches; Redlands Water Company, 30.0 miner's inches; Class B, Bear Valley certificates, 12.5 miner's inches; total, 266.0 miner's inches.

This company's works consist of a reservoir near Mentone of 6,500,000 gallons capacity, and one on Crafton avenue of 700,000 gallons capacity; also the following pipe lines: 19,000 feet of 12¾-inch, 440 feet of 10-inch, 13,850 feet of 8½-inch, 47,650 feet of 6-inch, 42,800 feet of 4-inch, 20,735 feet of 3-inch, 23,175 feet of 2-inch iron pipe.

MINOR SYSTEMS.

At Redlands is located what is known as the Cajon street division measuring box, by means of which a considerable portion of the water from the Redlands canal is measured out to various claimants. The device used presents many points of interest, and is shown in plan and section in fig. 196 on page 582.

The water from Redlands canal enters a bay through a 36-inch cement pipe. The structure is made of concrete and is 18 feet in length by 12½ feet in width and 5 feet in height. In this is placed a screen for catching trash and stilling the motion of the water. Passing through the screen the water approaches a series of weirs, and falling over these enters smaller compartments connected respectively with the conduits of various water companies. *A* is that of the Redlands Water Company; *B*, the West Redlands Water Company; *C*, the Mound City Water Company, and *D* the Barton Land and Water Company. At *E* are iron gates placed in the bottom of the box and used to turn additional water to any consumer when desired.

One of the chief features of interest is the use of weirs of the form designed by Cezare Cippolette for the Italian Government for use on the canal Villoresi. The sides of the weir are inclined outward on a slope of 4 to 1 or at an angle of 14° from the vertical. By so doing the effective length of the weir is constantly equal to the length of the base irrespective of the head of water. One side of each of these weirs is made to slide, so that it can be set at any given length of base. The sill of all the weirs being on the same level it results that the amount received by each claimant is proportional to the length of his weir. These are all made of thin iron plate set in concrete. This division is reported to be highly satisfactory.

The Mound City Land and Water Company is an incorporated body. Its 13-inch steel pipe line starts at the Cajon street division box and is laid in a southwesterly direction for a distance of 6 miles. Its water

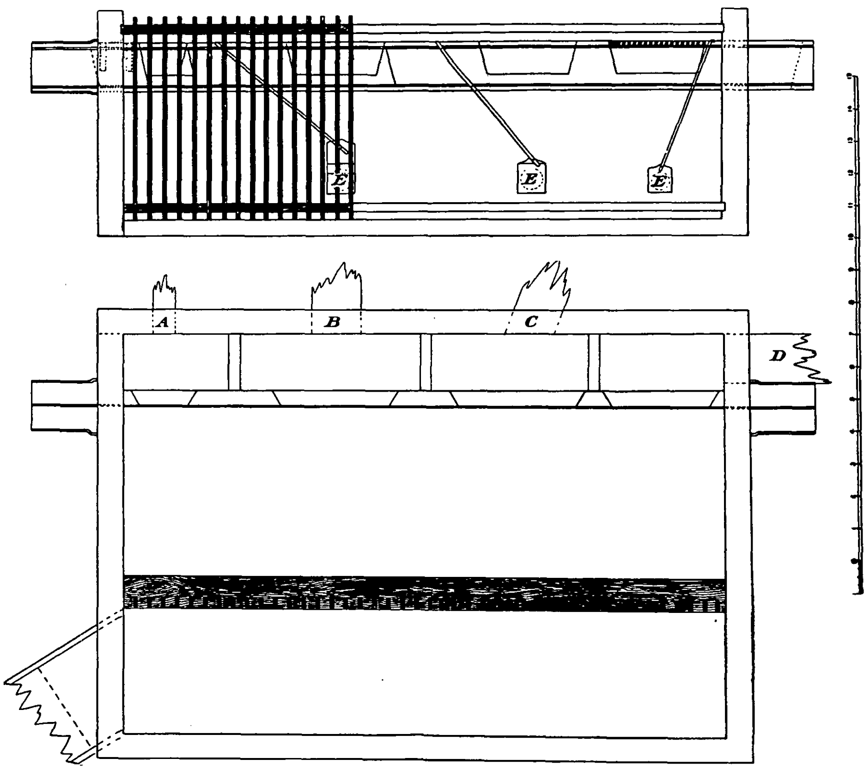

FIG. 196.—Plan and section of measuring box of Redlands Canal.

right is based on 250 Class A, Bear Valley certificates. These certificates, however, have never been transferred to the corporation.

The Drew pipe line starts from the Cajon street division box and runs in a westerly direction to the Drew tract. It is a cement pipe 18 inches in diameter. Its water right is based on Bear Valley certificates, Class A. There are about 300 acres irrigated under this system.

The Barton Land and Water Company takes water from the Drew pipe line and distributes it on the Barton tract. This water right is also based on Bear Valley certificates, Class A.

The West Redlands Water Company takes its water from the Cajon street division box, which is supplied from the Bear Valley Redlands canal. Its pipe line is 14 inches in diameter and is laid southwest from the box to San Timoteo Canyon. This company owns 766 Bear Valley certificates, Class A, and 5.71 miner's inches of deeded water. It supplies from 700 to 800 acres of land with water. The company is incorporated. Water is distributed in cement pipes.

The East Redlands Water Company irrigates 450 acres of land between Crafton and Redlands. Its water right is obtained from 214 Crafton Water Company certificates for 0.14 miner's inch each. It is an incorporated company. Its distribution is in cement pipes from the canals of the Bear Valley Company and the Crafton Company.

BEAR VALLEY IRRIGATION COMPANY.

The Bear Valley reservoir site was first surveyed by Fred Perris, for the California State engineer, in 1880. The first person to promote actively the construction of the dam was F. E. Brown, a graduate of Yale University, who was teaching in San Bernardino Valley at the time. Mr. Brown formed a company in San Bernardino, which purchased lands in the Bear Valley reservoir site, owned by the Southern Pacific Company and others. Construction on the dam was begun in 1883 and finished in 1884.

In 1886 contracts with the North Fork and South Fork associations of Highlands and Redlands, respectively, were entered into after much negotiation on the part of the water companies. The reservoir company contracted with the North Fork company to supply them with water as follows: June, 560 miner's inches; July, 600 miner's inches; August, 600 miner's inches; September, 500 miner's inches; October, 450 miner's inches; November, 400 miner's inches; or an average supply of 508 miner's inches monthly for six months each year.

The reservoir company purchased a half interest in the North Fork canal, and agreed to pay one-half of the expense of enlarging the system and operating it. The canal company in return made a tentative agreement by which the reservoir company could use its canals for one-half their capacity for conveying water to its patrons.

The agreement with the South Fork ditch or Sunnyside Company was to deliver to this canal, at the Sunnyside divide, 466.67 miner's inches from May to October, inclusive. The reservoir company enlarged the canals, and has since operated them, though a failure to comply with the contracts will cause them to forfeit all rights. In consideration of these agreements the canal companies concede all their rights on the river to the reservoir company, which is permitted to store water and regulate it at will.

The Bear Valley Irrigation Company was organized by those controlling the Bear Valley Land and Water Company, which constructed the works. The new company was incorporated for $4,000,000, and one-half of the stock was paid to the Bear Valley Land and Water

Company for its plant. As an evidence of the value of the plant at this time, all of the 3,600 shares of the land and water company not controlled by the new company were bought in by the parties managing the sale at $200 per share, which represents a total value of $720,000. The new company assumed all of the obligations of the old company.

The remaining stock was put on the market and sold at prices ranging from par to $160 per share. The company paid 15 per cent dividends on this stock for a number of years, largely from the sale of bonds of irrigation districts paid to it for the delivery of water, which in large part it has never supplied. It is scarcely necessary to say that a wreck came. The failure of this company has done more to injure arid America in general, and irrigation in particular, than any other one disaster. It occupied so prominent a position at home and abroad, and had been so repeatedly quoted, that its collapse was a widespread advertisement for ill. The personal sufferings of the victims from stock and water sales still haunt the land. Its failure is admitted by all to be due, not to the lack of natural opportunities, for these were so vast that it made it possible for them to obtain such astonishing credit, but to bad management. The company has been in the hands of a receiver since 1894.

The reservoir is a remarkably fine one, having few equals in southern California. Following is given a table of capacities with maximum heights of water at dam, ranging from 10 to 120 feet, taken from the Bear Valley Irrigation Company's surveys:

Capacities of Bear Valley reservoir.

Depth of water at dam.	Capacity.	Depth of water at dam.	Capacity.
Feet.	*Acre-feet.*	*Feet.*	*Acre-feet.*
10	14	55	30,010
15	52	57	34,040
20	159	60	40,476
25	411	65	52,428
30	1,558	70	65,065
35	3,347	80	95,500
40	7,166	90	131,100
45	13,358	100	171,200
50	21,139	110	214,850
53	[b] 26,463	120	260,836

[a] 1 acre-foot is equal to 43,560 cubic feet, which is equal to 1 acre covered 1 foot deep, or 7.2 six-month miner's inches.
[b] Present capacity.

The reservoir site is evidently an old lake bed, the waters from which have eroded their way through to Bear Creek. The walls of the narrow opening are granite. A shallow lake now exists at the extreme eastern end of Bear Valley which might be included in the reservoir site by building a dam 120 feet high. The eastern outlet of this lake drains toward Mohave Desert, and would in this case have to be closed.

RAINFALL AND RUN-OFF.

These subjects are discussed in the general description of Santa Ana River, on page 568. The rainfall at the Bear Valley dam, as recorded by the company, from September, 1893, to September, 1895, averaged 53.70 inches, the minimum being 37 per cent and the maximum 176 per cent of the mean. A comparison in detail with other local records indicates a lack of accuracy in this record.

The northeastern portion of the basin is exposed to the dry northwestern winds, which beat back and absorb the moisture from the rain clouds that approach from the southwest. The rainfall of the Pacific coast in the mountain regions rapidly decreases to the east of the crest of the range, but is locally heaviest just beyond the crest. The Bear Valley Basin is peculiar in that while it is on the eastern side of the range it drains to the west. The result is that while the rainfall record just beyond the crest, at the Bear Valley dam, may be 53.70 inches, the average during the last five years at Upper Holcomb Valley, which is over the divide in the Bear Valley drainage basin, 11 miles east of the crest, is 14.09 inches. A comparison based on a record of twenty-seven years at San Bernardino indicates a mean rainfall of 15 inches at Upper Holcomb Valley. The average for this basin is probably not more than 40 inches. Based on the record at the dam this would give a minimum for the basin of 15 inches and a maximum of 70 inches.

While it is difficult to determine the rainfall of this basin, it is more difficult to determine the run-off. The character of the rains and the way the storms are grouped affect the results, as well as evaporation, soil, and exposure. The basin is probably second-class in respect to run-off. It is largely covered with soil of a porous nature, and there is considerable vegetation. The mountains are not rugged. The area is 54 square miles. An estimate based upon observations in other portions of the State, under conditions somewhat similar, would lead to the following conclusions: The maximum run-off ought to be as great as 14,000 six-month miner's inches (280 second-feet), the minimum is probably as low as 1,500 such inches (30 second-feet), and the mean might be expected to be 4,000 such inches (80 second-feet).

These figures are merely approximations based on other localities. The company has compiled this information, but withholds it pending certain litigation.

The present capacity of the reservoir with its dam is about 3,700 six-month miner's inches (74 second-feet). The hold-over for minimum years should be at least 1,100 six-month miner's inches (22 second-feet), which would make available for sale from the reservoir, approximately, 2,600 six-month miner's inches (52 second-feet), or one-half the sum of a minimum year and the capacity of a full reservoir, from which evaporation should be deducted.

The minimum summer flow of Santa Ana River should also be considered. On July 27, 1896, this was 709 miner's inches above the junction of Bear Creek, which would probably more than make good the loss by evaporation from the reservoir. The latter, which has to be considered on reserve water for one and one-half years, has been estimated as 15 per cent. The outflow of Santa Ana Basin during the period of drought in August, 1898, was 2,300 miner's inches.

The following statement of the obligations of the company for the delivery of water is taken from a paper filed with the company by John G. North, of Riverside, California, on March 7, 1893, at a full meeting of the board of directors, protesting against a declaration of a dividend by the company in the face of its obligations.

The amount of water sold by the Bear Valley Company in 1893 was as follows: 7,200 Class A certificates, for .14 miner's inch each, 1,028.57 miner's inches; 73,875 Class B certificates, for .13 miner's inch each, 9,209.38 miner's inches; water conveyed by deed (approximately), 539 miner's inches; total, 10,777 miner's inches. This supply is for a continuous flow. There was also due the North Fork ditch, of guaranteed water, 508 six-month miner's inches and to the South Fork 467 six-month miner's inches, making a total of 11,752 miner's inches in all.

The certificates referred to are contracts to deliver water, and were sold by the company to the irrigators. At this time the company was paying 15 per cent dividends on an immense stock issue, and its credit was of the best. The protests of Mr. North were in vain, but the subsequent history of the company has justified his position. Many of the contracts with the irrigators have never been fulfilled, and, as has been said, the company is in the hands of a receiver.

The rights for this tremendous amount of water were paid for, and exist against the company. It has never been clearly understood how this water was to be collected and delivered. The flow of Santa Ana River, from its entire basin of 188 square miles, from July 1, 1896, to July 1, 1897, was approximately 8,650 miner's inches, six months' flow. A new dam at Bear Valley, to be 100 feet high, has been started, but it is unfinished, and the Santa Ana canal is not one-third complete. Both have been abandoned. It is stated that it was the intention of the company to carry the winter waters of Santa Ana and Mill creeks over to San Jacinto Lake, in the Santa Ana canal, which was to have a final capacity of 12,000 miner's inches. This consummation at present seems quite remote. The waters stored in San Jacinto Lake could be used at Perris, but not in San Bernardino Valley nor at Alessandro and Moreno. A public record of the available water supply would have prevented much of the consequent misery and financial loss.

BEAR VALLEY DAM.

Bear Valley dam was designed by Mr. F. E. Brown, of Redlands, California. It has been described by Schuyler in the Eighteenth Annual Report of this Survey, Part IV, pp. 682–685.

The structure, from an engineering standpoint, is the most interesting in southern California. Considered as a gravity dam, with the weight of the masonry alone to resist the water pressure of a full reservoir, it should have failed immediately, but it has not only stood this pressure, but also the thrust of a sheet of ice 2 feet in thickness and has remained and done effective service for thirteen years (Pl. LXIII).

It is a fact accepted by engineers that when the resultant of two forces—the weight of the masonry acting vertically through the center of gravity of any cross section of the dam and the pressure of the water acting at right angles to its water face and applied at two-thirds of the depth on the face—passes outside of the toe of the dam before intersecting the base, the structure will revolve around the outer toe and fail. It is generally considered good practice to require this intersection to come not only within the base of the dam but within the middle third of the base. In the case of this dam this intersection is far outside the outer toe and the overturning force is much greater than the gravity of the dam.

In fact, it would seem as if this structure had been built in special defiance of orthodox principles of dam construction. It is thus necessary to look elsewhere than to gravity for an explanation of its stability. When anything proves true in practice which seems untrue in theory, the trouble is that the conditions are not sufficiently understood to form a complete and correct theory. In this case the explanation is sought in the arch form of the dam, the idea being that the thrust of the water is conveyed to the abutments, as in the case of a vertical stone arch. The difficulty in accepting this explanation is that the vertical arch performs its duty by the crown being compressed enough to change its form slightly, so that the compression of the masonry conveys the load to the abutments. In the case of this dam, which is on its side as compared to the vertical arch, its lower side, or rather the foundation of the dam, is sealed to the bed rock of the canyon floor, and to move it is to break this connection, which would at once cause the dam to fail. The question has been the subject of a great deal of discussion by many eminent engineers, the conclusions being greatly at variance. The technical reader is referred to a paper concerning this dam, read by Herbert Vischner and Luther Wagoner before the Technical Society of the Pacific Coast,[1] and for a description of the Sweetwater dam near San Diego, to a paper by James D. Schuyler, consulting engineer, in the Transactions of the American Society of Civil Engineers.[2]

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[1] Strains in curved and masonry dams, by H. Vischner and L. Wagoner: Tech. Soc. Pac. Coast. November 1, 1889.

[2] Vol. XIX, p. 201.

The conclusions are difficult to reach. The arch apparently can not act at the base of the dam, because that can not and should not move, and it can only so act on the upper portion of the dam as the elasticity of the masonry will permit. Considered in this way, the strains must in large part be taken up and transmitted to the foundations, as well as to the abutments. The paper by Messrs. Vischner and Wagoner reaches this conclusion:

The result of our calculation leads us to conclude that arch action, as usually understood, adds but little to the strength of a curved dam, notwithstanding which the curved form may to a very marked degree afford additional resistance, and this in a manner less dependent on the radius of the curve than the arch theory implies.

The dam has never been considered satisfactorily safe. In fact, the only reason assigned for its frail section was the cost of cement at the dam, $15 per barrel, on account of the 70-mile mountain haul. The masonry is granite rubble in large blocks. There are 34,000 cubic feet of masonry and 1,600 barrels of cement in the structure. The masonry cost $22 per cubic yard, with a total cost of $75,000.

The outlet is through a gate 20 by 24 inches in a culvert on bed rock in the lowest portion of the depression. It is operated by a rod through a 6-inch pipe. All of the timber was left standing in the reservoir and has given much trouble, among other things interfering with the operation of this gate. The spillway is 8.5 feet below the top of the dam and is 20 feet wide.

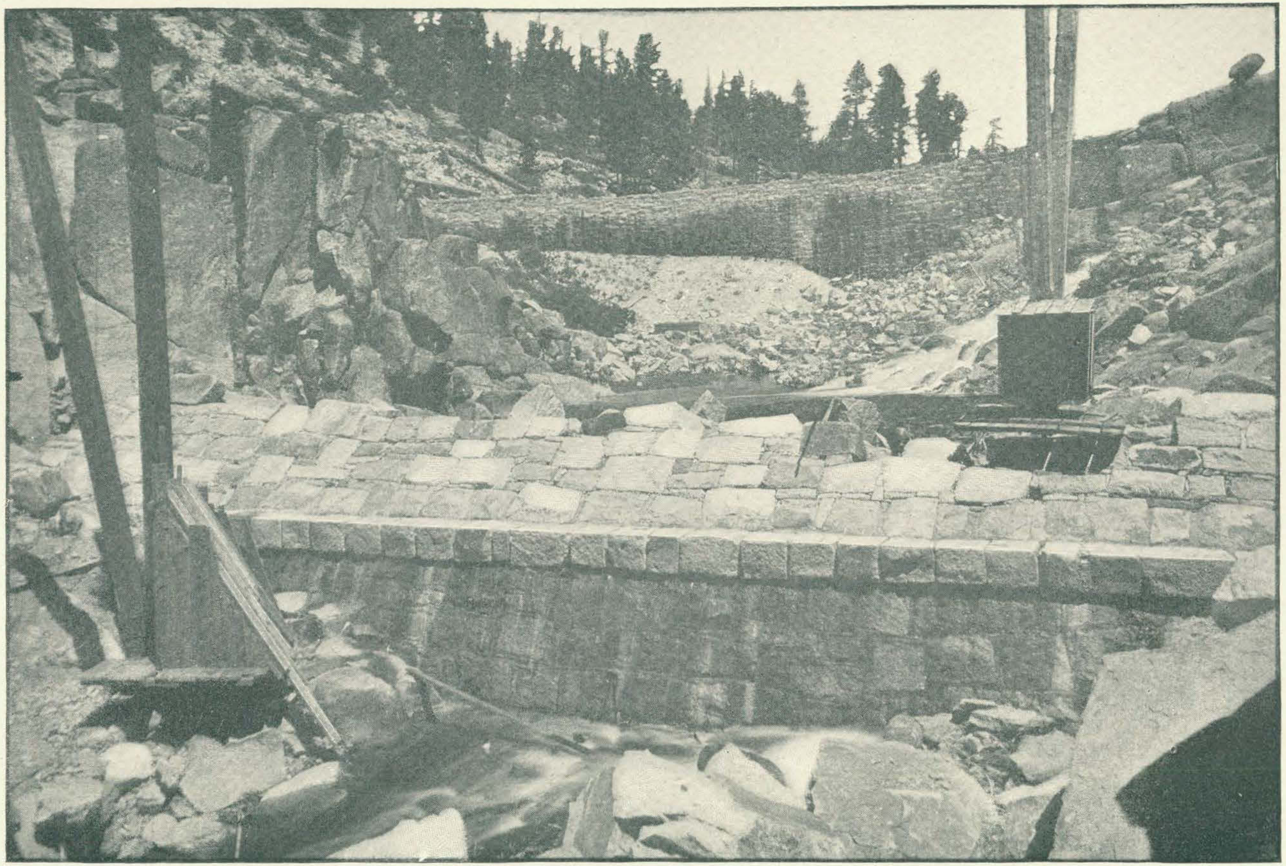
Several efforts have been made to strengthen the dam; the fill seen in Pl. LXIII being one of them. Concrete has also been used to strengthen the foundations. In 1892 a new dam was started about 200 feet down the canyon from the old one. The new dam was planned to be 100 feet high; the top would then have been 20 feet or more above the old one. This dam had its upper toe of first-class masonry built on bed rock. The lowest toe is built in a similar way, as shown in Pl. LXIII. The remaining portion of the dam was to be built dry, one-third of the bulk on each face to be laid up by hand dry, and the inner two-thirds to be of dumped rock in whatever form they might assume. The slope on the water face was 0.4 to 1 and on the outer face 0.6 to 1. Timbers were so built in the upper face as to permit of putting on a plank apron. This dam was designed by William Hammond Hall, consulting engineer, but the financial affairs of the company prevented its completion.

DIVISION OF WATER.

In the discussion of the North and South Fork ditches the arrangements for the division of water are treated at length, as is also the Alessandro allotment (see pp. 573–583). The following is a summary of the distributing conduits of the company:

NORTH-SIDE SYSTEM.

North Fork ditch (capacity, 1,500 miner's inches).—Beginning at a point at or near Santa Ana Canyon in the SW. ¼ sec. 4, T. 1 S., R. 2



BEAR VALLEY DAM, CALIFORNIA.

Foundations of incomplete dam in foreground; in background, the old dam, with material thrown against it to add strength.

W., and running in a northwesterly direction along the base of the mountains to a point west of City Creek on the south line of sec. 28, T. 1 N., R. 3. W.; thence to the southeast corner of sec. 29, T. 1 N., R. 3 W., having a total length of 8 miles.

The Beaver Valley Company owns an indivisible half interest in this ditch, and the right to run one-half the capacity, namely, 750 miner's inches.

Highlands ditch (capacity, 1,500 miner's inches).—Beginning at a point near the North Fork ditch in the NW. ¼ sec. 34, T. 1 N., R. 3 W., and running in a northwesterly direction along the base of the mountains to a point near the west line of sec. 19, T. 1 N., R. 3 W., having a length of 4 miles.

North San Bernardino pipe line (capacity, 1,400 miner's inches).—Beginning at the end of the Highlands ditch at a point near the west line of sec. 19, T. 1 N., R. 3 W., and running west to the northeast corner of North and San Bernardino streets, having a length of 2 miles; thence south 1 mile.

SOUTH-SIDE SYSTEM.

Green Spot pipe line (capacity, 455 miner's inches).—Beginning at a point on Santa Ana River in the N. ½ sec. 4, T. 1 S., R. 2 W., and running southerly to a point on the Mill Creek zanja in the SE. ¼, sec. 21, T. 1 S., R. 2 W., having a length of 3¼ miles.

Bear Valley and Redlands canal (capacity, 3,300 miner's inches).—Beginning at a point near the south of Santa Ana Canyon in the NE. ¼ sec. 8, T. 1 S., R. 2 W., and running in a southeasterly direction through the town of Mentone and continuing in the same general direction to Redlands reservoir at the head of Reservoir street in the city of Redlands, having a length of 5½ miles.

Cajon street pipe (capacity, 600 miner's inches).—Beginning at the Redlands reservoir at the head of Reservoir street in the city of Redlands, thence southwesterly to the divide at the head of Cajon street in the city of Redlands, having a length of one-half mile, and consisting in part of 1,900 feet of 30-inch cement pipe and 900 feet of 18-inch No. 14 steel pipe.

Judson & Brown ditch (capacity, 550 miner's inches).—Beginning at a point in the Bear Valley and Redlands canal, about one-fourth of a mile below the head of the same, which point is situated in the SE. ¼ sec. 8, T. 1 S., R. 2 W., and running in a southeasterly direction west of the Bear Valley and Redlands canal to a point in said Bear Valley and Redlands canal about 800 feet southeastly from the sycamore tree near the Sunnyside divide, which point is in the NE. ¼ sec. 19, T. 1 S., R. 2 W., having a length of 2¼ miles.

Lugonia avenue pipe line (capacity, 1,000 miner's inches).—Beginning at a point on the Bear Valley and Redlands canal at the crossing of Lugonia avenue in the town of Mentone and running west along said

Lugonia avenue to a point in the center of the Williams tract, which point is the center of sec. 20, T. 1 S., R. 3 W., having a length of 4½ miles.

Santa Ana canal (present capacity, 6,000 miner's inches).—Beginning at a point on Santa Ana River which is located in the NE. ¼ sec. 34, T. 1 N., R. 2 W., thence southeasterly along the southeastern slope of Santa Ana Canyon, crossing Warm Springs Canyon and continuing to a point on the ridge north of Deep Creek, thence southerly and southeasterly, crossing Deep Creek, Morton Canyon, and Mill Creek wash at the head of the Alessandro pipe line, which point is located in or near the center of the N. ½ sec. 22, T. 1 S., R. 2 W., having a length of 5½ miles.

Alessandro pipe line (capacity, 875 miner's inches).—Beginning at the end of the present construction of the Santa Ana canal on the south side of Mill Creek wash, which point is located near the center of the N. ½ sec. 22, T. 1 S., R. 2 W., thence southwesterly along the slopes of Crafton Hill through Blair's Pass, crossing Yucaipe Valley and Live Oak and San Timoteo canyons and continuing to the north end of the Alessandro tunnel, which point is located in the NE. ¼ sec. 26, T. 1 S., R. 3 W., having a length of 9.7 miles.

ALESSANDRO AND PERRIS SYSTEM.

Moreno main canal (capacity, 1,500 miner's inches).—Beginning at the south end of the Alessandro tunnel, which is in the SE. ¼ sec. 26, T. 2 S., R. 3 W., running thence southeasterly to the Alessandro reservoir, which is located in the NW. ¼ sec. 36, T. 2 S., R. 2 W., at the head of the Redlands boulevard of the Alessandro tract, having a length of one-half mile.

Redlands boulevard flume (capacity, 700 miner's inches).—Beginning at the Alessandro reservoir at the head of Redlands boulevard and running thence south along said boulevard to the head of the Redlands boulevard pressure pipe, which is about 200 feet north of Hemlock avenue, having a length of 1 mile.

Redlands boulevard pressure pipe (capacity, 500 to 50 miner's inches).—Beginning at the head of the Redlands boulevard flume on Redlands boulevard at a point about 200 feet north of Hemlock avenue and running thence south along said Redlands boulevard through the town of Moreno to Cactus avenue, which is the south boundary of the Alessandro tract at this point, having a length of 2¼ miles.

Manzanita avenue ditch, flume, and pipe (capacity, 300 miner's inches).—Beginning at a point in the Moreno main canal at or near Manzanita avenue, running thence west and southwest.

Ironwood avenue flume and pipe (capacity, 200 miner's inches).—Beginning at a point in the Redlands boulevard flume on Ironwood avenue, thence east along said Ironwood avenue to the northeast corner of lot 4, block 9, of the Alessandro tract, thence southeasterly to the northeast corner of lot 8, block 32, of said tract, having a length of 1¼ miles.

Grevilla flume and pipe (capacity, 650 to 400 miner's inches).—Beginning at a point on Redlands boulevard at end of Redlands boulevard flume, about 200 feet north of Hemlock avenue, thence southwesterly to and along Grevilla avenue to a point on Lassell street, about 200 feet north of Grevilla avenue, thence northwesterly to a point near the schoolhouse on the corner of Judson street and Ironwood avenue, having a length of 4¼ miles.

Grevilla avenue temporary flume (capacity, 200 to 100 miner's inches).—Beginning at a point on the Grevilla avenue flume and pipe line on Morrison street, thence westerly to and along Grevilla avenue to Judson street, having a length of 1½ miles.

Cottonwood avenue pressure pipe (capacity, 300 to 150 miner's inches).—Beginning at a point on the Redlands boulevard pressure pipe at the intersection of Eucalyptus avenue and Redlands boulevard, running thence southwesterly to the corner of Cottonwood avenue, making a slight detour to the south at Oliver street, to a point on Cottonwood avenue 660 feet east of Lassell street, having a length of 6 miles.

Oliver street pressure pipe (capacity unknown).—Beginning at a point in the Cottonwood avenue pressure pipe on Oliver street and running south along Oliver street to or about the south boundary of the Alessandro tract, having a length of 2 miles, more or less.

Perris pressure pipe (capacity, 420 to 210 miner's inches).—Beginning at the end of the Grevilla avenue flume and pipe at a point near the schoolhouse at the corner of Judson street and Ironwood avenue, thence running southwesterly to the corner of Alessandro boulevard and Elsworth street, thence south along Elsworth street through the town of Alessandro to the Perris well, at the head of wooden pipe, which is located near the quarter corner on the south line of sec. 35, T. 3 S., R. 4 W., and being on the dividing line between the Alessandro and Perris districts, having a total length of 7 miles.

Distribution system, Alessandro district.—A lateral system of conduits composed of vitrified cement and steel pipe, flumes, and ditches aggregating in length over 75 miles and covering about 10,000 acres of land, with delivery at the highest point of each 10-acre tract.

The townships and ranges referred to in the above statements are all from the San Bernardino base and meridian, and the streets and avenues noted in the description of the Alessandro and Perris system are those of the Alessandro tract.

Where water is distributed to the irrigators in pressure pipes and it is necessary to measure it as delivered, some device for stilling the jet before passing the water over a weir is needed. To meet these conditions, Mr. James Black designed, for the Lugonia avenue pipe line at Redlands, California, the measuring box shown in fig. 197. The water is discharged from the pipe against the end of the box away from the weir, and is passed through two compartments through openings but 4 inches wide, shown at *a*, *b*, before entering the third compartment,

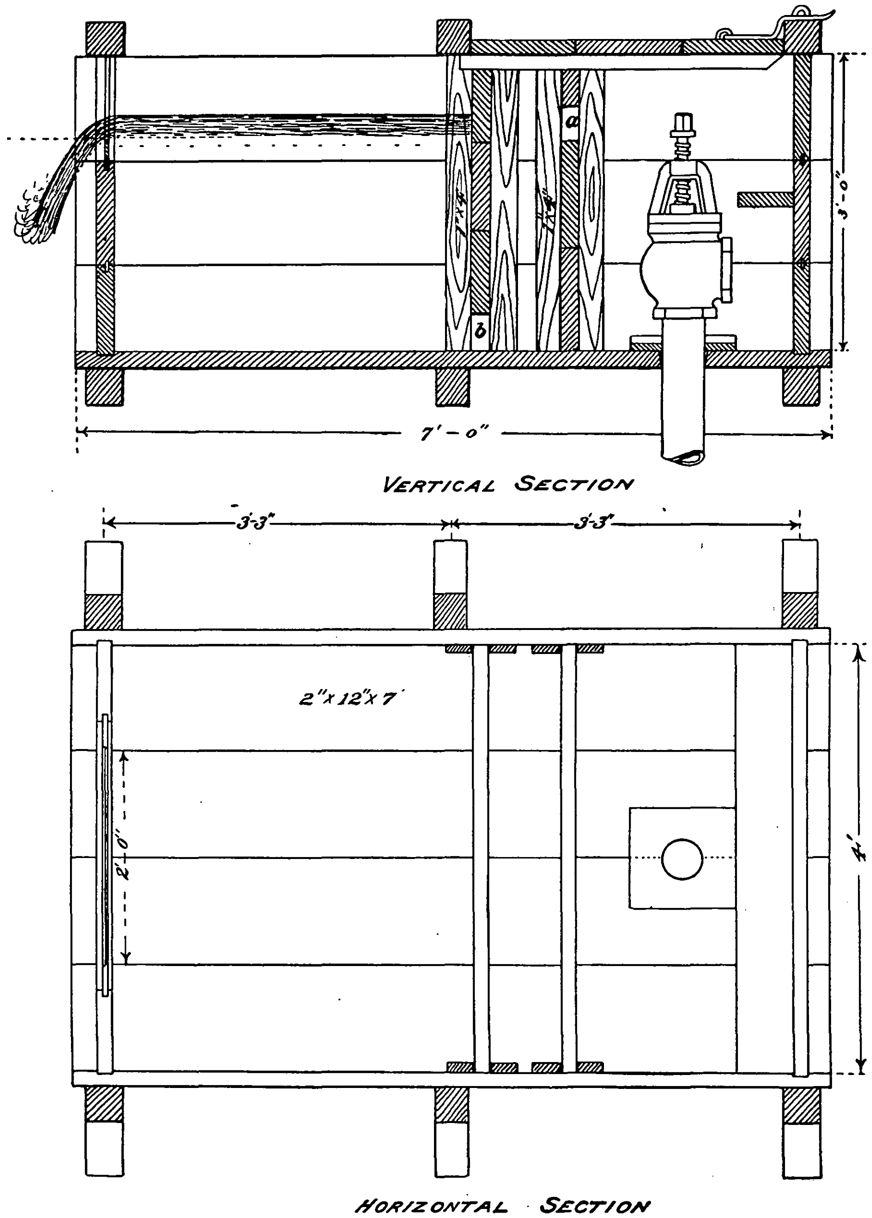


FIG. 197.—Vertical and horizontal sections of measuring box for 4-inch pressure pipe on Lugonia avenue pipe line.

which acts as the weir bay, from which it passes quietly over the weir. This is a simple and satisfactory arrangement.

Numerous details of interest are to be found in the method of distribution of water from the various canals and pipe lines taking water from the system of the Bear Valley Company. These matters have been

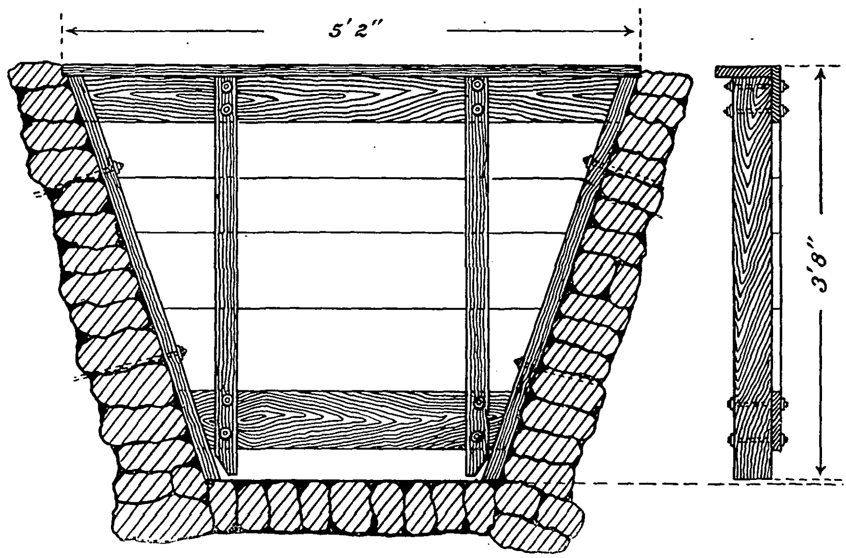


FIG. 198.—Check used on Bear Valley canals where water has low velocity.

discussed in part on pages 555 to 559, with the description of the Crafton system. The various forms of "stops," by which the height of the water flowing in a canal can be temporarily increased for diversion purposes, are shown in figs. 198 199, and 200. The purpose of these

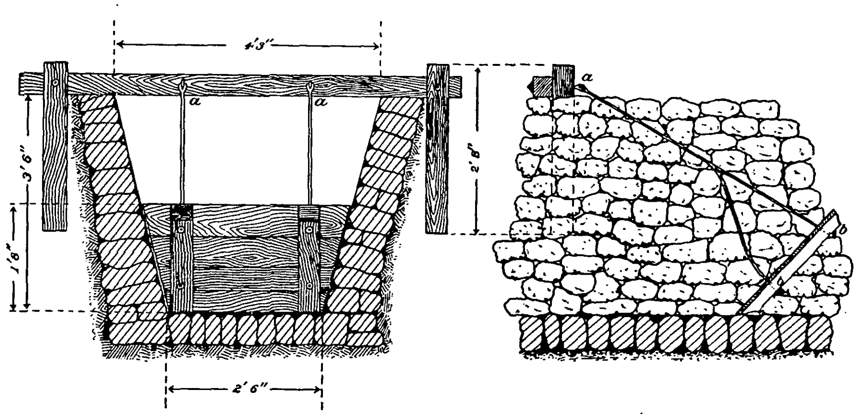


FIG. 199.—Check used on Bear Valley canals where water has a velocity of from 4 to 8 feet per second.

stops or checks is to raise the elevation of the water in the canal temporarily from its ordinary height, so that it will flow over weirs connected with the sides of the canal and leading to orchard laterals.

The check shown in fig. 198 is used where the canal has a low velocity, permitting the handling of flashboards. When desired the frame shown

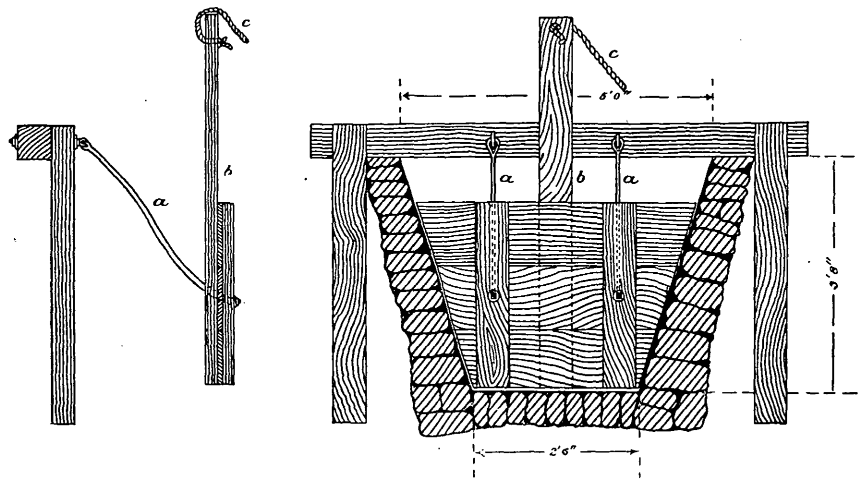


FIG. 200.—Check used on Bear Valley canals where water has high velocity.

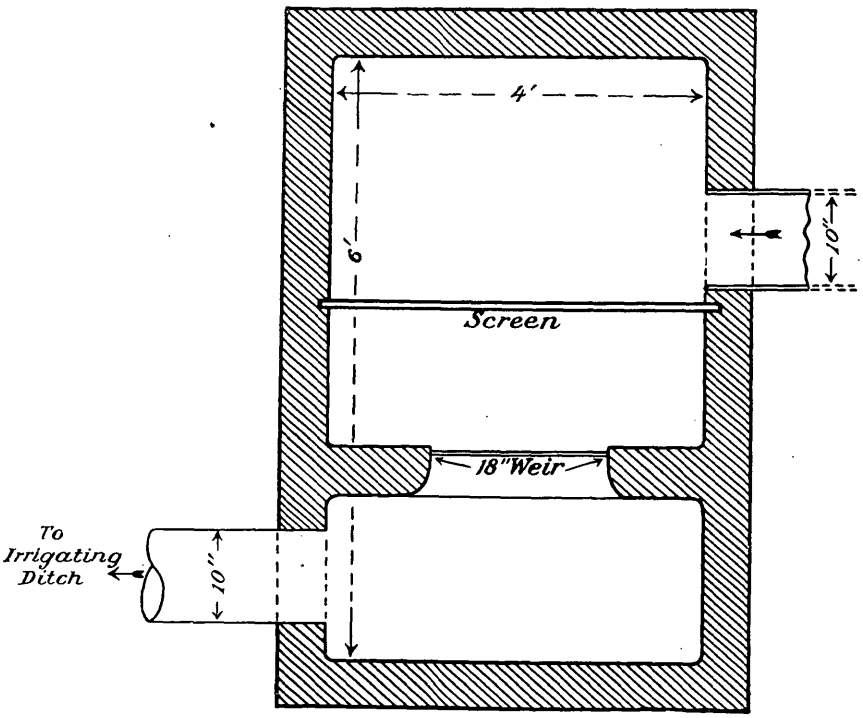


FIG. 201.—Plan of weir used in measuring water from the orchard laterals.

is lowered in grooves vertically and enough flashboards inserted to raise the water to the desired height.

The form illustrated by fig. 199 is used where the velocities are as high as from 4 to 8 feet per second. In this case the gate is held by 1-inch iron rods, which are hinged at *a* and rigid at *b*. The hinges *a* are fastened to a timber laid across the canal. When the canal is normal the gate is lifted entirely from the water. When it is desired to raise the elevation of the water for diversion purposes the gate is dropped into the canal, where it acts as an inclined weir, the weight of the passing water holding it down in position. The hinged rods permit it to be easily lifted out of the water when desired.

Fig. 200 shows a check which is also used in canals of high velocity. In this case a heavy wire or chain, *a*, is substituted for the iron rod of fig. 199. A lever, *b*, is attached to the check or gate to which a rope, *c*, is fastened. When not in use the check is laid on the side of the canal. When put into service it is placed in the canal, where it at first floats.

By drawing on the cord, *c*, the lower end is given a downward inclination and the passing water forces it to the bottom of the canal. The elevation of the top of the check is regulated by drawing on the cord, which is then tied to a post set in the bank of the canal. When the cord is untied the gate again floats on top of the water and is readily removed. This form of check in high velocities is liked best by the ditch tenders.

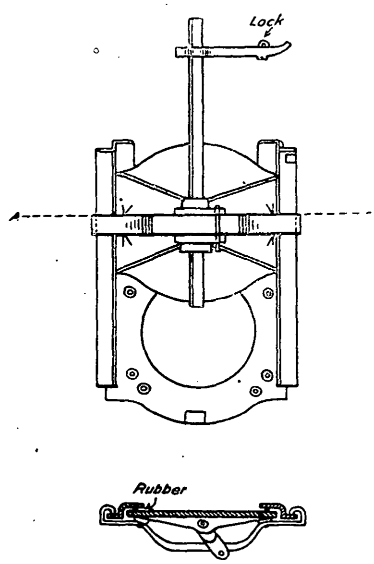


FIG. 202.—Elevation and section of Watson irrigating gate.

Fig. 201 illustrates one method of measuring the water. By means of checks in the canal the surface is raised until the water flows out through an opening in the side of the canal, which in this case is 10 inches in diameter. It is discharged into a rectangular compartment containing a screen to remove any floating sticks or weeds. The water passing through this screen acquires a comparatively uniform velocity, the wave motion being checked. From the screen it passes over a sharp-edged weir, upon which the height can be accurately measured and the quantity determined by suitable computation. Falling over the weir the water passes into a smaller compartment and out to the irrigating ditch through a 10-inch outlet.

One of the most urgent demands of the modern irrigation systems is for some form of module to take the place of the weir just described and which shall be free from the irregularity to which this is necessarily subject. An irrigating gate made in Santa Ana, California, and shown in fig. 202, has been found successful.

This is raised or lowered to the desired height by the standard traveling in the guide shown on the cross section.

The valve has a rubber gasket that bears on the valve seat, making a tight joint. There is an eccentric fast on the shaft, which when turned tightens or relieves the bearing of the gate on its valve. The handle is turned as in the case of a railroad switch stand, and it may be locked in place. It turns the shaft, but is raised and lowered on it for locking. The gate is set with a discharge pipe leading to a weir and is adjusted so that the desired head is obtained.

ALESSANDRO IRRIGATION DISTRICT.

In the spring of 1891 the Bear Valley Irrigation Company, which had just been organized and had bought all of the plant of the Bear Valley Land and Water Company, in return for stock, made arrangements with certain parties residing or to reside upon the land known as the Alessandro tract to act as trustees of an irrigation district to be formed. There were very few voters in the district, which contains 25,500 acres of land, but an election was held, the irrigation district organized, and a board of directors chosen of men either in the employ of the Bear Valley Irrigation Company or under its control. The Bear Valley Irrigation Company then voted an issue of 100,000 "Class B acre water-right certificates," each certificate being an agreement on the part of the Bear Valley Irrigation Company to supply the holder 0.13 miner's inch of water, measured under a 4-inch pressure, two hundred days in the year, provided the holder paid $2.56 per annum to the company as a fixed charge. Through the board of directors above mentioned the Bear Valley Irrigation Company made an arrangement by which it sold to the Alessandro irrigation district 51,000 of these certificates for the total sum of $765,000 in bonds of the district.

This water was to be delivered as follows:

	Miner's inches.
June 1, 1891	500
April 1, 1892	1,250
April 1, 1893	2,000
April 1, 1894	2,750
April 1, 1895	3,500
April 1, 1896	4,250
April 1, 1897	5,000
April 1, 1898	5,750
April 1, 1899	6,375

These bonds were issued by the district pursuant to an election called for the purpose of voting such bonds, and with the end in view of exchanging them for Class B acre water-right certificates. The bonds so exchanged for certificates comprised the whole issue for the district, amounting to $30 per acre upon the entire district. These lands were then sold to colonists.

These bonds were taken by the company and sold or pledged, but the proceeds, instead of being directed to the construction of a water conduit to convey the water from the reservoir to the district, or in providing increased storage capacity, were used in paying dividends upon its capital stock, the price of which rose as high as $160 per share. The par value of these shares was $100. More than $750,000 was thus paid out in dividends. In 1894, under a judgment in the case of James Gilbert Foster *v.* Bear Valley Irrigation Company, a receiver was appointed, and the property was eventually sold, the purchaser taking the property subject to a mortgage or deed trust for $300,000 to the Savings and Trust Company, of Cleveland, Ohio, and subject to the receiver's certificates which had been issued under order of the court during the receivership, and which were held to be a first lien upon the property. These certificates amounted to about $121,000.

In September, 1895, the Savings and Trust Company, mortgagee, and also holder of the receiver's certificates above mentioned, brought suit in the circuit court to foreclose the liens of the mortgage and the receiver's certificates. Under this foreclosure suit a new receiver was appointed, the old receiver having conveyed to a new corporation, known as the New Bear Valley Irrigation Company, the title to the property subject to the liens aforesaid.

The new receiver under mortgage foreclosure has held the possession of the property since the beginning of the present action in foreclosure. In the meantime the residents of the Alessandro irrigation district are using the water which they receive to the maximum amount of about 700 or 800 miner's inches, and which is conveyed to them through a pipe line of that capacity from the Santa Ana Canyon, about 20 miles distant. During the summer of 1898 less than 100 miner's inches was delivered to these lands. The district is called upon by the holders of the district bonds to pay interest in full on the entire bond issue, as the present holders are innocent purchasers.

Relying on a decision of Judge Ross in the United States district court, at Los Angeles, in the case of the Board of Supervisors of San Diego *v.* The San Diego Land and Town Company, which decision held that no company can sell water, but can charge only for its transfer, the present management proposes to repudiate the water contracts represented by its water certificates. It also takes the position that it can not be required to operate its plant at a loss, and in 1896 fixed as a reasonable compensation a charge of 37 cents for a run of 1 miner's inch for twenty-four hours, which at 0.25 miner's inch per acre for two hundred days would cost the irrigator $17.50 for the season. During the summer of 1897 the charge was fixed by the company at 20 cents, which would amount to $10 per acre. The district has asked the supervisors to fix the rate for the use of such water in accordance with law. The rate has been fixed and the users are in litigation with the receiver upon the matter, the receiver seeking to collect a higher rate than that fixed by the supervisors.

The settlers within the district have over 3,000 acres of land planted and cultivated in fruit, and were also making a success of the horticultural industry. The district would be one of the most thriving and prosperous settlements in California were it not for the handicap which they labor under in the matter of the district organization, the bond issue which they are now fighting in the courts, and the water complications, which bid fair to furnish abundant litigation for some time to come.

The above facts are not related for the purpose of making public a record that should be buried, but for the lesson to be learned. The Alessandro and Perris districts were formed under the celebrated State law known as the Wright Act, the constitutionality of which has been upheld by the United States Supreme Court. There are other cases of like nature in California, showing the great need of protection to the purchasers of land and water.

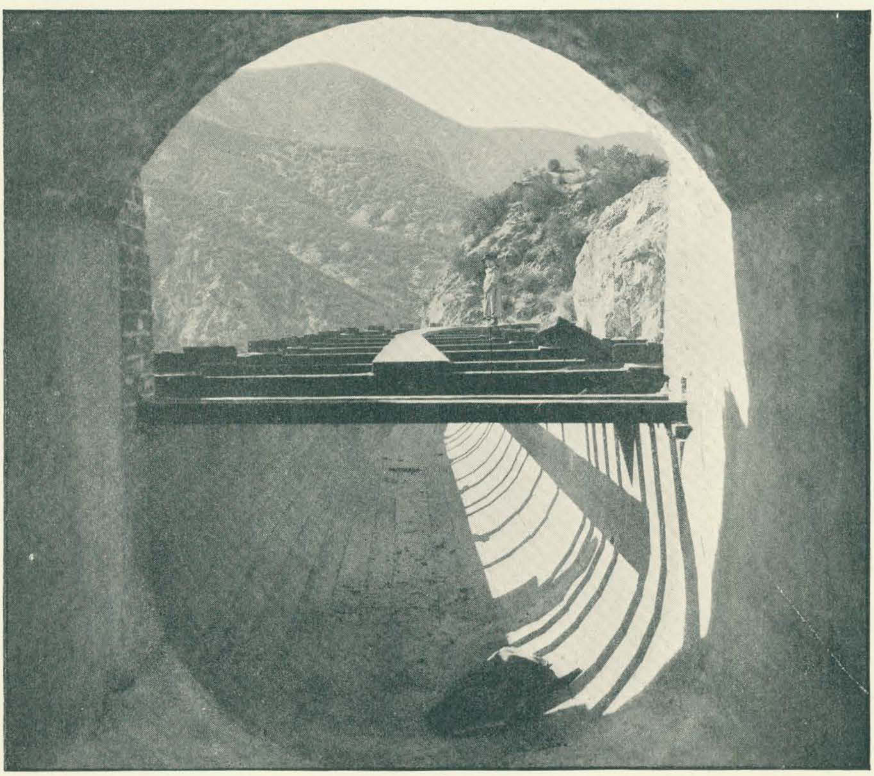
SANTA ANA CANAL.

The Santa Ana canal was designed to carry the waters of Santa Ana River and its main tributary, Bear Creek, as well as the waters turned into the latter stream from the Bear Valley reservoir in times of scarcity, to the lands of the Perris and Alessandro districts, some 15 miles from the headworks of the canal. When this work was started a line of steel pipe of a capacity of 900 miner's inches had already been constructed from Alessandro to Mill Creek, 9.7 miles of the distance.

The capacity of this canal was fixed at 12,000 miner's inches (240 second-feet), but the main portions of the conduit were constructed for a capacity of only one-half of this, or 120 second-feet, with the idea of afterwards enlarging it. It was not supposed that Santa Ana River and its tributaries would furnish a constant supply of 12,000 miner's inches, but it was intended that the conduit would serve to carry the surplus waters of the rainy season to suitable reservoirs, where the water could be stored and distributed to users when needed in the summer and fall months. Bear Creek has a large reservoir near its head waters—the Bear Valley reservoir, described on page 583, with a present capacity of 26,463 acre-feet, or 3,675 miner's inches, not including evaporation.

Santa Ana River proper has no storage reservoir, and as it has 188 square miles of drainage basin above the head of the Santa Ana canal there is necessarily a great deal of water that runs to waste nearly every year during the winter and spring months. It is proper to mention in this connection that a small reservoir site was surveyed and work commenced on the outlet tunnel for the purpose of storing the water of Santa Ana River, but on account of the financial embarrassment of the company this work was never finished. In fact all construction work was stopped, and the Santa Ana canal was turned into a temporary conduit to conduct 900 miner's inches of water from the river to the Alessandro pipe line.

A.



B.

SANTA ANA CANAL, CALIFORNIA.

A, Temporary headworks; *B*, Connection between tunnel and flume.

This reservoir would necessarily have been a regulating one, as it had a very small capacity for a very high and expensive dam. In other words, it would never have paid as a simple storage reservoir, but in case Santa Ana River and Bear Creek were flowing for a few days more than the Santa Ana canal could carry some of the surplus water could have been held in this reservoir until the discharge of the stream had fallen below the capacity of the canal, and in this way the reservoir might have been filled and emptied several times during the year.

The Santa Ana canal, which has been completed for only about 6 miles, offers some valuable lessons to the engineer, not only by the excellence of the work done in some places, but by its weak points in others.

FIRST DIVISION.

The first division of the Santa Ana canal for about 3 miles consists of tunnels, flumes, and pressure pipes, being located on the rocky, steep side of the Santa Ana Canyon. The design for the permanent headworks of the canal provides for a low crib weir, or overflow dam, crossing the canyon from wall to wall and built upon the natural bowlder of the stream. A sluice gate is to be constructed on the left bank that will maintain the channel of the river on that side of the canyon and which when closed will raise the water to such an elevation as to command entrance through the gates shown on the right-hand side of Pl. LXIV, *A*, into a fore bay, and thence through the headworks tunnel cut through the rock to the canal. Regulation will be accomplished by means of entrance gates, shown on the right of the plate. At present, diverson of water is made by means of a bowlder dam and wooden gate into a rock-lined canal leading to the headworks tunnel, the gates on the right now acting as regulators.

The river falls rapidly through the canyon; and as the canal does not have in any place a greater grade than 10 feet per mile, it results that at the place where the canal leaves the canyon it has an elevation of 300 feet above the water of the river. It then crosses Deep Creek with a wooden pressure pipe, as shown in Pl. LXVI, *B*; thence through a long tunnel to Morton Creek, with similar pressure pipe, and thence through a short tunnel to the mesa lands between Santa Ana River and Mill Creek, where the section is changed to a masonry-lined canal. This, with the exception of a few short flumes and the Mill Creek crossing, is the form maintained for the remainder of the conduit.

FLUME.

The first and most noticable feature in the canyon is the flume. It is made of 1¾-inch redwood staves, about 6 inches wide, is of circular form on the bottom, and has vertical sides about 12 inches deep at its 120-second foot capacity. It is 5½ feet wide in the clear on the top, and about 3 feet 3 inches deep in the center. A good view of this flume can be had in Pl. LXIV, *B*, taken from a photograph showing also the inside of a lined tunnel.

The flume is supported every 8 feet by a T iron, bent to the shape of the outside of the flume, and held from spreading by a wooden yoke on top. This T iron rests on a wooden sill cut to fit it, and this sill in turn rests on three concrete footings molded on the solid rock of the flume bench, and when softer material on the bench is encountered, on suitable midsills of California redwood, which has valuable lasting qualities in contact with earth. The staves are also held in place by ⅝-inch iron rods, two between each two T irons, so as to bring the weight of the water and the curved part of the flume itself between the footings on the vertical sides. These rods are bent to the shape of the flume and pass through wooden crosspieces on top. On tangents the

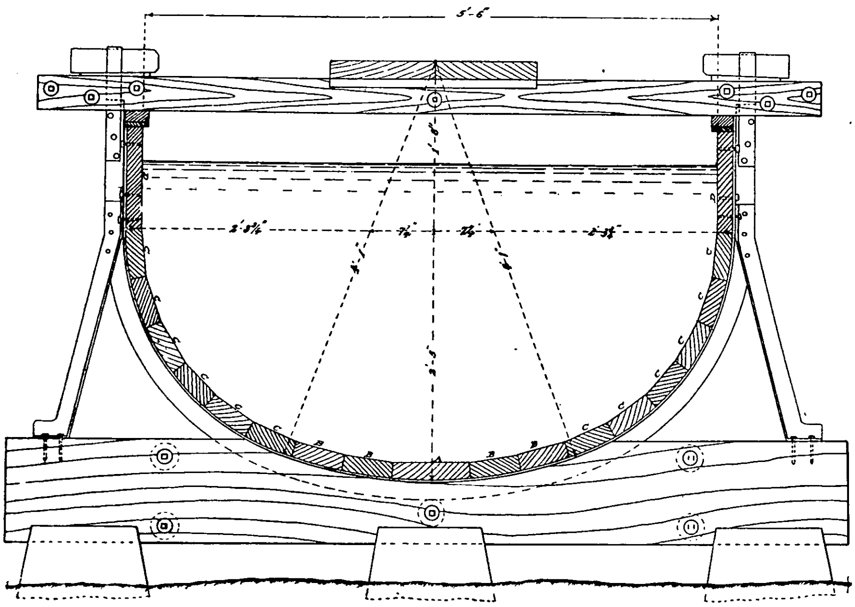
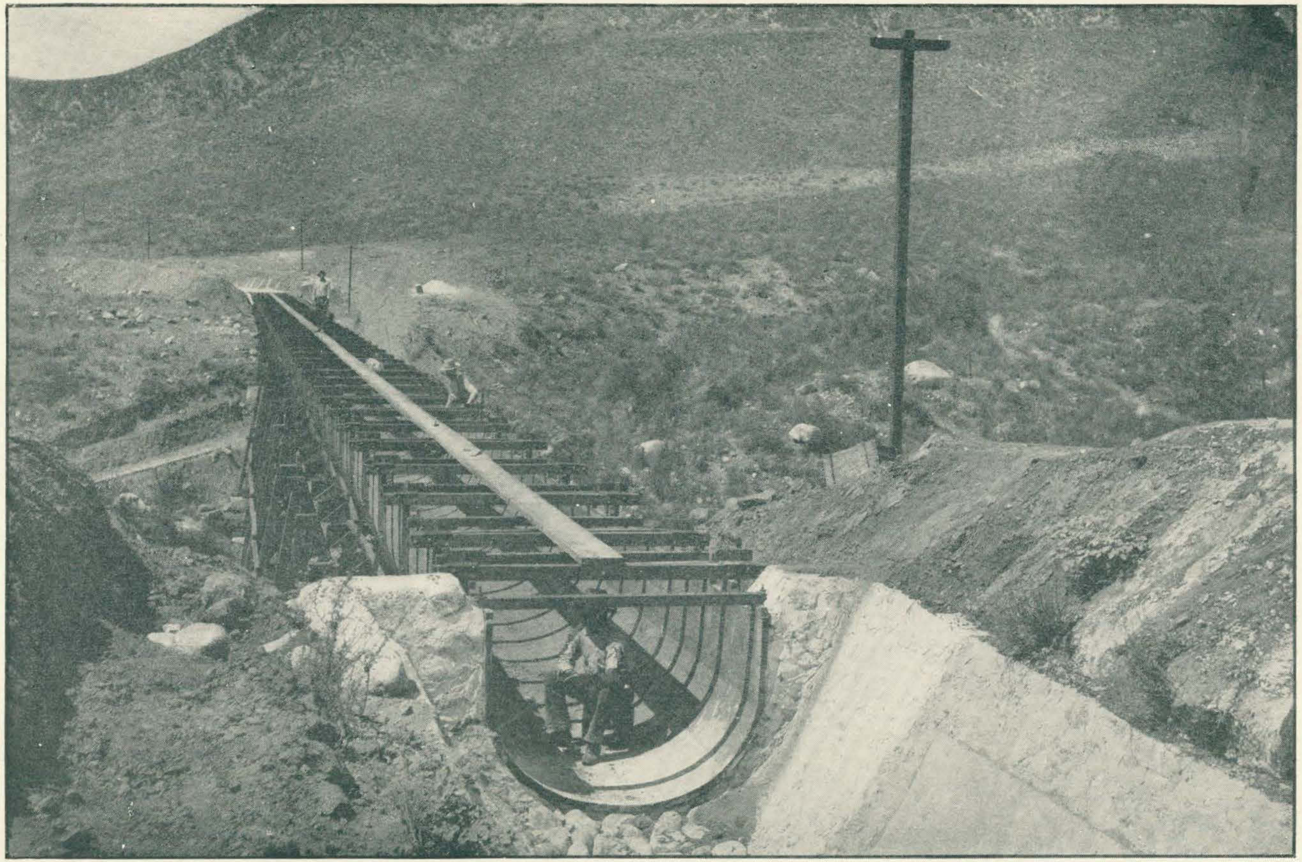


FIG. 203.—Section of combination iron and wood flume.

staves are 16 feet long, and on curves 8 feet, the minimum radius being 65 feet, the staves in all cases abutting on the center of the T-iron frames.

This is a fairly good arrangement on tangents, but the greater portion of the flume had to be built on very sharp curves to save tunneling and heavy excavation, and on curves it is not so good. During the construction of the flume a very interesting point was raised. In order to counteract the piling up of the water from the centrifugal force due to the velocity of the water rounding the curves, the outer concrete footing was elevated and the inner one depressed in proportion to the degree of the curve. The result was that, as the staves were rigid and could not well be twisted, the abutting joints could no longer be cut in vertical planes, and every stave had to be cut and



SANTA ANA CANAL ON THE MENTONE BENCHES, CALIFORNIA.

Showing flume supported on a trestle.

fitted by hand. If these concrete fittings had been level across, and the joints consequently in vertical planes, a miter machine would have saved considerable labor in the cutting of the staves. Such a machine was constructed, but could not be used.

The curved part of the flume, as shown in the cross section, fig. 203, was made in the shape of a three-centered arch, apparently with the idea of giving it a broader base. It would, however, have been very much simpler in cutting and fitting the staves if all of the parts had been of one circle instead of two.

The flume could have been reduced in width from 5 feet 6 inches to 5 feet 2 inches and had a semicircular bottom without practically increasing the amount of lumber or greatly lessening its hydraulic mean radius. The area of the full cross section as built is 15.5 feet, and when filled within 3 inches of the top of the sides the area of cross section of the water is 14.1 square feet, the wetted perimeter is 9.5 feet, and the hydraulic mean radius 1.48 feet. A semicircular flume filled within 3 inches of the top would have a cross-sectional area of water of 14.2 feet, a wetted perimeter of 9.57 feet, and the same hydraulic mean radius, the height of the flume being 3 feet 7 inches instead of 3 feet 3 inches. This latter would have been a better shape for tightening, as it is evident that the flatter the curve at the bottom the more difficult it is to make the joints tight. It would also have simplified the stave cutting and handling, and the flume could have been made just as firm on its foundations as the present one, with a slight saving of lumber in the yokes and sills.

This flume has many advantages over the ordinary, old style, square, wooden flume, and it has some weaknesses, which time and adverse conditions have brought out very clearly. The greatest advantage that can be claimed for it is that there is not a single nail in the flume proper from end to end. Again, it can be tightened by screwing up the nuts on the rods which pass around the staves and through the wooden yoke on the top. It is a good shape, giving a large hydraulic mean radius. It has comparatively few places where the wooden surfaces come in contact with each other, thus adding much to its life.

Its weaknesses may be enumerated as follows: It has a great many longitudinal joints, thus increasing the liability to leakage. Its butt joints, for every 8 feet on curves, are all in the same vertical plane, or nearly so, thus rendering it weak in the case of a slide coming against it from the inside of the curve. The method of tightening at the T irons, as shown in fig. 203, by straps and wedges passing above plates resting on the yoke, is not so effective as that of using simple nuts and threaded bolts as in the intermediate binders. Loss results from the great expansion and contraction that takes place in what is practically a surface of about 10 feet wide with 18 joints, when the flume is alternately wet and dry, and from care and attention needed to keep it tight.

The unusual shape of the lumber used in its construction is objectionable, every stave having a bead about one-eighth of an inch in diameter running along the side where it joins the next one. In case of extensive repairs it is necessary to have a great deal of this lumber in stock or else have it manufactured by especial order. An examination of the flume at present reveals a great number of leaks in the longitudinal joints, on the canal division, where there are several canyons crossed by flumes supported on trestle work. These leaks are caused by turning water which bears sand and fine gravel into the flume after it has been empty for several days without first cinching up all the binders.

Four to five days in the sunny climate of southern California is sufficient to thoroughly dry the staves and cause so much contraction of the wood as to open the joints and practically sever the connection of the staves at the bottom of the flume with those on the side, which are their natural support when the binders are tight. The consequence is that when the water is turned into the dry flume the staves in the bottom, which are only 1⅞ inches thick in the direction of the weight, are deflected in the middle of the 8-foot lengths, the ends of which rest on the T irons, and the water rushes through the joint, carrying sand and small gravel with it. This is caught in the opening by the little bead, and there it remains, thus keeping the joint open and preventing the flume from being made tight again by cinching, unless it is taken apart and all of the sand and gravel removed. This would be a tedious and inconvenient operation, necessitating the recalking and asphalting of the vertical joints.

The bending of the lower staves gives the appearance of weakness to the flume, and leaking has been attributed to this cause by some who have not understood the design of the intermediate binders. When these are kept tight the weight of the water in the 8-foot joints is carried by the vertical side of the flume, but when these are allowed to get slack the strength of the flume as a girder is destroyed, and leakage and distorted, bent, and broken staves are the result. The financial affairs of the Bear Valley Company have been in such a condition since the flume was built that it has had very little attention. It seldom, if ever, has had more than 1,000 miner's inches of water running in it, and it is safe to say that fully 15 per cent of the water turned in at the headworks never reaches the lower end of the canal, where the connection is made with the Alessandro pipe line.

There is difficulty in making a tight joint where the butts come together over the T-iron frames without interfering seriously with the flow of water in the flume. As arranged at present, these joints are calked with oakum and plastered over with asphalt. This work was carefully and well done, taking everything into consideration, but it is impossible to make this kind of a joint without leaving a little ridge of asphalt clear around the flume at every joint. This might not at first sight appear to affect the flow of water very much, but it apparently does lessen the amount which the flume was calculated to carry 36 per cent on an average for depths not exceeding 15 inches.

The following measurements of actual velocity have been made carefully by meter, and the calculated amounts are placed beside them to show the difference in each case:

Comparisons of calculated and actual capacities of Santa Ana Canal flume.

Depth at center.	Area.	Wetted perimeter.	Hydraulic radius (area divided by perimeter).	Velocity per second.	Calculated capacity.	Actual capacity.
Inches.	*Square feet.*	*Linear feet.*	*Feet.*	*Feet.*	*Second-feet.*	*Second-feet.*
14¼	4.26	5.75	0.74	5.45	23.25	12.19
12¼	3.43	5.33	0.65	5.20	17.83	13.31
10¼	2.75	4.91	0.56	4.60	12.65	9.78
12½	3.63	5.38	0.67	5.25	19.06	9.66
10¼	2.75	4.91	0.56	4.60	12.65	9.57
14⅜	....	....	....	3.37	23.76	15.00

The value of n in Kutter's formula was assumed as 0.01, being a fair assumption for planed lumber, but the above measurements show that all the conditions were not taken into account, because from the actual velocity the value of n would be nearer 0.015.

This is mentioned simply as an example of the difficulty in making practice agree with theory for even the most careful engineers. Great care was taken with the meter measurements.

WOODEN PRESSURE PIPE.

The next features of this work that attract the engineer's attention are the pressure pipes, of which there are 3, all 52 inches inside diameter and made of redwood staves bound with five-eighths-inch steel rods, with special castings of malleable iron, into which the rods are connected and tightened by nuts and screws on their ends. The distance between the binding rods is proportioned to the pressure that the pipe has to bear, with a factor of safety of 4.

The first of these pipes is at the crossing of Warmsprings Canyon. It is 540 feet long and under a pressure of about 25 pounds to the square inch in its lowest part. The Deep Creek pipe is 908 feet long, and under a pressure of 67 pounds to the square inch in its lowest part. The Morton Creek pipe is 680 feet long, and has the same pressure as that at Deep Creek.

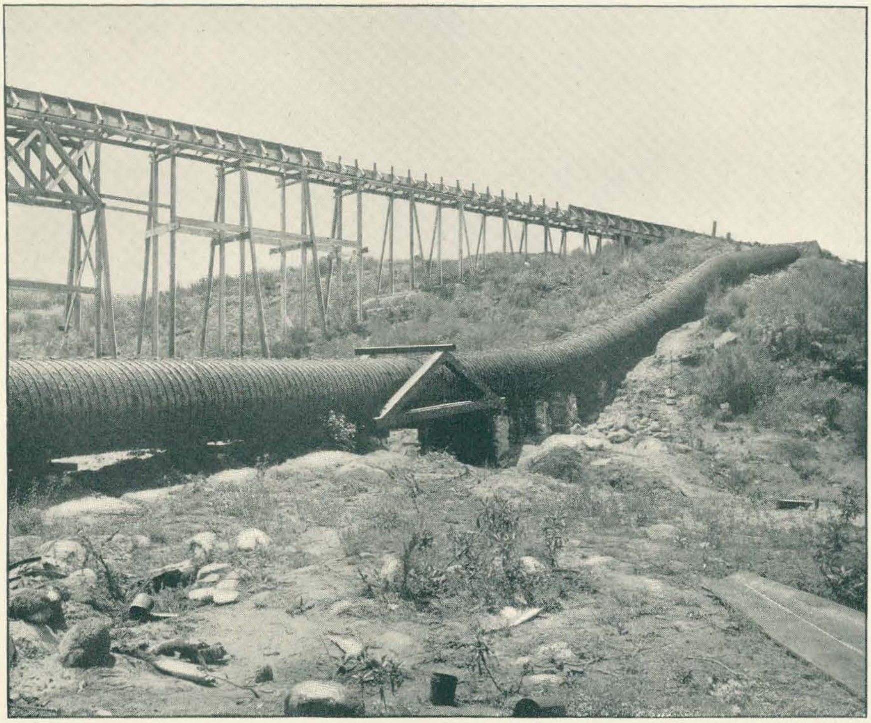
These pipes are made of clear straight-grained redwood staves about 6 inches wide, varying from 2 to 2½ inches in thickness, and of various lengths, as the butts are intended to break joints. The butt ends are connected with an iron dowel about ⅛ by 1½ inches by the width of the stave, let into saw kerfs three-fourths of an inch deep, in the ends of the butting pieces. This makes a very effective and tight joint, there being absolutely no leaks from the butt joints on any of the pipes of this work. The pipe is partly cinched up, and the staves are then driven tightly home, longitudinally, with a 12-pound maul, each stave being so driven.

In the first wooden-stave pipes made on the Pacific coast wooden dowels were used, but it was found that the swelling of the dowel as soon as water was turned into the pipes split the redwood and caused many leaks. Later methods of cinching have largely obviated this defect.

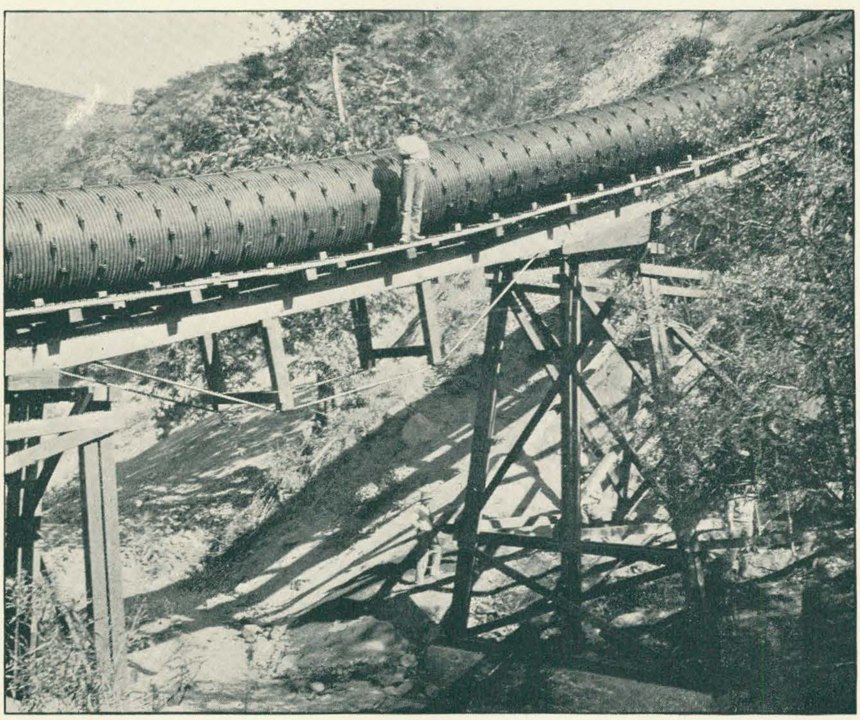
The longitudinal joints are made tight by a bead about one-eighth of an inch in diameter being run along the center of one side on each stave, so that when the rods are cinched up the bead sinks into the adjoining stave, and thus makes a small tongue and groove connection and a very tight joint. The wood in these staves is very straight grained and smooth, being planed on all sides, and gives an ideal coefficient of roughness, so much so that a wooden pipe of this class can always be of much less diameter than a metal or cement pipe carrying the same amount of water.

An interesting point about these pipes is that, unlike tanks or other vessels bound with iron or steel hoops, they can and should be tightened up as much as possible before allowing the water to be turned into them. The swelling of the wood which then takes place has only the effect of sinking the round steel rod into the surface of the redwood, while it would assuredly break a flat band or hoop of the same cross-sectional area as the rod. The reason is that, the surface of the flat band being so great, the crushing of the wood does not take place, and the band has to bear not only the pressure of the water, for which it is calculated, but the additional strain imposed upon it by the swelling of the wood, for which it is not calculated. How great this force is may readily be seen by the depth to which some of these pipes are indented by the steel rods. This point has been dwelt on because it is of great importance in connection with a question raised during the construction of these pipes.

The weak point of these pipes is that the diameter is so large and the staves so heavy that it is impossible to curve them sufficiently to rest on the ground all the way across deep canyons. It is necessary, therefore, to support them for varying distances on trestlework. This, if of iron or steel, would be very expensive, and being of wood is liable to be burned down at any time, for fires are of frequent occurrence in these canyons in summer. Under these circumstances the pipes can hardly be called permanent structures, and as the Deep Creek and Morton pipes cost from $10 to $12 per linear foot it is certain that steel pressure pipes laid under the ground would have been more permanent and much cheaper. A steel pipe of 54 inches diameter, under a pressure varying from 0 to 95 pounds per square inch, would need to be on an



A.



B.

VIEWS OF REDWOOD-STAVE PIPES IN CALIFORNIA.

A, Old flume and new stave pipe replacing it, Redlands canal; *B*, Pipe under 160-foot head, Santa Ana canal.

average one-eighth of an inch in thickness to give it a factor of safety of 4. Such a pipe would only weigh about 75 pounds per linear foot and would not cost over 6 cents a pound delivered, or $4.50 per linear foot. Allowing $1.50 a foot for excavating and back filling, this pipe could certainly have been built for a little more than half the cost and would have been much more permanent than the wooden pipe combined with the wooden trestle.

The interior of the wooden pipe is smooth and true. It is not liable to deteriorate like the steel or iron pipe. It is durable, is easily tapped, is capable of adjustment, and is altogether the nearest approach to an ideal conduit for water where, in the case of large pipes, the pressure does not exceed 40 pounds per square inch and the nature of the ground is such that curves of less than 250 feet radius will not be required.

The pipe shown in Pl. LXVI, *A*, was built on the Redlands canal near the mouth of Santa Ana Canyon, to replace the flume which is also shown. It is considered an improved form of construction because of the much greater length of life of the pipe, the fact that it is a much better conduit and is cheaper. In 1898 this pipe was examined, after it had been in service for ten years, and found to be in a sound condition. It has had no repairs. This has become a very popular conduit in the West, where iron is expensive and wood is cheap.

Pl. LXVII shows a 52-inch redwood stave pipe under a head of 160 feet. It will be noticed that the round iron bands which hold the pipe together and resist the bursting strain are only 3 inches apart. When the number of iron bands is so large, the weight of metal in the stave pipe becomes almost as great as that of an iron or steel pipe, and thus limits the economy of its use. Another serious fault in the stave pipe is that in a rough country it can not be bent to a sufficiently sharp radius to fit the ground. The minimum radius with 52-inch pipe is 240 feet, and for this reason this pipe is much higher up in the air than it is desirable to have it. With careful use, by keeping the pipe always full of water to prevent rot, the stave pipe should far outlive the iron pipe. An improvement that has recently been adopted on a power plant on San Gabriel River makes the sharp turns in the pipe line by putting in elbows of riveted steel pipe. These are made of sufficient diameter to fit over the ends of the wood pipe and the intervening space is rammed with cement.

TUNNELS.

All the tunnels on this division except one were intended to be of the same cross section when finished, or about 6 feet 3 inches wide by 7 feet 6 inches high from invert to roof. The amount of excavation varied with the material, an allowance being made in each case to suit the thickness of the lining to be adopted. Some of the tunnels were through hard granite rock and were left in the rough; others were lined with concrete on the floor and sides; one was lined with concrete and roofed with brick (see Pl. LXIV, *B*); one, about 1,600 feet long, was partly lined with concrete and plastered on the invert and 1 foot in depth on each side.

The long tunnels, of which there are two, one about 1,600 feet and one about 1,400 feet, are on a grade of 2 feet per 1,000, and the shorter ones, of which there are seven, varying in length from 40 to 240 feet, are on a grade of 1.75 feet per 1,000, the same as the flume. Much care was taken to keep the different parts of the waterway as nearly of the same capacity as possible, and where so many different forms of cross section had to be adopted this was not an easy matter.

One of the most novel and extraordinary features of this work is the tunnel through the Morton Ridge, near the end of Division I. The ridge is a "hog back" of cemented gravel and bowlders rising abruptly about 250 feet from Morton Creek on one side and sloping off more gently on the other side to the mesa land lying between Santa Ana Canyon and Mill Creek. The tunnel is about 500 feet long, is of circular cross section, 6 feet in diameter in the clear, lined with 3-inch planed redwood staves, backed with concrete, the latter being rammed in solid all around, between the wooden tube and the surface of the excavation. The peculiar arrangement of this tunnel is that it is on an upgrade in the direction of the flow.

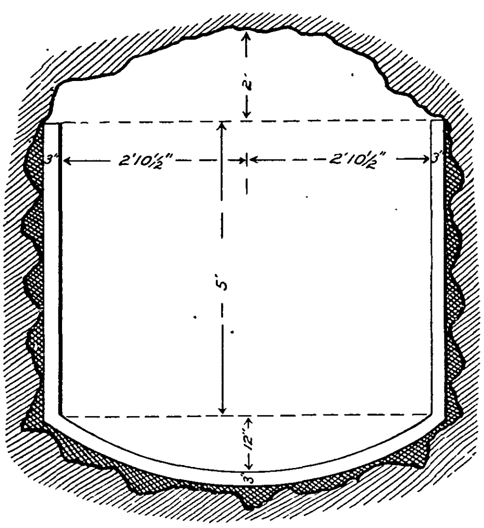
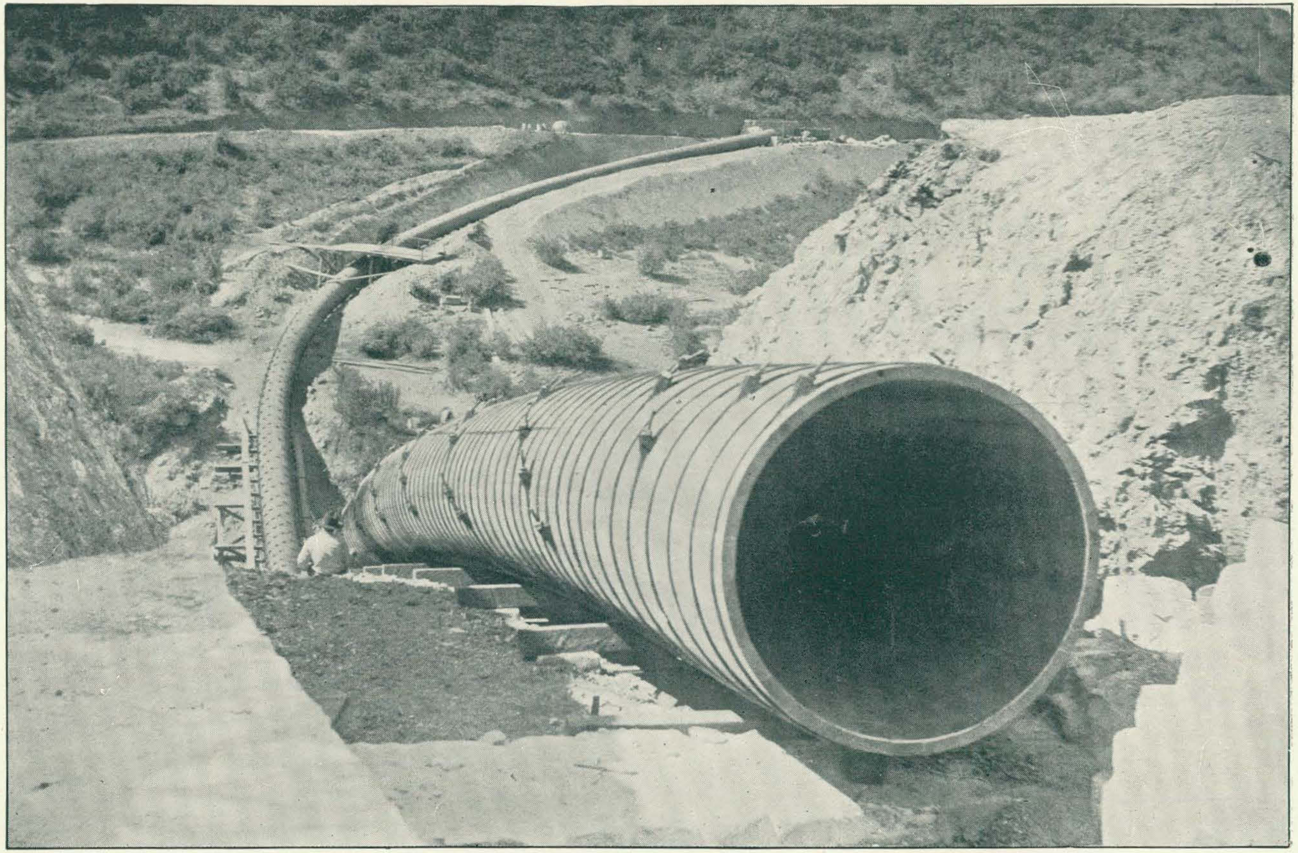


FIG. 204.—Tunnel section in rock, Santa Ana canal.

There seems to be no reason why a tunnel similar to the others could not have been constructed through the ridge at much less cost, as the material was comparatively easy to work and good to stand until lined. It is evident that the intention was to keep the wood lining always wet, so as to preserve it, but this could have been done more easily and cheaply by simply excavating a rough tunnel through the hill and continuing the Morton Creek wooden pipe through it to a junction with the canal on Division II.

As this tunnel is at the lower end of the Morton Creek pressure pipe, it was necessary to have a receiving chamber of some kind to connect the tunnel and the pipe. As the tunnel was dropped at this end to keep it always full of water, a wooden penstock about 16 feet high was built close up to the tunnel. On one side it was connected with the pressure pipe, and on the other side with the tunnel by means of a funnel-shaped arrangement of wooden staves, gradually merging into



REDWOOD PIPE CROSSING WARMSPRINGS CANYON NEAR REDLANDS, SAN BERNARDINO COUNTY, CALIFORNIA, ON THE MAIN HIGH LINE OF THE BEAR VALLEY CANAL.

The diameter of the pipe is 52 inches.

the tunnel lining. This penstock is simply a standpipe on the Morton Creek pressure pipe. Silt is deposited here and is extremely hard to remove.

The only apparent reason for putting the tunnel on an upgrade in the direction of the flow was to keep it entirely below the hydraulic grade line from the inlet of the Morton Creek pipe to the outlet of the tunnel at Division II, and thus keep the pipe and tunnel always full of water to preserve the wooden lining.

Of course the tunnel could have been dropped bodily parallel to grade line, but this would have meant a box at the lower end more than twice the depth of the diameter of the tunnel. To avoid this and to keep the velocity of the flow as uniform as possible, an incline at the lower end was substituted for the box, which would have made considerable change in the velocity of the water.

To accommodate the Morton Creek pipe to the lower tunnel it was necessary to curve the pipe so much that the staves could not be bent, and a series of chords were made in the pipe to allow of its entering the penstock on a level with the tunnel. This is open to criticism, as the sharp angles would, when the pipe was running at its full capacity, entirely destroy the uniformity of flow which the pipe otherwise would have. At the lower end of the tunnel another piece of stave pipe on chords of sharp curve was tacked to the tunnel lining, apparently to save masonry work in lining the sides of the incline. This is also destructive of the uniformity of flow so carefully provided for in all other parts of the work, and extra expense and poor work were made necessary by putting the tunnel below grade. The penstock is exposed to the elements on a steep sidehill 150 feet above the creek, with 60 or 70 feet of steep ridge above it, and if it is not knocked down by a slide from above, which would bring disaster to the expensive pipe below, it will presumably rot in a few years.

CONNECTIONS.

The connections between the different forms of waterway on this work are made in a very substantial manner. The change from flume to tunnel and from tunnel to flume does not require special mention, as the flume in each case is simply let into the tunnel about a foot and surrounded with a concrete wall bedded against the floor and sides of the tunnel (Pl. LXIV, *B*). No attempt was made to change gradually from one section to the other, as they were very similar and the slight difference in the calculated velocities did not seem to justify the expense.

In changes from flume to pipe, from pipe to tunnel, and vice versa, the difference in section was so great that a special chamber had to be designed to suit each case.

As there are three pressure pipes on Division I, there are six of these chambers: 2 from flume to pipe, 1 from pipe to flume, 1 from tunnel to pipe, and 2 from pipe to tunnel.

These chambers are designed with great care so as to avoid as much as possible any disturbance of the water. Five of them are well and substantially built of rough rubble masonry on concrete foundations and lined with cement plaster. One, from the Morton Creek pipe to the Morton Ridge tunnel, is a wooden penstock that has been already mentioned in discussing the Morton tunnel. The others, as well as the trestle supports under the pressure pipes, are designed to accommodate two pipes, although only one has been built. This was a needless expense and added to an already costly piece of work. Even if the company had been able to carry its land-speculation business at Alessandro to a successful issue, it is hardly probable that the canal would ever have been enlarged, owing to the fact that, as later measurements have shown, the water supply was not nearly so plentiful as was calculated upon before this work was commenced. When the pipe sloped down suddenly from the flume the bottom of the chamber was made on a curve joining the lines of flume and pipe so as to offer as little resistance as possible to the flow of water.

In one instance a horizontal curve was made in the walls of a connecting chamber to accommodate the flow from pipe to flume. Great care was taken in the construction of the chambers, as they are all situated at places where an accident would be fatal to the pipes, which are laid on steep inclines below them.

SAND BOX.

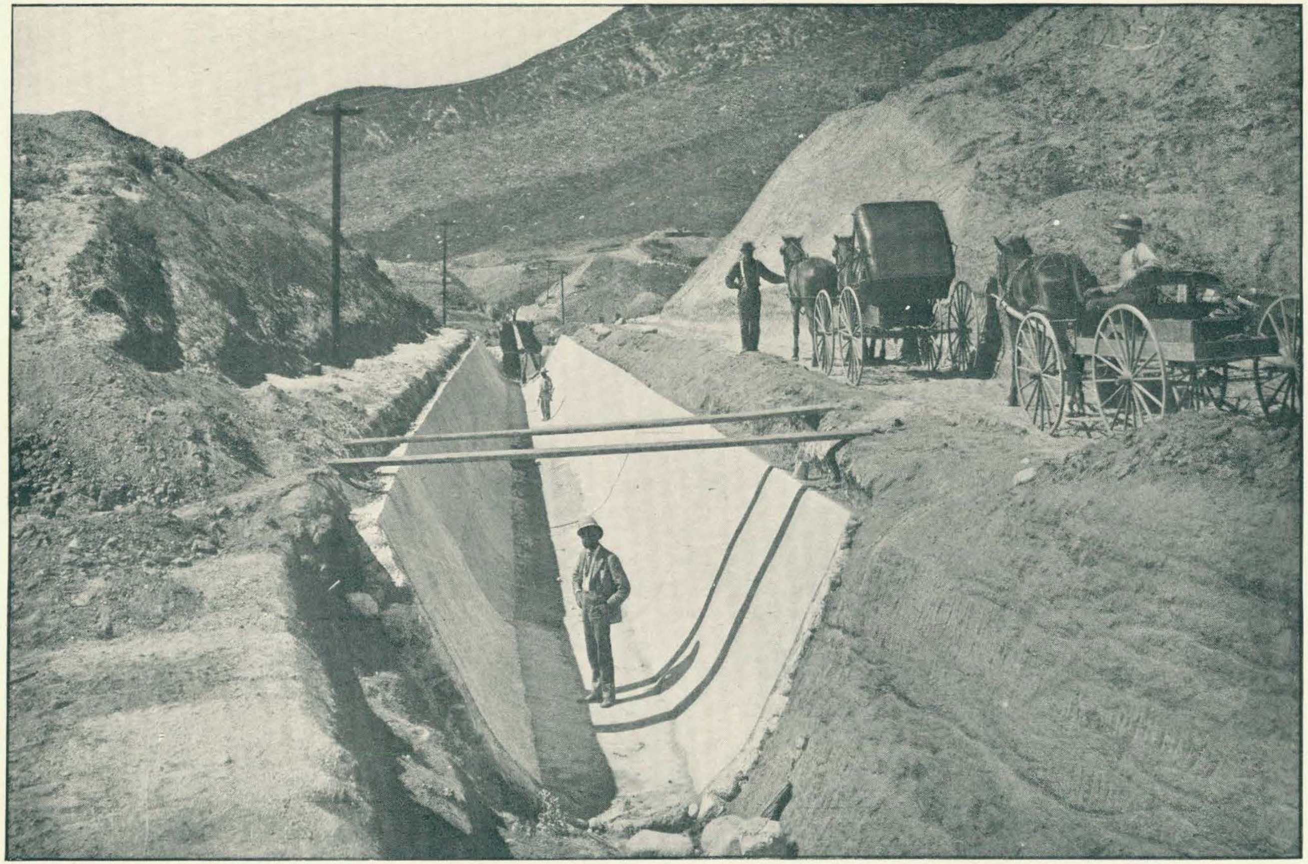
There is at present only one sand box on the work, and that is a substantial and well-built masonry structure, although it must be confessed that its capacity is very small for the amount of money it cost. It is about 60 feet long, 13 feet wide, and in the deepest part about 4 feet below the level of the flumes that enter it. The bottom part of this masonry box is cut up by cross walls and sloping floors into four prismoidal chambers with a sand gate in each. This class of sand box is mentioned in the description of the Crafton canal.

POWER DROP.

There is one power drop planned on this work, but it has never been finished. It is at a point where the flume is at a height of about 350 feet above the bed of Santa Ana River, but had the intention of conveying surplus water in winter to the San Jacinto reservoir been carried out only a very small constant supply of water could have been relied on, because in winter only a small quantity of water is needed in the ditches to Redlands and Highlands, which this drop commanded.

SECOND DIVISION.

Division II of the Santa Ana canal is about 2 miles long and is principally canal section, as shown in Pl. LXVIII. There are about six gulches or arroyos on this division, crossed by flumes of the same form as those of Division I, but 12 inches deeper. These flumes aggregate



SANTA ANA CANAL, CALIFORNIA.

Capacity, 240 second-feet (12,500 miner's inches).

about 1,500 feet in length. They rest on wooden trestlework, with bents 16 feet from center to center, and occasionally, where it is necessary to have a large water way underneath, on 32-foot trussed girders.

There are two or three arroyos crossed with earth embankments having drainage culverts underneath. The intention was to allow these banks to settle for two years and then excavate and continue the masonry lined canal through them. With this object in view, temporary rough wooden flumes were laid on these banks, of sufficient cross-sectional area to pass about 1,000 miner's inches of water for the Alessandro pipe line. These flumes have never been altered since laid in 1893, so that the actual present capacity of the Santa Ana canal may be said to be only 1,000 miner's inches.

One short stretch of the canal has been finished to the full capacity of 12,500 miner's inches (see Pl. LXVIII). This section is 12 feet 6 inches wide at the top, 7 feet 6 inches deep at the center, chord of invert 6 feet 6 inches wide, and versed sine 1 foot 6 inches. The lining was done with bowlders roughly broken to shape and laid in cement mortar. The walls were first built against the sloping sides of the excavation, which, being nearly all of the way in hard clay and cemented gravel, was made with side slopes generally of 2 on 1. The invert is simply paved and the chinks filled with coarse sand and spalls, with a layer of mortar roughly bedded on top, on which is laid the cement plaster lining. The walls are laid with more care to a rough surface and are from 8 to 10 inches thick on the top and about twice that thickness on the bottom.

As the material on this division is generally hard clay and the rainfall is very slight, there has been no trouble whatever experienced from the bulging or breaking of the walls from water lodging behind them, and the lined portion of the Santa Ana canal is a very substantial and permanent piece of engineering work. The grade of this portion of the canal is very light, as a low velocity was necessary to prevent the wearing away of the cement lining by the sand and silt which is sure to find its way into the water, especially during freshets.

The calculated velocity for the full section is about 5 feet per second, that of the flume being about 10 feet per second. Careful provision was made for changing gradually from canal to flume section and vice versa. An examination of the two sections seen in the plates will show that this was a difficult piece of work. The change from flume to canal was accomplished by building a wall across the canal, fitting the flume into this wall, and, by flaring or sloping surfaces of masonry, joining the edges of the flume to the bottom and sides of the canal. The change from canal to flume was accomplished by narrowing the canal section for about 8 feet and then continuing the contraction by a wooden flume 16 feet long, which gradually changed from this reduced section of canal to the flume section. The purpose was to change section and velocity without loss of head.

This flaring flume was built on the same general principles as the flume, being composed of redwood staves, cut and fitted to effect the warping of the surface from a 2 on 1 slope in the canal to a vertical plane in the flume. These staves were connected and tightened by yokes and binders similar to those used between the T-iron frames on the flume.

It is unfortunate that the affairs of the company have been in such a condition that this canal was never finished, as this was one of the many interesting points where engineers differed and were anxious to see the results in actual practice.

MILL CREEK BRIDGE.

The most notable piece of work on Division II is the Mill Creek bridge. Mill Creek at the point of crossing is a wide and sloping wash of waterworn bowlders, cobblestones, and gravel, with occasional beds of sand. The water course, which, except in the times of flood, is only 10 feet wide and a few inches deep, winds through the wash, and the channel is liable to change in every flood. The flume, which is of the same section as the others on Division II, is supported by nineteen steel Pratt truss spans of 48 feet each, resting on braced steel trestle piers on concrete footings. The depth of the bowlder bed being unknown, these concrete footings are about 8 feet deep, resting on a foundation of redwood planks. The footings of each pier are connected and surrounded with a casing of redwood planks, which forms a box, and the space between the footings is filled with cobbles and gravel. The bridge is 1,072 feet long from end to end. The spans are in couples, and the piers are alternately a rocker and a pair of trestle bents 16 feet apart and braced on all sides, so as to form a tower, the flume being carried over this tower by a 16-foot span of the Fink type.

The bridge is a very light structure, but it is carefully and economically designed, and as it is riveted throughout (no bolts being allowed) is likely to last a long time if kept painted. The steel piers are latticed channel posts, braced and anchored to the concrete footings.

The flume on this bridge is an improvement on the other flumes, as the butts break joint, the clumsy wedge and strap arrangement is done away with, and a simple nut and bolt and large washer substituted. A continuous strip of hard wood is also substituted for the wooden wedges and blocks on the top of each side of the flume, on which each yoke bears directly. The consequence is that there has never been any trouble with the flume on the Mill Creek bridge.

The frames are supported by the floor beams, which consist of two channels, separated sufficiently to allow the rib of the T-iron frames to drop between them. A special cast-iron chock is used under the frames in addition to the ordinary side brace, since the frame can not be let down into the channels, as was done in the case of the wooden sills on the other portions of the work.

This bridge and flume cost about $11 a running foot, and it seems singular that wooden pipe was not used instead. If one wooden pipe was sufficient for present purposes across Deep Canyon on Division I, there seems to be no reason why it would not have been more economical to use it in this case also, especially as it would have been under very low pressure, not to exceed 25 feet, and could have been put in, even doubled, for very much less than the cost of the bridge. Sunk 3 or 4 feet below the general level of the wash, it would have been practically safe from injury, as the tendency in all washes from the canyons in southern California is to build up instead of washing out, and a wooden pipe filled with water would under these circumstances be practically indestructible.

COSTS.

The total charges against the Santa Ana canal, including engineering, roads, trails, telephone lines, inclines, right of way, law expenses, etc., were about $250,000 for a length of 5.4 miles of conduit, or $8.76 per linear foot. This is a high price to pay for a canal, but it must be remembered that the first 3 miles of the work are in an exceptionally rough country, and that a great part of the expense was due to the connections necessary for the change from one form of cross section to another. There are about 40 of these connections on this piece of work.

The objection has been made that a good deal of money was spent in experimenting upon the work, but it was money well spent, and was trivial compared with the money actually thrown away by the loose financial management of the company's affairs.

Taken as a whole, the Santa Ana canal is the best example in southern California of a scientifically constructed conduit for the passage of irrigation water.

MINOR STREAMS TRIBUTARY TO SANTA ANA.

The minor streams flowing from the southern face of San Bernardino Mountains, with the areas of their tributary basins, in square miles, are as follows: East Twin Creek, 5.77; West Twin Creek, 10.66; City Creek, 22.20; Plunge Creek, 18.32; total, 56.95 square miles. These areas are planimeter measurements made on the topographic atlas sheets of the United States Geological Survey.

All the basins referred to above have southern exposures, the slopes being steep and rugged. Little timber grows on these, but there is a good growth of brush. Spasmodic streams might be expected from these basins, the summer flow being quite low, owing to the steep slopes and high evaporation. Unfortunately there are no reservoir sites in which to store the winter waters.

EAST TWIN CREEK.

This stream enters the valley to the north of the town of San Bernardino by a short and precipitous course. The first diversion was by a citizens' association of San Bernardino in 1870, the water being taken out at the mouth of the canyon in an earthen ditch, which ran directly to the city, a distance of 4½ miles. The soil being sandy, the greater portion of the water was lost by seepage. For this reason it was abandoned by the city people, and the irrigators near the mouth of the canyon sold out their rights.

About 1875 Seegars & Leedon appropriated this water. Their point of diverson was about one-half mile above the mouth of the canyon, on the west side. The water was used on the lands immediately adjoining. The diversion was in an open ditch of from 60 to 70 miner's inches capacity. These appropriators took up the lapsed rights of the first users.

John Hancock next filed on 1,000 miner's inches and bought out Seegars & Leedon. Other irrigators either ceased using the water or sold their rights. His diversion point was one-half mile above the mouth of the canyon, on the eastern side. This diversion was by means of a bowlder dam into a canal, which has since been cemented or laid with a 16-inch vitrified pipe. The loss from seepage in this canal in 1897 was 8 miner's inches, as determined by weir measurements, when it was flowing 65 miner's inches. There are 600 feet of cemented canal, 400 feet of vitrified pipe, 800 feet of earth canal, and the remaining portion is in rock of varying stages of disintregation.

John Hancock sold all his rights and titles to the Kansas City Real Estate and Investment Company. This company used and improved the canals built by Mr. Hancock, and continued using the water on the same land—all of secs. 24 and 25, and the eastern parts of secs. 14, 23, and 26, T. 1 N., R. 3 W., San Bernardino meridian. There are in all 700 acres irrigated from this source of supply.

The land has been subdivided and the water made appurtenant to the land, so that the owners of the land become owners in common of the water. The duty of water here is 1 inch to 7 acres. The canal is operated by an association and the water controlled by committees.

The average midsummer flow of this stream at the point of diversion is difficult to estimate, because of the diurnal variation. In summer a morning flow of 80 miner's inches might follow an evening flow of 50 miner's inches.

The midsummer mean flow is probably about 75 miner's inches. The minimum flow of the stream August, 1896, was 40 miner's inches. This is the year of least rainfall on record at San Bernardino. In January, 1897, the flow was 100 miner's inches.

The distribution is in iron pipes, under heads varying from 0 to 147 feet. This pipe was laid in 1890. An interesting feature in this system is that iron pipe of 14-gage was laid under the same general conditions of pressure and soil as some 16-gage steel pipe. Both pipes were dipped in asphalt. In 1897 the iron pipe showed very slight deterioration, while the steel pipe was nearly worn out. The iron pipe is Wood's charcoal, soft iron. The irrigation in this district is all by the furrow system. The most of the orchards are of citrus fruit. The duty of water depends upon the character of the soil, varying from 6 to 10 acres per miner's inch for this district.

Discharge measurements on East Twin Creek.

	Second-feet.
June 12, 1898	2.05
September 9, 1898	.73

This may be taken as minimum flow.

WEST TWIN CREEK.

The Savings and Banking Company of San Bernardino irrigate about 25 acres in Watterman Canyon, and the West Twin Creek Water Company divert from 50 to 100 miner's inches by means of a flume and irrigate about 160 acres to the southwest of the canyon. Citrus fruit is the principal product. All of the water goes on alternate days to these two localities.

Discharge measurements on West Twin Creek.

	Second-feet.
June 11, 1898	2.13
September 9, 1898	.38

This may be taken as a minimum record.

CITY CREEK.

This stream discharges from the 22.2 square miles of its basin 50 to 150 miner's inches. The water is diverted by means of a ditch, and is distributed by the City Creek Water Company over about 500 acres of land in the vicinity of Highlands on citrus orchards.

Discharge measurements on City Creek.

	Second-feet.
June 11, 1898	3.03
September 9, 1898	.07

This may be taken as a minimum discharge.

PLUNGE CREEK.

The course of this stream is short and precipitous, and the condition of its flow is erratic, large volumes of water being discharged in the winter and the summer flow going as low as 10 miner's inches (0.2 second-feet). In June, 1897, this stream was flowing 75 miner's inches (1.5 second-feet).

The first diversion was in earthen canals. The water is now diverted by means of a little bed-rock dam at a point 1¼ miles above the mouth of the canyon. In 1897 a cement-lined rock ditch, with a capacity of 200 miner's inches (4 second-feet), was constructed to the northwest along the base of the mountains for about 3 miles. There are about 200 acres of citrus fruits irrigated, lying above the North Fork ditch and near the asylum.

A small reservoir is used for storage purposes for a portion of the water, and a portion is run through the North Fork ditch and taken out again.

The cement canal was built by the East Highlands Orange Company. This company owns all of the water but "five hours' run;" that is, nineteen twenty-fourths of it.

Discharge measurements on Plunge Creek.

	Second-feet.
June 11, 1898	2.26
September 9, 1898	.20

This may be taken as a minimum measurement.

DEVILS CANYON.

The stream from this basin is owned by the Muscapiabe Land and Water Company. It is said that 200 acres of land near the mouth of this canyon are irrigated with this water.

MOHAVE RIVER.

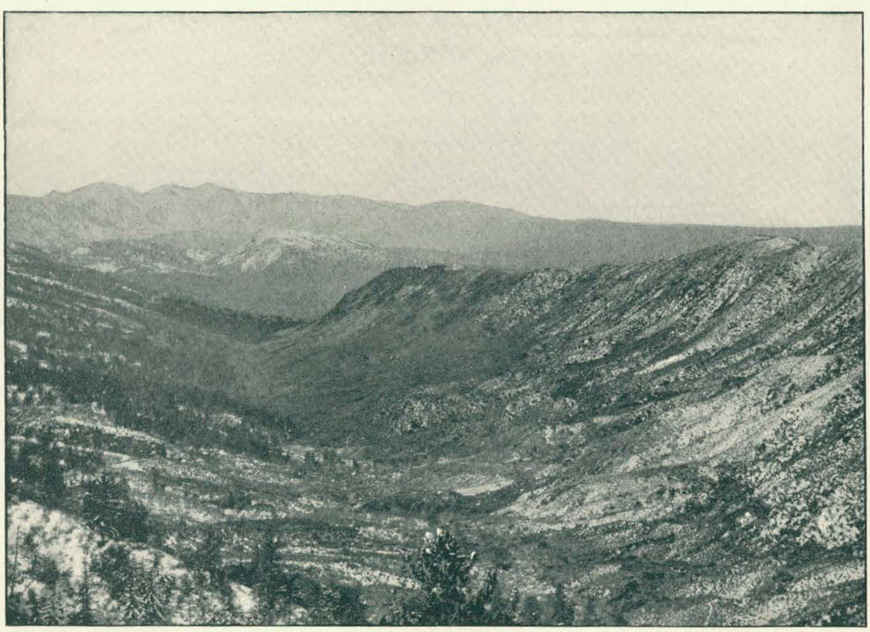
Mohave River rises on the northern slope of the Sierra Madre Mountains in San Bernardino County, California. Its course is semicircular, flowing progressively west, north, and east, and, as is common in the arid region, decreasing in volume as it progresses onto the plains, until the surface flow at last disappears in a sandy bed a short distance below Barstow. The head waters of this stream flow from elevations of 5,000 to 8,000 feet, and at an elevation of 1,900 feet disappear, the foothills of these mountains being 3,000 feet above the level of the sea.

On Pl. LXIX are views of the San Bernardino Mountains, that marked *A* being a winter scene in Little Bear Valley. This is immediately north of the crest of the San Bernardino Mountains and is the portion of the drainage basin of Mohave River, tributary to the Arrowhead reservoir storage basin, in Little Bear Valley. The snowfall in this locality is heavy, as shown by the view.

In Pl. LXIX, *B*, is shown a portion of the drainage basin of Mohave River, this being taken at a point below the altitude of the lines of the Arrowhead reservoir, the area shown in the foreground being tributary to the lower works on the stream located at Daggett and the proposed canals for Victor. The view illustrates the conditions in midwinter.

The basin may be classified in three parts: Mountainous portions, 251 square miles; foothills, 219 square miles; plains and desert buttes,

A.



B.

VIEWS IN SAN BERNARDINO MOUNTAINS, CALIFORNIA.

A, Winter scene at Little Bear Valley; *B*, Head of Mohave River, San Antonio Mountain in the distance.

1,000 square miles; making a total drainage area above Daggett of 1,470 square miles. These areas are measured by plainimeter on the county map.

To the west there are many mountains that drain toward Mohave Desert, but the streams, which are small and few in number, disappear as soon as they reach the hot sands of the desert. The general slope of this great valley is toward Mohave River from the west at the rate of 2 feet to the mile, but the rainfall is so light (about 3 inches per annum) and the summer heat so great that the run-off is at least not on the surface.

Mr. H. B. Hedges measured Mohave River on September 20, 1894, and found 30.66 second-feet at the Victor Narrows. September 27, 1895, he found 53.79 second-feet. The river sinks in the summer in the Mohave sand wash within half a mile of the mouth of the canyon, at the junction of the east and west forks, and the flow is then underground for 9 miles. It then rises to the surface, at a point 7 miles from the Victor Narrows, and increases in volume to that point. This amount is above midsummer average.

Mohave River has cut through a low range of hills a mile south of the town of Victor. The gorge is narrow, with abrupt granite cliffs on each side. A contour 145 feet above the bed of the stream at this point incloses 7,500 acres. This is the greatest natural reservoir site in southern California. The depth of bed rock at the dam site is over 50 feet, and it is said that it has never been found at midstream. This site is in position to catch the great flood of this basin. The water from it could be used on the northern bench lands of the Sierra Madre Mountains.

In the mountains of this basin the rains are frequently very heavy, often falling on slopes that are both rugged and steep, thus yielding floods which, pouring out of the hills far beyond the ordinary limit of surface flow into the desert, fill the porous sand and gravel of the river beds as they progress, and disappear as rapidly as they came. From twenty-four hours to a week later the bed of the stream at the surface will again be found dry. This is the general character of Mohave River. During the summer it flows in places, where the general position of the canyon walls or of the bed rock forces the water to the surface, in a stream of from 20 to 30 second-feet, rising and sinking on its uncertain journey as it encounters impervious material, and finally losing itself in the sand.

ARROWHEAD RESERVOIR COMPANY.

The Arrowhead Reservoir Company has partially constructed works for the diversion of the head waters of Mohave River into San Bernardino Valley. The drainage basins tributary to this system are the heads of both the East and West forks of Mohave River, and extend from Holcomb Creek on the extreme east to Huston Creek on the extreme west. The southern limit of the basin is the crest of San Bernardino Mountains, the northern and western limit the line of diversion, conduits and reservoirs extending from Holcomb Creek to the saddle on the crest at the head of the Arrowhead toll road, which is at a point on the range immediately north of San Bernardino, through which depression the line is to pass with a tunnel 5,900 feet long. As is usual with the mountains of southern California, the southern slopes, which are exposed to the summer sun and winter storms, are much more precipitous than those on the north. This basin, which is near the crest of the range, is not so precipitous as the slopes on the south or on the sides nearer the desert. The formation is wholly granitic, with soil covering, the bed rock seldom being on the surface in large quantities.

The slopes are from 2 to 1 to 4 to 1, the highest and roughest portion of the basin being Crafts and Butler peaks, which are 8,060 and 8,120 feet high, respectively. The gentle slopes and soil covering are favorable to the diversion works which are projected. Yellow pine, sugar pine, fir, and oak grow in considerable abundance, being thickest on the crest and diminishing toward the desert in both size and number of trees. The extreme northern portion of the basin is covered with brush only. In no place, however, are the forests so dense as those of the Sierras in northern California. A considerable portion of the area is included in San Bernardino Forest Reserve, created by act of Congress March 3, 1891, and extending from Cajon Pass to San Gorgonia Pass.

The following are the drainage basins tributary to the Arrowhead Company's reservoirs:

	Square miles.
Huston Flat	2.72
Grass Valley	2.72
Portion above canal	1.96
Little Bear Valley	6.60
Portion above canal	2.88
Deep Creek	14.51
Green Valley Creek	2.10
Crab Creek	4.25
Portion below Crab Creek	5.29
Box Canyon (approximate)	8.00
Portion below box	1.76
Area northwest of Crafts Peak	3.03
Holcomb Valley	30.49
Total	86.31

RAINFALL.

The meteorological work that has been carried on by the Arrowhead Company is of a most thorough and extended nature. This company is one of the few in the West to appreciate fully the value of information of this nature. It would seem imperative that the question of available water supply should be thoroughly understood before works are designed or contracts entered into for the sale or rental of water, yet, singular as it may be, few have grasped this truth. Many prominent engineers have reckoned without this definite knowledge and have built or designed works that have been much too large and have had to reduce the section of their conduits after construction was started. The Arrowhead Company has properly held back its work for a term of years pending the compilation of these records, through a sufficient length of time to establish the relation between maximum, minimum, and mean years of precipitation and run-off. Mr. H. B. Hedges was placed in charge of the engineering department of the company in 1893. He has made a special study of this subject, and it is due to his efforts in large part that these data were obtained.

It is evident that this information is of such nature as to be absolutely necessary, and that it should always precede construction. Owing to the great length of time needed to form accurate estimates on this subject many are discouraged before starting. In determining this information much has been learned as to the topographic influence on the amount of precipitation, evaporation, and run-off. The location of the rain gages of the company are indicated by small dots on the map (fig. 192).

It has been found that the storms approach these higher summits from the southwest, and that the rainfall is preceded by several days of wind from that direction. The rain is also preceded by a fog that drifts in from the same quarter, first through the low passes. In a short distance after passing the crest this encounters the arid desert air, and the fog mist is soon converted to aqueous vapor again and disappears. As the mist continues and increases it gradually prevails, covering the peaks and advancing toward the desert. The rain gages prove this condition to exist. The gage located in the passes on the crest shows more rainfall than those located on the higher adjacent ground. It is stated that one may watch the advancing storm from a pass, and by retreating up the sides keep out of the rain while watching the storm for an hour or more. In a rain of 4 inches as recorded at a pass, but 3 inches would not be unusual at an elevation of 500 feet above and adjacent to this location. As the storm advances toward the desert its elevation decreases, the temperature of the cloud increases with its descent, and the relative humidity at last falls below the dew point and precipitation ceases. Hence the rain gage of Holcomb Valley, which is 3 miles from the crest, shows about one-half the rainfall of the gages at the crest. The points where the greatest precipitation occurs are in the passes and small mountain valleys about one-half mile beyond the crest. In the rainfall table given below Morse's is such a location, and it shows a very heavy precipitation.

From the above it will be seen that much skill and care should be used in placing the gages so as to determine the mean rainfall of a basin. While gages should be placed in the valleys, if possible they should be also placed on the higher sidehills. The Arrowhead gages have been placed in series north and south, east and west, as nearly as practicable—for example, Daly Summit is on the crest, Morse's is one-half mile north, Grass Valley is 1½ miles north of the crest, Tunnel C 3½ miles north of same. The results show that the rainfall decreases as the storm moves east and north.

The rain gages used by this company are of the standard Government pattern, with catchment cups 8 inches in diameter. The effort is made to put the top of the gage in an open spot and about 30 inches above the ground or snow. It is interesting to note that in windy storms the depth of water falling in an evaporating pan 3 feet square is substantially more than that shown in the 8-inch circular rain gage.

A party of 4 to 6 men is kept in the mountains to make these measurements. As soon as a storm is over men are started out with horses or on snowshoes to make the round of the stations. An interesting fact determined by these measurements is that the snow is much drier to the north and east from the crest, especially in Upper Holcomb Valley. While at Grass Valley and Gate House the ratio of snow to water is about 5 to 1; in the Upper Holcomb Valley it is fully 10 to 1. The result is that the greater part of precipitation is lost by evaporation in Holcomb Valley.

LIST OF ARROWHEAD RAIN GAGES.

1. Lower Toll House; elevation, 2,100 feet; 1 mile up Waterman Canyon from mouth of south slope.
2. Oak Flat; elevation, 4,550 feet; near the head of Waterman Canyon, south slope.
3. Upper Toll House; elevation, 4,830 feet; on crest at head of Waterman Canyon.
4. Huston Flat; elevation, 4,500 feet; north slope, 1 mile north of crest.
5. Squirrel Inn; elevation, 5,300 feet; on crest of range.
6. Strawberry Flat; elevation, 5,650 feet; one-half mile north of the summit of Strawberry Peak (crest).
7. Morse's; elevation, 5,350 feet; one-half mile north of summit on side hill.
8. Daly Summit; elevation, 5,480 feet; on summit at head of Little Bear Creek.
9. Measor's; elevation, 5,480 feet; on summit at head of Little Bear Valley drainage basin.
10. Keffle's; elevation, 5,520 feet; summit at the head of Cooks Creek (Little Bear Valley drainage).
11. Heaps Peak; elevation, 5,550 feet; summit on north side on divide between Little Bear and Deep Creek.
12. Hunsacker Flat; Deep Creek Basin, 1 mile northeast of crest.
13. South Fork of Deep Creek; one-half mile north of crest.
14. East Fork of Deep Creek; one-half mile west of divide between Deep Creek and Bear Creek (Santa Ana).
15. Green Valley; elevation, 6,900 feet; at Bear Valley Toll House, 3½ miles north of main creek.
16. Crafts Peak; elevation, 7,100 feet; one-half mile north of peak, Holcomb drainage.
17. Upper Holcomb Valley; elevation, 7,200 feet; in Upper Big Bear Valley (Santa Ana) drainage, about 5 miles north of Old Bear Lake (Baldwin's) to 11.5 miles northeast of crest.
18. Cienega Redondo; elevation, 5,300 feet; on the north side of Holcomb Creek, 6 miles north of main crest, on "Desert side of Holcomb Basin."

19. Coxs Canyon; elevation, 5,250 feet; on north side of Holcomb slope, 7 miles north of crest, on "Desert side of Holcomb Basin."

20. Crab Park; elevation, 5,100 feet; in a flat 5 miles north of crest in Deep Creek Basin.

21. Gate House; elevation, 5,160 feet; 2 miles north of crest on north side of Little Bear Valley.

22. Fleming's mill; elevation, 5,025 feet; Little Bear Valley, in a flat 1½ miles north of crest.

23. Talmadge's; elevation, 5,100 feet; in a flat in Little Bear Valley at west end of reservoir, 1½ miles north of crest.

24. Section 9; elevation, 5,150 feet; in a flat at the end of Little Bear Valley Reservoir site, 2½ miles north of crest.

25. Grass Valley; elevation, 5,050 feet; in a flat 1½ miles north of crest, in center of proposed reservoir.

26. Summit between Grass Valley Creek and West Fork of Mohave Creek; elevation, 5,300 feet; 2½ miles north of crest.

27. Tunnel C; elevation, 4,920 feet; in a flat 3½ miles north of crest.

28. Tunnel No. 2, north end of; elevation, 4,900 feet; 3 miles north of Strawberry Peak (crest).

The Arrowhead Reservoir Company, for sufficient reasons, does not desire to make all of the information from these stations public at the present time, but has kindly furnished to the United States Geological Survey the data for the accompanying tables.

Seasonal rainfall, San Bernardino, California.

Year.	Inches.	Year.	Inches.	Year.	Inches.	Year.	Inches.
1870–71	13.94	1877–78	20.33	1884–85	10.81	1891–92	14.35
1871–72	8.98	1878–79	11.54	1885–86	21.83	1892–93	19.82
1872–73	15.10	1879–80	20.36	1886–87	14.50	1893–94	8.13
1873–74	23.81	1880–81	13.50	1887–88	17.76	1894–95	20.98
1874–75	13.65	1881–82	11.54	1888–89	20.97	1895–96	8.11
1875–76	19.90	1882–83	9.17	1889–90	25.45	1896–97	16.74
1876–77	9.52	1883–84	37.51	1890–91	18.08	1897–98	8.12
						Mean..	16.23

Table of rainfall at the stations of the Arrowhead Reservoir Company on San Bernardino Mountain and at the city of San Bernardino, California.

	Holcomb Creek.	Deep Creek.	Upper Holcomb. *a*	Green Valley.	Little Bear Valley.
Distance from crest..miles..	3	2.6	11.5	0.3	2
Elevation ....feet..	5,220	5,200	7,200	6,700	5,160
Precipitation (*b*)—					
1891–92..........inches..	....	....	....	....	26.64
1892–93 ....do....	19.13	46.00	*c* 11.70	43.07	41.56
1893–94 ....do....	14.56	18.55	15.27	22.04	23.08
1894–95 ....do....	33.27	43.36	21.80	49.93	48.65
1895–96 ....do....	8.61	11.85	7.90	18.49	13.28
1896–97 ....do....	19.87	33.12	13.50	....	33.48
1897–98 *d* ....do....	11.42	16.78	9.30	....	14.48
Mean	17.81	28.28	13.25	33.38	28.74
Mean based on San Bernardino.........	21.20	33.66	15.77	39.73	34.21

	Morse's.	Grass Valley.	Squirrel Inn.	Bear Valley.	City of San Bernardino.
Distance from crest..miles..	5	1.5	0.0	0.0	....
Elevation ....feet..	5,350	5,050	5,500	6,000	1,073
Precipitation (*b*)—					
1891–92..........inches..	....	....	....	38.00	14.35
1892–93 ....do....	70.75	....	*e* 31.47	44.32	19.82
1893–94 ....do....	38.69	*e* 17.79	30.47	19.75	8.13
1894–95 ....do....	68.72	58.16	50.34	50.00	20.98
1895–96 ....do....	25.20	17.30	17.54	....	8.11
1896–97 ....do....	54.50	....	40.65	....	16.74
1897–98 *d* ....do....	33.06	....	25.11	....	8.12
Mean	48.48	....	32.59	*f* 53.70	*g* 16.23
Mean based on San Bernardino.........	57.70	....	38.68	....	....

a NE. ¼ sec. 33, T. 3 N., R. 1 W.
b Years ending August 31.
c Record begun January 1, 1893.
d September 1 to April 30.
e Record begun December 1, 1893.
f Mean for twelve years.
g To April 30, 1898, mean for twenty-eight years.

All of these records, save those for Bear Valley and San Bernardino, are the result of their observations. A comparison is made between the Arrowhead and San Bernardino records, as follows: The record for the town extends over twenty-eight years and has a mean to date of 16.23 inches of precipitation. The Arrowhead records begin in 1891 and 1892; for example, Holcomb Creek record begins in September, 1892, and extends to the summer of 1898. During these six years a mean of 17.81 inches of rain is shown at Holcomb Creek. During the same period at San Bernardino the rainfall was 84 per cent of the twenty-eight-year mean. Accepting this Holcomb Creek mean as 84 per cent of a twenty-eight-year mean, a probable ultimate mean of 21.2 inches is obtained for Holcomb Creek. The probable ultimate mean for each section is thus obtained. Comparisons with the Bear Valley record lead us to doubt the accuracy of that record.

Mr. Sidney P. Waite, of San Bernardino, has furnished the record of precipitation of that station from 1870–71 to 1891–92, after which it was taken up by Dr. A. K. Johnson, who is now the observer for the United States Weather Bureau. Mr. Waite only ceased his records because a storm wrecked his apparatus. An interview was held with him in which he said that his gage had been procured from the Smithsonian Institution, at a cost of 25 cents. It was 20 inches high, had a 12-inch mouth, and was located in an open lot free from trees or other eddy-causing objects and was placed 4 feet above the ground. All the surroundings indicate that his contributions to the meteorological statistics of this region are reliable.

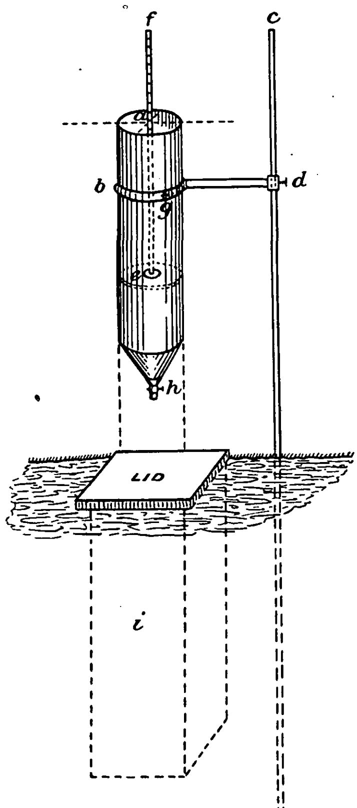


FIG. 205.—Apparatus for measuring evaporation from snow. *a*, Ordinary outer cylinder of a standard rain gage. *b*, Iron band that supports the cylinder to a standard *c*. *d*, Set screw that permits the entire apparatus to be raised to a desired level. *e*, False bottom that may be raised and lowered by the scale *f*. *g*, *g*, Screw clamps that permit the lifting of the entire cylinder from the band *b*, so that it may be weighed. *h*, Stopcock that may be used to draw off the water. *i*, Box into which the cylinder may be lowered if desired.

EVAPORATION.

A pan is set in a concrete bay, on a side hill at the Gate House, Little Bear Valley, at an elevation of 5,125 feet. There are a few large trees on the hill, but none within 100 feet of the pan. The topographic exposure is open from the southeast to the southwest, and slightly interrupted from the northwest to the northeast. Measurements for evaporation were made with a hook gage twice a day. The pan is a 3-foot cube iron basin, set in a concrete bay 5 feet square and 4 feet deep.

Mr. H. B. Hedges designed the apparatus shown in fig. 205 to determine the evaporation from snow, and also that for measuring percolations, shown in fig. 206.

The cylinder is filled either by falling snow, which is desirable, or by inverting and pressing down onto the snow plane. The cylinder with the snow is then weighed. The false bottom is raised so that the snow stands above the top rim of the cylinder for a number of inches, depending on the character of the snow, wet snow being lifted as much as 3 inches above the top of the cylinder. By means of the rod *c* and the screw *d* the top of the snow in the apparatus is adjusted to the top of the snow as it lies on the surrounding areas. The gap between the cylinder and the surrounding snow plane is carefully filled to produce uniform conditions. Each twenty-four hours the cylinder is removed with its snow and weighed. The loss in weight determines the evapo-

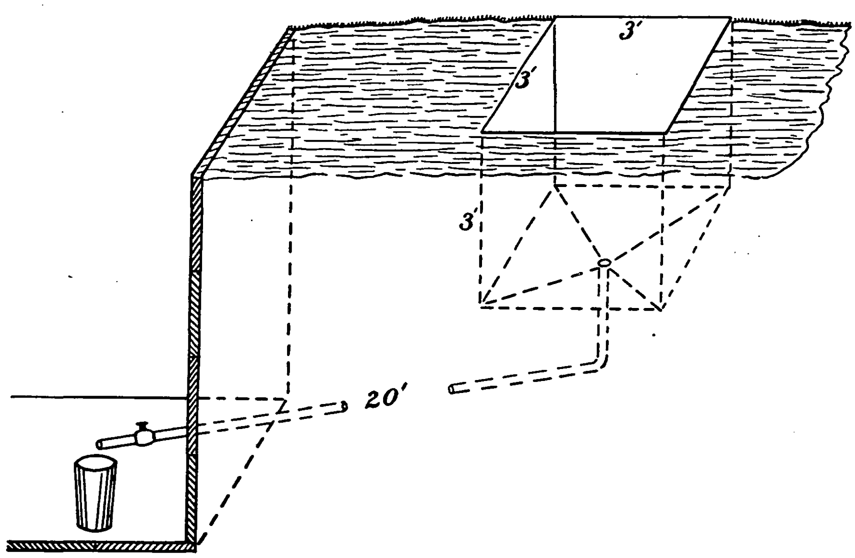


FIG. 206.—Apparatus for determining percolation of water through soil.

ration. The accumulated melted snow is then drawn off through the cock *h*. It was found that the iron tends to melt the snow, and it has been suggested that paper be used in its place as far as possible. Care is taken to maintain a contact between the snow bank and the sides of the cylinder to keep down the temperature of the cylinder; but a small space is kept between the snow extending above the top of the cylinder and the snow bank. As the snow is usually heavy and wet, little trouble has been experienced with drifts.

PERCOLATION.

A 3-foot tank of iron, as shown in fig. 206, was filled with earth, placed in the same condition as found in the hole from which it was excavated and tamped to its natural compactness. The water that penetrates is drawn off through a pipe and measured. The soil is of yellow clay, underlain by hardpan, the top being loam and disintegrated granite.

Previous to a storm the box is drained. Subsequent rainfall is measured on the standard rain gage. After the first and before the next storm, or at the end of the month, the water from the box is drawn off through the pipe and cock and is measured. The difference in volume, as indicated by rain gage and box, shows the amount of water penetrating the soil. The loss is evaporated from the surface of the soil. This box is located at the Gate House. The object is to determine the amount of water penetrating to bed rock.

The humidity ranges from 14 per cent up. The probable average humidity during the summer is about 25 per cent. During the winter months the average will probably be about 35 per cent. The winds from the north are very dry, varying from 15 to 20 per cent.

Precipitation, evaporation, absorption, etc., at the gate house of the Arrowhead Reservoir Company at Little Bear Valley.

[Elevation, 5,160 feet; latitude, 34° 16′ 10″ north; longitude, 177° 11′ 24″ west of Greenwich; San Bernardino County, California.]

Month.	Temperature.			Precipitation.	Evaporation.				Absorption of water penetrating 3 feet of soil.	Wind.		
					Water surface.		Snow surface.					
	Maximum.	Minimum.	Mean.		Inches.	Temperature.	Melted snow.	Exposure.		Total.	Maximum velocity.	Prevailing direction.
1895.	°	°	°	*Inches.*		°	*In.*	*Hrs.*	*In.*	*Miles.*		
March	71.0	18.0	42.4	8.82	1.12	38.0	0.64	192	......	4,787	24	SSW.
April	77.0	24.0	49.1	1.31	1.84	42.0	......	......	......	4,207	29	SW.
May	86.0	30.0	55.4	.24	5.39	58.0	......	......	0.17	3,723	30	SW.
June	84.0	31.0	62.2	.00	6.60	60.6	......	......	.00	3,589	35	S.
July	88.0	40.0	63.8	.00	6.30	67.1	......	......	.00	2,324	32	S.
August	89.0	38.0	66.2	Trace.	6.20	66.2	......	......	.00	3,032	27	S.
September	83.0	33.0	62.2	.00	5.05	58.6	......	......	.00	1,790	21	S.
October	84.0	32.0	54.5	.00	2.80	52.6	......	......	.00	2,120	12	SW.
November	69.0	22.0	38.8	2.65	1.20	42.0	.05	10	.00	3,070	19	SW.
December	70.0	14.0	38.9	1.75	.34	38.6	......	......	.00	2,217	23	N.
1896.												
January	67.0	22.0	42.5	2.38	.09	39.0	......	......	.00	2,848	15	SW.
February	68.0	22.0	43.4	Trace.	.81	43.0	......	......	.00	2,956	27	N.
March	73.0	15.0	41.5	4.21	.94	42.0	.55	107	.09	4,546	67	S.
April	65.0	23.0	41.7	1.72	3.39	44.0	......	......	.13	6,112	38	S.
May	81.0	26.0	52.1	.47	2.86	59.0	......	......	.00	3,953	30	SW.
June	96.5	36.0	64.1	.00	6.50	67.0	......	......	.00	4,727	30	SW.
July	90.0	37.0	68.3	.00	5.04	67.5	......	......	.00	4,465	27	SW.
August	88.0	43.0	66.2	.33	5.50	65.0	......	......	.00	4,061	25	SW.
September	88.0	32.0	58.7	.00	4.01	60.0	......	......	.00	3,683	19	SW.
October	74.0	27.0	54.3	2.30	4.05	54.0	......	......	.00	3,470	37	SW.
November	68.0	18.0	44.0	1.38	1.28	46.0	......	......	.00	3,950	30	SW.
December	69.0	23.0	42.3	1.98	1.23	39.0	......	......	.00	2,619	27	N.

Precipitation, evaporation, absorption, etc., at the gate house of the Arrowhead Reservoir Company at Little Bear Valley—Continued.

[Elevation, 5,160 feet; latitude, 34° 16′ 10″ north; longitude, 177° 11′ 24″ west of Greenwich; San Bernardino County, California.]

Month.	Temperature.			Precipitation.	Evaporation.				Absorption of water penetrating 3 feet of soil.	Wind.		
					Water surface.		Snow surface					
	Maximum.	Minimum.	Mean.		Inches.	Temperature.	Melted snow.	Exposure.		Total.	Maximum velocity.	Prevailing direction.
1897.	°	°	°	*Inches.*		°	*In.*	*Hrs.*	*In.*	*Miles.*		
January	57.0	18.0	35.2	5.16	.57	38.0	.72	335	.00	4,342	39	SW.
February	57.0	5.0	32.0	12.05	.24	38.0	.61	144	.34	3,422	41	N., SW.
March	60.0	18.0	33.4	10.17	......	......	1.21	288	1.35	5,448	45	SW.
April	77.0	25.0	51.1	.03	3.01	43.0	......	......	.55	2,867	30	N., SW.
May	85.0	33.0	56.3	.15	4.75	52.0	......	......	.01	3,986	20	SW.

NOTE.—The mean temperature is the average of the daily means.

Comparison of the rate of evaporation from snow with that from water at Little Bear Valley, California.

[Latitude, 34° 16′ 10″; longitude, 117° 11′ 24″; elevation, 5,160 feet.]

Date.	Wind.	Evaporation from water for month.	Rate of snow evaporation for the month (inches melted snow).	Ratio of snow to water evaporation.	Precipitation for the month.
	Total miles.	*Inches.*		*Per cent.*	*Inches.*
March, 1895	4,787	1.12	2.48	2.21	8.82
March, 1896	4,546	.94	3.79	4.03	4.21
January, 1897	4,342	.57	1.58	2.78	5.16
February, 1897	3,422	.24	2.82	11.75	12.05
March, 1897	5,448	*a* .48	3.12	11.75	10.17
Mean	4,509	.67	2.76	*b* 4.85	8.08

a The evaporation from the water surface during March, 1897, could not be measured. It is assumed that it was not greater than twice that of February, 1897, or 0.48 inch.

b The ratio of per cent of evaporation from snow, given as 4.85, is determined by multiplying the total number of hours' exposure by the per cent in each month and dividing the sum of the products by the number of hours.

The amount of water evaporated is measured for the entire month, while the snow evaporation is for much shorter periods of time. When the snow is covering the ground humidity would naturally be greater and the relative rate of evaporation much smaller; the presence of the snow would also have a chilling effect on the air. It will be noted that the rate of evaporation from snow in these instances is 4.85 times that of the water evaporation for the entire month, ranging from 2.21

to 11.75 times that of water. This wide variation is due doubtless to the direction and velocity of the wind, whether it blows from the desert or from the sea, and to the condition of the snow, whether it is dry enough to drift or not. The snow at this station is heavy and wet as a rule, reducing to water at the rate of 5 to 1, while farther toward the desert the winds and snows are drier, the snow reducing in Holcomb Valley at the rate of 10 to 1 as a rule. It is generally admitted that snow evaporation is much greater in Holcomb Valley. The table shows that at Little Bear Valley 34 per cent of the precipitation of snow is evaporated each month.

It would be better to say that this snow is evaporated at the rate of 2.76 inches of melted snow per month, which in this district would represent a depth of snow ranging from 13.8 to 27.6 inches, and this occurs during months when, as may be seen by the table (pp. 623–624), the rate of evaporation is very markedly below the normal. It should be remembered that as the season advances the snow is covered with a crust that protects it from evaporation, though at what rate is not known. Based on these figures, it would seem conservative to estimate that on the higher portions of the basin, where the snow lies on the ridges and peaks for about five months, and where wind velocities are high, the loss in depth must be fully 100 inches in snow depth (8½ feet), representing about 14 inches of water.

The writer has closely watched the disappearance of snow from a drainage basin in this range of mountains. A snowfall ranging in depth from 2 to 5 feet, in a basin of 200 square miles, has simply been so "licked up" by the desert wind that the snow would disappear in a few weeks without materially increasing the flow of the stream.

One is led to doubt if the northern mountains, where the snow is held for months until summer melting, when it is most used for irrigation, have much advantage over the southern basins, where the water must be caught and stored from winter floods that can not be retained.

RUN-OFF.

In addition to the other valuable physical data that this company has been collecting is its record of stream flow. Weirs have been placed in all of the creeks and clock recorders in the most of the weir bays. These recorders are of the type extensively used near Riverside, and give satisfaction. The cylinder is of wood, revolves vertically, and is driven by a clockwork with two strong springs. The holder of the pencil point is driven direct and works in two vertical guides. A bay to the side from the creek is selected to insure the safety of the apparatus. The side bay is connected with the creek by a line of vitrified tiling. The same difficulty is met here that always exists when a weir is put in a mountain stream—the bay at once fills with sand and the accuracy of the weir is destroyed. The greater the amount of water passing over the crest the greater the error. With a weir bay full of sand, and a head of 2 feet or more, errors of at least 25 per cent might be anticipated if the Francis weir formula were used, the weir indicating too little water. The Bazin weir formula would give much more exact results. A flume 25 feet long set on a level grade in the bed of the creek would keep itself free of silt and could be accurately rated by meter.

The observations of stream flow that this company have made they naturally prefer to retain for the present for their exclusive use. They will ultimately be furnished to the public.

In the face of existing records it is with hesitation that an attempt is made to estimate a quantity which is so extremely variable and difficult of determination. With a mean rainfall of 35 inches on the basin a run-off of 30 per cent may be anticipated, or 48,000 acre-feet, from 86 square miles of basin, or 6,600 six-month miner's inches. The minimum will probably be as low as 2,000 six-month inches, the maximum as great as 20,000 six-month inches. These figures are not given as absolute. They are based on observations under conditions somewhat similar in other portions of the State. The company's records have not been seen by the writer. It is a subject extremely difficult to judge at all.

The fluctuation that is here suggested between the maximum and minimum indicates the great need of storage works in this district. Not only is the annual variation great, but the seasonal variation is still greater. Fully three-fourths of the annual discharge passes off during the nonirrigating season, when the water can not be used. Fortunately this company is in a position to store as much water as they may elect up to 16,000 six-month miner's inches (322 second-feet).

WORKS.

The works proposed and in part constructed by this company are extensive. Beginning at a point on Holcomb Creek at an elevation of 5,200 feet, the stream is to be diverted, principally by means of tunnels and pipes. Open conduits, owing to ice and snow during the principal carrying season, are to be avoided as much as possible.

Other streams are appropriated in passing, the next in importance being Deep Creek. In this way the water from 77.03 square miles is diverted into the Little Bear Valley reservoir. After passing this reservoir small tributary streams are gathered in sufficient to make a total available drainage area of 86.31 square miles. The character of the district, while mountainous, can not be called rugged. Roads can be built along the line at a cost of from $200 to $300 per mile, and most of the material within 5 feet of the surface can be moved with the pick or plow. By establishing road connection to the Santa Fe Railroad, at Cajon Pass, much of the difficulty of getting material for the works can be overcome.

The line has not yet been finally located from Holcomb Creek to Little Bear Valley, but the length will probably be about 7 miles. The proposition is to divert all water, especially the winter storm waters, which will be fully 80 per cent of the entire amount, through the diversion canals to the Little Bear Valley reservoir, where it will be held for summer use. The length of the line from the Little Bear Valley reservoir to the divide, through which the water will pass into San Bernardino Valley, is, approximately, 14 miles. On this line three tunnels have been constructed: No. 1, 6,000 feet with approaches; No. 2, 2,000 feet with approaches; C, 2,200 feet with approaches.

These tunnels are in granite. No. 1 is the outlet from Little Bear Valley. The section on the two ends was 7 feet high and 8 feet wide, but this has been reduced 2 feet in width owing to a further knowledge of the water supply. Tunnel No. 2 and Tunnel C are on the line between Little Bear Valley and the divide. Two other reservoirs along the line between Little Bear Valley and the divide may be used to supplement the supply. The Grass Valley reservoir, which is above the elevation of the canal grade, has 2.72 square miles of independent drainage basin, and the Huston Flat reservoir, which is below the grade of the approaching conduit, just before it reaches the divide, forms a portion of the line. The foundations for a dam 160 feet in height have been laid at the Little Bear Valley reservoir. The dam is to be of concrete, but the plans are not available at present.

The following table shows the capacity with varying heights of dams. A total ultimate storage of 16,000 six-month inches is available. These capacities are taken from a map on a scale of 2,000 feet to the inch and are given only as approximate.

Capacity, etc., of Little Bear Valley, Huston Flat, and Grass Valley reservoirs at varying heights of dam.

[50 miner's inches are equal to 1 second-foot, or 724 acre-feet per year. 1 six-month miner's inch is equal to 7.24 acre-feet.]

Drainage system.	Drainage area.	Elevation above sea level.	Height of dam.	Area.	Capacity.
LITTLE BEAR VALLEY RESERVOIR.					
	Sq. miles.	*Feet.*	*Feet.*	*Acres.*	*Acre-feet.*
Basin	6.60	5,012	50	183.6	5,746
Deep Creek	14.51	5,062	100	449.0	21,561
Holcomb Valley	30.49	5,109	147	800.0	50,912
Other tributaries	25.43	5,122	160	884.0	*a* 61,855
HUSTON FLAT RESERVOIR.					
Basin	2.72	4,470	20	8.0	60
Other tributaries	3.84	4,500	50	55.8	947
		4,550	100	157.1	6,150
		4,600	150	283.2	17,138
		4,625	175	329.5	*b* 24,753
GRASS VALLEY RESERVOIR.					
Basin	2.72	*c* 5,065	40	66.3	1,320
		c 5,115	90	158.0	6,925
		c 5,200	175	386.5	*d* 30,062

a 8,540 six-month miner's inches.
b 3,420 six-month miner's inches.
c Approximate.
d 4,150 six-month miner's inches.

It has been estimated in the discussion of run-off from these basins that the probable mean is 6,600 six-month miner's inches (132 second-feet). However, it is not possible to catch all of this run-off, as a considerable portion of it will doubtless be in the nature of high floods that can not be conveyed in any ordinary or practicable conduit. The proportion that would be lost would require a careful study of the stream record and the cost of various-sized conduits.

If 5,000 six-month miner's inches (100 second-feet) is sold, the storage should be for 8,000 six-month miner's inches to provide for years of deficiency and for evaporation. This could all be stored at Little Bear Valley with a dam 160 feet high.

From the divide near Huston Flat it is proposed to drop the water that is to be distributed for irrigation to the valley below. A head for power purposes is thus available of fully 2,500 feet. This power probably could be used only in the summer, during irrigation. With a head of 2,500 feet and a volume of 100 second-feet over 20,000 horsepower could be developed.

Considered as a whole, the enterprise is ingenious and bold. It will be a costly plant, undoubtedly, but reservoired water is necessarily more expensive than water obtained by the simple diversion of a living stream. If properly planned, however, it is the most reliable source of supply for irrigation obtainable, and if substantially constructed, as is proposed in the system herein treated, is the safest and most satisfactory in the end. It may be said that the productions of the tributary land, planted to citrus fruits, are of the highest order, and are entitled to the most enduring and reliable water supply.

There is no question but that demand will ultimately spring up for all the water that the company can deliver. The lands commanded are the choicest in the State. They extend from Highlands toward Los Angeles, along the foot of the Sierra Madre range of mountains. There is no other system adequate for their irrigation.

The possibility of turning the head waters of Mohave River into San Bernardino Valley has been known for many years. Mr. Fred T. Perris, chief engineer of the Southern California Railway, at one time ran a line from Little Bear Valley through to San Bernardino Valley to determine the length of tunnel required for that diversion. This was done for the California State engineers. The reservoirs were at one time surveyed by the State engineers.

The present Arrowhead Reservoir Company is composed of a number of Cincinnati gentlemen. In 1890-91 these gentlemen investigated the project from both a business and an engineering standpoint and determined upon a study of the system and its gradual construction, which has since been continued, except for a short interruption in 1892. Mr. Adolph Wood is the general manager of this company. He resides in San Bernardino and has his office there. Mr. Fred T. Perris is now chief engineer, and Mr. H. B. Hedges is engineer in charge of the work. Mr. J. D. Schuyler, of Los Angeles, is consulting engineer.

SOUTHERN CALIFORNIA IMPROVEMENT COMPANY.

The floods that come down Mohave River from the mountains flow as far out in the plains as their sandy beds permit. In addition to these waters are those supplied to the streams perennially and which normally sink at the foothills. These percolate down the channel, probably at the rate of from 5 to 20 miles a year, depending on the slope and character of the voids in the stream beds. It is the water in these voids of the sand and that which percolates in the stream bed that the Southern California Company endeavors to obtain.[1]

The determining factor in the selection of the point for the construction of the diversion works of the Southern California Improvement Company was that the bed rock, or an impervious stratum, was found nearer the surface here than at any other place on the lower portion of the river, and, although the river channel is broad and the valley extends in an unrestrained way to the south from the surface channel, all things being considered, this was chosen as the most feasible place to put in the works of development.

The rock of the locality is favorable to the work. It is known as a porphyry and is found in every color. It disintegrates rapidly on exposure to the atmosphere and forms clay on the surface. The exposed rock in the hills is said to be thus melting away into clays, which are very soft on top and harder as the rock is penetrated. A foot from the surface the rock is usually quite solid. As this condition obtains on the sidehills next to the river, it is assumed that the clays that are found in much the same condition beneath the sands of the river bed are of like nature and gradually merge into crystalline rock, making an ideal condition for the stopping of the underflow of the river with sheet piles, which are here used. The piles are said to be driven from 1½ to 5 feet into this clay, the latter being covered with a varying depth of river sand.

The method of procedure in the construction of the work was to start a canal on a light grade far enough down in the valley to permit the water that was developed to flow away from the works as it was encountered. At the point where the canal enters the river bed, shown in Pl. LXX, *A*, the conduit is changed into a carrying flume. This is shown in the line A B on the plan, fig. 207. This flume is 5½ feet in the clear; the top, sides, and bottom are made tight to prevent any escape of the water which has been gathered above. In other respects it is constructed the same as the gathering flume described below. This carrying flume passes through the sheet piling and into what is called the "well." This is a junction bay into which it is the intention to have all the gathering flumes empty. The well is 10 by 6½ by 6½ feet, and is made of 6 by 8 inch timbers laid flat and bolted together.

[1] The writer investigated as many of the conditions in connection with this work as was practicable, but much of it is of such a nature that this could not be done.

The bottom is drifted into piling, which is driven into the bed of the river for the purpose of forming a foundation or anchor for the bay. The top is made of the same material, and two large trapdoors open from above. These doors may be fastened down solidly to the rest of the frame. The top of the well is on a level with the top of the sheet piling and 5 feet below the bottom of the river bed. The trapdoor on the top of the well opens into a temporary shaft that extends above the surface of the ground and permits entrance into the flumes. This shaft is made of 2-inch plank and is set on the main well, but is not fastened, so that in case of floods the shaft will be rolled away, and, the

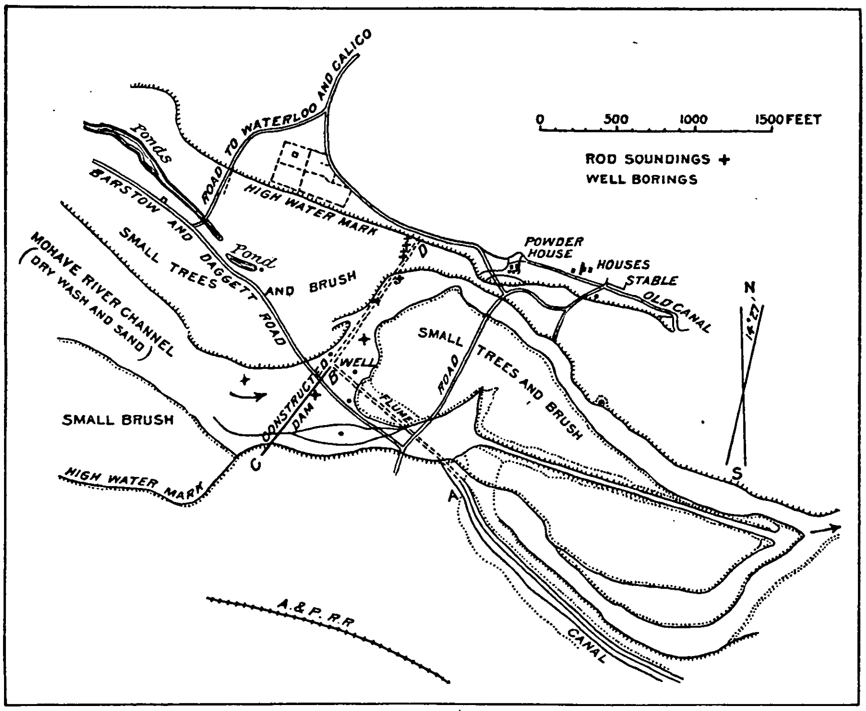
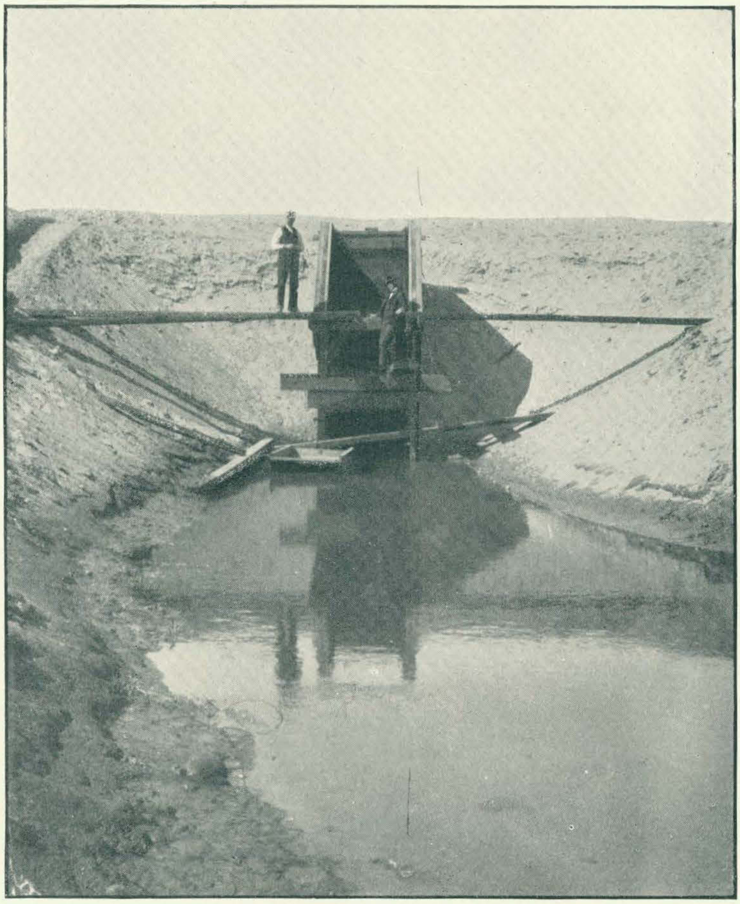


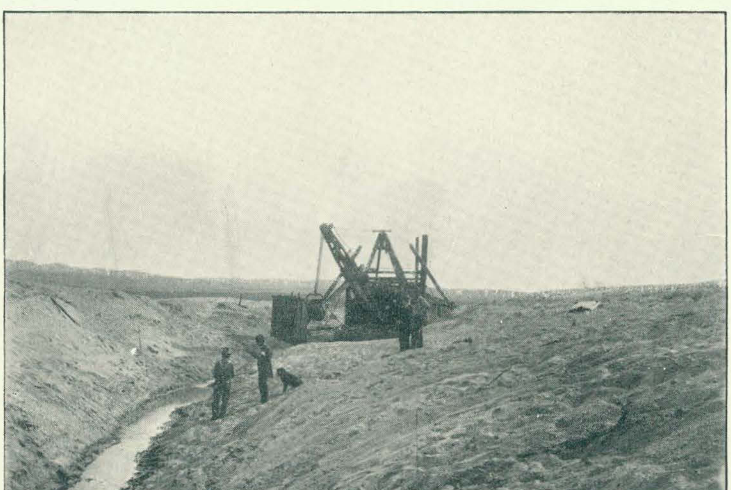
FIG. 207.—Plan of submerged dam on Mohavė River, near Daggett, California. (Copied by permission from Engineering News.)

doors of the well being closed, the water of the flood will pass over without encountering any obstruction.

The well being finished, the channel of the river was next opened along the line B C (fig. 207) with scrapers to a depth of about 10 feet, the water developed being permitted to pass out through the carrying flume. This scraper work having been excavated down into the water-bearing gravels, the gates of the well were closed and the open channel allowed to fill with water. The dredger then floated into place and the excavation continued to the desired depth. It was then floated away and beached, as shown in Pl. LXX, *B*, and the gates of the well



A.



B.

MOHAVE RIVER DEVELOPMENT WORKS AT DAGGETT, CALIFORNIA.

A Outlet: *B*, Dredger and excavation for gathering flume were opened, which by the drawing off of the water permits the laying of the flume. This same order was followed in the laying of the carrying flume.

The gathering flume is first constructed and placed, and then the sheet piling driven down below the flume (downstream), as shown in fig. 207.

It is the intention to drive a row of piling on the line C B D, fig. 207. These sheet piles are of ordinary type, being 3-inch Oregon pine plank, 12 inches wide, firmly bolted together, the lower end being sharpened to an edge. The lap of the plank is 3 inches, which permits the head being rounded to a diameter of 9 inches. These piles are driven with a 2,200-pound hammer through the sand and gravel into the clay, which is said to cover the top of the crystalline bed rock.

Up to May 1, 1896, the piling had been driven only for about 600 feet south from the junction bay or well at the center of the channel, as shown in the line B C, fig. 207. They are sawed off at a depth of 5 feet below the bed of the stream and below the level where the sand has become stratified. All of the flumes and piling are to be covered with sand as finished. By this method it is the intention to offer absolutely no resistance to the stream when in flood, and in that particular the plan is most wise, for it has been found that in placing the slightest obstruction in a torrential stream bed the obstruction will be subjected to the most violent attack from both water and bowlders. An excavation being made beneath, the obstruction will thus be undermined and knocked over.

The gathering flume is built from the well 700 feet south. It is made of 3 by 12 inch Oregon pine plank, except on top, where they are 4 instead of 3 inches thick, to support the weight of the gravel above. It is built square, 5½ feet in the clear, and in the manner in which timbers are framed for shafting, each being mortised into the other, and all being framed around 6 by 6 inch longitudinal timbers, which are set in the corners inside. A much more convenient form of flume for working purposes after construction, requiring no more material, would have been 6½ by 4½ feet.

The bottom of the flume is first made upside down, the plank being nailed on the longitudinal piece, then floated into place and turned over. The sides and top are then built onto it. Openings of five-eighths inch width are left in the sides and of 1⅛ inches in the bottom of the flume to admit the water. Four 4 by 8 inch sills were placed in the bottom of the cut for the flume to rest on. They were rammed well into the gravel and laid longitudinally.

Numerous water-development tunnels have been built in southern California in water-bearing sands and gravels, and have been lined by placing lagging on the top and sides on the caps and posts. These posts rest on longitudinal sills, but frequently have no floors. These tunnels have been successful in obtaining water, but they probably lose water by percolation where the grade gets above the water plane. In this case, where the sheet piling brings the water plane constantly above the flume grade, it would seem that the bottom of the gathering flume might have been dispensed with. As it is, one-tenth of the bottom is left open, and efforts have been made to keep these openings clear. The intention of the design was to prevent sand entering the flume too freely and interfering with the flow in other parts. The action of fine sand in the present case is to work into the openings in small quantities.

It has been found that driving the piling, after the flume was in place and only 2 feet from it, has been the cause of jamming the flume out of line and driving the gravel tightly into the openings. In the remaining portions of the channel the piling will be driven as much as 25 feet from the flume to avoid this undesirable result. The flumes are protected with gates, so that they may be kept full of water to prevent rot.

The work of driving the sheet piling across the river was less than half finished on May 1, 1896, the portion B D (fig. 207) not being completed. It is fair to presume that, when the channel is entirely closed to bed rock on either side of the river, a greater amount of water will be obtained than a direct proportion of the present amount of water flowing to the portion of the river bed than is now shut off. At the present time there is approximately 7 second-feet of water flowing from the carrying flume. In 1898 the works have not been finished and the company is bankrupt.

It is proposed to use this water on Minneola Valley, which is a desert at present, but with the aid of water very favorable agricultural results may be obtained. For the purpose of irrigation a charge of $22.50 per acre for the water right is made and an annual rental of $1.50. The duty of 1 second-foot to 250 acres is made. This is at the rate of $5,625 per second-foot for the water right and $375 annual income from rentals.

There are a large number of mines in the neighborhood, borax, iron, copper, silver, and gold being found near. These mines are paying $11.50 a ton for coal. A drop of 100 feet in the main canal has been planned for the purpose of developing power, which will be offered to the mines and used for general purposes. Mr. W. E. Robinson is general manager and vice-president of the Southern California Improvement Company. He designed these works and superintended their construction. The work has been well done, but the amount of water obtained is a great disappointment to the company.

THE ROCK WATERS OF OHIO

BY

EDWARD ORTON

CONTENTS.

ILLUSTRATIONS.

THE ROCK WATERS OF OHIO.

By EDWARD ORTON.

INTRODUCTION.

In the present report the rock waters of Ohio that are derived from a considerable depth as compared with ordinary wells, and also the flowing wells or fountains, that are to be found in certain districts of the State, are to be considered. Of the latter, only those flowing wells that have a considerable head or pressure and those that occur throughout districts embracing at least a few square miles of territory will be discussed. The number of wells whose waters rise to the surface or overflow feebly is large and there are many isolated examples of wells flowing with a considerable head, but the work of the Survey has not been conducted on a scale that will allow such cases to be treated here. The wells of the latter group are all drift wells and occur only where the drift deposits are found in thick sections, generally of 100 to 300 feet. The entire series of flowing wells as above characterized and restricted is confined to northwestern and western Ohio, principally to the counties of Williams, Fulton, Henry, Defiance, Van Wert, Mercer, and Auglaize.

Our knowledge of the rock waters of Ohio as above limited has been almost wholly derived from wells drilled in the search for oil and gas, a search which has been prosecuted for the last few years with great zeal and energy through all sections of the State, and particularly in northwestern Ohio. There is not a county in the State in which one or more wells have not been sunk in this interest during the last fifteen years, and in many counties such wells have been drilled by the score and the hundred.

Our knowledge of the water supply of the rocks penetrated by the drill is fragmentary and incomplete, despite the excellent opportunities to acquire it, for the reason that water was not included in the search that was in progress. Generally it was a hindrance and obstruction to the explorations that were being carried forward, and in most cases all that we learn is by incidental reference. In a number of cases, however, the supplies discovered in the rock series have since been utilized, sometimes in a large way, and many wells have since been drilled, the sole object of which was to obtain the water whose existence had been accidentally demonstrated.

In order to understand and appreciate the facts presented, it is necessary to have a clear idea of the geological series of Ohio and of its distribution throughout the limits of the State.

GEOLOGICAL COLUMN OF OHIO.

The geological series of the State consists of limestones, shales, sandstones, and conglomerates. The several elements are associated in the order indicated below:

Period.		*Formation.*	*Thickness in feet.*
PLEISTOCENE		21. Mainly glacial drift	0- 550
CARBONIFEROUS	COAL MEASURES	20. Upper Barren Measures	500 ±
		19. Upper Productive Measures	200 ±
		18. Lower Barren Measures	500 ±
		17. Lower Productive Measures	250 ±
	CONGLOMERATE COAL MEASURES.	16. Homewood sandstone	250 ±
		15. Massillon conglomerate	
		14. Sharon conglomerate	
	LOWER CARBONIFEROUS (WAVERLY GROUP).	13. Logan group	0- 300
		12. Cuyahoga shale	150- 450
		11. Berea shale and grit	25- 150
		10. Bedford shale and sandstone	50- 150
DEVONIAN		9. Ohio shale, Great Black shale	250-2,500 +
		8. Corniferous limestone	25- 100
SILURIAN	UPPER SILURIAN	7. Onondaga limestone	20- 600
		6. Niagara shale and limestone	150- 350
		5. Clinton limestones	20- 150
		4. Medina shale	25- 150
	LOWER SILURIAN (ORDOVICIAN).	3. Hudson River shales and limestones	300- 800
		2. Utica shale	0- 300
		1. Trenton limestone	300- 600

Each of these subdivisions will be briefly characterized with reference to the inquiry before us. Before entering on this review, the reader is reminded that the water-bearing strata of this series are (1) sandstones and conglomerates, the purer and coarser the better; (2) dolomitic limestone, when made porous by replacement; (3) soluble limestones, whether true or dolomitic, in which joints have been widened or channels have been dissolved under past or present conditions of drainage.

The strata of the Ohio section which are not water-bearing are (1) shales, the finer grained the less productive; (2) impure sandstones in which shaly particles fill the spaces between the sand grains to a greater or less extent, sandstones in which the cementing matter is carbonate of lime also belonging in this list; (3) limestones when lying below natural drainage and dolomites in the same situation which have not resulted from the replacement of carbonate of lime by carbonate of magnesia.

The porous rocks of this series are more easily recognized from the fact that they are from time to time occupied by petroleum or natural gas, for the reservoirs of these substances are in all cases water-bearing rocks.

With these facts in mind a brief review of the scale of the State will be made at this point. The several strata will be considered in ascending order.

TRENTON LIMESTONE.

Whether the Trenton limestone has any outcrop in Ohio is a disputed question. The late S. A. Miller, of Cincinnati, in a paper read before the Cincinnati Society of Natural History, first advanced the claim that the Point Pleasant quarries of the Ohio Valley belong to this horizon. The late W. M. Linney, of the geological survey of Kentucky, in a paper published in 1882, also held that the same mass of limestone belongs to the horizon above indicated. He based his belief on a series of closely connected sections which he had followed from undisputed outcrops of the Trenton in central Kentucky to this point. On the other hand, the late Joseph F. James, in a paper that appeared a few years ago, held, on paleontological grounds, that the Point Pleasant quarry rocks are indistinguishable from the Hudson River rocks of the Cincinnati section. Following the series southward by the records of the drill from the Findlay gas and oil field, I concluded that the limestone of Point Pleasant could best be referred to the Trenton horizon. This opinion I still hold.

But however the facts in regard to the strata outcropping in the Ohio Valley are construed, there is no room for doubt that the Trenton limestone underlies in characteristic and unmistakable form, at a depth of from 1,000 to 2,000 feet, all of the northwestern quarter of the State, and also that it occurs at a still shallower depth in southwestern Ohio. In fact, every consideration makes it probable that the Trenton limestone is the universal floor of the entire State; though its presence has thus far been proved at but comparatively few points in the eastern half, yet in every well drilled deep enough to reach its horizon the formation never fails to reveal itself with unmistakable distinctness.

The Trenton limestone of southwestern Ohio and of the Kentucky outcrops is a gray or light-blue limestone, occurring in somewhat heavy and fairly even-bedded courses. In composition it is, as a general rule, an impure limestone. This fact is well shown in the Point Pleasant limestones, which, whether or not they belong to the Kentucky Trenton, agree closely with the latter in both physical and chemical characteristics. Analysis of the Point Pleasant beds shows the following results:[1]

Analysis of Point Pleasant limestone.

Constituent.	Per cent.
Carbonate of lime	79.30
Carbonate of magnesia	0.91
Siliceous matter	12.00
Alumina and iron	7.00

[1] Geol. Survey Ohio, Vol. I, 1873, p. 374.

Most of the Trenton limestone of Ohio is of substantially this composition. It is scarcely necessary to say that a rock like this, especially when below drainage, is never in any sense a porous rock, and consequently can not be a reservoir of water, oil, or gas.

There is, however, a phase of the Trenton limestone, as revealed in the underground geology of northwestern Ohio and in adjacent portions of Indiana, which is porous to a high degree and which has become on this account within the last few years one of the most famous strata of the country. In the districts named it is a prolific source of oil and gas. The same phase finds an outcrop in the Galena limestone of Illinois and Wisconsin and in the Upper Division of the Trenton limestone of northern Michigan. I refer this phase to the second division of porous rocks, as described on a preceding page—that in which a dolomite has resulted from a replacement of one-half of the carbonate of lime by carbonate of magnesia. That such replacement has taken place seems certain from the following facts, viz: There are isolated areas of true carbonate of lime included in the dolomitic areas. Even in Findlay, which is a great center of Trenton dolomite, the limestone found in a single well proved to be true limestone instead of dolomite. This well was essentially unproductive. Again, in fragments brought up by the sand pump a crinoidal limestone is often represented. Such a limestone was originally a true calcareous rock, and the change to its present dolomitic condition is the result of chemical action subsequent to its formation. By this change its porosity can be well explained. The atom of magnesian carbonate occupies less space than the corresponding atom of calcium carbonate which it displaces, while the entire volume of the rock is supposed to remain unchanged. Dr. T. Sterry Hunt estimated that the porosity of Canadian dolomite ranges from 10 to 13 per cent. Prof. J. D. Dana has calculated the porosity of Ohio dolomite, and makes it from an eighth to a tenth of the volume of the rock.[1] Dr. George P. Merrill makes the porosity of a pure dolomite, on this theory of origin, to be 12½ per cent.[2]

It is only the uppermost beds of the Trenton limestone in Ohio that have suffered these transformations. Sometimes the change is confined to a very few feet; rarely it extends as far as 100 feet below the surface. The oil-well driller readily distinguishes the dolomitic beds by the appearance of the drillings. The dolomite constitutes what he calls the "oil sand" or "gas sand," as the case may be. This porous section of the Trenton limestone is not only a reservoir of oil or gas, but is equally available as a reservoir of water. A strong brine generally occupies it where gas or oil is wanting. A peculiarity of this brine is that the chlorides of calcium and magnesium frequently exceed in amount the chloride of sodium.

It is necessary to keep in mind what has already been stated, viz,

[1] Personal letter to the author.

[2] Rocks, Rock Weathering, and Soils, p. 160.

that the porous phase last described is local and limited in development, and that the great mass of the formation is essentially an impervious rock.

Though the Trenton limestone is the lowest stratum that has an outcrop in the State, we get in southwestern Ohio frequent evidences that a porous rock underlies it at a depth of 400 to 600 feet below its uppermost beds. In wells drilled to this level flows of a brine rank with sulphureted hydrogen rise to the surface. This brine is commonly known as "Blue Lick" water. The stratum which bears it can be called either an impure limestone or a calcareous sandstone. It is generally referred to the St. Peter's sandstone of the Calciferous horizon. Sometimes it has happened that many weak flows of brine have been found as the drill descended to unusual depths. This experience was especially marked in Springfield and Dayton, where the drill was carried to a depth of 1,200 to 1,600 feet below the top of the Trenton limestone.

UTICA SHALE.

The Utica shale is found in unequivocal and unmistakable characteristics in the deep wells of northwestern Ohio. It has the normal or typical features of the formation in New York in every respect, as color, grain, thickness, and even fossils. A few fragments of the shale brought up in the sand pump from the wells of Findlay, Bowling Green, and other localities have yielded at least two of the most characteristic fossils of the formation, viz, *Triarthrus becki* and *Leptobolus lepis*. This stratum can be traced in all directions from Findlay, where the original identification was made, as a bed of dark brown or black shale, 250 to 300 feet in thickness, expanding to the eastward and thinning to the westward and also to the southward. In the last-named direction it approaches the outcrop of the stratum in southern Ohio and northern Kentucky, and as followed southward the black shale is found gradually to disappear, being replaced by blue or gray limestone, interstratified, to some extent, with shale of the same color and indistinguishable from the underlying Trenton of the Kentucky scale. The limestone carries, however, some of the distinguishing fossils of the Utica, though not restricted to these, and has been positively identified as that formation on this ground alone. The lowermost 50 to 100 feet of the Cincinnati section have been thus referred by some geologists.

The Utica shale, as its name would warrant us in expecting, is, in the main, an impervious stratum. It is not, however, so close grained as many other shale formations, and pockets of gas and small reservoirs of salt water are frequently disclosed in it by the passage of the drill.

HUDSON RIVER FORMATION.

The Hudson River formation in Ohio, both under cover and in outcrop, is a series of interstratified shales and limestones. Both elements are generally gray or blue in color, and both are fossiliferous to a high degree, especially in the outcrops of the formation. The series as shown in southwestern Ohio is 700 to 800 feet thick, and the average undergound measure is not very far removed from these figures. But the volume of the stratum increases slowly from the center of the State eastward. Like the Utica, it grows thinner westward and southward. The shale is very close and fine grained, and, consequently, it is, as a rule, almost entirely impervious; but in exceptional instances pockets of gas, sometimes under high pressure, are found in it, and whenever such occur light veins of salt water are liable to be met. On the whole, it is under cover a typical representative of a dry or nonporous rock. In outcrop it is one of the poorest of water bearers. Shallow wells that are dug in it sometimes obtain a precarious and scanty supply of water highly charged with lime and other common minerals, the water seeping in from the beds that are traversed by the shaft, but there is not a formation of equal volume in the Ohio column that carries so little water as the Hudson River group.

MEDINA SHALE.

The Medina shale is found next in ascending order. It is the representative of a stratum of sandstone and shale that holds a very important and conspicuous place in the New York column. The sandstone, which is by far the more important element in this series, gives its name to the entire formation, which is accordingly known as the Medina sandstone. This stratum is made especially conspicuous by its color, which is prevailingly light red, though many beds of it are gray or white. The softer or shaly portions of the series are also red in color. The thin bed of red shale which occurs in southwestern Ohio, just at the junction of the lower and upper Silurian formations, was many years ago referred with some hesitation to the Medina horizon, on the basis of its position and color.[1] This reference has been abundantly sustained by the results of the drill during the last fifteen years. The Medina has been followed in consecutive well records from northern Ohio, where it is unmistakably present in a section normal as to thickness and color, to southern Ohio, where it is found in outcrop at the surface, and the red rock of the deep wells of Hancock County, for example, and that of the outcrops in Warren County are demonstrated to be one and the same. In the western half of Ohio this formation is almost entirely represented by shale, but in the eastern half sandstone courses, generally thin, are usually found. Sometimes even small pebbles occur in the Medina, both at the north and the south. Whether

[1] Geol. Survey Ohio, Report of Progress, 1869, p. 148.

the white sandstone, which is the gas rock of the Lancaster, Thurston, and Sugar Grove gas fields, belongs to the Medina horizon, or to the Clinton, to which the gas was at first referred, remains at present an open question. At any rate, the gas rock has not proved a prolific source of water at any point thus far. In New York and Ontario, however, it is a reservoir of gas and water on a very large scale.

CLINTON GROUP.

The Clinton series is one of the most distinctly marked elements in the geological scale of the country at large. Its outcrops are confined, so far as Ohio is concerned, to the southwestern portion of the State; here its thickness seldom exceeds 40 feet, and sometimes falls to less than 20. Under cover in central Ohio, to the eastward it seems to thicken to 60 or even to 80 feet in some sections. It consists of limestones of various grades, some of which show remarkable purity. It is often made up of crinoidal fragments so loosely cemented as to make in outcrop a water-bearing stratum. It graduates into calcareous shales below and also bears at its upper limit a peculiar deposit of fine-grained clay, bluish white in color, which proves impervious to percolating water. This layer does not often exceed 1 or 2 feet in thickness.

The Clinton is marked by high colors, owing to the presence of iron in it, which gives rise to various shades of red, yellow, and blue. A characteristic iron ore also occurs, fragments of which have been brought up from 2,000 feet or more in drillings. Aside from the facts already reported, it is on the whole an impervious stratum, but one of the finest lines of springs of the State characterizes the peculiar development above referred to. The water sinks through the crinoidal fragments of the formation until it reaches the underlying Medina shales, and at this point, which is the boundary between the Upper and Lower Silurian, the springs in question occur in fine development. These facts are well exhibited in Preble County.

NIAGARA SERIES.

The Niagara series, which comes next above the Clinton, is a compound system so far as its composition is concerned. Its lower portion is a fairly close-grained shale, while its uppermost division is mainly a dolomitic limestone of the type already described as due to replacement. The shale has a maximum thickness in Ohio of 100 feet, which is reached only on the southern border of the State. The limestone element of the formation shows a maximum of 300 feet in thickness; this is also reached in southern Ohio. The shale is a characteristically impervious stratum. The limestone is water bearing in some areas and in certain beds, but it is not to be counted water bearing on a large scale like a homogeneous sandstone of the same thickness and extent.

The Niagara shale includes in southwestern Ohio lenticular beds of a well-characterized limestone which is widely used and widely known as Dayton stone. This is impervious in itself, but is traversed by joints which often allow a fairly free descent of the water that reaches the surface of the limestone. The composition of the Dayton limestone is shown by the following figures:

Analysis of Dayton limestone.

Constituent.	Per cent.
Carbonate of lime	92.30
Carbonate of magnesia	1.10
Alumina and iron	0.53
Siliceous matter	1.70

Like the Medina shale already described, the Niagara shale attests its impervious character by turning outward much of the water that sinks to its surface. These springs, though generally lacking in strength, mark the horizon with great distinctness.

The limestone portion of the Niagara has proved a generous source of stored water in stations where it lies comparatively near the surface and has been exposed to atmospheric agencies in its pre-Glacial history, by which its seams and joints have been opened on a considerable scale. In such cases the surface water descends bodily to the impervious bed and furnishes in many instances a large supply of water. The latter has generally been clarified in its descent, but little or nothing has been done toward its purification. Wells drilled into this stratum are sometimes found to be charged with grosser impurities than are to be found in almost any other formation in our column, but the next element above it in like situations shares the same characteristics. The composition of the best phases of the limestone is indicated by the following analyses:

Analyses of Niagara limestone.

Constituent.	1	2	3	4	5
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Carbonate of lime	54.25	53.77	53.50	53.48	55.59
Carbonate of magnesia	43.23	44.76	45.79	42.25	43.76
Alumina and iron	1.80	.39	.39	.40	.42
Siliceous matter	.40	.59	.31	1.53	.28

1, Hillsboro; 2, Springfield; 3, Woodville; 4, Bowling Green; 5, Genoa.

ONONDAGA SERIES.

The Onondaga system, known in Ohio reports as the Water-lime, and perhaps including also beds of the Lower Helderberg series, is by far the most important limestone in the State so far as the areas occupied in outcrop are concerned and the thickness which it maintains, particularly in the northern and western portions of its area. Its maximum development in thickness is not far from 600 feet, but this measure is found only by the drill. In outcrop exposures it rarely reaches 25 feet, and perhaps never exceeds 50 feet. From these fine exposures in southern Ohio it thickens to the northward and eastward. In Highland County an included section shows it to be but 20 feet in thickness,[1] while in the deep well drilled at Columbus nearly 500 feet were referred to it on the satisfactory evidence of the drillings and the fragments that were brought to the surface. By far the most important areas of this stratum, so far as thickness is concerned, are covered with the deposits of the drift, which themselves are often very heavy. In composition the stratum can best be described as dolomite. For large districts the exposed portions of the series are exceptionally pure, constituting an almost typical double carbonate of lime and magnesia. This is shown in the following analyses, viz, of the Greenfield stone from southern Ohio and of the Genoa stone from the northern section of the State:

Analyses of limestones of Onondaga series.

Constituent.	1. Greenfield.	2. Rocky Ridge.
	Per cent.	*Per cent.*
Carbonate of lime	53.67	54.10
Carbonate of magnesia	42.42	44.27
Alumina and iron	1.30	0.29
Siliceous matter	2.42	0.87

In other districts, and notably in northwestern Ohio, while still dolomitic in general character, the rock is rendered to some extent impure by the presence of iron and alumina, which are so blended with it that its character is gradually changed. This type is most characteristically shown in Allen and Hardin counties. It is worked on a large scale in the quarries of Lima and Dunkirk for rough masonry and for railroad ballast. In color this phase is dark blue. The rock is very tough and stubborn. It bears abundant and unmistakable evidence of shallow-water origin in the shape of mud cracks which cover its surface. Ripple marks are not often found on it. It is mainly made up of thin beds, 2 to 4 inches in thickness, but occasional layers 6 to 8 inches thick are found. Fossiliferous beds occur here in better development than in most parts of its extent.

This type is not especially soluble, and the joints consequently have not become greatly widened in the course of its history, but they have sufficed after all to allow the surface water to descend with a

[1] Geol. Survey Ohio, Report of Progress, 1870, p. 283.

considerable measure of freedom, and the Onondaga series will be found to be the most important water-bearing stratum of the entire column of the State.

The second type of this stratum remains to be named. It is seen at its best in both northern and southern Ohio. At Greenfield it is remarkably even in its bedding, the courses usually ranging from 4 to 12 inches in thickness. The rock is a nearly pure dolomite, as the analysis already given shows, the principal foreign element being silica. It answers equally well for lime production and for building purposes; and is also used in a large way for curbings and crossings in city streets. It is not strong enough for block pavements, though sometimes applied to this use. Toward the north its bedding becomes uneven and its courses thin and irregular. In this condition, while often retaining its purity of composition, its main use is in supplying a fine quality of magnesian lime, as can be seen from the analyses already quoted.

This phase of the limestone is very soluble, and its joint planes are often open fissures which allow a very free descent of surface water.

Caves and underground channels are often found in this formation. They are far more frequent than in any other limestones of the State. Some of the most famous springs of the State belong to the Onondaga series, as, for example, Campbell's spring, in Pike County, and the Castalia spring of Erie County, both of which will be described at length on succeeding pages.

DEVONIAN LIMESTONE (CORNIFEROUS).

A limestone of Devonian age, which constitutes an important element in the geological column of the State, comes next in review. There are two fairly distinct divisions of this series, established on both paleontological and lithological grounds, known as the Columbus and Delaware divisions, but in an account of the relations of the formation to water no such division is required. The upper or Delaware portion of the series is distinctly less pure in composition, but no part of this series has in itself any storage qualities. Being a fairly pure limestone, its joints have been widened by solution where exposed to the atmosphere so as to allow a tolerably free descent of water from above, which does not, as a rule, descend into the earth to any considerable depth. A thin bed of shale or clay separates in many instances this limestone sheet from the stratum next below it, so that the formation now under consideration gives rise to numerous springs. The latter make many important contributions to the Scioto River in its course through Franklin County. Some of the springs furnish relatively large volumes of water and exemplify in their flow the general character of limestone springs, being evidently subterranean streams for a considerable distance back from their point of emergence. The famous Wyandot spring, that enters the river 5 miles above Columbus, well illustrates this mode of origin.

DEVONIAN SHALE.

The Devonian shale, a considerable and complex series, represents a half dozen stratigraphical elements, more or less, of the New York column, but in its Ohio development it consists essentially of fine-grained and impervious materials from top to bottom. It is perhaps the poorest reservoir of water that the State affords. Yet even in this great mass of shales some sandy zones occur which are occasionally found charged with gas, oil, or salt water. It is also to be noticed that where important sections of the shale have been exposed to the weathering agencies of the atmosphere for a long time a certain measure of permeability has been gained by them through the superficial enlargement of their joints and by the solution of some of their constituent minerals, especially by the decomposition of pyrites, which is generally abundant in the substance of the shale.

The Devonian shale ranges in thickness from 250 feet on its western outcrop to at least 2,500 feet in eastern Ohio.

The water that is supplied in exceptional localities by the shale is in all instances highly mineralized, carrying sulphureted hydrogen, sulphate of alumina, and sulphate of iron, as well as other compounds of this last-named element. The presence of sulphureted hydrogen is, in popular judgment, generally sufficient to place such springs in the list of medicinal waters, and many of them, not only in Ohio but in other States as well, have acquired reputation in this respect.

BEDFORD SHALE AND SANDSTONE.

The Bedford shale and sandstone make up in the large way a shale formation, and one which is consequently destitute of water, but the sandstone which constitutes its upper member in some parts of the State may possibly serve as a storage bed for water in limited quantities. No cases of this sort have, however, been noted.

BEREA SANDSTONE AND SHALE.

The Berea sandstone and shale form one of the most important of the reservoir rocks of our entire column, but for reasons that can easily be recognized, it produces fresh or potable water in but few and unimportant instances. It is essentially a drillers' rock. Salt water, oil, and gas are likely to be found anywhere in it, and its bituminous contents are sometimes extraordinarily valuable. It is the most important of the earlier developed oil rocks of Ohio and commands great consideration also in West Virginia and Pennsylvania. It is a gas rock in some territory, and when the reader is reminded that it constitutes the famous Murrysville gas sand in western Pennsylvania, he will see that no other stratum takes higher rank in this line. It is found to be an oil rock as soon as followed under cover. At Mecca, Trumbull County, it has proved a valuable repository of oil, and here its only cover is 20 to 50 feet of bowlder clay. In the Grafton oil field the Berea grit is less than 200 feet below the surface, and yet a small oil production has been maintained here for forty years. At no greater depth, in many instances, salt water is found in this formation; but it is when the stratum has 750 to 1,000 feet of cover that it gives the best results as a source of brine. The recent discoveries of vast beds of rock salt in various parts of the country have made it economically impossible to work any longer these deep stocks of weak brine, such as the Berea grit and other formations of our column so generally contain.

The thickness of the Berea grit ranges from 5 to 100 feet, and it is everywhere directly overlain by the Berea shale, a dark or black shale, 15 to 40 feet in thickness, which is not always easily separable from the next higher element in the series, namely, the Cuyahoga shale. The Berea shale is a close grained but rather soft deposit which has yielded easily to glacial erosion, and is therefore to a considerable extent wanting on the western outcrop of the grit, but its place is in such cases generally occupied by bowlder clay, which is as impervious as the natural cover would be. This fact accounts for the sparing occurrence of fresh-water springs along the outcrops of the Berea sandstone, to which attention was called on a previous page.

CUYAHOGA SHALE.

The Cuyahoga shale is at the best but an indifferent and capricious water bearer, but it is not so barren of water as the great Ohio shale—No. 9 of the table on p. 638. Though composed principally of fine-grained mud rock it also includes in some sections considerable bodies of sandstone, and no sections can be found of 200 feet or more in thickness that are altogether destitute of these sandy elements. Immersed as these sandstones are in shale, they very seldom furnish springs along their outcrops or supply potable water to the drill. Such water as they contain is generally saline.

LOGAN GROUP.

The Logan group is less definitely bounded and characterized than any of the formations that have so far been passed in review. In different sections of the State it consists of different elements, or at least of elements whose proportions vary greatly in different sections. Shales, sandstones, and conglomerates enter into its composition everywhere, but in the southeastern quarter of Ohio the dominant feature is a massive conglomerate that is found at its best in outcrop in Licking and Fairfield counties. It is in this element that the chief interest of the formation as a water bearer lies. Under cover this conglomerate, known as the Big Indian sandstone of the Ohio Valley, is a famous source of salt water and occasionally of oil and gas. Of course it is only when comparatively near its outcrop that it is found as a reservoir of potable water. It is not certainly known to furnish a public water supply to any town in the State at the present time. The conglomerate has a maximum thickness of 75 feet, but the entire formation measures not less than 300 feet in its full development.

CONGLOMERATE COAL MEASURES.

The Conglomerate Coal Measures form a division of our column which is well-nigh as important in its relations to water supply as it is in relation to other economic interests. In fact, its water production may be counted even more important than its coal production, looking to the future. In a few years the coal will have been exhausted from the rocks of this age, but they will still remain for an indefinite period a source of good water supply. This division is characterized by three great sandstones, more or less conglomeratic, that are separated from each other by shales, coal seams, fire clays, and even by thin beds of limestone and iron ore. The sandstones, or conglomeratic elements, are the three following, named in descending order: Homewood sandstone, Massillon sandstone or conglomerate, Sharon conglomerate.

Each of these divisions reaches a thickness in some portion of its extent of 80 to 100 feet. They are composed almost exclusively of coarse and clear quartz sand, among which are irregularly distributed quartz pebbles. The sand is occasionally fine grained for small areas, and layers of shale occur in the same regions, but as a rule the sandstones are freely open to water and seem to contain nothing which would in any way impair its purity.

LOWER COAL MEASURES.

The Lower Coal Measures of the Ohio scale are as thoroughly known to us as any other portion of our column. We find in them the sandstones named below, which are generally coarse in grain and of fair thickness, varying from 10 to 40 feet. All are water-bearing, though in many instances they have no fair chance to replenish their stocks when once reduced. The sandstones to be enumerated are the following: (1) The Kittanning sandstone, between the Lower and Middle Kittanning coals; (2) the Lower Freeport sandstone, an important and persistent element of the scale, particularly in southern Ohio, where it often makes the roof of the Middle Kittanning coal; (3) the Upper Freeport sandstone, a less massive stratum that overlies the coal of the same name. It is poor in grain, and springs occur but infrequently along its outcrops. All of these sandstones have faint conglomeratic phases.

LOWER BARREN MEASURES, UPPER PRODUCTIVE MEASURES, UPPER BARREN MEASURES.

The group of strata now to be considered constitute the three highest elements of the Ohio column. They are not as a rule so well known as those that have already been passed in review, but some of their strata are important in the present connection. The first seam to be named in the ascending order is one of the most important as a water-bearer in the entire list. It is the Mahoning sandstone, the lowest stratum of the Barren Measures. It is coarse or medium, never fine, in grain, and has unusual steadiness for a coal-measure sandstone. It has a considerable range in thickness, varying from 40 to 100 feet. It is feebly conglomeritic in places, especially in its uppermost portion.

There is a great deal of shale in the division which is not water-bearing. Limestones, some of them of considerable volume, also characterize this group. On the whole, these divisions must be counted poor in water. One of the highest elements in the series is the Pittsburg sandstone, but its quality in respect to storage of water is indifferent.

THE DRIFT.

The waters derived from the drift constitute by far the most important section of the supply of the State, but, aside from the few districts in which they appear in flowing wells from comparatively deep sources, they are not to be treated here. Mr. Frank Leverett's investigations, the report of which has already been published by this Survey,[1] have been mainly restricted to the ordinary drift wells of Ohio.

GENERAL CHARACTERISTICS OF WATERS OF DIFFERENT DEPTHS.

Before taking up the water derived from each of these different sources, we must consider a few general principles that apply to all.

1. The subterranean waters from a comparatively shallow depth carry, as a rule, dissolved carbonates. Lime and magnesia are the leading bases, but potassium and sodium sometimes also occur in small quantities. Iron is unfailingly present and often in notable quantity. These wells are common sources of potable supply.

2. Water from a greater depth holds dissolved chlorides as well. Chloride of sodium is by far the most common, but chlorides of magnesium and calcium are often added. Such waters are generally called saline. The presence of chlorides is seldom shown in water at less than 100 feet in depth, and where found they are confined to a few formations of the Ohio column. It is very rare that the drill descends to 300 feet without encountering saline water, or water too highly mineralized with other elements to be acceptable for the highest uses. Aside from that of a few wells in glacial drift, no water of the State is known that comes from a depth greater than 500 feet and still remains free enough from mineral solutions to warrant its use as potable.

3. Sulphates are generally found in the deeper waters, but are sometimes also found in the shallower waters. The most common compound is calcium sulphate, but sodium sulphate is not infrequent.

4. Sulphides also, particularly sulphureted hydrogen, though often

[1] Eighteenth Ann. Rept. (for 1896-97), Part IV, 1897, pp. 474-555.

rising to the surface in so-called sulphur springs, are especially characteristic of water found in limestones, and nearly all the water of the great Ohio shale system is characterized in this way. Sulphides pass into sulphates very promptly and by reactions easily understood.

DESCRIPTION OF WATERS FROM THE STRATA ABOVE NAMED.

The waters derived from the several formations above named will be next considered, and they will be taken up in the order of the preceding review. Only those cases will be treated at length in which conspicuous and important production is found in a stratum.

TRENTON LIMESTONE.

All the water that we know from the Trenton limestone in Ohio is that derived from deep drilling, or, in other words, from the oil and gas wells of northwestern Ohio. Our largest knowledge of it comes from the counties where the drill has been employed for the longest time and in the greatest number of wells. The counties are as follows: Lucas, Ottawa, Sandusky, Seneca, Hancock, Allen, Auglaize, Mercer, and Van Wert. Other counties adjoining those named make some additions to this list, but the most striking instances will be found in the counties named above.

The waters from this lower horizon, so far as examined, seem to have many features in common. They are all far removed from a potable character. All are highly mineralized and have a strong bitter or saline taste. They contain large quantities of chlorides of sodium, magnesium, and calcium. A marked peculiarity has been claimed for them in this respect, that the two compounds last named frequently exceed the first, or the chloride of sodium—a somewhat unusual feature in underground waters. It does not appear in all of this deep water. They are also universally rank with sulphureted hydrogen. Sulphates have not been reported in them thus far.

These waters are mostly artesian, as is shown by the fact that they rise under considerable pressure, sometimes, though rarely, flowing from the well mouth, but generally stopping from 100 to 300 feet below the surface. In some of the best marked examples, noted at the time when drilling was most active, twelve years ago, water was found to rise in widely separated regions to approximately the same absolute height, viz, to about 600 feet above tide. Whether the wells flow depends on the altitude of the surface. Where the surface is below the 600-foot line the water, of course, escapes from the well mouth; but where the surface is higher the water falls as much below as the height of the surface exceeds that figure. Subsequent observations, though comparatively few in number, have substantiated the same conclusion. One of the latest examples is found in the recently developed oil field of Oregon township, Lucas County. In a well drilled there in 1896 an amazing flow of salt water was unlocked in the Trenton limestone. The height of the surface at this point is somewhat less than 600 feet above tide, and consequently the salt water flowed strongly from the well mouth. The owner of the well applied a pump to it to reduce the salt water, if possible. After vigorous and steady work for many days he succeeded to the extent of bringing in a considerable amount of oil from its higher level in the rock. But the oil production was maintained only while the pumping was continuous.

In a well drilled at Lindsay, Ottawa County, in 1886, the salt water rose very nearly to the surface. The water came from a depth of 70 feet in the Trenton limestone and reached an altitude of practically 600 feet above tide. In Hancock County cases have occurred by the score in which the salt water rose in great volume, whenever tested by the pump, to the level named above, which might generally be reached within 100 to 300 feet of the surface. In Wood County a well on the Halsey farm produced for some time a thousand barrels of salt water per day. With the water it also yielded 300 barrels of oil for the first few months. The oil has since fallen away to less than 100 barrels, while the volume of water is maintained.

A careful study of the waters of the Trenton limestone was made by Dr. T. S. Hunt in his Chemical and Geological Essays. The results of his study are incorporated in an interesting paper in that volume. The waters that he discussed are not, however, deep waters, but are such as occur in springs and shallow wells in this formation in Canada. The analyses given by him show the same general constitution that characterize the deep waters of Ohio when the rock is penetrated to the same horizon. I append a number of Dr. Hunt's analyses:

Analyses of Trenton limestone waters.

[Grains to the gallon.]

Constituent.	Whitby.	St. Catherine.	Caledonia.	Lanoraie.
Sodium chloride	18.9158	29.8034	12.2500	11.1400
Magnesium chloride	9.5437	3.3977	1.0338	.2790
Calcium chloride	17.5315	14.8544	.2870	.2420
Potassium chloride	....	....	.0305	.1460
Barium and strontium chlorides	....	....	....	.0488
Sodium bromide	.2482	....	.0238	.0283
Sodium iodide	.0008	.0042	.0021	.0052
Magnesium bromide	....	....	.0238	.0283
Magnesium iodide	....	....	.0021	.0052
Calcium sulphate	....	2.1923	....	....
Silica	....	....	.0225	.0552
Barium and strontium sulphate	....	....	....	....
Calcium carbonate	.0411	....	.1264	.4520
Magnesium carbonate	.0227	....	.8632	.4622
Barium and strontium carbonate	....	....	.5555	.0243
Total solids	46.3038	50.6075	14.6893	12.8830

A deep water derived from some part of the Trenton limestone in a well drilled at Ripley, Brown County, Ohio, has been put on the market as a "Brom-Lithia" water. An analysis by Prof. Karl Langenbeck shows the following composition:

Analysis of water of well at Ripley, Ohio.

Constituent.	Grains per imperial gallon.
Silica	2.0300
Alumina	.0850
Ferrous sulphide	.0520
Ammonium sulphide	.7750
Calcium sulphide	18.6330
Magnesium sulphide	24.0890
Calcium hydrosulphide	3.2300
Calcium sulphate	1.8250
Magnesium bromide	.6570
Sodium chloride	663.4530
Potassium chloride	18.9800
Lithium carbonate	11.0500

A single analysis of the deep brine of the Trenton limestone from northern Ohio is here introduced. The work was done for the State board of health by Prof. N. W. Lord.

Analysis of water of Trenton limestone.

Constituent.	Grains per gallon.
Potassium sulphate	4.66
Potassium chloride	56.24
Sodium chloride	2,384.40
Calcium chloride	471.90
Calcium carbonate	25.83
Magnesium chloride	354.00
Iron oxide	.08
Alumina	.10
Silica and silicates	.72
Total solids	3,297.93

This water was taken from well No. 8 on the Halsey farm, Plain Township, Wood County, 2 miles west of the court-house square in Bowling Green. The well has been a generous producer of salt water and oil from the beginning. The depth from which both products are raised is 1,256 feet. The salt water does not flow from the well mouth, but when left to itself rises to considerable height in the well. The constant pumping to which this and hundreds of other wells in the vicinity are subjected has had a greater or less influence on the salt water. At the first drilling of the well it yielded 300 barrels of oil per diem and continued this production for a number of months. At the same time it yielded as much as 1,000 barrels of salt water. The oil production of the well has latterly fallen to 100 barrels per diem, but the water still continues in large volume. The character of the water is marked, as the figures given above show, but the chloride of sodium is in large excess over the other chlorides present. It will be remembered that in many examples of these deep waters from the old rocks the contrary has been claimed to be true. The claim has not been substantiated in Ohio.

A second analysis of the water is herewith given from the Hemmingray well at Newport, Kentucky. The water was found at a depth of 500 feet, or about 200 feet below the upper surface of the Trenton limestone. The analysis was made by Prof. N. W. Lord for the Ohio geological survey.

Analysis of water of Trenton limestone from well at Newport, Kentucky.

Constituent.	Grains per gallon.
Calcium sulphate	106.01
Sodium chloride	614.04
Magnesium chloride	54.17
Silica	.41
Alumina and iron	Trace.
Sulphureted hydrogen	(*a*)

a Undetermined, but in large amount.

This water was popularly called "Blue Lick water," and was imagined by some persons to produce beneficial effects when taken into the human system. For bathing it would unquestionably prove advantageous in certain forms of disease.

MEDINA AND CLINTON HORIZONS.

The geological elements indicated by the numbers 2 and 3 in the column on page 638 give no important or characteristic production of water anywhere in the State, for the reasons that can be understood by reference to the description of the several elements heretofore given. But at the junction of numbers 4 and 5, in southwestern Ohio, a remarkable line of springs occurs. These are all found on the outcrop of the Clinton limestone and largely on outcrops of outliers of this formation. In all such cases the drift is generally thin. The horizon is well marked geologically, as it is very near the dividing line between Ordovician and Silurian time (Lower and Upper Silurian). It is also, in many instances, conspicuous by reason of color effects. The Medina series is generally highly colored, a red band being its most striking element. As it is the only red stratum in the entire district, its presence is sure to be noted.

This line of springs led to the location of many farms in the original settlement of the country, and roadways connecting these tracts first occupied have, in some instances, been maintained to the present day. There is also an abrupt change of level in many cases, as one passes from the Clinton to the Medina horizon. The former is apt to occur in a terrace-like outcrop. Moreover, there is often a well-marked change in soils in passing from the higher to the lower level. A belt of unusual productiveness characterizes the slope below the Clinton limestone as a rule, and, since the buildings and improvements of farmers generally correspond to their success, the homes that are established along this boundary are more than usually attractive. It is probable that the escape of water at this level has something to do with the change in the character of the soil.

The water of these springs, and from this horizon generally, has, so far as known, no peculiar qualities. Most of it has passed through the thin beds of drift that overlie the limestone, and afterwards through 10 to 30 feet of Clinton limestone before reaching the impervious bed of Medina shale that turns it out to the surface. There are no conditions apparent that promise any unusual degree of purity, through filtration or other means; but so far as known, these sources have given an acceptable and approved supply to many thousands of people during the lives of several generations. It is geologically the lowest potable rock water that is known in the State.

The counties in which this line of springs occurs are named herewith: Preble, Montgomery, Warren, Greene, Clinton. Excellent examples of the phenomena above described are to be found on the margin of Spring Hill, in Warren and Clinton counties.

A considerable amount of water too highly mineralized for a potable supply is found at this same horizon when it is reached in the deep wells of northwestern Ohio. The Medina shale is the one safe horizon in which to set the casings of gas and oil wells that are to be carried down to the Trenton horizon. In that part of the State the Medina is usually a well-marked red rock, and, as observed above, it is a landmark that never escapes notice in the well section. There is one higher horizon, viz, the Niagara shale, where the casing can often be set successfully, keeping the well free from the invasion of deep rock water. It is never safe, however, to depend on this; but when the casing is set in the Medina shale, it has been found, in thousands of instances, to furnish sure protection to the well. From these deep wells we get in many instances waters rank with sulphureted hydrogen. Sometimes the water is more or less strongly impregnated with salt; and iron is often present in solution. No use has been made of these deep waters in any way, so far as I have been able to learn. The only obvious use is in medicinal baths.

The counties in which the deep wells of the Clinton are found are identical with the counties in which the Trenton limestone is petroliferous in the large way. The list will agree exactly with the list given under the deep wells of the Trenton limestone.

NIAGARA LIMESTONE.

The Niagara series consists of the Niagara shale and the Niagara limestone. The latter is also divisible into two or more elements, but they need not be distinguished here. The Niagara shale separates the Niagara limestone from the Clinton limestone. It is a close-grained and fairly impervious formation and, alike in outcrop and under cover, is a water-bearing horizon. The springs that are found on this line in the regions where it lies above drainage, are not so strong as those rom the junction of the Medina and Clinton, already described, but in Clarke, Greene, and Highland counties, a large quantity of water finds its way to the surface at this level, and many wells obtain water when drilled to this horizon. The latter statement applies especially to the districts about Springfield, Yellow Springs, Cedarville, Hillsboro, etc. Under deep cover, the water is of very much the same character as that just described.

But by far the most important contribution that the Niagara limestone makes to the water supply of the State is found in regions where it was a surface rock in the ages that intervened between the establishment of Ohio as dry land and the epoch of the glacial drift. During this last period there were large areas of the limestone exposed to the action of atmospheric agencies, protected only by the products of its own weathering. In such regions the joints of the limestone must have been widened and underground reservoirs and channels must have been established as parts of a general drainage system. Finally the drift came, covering and leveling up the entire surface of the country. The deposits which it brought sometimes allow the freest possible passage of water to the rock floor, and again, the bowlder clay shuts out the surface water almost completely from considerable areas. By reason of this irregular distribution of the pervious cover, the rocky floor still takes an important part in the water circulation of the country. The first example of this condition is found in the experience of Sidney, Miami County.

SIDNEY.

Some years ago the necessity of a public supply, especially for protection against fire, became evident to the people of Sidney, and waterworks were introduced at the public expense, with the Miami River, which flows through the center of the town, as the source. A reservoir was formed by damming the river above the town, but the quality of the water drawn was poor. In fact, it was used only for fire protection. It was justly considered unsatisfactory and unsafe for domestic use. In 1885 the excitement originating in the discovery of gas in Findlay in the previous year led the enterprising people in Sidney to try their fortune with the drill in the home field. A deep well was accordingly drilled in the fall and winter of that year, and in the course of the descent a surprising flow of water was found in the upper limestone series, which is here about 200 feet thick. It consists altogether of Upper Silurian elements. The series is as follows:

Section of well at Sidney, Ohio.

	Feet.
Niagara limestone	140
Niagara shale	40
Clinton limestone	20
Clinton and Medina shales	

The water found in the limestone was highly sulphureted, and although the flow was seen to be exceptionally vigorous, it attracted but little general attention at the time. The Trenton limestone, which was the goal of the driller, was found unproductive; but new companies were organized and other wells drilled, all of them showing the same general results, viz, neither gas nor oil in the Trenton, at least none of economic importance, but an abundant supply of water from the upper limestones. The water was under artesian pressure, and rose with considerable force from the well.

One of the abandoned wells, viz, that drilled on the Burkhardt property, was allowed to remain a flowing fountain, and has been sending out to the river a good-sized stream ever since it was drilled. The water was struck in the Clinton series 217 feet below the surface.

Finally, the demand for potable water for the town became more urgent, and the deep supply in the upper limestones came to be considered in this connection. During the present year, 1897, the town has taken up the matter in earnest and has expended $80,000, in addition to $40,000 spent in the establishment of the older plant.

Four wells have been drilled and the water found has been turned into the city pipes. The reservoir has been entirely abandoned. All the wells are located in the river valley and in the center of the corporate limits of the town. The section found is as follows:

Section of well at Sidney, Ohio.

	Feet.
Gravel filled with water	30
Niagara limestone	90

The section shows that the wells obtain their supply from the lower Niagara. If they had been carried deeper, they would undoubtedly have soon struck sulphur water, as was the case with all that were drilled for gas. Water was found in the limestone all the way down. By its ascent in pipes connected with the wells, it shows an artesian head of 17 feet, and in one case in the town a head of 25 feet was reported. The flow from a 6-inch pipe at the wells, rising 3 feet above the surface of the ground, makes a splendid and imposing exhibition. (See Pl. LXXI, *B*.)

The supply for the town is ample for every purpose. The maximum production of the present year is 936,000 gallons in twenty-four hours; the average, 400,000 gallons. The wells could, without doubt, maintain even the maximum for a long time.

A well at a brewery a few hundred yards south of the waterworks, drilled into the limestone to the same depth as the city wells, obtains the same artesian flow, but finds it affected by the pumps of the city plant. When these are taxed, the flow of the brewery well becomes intermittent.

The water is thoroughly acceptable for domestic use, but for steam boilers constant care and outlay are required. The sediment and crust deposited on boilers will make sometimes a deposit of an inch in two weeks' time.

An analysis of the water, recently made by Prof. C. C. Howard for the State board of health, shows the following composition:

Analysis of water from wells at Sidney, Ohio.

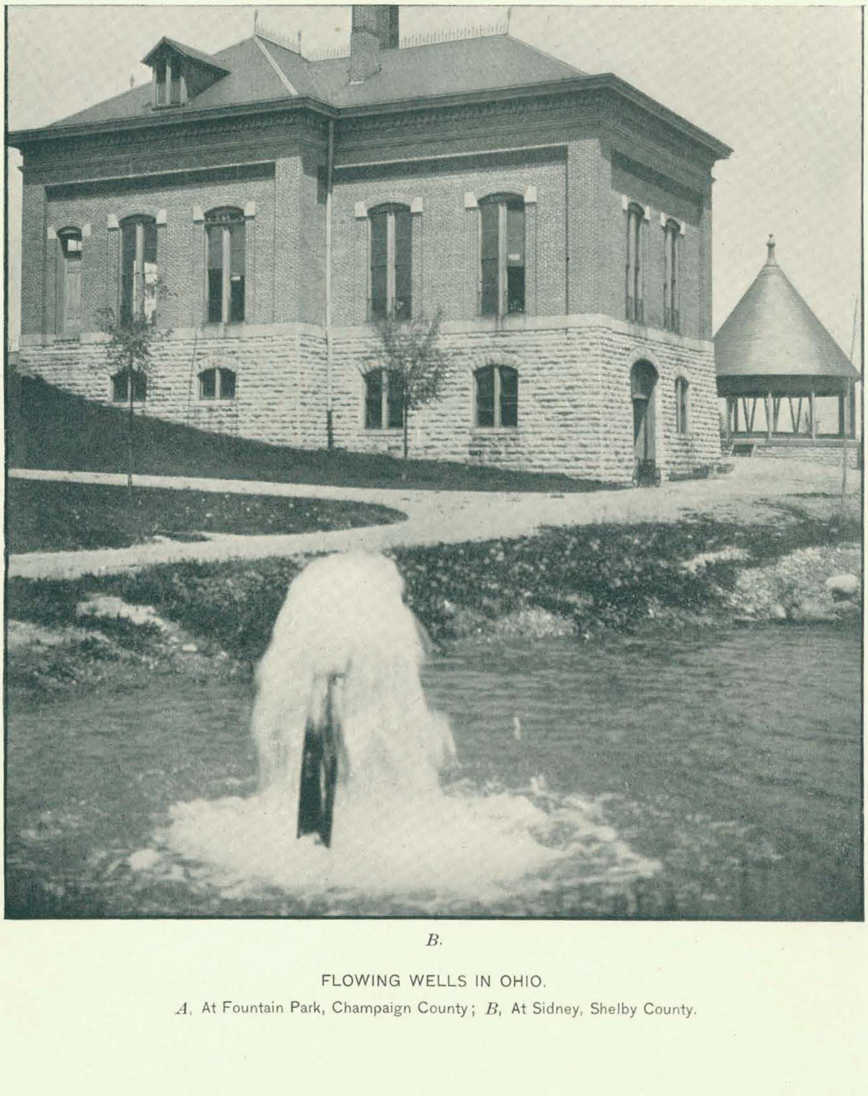
Constituent.	Grains per gallon.
Calcium sulphate	23.85
Calcium carbonate	40.06
Magnesium carbonate	20.50
Sodium chloride	.09
Total solids	84.50

The explanation of the high percentage of sulphate of lime is undoubtedly found in the fact that the water originally contained more or less sulphureted hydrogen. By its oxidation, the sulphur appears in the form of sulphuric acid, and this takes the lime from a certain amount of carbonates in the water.

CELINA.

Public water supply was established in this village in 1895 at an outlay of $50,000. Six wells have been drilled, the first three to a depth of 175 feet, the others to a depth of 300 feet. The wells are located 1¼ miles northwest of the court-house. The drillers find 80 feet of drift, 120 feet of Niagara limestone, and 60 feet of Niagara shale and Clinton limestone. They seem to have been drilled deeper than the water supply would require. Probably their entire stock is derived from 200 feet of the total depth. The supply is large and the capacity of the wells has never been reached by the pumps. The water rises to within 30 feet of the surface. The wells affect each other noticeably.

A.



B.

FLOWING WELLS IN OHIO.

A, At Fountain Park, Champaign County; *B*, At Sidney, Shelby County.

The quality of the water is not entirely satisfactory. It is too hard for many household uses and is particularly objectionable for steam-boilers. An analysis made by Prof. C. C. Howard in 1896 showed 251 grains of total solids to the gallon. The composition of the water has considerably changed in the interval between the analysis and the present time. Prof. N. W. Lord finds the following substances in an analysis recently completed.

Analysis of water from wells at Celina, Ohio.

Constituent.	Grains per gallon.
Potassium sulphate	0.62
Sodium sulphate	15.90
Calcium sulphate	46.36
Magnesium sulphate	19.55
Magnesium carbonate	10.02
Sodium chloride	1.46
Iron and alumina	0.45
Silica and silicates	1.00
Total solids	95.36

It is of course recognized that the large percentage of common salt in this water does not imply its previous sewage contamination. It is distinctly a product of the rock strata from which the water is obtained.

ST. MARYS.

A public supply was introduced into this village in 1895. The drilling for oil and gas had been so extensive in this region that the underlying sources of potable water were well understood, and no preliminary tests were needed in locating the public supply. Four wells were drilled in 1895 at a point conveniently located within the corporation limits, the first to a depth of 155 feet, the second to 265 feet, and the others to about 280 feet, all terminating in Niagara limestone. The first well did not produce so much water as had been expected and a torpedo was exploded in it to increase its flow, but no advantage was derived therefrom. It yields to the pump 200,000 gallons per diem, while the second produces 700,000 gallons per diem. The combined average daily capacity of the four wells is estimated to be 2,000,000 gallons.

An analysis of the water was made by Messrs. Werner and Simonson, of Cincinnati, which showed the qualities named below:

Quality of water from wells at St. Marys, Ohio.

Temporary hardness (carbonates of lime and magnesia)	31.50
Permanent hardness (sulphates of lime and magnesia)	5.00

The supply has been approved by the State board of health, and is coming to be generally used by the people of the village. Wells of this class may be obtained over an area of several square miles in the vicinity of St. Marys.

FOUNTAIN PARK.

A few examples of excellent supplies of water derived from the porous or Guelph division of the Niagara limestone remain to be noted. The first occurs at Fountain Park, a station on the Pittsburg, Cincinnati and St. Louis Railway, in the northeastern corner of Champaign County. (See Pl. LXXI, *A*.)

The discovery of this source of water was made about sixteen years ago. A well was drilled in 1882 to a depth of 62 feet, about 20 feet of which was limestone, on the farm of Mr. A. J. Smith, and water flowed from the well mouth. It was at once observed that the water carried iron enough to leave a rusty stain on surfaces over which it flowed, which is by no means unusual. To this observation another was presently added, viz, that a knife blade held in the water became magnetic. The discovery was at once heralded that a new fountain of "magnetic water" had been found in this portion of the State. Others had been previously known there.

Just how the popular delusion in regard to certain waters being magnetic originated it is impossible to say. The earth is a magnet, and iron rods and pipes set vertically in it take their part in magnetic phenomena. The steel drill with which all deep wells are sunk always becomes permanently magnetic, and the iron casing of such wells becomes at least temporarily so. Similar phenomena can be found in every deep well without regard to the character of the water. But why one well or spring should be called magnetic rather than another is a matter of caprice or accident that can not be explained. No water is ever called so that does not flow through a vertical iron pipe, and all waters having this mode of egress have equal right to the name.

Presently it was determined that as the water flowed and was magnetic it must be utilized. A good hotel was forthwith built and equipped with bath houses. It was designed especially for summer use. Other wells were drilled, including one deep well with a 6-inch casing. This was sunk to a depth of 2,300 feet with the hope of reaching gas or oil. The territory has been pretty thoroughly tested with respect to flowing wells, and fourteen in all have thus far been developed in the immediate neighborhood. They are all included within 150 acres. All the flowing water comes from the rock, and in the deep well the main supply is derived from 114 feet. This fills the 6-inch pipe and has a pressure head of 14 feet. In other wells on higher ground the head is reduced proportionately. These wells affect each other, but are not influenced by rainfall or the accidents of the seasons, so far as noted. The waters from different depths in the rock have distinctly different characters. The analysis of the water of the first well drilled was made by Mr. E. S. Wayne, of Cincinnati, and shows the following composition:

Analysis of water from well at Fountain Park, Ohio.

Constituent.	Grains per gallon.
Chloride of sodium	13.64
Chloride of calcium	4.22
Chloride of magnesium	2.12
Sulphate of potash	2.61
Carbonate of lime	26.24
Carbonate of magnesia	11.41
Carbonate of iron	0.16
Silica	0.24
Organic matter	0.39
Total solids	61.03

This water is found to be laxative in its physiological effects, as its mineral constitution would lead us to expect.

Well No. 2, near the hotel, comes from a shallower depth and has more of the character of drift water. Its composition, as determined by Prof. H. A. Weber, of the Ohio State University, is shown in the following table. This water is counted astringent, but it is hard to see how it can differ from the water of ordinary wells. A small amount of sulphureted hydrogen is dissolved in it.

Analysis of water from well at Fountain Park, Ohio.

Constituent.	Grains per gallon.
Carbonate of lime	15.293
Sulphate of lime	.087
Carbonate of magnesia	1.367
Sulphate of magnesia	10.769
Carbonate of iron	.160
Chloride of sodium	.539
Sulphate of soda	1.186
Sulphate of potash	.426
Silica	1.225
Organic matter	.230
Total solids	31.282

The water from well No. 2 is largely sold in Columbus as a table water. It is considered satisfactory by those who use it.

The water of the deep well, well No. 3, of the hotel property, comes, as has been said, from about 114 feet in depth. It has a flow of great volume, but actual measurements have not been made. If left to flow unimpeded from the 6-inch casing it reduces the head of all the surrounding wells. Its composition is shown in the following analysis, made by Prof. H. A. Weber:

Analysis of water from well at Fountain Park, Ohio.

Constituent.	Grains per gallon.
Carbonate of lime	14.242
Sulphate of lime	.099
Carbonate of magnesia	1.457
Sulphate of magnesia	9.296
Carbonate of iron	.221
Chloride of sodium	.480
Sulphate of soda	.274
Sulphate of potash	Trace.
Silica	1.390
Organic matter	.251
Total solids	27.710

The topography of the district is interesting. The surface is occupied by a moraine of recession, and is beautifully diversified by low hills and hollows. The district is one of the most beautiful in central Ohio.

Brush Lake occupies one of these hollows or depressions in the drift sheets. The lake has an area of 11 acres, and its greatest depth is 80 feet. In its northwestern corner there are indications of the ingress of spring water in considerable volume.

PLAIN CITY.

On the same line of railroad, 15 miles farther eastward, another example of strong flowing water, apparently from the same geological source, was found during the epidemic of drilling, which has several times been referred to in this discussion. A deep well, projected at Plain City in 1889, was carried down to a depth of 1,700 feet, when the tools became fast and the drilling was necessarily abandoned, but in sinking it a powerful flow of water was struck at 387 feet. The water showed a head of 18 feet of pressure, but as the location was below the general level of the country the head would be but 4 or 5 feet above the ordinary level of the drift plains.

A second well was located near the first, and repeated its experience so far as rock water was concerned. This well was drilled 2,000 feet deep, and, according to the recollection of those interested, was carried about 30 feet into the Trenton limestone.

A destructive fire swept through the business part of the town in

1894, with which the residents found themselves utterly unable to cope. This led to the recognition of the imperative need of an adequate water supply—a need that was emphasized by the frequent occurrence of typhoid fever in the village. The great flow of cool, clear, excellent water constantly escaping from the casings of the two deep wells was before the eyes of the people, and it did not take long to decide upon the proper course to pursue. A public water supply from this source was decided upon, the village was bonded for $35,000, and a modern waterworks plant was forthwith installed. Both of the sources of dangers above referred to—fire and fever—have been effectually disposed of by the introduction of this deep water. Not a case of typhoid has ever occurred in families where the deep water has been in use, and fires are extinguished so promptly that some of the people are disposed to believe that the water must have some element not found in ordinary water to account for its effects; but of course there is no foundation for such a belief.

The water does not, however, answer at all for boiler use, as its mineral contents indicate. The following analysis was made for the State board of health by Prof. N. W. Lord:

Analysis of water from wells at Plain City, Ohio.

Constituent.	Grains per gallon.
Potassium sulphate	0.70
Sodium chloride	1.94
Sodium sulphate	1.86
Calcium sulphate	13.60
Calcium carbonate	8.90
Magnesium carbonate	10.30
Oxide of iron and alumina	0.22
Silica	1.72
Total solids	39.24

HARRISBURG.

The third case of a vigorous supply of flowing water from the porous Niagara, where it occurs under deep cover, has recently been developed at Harrisburg, on the line of the Midland Railroad at the crossing of Big Darby. The Devonian limestone has an outcrop here, and, as is not infrequently the case, it is charged with considerable quantities of inspissated petroleum. This petroleum has undoubtedly a local origin and has no significance whatever as indicating a source of deep oil, but facts were differently construed by local observers. A company was formed two years ago to drill a deep well at this point. The Trenton limestone was not reached, but as has so often happened elsewhere, an excellent flow of water was found. The main production comes from a depth of about 400 feet (390 to 405). Recently measured by Prof. C. N. Brown, of the State University, its production was found to be about 850,000 gallons per diem. The flow is sufficient to run steadily a 9½-foot water wheel, which is applied to grinding grain, sawing lumber, and the like. (See Pl. LXXII.)

The record of the well leaves no doubt as to the horizon from which the water comes. It is certainly derived from the Guelph division of the Niagara limestone. The composition of the water is shown in the following analysis made by Prof. N. W. Lord for the State board of health. The figures indicate grains to the United States gallon.

Analysis of water from wells at Harrisburg, Ohio.

Constituent.	Grains per gallon.
Potassium sulphate	0.51
Sodium chloride	2.72
Sodium sulphate	2.91
Calcium sulphate	14.61
Calcium carbonate	7.42
Magnesium carbonate	9.76
Oxide of iron and alumina	0.12
Silica	1.60
Total solids	39.65

The close agreement of the waters of the Plain City and Harrisburg wells in the details of their mineral composition is strikingly shown in the last two analyses given.

ONONDAGA LIMESTONE.[1]

This great division is by far the most important source of underground water for all the higher uses that is to be found in the State. The thickness of the formation and its area, greatly exceeding those of all the other limestones of our column, make the statement both intelligible and probable. Its soluble character also comes into the account. It seems certain that some beds in the series have been dissolved in a larger way than others, thus giving rise to what appear to be water horizons in an essentially impervious rock.

The principal factor in the storage quality of the series results from the vast periods in which it constituted the surface of the State, overspread only with the results of its own decay. During these ages, covering the time from the Appalachian revolution, when the State became dry land, to the advent of the Glacial period, the surface of

[1] The Water-lime and Lower Helderberg limestone of Ohio reports.

FLOWING WELL AT HARRISBURG, FRANKLIN COUNTY, OHIO.

Six-inch pipe. Well turns a 9½-foot water wheel.

the State undoubtedly stood, for at least a portion of the time, at a higher level geographically than it now holds. The joint planes of limestones would consequently be widened and the underground drainage in this rock indefinitely extended and enlarged. Only thus can the present state of the buried limestone be understood or explained. That the limestone once stood at a higher level in its relation to the main drainage streams is evident from the fact that the drill often finds empty chambers several feet in depth as much as 100 or even 200 feet lower than the present drainage systems.

In recording the storage quality of the Onondaga limestone and the use already made of water derived from it by the towns of Ohio it is easy to see that a beginning only has been thus far made. More and more cities, villages, hamlets, and isolated homes will learn to avail themselves of the vast amount of duly purified though somewhat highly mineralized water which is stored in the joint spaces and rock chambers prepared by the processes of solution of earlier ages.

Among the cities and villages that are already depending on the waters of the Onondaga limestone the following may be named: Delphos, Lima, Kenton, Upper Sandusky, Bellefontaine, Marysville, Sabina, Mount Sterling, Plain City. I will speak briefly of the supplies that several of these towns have secured.

DELPHOS.

This town has put in a plant at public expense during the last two years, expending $70,000 up to the present time. A location was selected in the valley 1 mile south of the town. At this point only 16 feet of drift covered the limestone floor. Indeed, there is but a thin covering of the glacial deposits in all the immediate region, as has been established by the numerous wells that have been drilled here within the last few years. The ordinary drift-water wells of the region are but 15 to 18 feet deep, but the drilled wells of later years have been carried down from 60 to 80 feet deep, or from 40 to 60 feet into the rock, and great improvement in the water supply has resulted.

At the pumping station established by the city a receiving well was dug 40 feet in diameter and 38 feet deep. This is made a common reservoir for a series of seven wells, which are set in some instances within 50 feet of each other. The wells are all 8 inches in diameter and all are 300 feet deep. There was no particular vein of water found, but additions were made all the way down, and at the depth where the drill was stopped a test of the first well showed a volume large enough to meet the requirements of the town. It has not been demonstrated that the seven wells are necessary, and it is possible that one would do the work of the entire series. Certainly they are all intimately connected, as the water rises and falls in all together. Under normal conditions, while it does not flow, it comes within 8 feet of the surface. Siphons are set at a depth of 25 feet, opening into the receiving well, and are so adjusted as to charge themselves. In one of the wells an air lift is located at 125 feet below the surface, and it is found to work with great advantage on the entire supply. The depth to which the wells were drilled rendered it inevitable that their supply would be more or less contaminated with sulphureted hydrogen. This substance works against the good name of the water that carries it, and the village supply at first suffered some disadvantages from this source, but by the aeration of the water the odor of the gas is entirely removed. The compressed air of the air lift is also turned into the reservoir for a few minutes each day with satisfactory results.

Water was found in the first well at a depth of 150 feet in such quantity that the authorities in charge proposed at first to arrest the work at this point, but a sample was submitted to the State board of health for analysis. While the water was not condemned it was criticised as exceptionally hard. According to the analysis the total solids amounted to 73 grains to the gallon, of which about one-fifth was composed of sulphates of lime and magnesia. Most of the public water supplies are now known to exceed these figures, but under the influence of the warning the trustees proceeded to sink their well deeper, and at a depth of 300 feet obtained a new supply, which was counted by the people of the town "soft" in comparison with the earlier supply. An analysis recently made for the State board of health by Prof. N. W. Lord gives the following result:

Analysis of water from well at Delphos, Ohio.

Constituent.	Grains per gallon.
Potassium sulphate	0.56
Sodium sulphate	2.22
Sodium chloride	1.98
Calcium carbonate	12.65
Calcium sulphate	4.53
Magnesium carbonate	9.37
Iron oxide	0.11
Alumina	0.13
Silica and silicates	1.18
Total solids	32.73

If the analyses fairly represent the two grades of water, the grounds of the preference that is expressed by the people of the village are obvious and justifiable. But it is hard to understand how a lower vein of water in the same limestone stratum can carry less mineral matter than the higher. The two analyses quoted show in the 300-foot supply less than half the total solids found in the 150-foot level.

The maximum production of the system thus far has been 250,000 gallons per diem, but a steadily increasing use is sure to follow the introduction of the new supply.

LIMA.

The water-supply plant of Lima is owned and controlled by the city. The work was begun with the construction of a reservoir, formed by ponding a small stream which flowed a mile east of the town, but this scheme proved a failure in every respect. The water obtained was unsatisfactory in quality, and in time of drought a failure in quantity was experienced which was fatal. This result led to a search for a supply in the underlying strata, the storage quality of which had been abundantly demonstrated during the last dozen years in the scores and hundreds of oil wells that had been drilled in the region. In numerous wells large flows of water had been found in the upper limestone. The city turned to the use of these deep waters in 1894. Six wells, located near the earlier plant, were drilled at this time and were from 118 to 180 feet in depth. The waters seem to be derived from two principal horizons, one located at 117 feet below the surface, and the other 170 below. The drift cover is shallow in the entire region, 8 to 20 feet covering most of the sections. The wells were drilled 8 inches in diameter, and all of them flow naturally. The strongest of the group is an abandoned oil well, bought by the city in the drought of 1895. Since that time it has rendered material service to the waterworks. This well obtained its supply from a depth of 117 feet.

Another fine water vein was struck at the depth named above, on the Fetter farm, one-half mile east of the city well, and again in a third well one-half mile farther east. That these wells are directly connected was proved by the fact that the city pumps when in operation had an effect on both, cutting off their artesian flow entirely. The steadiest and severest pumping never lowers the head more than 15 feet, and when the pumps are stopped only a few seconds are required for the wells to regain their head. The maximum production was found on a special test to be 1,500,000 gallons per diem, and it seems as if this production could be maintained.

As already noted, however, the rock water supply was preceded by a surface supply of unsatisfactory water. The old system was not abandoned on the introduction of the new, but the two are united, and consequently affect each other more or less. The reservoir water is preferred by all who use water for steam production, on account of the excessive hardness of the rock water. By an analysis made for the State board of health at the introduction of the rock water the total solids were found to reach the unusual figure of 112.8 grains to the gallon. By a later analysis, also made for the State board of health, the total solids reached a still higher figure, viz, 125.525 grains to the gallon. The results of the last analysis are given below:

Analysis of water from well at Lima, Ohio.

Constituent.	Grains per gallon.
Calcium sulphate	49.446
Calcium carbonate	40.100
Magnesium carbonate	35.748
Sodium chloride	.231
Total solids	125.525

The unwillingness of those using steam to introduce water of this character into their boilers can be well understood, but the objections on hygienic grounds are not so strong as might appear from the record. There is but slight probability, for example, that the large percentage of common salt reported is derived from organic pollution. The presence of salt in most of our deeper rock waters is well known.

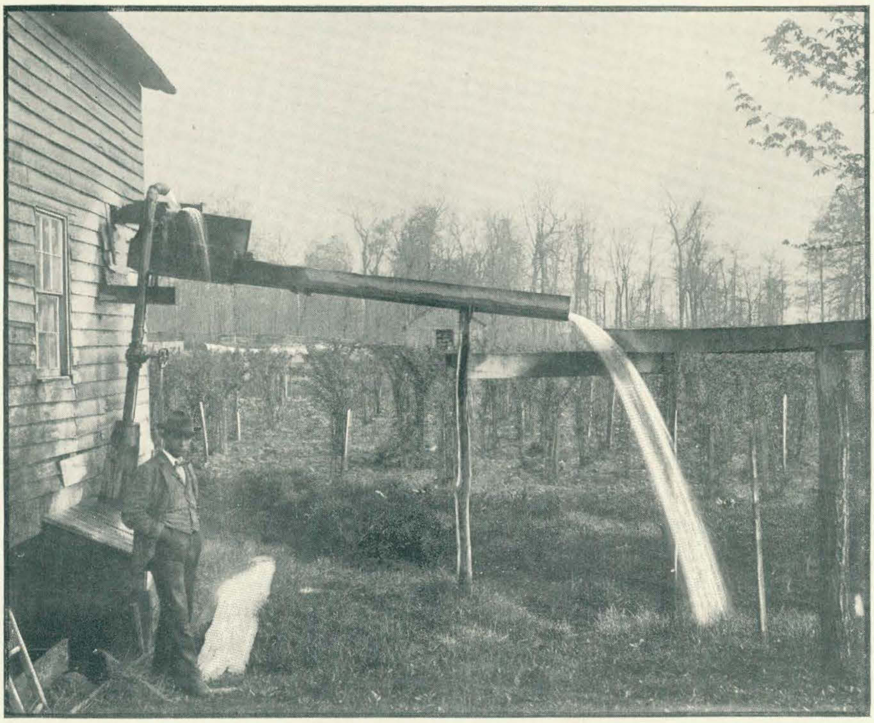
While the character of the water for steam production is somewhat improved by the largest possible proportion of surface or reservoir water, the domestic use is undoubtedly rendered less satisfactory by such admixture. The open reservoir allows a much freer development of minute forms of animal and vegetable life than are present in the city supply. This fact militates to some extent against the good repute of the water.

KENTON.

This town has made exclusive use of rock water from the first. The plant was originally put in by a private company, but the village corporation retained the right to purchase, and a few years ago exercised this right, paying $60,000 for the plant at that time. It has since expended a considerable amount upon the works.

The town is in the region of shallow drift already described. The deposits of the glacial period do not, as a rule, exceed 10 to 30 feet. The rock nearest the surface at the waterworks station is the peculiar type of the Onondaga limestone called by Prof. N. W. Winchell the Tymochtee shale. It is here thin bedded but scarcely shaly in structure. It is dark blue in color and carries many black films on the surfaces of the several layers. No fossils are apparent in this division. No other exhibition of precisely this character of rock has been reported in the numerous wells drilled in the region for oil, gas, or water during the last ten years. It proves troublesome to the driller.

An excellent opportunity to study the formation is afforded in the large well at the pumping station. The excavation is 100 feet or more



A.

B.

FOUNTAIN WELLS IN EAST UNION TOWNSHIP, WAYNE COUNTY, OHIO

A, On farm of John S. Amstutz; turns a 12-foot water wheel. *B*, At schoolhouse No. 7; 3-inch pipe.

in diameter at the surface and is carried vertically down for 25 to 30 feet; then, in the southern half of the pit, the rock was further taken out to a depth of 25 or 30 feet additional. Within the deepest area three wells were drilled, these being added to ten others in the same immediate neighborhood, all located in the valley of the Scioto River, which is but a small and insignificant stream at this place. All the wells found water at about 125 feet below the natural surface. The water appears in a fairly strong vein and is cold and clear, and the supply is perfectly steady. There is nothing to hint at any close connection of the water vein with rainfall, for in times of severest drought just as much water can be pumped as at other seasons. The average production of 450,000 gallons per diem is a little in excess of the producing power of the wells; at least, the pumps are obliged to labor constantly night and day to keep up the supply, and when, for any reason, the draft is temporarily reduced, the water is found forthwith at a higher level in the well.

To reinforce the supply, the present trustees have made trial of a field 1½ miles south of the court-house, at the Calhoun farm, on Taylor Creek. During the last year a well was drilled there to the horizon upon which the city wells depend, and a notable supply was found available, which the city engineer counted good for 600,000 gallons per diem, but the voters of the town have refused to furnish the funds necessary for bringing in the new supply. It is, however, a great thing to know that such an addition can be made to the system whenever the necessity becomes urgent. The Calhoun well is artesian, flowing with a small supply from the top of the pipe.

A remarkable flow of excellent water was struck in explorations made for gas on the McVitty farm, 3½ miles northeast of the Calhoun well. This well was begun on outcropping Niagara limestone, and draws its water entirely from this formation. It still continues to be a vigorous fountain, and the flowing water finds its way to streams that supply Findlay. A recent analysis made for the State board of health by Prof. C. C. Howard gives the following results:

Analysis of water from well on the McVitty farm, near Kenton, Ohio.

Constituent.	Grains per gallon.
Calcium sulphate	76.97
Calcium carbonate	10.29
Magnesium carbonate	18.83
Sodium chloride	.27
Total solids	106.35

UPPER SANDUSKY.

This town is supplied with water by a private company, made up mainly of nonresident capitalists. The waterworks were established in 1889. Water is taken from the Sandusky River, and from a shallow well dug into the rock by the side of the river not more than 50 feet distant from it. The well, however, receives its supply from the landward side, through what are termed "horizontal crevices." Though coming apparently from the land, the water may, of course, have been derived from the river at a higher elevation in its course. The well is 85 feet in diameter at the top, 70 feet at the bottom, and 17 feet 3 inches in depth, the lowest 3 feet only being in limestone. It is about 65 feet below the public square. No water is derived from the drift deposits which cover the limestone at this point. The drift of the valley generally consists of a foot or two of blue or drab clay, below which is ordinarily found a mass of cemented clay that seems thoroughly impervious to water. When first dug the well was tested and its daily production was found to be 500,000 gallons. Sulphur water is so common in all this region that the company feared to go lower, owing to the danger of striking a strongly impregnated vein. Before resorting to this shallow supply, two wells were sunk in the rock, one to a depth of 28 feet and the other to a depth of 80 feet. Water was found in abundance in both, but both supplies were rejected because of the large amount of sulphureted hydrogen present. Mr. John Henderson, superintendent of the works, thinks that the production of the present well has increased by 50 per cent since it was first sunk. Such a result is not in itself improbable.

Part of the water pumped, as already stated, is from the river direct, and there is no way apparent of determining the proportions that these two sources contribute to the pumps. The river water is naturally well stocked with microscopic life during the summer months, and also with small fish and the lower forms of vegetation which abound in such running waters. Strainers and filters are brought into requisition, so that comparatively little trouble results from this source.

Though sulphureted hydrogen is not found in the water supply, the results of analysis show very clearly that it has been there and that its sulphur has been converted by oxidation into sulphuric acid. A recent analysis by Prof. C. C. Howard, for the State board of health, shows the mineral composition indicated below:

Analysis of water from well at Upper Sandusky, Ohio.

Constituent.	Grains per gallon.
Calcium sulphate	170.880
Calcium carbonate	.691
Magnesium carbonate	24.576
Sodium chloride	.138

These figures show that the lime, which undoubtedly entered the water principally as bicarbonate, has been almost entirely converted into sulphate. While calcium sulphate is not unusual in the Onondaga limestone, it does not seem probable that the water obtained any large proportion of the sulphate which it carries by the direct solution of this substance. An easier explanation of its presence is at hand, as already indicated. The figures of the analysis demonstrate this view. They show an extraordinary amount of calcium sulphate, with an insignificant quantity of calcium carbonate, which latter element we know can never be absent from atmospheric water traversing limestone rocks.

The percentage of calcium sulphate is the highest yet reported from the potable waters of Ohio.

DELAWARE.

The water supply of this town is also under control of a private corporation, which began its work in 1889. Its first well was located in Olentangy Valley, about 2 miles northeast of the town. The well was 36 feet in diameter and also 36 feet in depth. The deposit through which it passed was called "black gravel," the color being due to the abundant fragments of black shale distributed among the ordinary limestone pebbles of the drift.

This well furnished, when first struck, a good supply, but when summer droughts came on its volume was reduced below the limit of safety. After an experience of several years the company determined to make trial of the rock in the immediate neighborhood of the well. Capt. C. W. Wiles, the superintendent, was led to expect success by the occurrence of a spring emerging from the rock in a small island in the river. Seeing water thus issuing from the rock, Captain Wiles was led to believe that the use of the drill would not be unavailing. The severe drought of 1895 had made some increase indispensable to the maintenance of the city supply, and drilling was therefore undertaken in the spring of 1896. The location of the well is near the plant already established. The section found in the descent is as follows:

Section of well at Delaware, Ohio.

	Feet.
Soil	6
Gravel, mainly coarse	10
Gravel and sand	4
White limestone	60
"Brown sandstone"	70
Blue limestone	4
"White sandstone"	10
Limestone	10
"Soapstone"	6
Limestone, light in color	15
Shale, black	

This series may be geologically distributed as follows:

	Feet.
Drift	20
Corniferous limestone (Devonian)	60
Onondaga limestone (Silurian)	175

Water was found all the way down. It began to rise under artesian pressure as soon as the limestone was penetrated. By the time the drill was 45 feet down the water had risen to 35 feet in the well. No important additions were made after a depth of 225 feet was reached; but as the driller's apparatus was prepared to sink to 250 feet the work was continued to that point, and even 5 feet below. A shale as black as the darkest of the Ohio shale was found at this point, and this would by itself have led to the suspension of the drilling, irrespective of the necessity imposed by the length of the cable. The so-called "sandstone" of the Onondaga column proved on examination to be, as might have been expected, magnesian limestones. The water is artesian, but the head is not more than 3 feet, and the flow is correspondingly feeble. On the application of proper tests the well was counted good for 60,000 gallons per diem. During the drought of October, 1897, the addition from this source to the drift well supply was timely and effective. The production of the well has been greatly increased by putting in an air lift at a depth of 140 feet, the air being under a pressure of 45 pounds. It increases the yield of the well so much that the pump easily outruns its capacity. After two hours' work of the pumps, an hour's interval is required for the well to recover its normal supply.

The daily average of production of rock and drift water combined for the month of November, 1897, was 277,600 gallons. The maximum monthly average for last year was 368,945 gallons.

The mineral constitution of the water is shown in the following analysis, made for the State board of health by Prof. N. W. Lord:

Analysis of water from well at Delaware, Ohio.

Constituent.	Grains per gallon.
Sodium sulphate	1.58
Potassium sulphate	0.44
Calcium sulphate	17.00
Calcium carbonate	11.00
Magnesium carbonate	11.75
Sodium chloride	0.22
Silica and silicates	1.11
Total solids	43.47

The water is used in considerable quantity by the railroads and by the electric-light company. No unusual complaint has been made against it on the ground of hardness. It is said that the rock water does not appear to be more objectionable than the drift water, but perhaps exclusive use of the former would bring ground of complaint.

MARYSVILLE.

Marysville is another town making use of water from the Onondaga limestone for its general supply, which is furnished by a private company, of which John F. Zwerner is president and manager. The company began its work about 1890. The fact that underground water was available to the town had been demonstrated by the Marysville Gas and Oil Company, organized to test the Trenton limestone in the immediate vicinity. The well was a failure as to the purpose for which it was undertaken, but an abundant supply of water was found all through the upper limestones. At 145 feet a strong vein was reached, and at 375 feet a vein highly impregnated with salt and sulphur was struck. All of this water was under artesian pressure. The vein last named was forthwith utilized by the building of a bath house near the well, and this is still maintained. The salt and sulphur water is not abundant enough to meet all the demands of the establishment. It is probable, if there were enough of this water, that it would gain a reputation as a medicinal agent in certain forms of disease. It is quite similar in composition to that of Mount Clemens, Michigan, which has become an important health resort.

The water company began its operation by drilling four wells in the drift in the valley, east of the court-house. They found water enough and proceeded to supply the town, but after several years' use it was found to be more or less impregnated with iron and perhaps to some extent with the sulphurous products previously unlocked by the so-called gas well. During the present year this first supply has been abandoned and the entire plant has been made to depend on a water vein reached in the rock at a depth of 148 feet below the surface, immediately adjoining the city wells. The drift was 88 feet, and at a depth of 60 feet in the limestone the drill dropped 3 feet, having struck one of the chambers already alluded to, which stand for pre-Glacial weathering and erosion, effected when this portion of the State was at a higher altitude. The water was found in a dark-blue limestone, which is characteristic of the Onondaga series.

The water vein found at this point proved to be exceptionally vigorous. It rose to within 8 feet of the surface, and a test of its capacity, made at the time it was finished, showed a production of 1,200,000 gallons in ten hours' time. The entire supply of the town has since been drawn from this source, the average daily production ranging between 500,000 and 800,000 gallons. The discovery is one of vital importance to Marysville and to the entire neighboring district.

An analysis of the Marysville water made by Prof. N. W. Lord is herewith appended. It is furnished by the State board of health.

Analysis of water from wells at Marysville, Ohio.

Constituent.	Grains per gallon.
Potassium sulphate	0.62
Sodium sulphate	6.45
Calcium sulphate	43.07
Magnesium carbonate	16.78
Magnesium sulphate	5.29
Sodium chloride	1.65
Alumina and iron	0.40
Silica and silicates	1.63
Total solids	75.89

Of the total solids it will be observed that 55.48 grains, or nearly five-sevenths, are sulphates, but about an eighth of these are alkaline and reduce somewhat the hardness of the water.

MARION.

The principal water supply of Marion is furnished by a private company, organized in 1890 under the laws of New Jersey, by capitalists of that State. Thus far, it has drawn the water it supplies to the town mainly from several drift wells, connected with a shallow reservoir, but in addition it has drilled five wells, each 10 inches in diameter and 200 feet deep. These wells reached the rock at a depth of 55 to 60 feet; but in the immediate neighborhood there are many thinner sections of drift reported. Some do not exceed 10 feet. Water was found all the way down, and a considerable production is promised; but the rock wells are counted as merely auxiliary to the reservoir system, and have not been fully incorporated in the plant. Mineral analyses of the water of the reservoir and the wells seem to show but little excess of total solids in the rock water above that of the reservoir. The figures apparently indicate a considerable amount of sulphates in both. The drift water is not thoroughly satisfactory to the company nor to its patrons, chiefly because of the large percentage of organic matter derived from the growth of fresh-water algæ in the reservoir, and it is probable that Marion will be obliged to follow the example of most of its neighbors and depend largely or entirely on the rock supply.

The heavy pumping of the drift wells for the city line has exhausted many of the farmers' wells in the neighborhood. The latter are, as a rule, shallow, ranging in depth from 10 to 20 feet.

BELLEFONTAINE.

This town furnishes another excellent example of missing the direct object of its search and of finding instead what is worth infinitely more. It sought for Findlay gas or Lima oil in the Trenton limestone, and would have counted itself supremely fortunate if it had found either. If it had been successful a short-lived excitement would probably have resulted, giving rise to great expectations impossible of realization, and accompanied by an extravagant advance in the price of real estate. After a few years the gas would have been exhausted, the factories established on it would have been dismantled, and the fictitious values of real estate would have gone through a painful readjustment. Thus the entire community would have slowly recovered from the effects of the speculative debauch called a "boom." If oil had been found the experience of the town would have been less unfavorable, but in any case this underground wealth would soon have been exhausted without necessarily leaving any great permanent advantage to the town.

All this Bellefontaine missed, but found instead an invaluable supply of pure water, unnoticed at the time, and forced upon its attention only by the failure of other sources of water supply, but bound to continue, now that it is discovered, through generations and centuries, and, indeed, as long as the general conditions of the Mississippi Valley remain essentially undisturbed.

In 1886 while drilling the trial well for gas, known as the Carter well from the name of the owner of the lot on which it was located, the drift deposits were found to be about 80 feet thick. At 160 feet a great volume of delightfully cool and clear water was struck, which carried, however, a small quantity of sulphureted hydrogen. It rose with great force and showed a head of pressure of at least 12 feet above the surface. The water was allowed to flow unobstructed for several months. An examination of the record of the well shows that the water was found in the Onondaga limestone, the great stratum in which so much of the water supply of central Ohio is now being found.

The town had recognized the necessity of a public supply some years before this discovery was made. In 1883 work was begun under a board of trustees elected for this purpose. They called to their aid a hydraulic engineer from northern Ohio. Under his advice their first reliance for a supply was on springs rising in the high ground to the eastward, and also on impounded water from a small stream which flowed through the town, also from the eastward. A reservoir was constructed and the town was piped. The pressure from the reservoir was 90 pounds to the square inch at the public square, and, so far as this element is concerned, it furnished ample protection against fire for the highest buildings of the town. But the supply proved far from satisfactory. It was inadequate much of the time, and in summer what there was of it was warm and offensive to both taste and smell. In short, the works proved a failure both as to quantity and quality. Consequently the sight of such a noble fountain from the underlying rocks as the so-called gas well yielded was highly appreciated, and the attempt was at once made by the waterworks trustees to reach the same source by drilling on the high ground near the reservoir to the horizon struck in the well. This well was carried down 325 feet, but water was not found in important amount. The pressure of a summer drought was upon the board, and the decision was soon reached to come down to the source of rock water already described. The gas well, so-called, was purchased by the trustees and a pumping station was established. A second well was drilled forthwith to a depth of 160 feet. The water vein struck in the first well was found also in the second, which was distant but 50 feet from the first. Analysis of the water was made in June, 1888, by Prof. C. C. Howard, of Columbus, giving the following results:

Analysis of water from well at Bellefontaine, Ohio.

Constituent.	Grains per gallon.
Carbonate of lime	8.33
Sulphate of lime	3.62
Carbonate of magnesia	5.19
Sulphate of alumina	2.92
Chloride of sodium	.42
Total solids	20.48

Professor Howard called attention to the low proportion of calcium salts in this water. The water was not so hard as most rock water, or even as much drift water. He also noted that the sulphates would protect from corrosion the lead pipes which carried it.

A second analysis was made by the same chemist during the present year for the State board of health, with the following results:

Analysis of water from well at Bellefontaine, Ohio.

Constituent.	Grains per gallon.
Carbonate of lime	20.44
Carbonate of magnesia	3.56
Sulphate of lime	3.82
Sulphate of alumina	0.00
Chloride of sodium	0.015
Total solids	27.84

The figures do not agree in all respects with those first obtained. The calcium salts are still low for rock water from this horizon, but they are 150 per cent higher than the proportions reported in the first analysis. The sulphates agree approximately in both analyses. The proportions of magnesium carbonate differ largely, and no sulphate of alumina is reported in the last result, while nearly 3 per cent is found in the first. This substance is very rarely reported in Ohio waters, and, all things considered, it seems probable that some change has taken place in this rock water, owing to the circulation given to it through the action of the pumps. Common salt is only one-third as much in the last analysis as in the first.

The present supply has seemed to meet fully all hygienic demands. Typhoid fever and diphtheria were formerly of frequent occurrence in the town, but have entirely disappeared, and in other respects the new water supply has fully approved itself.

The pumping capacity of the two wells is 1,500,000 gallons per diem, and a daily average of about 1,000,000 gallons is furnished at the present time. The railroads passing through Bellefontaine make large use of the city water. In September last the Cleveland, Columbus, Cincinnati, and Indianapolis lines used 5,000,000 gallons.

TOLEDO.

This city also comes into the present list from the fact that it has numerous artesian wells that obtain their water from the great limestone series that underlies it. These wells range in depth from 175 to 400 feet. At the present time the new ones that are drilled are generally carried from 250 to 325 feet. The earliest wells obtained flowing water at 175 feet, but the supply is not abundant. A 6-inch well, yielding 20,000 to 30,000 gallons per diem, is counted a successful well, and sometimes the production does not exceed 1,000 gallons. Since their multiplication, the wells have ceased to flow, but the water still rises about 100 feet from the horizon where it is found.

If the views already advanced as to the mode of storage of water in these limestone strata are correct, it would appear that during its pre-Glacial history northern Ohio stood at least 300 to 400 feet higher than now. The action of the atmosphere could have then taken effect on the joints of the limestone and on the material of the rock itself, which now lies far below any present possibilities of such action, for the deposits of the drift within the boundaries of Toledo are usually found to be about 80 feet thick. Many other facts, harmonizing well with the views here presented, as to the pre-Glacial action of the atmosphere on limestone rocks, have been gathered in northern Ohio.

TIFFIN.

This city has secured an excellent supply of rock water for its varied necessities, unless an exception should be made in the matter of water for boilers or steam production. Seven wells have been drilled, each of them 10 inches in diameter and averaging 260 feet in depth. They are located in the valley of Sandusky River, the bed of which consists of bare rock for several miles on each side of Tiffin. It is possible that a greater number of wells have been drilled than is absolutely necessary for the uses to which they are put, and the depth of the wells may be greater than necessity or advantage requires. Perhaps five wells 100 feet deep would produce as much water as the entire system now supplies. The quality of the water would certainly not be inferior. The wells are arranged practically in line, the extremes being 1,800 feet apart. They are connected together and the pump draws directly from them. The average demand for summer water is at present about 1,250,000 gallons per diem. When the pumping is steadiest the level of the water is found to sink in all the wells alike, and the common origin of their water is thus shown.

The present limit of depth has been maintained so as to escape the sulphur water that would certainly be reached a little lower in the series. All the facts pertaining to this underground water have been thoroughly learned in the course of the extended search for gas and oil that has gone forward in and around Tiffin during the last twenty years.

Before drilling the wells in the rock, the waterworks board seriously considered the project of going to the famous Mohawk Springs, a few miles south of the city, for its supply, but measurement showed the daily production of the springs to be but 500,000 gallons, which was altogether inadequate for the demand even at that time. The expense of piping the water from the springs would have been heavy, and this was also considered in the final determination of the question.

No analysis of the city water was obtained, but it is fair to consider it of the usual type of water from the Onondaga limestone, i. e., moderately or excessively high in sulphates and carbonates of lime and magnesia.

CLYDE.

West and north of the village of Clyde artesian wells of large production have been known for a number of years, but the water is generally charged with sulphureted hydrogen. The De Witt well, 1½ miles west, and the Durland well, 4 miles north of the village, are good examples of this class.

The village has spent $40,000 in the last few years in putting in a public water plant. It began with drift wells, and had five such wells at its disposal, when it began its public distribution. These wells are 55 to 60 feet in depth. A large reservoir was added, 15 feet square and 45 feet deep, which reached a water vein, and from which the pumps drew their supply. The water in the wells was artesian, their overflows being conducted to the reservoir above named.

In these drift wells a hard and solid stratum was found at the bottom that was counted rock by those employed in sinking the wells, but it has proved to be nothing more than a bed of cemented sand and gravel, for in subsequent work the drivepipe was forced through this stratum, and a considerable thickness of drift was found below it.

The experience referred to in the preceding statement was gained in 1896, when the waterworks trustees determined to add one rock well to the seven drift wells already in use. The rock well was carried down 230 feet, the last 10 feet of which were in the great sheet of Onondaga limestone. Water was found at the top of this stratum under artesian pressure, the water rising to within 4 or 5 feet of the surface. The entire public supply of the village has since been furnished by this well, but it does not exceed 125,000 to 130,000 gallons per diem. The drift wells draw their supply from a common source, as is proved from the action they exert on each other. When the reservoir is pumped low all the wells that supply it cease flowing.

The water from the shallow wells is counted harder than the rock water, but as no analyses are at hand we are not obliged to adopt this opinion.

BELLEVUE.

This village, like so many already named, obtains its water supply from the Onondaga limestone series, and as in so many cases already noted, it has derived its experience as to underground water from its efforts to find gas or oil while the spell of Pittsburg and Findlay were in force upon the entire State.

A shallow cover of lake sand and gravel, together with occasional patches of bowlder clay, constitute the surface in and immediately around Bellevue. The bedded rock is easily reached at many points. Creech's quarry, one-half mile west of the village, has been worked for a long term of years and on a large scale. The quarry shows a total thickness of 50 feet. The strata belong high up in the great formation with which we are now concerned, viz, the Onondaga or Lower Helderberg limestone. This rock, as found here, is exceedingly permeable, through causes that have been explained in the preceding discussions. In particular it is everywhere traversed by two sets of divisional planes, locally called "joints" and "crevices." The latter of these are described as always vertical, while the "joints" may depart to some extent from the perpendicular. There can be little doubt that the two regular sets of joints of stratified rocks are the dividing planes in this case. By reason of these open passageways, communicating freely with one another by a thousand connecting channels, Bellevue and its immediate neighborhood are provided with a very effective drainage system. All surface water is promptly carried off by excavations in the drift to the surface of the rock. The need of sewers has never been experienced here. It is also known that a strong flow of water sets through the limestone toward the lake—that is, to the northward. As will presently be shown, the village avails itself of this flowing water for a public supply, consequently it protects the region beneath which its water supply passes. The artificial sink holes above referred to are allowed by the council only to the north of the districts in which the waterworks are located.

The waterworks board of the village drilled their first well within 4 feet of the abandoned gas well. Water was found in large volume at 185 feet, but it was so strongly impregnated with sulphureted hydrogen that it was abandoned as unsatisfactory for public use. It was thought at the time that the contamination came from gas escaping from the Trenton limestone which was reached in the preceding well. But such mode of origin is not necessary. There are many nearer sources in the series that underlies Bellevue.

A second well was drilled in 1895 to a depth of 204 feet. Water was found at 60 feet, which evidently flowed to the northward, but it was thought better to go deeper. At 196 feet the tools dropped 18 inches through an existing cavity, which must stand for subaerial solution and removal at some earlier day. At a depth of 204 feet the drill was stopped and a double-acting pump was set at work for seven days continuously. The production of the well was found to be 500,000 gallons per diem, and at tho end of this prolonged test the water in the well was found 19 feet higher than at the outset. The average consumption of the town is very near the average production of the well, but impounded water is preferred for steam production in the village, and this is separately furnished. The open character of the underlying rock is well shown by the fact that in drilling very few chips are brought up. As the rock fragments are consecutively set free some current of water carries them out of sight.

CASTALIA.

The noblest fountain of Ohio still remains to be named. It emerges directly from the Onondaga limestone. It is located in Margaretta Township, in the northwest corner of Erie County, about 3 miles south of Sandusky Bay. Its highest springs are 57 feet above the level of Lake Erie. The ground rises at a fairly rapid rate to the southward, its altitude increasing 150 feet in the course of 3 or 4 miles. The fountain of Castalia, as was well shown by Newberry,[1] takes the part of a considerable stream in unwatering 125 to 150 square miles of territory which has no surface drainage. This area comprises the following townships in whole or in part: Margaretta and Groton, Erie County; York, Sandusky County; Lyme, Huron County; Thompson, Seneca County.

This underground stream bears a little west of south from its outlet. Its course is marked by numerous sink holes and caverns. The drift is shallow throughout the entire area and there are numerous exposures of thinly covered rocks. At Bellevue underground streams having a strong flow to the northward are struck whenever wells go into the rock. Near Flat Rock station, a few miles south of Bellevue, a considerable cave in the limestone has recently been discovered. It is no doubt a part of the underground chambers through which the stream that emerges at Castalia is fed.

At the points of emergence of the water and northward to the bay the surface has been filled by vegetable growths, accumulated for thousands of years, to a depth of 20 to 50 feet. Extensive sheets of

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[1] Geol. Survey Ohio, Vol. II, 1874, p. 186.

travertine have been deposited at different stages, covering square miles in extent. The travertine consists of nearly pure carbonate of lime, though the rock from which it is dissolved is almost a typical dolomite. The entire area from the emergence of the water to the shores of Sandusky Bay constituted an extensive marsh or swamp when it first came under the eye of man.

These Castalia springs were used for milling purposes for three-fourths of a century. An extensive paper factory was once in operation here, and a flouring mill later took its place.

Through these vegetable accumulations above referred to, the water rises with a strong ascending force from the underlying rock to the surface, forming boiling springs of great volume. The most notable of these springs is called the Blue Hole. It is 75 feet in diameter and about 45 feet deep. Its discharge is 5,000 gallons per minute, or 7,200,000 gallons per diem. The temperature of the water, which is the same throughout the year, is 48° F. The upper springs, from the same underground source, add about 20,000 gallons per minute, making the total outflow of the stream 36,000,000 gallons per diem. The water is exceptionally clear. A white pebble dropped into the Blue Hole can be distinctly followed by the eye until it reaches the moss at the bottom. The water is so little aerated that fishes placed in it die at once from want of oxygen.

In mineral contents the water agrees closely with the general type of waters derived from the Onondaga limestone.

An analysis made by Dr. J. Lang Cassels, of Cleveland, shows the following composition:

Analysis of water from the Castalia springs.

Constituent.	Grains per gallon.
Chloride of potassium	0.665
Chloride of sodium	.685
Chloride of magnesium	2.814
Sulphate of potassium	2.656
Sulphate of soda	.587
Sulphate of magnesia	5.986
Sulphate of lime	6.952
Carbonate of lime	57.752
Carbonate of magnesia	8.432
Carbonate of lithia	.910
Carbonate of iron	1.632
Alumina	1.842
Silica	2.089
Organic matter	.900
Total solids	93.967

The water, though spread out over many acres of land (13 acres) and nowhere except at the springs more than a few feet in depth, never freezes. The streams flowing from these sources were known in early times as cold creeks, the several subdivisions of which received different designations.

Advantage has been taken of late years of these cold and clear waters to establish trout preserves. Two companies are now established here provided with clubhouses, cottages, etc.

The Castalia Trout Club Company owns 104 acres of land, having bought up the old mill site and removed the structures formerly placed there. It has led the water through its grounds by tortuous channels, some of them 15 or 20 feet wide, and has thus secured a total length of 6 miles of stream within its boundaries. Pools, rapids, and cascades abound along the course of the stream and prove excellently adapted to the habits and dispositions of brook trout (*Salmo fontinalis*), with which the waters have been stocked. Fresh water crustacea and small fish abound, which furnish a natural food supply for the trout, and all conditions prove excellently adapted to its full development, although it is not native to the waters of Ohio.

CORNIFEROUS LIMESTONE.

The formation now to be considered is of small importance as a source of water in Ohio, mainly because of its comparatively small area. Furthermore, its natural cover in the rock series is the Ohio shale, which is an impervious formation when any considerable amount remains. We have, however, a few instances in which flowing waters and generous springs issue from this sheet of limestone, but no instance of its use as a source of public water supply occurs in the State so far as known.

COLUMBUS.

In a small district of this city several flowing wells drilled to the horizon here indicated have been struck. The water in them is strongly impregnated with sulphureted hydrogen, but it is not certain that this feature is due to the limestone. In fact, it is rather probable that the sulphurous character of the water is derived from the thin band of shale overlying the limestone. The drift of the immediate region also abounds in fragments of shale, and particularly in the pyrite nodules of this formation, which, being harder than the rock that originally inclosed them, have survived while the shale has perished. The wells in question are all located on West Mount and Main streets, near the intersection of Canal and Water streets. There are four wells to be counted in this series, the first one having been drilled in 1884 and the others within two or three years thereafter. They belong to Schaweker Bros., tanners; T. Lewis & Sons, tanners; The Columbus Soap Works, and Hardesty Bros., millers.

All these wells appear to reach the same horizon of water, though the difference in their production is large; but the production of one affects the rest to a considerable extent. It has been impossible to get the exact records of the drilling on account of the interval since they were put down, but it seems fairly well settled that all of them penetrated a thin bed of the Ohio shale at a depth of about 100 feet below the surface before striking the limestone, and that the principal water vein is met a few feet below the surface of the limestone. In the Lewis well the greatest supply comes from 132 feet. The water has a constant temperature of 52° F., and on this fact its most important uses depend, viz, for the condensation of steam in the flouring mill and for preserving hides in the tannery in the warm weather of summer.

The water is so rank with sulphureted hydrogen as to be disagreeable to many, but by others it has been counted medicinal in its effects, and for a time it was regularly sold through the city from a wagon employed for this purpose.

Before getting down to the sulphur water other water veins were struck in drilling through the drifts; but only the rock water proved artesian, and its flow shows but a comparatively slight head of pressure. The Hardesty well is a particularly strong one.

In the northern part of the city there are several flowing wells from the drift, the most vigorous of which is one drilled a year ago at the corner of Eleventh avenue and Fourth street. The well is shallow, but its original volume was large. It yields the ordinary quality of the drift water of the region. The Ohio shale lies but a few feet below the surface here, and the ground rises to the eastward with a considerable grade. The natural drainage is westward, and a large body of water is moving in this direction upon the sloping surface of the shale and through the drift that covers it, when the latter consists of gravel. There is no apparent chance for this water to secure adequate purification if once seriously polluted; but, flowing from the well as it does with a strong current, it impresses those who see it as coming from a deep source, and therefore as possessing all the characteristics of rock water.

A fine spring enters the Scioto River from the westward a few miles below Columbus. It is known as the Wyandot spring, tradition connecting it with the Indian occupation of the country a hundred years ago. This spring shows all the characteristics of a limestone spring. It emerges from the joints of the Corniferous limestone, duly widened by solution. There is but a shallow cover of drift in the immediate region. Undoubtedly, if we could follow back this vigorous flow to its source we should find a considerable underground stream, draining a large territory, receiving tributaries from both sides, after the fashion of surface streams of like volume. The Scioto River is known to receive notable accessions to its flow from sources like this.

Some of the water referred to this stratum may properly be referred to the Ohio shale, immediately overlying, since it is affected by its contact with or stay in that formation.

OHIO SHALE.

It is only at the junction of the great shale stratum with the Devonian limestone that any considerable production of water can be referred to the formation named above. Water finding its way through the lower beds of the shale attacks and dissolves the underlying limestones to a greater or less extent, and when the conditions are favorable large springs appear at this horizon.

An excellent example of these conditions can be seen in the well-known sulphur spring 6 miles above Worthington, in the Olentangy Valley. The spring comes in from the eastward. It has a strong flow, and the water is heavily charged with sulphureted hydrogen. A white precipitate of sulphur discolors the Olentangy River for about a dozen rods below the point where the spring enters the river.

The famous spring of the Sunfish Valley, in Pike County, known as Campbell's spring, comes under this head; that is, it emerges from the rock just at the junction of the shale and limestone. The limestone at this point is not, however, the Devonian limestone, but by overlap the shale here rests on the Onondaga. The shale from under which this spring comes to light rises into uplands 300 to 400 feet above the valley level. The spring has volume enough for a mill stream when it first comes to light, but it is too near the level of the valley to give the necessary head. Some years ago an attempt was made to obtain mill power from it by confining it in a water tower built of stone for this purpose; but as soon as a foot or two of head was reached in the tower the stream burst out in a new place 50 to 100 feet above its old point of escape, rendering all the work done futile.

The water of Campbell's spring is not sulphurous, and its character has not therefore been affected by the overlying shale. It is probable that the traditions of the neighborhood in regard to the spring are well founded, viz, that it has its origin in a surface stream flowing in a valley several miles westward which disappears abruptly, passing out of sight in the upper beds of the limestone. The quality of the water and the general conditions of the spring agree very well with this explanation.

In a well drilled 100 feet into the Ohio shale, near the center of the village of Worthington, a small amount of water was found, but it was too highly mineralized to allow its use as a potable supply. The mineral content of the water was principally sulphate of alumina, but the percentage was not determined. Iron is always present in large amount in this shale water. Water is also found in the great shale formation when the latter is overlain by considerable deposits of drift, as in the extreme northwestern counties of the State. In such cases the water carries notable quantities of common salt, as a rule. In numerous instances the quantity is so large as to make the water unsuitable for use as household supply or as stock water.

WAVERLY GROUP.

No characteristic quality or condition has been noted in any of the strata composing the Waverly group, so far as the water supply is concerned, except in a single instance to be noted later. The entire group is poor in water. In large areas, in which the lowermost and middle elements make the surface rocks, there is an almost complete lack of water, as shown in springs. In summer droughts such regions become almost uninhabitable for man and beast, except as rain water has been previously stored by artificial means.

MEDINA.

A single public supply is found in the upper portion of the Cuyahoga shale at Medina. The drift water of this region is excessively hard, and consequently gives much trouble to those who use it in steam boilers. To secure a supply that would relieve them from this difficulty has been an object of resolute search on the part of a few manufacturers in the town, among whom Mr. A. I. Root has been especially active and enterprising. In this search Mr. Root has drilled seven wells at his own expense, the wells ranging in depth from 25 to 160 feet. He found that it is only by effectually shutting off the water derived from the drift that the character of the rock water can be recognized.

When, eight or ten years ago, all the enterprising towns of Ohio entered on the search for gas or oil in their immediate neighborhood, a small supply of water, differing in quality from the water in the drift, was struck in the trial well that was drilled at Medina in this interest. The gristmill located near the well availed itself of the discovery and found the water well adapted to boiler use, although it is somewhat saline. The rock water of the entire region has, however, this character. But after learning the experience of the mill in obtaining water free from lime salts, Mr. Root determined to further test the rock on his own ground at the horizon which had been already developed. He was rewarded by a moderate yield of water that was free from lime, the surface and drift waters having been carefully excluded.

Influenced by this experience, the village decided, in 1895, to establish a public water supply, and up to this time it has invested about $7,500 in its plant. Two wells, 8 inches in diameter, were drilled in the valley near the original trial well and near the mill. The drift at this point is but 10 to 12 feet in thickness, and at 40 feet, in a sandy shale, a moderate water vein was struck; and again at 80 feet a vein that was counted excellent was reached. The pumps were set to work upon the supply and the yield of the new well was estimated at 90 barrels an hour, but at present its production is found on steady pumping to be about 70 barrels an hour, which is at the rate of 53,000 gallons a day; but as the pumps run only fifteen hours out of the twenty-four, the present production does not exceed 35,000 gallons a day.

The water is popularly called "soda water." It corrodes iron pipes when reaching them in contact with the atmosphere, but in boilers it works very satisfactorily. When used for sprinkling the streets it leaves a white crust on evaporation. It is also used as potable water, but with scant favor. The State board of health, after a chemical analysis, gave it approval, though rather grudgingly. So far as the hygienic indications were concerned, there was nothing to condemn the water, aside from the large percentage of common salt, but as this is known to be a constant product of the rock water of the region, no unfavorable conclusions were drawn from its presence. The unusual percentage of total solids naturally attracted attention, but as they were found to be referable neither to temporary nor permanent hardness, but principally to sodium sulphate, the water was not condemned. It is found by experience, however, to be unwholesome when used as a regular supply for drinking water. The total solids in the two analyses were found to be respectively 243 and 238 grains to the gallon, while the chlorine in the first analysis showed 33 grains to the gallon, and in the second 69 grains to the gallon. Of the total solids, common salt constitutes, as is seen, an important part.

The Medina water is thus seen to be a distinctly alkaline water, and this fact accounts for the approval it receives for boiler use. The discovery is one of great importance to a number of counties in northern Ohio, in which drift water is now exclusively used in boilers. The constant expense for chemicals to destroy the scale and the frequent interruption of business in getting rid of the obstructing products, together with the shorter life of the boilers themselves, make the discovery of soft water—for such, practically, alkaline water is—an important desideratum. Parts of Trumbull, Geauga, Cuyahoga, Wayne, Ashland, Richland, and Holmes seem to be included in this list.

As already noted, the ordinary wells in many parts of Medina County, and particularly to the south of the county seat, carry a notable amount of common salt. In a few cases it is found necessary to reject the water on this account.

A well drilled by the Electric Light and Power Company of the village, a little west of the wells already described, found water of the same quality at the same horizon, but obtained a much more abundant supply.

A third analysis recently made by Prof. C. C. Howard for the State board of health gives the following somewhat surprising results:

Analysis of water of well at Medina, Ohio.

Constituent.	Grains per gallon.
Sodium sulphate	288.70
Sodium carbonate	62.88
Magnesium carbonate	0.42
Calcium sulphate	3.05
Sodium chloride	6.066
Total solids	361.12

Water such as is here shown differs in a marked degree from any other water known in the State. Its alkaline quality is pronounced. It will also be noted that the total solids greatly exceed in this analysis even the high figures previously reported.

ORRVILLE.

It seems necessary to refer the excellent water supply of Orrville to the Logan sandstone, which is the conglomeratic phase of the Waverly group, though some doubt may exist as to whether the water is derived from the Waverly conglomerate or from the first pebble rock that overlies it, namely, the Sharon division of the Carboniferous conglomerate. On the whole the reference here made seems the more probable.

The Logan conglomerate is a less important element in northern than in central Ohio, but it is generally a porous rock made up of coarse sand in which pebbles, often of large size, are embedded. It is a water-bearing stratum wherever found at the surface. It forms a prominent shoulder of high ground in Richland, Ashland, and Wayne counties, which had a very important effect in arresting the advance of the ice sheet in this part of the State. Because of its resistance to degradation, and its consequent high altitude, the glacial boundary makes nearly a right angle here, changing its direction from west to nearly south. A physical model of the State brings out the cause of this abrupt deflection in a striking manner.

Within the last four years Orrville has adopted a public system of water supply, and its experience has been thus far favorable in all respects. The work has been carried forward efficiently and economically, and the entire population shares in the advantages that an excellent water supply gives to a town. At the outset of their labors the trustees tested the public square of the village, hoping to find a centrally located supply available. A well was drilled 150 feet deep at this point, but though water was struck in both drift and rock, no flow was obtained, and, since fine flowing wells are common in the region, the well was consequently counted a failure. They next turned their attention to the low ground north of the center, where on several previous trials made by the neighboring farmers excellent fountains had been obtained. Two acres were purchased here. These constitute a part of the old lake bottom that gives rise to so much excellent garden land around Orrville. The altitude of the ground purchased is about 1,025 feet above tide, or 35 feet lower than the railway crossing to the southward. Four wells were drilled here from 102 to 158 feet in depth. The wells were 8 inches in diameter when begun, but were afterwards reduced to 6 inches. The cover of drift was found to be about 30 feet thick. When the rock was reached water was at once found, but the amount increased as the drill descended. Perhaps the drilling was continued after the full increase of the supply had been reached. None of these public wells show a remarkable production, but one of the number yielded for six weeks 125,000 to 140,000 gallons per diem. The four wells are connected now and the maximum production thus far has been 225,000 gallons in twenty-four hours. The severe drought of the autumn of 1897 seems to have had a temporary effect upon the production of the wells. The character of the water is not in full accord with its sandstone origin. It has obtained some mineral matter from the drift through which it must have passed into the rock. An analysis made by Prof. H. A. Weber of the Ohio State University gives the following results:

Analysis of water from well at Orrville, Ohio.

Constituent.	Parts in 1,000,000.
Organic matter	7.44
Chlorine	9.00
Mineral matter	285.00

This is equivalent to 19.95 grains to the gallon. Professor Weber remarks in his report that the Orrville water is chemically one of the best drinking waters he has examined in the State. In boilers it forms a thin scale, but gives less trouble of this kind than most Ohio waters. The railroads passing through Orrville approve the water and make large use of it for their locomotives.

Mr. D. F. Griffith, who has a flouring mill on the east side of the corporation, has drilled a well which obtains its water supply from about 100 feet below the surface, and flows 31 barrels per hour. The total depth of the well is 150 feet.

Mr. Henry H. Forrer has a fountain well obtained at a depth of 72 feet, 1½ miles east of the village. Most of the flowing wells of the neighborhood show a pressure head of 10 to 12 feet. In the Forrer well but 10 feet of drift was found above the rock. A conglomerate stratum crops out near the well, which is referred to the Sharon conglomerate by the former geological survey of Ohio, but this reference does not decisively settle its character.

EAST UNION.

In some of the townships south of Orrville, and notably in East Union, there are several artesian wells, and some of them are of remarkable character. They are well represented by the fountain of Mr. John S. Amstutz, who resides 6 miles southwest of the village of Orrville. (See Pl. LXXIII, *A*.) Twenty years ago he drilled a well to the depth of 120 feet. The drift was but 12 feet thick, under which the Cuyahoga shale was reached. He continued in this formation, known as "mud rock," for 108 feet. At a depth of 99 feet he struck a notable vein of flowing water, which rose to a head of 24 feet, a fact unprecedented in this

State so far as my knowledge goes. The head has since been reduced to 14 feet. The original production of the well was 6 barrels a minute, or at the rate of 250,000 gallons per diem. The water originally rose with such force as to throw out stones 2 or 3 inches in diameter.

The happy thought occurred to Mr. Amstutz to utilize the power of this surprising water head. Accordingly he constructed a water wheel 12½ feet in diameter, to which the waste of the flowing well was conducted. By means of this power he grinds feed for his stock and executes other mechanical work appropriate to the needs of a farm.

A notable fountain is also found in a well drilled for schoolhouse No. 7, East Union Township, 7½ miles southwest from Orrville. (See Pl. LXXIII, *B*.) The well is 89 feet deep, and its flow completely fills a 3-inch pipe. Its splendid production makes it well known throughout this part of the country.

NEW LONDON.

This village has no public water supply and a comparatively small number of satisfactory private wells. The latter are either shallow drift wells or deep and expensive drilled wells, the latter operated mainly by wind pumps. Of deep wells the number is small.

The drift beds in the village and in the immediate vicinity are generally heavy. Sections of at least 100 feet of bowlder clay are of usual occurrence, and these are often dry from start to finish, particularly after 10 or 15 feet of the uppermost beds have been passed.

The first bedded rock to be reached below the drift is the Cuyahoga shale, but as this is for the most part destitute of water the Berea grit constitutes the objective point of the driller. The upper portion of the Berea is found to be moderately productive of potable water, but salt is generally found in the water when the drill is continued to the bottom of the sandstone formation. Occasionally, however, the Cuyahoga shale assumes a sandy character and yields an acceptable supply for a farm, including domestic use and provision for stock. Such an example is to be found on the farm of Mr. A. Crittenden, a little east of Ruggles Corners.

In the village the well of Mr. George E. Washburn may be taken as a representative of the deep wells of the vicinity. He found 105 feet of drift, casing the water off to that depth. Below this there were but 60 feet of Cuyahoga shale, the balance of the formation having yielded to preglacial waste and glacial erosion in past time. At 150 feet the Berea shale—the band of black shale that directly overlies the Berea grit—was struck. Of this the usual thickness—15 feet—was found, and at 165 feet the surface of the Berea sandstone was reached. The uppermost 20 feet of the stratum were moderately coarse in grain, and water appeared in it in fair quantity. As the drill descended salt water came in. The work was continued until a total depth of 235 feet was reached. The entire thickness of the Berea was penetrated and possibly a few feet of the underlying Bedford were included in the well section. If all the rock below 165 feet is assigned to the Berea grit its thickness here is 70 feet.

This well is a failure as a source of domestic supply, and also for stock water, though horses will drink it when very thirsty. If the drill had been stopped at 185 feet the well would in all probability have been at least moderately successful.

The Arnold well, also located within the village limits, reaches the Berea grit by a section very like the one already described, but does not penetrate the entire stratum, and thus furnishes water of acceptable quality. The wind pump connected with it will fill a 200-barrel tank in about fifteen hours.

North of the village salt water in wells has not been reported as troublesome.

Mr. D. W. Smith, of New London, is the reliance of this entire district in the matter of drilling wells. He has made himself thoroughly familiar with the underground geology of the region, and his observations are of great interest and value. He has come to believe that the water question is steadily becoming a more difficult one for this part of the State, because of the drying out and consequent hardening of the great sheet of bowlder clay which covers the country. He claims that an increasing percentage of the rainfall escapes in the run-off. I am not prepared to express an opinion on this question.

CARBONIFEROUS CONGLOMERATE.

The group of three great sandstones now to be considered has a much more important relation to water supply than the formation last discussed, although the present group does not equal in volume the preceding one.

The lowest stratum is the Sharon conglomerate, which is often a white and pebbly sand of great purity. Near Youngstown, in Trumbull County, it occurs in fine development as a surface rock. Quarries have sometimes been opened in it. The stone from which the fine residence of the late Hon. Chauncey Andrews was built was derived from this source. This stratum probably takes part in the water supply of more than one town in northern Ohio, but the only case in which the public supply can positively be referred to it is that at Massillon.

MASSILLON.

A private company holds the franchise for supplying this thriving and important city with water. It is known as the Massillon Water Supply Company, the principal stockholders being eastern capitalists. The present company bought out an older company in 1887, paying $80,000 for the franchise and plant. Up to the present date the company has made a total investment of about $300,000.

The original company obtained its water supply from Sippo Lake, and this proved unsatisfactory to the people of the city in every respect. It had all the disadvantages of an inadequate surface supply.

In 1890 the present company undertook to find a new and approved supply, and in this interest drilled a 6-inch well in the valley west of the town. It found 73 feet of drift at this point. The first rock reached was a pebbly sandstone, which is referred with confidence to the Sharon horizon. This stratum seems to have continued, with but slight changes, to a depth of 200 feet. The drill was kept at work for a further depth of 60 feet, but no new stocks of water were reached after the sandstone was passed. The rock in which the water was found was popularly identified with the Massillon sandstone, but this identification is certainly erroneous, for the great Massillon quarries rise 75 to 100 feet above the river not more than 1,000 feet distant from the location of the well, while the water-bearing sandstone is not reached until the drill has descended 60 feet below the same level.

The supply of water from well No. 1 has proved generous. For three years it was made to yield 500,000 gallons daily. The water betrays contact with other formations than the sandstone, as the following analysis shows. The results of the analysis seem to stand for careful work, but I was unable to find where or by whom the analysis was made, except that it is credited by the company to Professor Smith.

Analysis of water from well at Massillon, Ohio.

Constituent.	Grains per gallon.
Potassium sulphate	0.13
Sodium sulphate	1.16
Sodium chloride	.76
Sodium phosphate	Trace.
Calcium sulphate	.79
Calcium bicarbonate	12.65
Magnesium bicarbonate	5.47
Alumina	.005
Silicic acid	.59
Iron bicarbonate	.06

That the water comes from a more elevated situation is apparent from the fact that it begins to flow as soon as the sandstone is struck. It attains a final head, however, of but 5 feet above the well mouth. A temperature of 52° F. is maintained throughout the year. The analysis shows a considerable amount of temporary hardness, expressed in the analysis by 18.12 grains of calcium and magnesium bicarbonates to the gallon. Some complaint is made of this by persons using the water for steam production. Local changes in the rainfall of the region do not seem to affect the production of the well.

In 1893, 4 acres of ground in the river bottom and adjacent to the location of well No. 1 were purchased, and five new wells were drilled here. All are 6 inches in diameter and 200 feet deep. Well No. 2 found 60 feet of drift, while in another but 12 feet were found, and in a third location the drift was penetrated to a depth of 150 feet without reaching bottom. The location was on this account abandoned.

It was at first proposed to place all the wells near together to secure the greatest economy in pumping, but after four were sunk it became evident that the wells affected each other, consequently longer distances were established between the wells already drilled and the two remaining. Well No. 5 was located at least 600 feet from the nearest of the old wells, and well No. 6 about 1,000 feet from any other. The quality of water from all the wells is counted identical, but the several wells vary to a considerable degree in their production. Where the grain of the sandstone grows finer the production is correspondingly diminished.

The capacity of the system has never been fully tested. The maximum production reached thus far is 1,000,000 gallons per diem.

The water seems to meet all hygienic demands. Not a single case of typhoid fever is known to have occurred where the city water has been exclusively used. This scourge is not of rare occurrence in parts of the town which depend on wells or other local supply.

At the grounds of the new asylum, 1½ miles south of the court-house, two 6-inch wells have been drilled to a depth of 250 feet. They yield a good volume of water, but it does not rise higher than 190 feet in the pipes, which is 60 feet below the surface. The water has not been analyzed, to my knowledge, but for some reason it was reported as distasteful to the workmen employed in the construction of the buildings.

CUYAHOGA FALLS.

This village has thus far provided no public water supply, but nevertheless it relies almost entirely upon rock water. The Sharon conglomerate appears in great force in this region, and the Cuyahoga River has cut a post-Glacial valley through it, 50 to 100 feet deep, providing everything that can be asked in the way of natural sections. Thin layers of clay are occasionally interstratified with the pebble and sandstone beds, and some of them are persistent enough to make local water-bearing horizons. There seems to be one of these horizons about 60 feet below the general level of the village, to which the private wells which supply most of the people with water are generally sunk.

Throughout the entire territory, but particularly in the higher portions of the valley, beds of drift are found which sometimes reach a thickness of 50 to 75 feet, but do not often exceed 30 feet. They consist largely of sand, derived from both the Glacial and pre-Glacial waste of the great conglomerate ledge which makes the surface rock of this entire district. Deposits of clay carrying more or less calcareous matter are, however, occasionally found in the drift series.

Springs are of frequent occurence along the natural outcrops, or sections rather, of the conglomerate. One of fine volume is almost central in its location. The water of most of them contains lime, though not in large amount. The springs undoubtedly derive this element from the drift beds through which almost all even of the sandstone water is obliged to pass.

Well-considered plans for a complete water supply for the village, prepared by a competent and experienced engineer, Mr. John Paul, have already been approved by a majority of three to one on a popular vote. It is probable that these plans will be carried out in the immediate future.

CARBONIFEROUS SYSTEM.

The water supply of the large and varied rock system that we are now to consider stands by itself in this respect, viz, that while heavy beds of sandstone, some of them coarse and conglomeratic, which would serve an admirable purpose as reservoirs, are included in it, the system contains so many impervious beds, in layers and bands of fire clay and in strata of shale and limestone, that no adequate provision is found for filling the reservoirs, or, at least, for constantly replenishing them where they are made the basis of a public water supply. For this reason, the entire series must be pronounced poor in rock water. Supplies for dwellings and farms can be secured almost everywhere, and in the majority of instances the character of the water obtained is all that could be asked, but any considerable and growing towns that are located within the boundaries of this formation, if forced to rely on rock water, are confronted with a difficult problem in the matter of an adequate supply. Illustrations of the facts involved will be found in the few instances in which the trials have been already made.

It is to be further noted that the towns nearest to the boundary of the formation are more favorably situated in this respect than those that lie well within the Coal Measures, for upon the boundary uncovered areas of the great sandstones that belong in the series are more likely to be found.

It is also to be observed that the drift beds, which are the great storage basins of the rainfall for such portions of the State as they occupy, are entirely wanting over most of the Carboniferous territory. The proximity of the glacial boundary, with its beds of drift, serves much the same purpose as the outcrops of the sandstones.

On the other hand, most of the cities and larger villages situated within the Coal Measures find easy access to the great waterways of the State, and have it in their power to obtain ample and, by the use of adequate systems of purification, safe water supplys from the rivers in the valleys of which they are situated. In such a list are to be found Youngstown, East Liverpool, Steubenville, Bellaire, Pomeroy, Marietta, Ironton, Zanesville, and Coshocton—in other words, the principal towns in the Ohio Valley and on Muskingum River, the largest tributary of the Ohio.

CANTON.

This town, while well within the Coal Measures, lies upon the main terminal moraine of the State, and derives considerable advantage in respect to its water supply from this fact. All the territory to the northward of the city is drift covered, and heavy deposits of gravel and gravelly clay are common here, from which small lakes and spring-fed streams derive their waters. The streams that run through Canton are the several forks of the Nimishillen, which is an important tributary of the Tuscarawas River, but these take more or less drainage from coal mines and clay works, and also from the farming districts through which they pass. Certainly the water which they bring to the city is more or less impure and unsatisfactory. Along two of the main branches of the Nimishillen, above the town, swamps of considerable size occur, and when the water question was first discussed by the city these were believed to be underlain by considerable deposits of drift gravel, from which it was thought that water could easily be obtained in large amount. The results of exploration have not justified these expectations.

Eight years ago necessity compelled the city to act in the matter of public water supply. Attention was first turned to the nearest of the swamps already alluded to, viz, that on the west fork of the creek, about 2 miles above the city limits. The record of the drilling at this point showed 6 feet of black muck, 5 feet of clay, and but 4 feet of sand and gravel, below which the bed rock was struck.

The first stratum reached was the well-known Lower Mercer limestone. It was 3 feet thick, and next below it came 60 feet of shale, called "slate" by the driller. Then 50 feet of sandstone occurred, in which a moderate stock of water was found. Another and heavier deposit of shale was next recorded, below which a second sandstone of the same thickness as the first, viz, 50 feet, was met, and, like the first, carried a stock of water. The first well was carried to a depth of 365 feet, but no additions to the water supply were made below 275 feet, and consequently all the subsequent borings were limited to this depth. The water rose under artesian pressure, but did not flow from the surface of the trial well.

Thirty-five wells have since been added to the first, the record of which has been partially given above. They all strike the water horizons reached by well No. 1. In all, artesian pressure was manifest, and in four of the number the water flowed from the well mouth, but in a feeble stream. The head of pressure in no case exceeded 2 feet.

These wells are divided into two groups, viz, 6 in the northern part of the field and 28 in the southern part; but their total production does not exceed 1,000,000 gallons per diem, which is an average of less than 30,000 gallons to the well. But this amount is only one-third of the demand of the city. Consequently, two-thirds of the supply is drawn from the raw water of the West Branch. The character of this water has been already noted, and by its admission to the city supply the quality of the whole is unfavorably affected.

The rock water is known as "race water," because it comes to the pumping station through an old mill race. The yield of the wells does not appear to have been reduced since they were first drilled; but as the city has been growing rapidly meanwhile, the supply has become inadequate, and its inadequacy becomes more and more noticeable.

The waterworks board has recently been considering an increased supply of water of the best available quality, and has directed its attention to the Middle Fork of Nimishillen Creek. The drainage area of this stream is 45 miles, against 35 square miles for the West Branch. It was also hoped that larger deposits of gravel would be found in this valley than in the valley to the westward. Two wells have been located in the new field, but the results of the exploration have thus far been in some respects disappointing. The bedded rocks were found at a like shallow depth, as in the western valley. The sections of two drift wells are as follows:

Sections of wells in the valley of the Middle Fork of Nimishillen Creek.

Material.	No. 1.	No. 2.
	Feet.	*Feet.*
Sand and gravel	14	19
Sand rock	10	8
Shale	49	48
Sand rock	48	55
Total	121	130

The lower sand rock proved in both wells to be a much more vigorous source of water than the sandstones of the western wells. In both there is an artesian head of 6 feet, and on a pumping test, continued for several hours, well No. 1 produced 150 gallons per minute, and well No. 2, 240 gallons per minute. These figures are at the rate of 216,000 and 345,000 gallons per day, respectively, or nearly ten times the production of the first series of wells. The water in the casing was lowered by the pumping test a few feet, but in well No. 2 it flowed again from the wellhead twenty-two minutes after a test of three hours had been completed. This source has not yet been added to the city supply, but it is full of promise in this regard.

The waterworks and sewage-purification plant of the city are under the charge of Mr. L. E. Chapin, city engineer, who has an excellent reputation throughout eastern Ohio in these lines of work.

The experience of Canton is typical and representative for the Coal Measure territory, except that the production of the Middle Fork wells is better than most towns have reason to expect.

LOUISVILLE.

This village is small, but it has wisely provided its people with public water. Two wells have been drilled, 114 feet in depth and 6 inches in diameter. They have proved eminently successful in every respect. They are found to yield 750,000 gallons in twenty four hours, and the quality of the water is approved. The village lies within the drift area of the State, and doubtless receives some advantage from this fact.

CARROLLTON.

From Mr. L. E. Chapin, who constructed the works for this village, it is learned that five wells have been drilled for public supply, each 100 feet deep and 10 inches in diameter. The surface deposits in the valley, where the wells were sunk, were found to be 40 feet thick. The best of the wells has been found to produce 7,000 gallons an hour, which is at the rate of 168,000 gallons a day. But pumping at this rate makes too heavy a draft upon the stock of rock water, as is seen by the rapid reduction of its level in the pipes. The wells obtain their water from the sandstones of the Lower Productive Coal Measures, and presumably from the Kittanning sandstones. The water in these wells rises under artesian pressure but does not flow.

CADIZ.

The following facts as to the public supply of Cadiz have been gathered from the report of the State board of health for 1895:

The village water works were established under the direction of Mr. L. E. Chapin, consulting engineer.

Five wells have been drilled for the public supply to a depth of 212 feet. The wells are of different diameters, one being 8 inches and the others 5⅝ inches, which is the usual size of oil wells. The average production of the system is about 250,000 gallons per diem. But this amount is somewhat in excess of the natural production of the rocks, as is shown by the fact that the level of the water is drawn down fully 100 feet.

COLUMBIANA.

This town introduced a public water supply in 1895, an account of which is given in the report of the State board of health of that year. The wells are 72 feet deep, the uppermost 22 feet of the section being unconsolidated materials and the lower 50 feet being in sandstone. The water rises in the wells to within 4 feet of the surface. In tests that have been made the production of a single well has been found to be a little more than 3,000 gallons an hour, which is at the rate of about 75,000 gallons a day. The sandstone from which the water is derived is some division of the Lower Productive Measures.

FLOWING WELLS.

PRELIMINARY STATEMENT.

As stated in the introductory paragraphs of this report, only those flowing wells of the State are to be treated here that are found in considerable areas, that derive their water from a considerable depth, and that have also considerable head of pressure. To render these qualifying terms serviceable it becomes necessary to specify more particularly what they severally cover. The areas to be considered will range from 5 square miles upward, the largest probably not exceeding 25 or 30 square miles. The head of pressure in the regions to be reviewed is seldom less than 5 feet, and is often several times this amount. The depth of the wells generally ranges between 50 and 250 feet, but in a few instances account is taken of wells of even less than 50 feet.

The wells of the class now to be discussed belong entirely to the drift. It is true that some of them derive their water from the uppermost beds of deeply buried rock strata, but it is mainly the arrangement and disposition of the drift beds, after all, that gives the artesian character to these fields.

The facts as to the actual elevation of the rocky floor of the State in the regions which have been overrun by the glacial drift are of great interest. They involve the large questions of the pre-Glacial drainage systems of large parts of Ohio, and thus lead us to some surprising and unexpected conclusions. The work of investigation is still going on, but it seems to be already established that the Ohio River, as we now know the stream, is of recent origin, and that the main volume of water gathered in it at the present time originally flowed across the State to the northward as far at least as Auglaize and Mercer counties, where it turned to the westward, toward the present lines of Wabash drainage in Indiana. The facts that support such a conclusion, so far as central and northwestern Ohio are concerned, have been principally accumulated through records of the deep wells drilled for oil and gas during the last twelve years. Wells have been sunk by the hundred in the regions referred to, and if the facts as to the thickness of the drift had been carefully recorded as discovered by the driller, the records would have proved of priceless value to the geologist. As it is, multitudes of these records have been lost beyond recovery. The great oil companies, however, have kept records that are even now available, and for many hundreds of wells, located accurately so far as the particular fraction of the quarter section in which they were drilled is concerned, we can learn the exact thickness of the drift. The drilling of water wells has in some cases added valuable facts to this series, as will presently appear.

It is becoming increasingly evident that connected investigations are necessary for the final determination of these questions. But inasmuch as the discovery of the particular localities where the rocky floor has been deeply eroded is altogether haphazard and accidental, depending on the caprice of the driller in locating his wells, the exact courses of the old drainage systems can not be settled at present. It is not too much to expect, however, that their general direction can be made out with a good degree of confidence. What is needed in this connection is a model, or at least the data for a model, of the rocky floor of the State. In the region where drilling has been carried on most largely sufficient data are already available for this purpose. The elevations of the rocky floor above tide can be determined for many consecutive miles, and the general direction of the old valleys can thus be clearly established. The State could do no better work in connection with its geology than to make use of all accessible data of this kind at once in constructing a model of the rocky floor of northwestern Ohio.

It is possible, however, that the question may be complicated by recent warpings of the earth's crust. We know that in New York and Ontario, at least, there has been considerable differential movement of the surface since the disappearance of the glacial ice.

FLOWING WELLS OF NORTHWESTERN OHIO.

The best-known fields of flowing waters within the State are to be found in its extreme northwestern corner, viz, in Williams, Defiance, and Fulton counties. Several subordinate divisions of this flowing-well territory are to be recognized, one including Bryan, another Hicksville, a third West Unity, while still other districts are to be found in the southeastern and northwestern townships of Fulton County. Several minor divisions will also be discussed. Whether all these districts deserve to be considered together as parts of one general field is not established. They have been so regarded generally by the more intelligent observers of the region, and have usually been referred to an ancient water course or buried river channel that could be followed by means of these fountains from the western end of Lake Erie to the Indiana line. Dr. Wood, a former resident of Toledo, thought he could trace by means of flowing wells an ancient channel through the whole interval. As he regarded it, this river must have been a tortuous one, and it would now be considered much more so if it were made to include all the flowing wells that have since been developed. The breadth of this old valley would, on such an identification, be considerable, if measured by a line at right angles to the main trend of the fountain belt. In some instances it would reach 6 or 8 miles.

In general terms, it is true that the best characterized flowing-well territory extends in a northeast direction from Hicksville, by way of Bryan, to the south of West Unity and into Gorham and Chesterfield townships of Fulton County. The territory continues to the northeast into Lenawee County, Michigan, in one part of which almost every farm has a fountain. The following townships are included in the above-named belt: In Defiance County, Hicksville, Mark, Farmer, and Washington; in Williams County, Pulaski, Center, Springfield, and Brady; in Fulton County, Franklin, Gorham, Chesterfield, and Dover. By geographical rights, German township, of Fulton County, should be added to the list, but no record of flowing wells within its limits has come to hand. But even if fountains are at present wanting, it may well be because proper effort has not been made to develop them.

The main belt can also be described as extending along the course of Tiffin River (Bean Creek). Several of the townships named are traversed by this stream.

The topography of this entire region is simple. The surface approximates a plain, but there is fall enough in almost every part of the district named to give good current to the surface drainage. In any case the valleys of the region are but shallow furrows in the drift.

The altitude of a few of the principal points above tidewater will be given here, derived from the railroad elevations at the stations named: Hicksville, 762 feet; Mark Center, 731 feet; Bryan, 767 feet; Stryker, 175 feet; West Unity, 775 feet (approximately). The inclination of the general surface is southeastward, but the principal streams of Williams County flow southwestward. The part of Defiance County included in this belt delivers its surface drainage to the Maumee River.

The most marked features of the district are moraines of the Glacial period and old beaches of Lake Erie. Several of these moraines and beaches cross the counties named, exercising a great influence upon the surface drainage.

The geology of the district is as monotonous as any area made up of the glacial drift can be. The thickness of the drift beds generally ranges between 75 and 150 feet, and no outcrop of the underlying rocks occurs. The first sheet of rock that is struck after the drift beds have been penetrated is the great shale formation known in our geology as the Ohio shale. We nowhere find in this part of the State the normal cover of the shale, and can not therefore determine its full thickness, but in adjacent counties of Michigan and Indiana entire sections occur, and we learn from them that the normal volume of the shale series in this part of the country is less than 300 feet, perhaps not much above 200 feet. At Delta a section of 133 feet was found by the drill; at Wauseon, 194 feet, and at Bryan, 157 feet.

In the field now under consideration we seldom meet more than 100 feet of the shale, and it is often reduced to 25 or 30 feet. From these facts we learn that the larger portion of the shale, besides its normal cover, was eroded during pre-Glacial time. Such a fact need occasion no surprise, for the shale is a soft rock and obviously an easy prey to erosive agencies. Moreover, the time during which it stood exposed to atmospheric waste was certainly long, aggregating many millions of years.

The drift is composed largely of bowlder clay, yellow at the surface and blue below; but all of the country that is here considered was subsequently overrun for protracted periods by the waters of Lake Erie, when they stood 200 feet higher than at present, and a blanket of lacustrine deposits, viz, the first and second beaches, constitutes the present surface. In these last-named formations we find stratified clays, sands, and gravels, with a sparing distribution of bowlders. This blanket does not reach a great thickness in any part of the field. It is very irregular, but its deposits seldom exceed 20 feet in thickness. The prevailing and characteristic feature of the blanket is lake-sand, the beds of which give rise to multitudes of shallow-water wells, upon which much of the country when first occupied entirely depended.

The bowlder clay carries within it many lenticular beds of sand and gravel, which sometimes reach the surface. Some beds receive and store rainfall and discharge water in the shape of springs. A very fine-grained clay, free from pebbles and grit, is occasionally met with. It is as tenacious as wax and makes trouble for the driller when encountered in wells. It is called the "beeswax clay."

Another and constant element is what is called by the driller "hardpan." It consists of gravel, fine and coarse, with the spaces between the pebbles packed close with clay. The hardpan does not admit the passage of water and is consequently always dry. It occurs in beds of 10 to 40 feet.

The lowest formation of the drift series is a streak of gravel, the constituent fragments of which vary greatly in size. Some of the pebbles are 3 or 4 inches in diameter; others are of the size of grains of wheat or even smaller. This is the water-bearing stratum of the country, on which most of the fountains absolutely depend for their supply.

Next to the rock, a streak of cemented (?) gravel is sometimes met. It never exceeds a few inches in thickness. This horizon when found, is also water-bearing. In considerable districts all wells obtain their supply from the upper surface of the shale, and many fountains have the same source. This water is often slightly saline and more frequently sulphureted.

The several fields will now be briefly described.

BRYAN.

This is the best known field of flowing water in Ohio, and no district has thus far found a better or more durable water supply. In its early days the village had much difficulty in obtaining water for domestic use. Shallow wells were the entire dependence of the first settlers, but the water thus obtained necessarily became contaminated by surface impurities and the health of the people suffered much in consequence. In any case, these wells were unable to furnish water enough for protection against fire, and by the year 1840 it had come to be recognized by all that an improved water supply was essential to the prosperity and protection of the town.

The history of the first flowing well, though it goes back only fifty to sixty years, is not free from contradictions and discrepancies, but a circumstantial account from one source relates that Dr. William Trevitt, of Columbus, who owned a large number of village lots and was consequently interested in the growth and prosperity of the town, recognizing the necessity of a new water supply, offered a man named Wyatt one of his lots if he would find somewhere near the public square better water. Mr. Wyatt began the search and located a well near the old hotel at the southeast corner of the court-house square. After laboring many days, he left the excavation one night with a depth of 43 feet. Returning in the morning he found the well full to the top and running over. The water was evidently from a deep source. The problem was solved and the prosperity of the village was assured.

Other wells followed in short order. Most of them were 50 to 60 feet deep, and they developed a head of pressure varying from 1 to 6 feet. In some wells, however, the water rose, when properly confined, to the second stories of dwellings. But the village was growing to the eastward, and in this direction the surface declined, becoming a few feet lower than the public square. Flowing wells were found at shallower depths in this direction, and as their number increased it was found that the head of pressure in the older wells began to decrease. In short, it soon became evident that if the town was to retain flowing water it would be necessary to find some new horizon. Wells retaining their artesian character were in this new search gradually increased in depth to 80, 100, and 125 feet. In other words, new veins had been reached. It is claimed that the quality of water from these veins is distinct, differing in amounts and kinds of mineral elements; but in default of analyses we must conclude that such differences can not be important.

About 1893, the village undertook a public water supply. A lot was purchased and five 8-inch wells were drilled. But the water-bearing stratum when struck proved to be thin and the production correspondingly small. A new location was accordingly secured and eight 3-inch wells were drilled which found an unusually good vein of water-bearing gravel at 100 to 125 feet. Every well completely filled a 3-inch discharge pipe. The flow of the strongest was measured and was found to yield 80 gallons a minute, or more than 100,000 gallons a day. The entire series produces 240 gallons a minute; but this production has affected the other wells within and around the corporation, destroying, as a rule, their artesian character.

In Pulaski township, outside of the corporation of Bryan, not less than 200 fountain wells have been drilled from first to last. Though called by this name, not all are really living fountains at the present time. but all have been such at an earlier date, and the water still rises nearly to the surface. On farms at a distance of several miles from the village the old conditions are best preserved.

The total thickness of the drift has been determined in drilling wells for gas and oil in and near the town during the last ten years. Four examples show the length of drive pipe to be respectively 146, 154, 176, and 157 feet. These thicknesses cover a range of a mile or more.

Water is found in the limestone series underlying the shale in considerable quantity, and the limestone water is also artesian, rising 18 to 20 feet above the surface of the ground. That obtained in the upper beds of the limestone is generally potable, but sulphur water is soon reached as the drill descends. These facts are in keeping with the geological character of the Corniferous and Onondaga limestones, as previously described. From one of these deep wells an extraordinary volume of water was produced, keeping a 6-inch pipe completely filled with its flow. Sulphureted water is occasionally found in drift springs in the neighborhood. Such cases would seem to be in some way connected with the shale system that underlies the country or possibly with large masses of shale in the drift.

The Bryan district has enjoyed and still enjoys in its fountain wells a great advantage over much of the surrounding country. They add to the value of farming lands, and especially to their salable quality. It would be hard to overrate the convenience and serviceability of such a water supply.

STRYKER.

This village is located in Springfield township, 7 miles east of Bryan; but while there are many flowing wells in the township, the conditions of their flow differ to some extent from those reported in the township previously described.

Well-diggers of large experience and thoroughly acquainted with the region estimate the number of flowing wells in this township as but little, if any, less than 100. From the same sources the general section of the drift of this region has been obtained. It is as follows:

General section of drift near Stryker, Ohio.

	Feet.
Soil and subsoil	2 to 5
Yellow clay	10 to 15
Blue clay	40 to 60
Hardpan	15 to 40
Water-bearing gravel	0 to 30
Ohio shale struck at	140 to 150

When a bed of clay is found below the hardpan it is generally of the "beeswax" variety, already described, i. e., fine grained and free from pebbles. Water is sometimes found on top of the hardpan as well as below. In such cases there are a few inches at least of sand or gravel covering the hardpan; but in most instances in this township the uppermost beds of slate constitute the real water-bearer. It is in this fact that the difference, referred to above, between the wells of Springfield and Pulaski townships lies. The driller does not, as a rule, go more than 10 feet into the shale. Experience has shown that if good water is not found within this limit it is not likely to be found at all. The water derived from the shale is generally counted less hard than the water from the drift gravels, but no analyses are at hand to establish or disprove the claim. On its face it seems improbable, as all the water borne by the shale must have come through the drift. The shale water, when obtained from the formation below its uppermost beds, is generally charged with sulphureted hydrogen. It is also saline in many instances.

The wells unquestionably grow weaker as their number is multiplied. One well often cuts off several that have preceded it in the same neighborhood. For example, the mill well in the village is 155 feet in depth. When worked hard the other wells of the village cease to flow. But the mill well is not drawn upon during the night and by morning all the wells recover their head and resume their flow.

In a few instances the drill has been carried deep enough to determine the thickness of the Ohio shale. Though there is considerable variation in this stratum, the cases in this township are few in which it exceeds 100 feet.

In a well that was being sunk in the village in the fall of 1896 an opportunity was afforded to examine the hardpan which had just been reached. It consisted of fine gravel of the size of wheat grains, distributed through a compact bed of clay. Bowlders are sometimes struck in the hardpan and also in the blue clay. In one well east of town the size of a deep bowlder was so great that after the derrick had been moved 5 feet the same obstruction was again encountered. The derrick was once more moved, and in this case 3 feet from the first station and in an opposite direction from the second trial, and the drilling then went forward without obstruction.

The original head of pressure was never great, but by the multitude of fountains it has been so reduced that the owners of wells are obliged to be satisfied with any flow of water whatever. But in any case the water is always near at hand. Pumps have but little lifting to do.

In 1865–1867 a well was drilled in town to a depth of 860 feet in the search for oil. At 230 feet a considerable volume of mineral water, of very much the same character as the mineral water of southern Michigan, was struck, and it reached the surface in geyser fashion. Several veins of gas had been found at different horizons as the drill descended, and the gas rising with the water caused it to flow intermittently after the manner of a geyser, as above indicated. A sanitarium was erected in the course of a few years to give the people an opportunity to avail themselves of the peculiar water yielded by the well. In 1870 an analysis of the water was made by Dr. S. H. Douglass, of the University of Michigan, and the following results were obtained:

Analysis of water from well at Stryker, Ohio.

Constituent.	Grains per gallon.
Chloride of magnesium	118.96
Chloride of sodium	281.86
Sulphate of potassium	185.34
Carbonate of calcium	68.30
Carbonate of iron	9.93
Sulphureted hydrogen	4.49
Silica	2.63

In a note appended, it is mentioned that the amount of sulphureted hydrogen originally present in the water was greater than the figures above given would indicate.

In the well the thickness of the drift was found to be 129 feet, and from this figure we can determine the altitude of the upper surface of the shale here. It is 586 feet above tide, and but 13 feet above the present level of Lake Erie.

WEST UNITY.

A fine field of flowing water is found along the valley of Tiffin River, in Brady township. Better examples of this type of wells can not be asked for than are to be found on the farms of Mr. G. L. Martin, Mr. William Miller, and others in the same neighborhood, 2 to 3 miles south and east of the village above named. The depth of the wells in this district is shallower than in other parts of the county. On the Martin farm, where there are four flowing wells, a strong and persistent flow is derived from 28 feet. Two of them, at depths of 43 and 54 feet, respectively, yield well-marked sulphureted water. The deepest flowing well of the township reached the shale at 110 feet, but the drill went through the shale to the limestone and artesian water rose from this last-named source. The shale was 100 feet thick. Its upper surface was, therefore, about 625 feet above tide. Whether this observation is a representative one there has been no opportunity to determine. The thickness of the drift is about the same that is generally reported for the region, i. e., 100 feet.

Farther northeast are the townships of Franklin, Dover, Gorham, and Chesterfield, Fulton County. This area includes a large number of flowing wells of excellent character. In Gorham township the pressure head is sometimes 20 feet. While every trial is not successful, success attends so many undertakings that every farmer counts upon a fountain when he drills a well of even moderate depth. These same conditions extend beyond the State line into Michigan. Almost every farm in the vicinity of Morenci, Lenawee County, has a good flowing well.

HICKSVILLE.

Returning now to the so-called belt of flowing water, we find at its southwestern extremity one prominent division that remains to be described, viz, the Hicksville field. There are more than fifty flowing wells in operation in this village and township, and the work of testing the territory is constantly going forward, particularly when summer droughts are upon the country.

The first flowing well of the village was struck in 1857 in the rear of the Central Block, at a depth of 71 feet. The second well was drilled a year or two later south of the village, on the farm of Judge Patton. It was only 50 feet deep, but it proved entirely satisfactory. The deeper water horizons of the drift were not tested here until 1895. This testing was done by the village corporation in its search for a public water supply. A beginning had been made in this line five years before, when four wells were drilled to a depth of about 40 feet. They proved artesian, but their head was feeble and their supply was affected to a dangerous extent by the droughts that occurred. In 1895, in particular, the ground water of northwestern Ohio was greatly reduced, and the public supply of Hicksville was overtaxed, so that the village authorities determined to sink deeper wells. Two new wells were located near the old ones, and instead of stopping at 70 feet their depth was doubled. The result was in every way satisfactory. The water rose in large volume and with a head of pressure of 11 feet.

The Coulter well in the village gives a clear section of the general arrangement of the drift beds for this region. The well was begun in the old beach that passes through the town and was carried to the black waste which is the immediate cover of the Ohio shale. The record is as follows:

Section of well at Hicksville, Ohio.

	Feet.
Sand and gravel	9
Yellow clay	4
Quicksand	1
Blue clay, numerous sand veins, 5 to 6 inches thick, intercalated	94
Blue hardpan	19
Blue clay and sand	15
Ohio black shale at	142

The well flowed 56 gallons a minute, which is at the rate of 80,640 gallons, or 2,200 barrels a day.

MARK TOWNSHIP.

This township, in Defiance County, is also included in the belt of flowing wells. A fine well was struck one year ago, 1½ miles north of the center at the Laws Tile Works, and a half mile west of that point another successful well has been drilled. On the Coy farm a fountain of unusual volume has recently been struck. All the conditions seem similar to those of Hicksville township, and a considerable number of flowing wells have already been drilled.

In Farmer and Washington townships, northeast of Hicksville and Mark, fountain wells have abounded for the last forty years, and it is understood that the conditions are similar here to those in the territory already described.

The northeast and southwest belt of fountain wells already described can be followed still farther within the limits of Ohio. Carryall, the northwestern township of Paulding County, adjoining Hicksville, has flowing wells by the score, and their occurrence stands for a measure of uniformity in the geological conditions of the region so favored. It is in the northern portions of the township, and largely in sections 2, 3, 4, 5, 10, 11, that the fountains have chiefly been found. Every farmer, in drilling for water, expects a flowing well, and but few are disappointed.

The wells are not so deep as in the fields already described. All of them go, however, to the bedded rocks, which are reached at 30 to 50 feet.

Not all wells that are drilled to the rock are successful, and it is also to be noted that artesian water is occasionally found before the rocky floor is reached by the drill.

SWANTON.

In and around Swan Creek township, Fulton County, there is still another district of fountain wells which can not by any reasonable construction be considered as belonging to the "belt" already described.

The first artesian well at Swanton was discovered in 1862, on the Hepfinger farm. Flowing water was found at a depth of 40 feet, and the well has furnished a strong and steady supply from that time to the present. Nevertheless a prolonged drought, like that of 1895, reduces the flow, but does not destroy it. In the vicinity of the village there are not less than 7 of these fountain wells. A well in this district is counted good when it yields 500 barrels per diem.

The conditions in this region are very like those already described in the vicinity of Stryker. The Ohio shale, which is the underlying rock, is the water-bearer. All wells are drilled entirely through the drift series. The general section is as follows:

General section near Swanton, Ohio.

	Feet.
Lake sand	18
Blue clay	30
Sandy clay	Uncertain.
Hardpan	3 to 15
Gravel	3 to 9
Ohio shale struck at	50 to 75

Southeast of Swanton there are a number of flowing wells, extending toward Whitehouse and Waterville. In this direction, however, a change in the bed rock occurs, limestone underlying the drift instead of shale.

Looking at the facts as developed at Swanton, and yielding to the natural tendency to put isolated facts into a connected and thus a more intelligible series, it would be justifiable to conclude that Swanton belongs in a belt of flowing water which extends in a northwesterly and southeasterly direction. Certainly flowing wells are to be found in both directions; but a broader, or at least an earlier, generalization has already assigned the flowing well district of northwestern Fulton County to a northeast and not to a southeast belt.

WAUSEON.

This village is not at present supplied by flowing wells, but, nevertheless, its waters deserve to be called artesian. At a few points where the proper tests were first made the water originally flowed, but the multiplication of these deep wells has cut off the small head that was at first found. The water still rises to within 15 or 20 feet of the surface through considerable areas, and its artesian character can be assumed on this ground.

The drift of the immediate region is 140 to 160 feet thick. The uppermost 10 to 15 feet consists of yellow clay, oxydized. Below comes blue clay, often so charged with slate fragments and waste as to be almost black. Thin seams of sand are irregularly distributed through the mass. Large bowlders, though rare, are not unknown. The boundary between the yellow and the blue clays is not sharp or well defined. The change in color simply marks the line to which surface water has been able to descend. The blue clay reaches a general thickness of 130 to 150 feet.

Below it about 5 feet of hardpan is found. This is here described as cemented gravel. Under it a few inches of sand are generally found, and then the Ohio shale is reached. This last formation is usually covered for a few inches with its own fragments.

The shale is the main water-bearer of this central district of the county; but since the body of the formation is impervious, its storage quality can consist only in the widened joints and the generally fractured surface resulting from its prolonged exposure in pre-Glacial time. Water descends through the drift by channels, the existence of which we are obliged to infer, but the location of which we can never expect to determine, carrying with it the soluble minerals of the beds through which it has been filtered, and diffuses itself through the fractured surface above described. Its principal storage basins must be, as already remarked, the widened joints of the shale, and this will account for the frequent failures to obtain water. Of the deep wells in and around the village it is estimated that one-third have proved dry holes. Sometimes if the derrick is moved but a few feet the new well is successful.

Three trials were made, however, on one village lot at Wauseon, and all were failures. On the next lot a good well was obtained at the first trial. A well in this region is counted good when it can be depended on for at least 10,000 gallons, or 330 barrels, per diem.

The hardpan of this region is described as cemented gravel, and the drillers report it to be as hard to penetrate as ordinary sandstone. Wells are drilled into the shale generally a few inches, and seldom more than a few feet.

All the shale water of this district contains a noticeable trace of common salt, but the percentage is so small that it soon passes unnoticed by those who make constant use of the water. It rarely occurs in amount large enough to make the water distinctly objectionable. Its normal presence in the shale water needs to be noted by chemists who are called upon to make analyses of the water of this class of wells.

A deep well drilled here for gas or oil at the time of the Findlay excitement found the shale series in the village to be 194 feet in thickness, and 1 mile northward a white shale, 18 to 20 feet thick, was found overlying the black shale. The "white shale" is probably the Bedford shale, which is the normal cover of the Ohio shale. It is thus probable that nearly the entire Ohio shale section is found at Wauseon.

Inflammable gas is frequently struck in drilling through the drift and almost always when the shale horizen is reached, but it is seldom found in large enough volume to be of economic value. In a few cases it has been utilized in a small way. Occasional "blowers" are met which are noisy and troublesome for a few hours or days.

The gentle roll or ridge 1½ miles west of the court-house, which is known as Wauseon Summit where it crosses the Lake Shore Railroad, has an altitude of 15 or 20 feet above the general surface of the surrounding country, and increases the depth of water wells by this amount. The ridge is a part of the second beach formed when the level of Lake Erie was 200 feet higher that it now is.

An old trough or valley in the shale has been brought to our knowledge by the drilling of water wells south and east of the village. It lies about 1½ miles south of the court-house. It can not be more than a quarter of a mile in width and may not be more than an eighth. There is no sign whatever of its existence upon the surface of the district which it traverses. It was discovered by the fact that wells reaching to the surface of the shale are about 140 feet deep for 1½ miles south of the town; but suddenly the depth to the same boundary increases to 225 feet, while a little farther on the old figure is restored. The general depth of wells for many square miles is about 140 feet. A valley 225 feet deep is lower than the surface of Lake Erie by 30 or 40 feet. It would carry drainage away from Lake Erie, not toward it. By continuous drilling the course or direction of the valley has been roughly determined for a distance of about 9 miles. It bears directly west for 5 miles, passing a little south of Pettisville. From the point of beginning it can be traced northeastward, and various departures from a straight course are shown by the deep wells that indicate the old valley. The depth is said to increase slowly westward, but no figures were obtained, and the direction and further course have not been determined. Facts to be accumulated in the future development of the country will clear up these points and show the direction and the office of this ancient valley. It is filled with sand and gravel and is thus a great receptacle for water. The water supply of Wauseon has always been recognized as a difficult problem. It is possible that it will not be solved until the great channel to the southward is drawn upon.

SUMMARY OF GEOLOGICAL CONDITIONS IN NORTHWESTERN OHIO.

The fountain districts of northwestern Ohio, some of the prominent facts and features of which have now been put on record, have several geological conditions that are common to its whole extent:

1. The entire region is underlain by the Ohio shale, i. e., the Ohio shale is the first rock stratum to be reached below the drift. The shale series constituting this floor is a remnant of a much larger series of shales belonging to the same general class of rocks. Above the Ohio shale in its entirety there are geologically due, in the order named, the Bedford shale, the Berea grit, the Berea shale, and the Cuyahoga shale, in all 400 to 500 feet of soft rock. The only exception would be found in the Berea grit, but this is often thin and impure and would give way to erosive agencies nearly as easily as shale. We are obliged to conclude that several hundred feet of what was originally deposited as shale rock have been removed, from most of the area, mainly by atmospheric agencies. We find at Delta 133 feet of the shale series, and at Wauseon 194 feet. As previously remarked, it is probable that in the latter case we have an approximately complete section of the Ohio shale for northwestern Ohio. But though the sections of the shale throughout the district are unequal, the surface of the country is approximately level. Its altitude ranges between 700 and 750 feet above tide. This uniform elevation was brought about largely by the glacial deposits which have filled up the hollows and furrows due to former denudation, and which have gone far toward restoring the surface to its original monotony. But another agency is to be taken into account in this connection.

2. The shale series itself had been reduced to nearly one level before the drift storm overspread it. The old agencies of erosion had practically completed their work upon it in pre-Glacial time, as the following elevations of the shale floor show:

Elevations of the shale floor in northwestern Ohio.

	Feet.		Feet.
Delta	704	Stryker	588
Wauseon	612	Bryan	611
Pettisville	610	West Unity	625
Archibald	584	Hicksville	634

The average elevation of the shale floor according to these figures is 621 feet, or, omitting the first example, which is somewhat out of correspondence with the rest, the average is 609 feet. This seems to show that the region was practically base-leveled before the drift.

The only fact that seems to militate against this conclusion is one already cited, that a valley 85 feet deep and not more than a quarter of a mile and perhaps not more than an eighth of a mile in width is found traversing the shale in the central part of the county. When erosion has done its perfect work, as in a base-leveled country, it is not likely to leave valleys of such a character as the one here described. We should expect them to be wider and shallower.

3. Two important facts in connection with the storage of the large quantity of water of the counties now under consideration are found (*a*) in the effect of erosion which the soft rocks of the original surface have undergone, and (*b*) in the great amount of gravelly drift which has been dumped into the basin formed by the wearing away of the shale.

(*a*) The rock floor lies at a distinctly lower level than that of the district immediately south of it. From the Wabash Valley southward limestone constitutes the floor of the country, and this everywhere stands at a noticeably higher level than the shale region which it bounds.

(*b*) The drift deposits which have been laid down upon the region under consideration certainly exceed 100 feet in average thickness. They constitute a varied series and stand for several distinct stages in the complex and puzzling history of the great ice age. The division termed "hardpan," for example, throughout the district, is everywhere sharply distinguished from the bowlder clay, and these two elements must have a different history.

FLOWING WELLS IN MERCER COUNTY.

The artesian wells of Paulding and Van Wert counties, aside from the northwestern corner of Paulding County (Carryall township), already described, are excluded from present consideration because of the shallow depths at which they are found and because of the lack of large connected areas in which they occur. There are large districts in these counties in which the drift does not exceed 15 to 20 feet in thickness, and in comparatively small portions does it exceed 40 feet. Flowing wells are scattered throughout these entire areas, one here and another there, but they do not reveal any general structure.

A somewhat different state of things appears in Mercer County. The drift is deeper, and entire townships can be described as flowing-well territory, though not every well that is drilled within their limits proves to be artesian. The northern townships, viz, Black Creek, Dublin, Union, Hopewell, Center, and Jefferson, show this character more prominently and connectedly than the southern portions of the county, with the exception of Franklin and Butler.

In Black Creek township the general depth of the wells, up to 1895, when the severe drought of the summer of that year reduced the ground water so seriously that it became necessary to obtain a new source, was 45 to 50 feet. At this time many of the wells were deepened, being drilled to a depth of 90 to 110 feet, and with the most satisfactory results. The head of pressure is 4 to 5 feet. Flowing wells are known in sections 10, 11, 15, 22, 23, 24, 25, and 34. In single sections many flowing wells have been obtained.

In Dublin and Union townships the depth of the wells ranges between 20 and 85 feet, but the thickness of the drift is often as much as 40 feet. A typical section of the drift may be given in the following terms: Soil, 2 feet; yellow clay, 7 feet; gravel, 7 feet (uncertain); hardpan, 20 feet; rock.

In Jefferson township the drift is 50 to 75 feet. The head of pressure sometimes exceeds 10 feet.

In Franklin township the general depth of the flowing wells is 40 to 50 feet, but the rock lies deeper and the more permanent water supply is found by sinking wells to the surface of the solid floor. This is one of the townships that has been overrun by the drillers of deep wells for gas and oil, and these wells have, in numerous instances, cut off previously flowing fountains, in some cases at a distance of 1½ miles. If the artesian flow of the deep wells is arrested the old wells after a time resume their production.

In Butler township fountains are common in sections 11, 12, 13, 23, 24. Some of them show a head of pressure of 10 feet.

The general succession of beds through which water is reached in this township is very similar to that already reported for Dublin and Union, viz, soil, 2 feet; dark or black clay, 6 to 10 feet; blue clay, 10 feet; hardpan, 5 to 20 feet; gravel and water.

In some parts of the county flowing water is so easily obtained that a farmer will drive a pipe 15 to 20 feet in any field in which stock is to be kept for a time, and when the pasture is exhausted will withdraw the pipe and establish it in a new location.

DEEP PRE-GLACIAL CHANNELS IN ALLEN, AUGLAIZE, AND MERCER COUNTIES.

By the deep drilling that has been done in the counties named above in such large amount during the last ten or twelve years some facts of unusual interest have been developed as to the pre-Glacial drainage system of this part of the State, and within the same territory the strongest artesian wells of the State have been developed. A brief account of these two lines of facts will be given here.

In Allen County the deep excavations that will be noticed are first brought to light within the limits of the city of Lima. A channel has there been revealed 170 feet below the surface. In Perry township a deep channel, or a series of deep channels, has been revealed by drilling in the following-named sections, the thickness of the drift being as indicated by the figures given:

Thickness of drift in Perry township, Ohio.

Section.	Feet.
17	195
20	235 248
21	238 255
22	205 211
28	230 258
29	244

In Shawnee township:

Thickness of drift in Shawnee township, Ohio.

Section.	Feet.
2	178
3	200
10	194 265
11	265
13	281
25	204

In Duchouquet township, Auglaize County:

Thickness of drift in Duchouquet township, Ohio.

Section.	Feet.
3	428
34	300 335 340

In Moulton township erosion to an equal degree has taken place, but the data have not been secured.

In St. Marys township:

Thickness of drift in St. Marys township, Ohio.

Section.	Feet.
2	228
8	400 401 402
9	249 396
11	480
12	400
13	350
15	104 406 406 406
22	392

In Center township, Mercer County, section 29, the thickness of drift is 400 feet.

In Dublin township, Mercer County, section 16, the thickness of drift is 319 feet.

In Jefferson township the greatest ascertained thickness of drift is 400 feet.

In Franklin township:

Thickness of drift in Franklin township, Ohio.

Section.	Feet.
35	400 402 414 444
35, southwest quarter	398
35, east half	430
32, east half	430
2, southeast quarter	367
31, southwest quarter	326

In Marion township:

Thickness of drift in Marion township, Ohio.

Section.	Feet.
13	444 500
11, northwest quarter	388

In Granville township:

Thickness of drift in Granville township, Ohio.

Section.	Feet.
26, northeast quarter	280
26, southwest quarter	330
24, northeast quarter	270 280

In this region the first stratum below the drift is either the Onondaga limestone or the Niagara limestone or, in a few exceptional cases, the Medina or the Hudson River shales. The first-named stratum is struck in Allen County and in Duchouquet and Moulton townships of Auglaize County. In St. Marys township, Auglaize County, and in Mercer County the first rock reached is the Niagara, or, in the exceptional cases named above, the Medina or Hudson River shales. This limestone floor has been gashed and dissected by the work of a great river system continued through protracted ages. Channels, main and tributary, have been cut from 100 to 400 feet below the general surface of the limestone. Where the Niagara limestone made the pre-Glacial rocky floor, erosion to such a depth would necessarily penetrate its entire thickness and the underlying Clinton limestone as well, and bring the level of the erosion down into the soft rocks of the Medina or Hudson River shales. This is what the driller finds. The drivepipe of these deep wells meets with no cap limestone whatever, but strikes the original rocks in the fine-grained shales of the series named above.

The main channel of the old river can be plainly followed from St. Marys in a line extending almost directly west through the Mercer reservoir, but a little to the north of the middle line of this body of water. Just before it reaches the west end of the reservoir it receives an important tributary, the course of which can be traced fully 11 miles northward through Jefferson, Center, and Dublin townships by strings of drivepipe 320 to 400 feet in length. This part of the ancient stream came from the north, but after leaving the reservoir the main channel bends abruptly south and afterwards bears to the east, so that for the next 8 or 10 miles its direction is approximately southeast. It has not been located so closely in Franklin and Marion townships as in those previously named, but it turned west once more in Marion township, where drivepipe of 500 feet has been recorded in a single instance.

As the main channel is followed through the reservoir its breadth is found to be 1 mile to 1¼ miles. The northern tributary already described is much narrower, and though of about the same depth as the main valley its breadth is less than one-fourth of a mile.

It is a singular coincidence that the modern reservoir should be located directly above the deepest pre-Glacial valley of the State. It is still more surprising that after this part of the country had been converted into a permanent lake we should by any chance be able to learn the thickness of the drift under the surface of the water. This last discovery has come about through the enterprise of the oil-well driller. Productive oil territory having been followed directly up to the margin of the reservoir, it was evident that the chances of finding good oil wells were not lost because the surface happened to have a shallow covering of water over it. The consent of the State authorities to drilling within the reservoir was finally obtained, and wells by the score and the hundred have since been drilled there. In sections 7, 8, 16, and 17 of St. Marys township and in sections 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, and 18 of Jefferson township the long and irregular lines of drivepipe already referred to have been found necessary.

It could not be otherwise than that this channel would be struck by the driller at various points of its declivity, sometimes on the edge, sometimes half way down the slope, and occasionally, perhaps, at its greatest depth. The longest string of drivepipe that has been reported from the reservoir is 406 feet, in the northwest corner of section 15. At one "location" 400 feet from this point only 100 feet of drivepipe were required. In section 8 one driller found 400 feet of drivepipe required in each of two wells, 401 in a third, and 402 in a fourth well. In another instance, by a change of one "location" a distance of 400 feet, the necessary drivepipe was increased from 97 to 240 feet. In Union township, on the northern tributary, the drivepipe was lengthened from 40 to 100 feet in a single "location." This was on the J. H. Coil farm near Mendon.

The main channel can be traced from section 11, St. Marys township, to Celina. On section 11, St. Marys, is located the Barrington well, presently to be described, the most remarkable flowing well of the State.

On the C. Wilkins farm, in the same section, four successive wells showed 90, 215, 240, and 350 feet of drivepipe. These wells are all to the south of the main channel. Another of the Wilkins wells was located, as the event proved, exactly on the brink of a precipitous wall several hundred feet in height. The driller struck the rocky floor, as he thought, at 180 feet, but after advancing a few inches he found that he was in drift clay again. It is reported that as he drove still deeper he continued to strike projecting shelves of the rocky wall as far down as 370 feet, and here he finally abandoned the location.

The main channel, as at present recognized, passes from the west end of the reservoir southward toward Montezuma, thence southeasterly, near Chickasaw and St. Johns, reaching its deepest point west of the latter place in Marion township, where, as already noted, 500 feet of drivepipe were required.

Fragments of old channels have been struck in Washington township, Auglaize County, near New Knoxville, and in Dinsmore township, Shelby County. At Anna Station drivepipe exceeding 400 feet in length was called for, and the drift was not penetrated after all. In section 15, German township, 444 feet of drivepipe were used in one well. This is probably in a main valley. It may possibly connect with the extreme thickness of drift reported from St. Paris, Champaign County, which exceeded 530 feet.

The northern tributary, which has already been referred to in several connections, demands another word. It has been traced through the east line of sections of Dublin and the western sections of Center as far as the reservoir.

To find the elevation above tide of the channels that have now been hinted at rather than described, all that is necessary is to subtract the length of drivepipe from the elevation of the wellheads. Applying this to the drilling that has now been passed in review we find that the main channel in the reservoir has a maximum depth of 462 feet above tide (868 — 406). The 500 feet of drivepipe in Marion township shows an elevation of the rocky floor of 425 feet above tide (925 — 500). The exact location and consequent exact elevation of the well in question have not been ascertained.

The filling of the old channel within the limits of the reservoir is declared by competent observers to be essentially different from the usual deep drilling of this part of the State. It consists of soft, fine, whitish clays, free from bowlders or gravel streaks, through which the drivepipe can be easily forced.

ARTESIAN WELLS OF THE DEEP CHANNELS.

Decidedly the strongest flowing wells of Ohio are found in the deep buried channels. Within the limits named they are to be counted by the score, but so far none of them has been turned to practical account. A few will be specifically named. In sections 15 and 16, Shawnee township, Allen County, in what is known as the Children's Home neighborhood, several wells have been struck at a depth of 200 to 250 feet. The water rises with at least 2 feet of head between $8\frac{1}{4}$ and $5\frac{5}{8}$ casing and flows off in a large stream. The present outflow from one of these wells is estimated at not less than 2,400 barrels per diem.

Throughout Moulton township similar phenomena are of frequent occurrence. The channels marked by deep drivepipe pass through this township. But flowing wells reach their highest mark in St. Marys township. A number of old channels meet and unite within this and the adjoining townships. Large quantities of river gravel, some very coarse, fill these old beds, and the water contained in the gravel basins is in reality the equivalent of a lake. It is under enormous pressure. The highest head that has been noted is given at 40 feet, but this figure is probably an estimate and not the result of careful measurement. At any rate, the pressure is beyond all precedent among the artesian wells of the State.

A well drilled on the farm of Mrs. Caroline Barrington, section 11, St. Marys township, gives perhaps the most surprising record. When the drill reached the gravel of the old channel a mighty flood of water poured into the casing and rose to a height of 20 feet in an unbroken column. It would probably have gained a height of at least 30 feet in an inclosed pipe. With the water a shower of gravel was thrown out, falling back into the derrick. Several wagon loads of gravel were accumulated here in this way. Though all the gravel was obliged to come through the 6-inch casing, a single stone was found that weighed 6½ pounds.

This flow was struck at 350 feet. The casing was finally driven to a depth of 364 feet. At a depth of 360 feet a log of considerable size was found imbedded in the drift. Wood has been reported in a number of these deep wells. In a well drilled on the Hickman farm, in Butler township, a log of light-colored timber, apparently as much as 3 feet in diameter, was found at a depth of 60 feet. Again, in section 19, Marion, a good-sized log, dark in color, was struck at 270 feet. In this last well, which was drilled on the Grieshof farm, the depth of the drift was 444 feet. Great floods of water have been struck at the same horizon throughout the reservoir.

ACKNOWLEDGMENTS.

The facts that have been reported in the preceding pages have been gathered from various sources, some of which are indicated in connection with the statements with which they are associated, but the very interesting revelations as to the deep channels of Fulton County and also of Auglaize and Mercer counties can be more definitely credited. Without making the persons named responsible for particular statements, it is only just to say that my chief sources of information are embraced in the following list. To these persons I return herewith public acknowledgment of the value of the information supplied by them:

Wauseon: W. H. Harper, A. B. Robinson, W. W. Croninger.

Lima: A. C. Reichelderfer; the Ohio Oil Company, by J. C. Lafkin, manager; the Manhattan Oil Company, by W. H. Holmes, manager.

St. Marys: Neely & Clover, A. B. Curtin.

Celina: I. F. Rodebaugh, C. W. Andrews, H. B. Bennett, Isaac Brandon, George Houser, B. C. Miller, Joseph Palmer.

Chickasaw: R. E. Hill.

PRELIMINARY REPORT ON THE GEOLOGY AND WATER RESOURCES OF NEBRASKA WEST OF THE ONE HUNDRED AND THIRD MERIDIAN

BY

NELSON HORATIO DARTON

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ILLUSTRATIONS.

PRELIMINARY REPORT ON THE GEOLOGY AND WATER RESOURCES OF NEBRASKA WEST OF THE ONE HUNDRED AND THIRD MERIDIAN.

By Nelson Horatio Darton.

INTRODUCTION.

This report is based on field work of the season of 1897. It is designed mainly to furnish information in relation to the geologic structure and the prospects for underground waters. A general account will also be given of the overground waters and their present and prospective use for irrigation, etc. The region is the portion of Nebraska lying west of the one hundred and third meridian, comprising Sioux, Scotts Bluff, Banner, and Kimball counties, the western portions of Cheyenne and Boxbutte counties, and the central and western portion of Dawes County; in all, an area of 7,400 square miles, adjoined on the west by Wyoming, on the north by South Dakota, and on the south by Colorado. It lies on the Great Plains south of the Black Hills of South Dakota. The Scotts Bluff, Banner, and Cheyenne counties areas were examined in detail, but time did not permit more than a general reconnaissance of the adjoining regions. I was assisted by Mr. C. A. Fisher and Mr. F. H. Ainsworth. Mr. Fisher obtained the data for the greater part of Kimball and Boxbutte counties. For several months I was accompanied by Prof. E. H. Barbour, the acting State geologist of Nebraska, who did much to further the progress of the work.

Numerous data in regard to irrigation in the Niobrara River, White River, and Hat Creek basins were kindly furnished by Mr. J. M. Wilson, the State engineer.

TOPOGRAPHY.

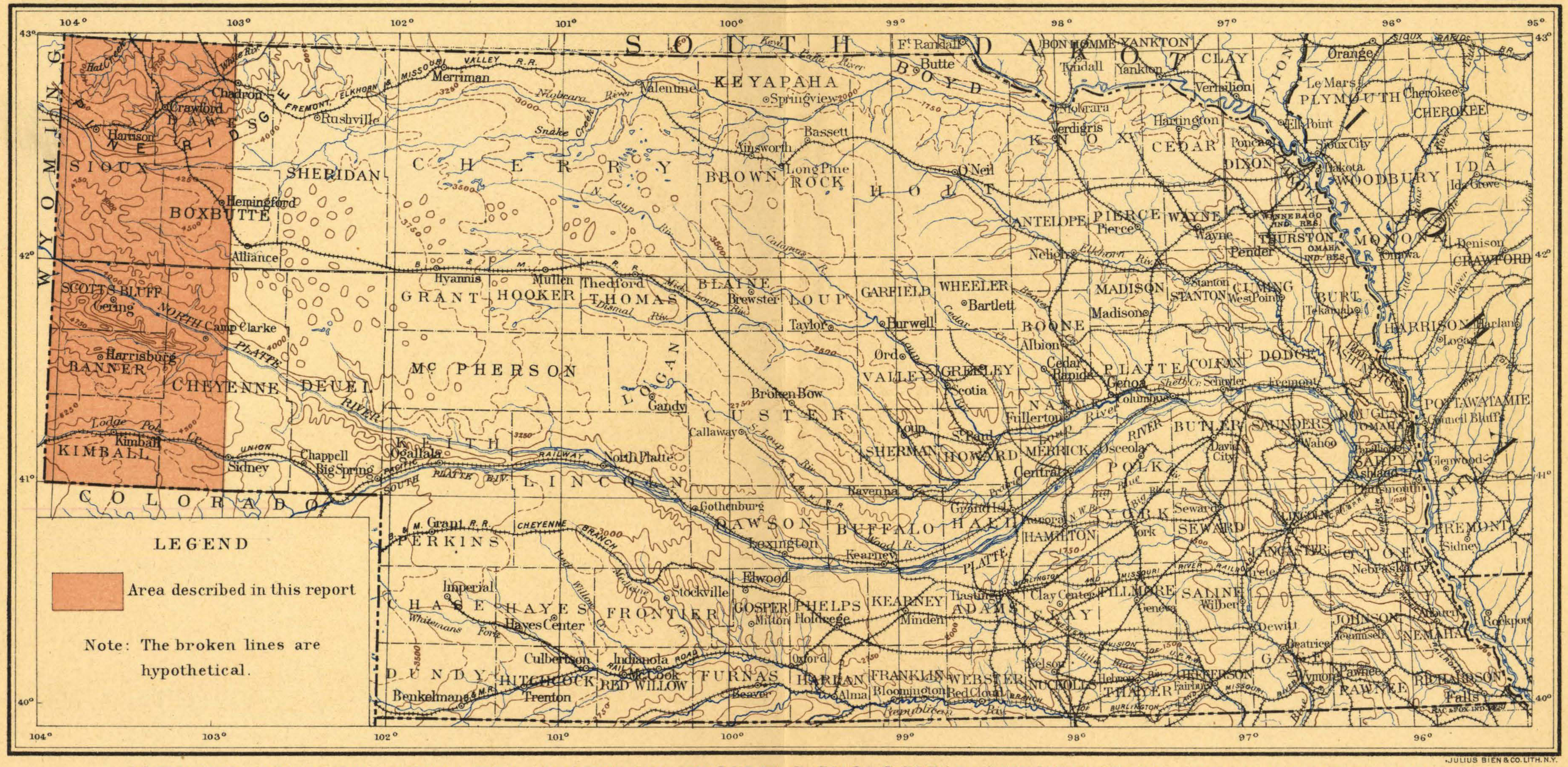
General features.—The region is a typical portion of the Great Plains, which extend far eastward from the foot of the Rocky Mountains. To the south this portion of the plains is traversed by the deep, broad valley of North Platte River and the smaller valleys of Niobrara River and Lodgepole Creek; to the north, at the valleys of White River and Hat Creek, it gives place to lowlands extending to Cheyenne River at the southern foot of the Black Hills. The northern edge of the plains presented toward these lowlands is marked by a great escarpment, or line of steep slopes, which is known as Pine Ridge. It begins in Wyoming and is the most conspicuous topographic feature in northwestern Nebraska.

Pl. LXXIV has for its base a topographic map of the region, with contour lines 100 feet apart. These contour lines indicate heights above the sea, and they are numbered accordingly. The lines for every even 500 feet are made heavier than the others. Contour lines are lines of equal elevation, consequently they are drawn along the slopes of valleys like level irrigation ditches, in this case 100 feet apart vertically, extending up the side valleys and running out around the points of projections. They encircle detached hills, and an isolated hill rising 500 feet above the plain would be indicated by five of the 100-foot contour lines. From the foregoing statement, it will be seen that contour lines are crowded near together on steep slopes, but are widely separated on the plains and in the river bottoms. Thus, they indicate the shape of the land as well as its elevation.

For Banner, Scotts Bluff, and portions of Cheyenne and Sioux counties, the contour map is based on the detailed maps, with 20-foot contour lines, of the Scotts Bluff,[1] Camp Clarke,[1] and Whistle Creek quadrangles of the United States Geological Survey. In other portions of the region it has been necessary to employ barometer readings and local observations extending from points of known heights on the several railroad lines. These approximate data are distinguished on the map by broken contour lines. Pl. LXXV is a view of a relief map of Nebraska, which also shows the configuration of this area.

High table.—The original surface of the region to which this report relates was a relatively smooth plain, which sloped gently to the east. This plain was uplifted in early Pleistocene time, and the rivers extending across it excavated valleys of greater or less width and depth, soon giving rise to the broader features of the present configuration. The remains of the plain lie between the valleys, where they constitute wide areas of high table-lands, smooth or very gently rolling in contour, and sloping to the east. The widest areas of this table lie on each side of the valley of Lodgepole Creek, and extend north from the valley of North Platte River to the great escarpment of Pine Ridge, where there is an abrupt descent of over 1,000 feet to a region of low rolling plains, which extend to Cheyenne River at the southern foot of the Black Hills. Some features of this great escarpment are shown in Pls. LXXV, LXXXI, XC, and XCIV. The broad area of table terminating in Pine Ridge is traversed by the wide, shallow valley of the Niobrara, south of which it is surmounted by irregular zones of sand hills. The edge of the table descending to the valley of North Platte River presents steep slopes deeply notched by canyons.

[1] The topographic atlas sheets of these two quadrangles have recently been issued by the Survey and may be obtained by remitting 10 cents (5 cents for each) to the Director, United States Geological Survey, Washington, D. C.



CONTOUR MAP OF NEBRASKA, COMPILED FROM U. S. GEOLOGICAL SURVEY MAPS AND RAILROAD DATA

BY N. H. DARTON 1898.

Scale

40 20 0 40 80 120 MILES

Contour interval 250 feet.

RELIEF MAP OF NEBRASKA, BY N. H. DARTON, 1898.

Next south, there is an outlying area of the high plain, preserved as a long, high, narrow ridge lying between the valleys of Pumpkinseed Creek and North Platte River. This ridge is so narrow and so deeply invaded by canyons that it has lost the flat-topped character, except in a few small areas of its widest portions. Its summits, however, in many cases rise to the plateau level. The ridge owes its isolation to a former branch channel of Platte River which at one time flowed through the Pumpkinseed Valley. Eight miles south, across the valley of Pumpkinseed Creek, a branch of North Platte River, rises the steep face of the wide area of high table-land extending to the valley of Lodgepole Creek, and continued far into Colorado beyond that valley. The altitudes on the table-land average about 4,300 feet along the one hundred and third meridian, and increase to nearly 5,000 feet in the vicinity of the Wyoming line. In the southwestern portion of Banner County, and again in the extreme southwestern portion of the State, the altitudes somewhat exceed 5,300 feet. Here is found the highest land in the State. Scotts Bluff has the reputation of being the highest point, but its altitude is only 4,662 feet. Wild Cat Mountain, which has shared the claim as the highest point, is 5,038 feet, or fully 300 feet lower than the highest points on the high table along the Wyoming line.

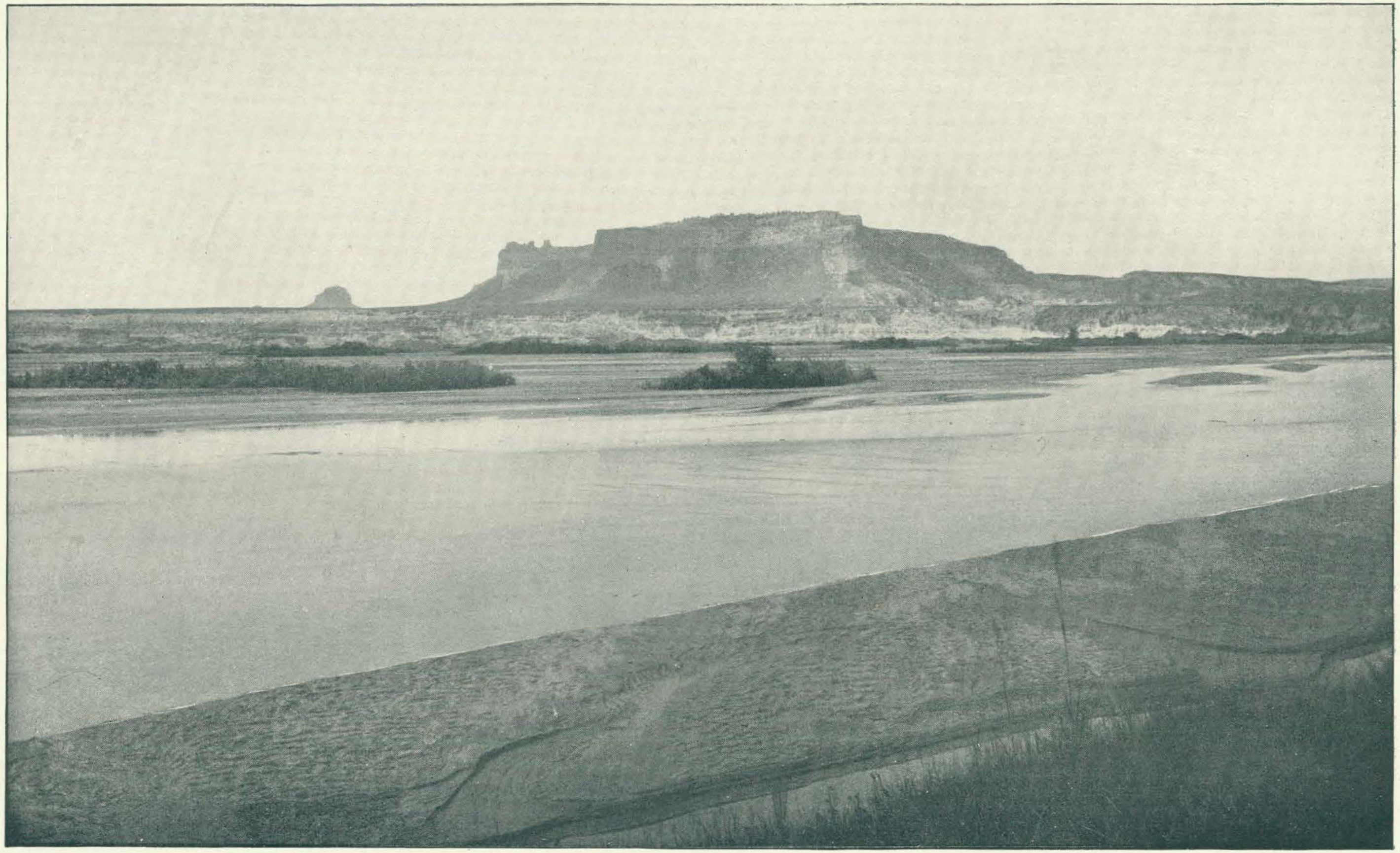
North Platte Valley.—The region is traversed near its center by the broad valley of North Platte River, a stream which enters the State from Wyoming and carries the drainage of a wide area in the Rocky Mountains. This valley has been excavated from the plain which, as before stated, originally extended unbroken entirely across the western Nebraska region. The depth of the valley averages in the greater part about 700 feet, and its width varies from 10 to 15 miles. The slopes along its sides present many irregularities. There is first a broad flat along the river, which rises only a few feet above the water. This flat merges into irregular terraces, rising for about 200 feet, with slopes of varying degrees of steepness. Then come steep-sided projections of high lands extending from the edge of the high table above and separated by canyons which are cut into the margin of the table for some distance. These canyons have been excavated by small streams which flow into Platte River in times of heavier rainfall. The higher slopes of the valley are marked by cliffs and buttes of varied form and height, which often are very imposing in appearance. On the south side of the valley there rises an irregular ridge of striking prominence, cut off from the main high table to the south by the wide valley of Pumpkinseed Creek. The greater part of this ridge varies in width from 3 to 6 miles, with long projecting spurs and occasional outlying buttes. Its crest is relatively uniform in height, about 800 feet above the bottom of the Platte Valley. In the vicinity of the Wyoming line its altitude diminishes greatly, but it is practically isolated from the high tables southward. The main axis of the ridge is about 7 miles south of the river, but several spurs extend nearly to the river. One of these terminates in Chimney Rock, shown in Pl. XCVII; another at Castle Rock, shown in Pl. CV; and a third at Scotts Bluff, shown in Pl. LXXVI. To the eastward this ridge terminates in two outlying buttes, known as Courthouse and Jail rocks, shown in Pls. LXXVII and LXXVIII. It also sends a branch ridge out into the Pumpkinseed Valley, on which there are some particularly high knobs, one of which is known as Wild Cat Mountain and the other as Hogback Mountain, in which an altitude of somewhat over 5,000 feet is attained. The western part of the ridge has an altitude of 4,860 feet. Scotts Bluff has an altitude of 4,662 feet and Courthouse Rock 4,100 feet. The ridge is deeply invaded by numerous canyons, which have cut away nearly all its original tabular surface. Toward its eastern extremity its lower slopes bear extensive accumulations of sand hills, notably in the region south of Camp Clarke.

The Pumpkinseed Valley south of this ridge is elevated somewhat above the valley of North Platte River, into which it opens at Lapeer. It varies in width from 7 to 12 miles. It is characterized by gentle slopes, which extend north to the steep slopes and buttes of the ridge above described and to the south to the cliffs and canyons at the edge of the high table. Lawrence Fork, the principal branch of Pumpkinseed Creek, occupies a valley which heads to the south and west on the surface of the table-lands.

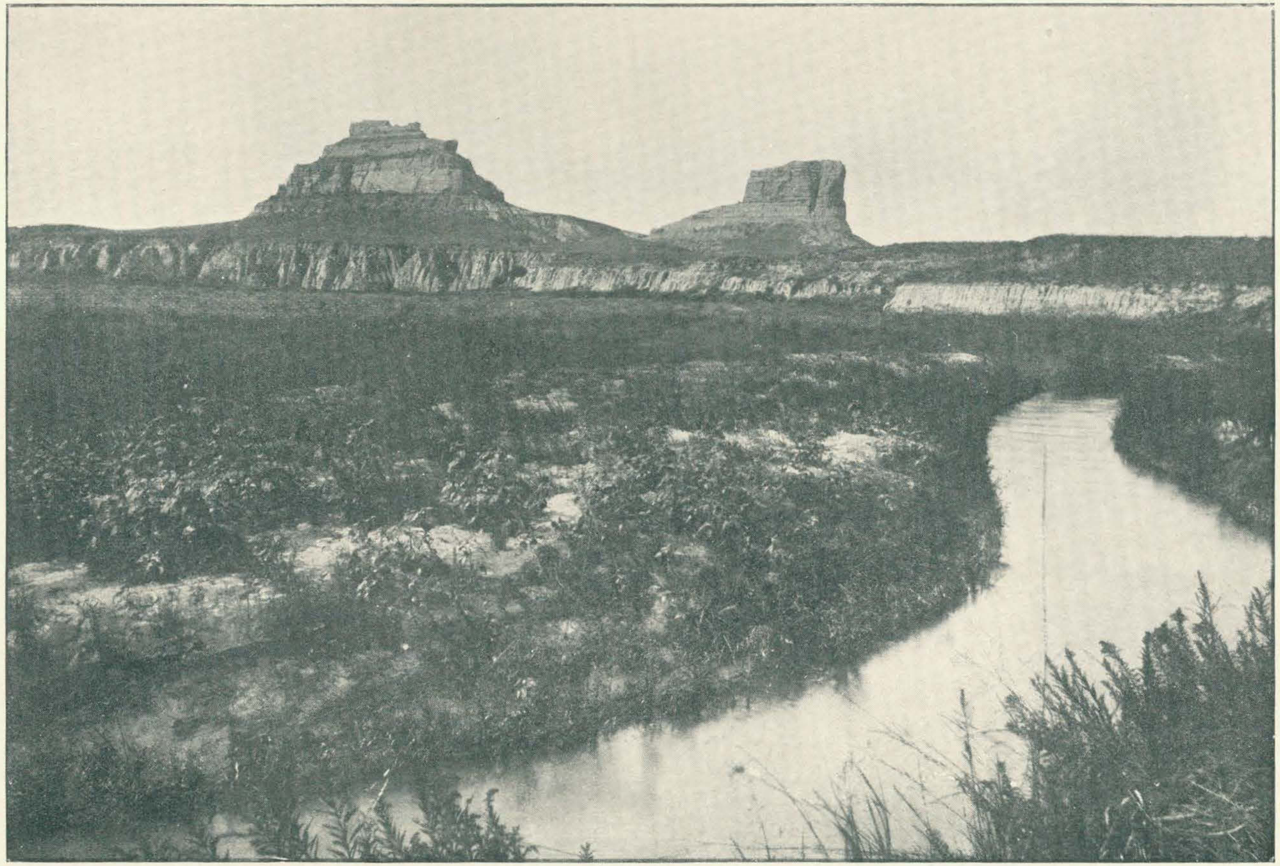
Lodgepole Valley.—Lodgepole Creek has cut a narrow, steep-sided trough in the plains to a depth averaging 300 feet. The valley contains a flat which has a declivity of about 17 feet to the mile, having an altitude of about 4,100 feet on the one hundred and third meridian and nearly 5,000 feet at the Wyoming line. Its average width varies from 1½ to 3 miles. The principal branch is Sidney Draw, the two forks of which rise on the table-land in the vicinity of the Colorado line.

Niobrara Valley.—The Niobrara River flows in a wide, relatively shallow valley, high up on the table-lands lying between the valley of North Platte River and the crest of Pine Ridge. It enters Nebraska from Wyoming, flows southeast for 20 miles, and then nearly due east. At the Wyoming line its altitude is about 4,700 feet, and at the one hundred and third meridian about 3,900 feet, which indicates a gradient of 13 feet to the mile. The valley bottom is seldom over half a mile in width, with gentle slopes interrupted by occasional low cliffs. The bottom of the valley is only from 400 to 500 feet below the crest of Pine Ridge, and it is uniformly about 400 feet above the level of North Platte River along a north-northeast and south-southwest line, while to the north the lowlands beyond Pine Ridge are at altitudes about 600 feet lower than Niobrara River.

White River Valley.—White River rises in Pine Ridge, near Harrison, at an altitude of about 4,800 feet, or several hundred feet higher than Niobrara River, a short distance to the southwest. It flows to the east, and has excavated a gorge in the northern face of Pine Ridge, which has a fall of 1,100 feet in the first 20 miles, a declivity of 55 feet to the



SCOTTS BLUFF, FROM NORTH SIDE OF NORTH PLATTE RIVER.
Dome Rock in the distance.



COURTHOUSE AND JAIL ROCKS, FROM THE SOUTH.

Courthouse Rock irrigation canal in the foreground.

mile. Near Crawford the valley of White River merges into the rolling plains at the foot of Pine Ridge, and then extends northeast as a wide, shallow depression among rolling hills, in which its declivity is only 20 feet a mile. Its altitude at the one hundred and third meridian is about 3,100 feet. The river receives many streams from the deep canyons in the northern front of Pine Ridge, and a number of intermittent creeks from the rolling country northward.

Hat Creek Basin.—Hat Creek is a branch of the South Fork of Cheyenne River. It rises in a canyon in the north front of Pine Ridge, in Sioux County, and receives numerous branches also heading in this front. To the east, where Pine Ridge trends southeast and passes around toward the head of White River, the divide between the Hat Creek and White River drainages is a low, narrow ridge, which projects from the spur of Pine Ridge, near Adelia, and extends far to the northeast into South Dakota. The highest points on this divide beyond Round Top, the high spur of Pine Ridge, are some outlying mounds, of which the most conspicuous is the Sugar Loaf, due north of Adelia. Where the ridge is crossed by the Burlington and Missouri River Railroad, north-northwest of Adelia, the altitude is 3,816 feet. From the Sugar Loaf northeast the ridge is moderately high for some distance, and then gradually diminishes in height. It is crossed by the Deadwood line of the Fremont, Elkhorn and Missouri Valley Railway at an altitude of about 3,650 feet.

The upper portion of the Hat Creek Basin consists of deep canyons extending far into the north front of Pine Ridge. The sides of these canyons rapidly diminish in height to the north, and soon give place to a region of low rolling hills having a generally gentle slope northward. On the South Dakota line the altitude of Hat Creek is about 3,500 feet.

Sand hills.—There is in this portion of western Nebraska a narrow extension of the great sand-hill area of Nebraska. The hills are comprised in a series of detached groups, lying mainly in the northern portion of Cheyenne and the south-central portion of Sioux counties, which cover an area of about 300 square miles. Their distribution is shown on the map, Pl. LXXXIV. The hills are mainly from 50 to 150 feet in height, and the areas consist of assemblages of irregular dunes with intervening basins and valleys. In T. 26, R. 55, and T. 27, R. 56, there are some exceptionally high sand hills, which rise somewhat over 5,000 feet in altitude, or from 200 to 250 feet above the surrounding plain. The lower dunes are in greater part covered with a scanty growth of grass, but there are many areas of considerable extent in which the sand is bare and loose. These localities are generally "blowouts" on the northwest slopes of the larger dunes. There is an extensive local sand-hill area along the south side of the valley of North Platte River, on the slopes south of Camp Clarke, which extends as far eastward as the vicinity of Courthouse Rock. The width of this belt is but 5 miles at most, and its length about 15 miles. An area of smaller size lies just west of Chimney Rock.

GEOLOGY.

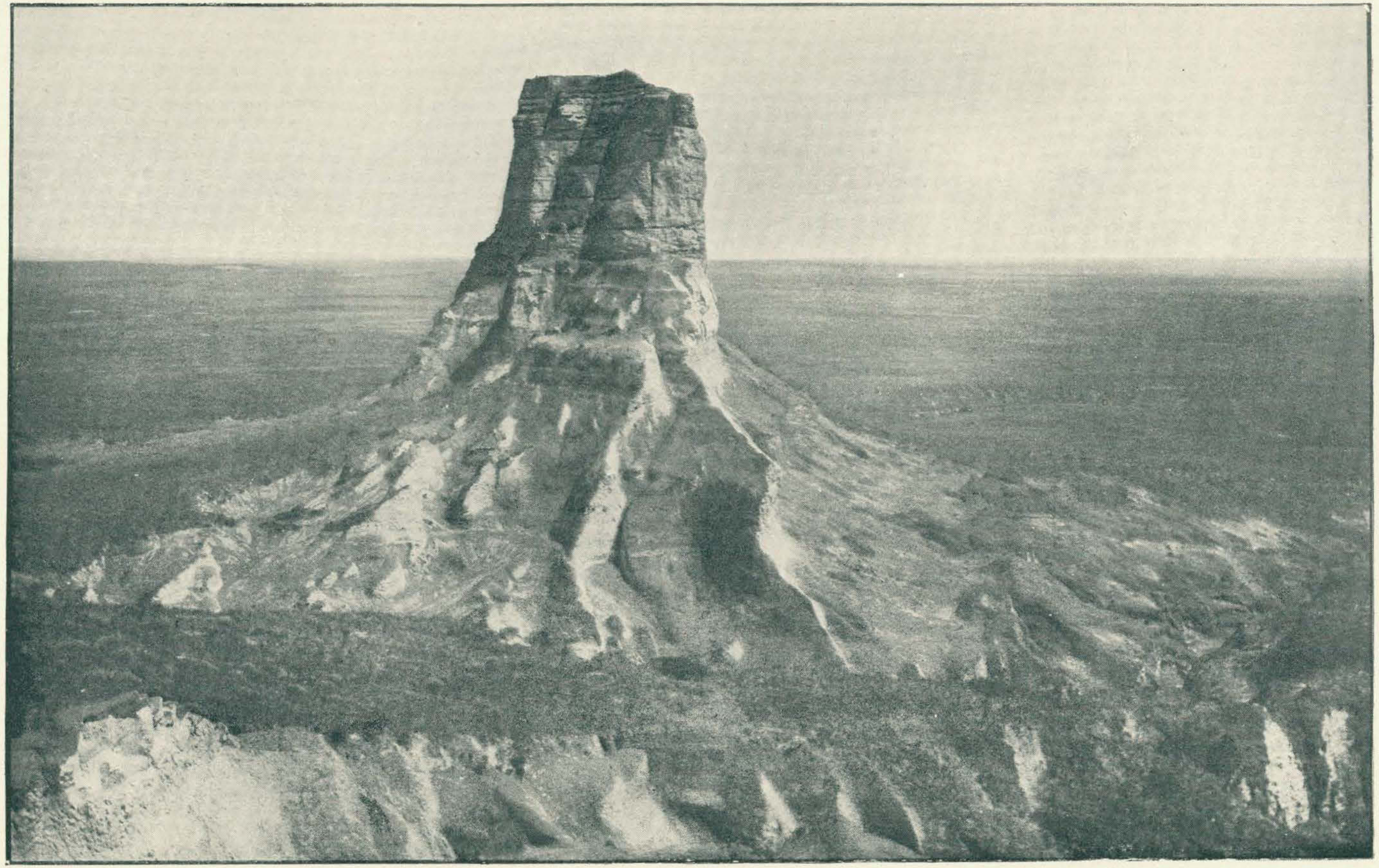
GENERAL GEOLOGY OF NEBRASKA.

The geology of Nebraska presents broad structural features which it is necessary to outline before a clear idea can be given of the local relations in the western portion of the State. The principal formations which outcrop are extensive sheets of sands and clays of Cretaceous, Tertiary, and Pleistocene age, underlain by Carboniferous limestone, which outcrops in the southeastern counties. In the map, Pl. LXXXII, an attempt has been made to indicate the present state of knowledge of the distribution of the principal formations. It is based on a large number of new data from personal observations made during the last three seasons. In the cross section, Pl. LXXXIII, are shown the principal structural relations of the formations. The following list sets forth their order, age, and salient features:

Table of geological formations in Nebraska.

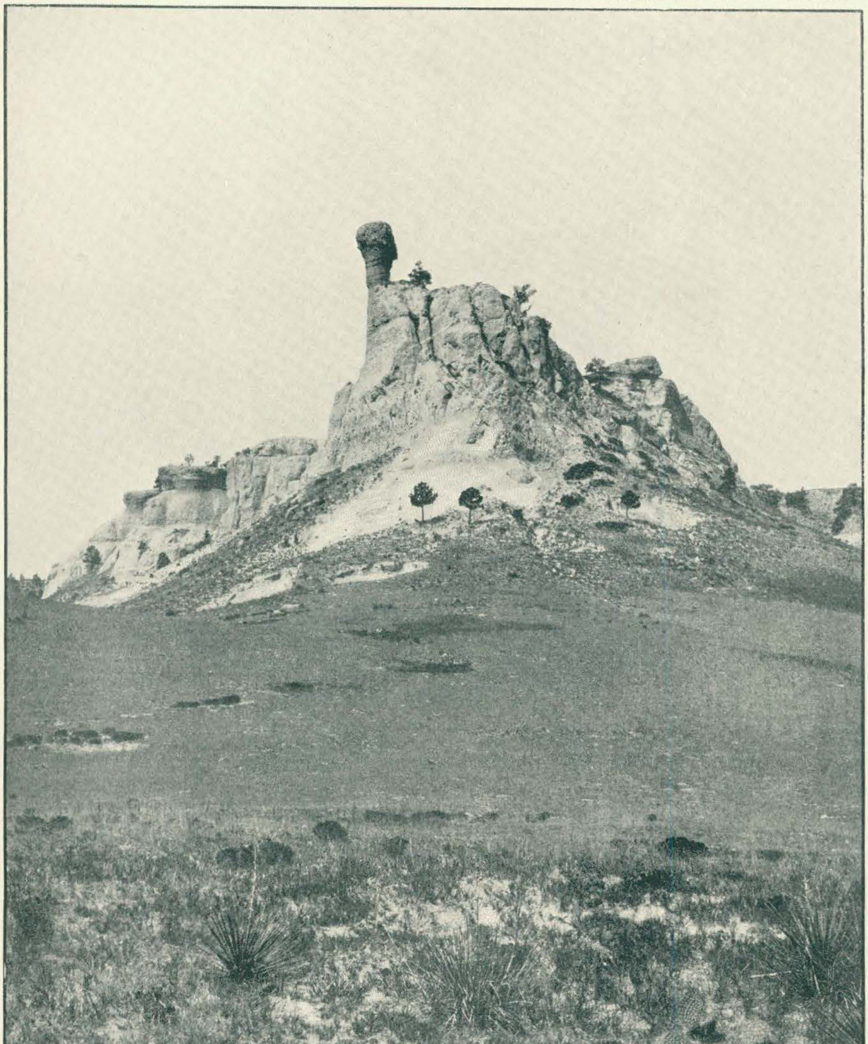
Age.	Name.		Predominating characters.
Pleistocene	Alluvium		Sand, loam, and gravel in valleys; talus on slopes.
	Sand hills		Sand mainly in dunes, due to wind action.
	Loess		Fine sandy loam of pale brownish-buff color.
	Drift		Bowlder clays and sands of glacial origin, and sandy clays, sands, and pebble beds.
	Equus beds		Gray sands.
Pliocene ?	Ogallala formation	Loup Fork beds.	Calcareous grit, sandy clay, and sand.
Miocene	Arikaree formation		Gray sand with beds of pipy concretions.
	Gering formation		Coarse sands, soft sandstone, and conglomerate.
Oligocene ?	Brule clay	White River group.	Pinkish clays, hard, and more or less arenaceous.
	Chadron formation		Pale greenish-gray sandy clay.
Cretaceous	Pierre clay		Dark-gray clay or soft shale.
	Niobrara formation	Montana group.	Chalky limestone and shale.
	Benton shale		Dark-gray or black shale or clay.
	Dakota sandstone		Brown sandstone.
Carboniferous	Permian limestone		Buff limestones and shales.
	Cottonwood limestone		Massive limestone of light color.
	Wabaunsee formation		Limestones, shales, sandstones, and thin coal beds.

Alluvium.—Owing to the softness of the Cretaceous and Tertiary formations which constitute the surface of the greater part of Nebraska,



JAIL ROCK, FROM THE WEST.

Gering sandstone on Brule clay. Valley of North Platte River in the distance.



SMOKESTACK ROCK, FROM THE EAST.
Showing outliers of conglomerate in Arikaree formation.

the river valleys are wide, and they are floored to a greater or less depth with deposits of alluvial materials brought by the streams at various stages of their development. The largest alluvial areas are along the valley of Platte River, which has a width of 15 miles in the central portion of the State. Southwest of Omaha, where the river crosses the hard rocks of the Carboniferous which rise in the eastern part of the State, its valley is narrowed greatly. The valleys of Republican, Blue, Nemaha, the Loups, Elkhorn, and Niobrara rivers contain alluvial deposits of moderate width, and all the smaller valleys contain local alluvial materials to a greater or less degree. The deposits are mainly sands and loams, intermixed with pebbles in some localities, and occasionally associated with local beds of clay and accumulations of peat and diatomaceous earth.

Sand dunes.—A wide area of central Nebraska is occupied by wind-blown sands, constituting the great sand-hill district. Its area is about 24,000 square miles. The sand in this district is blown into high ridges and hills, but there are numerous intersecting valleys of various size which constitute a moderate proportion of the area. There are local accumulations of wind-blown sand of considerable extent along the valley of Platte River south of Kearney, along Loup River north of Grand Island, along the south slopes of the North Platte Valley west of the one hundred and third meridian, and in Chase, Perkins, and Lincoln counties.

The sands were largely derived from the Arikaree formation, but it is also probable that they are in part the remains of formations of early Pleistocene age or an extension of the Equus deposits or the loess.

Loess.—The loess occupies more than one-third of the area of Nebraska, usually giving rise to level plains, which it underlies to a thickness of about 100 feet. The widest area is in the table-lands south of Platte River. To the northwest it is overlapped by the sand hills, but it extends far north in the eastern portion of the State and to the southwest to Dundy County. On the divides it is limited on the west by the high lands in Chase and Hayes counties, but extends farther up the valley of Republican River. The western margin in Deuel County is marked by high ridges of Tertiary formations, which constituted a shore against which the loess was deposited. The material of the loess is a fine sandy loam, somewhat calcareous, and chiefly of a pale brownish yellow color. Occasionally streaks of sand and old soil are found, and some portions are slightly more argillaceous than usual. The deposit is of a remarkably uniform texture, compact, but perfectly soft. Much of the water falling upon its surface is absorbed, but on steep slopes there is rapid excavation wherever a rivulet gets a fair start. In the lower part of the formation, possibly underlying it and entirely separate, are deposits of volcanic ash, usually mixed with more or less fine sand, but often consisting almost entirely of fine shreds of volcanic glass.

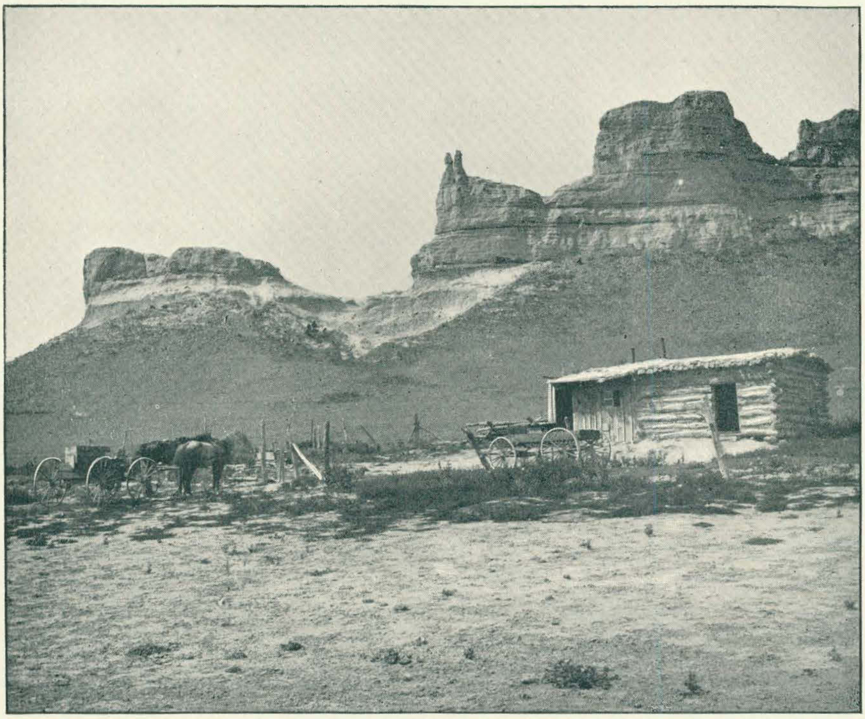
The thickness of the loess is variable, but over a wide area of the central portion of the State it averages 100 feet. It has similar thickness at most points near Missouri River. In the region of drift hills about Lancaster County the thickness varies from 20 to 100 feet.

The loess is generally fossiliferous, containing many species of fresh-water and land shells.

The loess is the product of a relatively long period of deposition at the close of glacial times. In the wide area in central Nebraska it was deposited by Platte River at a stage when the river spread as a wide plexus of streams over the divide south of its present course. The deposits extend far up the slopes of the high drift hills about Lancaster County, and probably the greater portion of this area was originally entirely covered by earlier loess. Missouri River spread a wide mantle of loess across the eastern margin of the State, and in the later stages of deposition this loess was deposited in the lower, wider valleys among the drift hills.

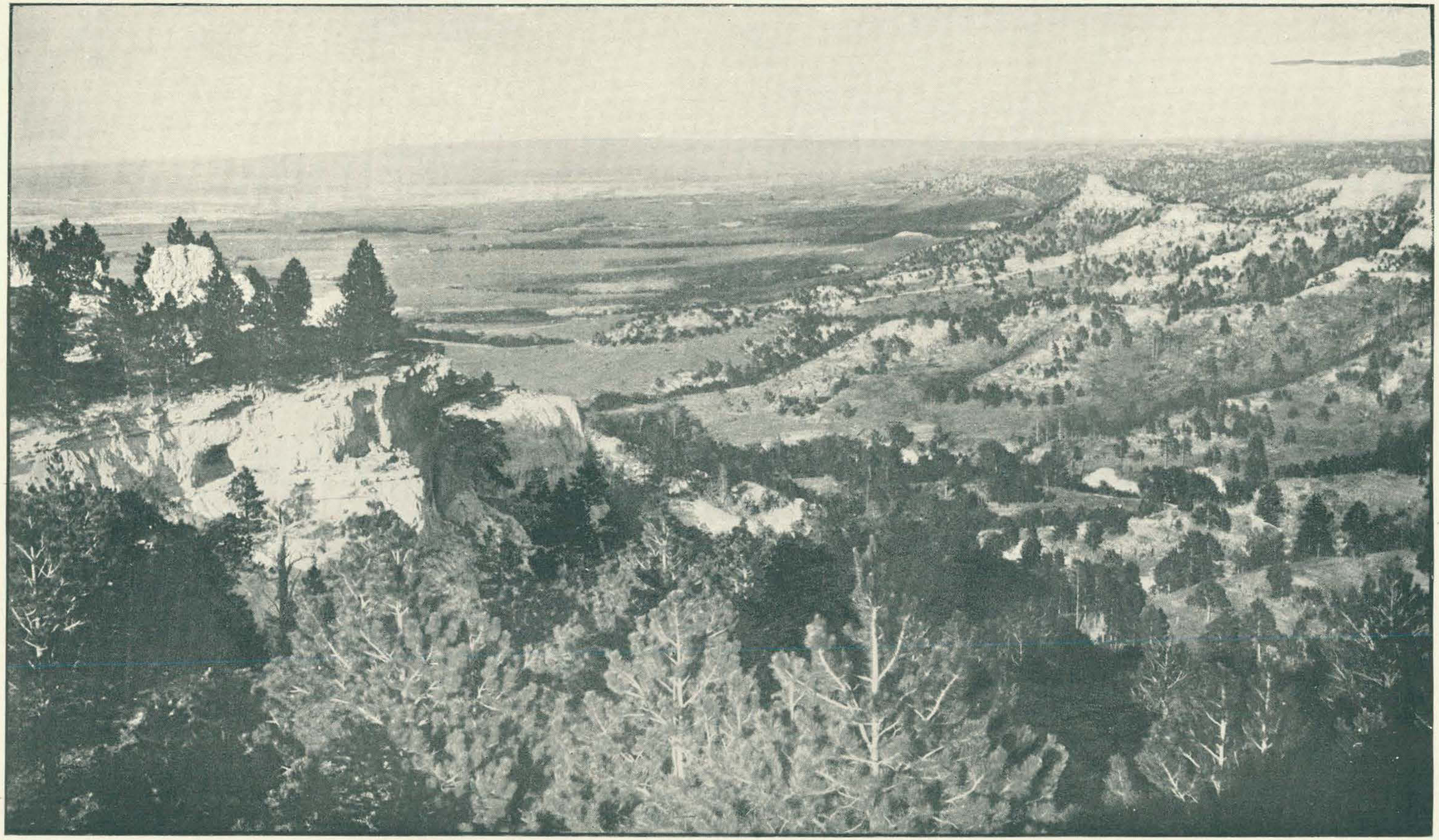
Drift.—The glacial drift covers the greater part of Nebraska east of longitude 97° 30′. It is a product of the Kansan epoch of the drift period, when a lobe of the glacier extended to Kansas River. Extending west from the glacial-drift border there is a thin sheet of sands and gravels which is continuous under the loess to beyond the one hundred and second meridian. The greater portion of the glacial drift consists of blue and gray bowlder clays. There are locally included sand beds, and in some localities extensive deposits of bowlders. The pink Sioux quartzite, often in very large masses, is a conspicuous feature of the drift, but there are many other rocks associated with it. Wide areas of clay surfaces with only a few scattered bowlders occur, and there are other areas of light sandy clays, particularly on the higher level lands, which appear to be loess merging into the glacial drift. The drift is thick in Lancaster and Gage counties. It thins rapidly toward Missouri River, where it is usually represented by a thin layer of gravel underlying the thick mantle of loess. The thin drift sheet, which extends far west from the glacial-drift margin under the loess, is usually sand or sandy clay, commonly of pinkish color. To the north it is often represented by coarse sand, and to the west it merges into a gravel bed. Pebbles of a great variety of rocks, apparently mainly of Rocky Mountain origin, occur throughout. The westernmost extension observed of this deposit was in the table-land north of Big spring, in Deuel County, where it was represented by a bed of gravel 20 feet thick underlying 100 feet of loess.

Ogallala formation.—Extending from Kansas and Colorado far into Nebraska there is a calcareous formation of late Tertiary age to which I wish to apply the distinctive name *Ogallala formation.* It is a portion, if not the whole, of the deposit which in Kansas and southward has been called the "Mortar beds," "Tertiary grit," and other names. It has been regarded as a portion of the Loup Fork formation. It is extensively developed in the western part of Nebraska, in the region



A. "TWIN SISTERS," BANNER COUNTY, NEBRASKA.

B. WIND EROSION IN GERING FORMATION, BANNER COUNTY, NEBRASKA.



NORTH FACE OF PINE RIDGE, LOOKING NORTHEAST OVER HAT CREEK BASIN.

Showing cliffs of Arikaree formation. Bad lands in Brule clay in the distance.

(From photograph by E. H Barbour, University of Nebraska.)

about Lodgepole Creek and the area between Platte River and the Kansas line west of the ninety-ninth meridian. It thins out in Banner County and in the central part of Cheyenne County, giving place to the northwest to an underlying member of the Loup Fork series. It crosses North Platte River in the western part of Deuel County, but its limits in the central and northern portions of the State have not been ascertained. It appears to underlie a portion at least of the great sand-hill district. In its typical development the Ogallala formation is a calcareous grit or soft limestone containing a greater or less amount of interbedded and intermixed clay and sand, with pebbles of various kinds sprinkled through it locally, and a basal bed of conglomerate at many localities. In places it merges into a light-colored sandy clay, generally containing much carbonate of lime in streaks or nodules. The pebbles it contains comprise many crystalline rocks, which appear to have come from the Rocky Mountains. These pebbles accumulate on the disintegrating surfaces of the Ogallala formation, and they appear to have contributed largely to the gravel bed underlying the loess to the eastward.

Arikaree formation.—In the western portion of Nebraska there is found underlying the Ogallala formation a series of sands of gray color everywhere characterized by layers of dark-gray concretions which often have tubular form. This formation enters the State from Wyoming, and has been found to thin out under the Ogallala formation in the eastern portion of Banner County. It has a thickness of 400 feet in Scotts Bluff County and of 500 feet in Sioux and Dawes counties, the amount increasing as the Arikaree displaces the Ogallala formation northward. It is extensively exposed along Niobrara River, apparently to the east of Valentine, and it is seen occasionally along the western edge of the sand-hill district, but it has not yet been distinctly recognized in the region drained by the Loup Forks or along Platte River east of Cheyenne County. In its upper portion are beds containing the large Dæmonelix of Barbour. The name Arikaree has been applied to the deposit for the reason that the Arikaree Indians were at one time identified with the area in which it is most largely developed. It is distinctly separated from the Ogallala formation by erosional unconformity and overlap, which is clearly illustrated in the western portion of the State. The formation includes a large amount of volcanic ash, as a general admixture in its sediments as well as in beds of considerable extent and thickness. It also contains a number of channels filled with conglomerate, which will be described in detail later. (See page 745).

Gering formation.—This formation, like the Arikaree and Ogallala formations, was differentiated in the summer of 1897. It consists of laminated, massive, and cross-bedded, light-gray, mainly coarse sands and soft sandstone at the base of the Arikaree formation. The character of the deposits and the abrupt change from the typical Arikaree formation has afforded a basis for the discrimination of this formation. It has been found in Scotts Bluff, Banner, Cheyenne, Sioux, and Dawes counties, and locally attains a thickness of 200 feet. It often comprises two members, more or less distinctly separated by unconformity, and it lies unconformably on the Brule clay. The materials are sands, which vary from coarse to fine, and they are often sufficiently lithified to be classed as soft sandstone. At the base there is usually more or less conglomerate of local origin. In some districts the formation thins out and appears to be entirely absent, but possibly in this case it has simply lost its distinctive characteristics, so that it would be overlooked as the lower portion of the Arikaree formation. In some cases where the formation is thought to be absent there is seen to be unconformity below the Arikaree beds.

Brule clay.—The White River beds in their extension from South Dakota into Nebraska, present some differences in stratigraphic range and relations. They expand considerably and include, at their top, beds which appear not to be represented in the typical regions. Accordingly, to afford distinct definitions for the members in Nebraska I have introduced the designation *Brule clay* and separated the underlying Titanotherium beds as the *Chadron formation.*

The Brule clay consists mainly of a hard, sandy clay, of pale-pink color. Its thickness averages about 600 feet in the vicinity of the Wyoming line, but the amount diminishes greatly eastward. In the vicinity of the one hundred and third meridian in the northwest corner of the State the amount is 320 feet. The formation has not been recognized east of longitude 101° 30′, where it appears to sink beneath the surface in the Platte Valley. It extends far to the northeast in South Dakota.

Chadron formation.—Lying under the Brule clays there is a thin sheet of light-greenish colored sandy clay, the basal member of the White River series, known as the "Titanotherium beds." Its outcrops extend in a narrow zone across the northern portion of the State, and it is apparently exposed along North Platte River near the Wyoming line. It is known to underlie portions of Colorado and South Dakota, but it appears not to extend far eastward in southern Nebraska, for it is absent along Republican River. It is reported that Titanotherium remains were obtained near Longpine, but nothing has been learned of the relation and extent of the beds in that locality.

Pierre clay.—All of Nebraska west of the ninety-eighth meridian is underlain by the Pierre clay. Its surface outcrops are in the lower portion of the Niobrara Valley, the Republican Valley, and the extreme northwestern corner of the State, but it is probable that careful search may reveal outcrops in the valley of the Platte River in the vicinity of the ninety-sixth meridian. The formation is a thick mass of dark-gray or bluish clay or soft shale. Its thickness is probably at least 2,000 feet in the central-western portion of the State.

PRELIMINARY GEOLOGIC MAP OF NEBRASKA, BY N. H. DARTON, 1898

Scale

25 0 25 50 75 100 125 MILES

$\frac{1}{2.500.000}$

PLEISTOCENE

ALLUVIUM (Only the wider areas are shown)

SAND HILL DISTRICTS (The sand hills lie on unclassified tertiary formations which outcrop in some of the valleys.)

LOESS (Underlain by drift which is of glacial origin east of the line – – – – – Some higher portions of glacial drift area appear to be bare of loess)

TERTIARY

OGALLALA FORMATION

ARIKAREE FORMATION (Overlain by Equus beds to the northeast.)

GERING FORMATION

BRULE CLAY

CHADRON FORMATION (Titanotherium beds)

UNCLASSIFIED TERTIARY (Mainly Arikaree and Ogallala formations or "Loup Fork")

CRETACEOUS

PIERRE CLAY

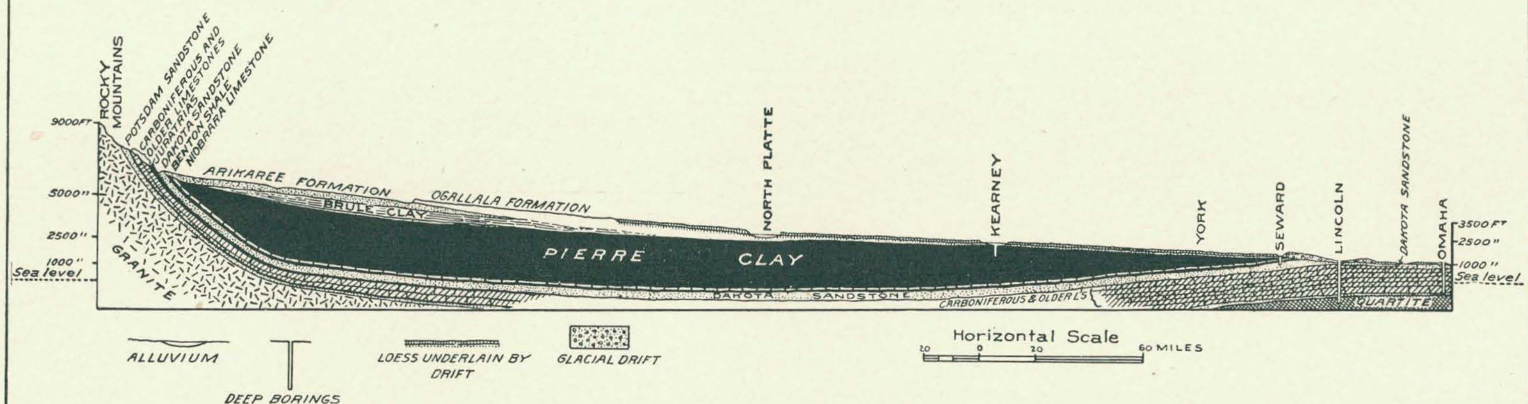
BENTON AND NIOBRARA FORMATIONS

DAKOTA SANDSTONE

CARBONIFEROUS

PERMIAN LIMESTONE

COTTONWOOD AND WABAUNSEE FORMATIONS



CROSS SECTION FROM THE ROCKY MOUNTAINS TO OMAHA, ACROSS NEBRASKA.

Niobrara and Benton formations.—Underlying the Pierre clay there is a series of chalky limestones known as the Niobrara formation and slabby limestones and shales known as the Benton formation. They have a thickness of about 450 feet to the east, but thicken to the west. At the base there are about 200 feet of dark shales, next follow slabby limestones containing Inoceramus, then a member consisting of shales, and at the top the Niobrara formation with its chalky deposits characterized by thin hard beds filled with *Ostrea congesta.* The formations cross the eastern portion of the State, and underlie all of the area west of the vicinity of the ninety-seventh meridian, but they are so deeply buried under drift and loess that outcrops are rarely visible. The most extensive exposures are along Missouri River extending from near the ninety-seventh to the ninety-ninth meridian, and along the Republican Valley from Alma to near Superior. The formations are exposed at intervals across the eastern portion of the State in each of the larger valleys and some of the branches. The more notable of these small outcrops are at Genoa, north of Germantown, near Crete, at Pleasant Hill, and in Beaver Creek north of Dorchester. There is an exposure of dark shales under some ledges of Inoceramus limestone in Big Blue River at Milford, which are Benton. During the summer of 1897 upper Benton and Niobrara beds were discovered rising in a prominent anticline along White River in the vicinity of Beaver and Alkali creeks, in the northwest portion of the State.

Dakota sandstone.—The Dakota sandstone underlies nearly all of Nebraska, and outcrops in a narrow belt extending from Missouri River to the vicinity of the ninety-seventh meridian. It is gray or brown sandstone, containing streaks of clay of greater or less size, and its aggregate thickness is about 400 feet, including a basal series of Lower Cretaceous sandstone. Its surface passes under the Benton shales, and with the low westerly dip and gradual increase in altitude of the State to the west, the Dakota sandstone is soon deeply buried. In the central portion of the State it probably lies over 2,500 feet below the surface. In its outcrop area it is heavily covered by drift and loess, but there are numerous exposures in the banks along Missouri River in Dakota County—which was the type locality of the formation—along Platte River from Ashland nearly to Plattsmouth, along the valley of Salt Creek and its branches, at Beatrice, and in the valley of Little Blue River in Jefferson County. The formation carries the great artesian-water supplies, which are so extensively developed by wells in eastern South Dakota and on low lands in Knox, Cedar, and Boyd counties, Nebraska.

Carboniferous formations.—The Carboniferous limestones, shales, and sandstones underlie all of Nebraska, rising to the north and northwest about the Black Hills and on the slopes of the Rocky Mountains, as shown in Pl. LXXXIII and fig. 228, on page 764. The outcrops in eastern Nebraska are in Douglas, Sarpy, Cass, Lancaster, Otoe, Gage, Johnson, Pawnee, Nemaha, and Richardson counties. The rocks are hard and would give rise to more prominent features in this region if it were not for the heavy covering of glacial drift and loess. As it is, the exposures constitute cliffs along Platte River from Ashland to Plattsmouth, and thence at intervals along Missouri River to the southeast corner of the State, and occur in scattered outcrops along the valleys of Big Blue, Nemaha, and Little Nemaha rivers and Weeping Water, Turkey, and Southeast Salt creeks and their branches.

The rocks of the Carboniferous period in this region comprise formations of Permian and upper Coal Measure or Missourian age. The Permian outcrops are probably restricted to the valley of Big Blue River from Beatrice southward. The rocks are mainly magnesian limestones of light color with interbedded shales. They are extensively exposed south of Beatrice, at Rockford, Blue Springs, Wymore, and Holmesville. The other Carboniferous members appear to comprise the Cottonwood and Wabaunsee formations of the Kansas geologists. They consist of limestones, shales, and sandstones, which contain thin coal beds in some localities. Professor Prosser has made a preliminary examination of the Carboniferous of Nebraska, and identifies as Wabaunsee the exposures about Peru, Aspinwall, Nebraska City, Auburn, Tecumseh, Dunbar, Nehawka, Weeping Water, and in the long section along Platte River, near Louisville. The Cottonwood limestone, a massive bed full of Fusulina, was recognized west of Auburn about Glen Rock and Johnson, and the same beds extend over the higher lands of western Richardson and Pawnee counties.[1] In the deep borings, which have been made at various points in the southeastern corner of the State, it has been found that the Carboniferous formations have, in all, a thickness of about 1,200 feet, of which about 200 feet are Permian. In the deep well at Lincoln the lower limestones were found to be 835 feet thick and underlain by 800 feet of magnesian limestones of undetermined, but probably in part Devonian age; this, in turn, by limestone apparently of the Trenton formation, extending from 1,813 to 1,947 feet; a supposed representative of the St. Peter sandstone, having a thickness of 61 feet; 113 feet of magnesian limestones, supposed to be the Magnesian limestone of the Mississippi Valley; and a red sandstone, extending from 2,121 to 2,192 feet, thought to be Cambrian. This was found to lie on a red quartzite—penetrated for 270 feet—supposed to be an extension of the Sioux Falls quartzite of Algonkian age, which is underlain by granite rocks northward.

There are possibly two other formations underlying portions of Nebraska but not reaching the surface. To the northwest there is doubtless an extension of the Juratrias red sandstones and greenish sands and clays which are exposed so conspicuously about the margin of the Black Hills, only 55 miles distant from the northwest corner of the State. They lie between the Carboniferous limestone and the

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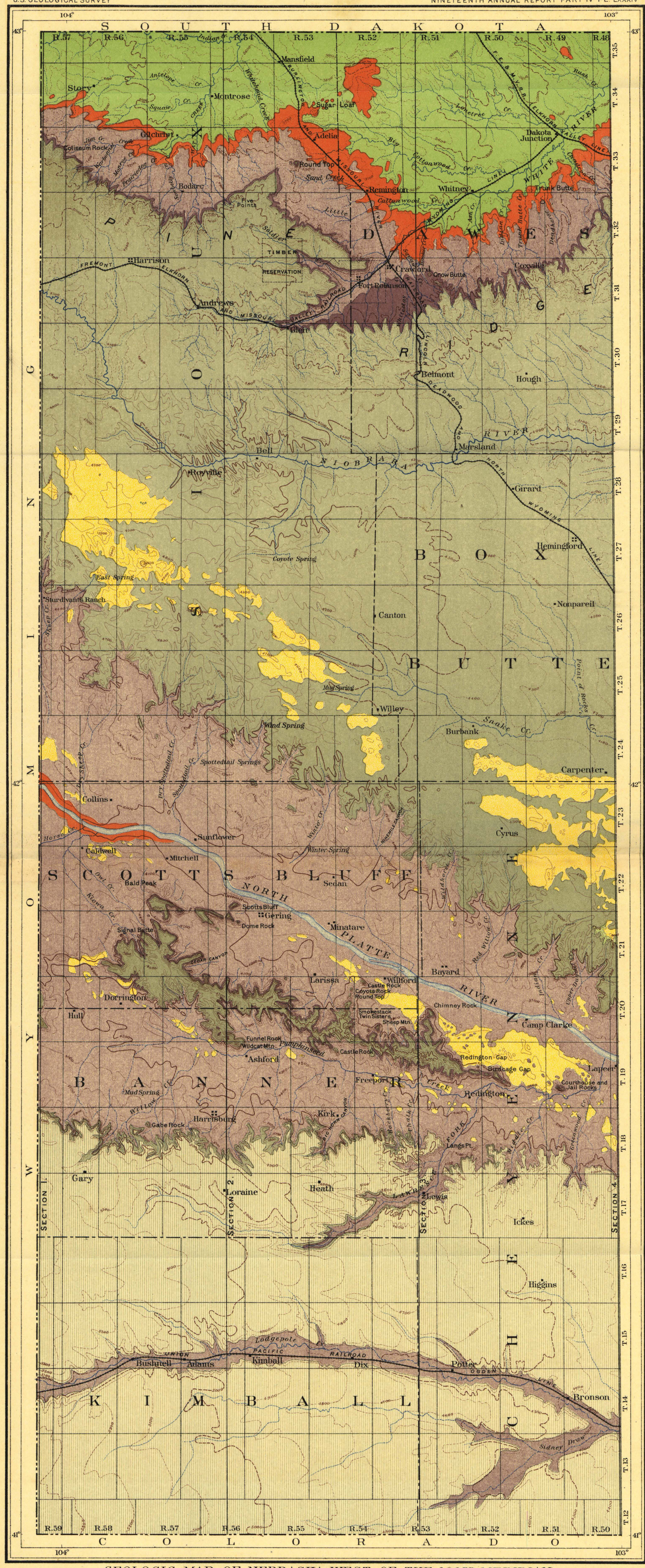
[1] Jour. Geol., Vol. V, 1897, pp. 1-16.



GEOLOGIC MAP OF NEBRASKA WEST OF THE 103RD MERIDIAN

BY N. H. DARTON

Contours generalized from maps of U.S.Geological Survey

Contours approximated from R.R.levels and barometer readings

Scale

5 0 5 10 15 20 25 MILES

Contour interval 100 feet

TOPOGRAPHY FROM U.S.G.S. MAPS AND ORIGINAL OBSERVATIONS

DUNE SANDS

GRAVEL, AGE UNKNOWN

OGALLALA FORMATION

ARIKAREE FORMATION

GERING FORMATION

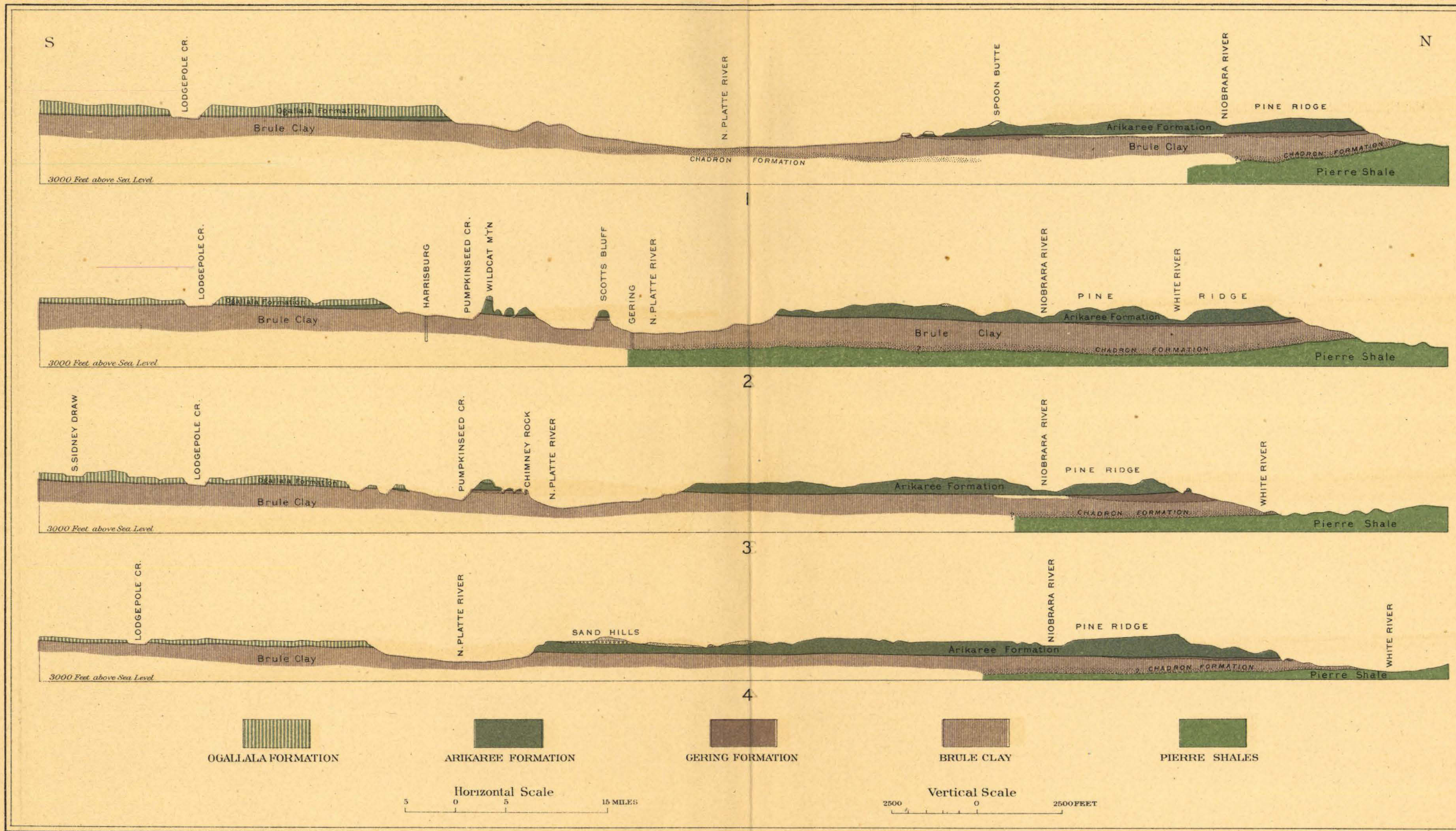
BRULE CLAY
widely overlain by gravel and alluvium along valleys and partly covered by wash on slopes

CHADRON SANDS
(Titanotherium beds)

PIERRE CLAY

Streams dry or underground in summer

JULIUS BIEN & CO. LITH. N.Y.



JULIUS BIEN & CO. LITH. N.Y.

GEOLOGIC SECTIONS ACROSS NEBRASKA WEST OF THE 103RD MERIDIAN, LOOKING WEST

BY N. H. DARTON, 1898

Dakota sandstone, as shown in the sections, Pl. LXXXIII and fig. 228, on page 764. They are absent in the eastern portion of the State, but in part are extensively developed in Kansas.

The other formation which may extend into Nebraska is the Laramie sandstone, which lies between the Pierre shale and the Tertiary formations in northeast Colorado. It would not be surprising if this formation should be found to underlie a portion of extreme western Nebraska, but it is known to be absent in the Republican Valley as far west as Dundy County, and in the region north of Pine Ridge, in Sioux and Dawes counties.

GEOLOGY OF THE REGION WEST OF THE ONE HUNDRED AND THIRD MERIDIAN.

GENERAL RELATIONS.

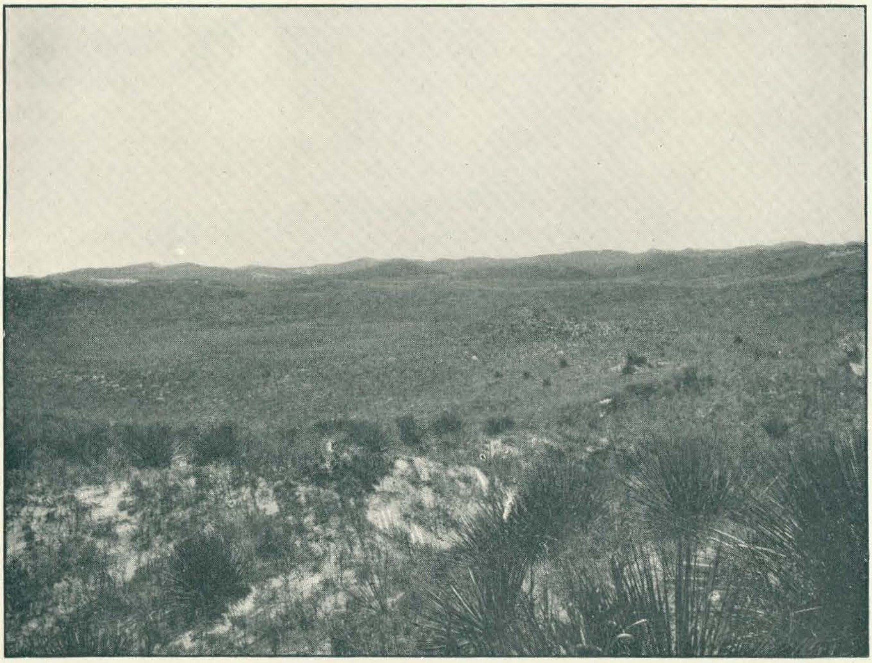
The formations of this region comprise alluvium and dune sands and Ogallala, Arikaree, Gering, Brule, and Chadron formations, lying on a thick mass of Pierre clay. The loess and drift are not present. The distribution of these formations, except the alluvium, is shown on the geologic map, Pl. LXXXIV. Their structural relations are shown in the series of cross sections, Pl. LXXXV. The older formations underlying the Pierre shale do not reach the surface nearer than the southern slopes of the Black Hills, where, as shown in fig. 228, they rise in regular succession.

The relations of the formations, as shown in Pls. LXXXIV and LXXXV, are relatively simple. There is a broad, thick sheet of Brule clay, underlain by a thin layer of Chadron formation, lying on the irregular surface of the Pierre clay, which outcrops in the region north of the foot of Pine Ridge. The Gering formation is a thin sheet of coarse sand and soft sandstone which lies on the Brule clay mainly in channels. It appears to outcrop continuously along the northern front of Pine Ridge, about halfway up the slope; it has been recognized at one point on the north slope to the valley of North Platte River. It is extensively developed in wide channels in the ridge lying next south, but it is absent in the table-land south of Pumpkinseed Creek, except probably in a small outlier exposed far up the valley of Lawrence Fork. The Arikaree formation, consisting of fine sands with dark-gray pipy concretions, constitutes the crest of Pine Ridge and the table-land extending north of the Platte Valley. It also heavily caps the ridge lying between the valleys of the Platte and the Pumpkinseed, but it thins rapidly to the south and east in the high table-land south of the Pumpkinseed Valley, and dies out east of the mouth of Lawrence Fork. The Ogallala formation, consisting mainly of light-colored pebbly sands cemented by carbonate of lime, covers the table-land south of the Pumpkinseed Valley, lying on the Brule clay to the east and on a thickening wedge of the Arikaree formation to the west. Outlying masses cap certain high points on the ridge north of the Pumpkinseed Valley, and it may possibly be present on the higher portions of the table-land north of Platte River, together with outliers of the Equus beds. The larger sand-hill areas are on the table-land north of the valley of Platte River, but smaller areas are found in both Platte and Pumpkinseed valleys. Alluvium, which is not represented on the map and sections, floors portions of the valleys and merges upward into wash and local talus on the slopes of the hills.

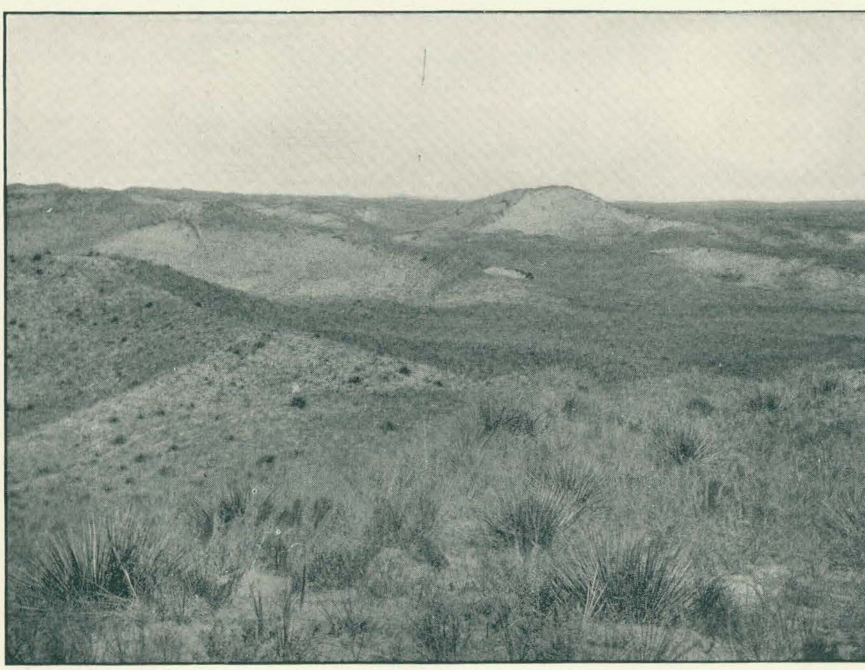
ALLUVIAL FORMATIONS.

On the lower slopes adjacent to North Platte River and along the other streams of the region there has been deposited a greater or less thickness of materials brought by the streams from the higher lands. In the valley of Platte River there is a wide zone of bottom lands bordering each side of the river, on which is found a mantle of alluvium, several feet thick, lying on the older formations in which the river valley was cut. The materials consist mainly of sandy loams with occasional coarse constituents. On the adjoining terraces above is found a mantle of sand and gravel, deposited when the river was much higher than it is now. The gravels contain many rocks from the Rocky Mountains, comprising granites of various kinds, quartzites, chalcedonic vein stones, often of considerable beauty, and a small variety of eruptive rocks. The materials vary in size from coarse sand to moderately large bowlders. The coarser deposits give rise to long narrow ridges or lines of knobs, while the materials of intermediate coarseness cover terraces, which in some cases extend back from the river bottom for several miles. It is claimed that small showings of gold have been panned from these formations at several localities. In the valleys of the Lodgepole and Pumpkinseed creeks and White River the alluvial materials are mainly in narrow belts of bottom lands, and consist chiefly of local materials. In the valley of Pumpkinseed Creek, however, there are at higher levels extensive deposits of coarser gravels containing rocks from the Rocky Mountains similar to those along Platte River. It is probable that this river at one time sent a branch stream through the wide depression now occupied by Pumpkinseed Creek and spread the gravel on the high terraces. At that time the ridge lying north of Pumpkinseed Creek was an island in the midst of a wider Platte River, but the valleys were not so deep as they are now. Nearly every stream flowing out of the high lands has brought down more or less alluvial material in the shape of sand or local gravel, which merges into the alluvial deposits of the larger valleys. There is also on nearly all of the slopes adjoining the valleys a talus of wash of sand and clays from above, which often covers the underlying formations to considerable thickness.

None of the alluvial formations have been shown on the geologic map, Pl. LXXXIV, because some of their relations are too intricate for accurate representation on a small scale.



A.



B.

TYPICAL SAND HILLS IN WESTERN CHEYENNE COUNTY, NEBRASKA.

A, Leeward side, looking west; *B*, Windward side, looking southeast, showing blowouts.

SAND DUNES.

The sand hills are a distinct geologic formation in this region, in part contemporaneous with the alluvial deposits along the bottoms of river valleys. They are in process of formation and modification by the strong winds, and are in a measure still moving to the southeast. Two typical views of the sand-hill region are reproduced in Pl. LXXXVI. The sand now constituting the sand hills was derived mainly from the Arikaree formation, which has been carried over the plains by the wind and accumulated about the obstructions. The manner in which the sand is blown away is well illustrated in Pl. XCI, *A*. The sand dune areas in the North Platte Valley no doubt derived a portion of their material from the sand banks and other alluvium of the river which has been blown by the wind and lodged against obstructions. This is particularly well illustrated in the area which abuts against Chimney Rock. The small areas about Caldwell and Dorrington and at other points in the Pumpkinseed Valley are probably of similar origin, except in a few cases where local sources have supplied the materials.

OGALLALA FORMATION.

The Ogallala formation is the uppermost division of the Tertiary deposits of this region. It constitutes the high table-lands on both sides of the Lodgepole Valley, and caps the several small high summits about Wild Cat Mountain, northwest of Ashford. As before explained, it is in the main the extension of the "Tertiary grit," "Magnesia," or "Mortar beds" of the Kansas geologists. It consists of an impure calcareous grit, or sand cemented with carbonate of lime. At its base there are often beds of conglomerate with pebbles, consisting mainly of gray sandstone or limestone. Throughout its mass there are scattered pebbles of crystalline rocks from the Rocky Mountains, streaks of pebbly sand, and thin ledges of sandstone. The harder calcareous beds are of white or cream color, and outcrop in irregular cliffs along the slopes of depressions. Some softer intercalated beds of sandy character are of light-pinkish color. The formation has a relatively level surface, which constitutes the floor of the high table-land of Kimball County and the southern portion of Banner and Cheyenne counties. When the rock disintegrates on the surface a greater or less accumulation of sand and scattered pebbles remains, often constituting a soil of greater or less thickness. This soil when irrigated usually proves to be very productive. The general thickness of the Ogallala formation varies from 150 to 300 feet, the greater amount being along the Wyoming line, in the northwestern corner of Kimball County. As the surface has been more or less eroded, the original thickness is unknown. The altitude of its base is 4,100 feet south of Lapeer, 5,200 feet west of Harrisburg, 4,300 feet near Bronson, 5,100 feet west of Bushnell, and 5,000 feet on Wild Cat Mountain. The wider relations of the Ogallala formation to the older Tertiary formations are shown in the cross sections in Pl. LXXXV. In these sections it will be seen that in Lodgepole Valley it lies directly on the Brule clay; along the south side of the Pumpkinseed Valley it lies on the Brule clay to the east, and then on the Arikaree formation, which comes in and gradually thickens, to the west. An exposure of its basal conglomerate is shown in Pl. LXXXVII. At this exposure the Arikaree beds are thin, as shown in Pl. LXXXVIII, *C*. It is everywhere clearly separated below by erosional unconformity, and its base is usually a shore deposit of pebbles

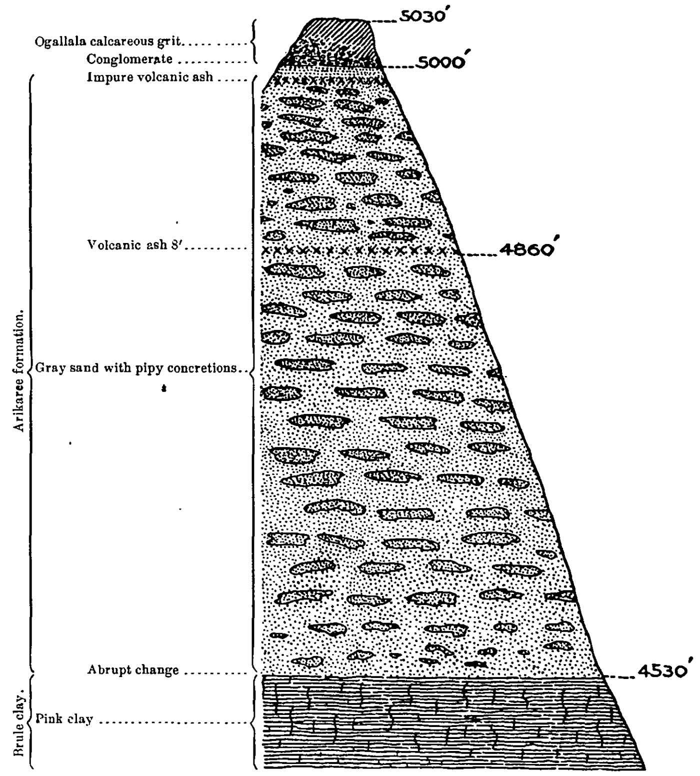


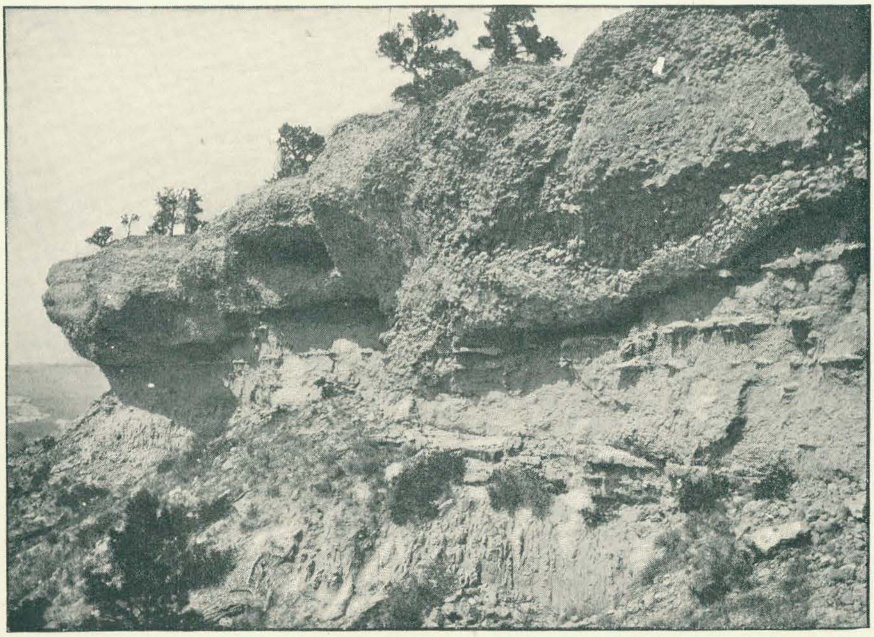
FIG. 208.—Columnar section of formations exposed in Wild Cat Mountain and vicinity, Banner County, Nebraska.

of gray siliceous and calcareous rocks. In the outliers about Wild Cat Mountain the thickness is about 50 feet, and the formation lies on a thick mass of Arikaree formation, from which the basal conglomerate is very distinctly separated by an unconformity. The relations in this vicinity are shown in fig. 208.

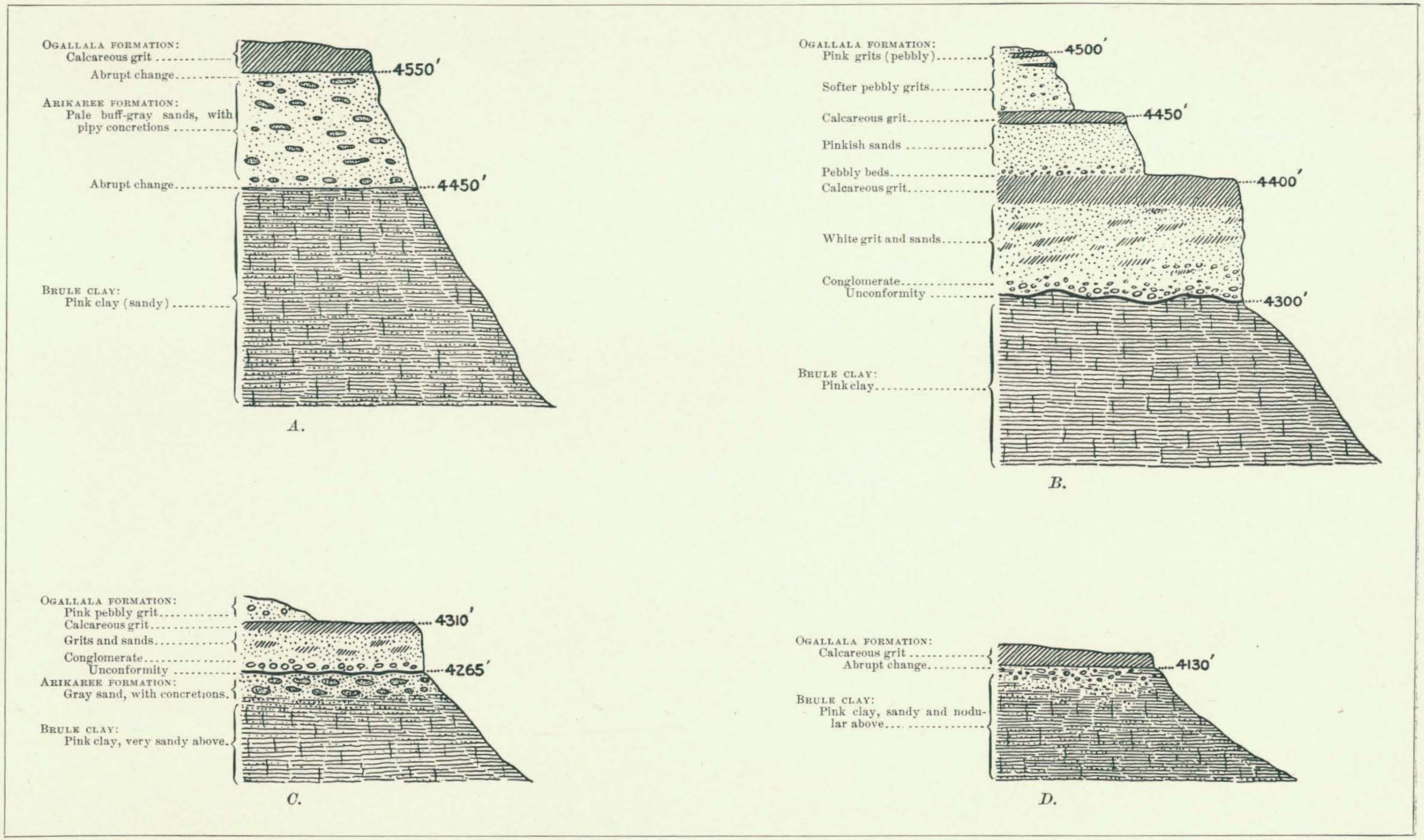
Some typical sections illustrating the relations of the formations are given in Pl. LXXXVIII. There may possibly be a small area of Ogallala formation to the east on portions of the table-land north of North Platte River, but it was not distinguished. A few vertebrate remains were collected in this formation, and it was found to contain the smaller Dæmonelix forms in considerable abundance in some localities.

A. CONGLOMERATE AT BASE OF OGALLALA FORMATION 5 MILES SOUTH-SOUTHEAST OF REDINGTON, CHEYENNE COUNTY, NEBRASKA.

The conglomerate lies on Arikaree formation.



B. CONGLOMERATE IN ARIKAREE FORMATION 3 MILES DUE SOUTH OF LARISSA, SCOTTS BLUFF COUNTY, NEBRASKA. LOOKING NORTHWEST.



SECTIONS OF EXPOSURES OF ARIKAREE AND OGALLALA FORMATIONS AT AND NEAR LANGS POINT, NEBRASKA.

A, 8 miles west of Langs Point; *B*, At Langs Point; *C*, 5 miles east of Langs Point; *D*, 10 miles east of Langs Point.

ARIKAREE FORMATION.

The Arikaree formation attains its greatest development in Pine Ridge, where it presents a thickness of about 500 feet. It constitutes a wide area of table-land extending from Pine Ridge to the northern margin of the valley of North Platte River. It occupies the ridge lying between the valleys of North Platte River and Pumpkinseed Creek, and to the southwest it is exposed in the slopes of the table-lands next south. The formation consists mainly of fine sand containing characteristic layers of hard, fine-grained dark-gray concretions, often consisting of aggregations of long, irregular, cylindrical masses. These, for convenience, have been called "pipy concretions." They vary in thickness from a few inches to several feet, but from 10 to 15 inches is a fair average. Their trend is east-northeast and west-northwest with surprising regularity. The layers are often many square yards in area. A typical exposure of the concretions is shown in Pl. XCI, *B*. The sands vary from loose to fairly compact, and some are argillaceous. The colors are uniformly light gray. Owing to the presence of the hard concretions, the formation generally gives rise to ridges of considerable prominence. The steep escarpment of Pine Ridge consists almost entirely of Arikaree cliffs, of which typical views are given in Pls. LXXXI, XC, and XCIV. The relations of the Arikaree formation to associated deposits are particularly well exposed in the slopes adjoining the Platte and Pumpkinseed valleys. The formation lies on the Gering beds at many points, but in some areas appears to rest immediately on the surface of the Brule clay. There is often no evidence of unconformity in either case. Usually there is an abrupt change in the character of the materials as the coarse beds of the Gering formation give place to fine massive Arikaree sands containing the pipy concretions. In some cases this concretionary development appears to have extended down into the Gering sediments, especially locally where these sediments are fine sands. This relation is illustrated in fig. 209, and possibly also in fig. 221, on page 753.

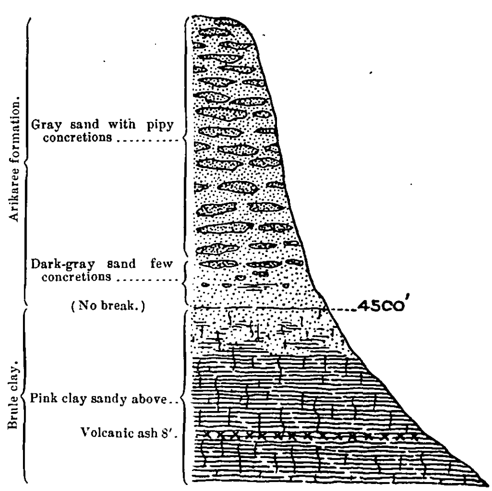


FIG. 209.—Section 6 miles southwest of Gering, Nebraska, showing relations of Arikaree and Brule formations.

There is a possibility that the upper member of the Gering formation is a basal portion of the Arikaree formation, as suggested at some localities, which would often add difficulty to the identification of the Gering formation where it consisted of only one member. Along the north side of the Platte Valley, the south side of the Pumpkinseed Valley, and in portions of the ridge between these two valleys the Arikaree formation appears to lie directly on the Brule clay. In these instances there is often either only a faint suggestion of unconformity between the two formations when the exposures are carefully examined or simply a very rapid change from sandy, pinkish Brule clay, with some small siliceous concretions, to fine gray sands, with the typical character and pipy concretions of the Arikaree formation. Fig. 210 shows the usual relations presented in the exposures along the north side of the Platte Valley.

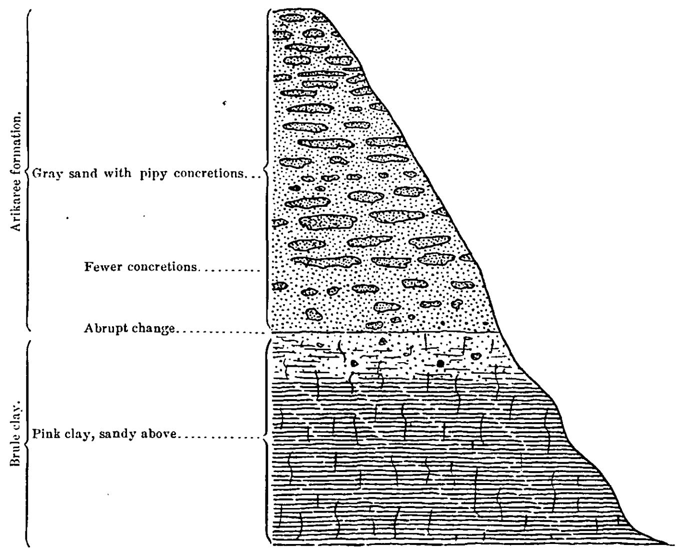


FIG. 210.—Section of Arikaree and Brule formations on the north side of the valley of North Platte River.

In Pl. XC, *B*, is shown an exposure in which there is marked unconformity between Arikaree and Brule deposits, and other exhibitions of similar relations are shown in sections *A* and *C* of Pl. LXXXVIII, sections *C* and *D* of Pl. C, and Pls. XCIX and CI. The relations of the Arikaree formation to the Ogallala formation are described on page 742. The two formations are sharply separated by an abrupt change in character of materials, and the basal Ogallala beds are mainly conglomeratic. The thinning out of the Arikaree deposits to the southeast is clearly illustrated in many exposures south of Redington. All along the northern edge of the table-land in Banner County the formation has less thickness than it presents in the ridge north, where, in the vicinity of Wild Cat Mountain, it is nearly 500 feet thick. Southwest of Harrisburg the amount is about 150 feet; south of Freeport it is 100 feet. as shown in Pl. LXXXVIII, *A;* in Hackberry Can-

SMOKESTACK ROCK, LOOKING EAST; NEAR VIEW.

Conglomerate in Arikaree formation.

A. BUTTE OF ARIKAREE FORMATION, EAST SIDE OF SOWBELLY CANYON, SIOUX COUNTY, NEBRASKA.

B. ARIKAREE FORMATION ON BRULE CLAY, SOUTHWEST PORTION OF SIOUX COUNTY, NEBRASKA. LOOKING EAST.

yon it is 40 feet; and at Langs Point Arikaree beds are absent, the Ogallala conglomerate here lying directly on the Brule clay, as shown in section *B* of Pl. LXXXVIII. Southeast of Langs Point there are a few thin outlying lenses of Arikaree beds, one of which is shown in section *C* of Pl. LXXXVIII; but thence to the east it thins out and the typical relations presented are those shown in section *D* of Pl. LXXXVIII. In the upper portion of the valley of Lawrence Fork there is an outlying area of the formation, only a few feet thick, between supposed Gering and Ogallala formations, as shown in fig. 215 (p. 749).

The Dæmonelix in various forms occurs extensively in this formation; and in Pine Ridge, in Sioux County, the large forms of the "Devil's corkscrew" are found in very great abundance in the upper beds of the formation. Prof. E. H. Barbour has described these forms in detail and given an account of their mode of occurrence.[1] The larger forms

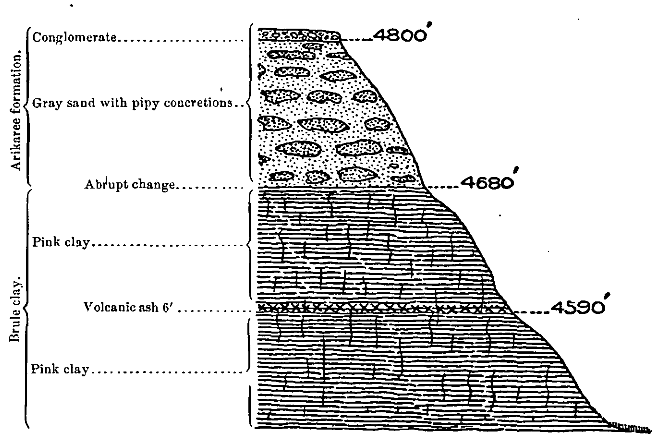


FIG. 211.—Section 4 miles northwest of Dorrington, Nebraska, showing the relations of conglomerate in Arikaree formation.

are most abundant in the upper portions of the depressions north of Harrison, but they were observed also as far east as Andrews, for some distance in the valley of Niobrara River above Royville, and as far west as Lusk in Wyoming. The smaller forms are very generally present throughout the region, and they also occur in the Ogallala formation. In Pl. XCII is shown an exposure of typical Dæmonelix beds containing the large corkscrew forms. It is believed that no one observing these fossils in the field would have any doubt as to their vegetal nature.

In a portion of its area the Arikaree formation has been observed to contain a series of old channels filled with coarse conglomerate. The occurrence of this conglomerate is apparently restricted to the ridge lying next south of North Platte River and to the vicinity of Spoon Butte, near the head of Sheep Creek, in Sioux County. The horizon is somewhat above the base of the formation, and the conglomerate is

[1] Bull. Geol. Soc. of America, Vol. VIII, pp. 305-314, 1897.

distinct from some local beds of coarse deposits occasionally noticed at or near the base of the formation.

Some of the relations of these conglomerate-filled channels are shown in section *F*, of Pl. CI, and in Pls. LXXIX, LXXXVII, and LXXXIX, and fig. 212. Beginning at the east, the first outcrops observed were

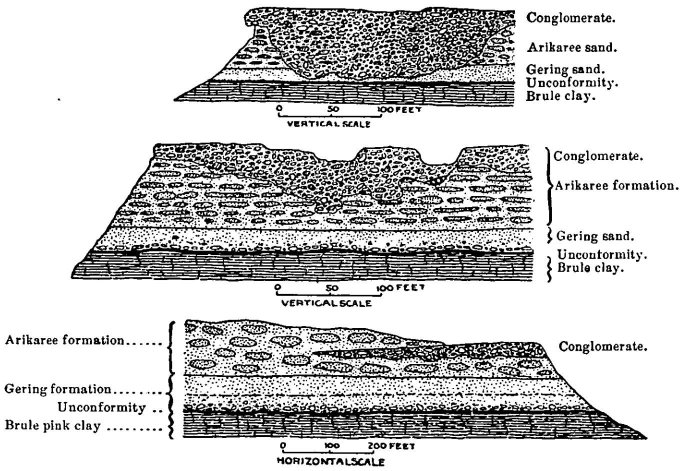


FIG. 212.—Section 8 miles south-southeast of Gering, Nebraska, showing relations of conglomerate in Arikaree formations.

in Smokestack Rock, in Banner County. They were next seen at intervals westward along the south line of Scotts Bluff County, in buttes and high points, as far west as the meridian of Gering, and detached areas are exposed on the north side of the ridge southwest of Gering. The last outcrop occupies a point 3 miles north-northwest of Dorrington, near the western end of the ridge, where it has the relations shown in fig. 211.

It is probable that the channel is continuous under the ridge between these points. Some features of the more prominent exposures are

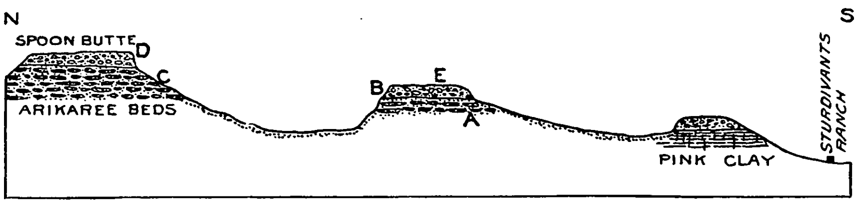
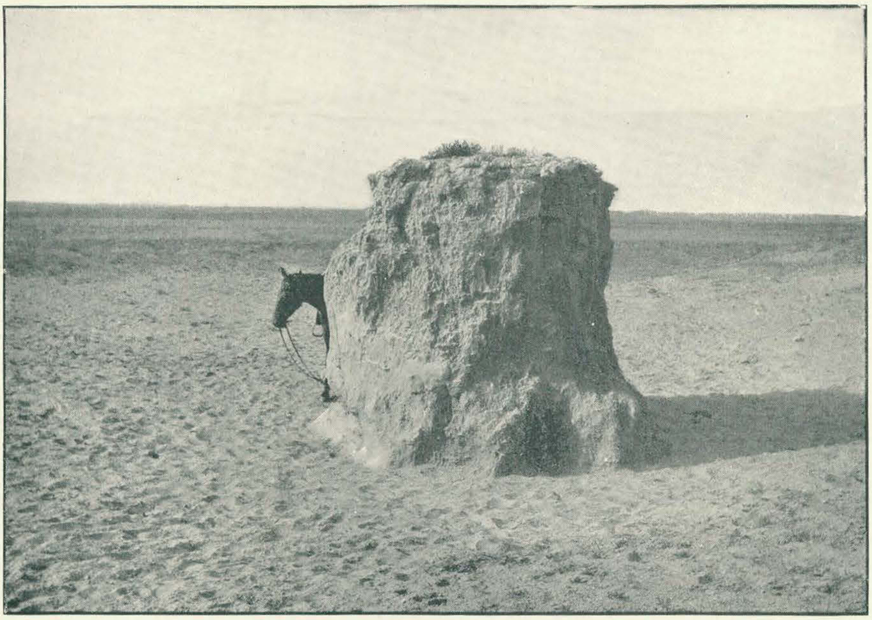


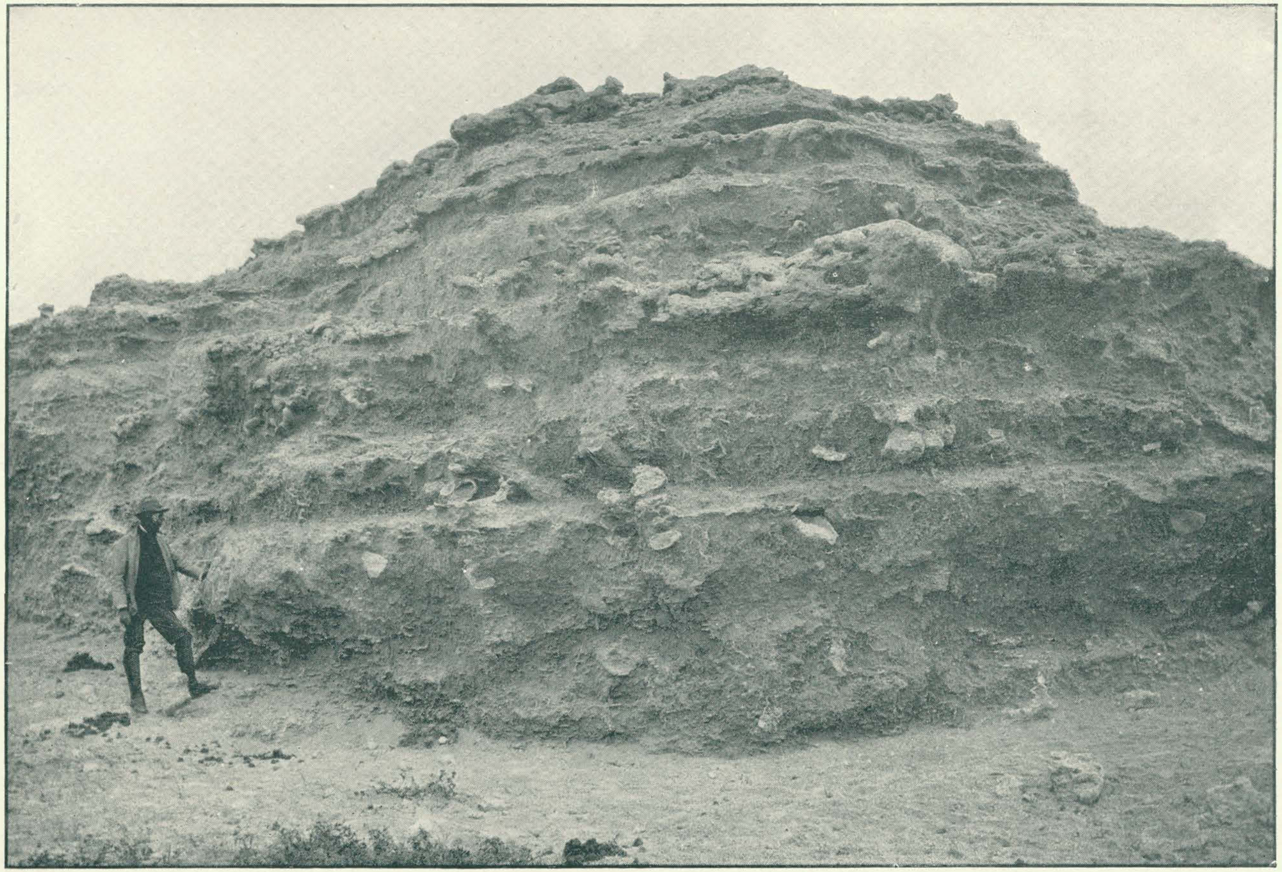
FIG. 213.—Cross section from the eastern end of Spoon Butte southward to Sturdivant ranch looking east.

shown in Pls. LXXXVII and LXXXIX. The material is a conglomerate of pebbles and bowlders of gray sandstone, generally firmly cemented by siliceous matrix. The greatest thickness observed was 30 feet, in the high point 3 miles south of Larissa. The Smokestack Rock exposes about 25 feet. At many localities it may be seen that



A BLOWOUT WITH CORE, ARIKAREE FORMATION, SIOUX COUNTY, NEBRASKA.

B. PIPY CONCRETIONS, ARIKAREE FORMATION, SCOTTS BLUFF COUNTY, NEBRASKA.



DÆMONELIX BEDS IN ARIKAREE FORMATION AT HEAD OF LITTLE MONROE CANYON, SIOUX COUNTY, NEBRASKA.

the beds lie on typical Arikaree deposits, as shown in Pl. LXXXVII, *B*, and they are overlain by typical beds of the same formation. This relation is shown in figs. 212 and 219 (pp. 746, 752).

In the Spoon Butte and adjoining ridges the conglomerates are of somewhat different character, consisting in large part of crystalline rocks and apparently lying on a steeply sloping surface. The relations are shown in fig. 213.

In this vicinity it was not practicable to ascertain the relations to overlying beds.

The Arikaree deposits contain a large amount of volcanic ash, mainly as a constituent intermixed with the sand, but there are also several distinct beds of ash at one or two horizons, though only of local occurrence. The relations of these beds are indicated in section *A* of Pl. CI and figs. 208, 214, 217, 219, and 225, and some further information regarding them will be found on page 760.

Molluscan fresh-water fossils of several species have been found in this formation, but they are not sufficiently distinctive to indicate its age precisely. One abundantly fossiliferous locality was discovered south of Gering, where the matrix was a thin bed of diatomaceous earth. Vertebrate remains were collected in small numbers.

GERING FORMATION.

Underlying the Arikaree formation, in a portion of the area, there is a series of coarse sands, often containing pebbles, which appears to be an entirely distinct formation. It is not separated by unconformity, but it has distinctive characters over an area of considerable extent. In its typical exposures it is separated from the Brule clays by a clearly marked unconformity, some of the features of which are shown in Pl. XCVIII. Its thickness varies from a thin wedge to over 200 feet. Its relations are extensively exhibited in the ridge lying next south of North Platte River, and it is thick and apparently in a continuous sheet along the northern face of Pine Ridge. The southernmost exposures are some doubtful ones on Lawrence Fork, near its head. In Pls. XCIX, C, and CI and figs. 214 to 224, the stratigraphic relations of this formation are illustrated. Its greatest development in the Platte Valley is south-southwest of Gering, where 200 feet are exposed, and about Chimney Rock, where a thickness of about 145 feet is attained. It is over 100 feet thick in Courthouse Rock and in the vicinity of Bird Cage Gap and Redington Gap. To the west and south it thins out, and at some points along both sides of the ridge it is apparently absent, or possibly where it appears to be absent it is represented either by clayey members which are not distinguishable from the Brule clay, or by fine sand with concretions resembling Ogallala beds. Its absence is almost certain in the ridge about Wild Cat Mountain. In Scotts Bluff the relations of the formation are very distinct and 60 feet are exposed. On the slopes north of Platte River the formation appears to be absent, except in a small area near the southwest corner of Sioux County, where the features shown in fig. 214 indicate that the formation is probably present locally.

Along the north face of Pine Ridge the formation presents the features shown in figs. 226 and 227 (pp. 757, 758), and Pl. XCIII.

Some further facts and inferences as to its relations are shown in cross sections in Pl. LXXXV. No definite evidence of the continuance of the formation could be found in the slopes south of Pumpkinseed Creek except in the valley of Lawrence Fork, in sec. 4., T. 16, R. 54, where there is an exhibition of the features shown in fig. 215.

In the Lodgepole Valley the Arikaree formation appears to lie directly on the Brule clay, both the Gering and Ogallala formations being absent.

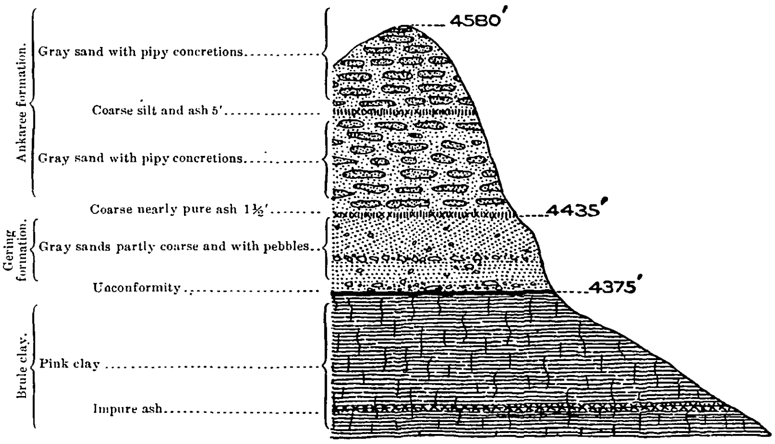
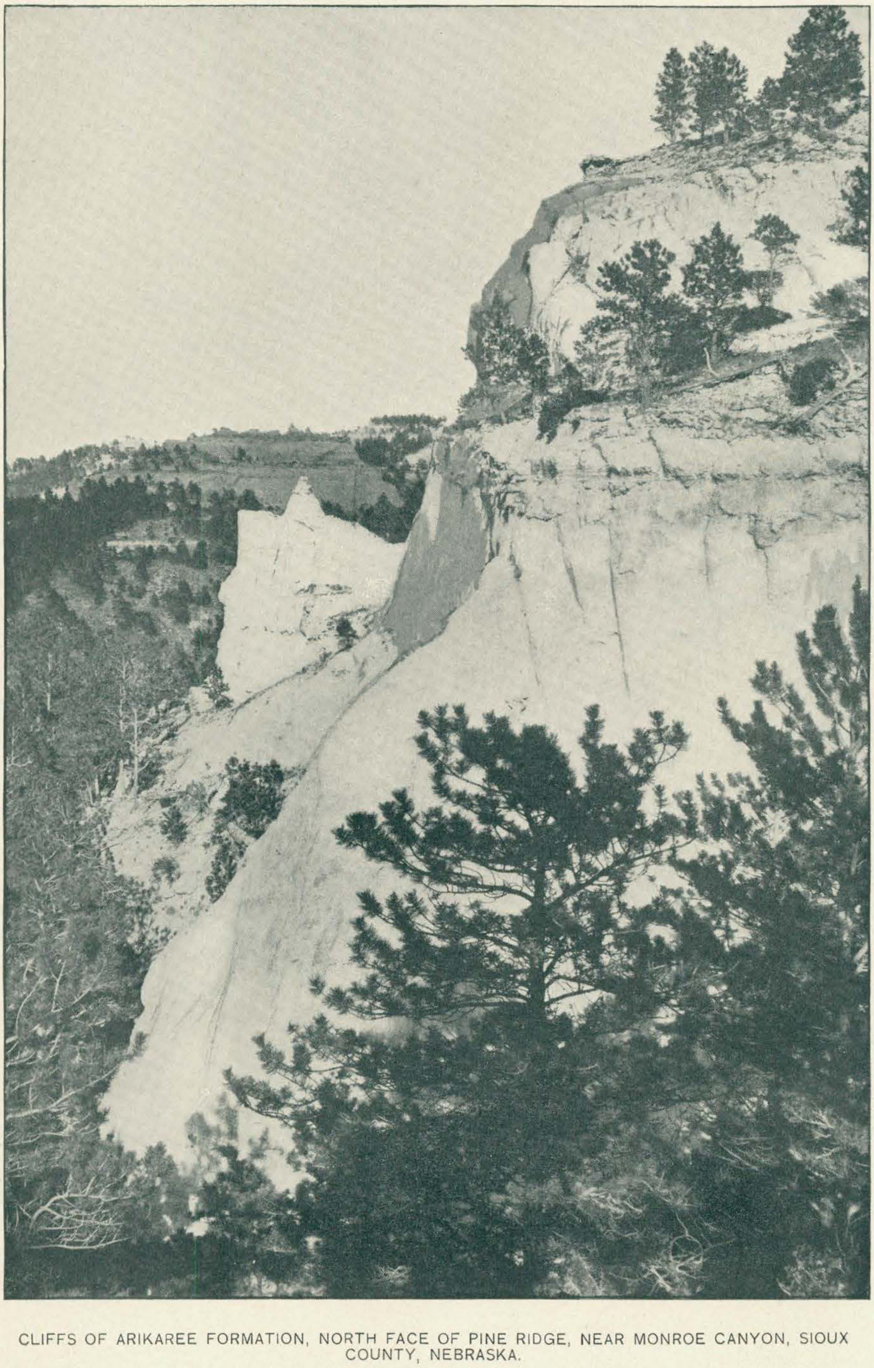


FIG. 214.—Section of bluff in southwestern corner of Sioux County, showing relations of supposed Gering formation.

The Gering formation presents many local features of stratigraphy, particularly in the ridge between the valleys of Platte River and Pumpkinseed Creek. Beginning at Jail Rock, there are instructive exposures at frequent intervals to the western end of the ridge. At Courthouse Rock there are presented the relations shown in section *A* of Pl. XCIX. At an altitude of 3,940 feet the distinctive Brule clay is unconformably overlain by the Gering formation, apparently comprising two members, separated by marked unconformity by erosion. In both members there are coarse beds below containing local conglomerate, merging upward into sand, and finally into sandy clay. The total thickness is 110 feet. The characteristic Arikaree formation capping Courthouse Rock begins abruptly, but with no sign of unconformity. Jail Rock, as shown in Pl. LXXVIII, is capped by the Gering formation. The two members of this formation present about the same relations at Birdcage Gap as shown in section *B* of Pl. XCIX; but they have somewhat greater thickness. In the pinkish sandy clay, at an altitude of 4,080 feet, there was found a portion of the skeleton of a new

GERING FORMATION WITH FAULT, BURLINGTON AND MISSOURI RIVER RAILROAD CUT ONE-HALF MILE SOUTH OF RUTLAND SIDING, DAWES COUNTY, NEBRASKA.



CLIFFS OF ARIKAREE FORMATION, NORTH FACE OF PINE RIDGE, NEAR MONROE CANYON, SIOUX COUNTY, NEBRASKA.

(From photograph by E. H. Barbour, University of Nebraska.)

species of Dinictis.[1] A view of the relations in Birdcage Gap is given in Pl. XCV.

At Redington Gap the upper member of the Gering formation is not distinguishable and the total thickness is less. A local bed of volcanic ash 5 feet thick appears to mark the top of the formation. The principal features are shown in section *C* of Pl. XCIX. Three miles northwest of Redington Gap there was found the section shown in Pl. XCIX, *D*. The Gering formation here presents the usual basal beds of coarse material lying unconformably on the Brule clay. The change

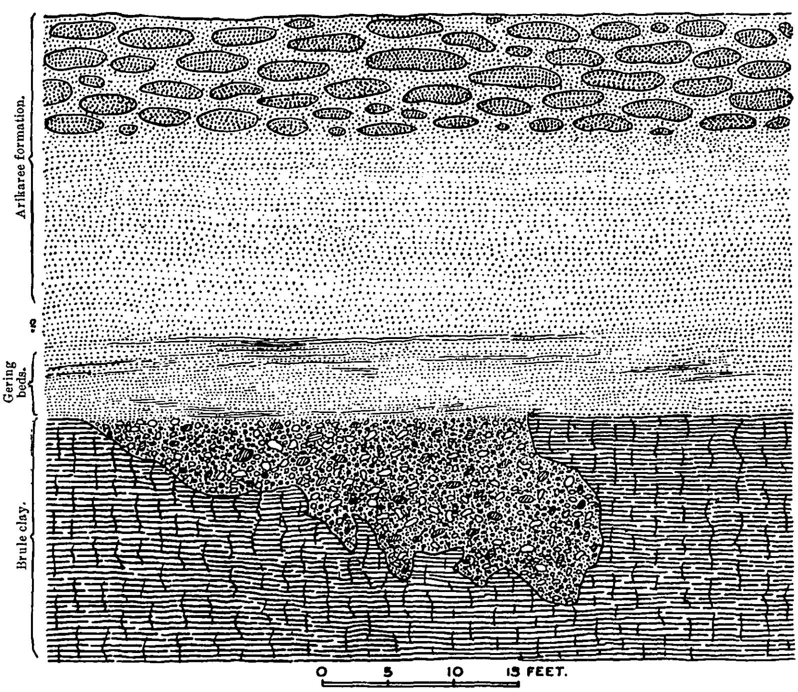


FIG. 215.—Details of unconformity between Brule clay and supposed Gering deposits in valley of Lawrence Fork, sec. 4, T. 16, R. 54.

to the Arikaree formations above is abrupt but not marked by unconformity.

Approaching Chimney Rock there are presented the features shown in sections *E* and *F* of Pl. XCIX. The thickness of the Gering formation here averages about 125 feet, and there is much local variation in the stratigraphy. Coarse basal beds are often exposed lying unconformably on the Brule clay. A thin local bed of volcanic ash is conspicuous in some exposures. Chimney Rock consists of a spire of Gering formation rising from a conical hill of Brule clay. The material is a gray, thinly bedded, soft sandstone with slightly coarser materials at its base. The unconformable contact with the Brule clay is at an

[1] Recently described by F. A. Lucas as *Dinictis major*, Am. Jour. Sci., 4th series, Vol. VI, 1898, pp. 399-400

altitude of 4,100 feet, and there is here considerable carbonaceous material, strongly suggestive of an old soil. At an altitude of 4,135 feet there is a faint unconformity and two thin beds containing volcanic ash. Two views of Chimney Rock are given in Pl. XCVII, and the relations of the formations are shown in section *A* of Pl. C.

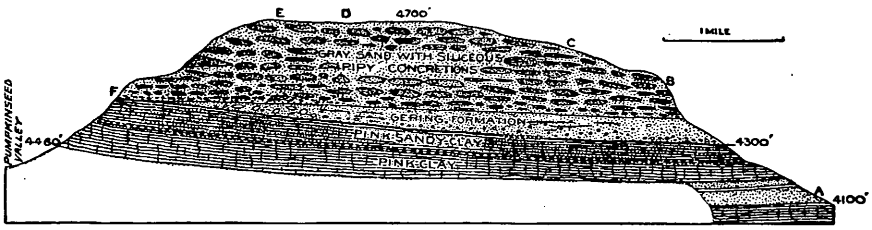


FIG. 216.—Cross section of ridge 10 miles south of Gering, Nebraska, looking west.

Southwest of Chimney Rock the Gering formation greatly decreases in thickness, but it continues to present its characteristic features, as shown in sections *B* and *C* of Pl. C. The two members are well characterized as far as the east side of Sheep Mountain. Along the south side of this butte the basal member of the Gering formation is, in places, not clearly separable.

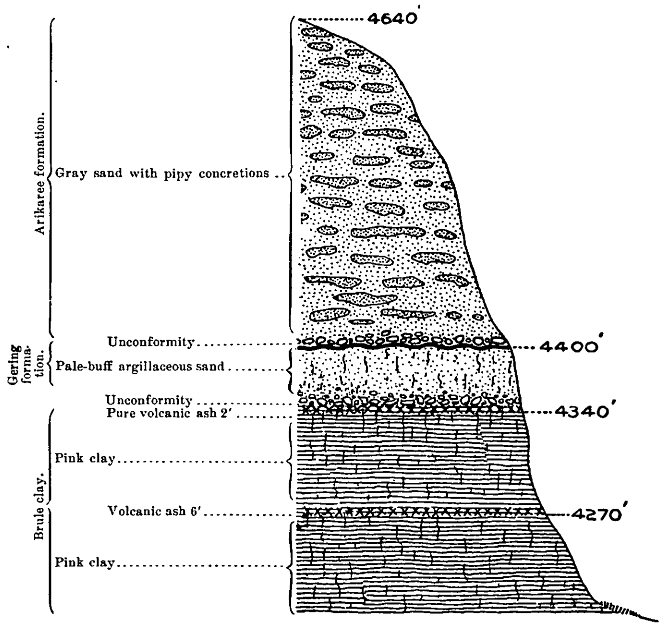
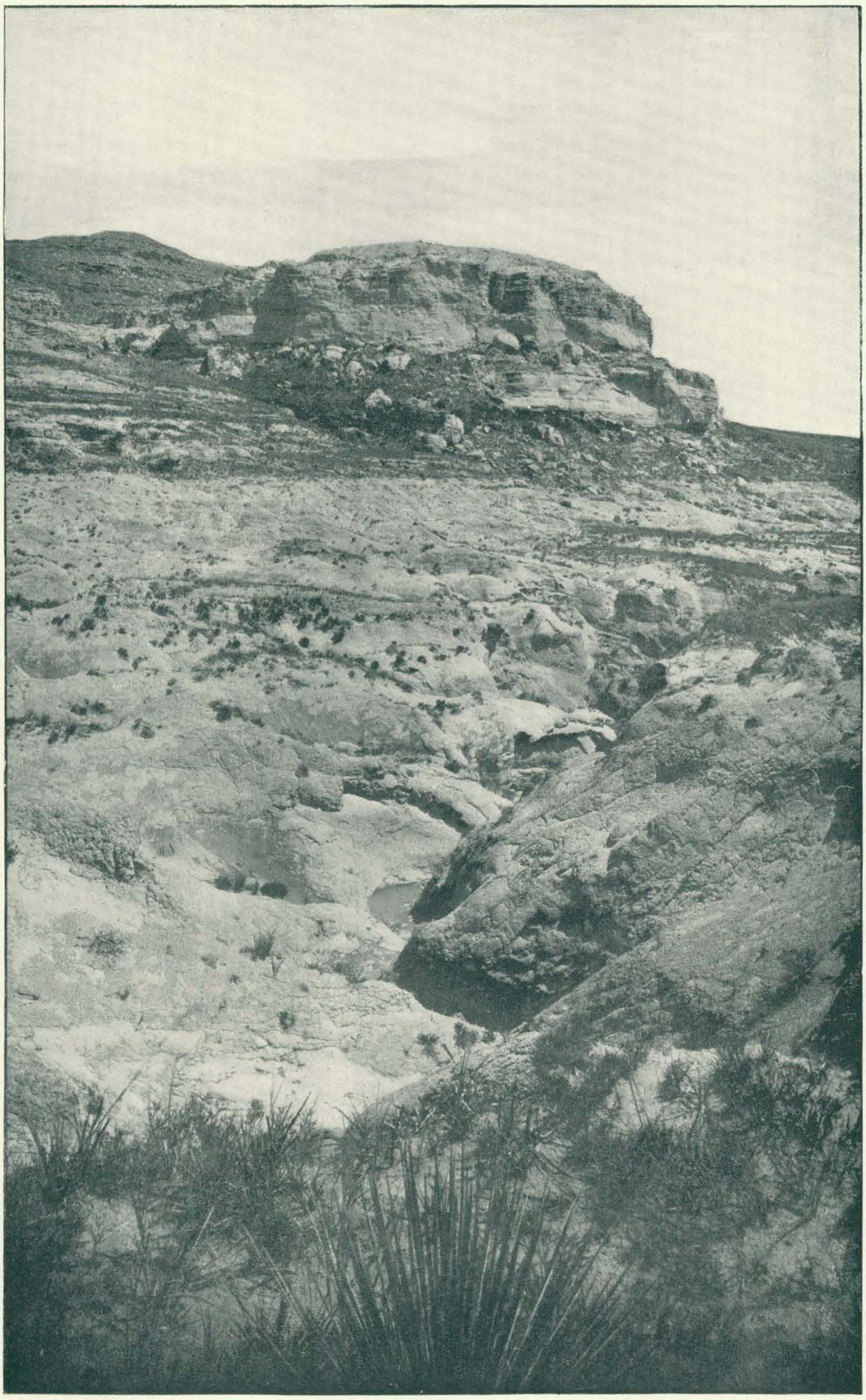
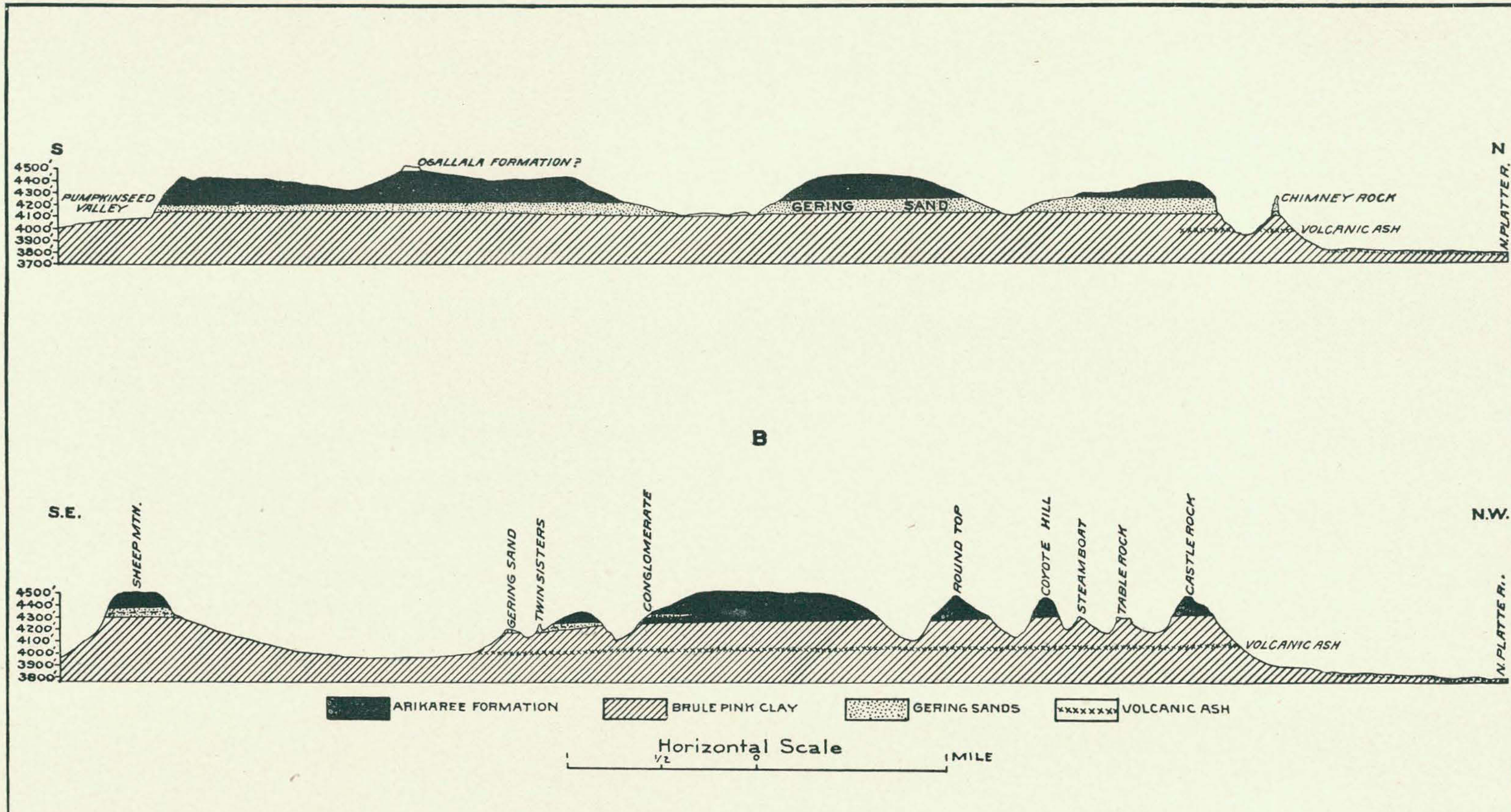


FIG. 217.—Section 8 miles due south of Gering, Nebraska.

At the curiously sculptured Twin Sisters, which are of Gering formation, the unconformity is finely exhibited, as shown in Pl. LXXX, *A*. The materials consist of coarse sands and soft sandstone, merging upward into a 6-foot bed of pinkish sandy clay, above which there is



ARIKAREE FORMATION, GERING FORMATION, AND BRULE CLAY, IN BIRDCAGE GAP, CHEYENNE COUNTY, NEBRASKA. LOOKING NORTHEAST THROUGH THE GAP.



CROSS SECTIONS SHOWING RELATIONS OF FORMATIONS NEAR CHIMNEY ROCK AND HORSESHOE FLAT, NEBRASKA.

a moderately sharp break, followed by an upper member of gray sand which constitutes the heads and shoulders of the "Sisters." Some of the relations in this vicinity are shown in section *B* of Pl. XCVI, which also shows the apparent thinning out of the formation a short distance northward.

The Gering formation appears to be absent at the Smokestack, and in Round Top, Coyote Hill, and Castle Rock. In Castle Rock, as shown in section *D* of Pl. C, the Brule clays become sandy in their upper portion, but present no suggestion of stratigraphic break until the base of the well-characterized Arikaree deposits is reached, at an

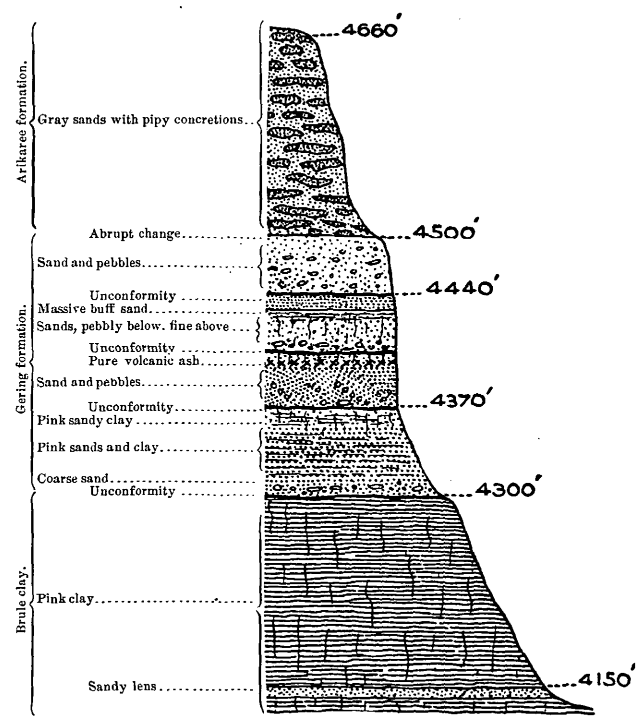


FIG. 218.—Section of Gering and associated formations 6 miles south-southwest of Gering, Nebraska.

altitude of 4,340 feet, where there is an unconformity marked by a bed of white clay a foot thick on a carbonaceous surface, strongly suggestive of old soil. This soil and the relations of the formation indicate that there was here a land surface while the Gering formation was being deposited to the south.

The Gering formation extends continuously for several miles west from the Twin Sisters. At a point 4 miles west-northwest it has the relations shown in section *F* of Pl. CI, consisting of two members with an aggregate thickness of 120 feet. It contains the usual coarse beds at the base of each member, and in the base of the lower member there is a 2½-foot bed of pure volcanic ash. In the next bluff, 1½ miles northwest, there are exposed the features shown in section *C* of Pl. CI. In the next 1½ miles the formation thins rapidly, as shown in section *B* of Pl. CI, and it appears to thin out locally to the south and at intervals to the west.

In the high butte 2½ miles west-southwest of Larissa, as shown in section *A* of Pl. CI, the Gering formation is probably represented by a thin wedge of laminated sandstone, which is exposed on the south slope but is absent to the north. In the buttes south of Gering the formation occurs in irregular masses and for some distance is not over 50 feet in thickness. Its relations in this vicinity are shown in fig. 216, at B and C.

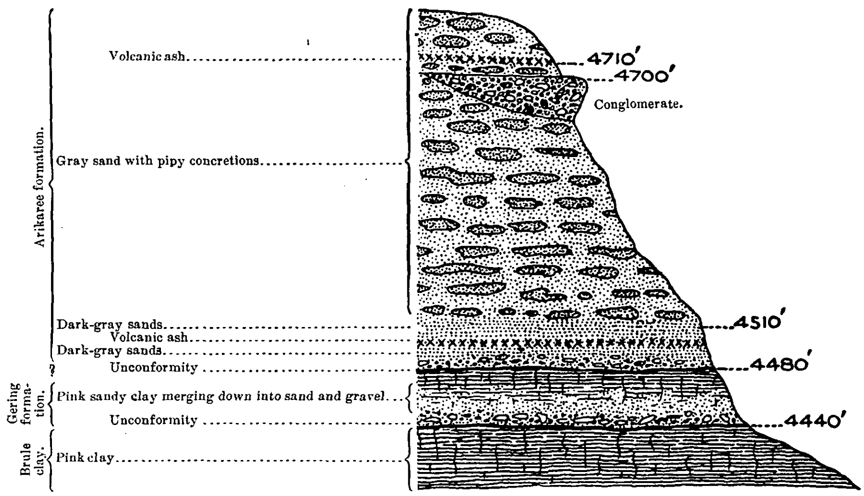


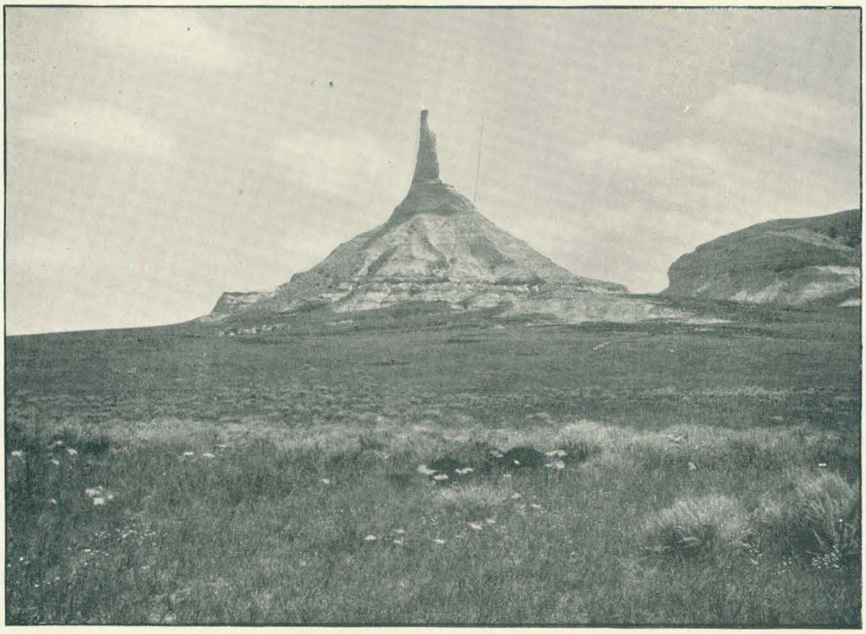
FIG. 219.—Section of Gering and associated formations 7 miles south-southwest of Gering, Nebraska.

At *B* in this section the Gering beds consist of sand and sandy clay, with streaks of conglomerate at their base. There is a very abrupt change to Arikaree beds at their summit. The details of stratigraphy at *B* are shown in fig. 217.

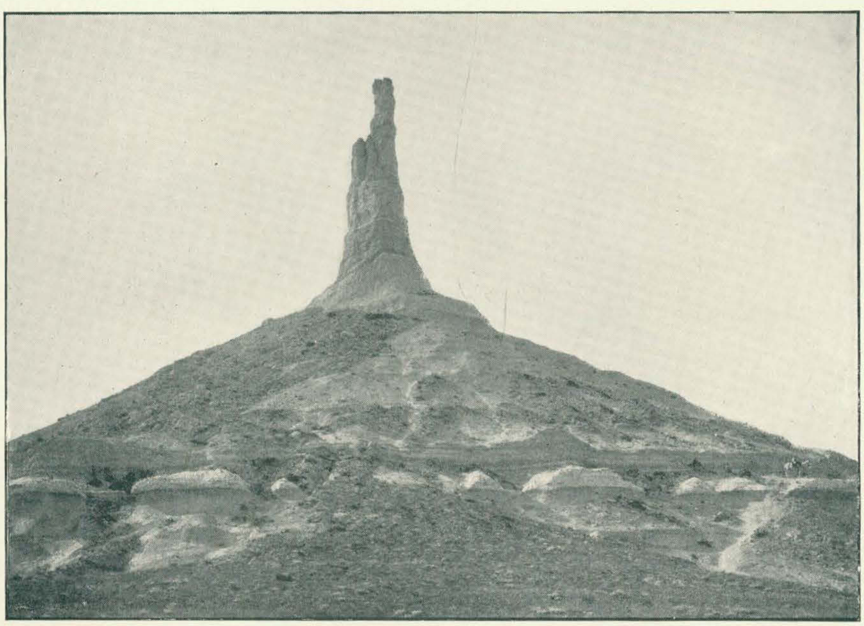
At this exposure there is a bed of volcanic ash in the base of the Gering formation, with alternations of sands and sandy clays above to a sharp unconformity at 4,390 feet. Above this unconformity are sands, pebbly at base, which appear to merge up into the Arikaree beds. They may, however, constitute the upper member of the Gering formation.

In the very prominent point in the northwest corner of R. 55, T. 20, 6 miles south-southwest of Gering, the formation attains its maximum development for this district, having a thickness of 200 feet and the composition shown in fig. 218.

A mile south of this exposure the Gering beds have the character and relations shown in fig. 219, which illustrates the thinning to the south.



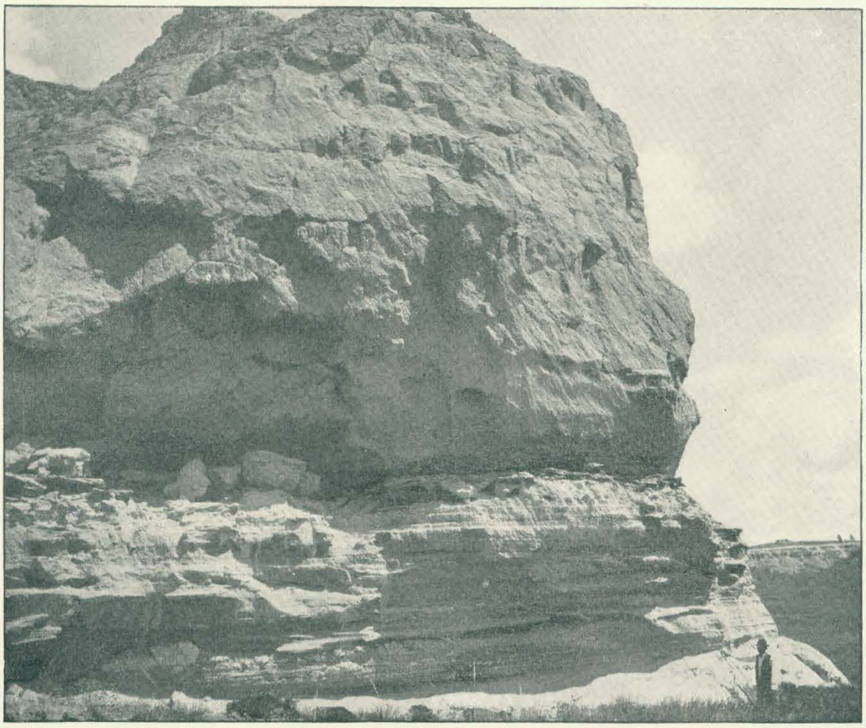
A.



B.

CHIMNEY ROCK, CHEYENNE COUNTY, NEBRASKA.

A, From the west, showing volcanic-ash bed; *B*, From the east, Gering sandstone on Brule clay (the horse is on a bed of volcanic ash).



A.

B.

GERING FORMATION, LYING UNCONFORMABLY ON BRULE CLAY, CHEYENNE COUNTY, NEBRASKA.

A, With conglomeratic beds, 4 miles northwest of Redington (the man's hand is at the contact); *B*, 2 miles southwest of Chimney Rock.

The unconformity at 4,480 feet may be either in the Gering formation, separating it into two members, or at the base of the Arikaree forma-

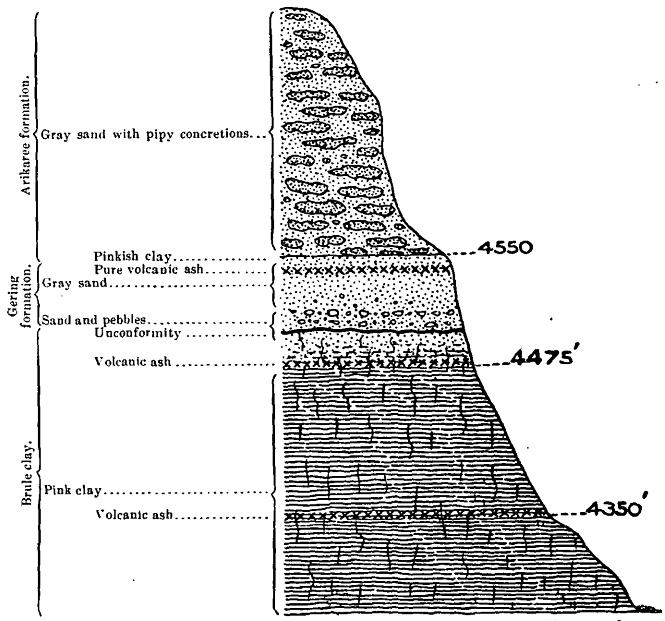


FIG. 220.—Section of Gering and associated formations in Cedar Canyon, 8 miles southwest of Gering, Nebraska.

tion, here including coarse beds and a thin layer of nearly pure volcanic ash. West of this vicinity the formation again thins rapidly,

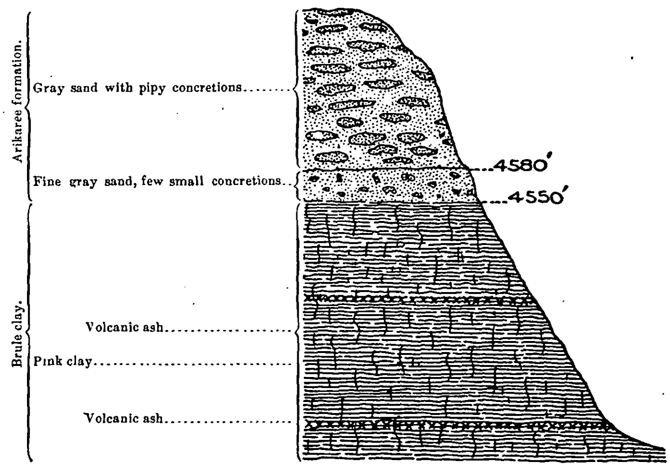


FIG. 221.—Section of Gering and associated formations at the mouth of Cedar Canyon, 7 miles southwest of Gering, Nebraska.

and on the north side of the upper part of Cedar Canyon it has the relations shown in fig. 220.

One mile northeast of this exposure, in the high point at the mouth of Cedar Canyon, the formation is only doubtfully recognized with the relations shown in fig. 221. In other places to the west and north for some distance the formation is either absent or very thin and not well characterized.

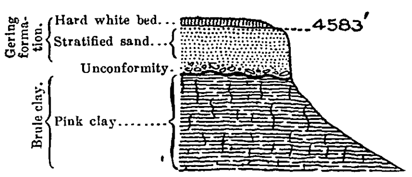


FIG. 222.—Section at Signal Butte, Scotts Bluff County, Nebraska.

In the Scotts Bluff ridge west of Gering the Gering formation has a thickness of 60 feet. It is finely exposed in the butte of which Scotts Bluff is the north face, where its relations are as shown in fig. 225. Some of its features may also be seen in Pl. CII. Dome Rock exhibits 50 feet of the Gering formation, capped by a small mass of Arikaree formation. In the vicinity of Signal Butte the Gering formation appears to be represented by 60 feet of laminated dark-gray sands or soft sandstone lying unconformably on the Brule clay, the unconformity being strongly marked. At the top of the butte there is a cap of thin, hard, white, calcareous deposit, which extends widely in the vicinity. The relations are shown in fig. 222.

The Gering formation is developed in places north of Dorrington with the relations shown in fig. 223. The thickness is 50 feet, and the

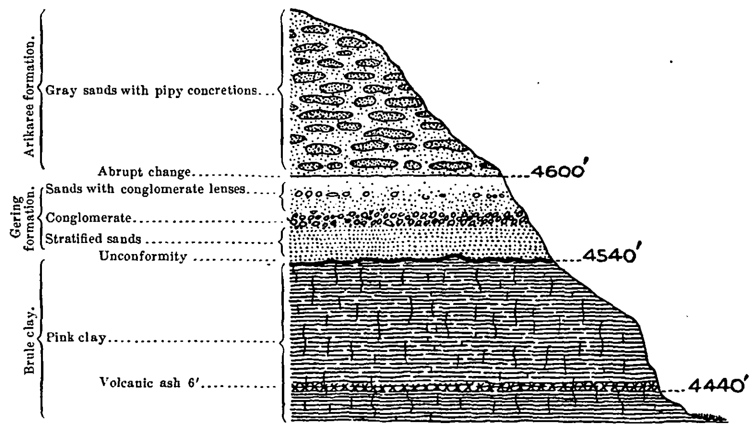
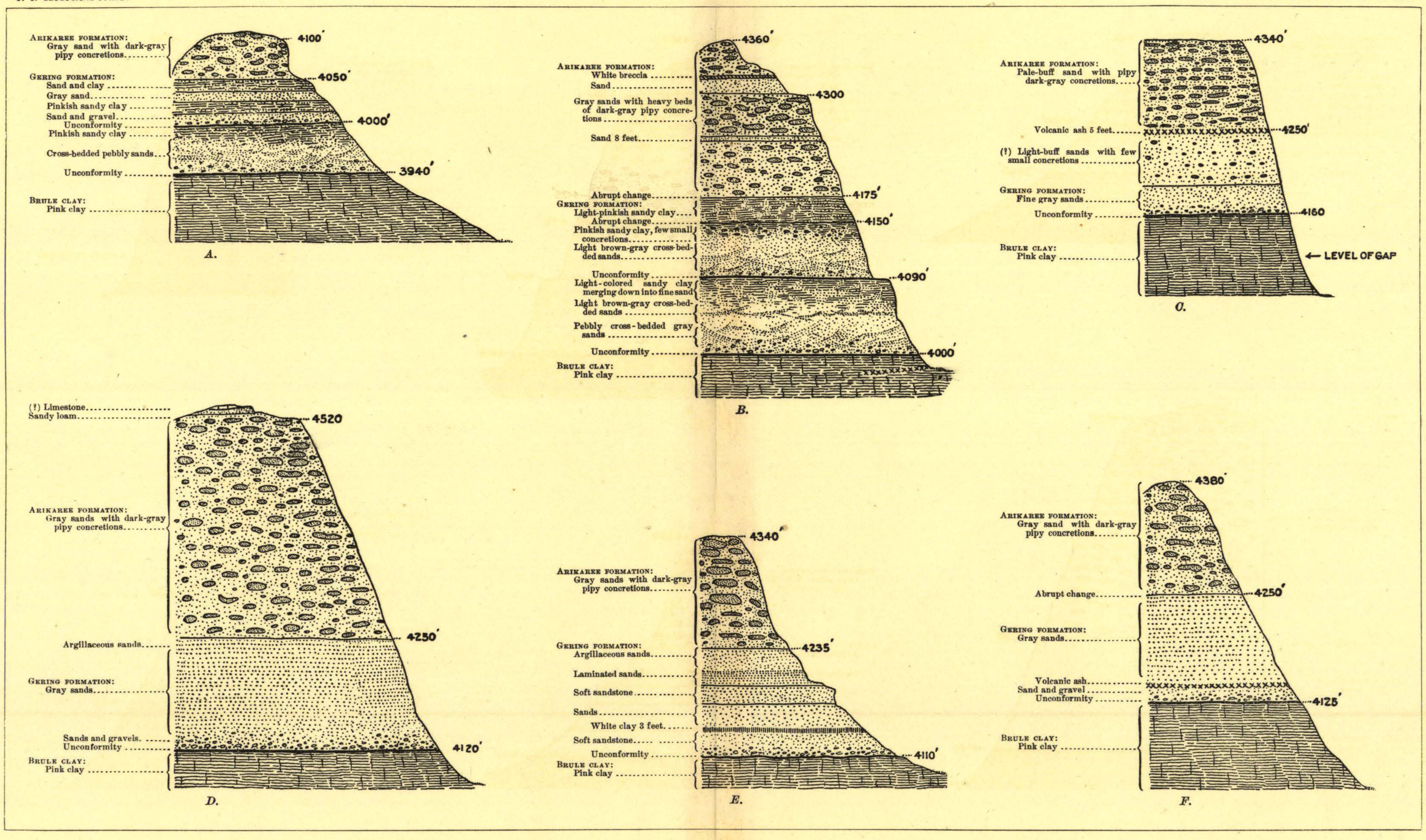


FIG. 223.—Section of Gering and associated formations 2 miles northeast of Dorrington, Nebraska.

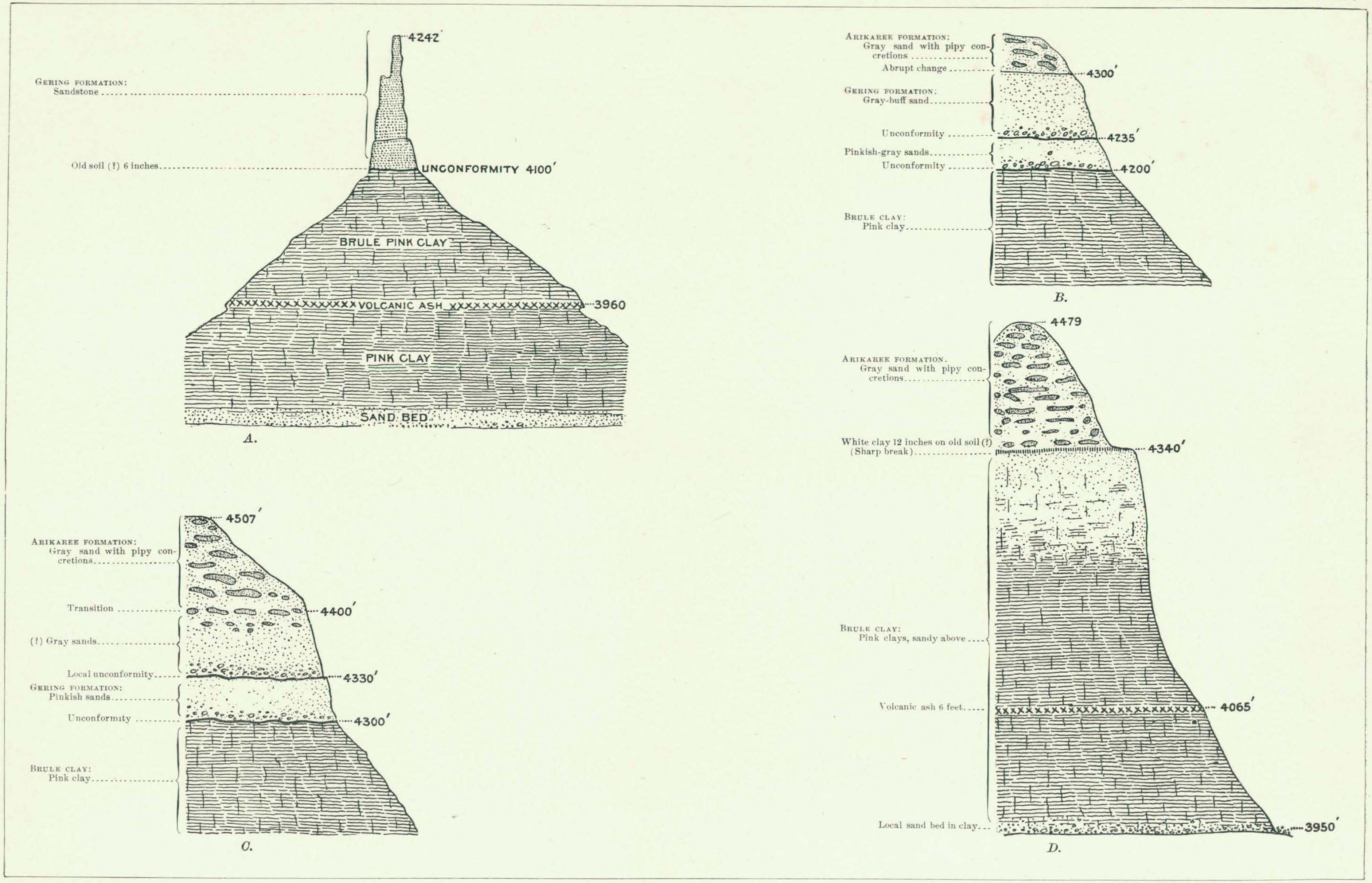
coarse basal beds lying unconformably on the Brule clay are finely exposed at several points. The formation also here contains a thin bed of volcanic ash near the top.

Along the south side of the ridge from Dorrington to Ashford the formation is either absent or not characteristic. Near Funnel Rock the Arikaree beds lie unconformably on the Brule clay, as shown in fig. 224. In the region north-northeast of Ashford the Gering formation is very distinct again for a few miles, especially high up in the canyons which are cut into the ridge. In two of these canyons the outcrop is marked by large springs. The relations in this vicinity are



SECTIONS OF EXPOSURES SHOWING THE RELATIONS OF GERING AND ASSOCIATED FORMATIONS, CHEYENNE COUNTY, NEBRASKA.

A, At Courthouse Rock; *B*, At Birdcage Gap; *C*, At Redington Gap; *D*, 4 miles south-southeast of Chimney Rock; *E*, 3 miles south-southeast of Chimney Rock; *F*, 1 mile south of Chimney Rock.



SECTIONS OF EXPOSURES SHOWING THE RELATIONS OF GERING AND ASSOCIATED FORMATIONS FROM CHIMNEY ROCK TO CASTLE ROCK.

A, At Chimney Rock; *B*, 3½ miles southwest of Chimney Rock; *C*, At Sheep Mountain; *D*, At Castle Rock.

represented at D, E, and F in fig. 216 (p. 750). At D, high up a canyon, there is a fine exposure of 50 feet of coarse Gering beds lying unconformably on Brule clay and fairly sharply separated from Arikaree beds. At E, farther down the canyon, similar relations are exhibited. At F, on the point at the mouth of the canyon, there is no trace of the coarse beds; the fine sand, similar to that of the Arikaree deposits but with smaller and more widely scattered concretions, lying directly on the Brule clay with faint unconformity apparent. Farther east, at Castle Rock, in Banner County, and in the prominent point 1½ miles west of this rock, the identity of the formation is not satisfactorily established. The relations at these localities are shown in sections *D* and *E* of Pl. CI. In the bluffs on the south side of the ridge, northeast of Redington,

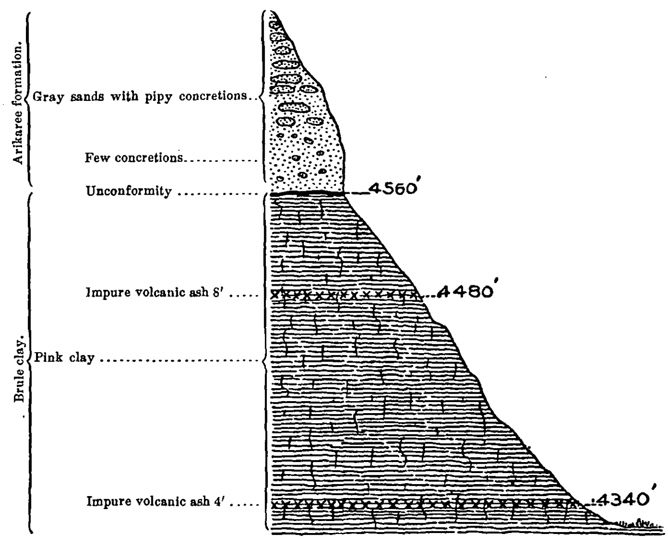


FIG. 224.—Section in vicinity of Funnel Rock, 1 mile north of Ashford, Nebraska.

the Gering formation is again recognized. Its unconformity to the Brule clay is often finely exposed in this vicinity, as shown in Pl. XCVIII, *B*.

BRULE CLAY.

This thick mass of sediment which underlies the greater part of the region consists mainly of massive clay or a mixture of fine sand and clay, of pale flesh color. It is widely exposed in the valleys of North Platte River and Pumpkinseed Creek, extends along the lower portion of the northern slope of Pine Ridge, and is bared in the narrow depression of Lodgepole Creek and Sidney Draw. In the valley of the North Platte it is often widely overlain by alluvial deposits, and this also is the case to a less degree in the smaller valleys. Along the foot of Pine Ridge the formation is largely covered by wash and talus, and by a small amount of alluvium along White River and its tributaries. The formation underlies all the high table-lands, where, as shown in the sections of Pl. LXXXV, it is thickly covered by the later Tertiary deposits. North of Pine Ridge it has been deeply eroded, and beyond a narrow zone of outcrops of the underlying Chadron beds the Pierre clay succeeds as the surface formation. There are extensive expos-

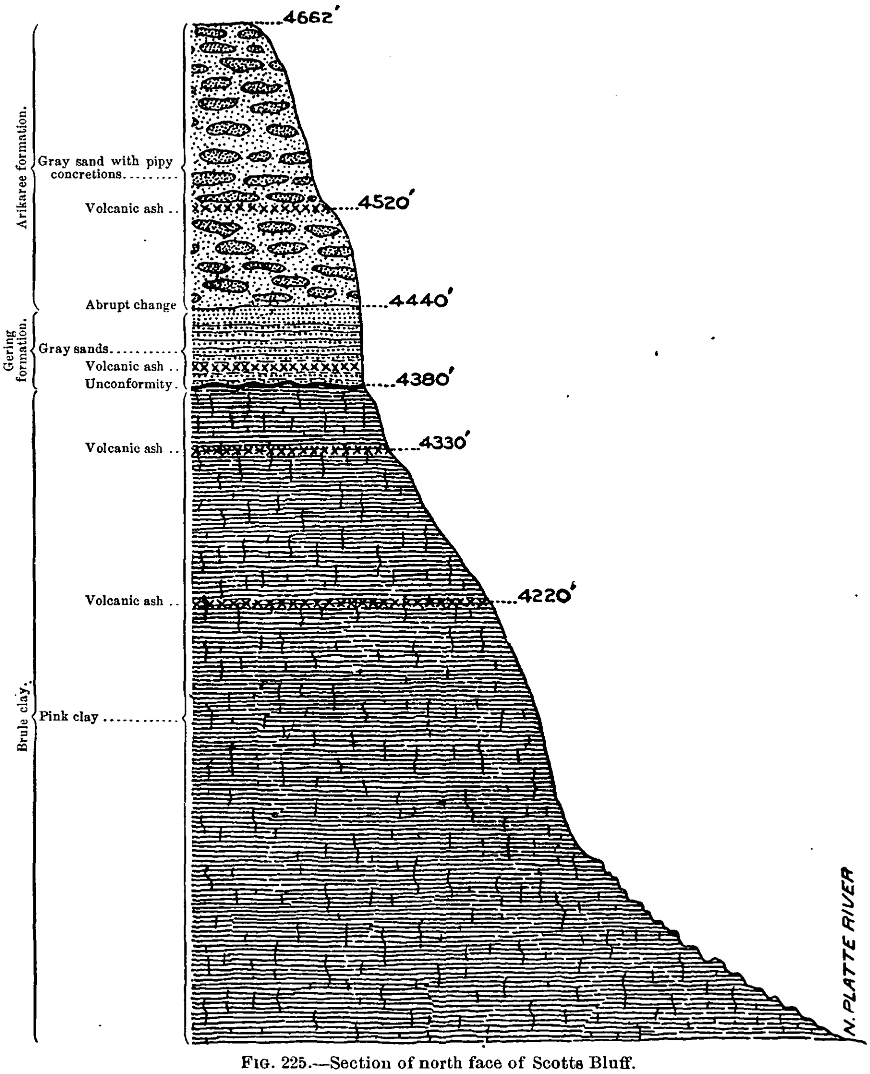
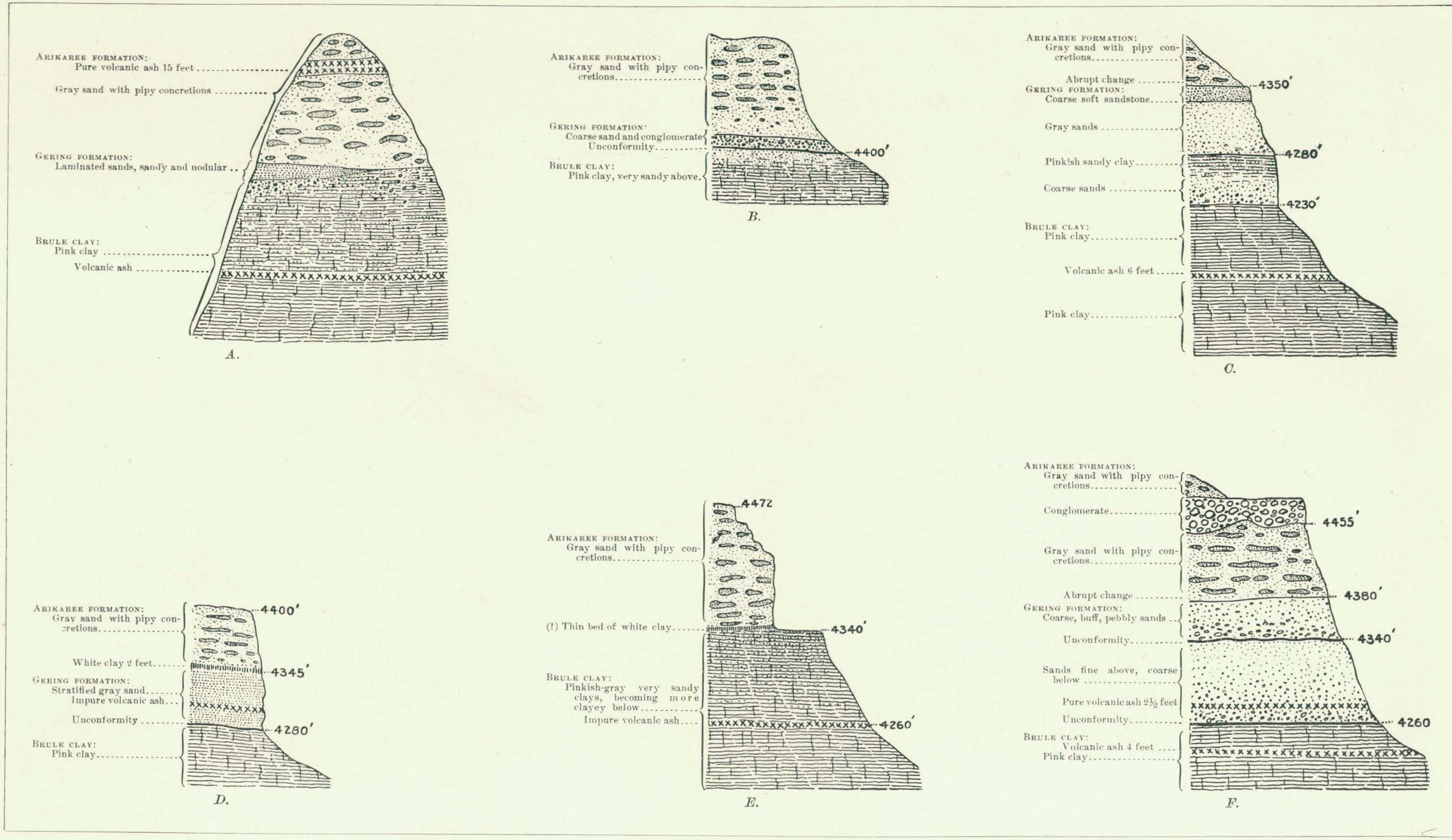


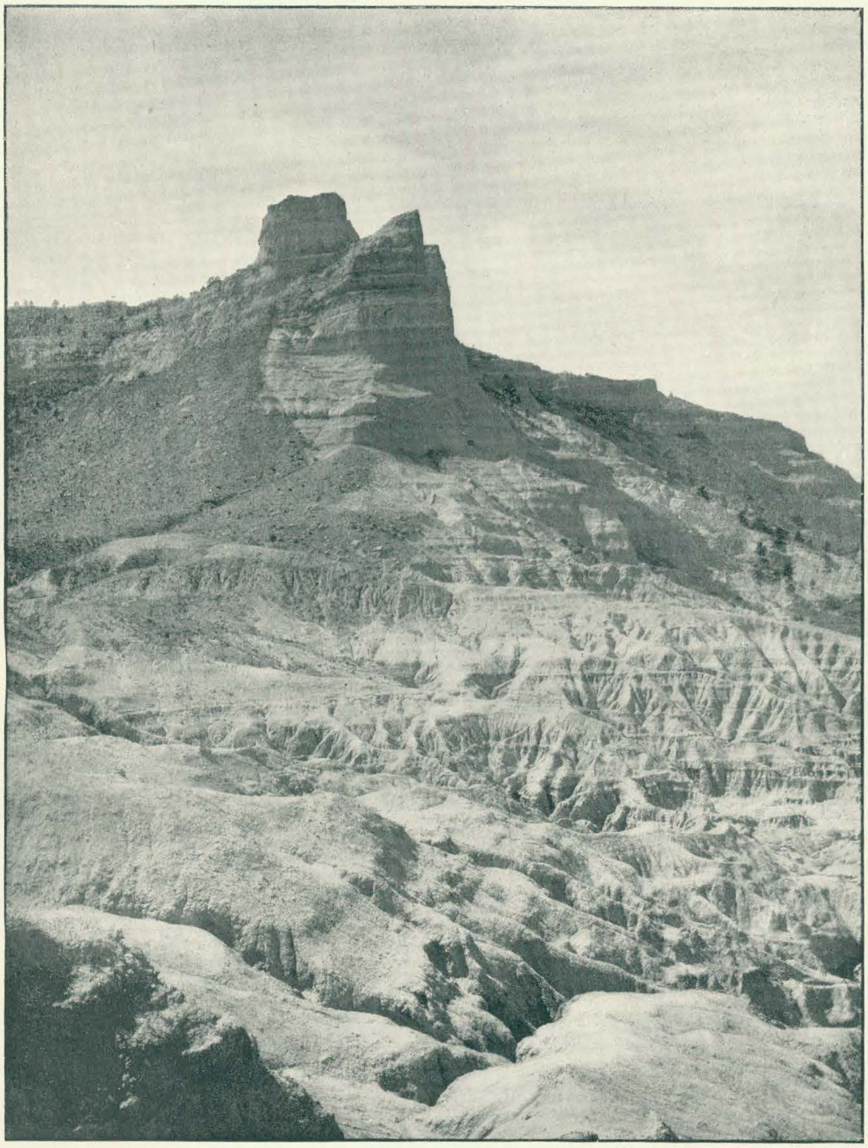
FIG. 225.—Section of north face of Scotts Bluff.

ures of the Brule clay in the northern face of Scotts Bluff, where, from the base of the overlying Gering beds to the river, there is a vertical interval of 500 feet of continuous outcrop, and the formation has a small additional thickness below the level of the river. (See Pls. CII, CIII, and CIV.) Along the northern front of Pine Ridge the formation



SECTIONS OF EXPOSURES SHOWING THE RELATIONS OF GERING AND ASSOCIATED FORMATIONS SOUTH AND SOUTHWEST OF LARISSA, NEBRASKA

A, 2½ miles west of Larissa; *B*, 2½ miles southwest of Larissa; *C*, 2 miles south-southwest of Larissa; *D*, 1½ miles west of Castle Rock, Banner County; *E*, At Castle Rock, Banner County; *F*, 3 miles south of Larissa.



NORTH FACE OF SCOTTS BLUFF.

Brule clay overlain by Gering and Arikaree formations.

averages 600 feet in thickness, but beginning near Crawford it gradually thins to the east to about 350 feet in the vicinity of Chadron. In Round Top, just west of Adelia, there are 655 feet of Brule beds.

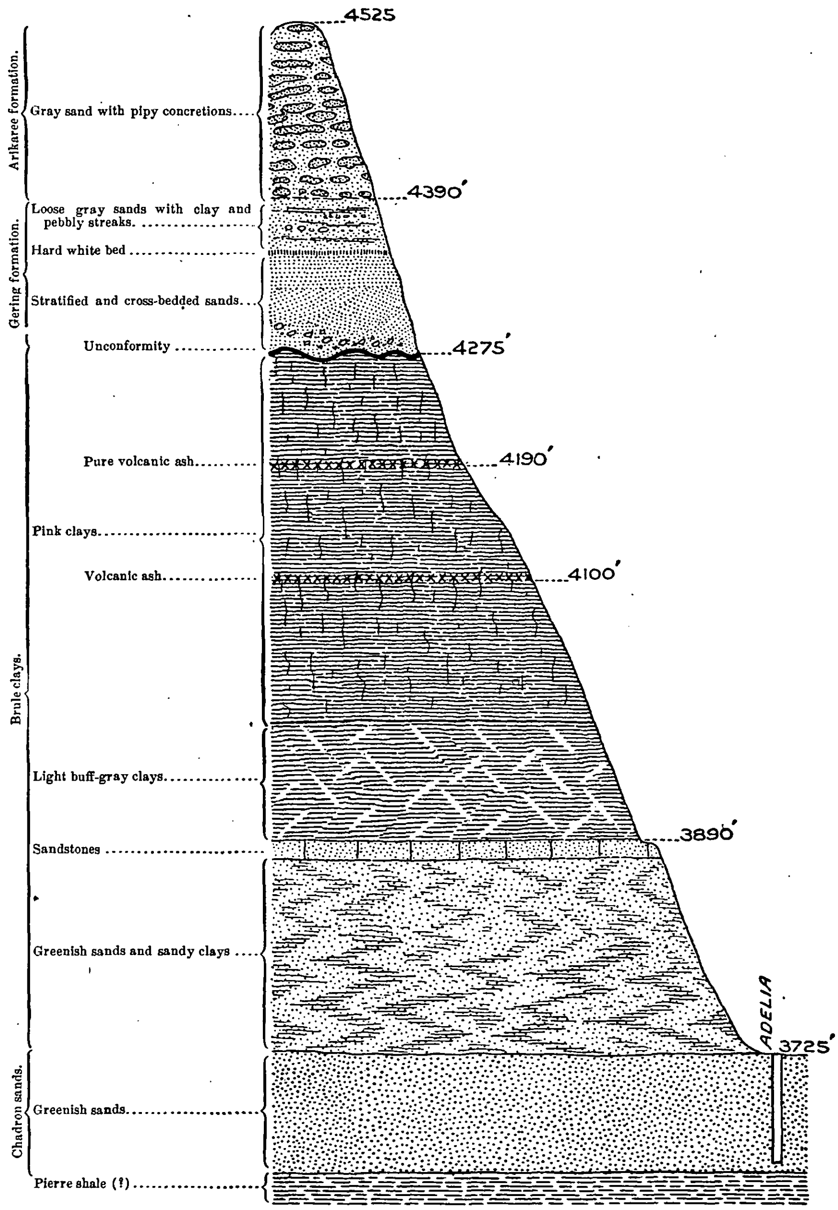


FIG. 226.—Section from Round Top to Adelia station, Sioux County, Nebraska.

In the region southeast of Gering the Brule formation contains or is underlain by a bed of coarse material which appears to extend several miles. It consists of coarse, cross-bedded sand and conglomerate lying about 120 feet below the top of the formation. The thickness varies from 10 to 80 feet, the thickest portion appearing in canyons and buttes 5 to 6 miles south of Gering. The relations in this vicinity are illustrated in fig. 216 (p. 750), and one of the finest exposures is shown in Pl. CV, *B*. There are other exposures north of Larissa and northeast of Chimney and Castle rocks, as shown in sections *A* and *D* of Pl. C. In the area near Larissa and south of Gering there is also associated a thin bed of very compact limestone, which again outcrops north of Sunflower.

In the bad lands about Adelia station on the Burlington and Missouri River Railroad there are extensive exposures of the Brule and associated formations. (See Pls. CVI and CVII and fig. 226.)

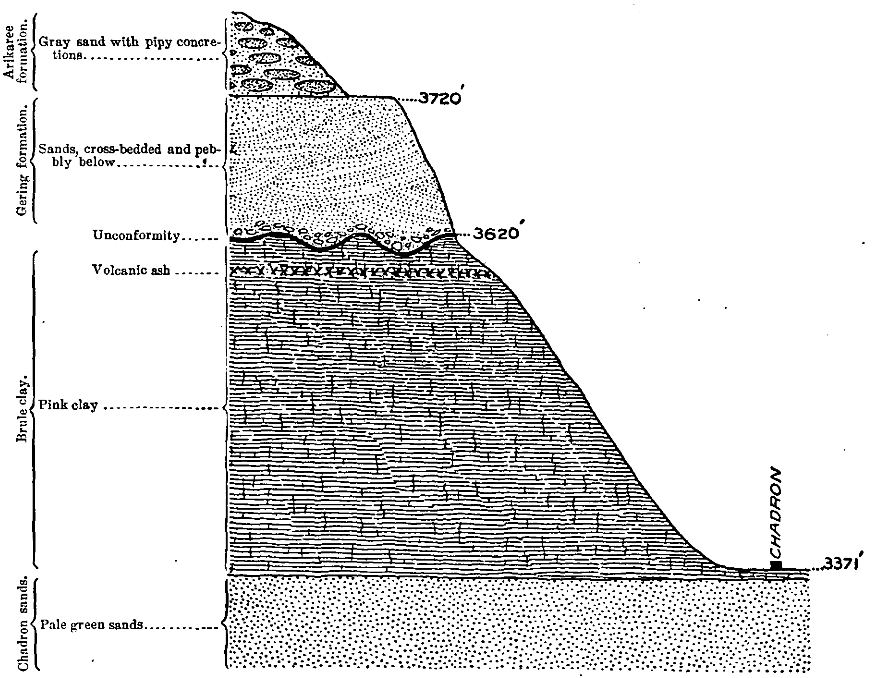
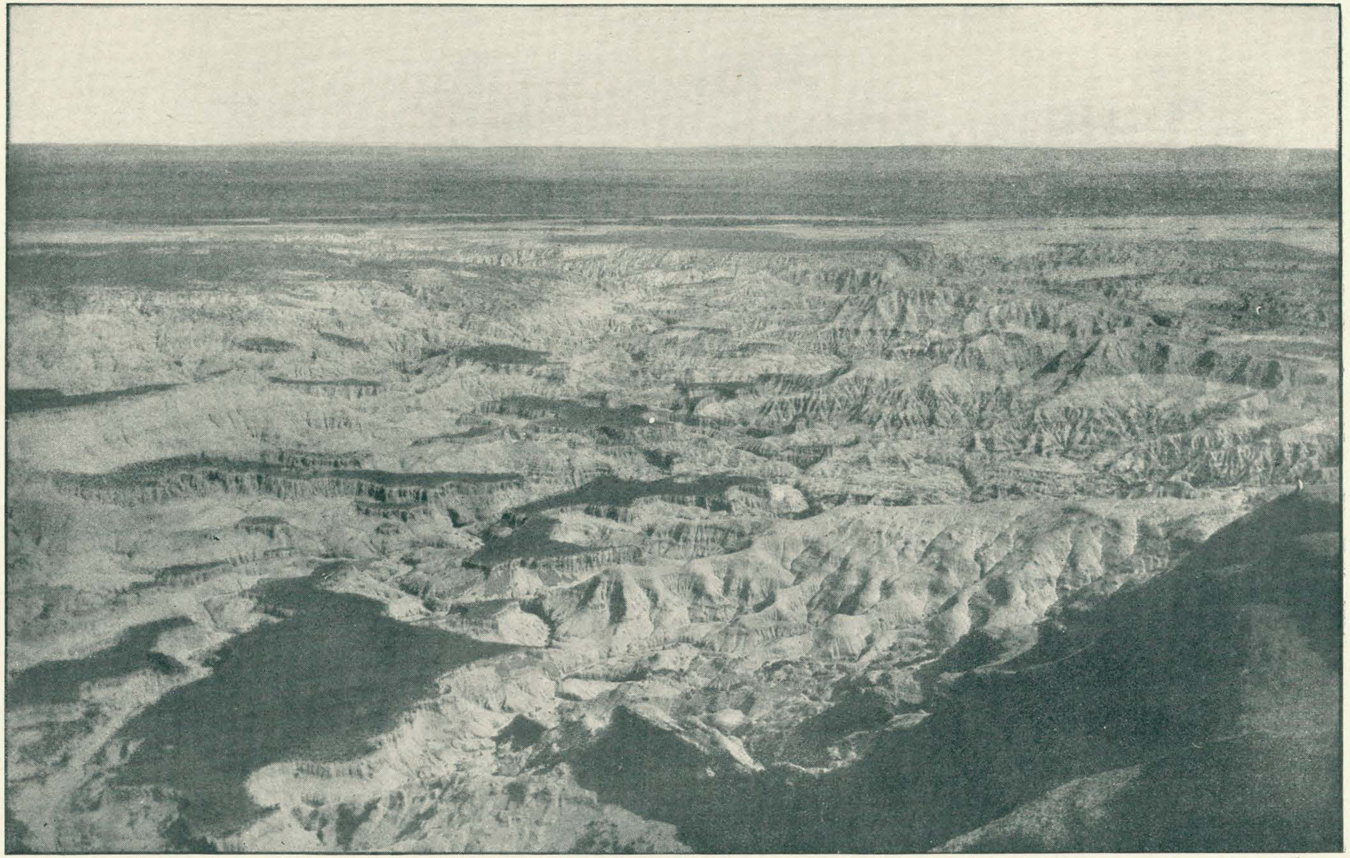


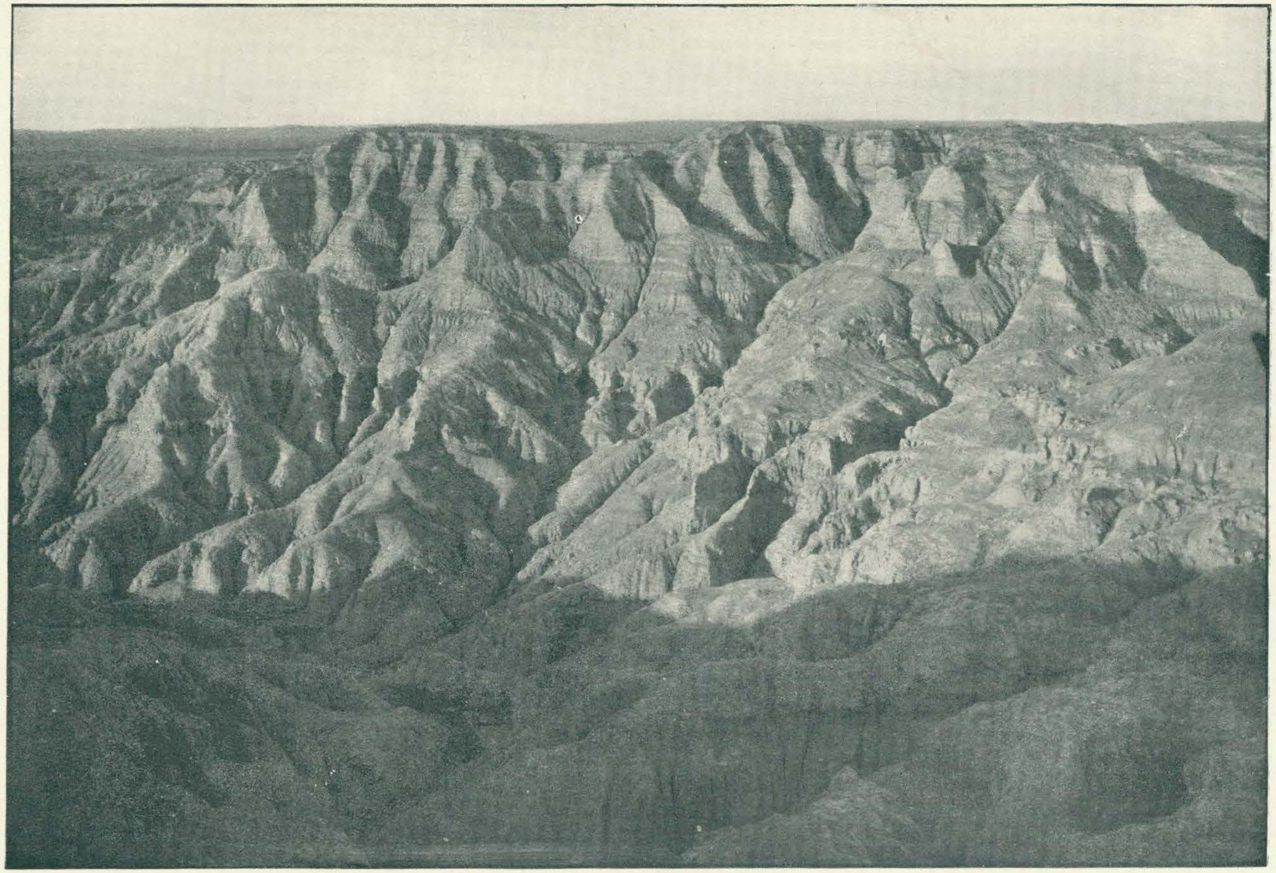
FIG. 227.—Section at Chadron, Nebraska.

This section closely resembles the typical section in the Big Bad Lands in South Dakota, but appears to include some higher beds. The alternation of greenish and pinkish clays with brown nodular layers lying on the Chadron sands is similar to the Oreodon series and yields many of the same mammalian remains. The sandstone next above probably represents the Metamynodon series, and in it was found a fragment of a tooth, probably of Metamynodon. The overlying clays can be less definitely correlated, especially those toward the top, which I believe are higher than the highest beds represented in the Big Bad Lands. They contain two beds of volcanic ash, the upper one 12 feet thick, of nearly pure material, in flat, glassy scales, not so vesicular as



BAD LANDS AT THE FOOT OF SCOTTS BLUFF; GENERAL VIEW, SHOWING FRAGMENTS OF THE PLAIN FROM WHICH THE BAD LANDS WERE ERODED.

North Platte River in the distance.



BAD LANDS AT THE FOOT OF SCOTTS BLUFF: NEAR VIEW.

usual. Along the eastern extension of Pine Ridge the intermediate beds, those extending from 4,000 to 3,725 feet in the Round Top section, soon thin out and the Chadron formation is overlain by the flesh-colored clay, with its volcanic ash layer near the top. A section at Chadron is given in fig. 227.

CHADRON FORMATION.

This basal formation of the Tertiary series outcrops in a narrow zone along the lower slopes north of Pine Ridge, just outside the margin of the overlying Brule clays. There is also a small area of outcrop in the valley of North Platte River in the vicinity of Caldwell. The deposits have heretofore been known as the "Titanotherium beds," from the frequent occurrence of remains of several species of a large mammal which has been named the Titanotherium. As the large bones and peculiar teeth of this animal are very distinctive features, an illustration of a skeleton is reproduced in Pl. CVIII, to aid in identification of the formation. The predominating material of the formation is sandy clay of light greenish-gray color, usually with coarser beds at the bottom, including deposits of gravels often several feet thick. The beds above these gravels are often of bright dark-red color, notably in the region about Adelia. The thickness of the formations varies from 30 to 60 feet in the outcrops along the foot of Pine Ridge. It thickens considerably in the vicinity of Adelia, where there are included some masses of dark gray and buff sandstone of coarse texture. At many points around its outer margin the Chadron sands may be seen lying on the irregular, black or generally rusty surface of the Pierre shale.

PIERRE CLAY.

The entire region to which this report relates is underlain by the Pierre clay, a thick mass of dark-colored clays or shales constituting the upper member of the Cretaceous formations in some portions of the Plains. Possibly under the southwestern corner of Nebraska the Tertiary formations are underlain by the edge of the Laramie formation—a series of sandstones higher in the Cretaceous—but of this there is at present no evidence. The Pierre shale outcrops in the northern portion of Sioux and Dawes counties, as shown in Pl. LXXXIV. The surface of the formation rises somewhat with the general upward slope of its beds toward the Black Hills uplift, and it is exposed by the erosion which has removed the Tertiary formations over the lowlands extending from the valleys of White River and Hat Creek to the foot of the Black Hills. The dark shale gives rise to a rolling region of scant vegetation and poor water supply. Exposures are frequent, and the dark-yellow or rusty surfaces due to the oxidation of the iron pyrites in the shale are characteristic features of the area.

Distinctive fossils of numerous marine mulluscan species are abundant in the Pierre clay. The fossils are often preserved in concretions of gray siliceous matter of lenticular form, which abound in the upper portion of the formation. The precise thickness of the Pierre shales is not known, but it probably exceeds 2,000 feet.

NIOBRARA LIMESTONE.

The Pierre shale is underlain by the Niobrara limestone, but this formation does not reach the surface in the portion of Nebraska west of the one hundred and third meridian. As, however, it would be reached by deep borings for artesian water, some of its characteristics should be pointed out. Its thickness is about 50 feet. It consists mainly of a massive dark-gray chalk or soft limestone, which weathers to a buff or light-cream color when exposed to the atmosphere. The formation can be readily recognized by the very distinctive fossil *Ostrea congesta*, which is nearly always present in abundance in thin hard layers. In order to aid the well driller in identifying this formation in borings, an illustration of this fossil is introduced in Pl. CIX.

BENTON FORMATION.

Underlying the Niobrara limestone and abruptly separated from it are the Benton shales, which have a thickness of 600 or more feet. They contain thin layers of sandstone and limestone; one of the latter, about 400 feet above the Dakota sandstone, is filled with the Inoceramus shown in Pl. CIX. The formation lies far below the surface along the South Dakota line, but outcrops extensively in the vicinity of Edgemont, having the relations shown in fig. 228.

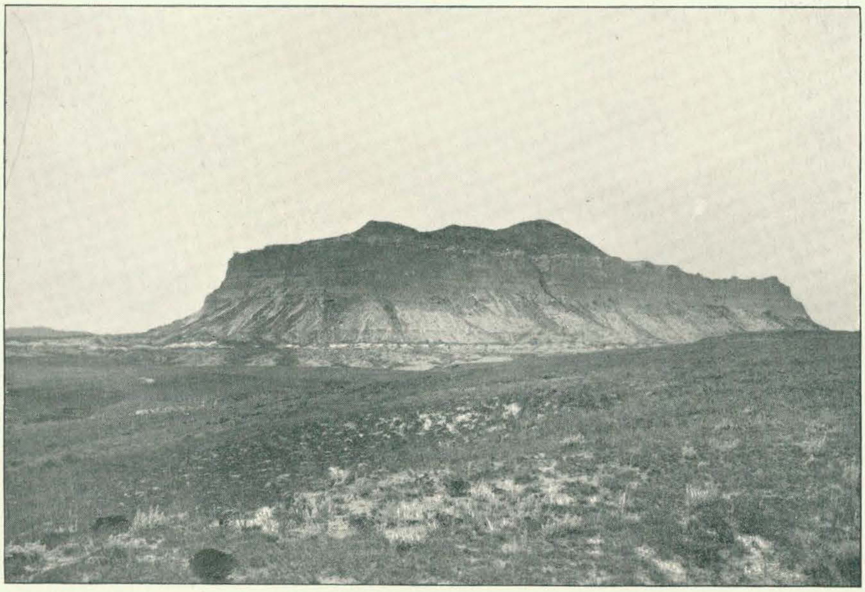
DAKOTA SANDSTONE.

This is the water-bearing sandstone of South Dakota and northeastern Nebraska, and it underlies all the region to which this report relates. It is a gray or brownish sand rock, occurring in thick beds, with intercalated lenses of shale or clay and occasionally thin seams of coal. Its relations in the northern part of the area are shown in fig. 228 and Pl. LXXXIII. Its lower beds are of Lower Cretaceous age.

VOLCANIC ASH.

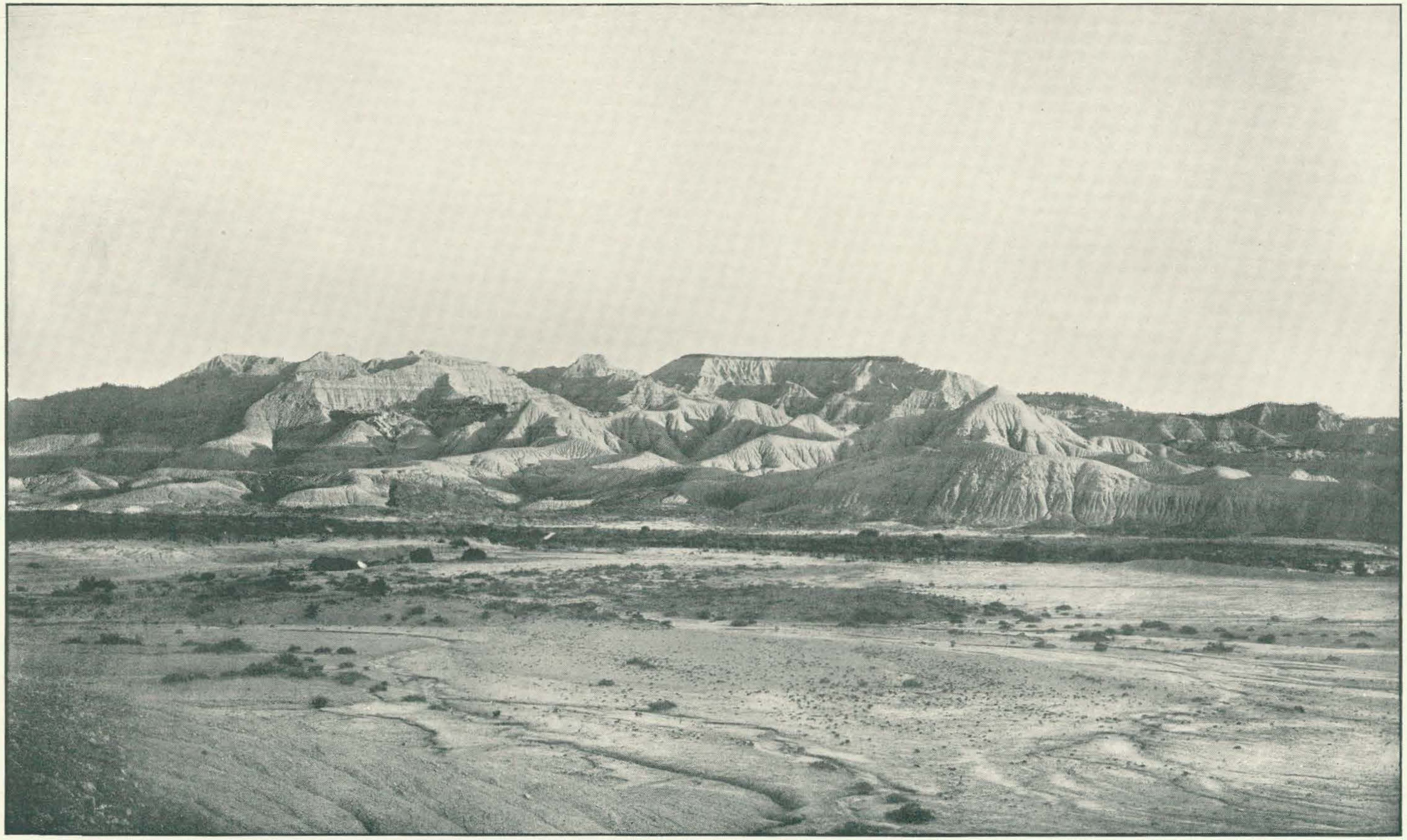
In studying the geology of this region it was found that several formations contained extensive deposits of volcanic ash. Some of this material was found in the Chadron formation, two very widespread beds occur in the Brule clay, lenses of the ash are often included in the Gering formation, and there is a general admixture of ash as well as a number of thick beds of it in the Arikaree formation. So far as observed, it is rare in the Ogallala formation. In the central and eastern portion of the State it occurs mainly in the lower portion of the loess.

The ash deposits are usually more or less mixed with clay or sand,



A. CASTLE ROCK, SCOTTS BLUFF COUNTY, NEBRASKA, FROM THE EAST, SHOWING BED OF VOLCANIC ASH NEAR THE FOOT OF THE SLOPE.

B. LENS OF COARSE MATERIAL IN BRULE FORMATION, 4 MILES SOUTH OF GERING, NEBRASKA.



BAD LANDS OF BRULE FORMATION, WEST OF ADELIA, SIOUX COUNTY, NEBRSAKA. LOOKING NORTHWEST.

(From photograph by E. H. Barbour, University of Nebraska.)

but there are many beds in which the deposits are thick and pure. They promise to have considerable commercial value, mainly for polishing powder.

The most persistent layer is in the Brule clay, at an average distance of about 70 feet below its top, in the ridge next south of North Platte River. This bed is shown in Pls. XCVII and CV, *A*. A lower bed, usually much less pure, occurs from 80 to 100 feet below the upper one. On the north side of Pine Ridge these two horizons are recognized in some of the higher beds in Sowbelly Canyon and at Round Top and near Chadron, as shown in figs. 226 and 227. The volcanic ash occurring in the Gering formation is usually restricted in extent and variable in relations. It is, however, often exceptionally pure.

The Arikaree formation contains a sprinkling of ash almost throughout its extent. In some of the bluffs southwest of Gering a thickness of 100 feet of sandy clays of this formation was observed which contains a fairly large proportion of ash. In the high isolated butte 3 miles west by south from Larissa there is a 15-foot bed of nearly pure ash, with pipy concretions scattered through it, in the midst of the Arikaree formation. In Wild Cat Mountain beds of ash were found at intervals nearly to the cap of the Ogallala formation. The formation contains a large admixture of ash in the vicinity of Fort Robinson, and again at Round Top, near Adelia, as shown in fig. 226 (p. 757).

The ash in these formations was probably derived from volcanoes in the Rocky Mountain region, for there is no evidence of Tertiary volcanoes in the vicinity. The ash was undoubtedly borne on the winds and deposited in the waters which laid down the several Tertiary formations. When the ash came in large volume, or there was very little other sediment, pure deposits resulted, but ordinarily there was considerable admixture of the fine sand and clay.

UNDERGROUND WATERS.

GENERAL CONDITIONS.

The relations of underground waters in this region present a variety of features. In many localities there are large supplies at moderate depths, and in other places the amount of waters in reach of the average farmer is so small as seriously to interfere with the settlement of areas of considerable extent. This has been particularly the case where large volumes of water were needed for cattle. The greatest difficulty in obtaining water has been in the area of the Brule clay back from the rivers and in the region underlain by Pierre clay. In the flats adjoining the river in the Platte Valley and in the Lodgepole Valley water supplies are usually obtained in wells from 10 to 40 feet in depth. On the table-lands on both sides of the Lodgepole Valley waters are obtainable in large volume from wells from 150 to 300 feet deep, the depth increasing gradually westward. In the Niobrara Valley supplies of water are obtained from shallow wells in the narrow strip of alluvial deposits near the river, and farther back on the table-land plenty of water is found at depths varying from 50 and 100 feet on the lower slopes to 300 feet in some of the highest areas to the northwest. In the sand hills water accumulates in basins at moderate distances below the surface, so that shallow wells ordinarily obtain satisfactory supplies.

Along the outer edge of the Brule clay area north of Pine Ridge water is usually found in the underlying Chadron sands. In Pl. CX are shown the depths to water supplies in the western Nebraska region, based on observations of the water level in wells and springs and determinations of the geologic relations of the water-bearing formations.

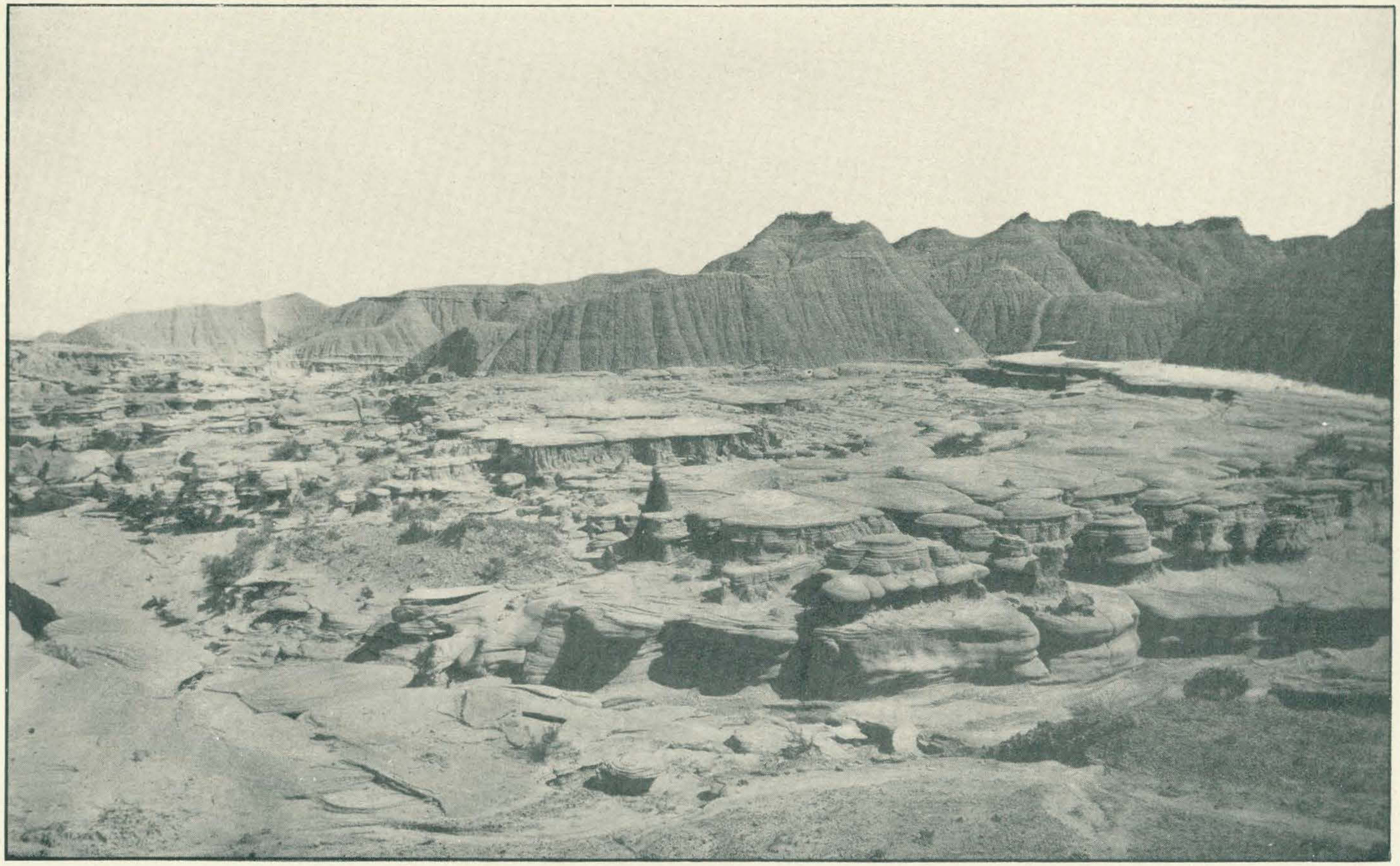
WATER HORIZONS.

In the alluvial formations along Platte, Niobrara, and White rivers and Lodgepole, Pumpkinseed, Snake, and Hat creeks, and some of their branches, the water supply constitutes an underflow. Along the Platte this underflow is of large volume, but in some areas the water is somewhat alkaline. In the Pumpkinseed Valley at some localities, and in the greater portion of the White River and Hat Creek valleys, where they traverse the Pierre shales, these water supplies are often unsatisfactory both in quantity and in quality.

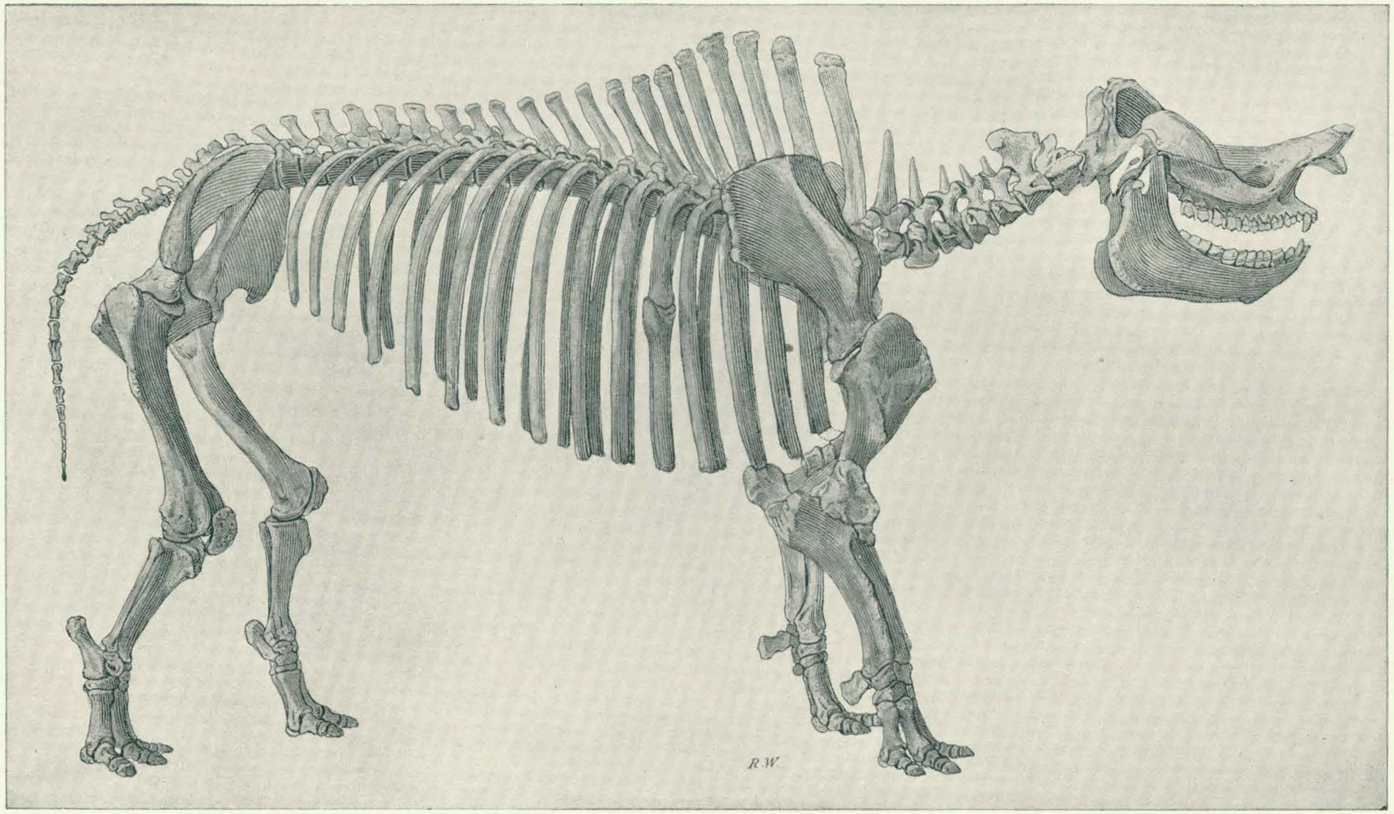
The next horizon is at the base of the Ogallala formation, which supplies water for many wells on the table-lands on both sides of the Lodgepole Valley at depths varying from 100 to 300 feet. The volume of water appears to be large at nearly all localities. At some places the waters are obtained high up in the formation, but the principal supplies are in the basal beds. At many points along the northern margin of the table these waters flow out into the canyons as springs of greater or less force, of which the most noteworthy are those on Greenwood, Middle, Hacksberry, and Bighorn creeks, in Lawrence Fork Canyon, and at Gabe, Long, and Duggers springs.

The Arikaree formation is a general reservoir for water which is nearly everywhere available in the table-lands lying between the valley of North Platte River and the crest of Pine Ridge. In some areas it is necessary to sink wells to the base of the formation where the materials are rather coarser than those higher up, but ordinarily the higher beds yield satisfactory supplies. These waters flow out at the surface in springs of greater or less magnitude in many canyons along the front of Pine Ridge; at a few widely scattered points in the Niobrara Valley, notably at Coyote Spring and at Royville; in the Snake Creek Valley, at Point of Rock Spring and Mud Spring; and along the north slope of the Platte Valley, at the spring near the head of Sheep Creek and the springs near the heads of Red Willow and Indian creeks.

The Gering formation contains water throughout its area, but it does not appear to be reached by many wells. Numerous springs on the ridge south of North Platte River flow from this formation at the surface of the Brule clay. Along the front of Pine Ridge there are a



"TOADSTOOL PARK" IN BAD LANDS NORTHWEST OF ADELIA, SIOUX COUNTY, NEBRASKA (BRULE FORMATION).



TITANOTHERIUM ROBUSTUM.

One twenty-third ($\frac{1}{23}$) natural size.

number of springs which flow out of these beds, and possibly some of the deeper wells on the summit of Pine Ridge obtain their water from this horizon, but ordinarily ample supply is reached at a less depth in the overlying Arikaree formation.

The Brule clay immediately underlies a wide area of the high slopes of the North Platte and Pumpkinseed valleys and yields water supplies to many wells. It is known as "hardpan" to the well drillers. In most cases, however, the volume of the water is small, and its quality is often unsatisfactory. Numerous abandoned houses in these valleys usually indicate that prospective settlers have been unable to obtain water supplies at moderate depths from the Brule clay. Where water occurs it is in crevices and fissures, which traverse the clay at moderately frequent intervals, but the volume of water depends on many factors, and there is seldom a good chance to obtain a large supply. In the area north of Pine Ridge the wells usually penetrate through the Brule clay into the underlying Chadron sands, which almost invariably contain fairly large volumes of water. It is a source of supply to a number of farmers and ranches. The water is not always of satisfactory quality, and in the wells at Adelia and Crawford it has been found unsuitable for locomotives. This formation underlies the Brule clays in the Platte and Pumpkinseed valleys, and probably would often yield water there to wells a few hundred feet in depth. Some years ago a well was sunk at Gering to a depth of 331 feet, which obtained a promising flow of water, possibly from Chadron sands. Owing to the small size of the pipe and certain accidents in boring, the well did not continue to flow, and clogged up so that it was a failure. As water supplies are particularly scant in the region about Gering and in the valleys to the south, it is very unfortunate that this boring was not given a fair trial. At Harrisburg, on the south slope of the Pumpkinseed Valley, a boring has recently been made to a depth of 790 feet without obtaining a flow. Judging from the small samples of the borings which were seen, the well passed through the Chadron sands, but it did not obtain a sufficient supply of water. As the altitude of the boring is 4,500 feet, or 600 feet higher than Gering, it was not to be supposed that the sands would here yield a surface flow. Below the Chadron sands there is a great mass of upper Cretaceous shales. It is not known whether the edge of the sandstone of the Laramie formation extends into southwestern Nebraska under the Chadron sands, but if it does, we should expect it to yield a water supply that would rise to an altitude of about 4,500 feet. In the Pierre shale there are no chances for water. In the area in which this formation is at the surface, in northern Sioux and Dawes counties, great difficulty has been experienced in obtaining water supplies for local use, and the water found has generally proved to be of unsatisfactory quality.

DEEP-SEATED WATERS.

In the older formations which underlie Nebraska there are wide-spread sheets of permeable deposits which carry large volumes of water. In the region to the west these deposits lie at a great depth, and many of the higher lands are probably above the level to which the waters would rise to afford surface flows. Owing to the failure of any boring in the central and western portion of the State to reach the deep-seated water-bearing beds, there is lack of definite knowledge as to their depth, but there can be no doubt of their presence. The section constituting Pl. LXXXIII illustrates the general relations of the two principal deep water-bearing formations—the Dakota sandstone and the Carboniferous and underlying limestones. In eastern South Dakota the Dakota sandstone yields to many wells large volumes of excellent water under high pressure. In eastern Nebraska, where the formation approaches the surface, it is also the source of water supply, at first to wells of moderate depth and then to innumerable springs. The Carboniferous and

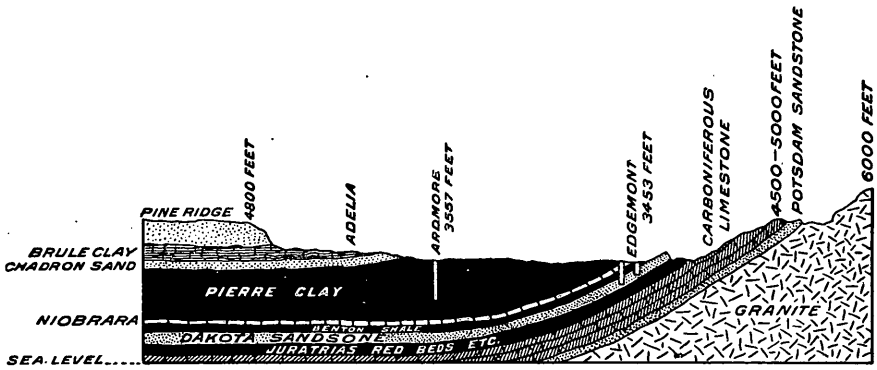
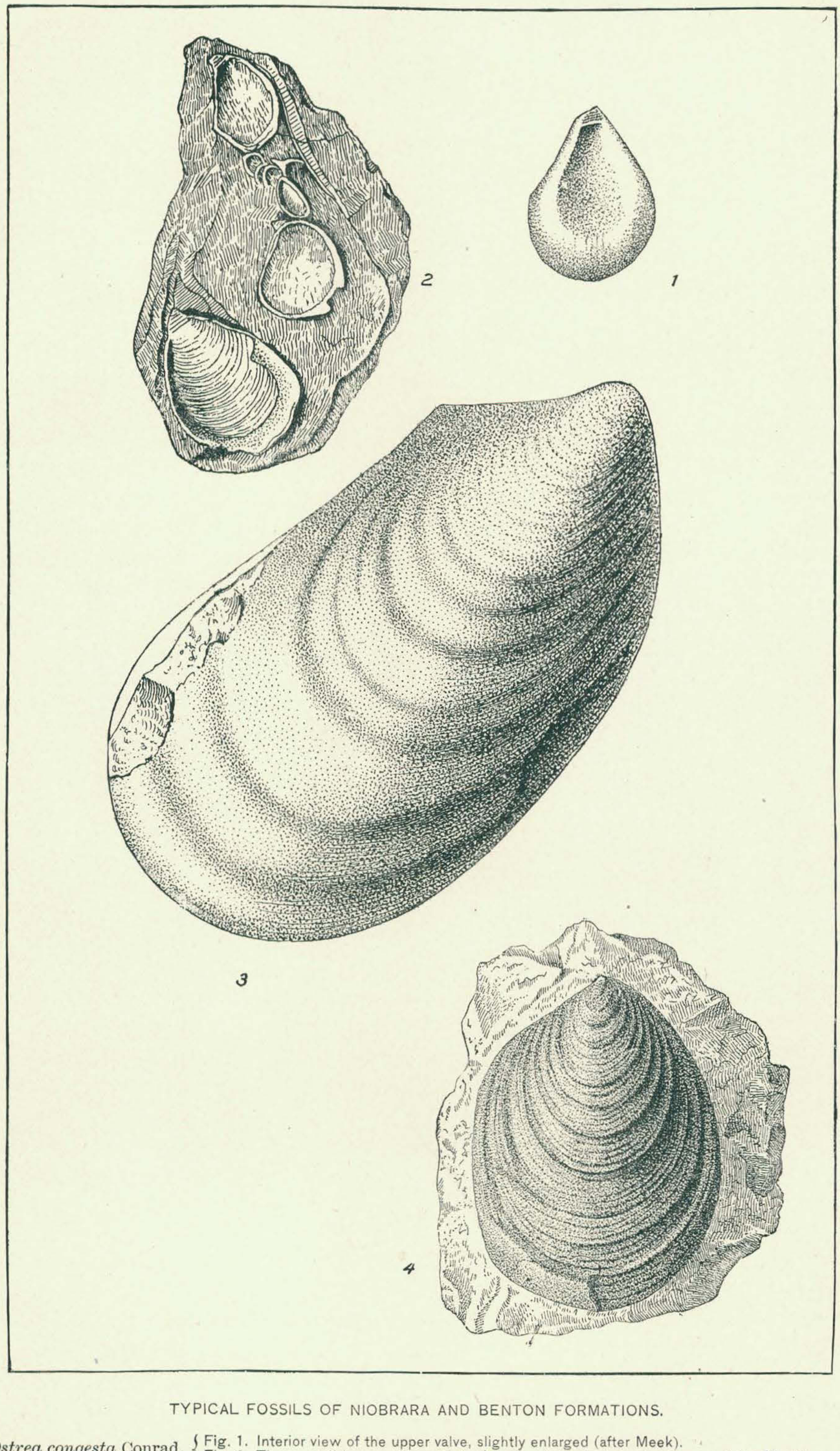


FIG. 228.—Section from Black Hills to Pine Ridge.

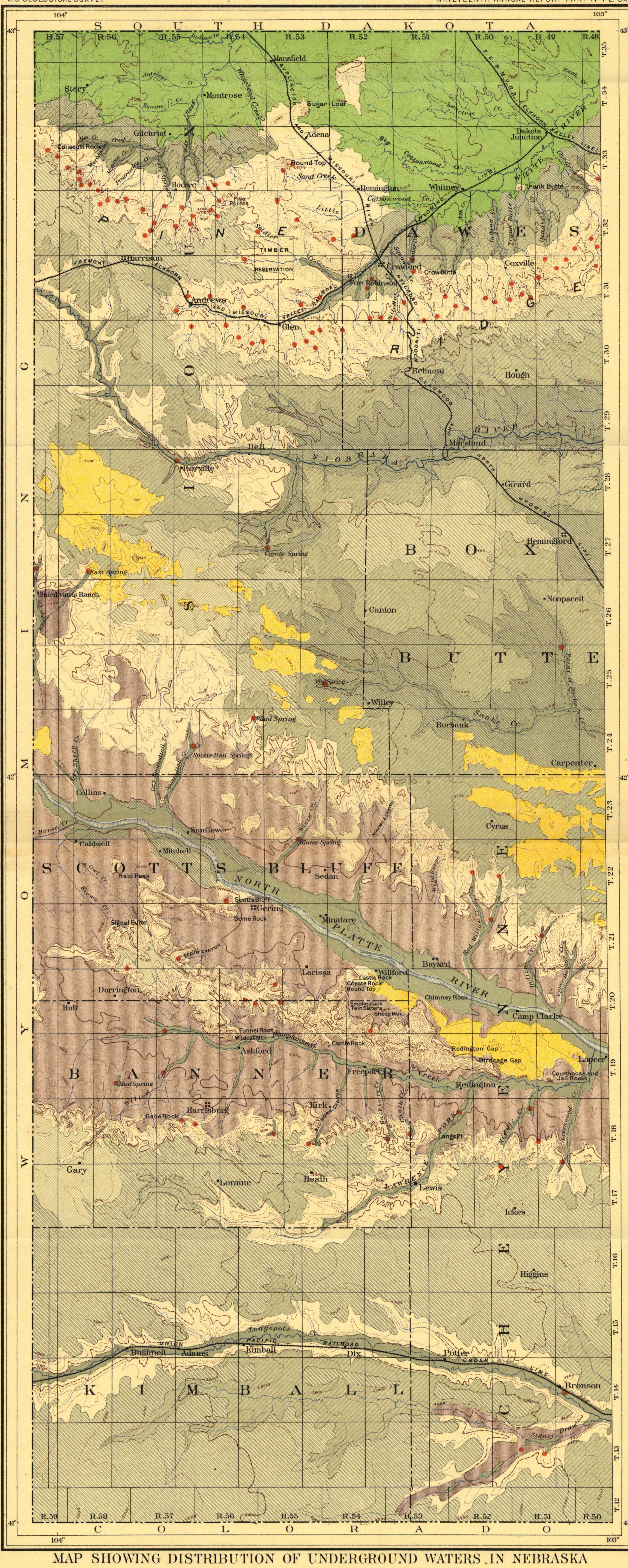
underlying formations yield water to numerous wells between 650 and 1,500 feet deep in eastern Nebraska, Iowa, etc. These waters pass into the formations along the foothills of the Black Hills and the Rocky Mountains at altitudes of from 3,000 to 6,000 feet in greater part, and have considerable pressure and head far to the east. This pressure and head, however, gradually decrease as the formations reach or approach the surface, the water then being free to escape. The waters in the Dakota sandstone lose their head entirely in eastern Nebraska, where the formation outcrops. The waters in the underlying Carboniferous limestones and older formations retain a moderate amount of head throughout Nebraska. Some of the factors bearing on the occurrence of these deep underground waters are shown in Pl. CXI, and in Pl. CXII are shown some of the conditions of occurrence of the waters in the Carboniferous and underlying formations in the vicinity of Omaha, Nebraska. It will be seen in Pl. CXII that the head is relatively constant near 1,100 feet above sea level over a wide area about



TYPICAL FOSSILS OF NIOBRARA AND BENTON FORMATIONS.

Ostrea congesta Conrad. { Fig. 1. Interior view of the upper valve, slightly enlarged (after Meek).
Fig. 2. Three small lower valves attached to the shell of a large Inoceramus (after Meek).

Inoceramus labiatus Schloth. { Fig. 3. Right valve of an elongated specimen (after Meek).
Fig. 4. Small right valve with unusually strong concentric ridges



MAP SHOWING DISTRIBUTION OF UNDERGROUND WATERS IN NEBRASKA WEST OF THE 103RD MERIDIAN

BY N. H. DARTON

Contours generalized from maps of U.S. Geological Survey

Scale

Contours approximated from R.R. levels and barometer readings

Contour interval 100 feet

Water within 25 feet of the surface in alluvial deposits

Water 25 to 100 feet deep

Water 100 to 200 feet deep

Water 200 to 300 feet deep

Water 300 to 350 feet deep

Sand hills with water usually within 25 to 50 feet of the surface

Region of Brule clay, in part overlain by alluvial sands. Water in crevices in "hard pan" quantity and depths variable

Region of Pierre clay, water supplies scanty and often of bad quality

Steep slopes and canyons predominating

Springs

Streams dry or underground in summer

JULIUS BIEN & CO. LITH. N.Y.

Omaha, but there is a slight rise to the west even in a few miles. At Lincoln it is 1,210 feet above sea level. The increase of head and pressure to the west and northwest is gradual, for the distance is great, but the amount becomes large as the Black Hills and Rocky Mountain zones of intake are approached. In Pl. CXI figures are given showing the altitudes along these zones and along the outcrop areas east which will afford some idea of the head to be expected in the intermediate region. In the diagram, fig. 229, there is shown a piece of physical apparatus which illustrates the gradient of head between a leak on the one hand and the source of pressure on the other, representing closely the relations which have been found to exist in the South Dakota artesian basin and probably prevail in a measure also in central and eastern Nebraska, where the head of the deeper-seated waters diminishes eastward.

Data are not sufficiently definite as yet for a precise determination of this gradient of head across western Nebraska, but it is apparent that in some of the valleys westward the head is probably higher than the altitude of the land, so that there are prospects for surface flows.

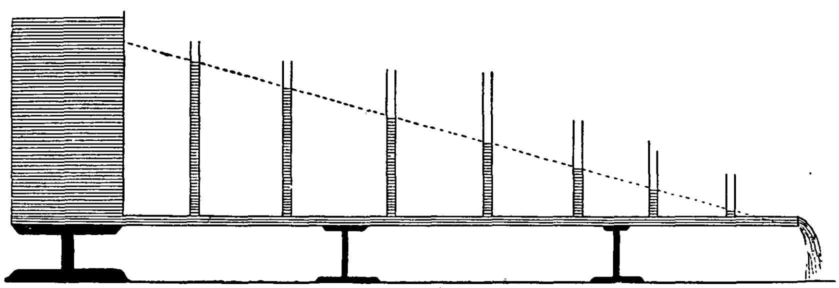


FIG. 229.—Diagram of apparatus illustrating the declivity of head of liquids flowing from a reservoir.

In order to reach the deep-seated waters in western Nebraska it is necessary to penetrate the Tertiary formations, the Pierre clay, the Niobrara limestone, and the Benton shale, to the Dakota sandstone, which should be expected to yield a large supply of excellent water. An attempt was made to reach this horizon in a deep boring at Chadron some years ago. A depth of 1,100 feet was attained, when the boring was abandoned owing to great difficulty in penetrating the Pierre shale. More recently an attempt has been made at Ardmore by the Burlington and Missouri River Railroad, which attained a depth of 1,500 feet apparently without reaching the bottom of the upper Cretaceous shales. These shales can be penetrated only by skillful well drillers, and it is necessary to begin with casing 12 or 14 inches in diameter at the top, as the size will have to be reduced occasionally as the boring progresses. The depth to the Dakota sandstone at Crawford will probably prove to be 2,000 feet, and in the valley of North Platte River the amount may be somewhat more. There is possibility of obtaining a flow in these localities, although the altitude is somewhat greater than that of the Dakota sandstone outcrops along the southern margin of the Black Hills. It is to be expected that the pressure of water in the Dakota sandstone would increase to the southwest toward the Rocky Mountains.

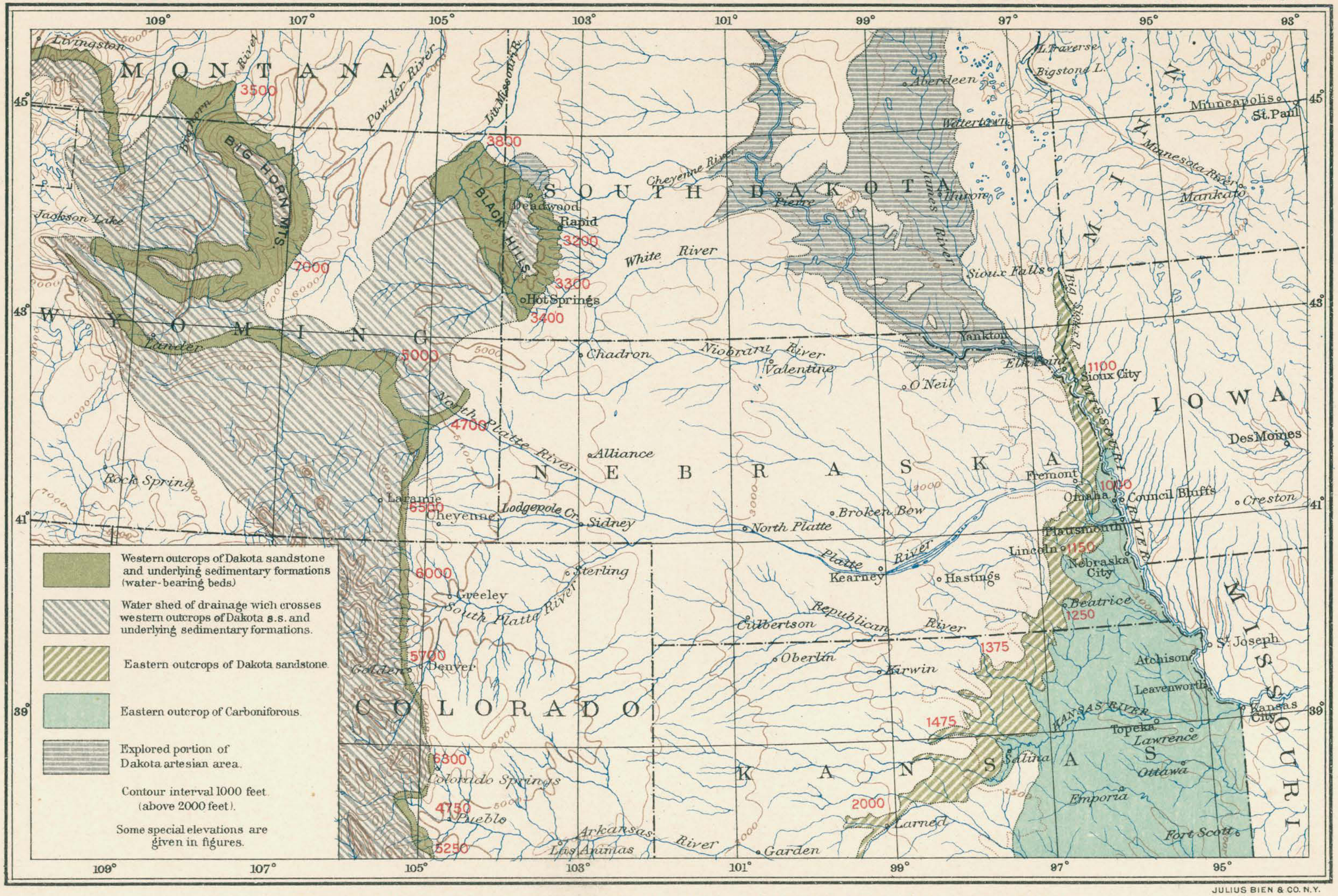
Underlying the Dakota sandstone, with a series of gray and red sandstones intervening, are the limestones of the Carboniferous age, which contain water in considerable volume and with somewhat greater head than the waters in the Dakota sandstone. These are the same beds as those yielding flows in the Missouri Valley about Omaha, and there is fair reason to believe that they would prove a satisfactory source of water supply in other portions of Nebraska.

SPRINGS.

Several of the water-bearing formations reach the surface along the valley slopes, where their outcrop is marked by the presence of springs. The location of the greater number of these springs is shown in Pl. CX. The Arikaree formation in the high area north of the valley of Platte River supplies numerous springs, notably along the northern front of Pine Ridge. The basal beds of the Ogallala formation also yield springs in the canyons south of the valley of Pumpkinseed Creek, and along both sides of the valley of Lodgepole Creek. The most extensive series of springs is along the north front of Pine Ridge, at the base of the Arikaree formation and from the underlying Gering sands. All of the larger canyons contain springs of considerable volume, often at a succession of levels. Sowbelly Canyon is particularly favored in this respect, but the other valleys, from Jim Creek to Chadron Creek, also have good water supplies from these sources. Even on Round Top there is a fine spring just above the top of the Brule clay bad lands. In the Brule clay area springs are rare and the volume of water is small. In the underlying Chadron beds there is more or less water at all points, which gives rise to seeps and springs along the outcrop zone of these beds north of Pine Ridge. In the Pierre shale region, next northward, springs are rare, superficial in origin, small in volume, and usually highly mineralized with iron, gypsum, or alkalies. A characteristic spring in this area is shown in Pl. CXIII. This view shows the opening from which the water emerges and the thick crust of alkali which has been deposited.

Along the Niobrara Valley there are occasional springs, mainly in the immediate vicinity of the river. Whistle Creek practically heads in Coyote springs, at an altitude of 4,520 feet, in the center of T. 27, R. 53. The more important springs along the northern side of the valley of Platte River are East spring, Spottedtail spring, Wind spring, Winter spring, the springs near the head of Sheep Creek, and those at the head waters of Red Willow and Indian creeks. They are derived from the lower portions of the Arikaree formation, except the Spottedtail and Winter springs, which emerge from alluvium in valley bottoms.

In the ridge between Platte River and Pumpkinseed Creek there are



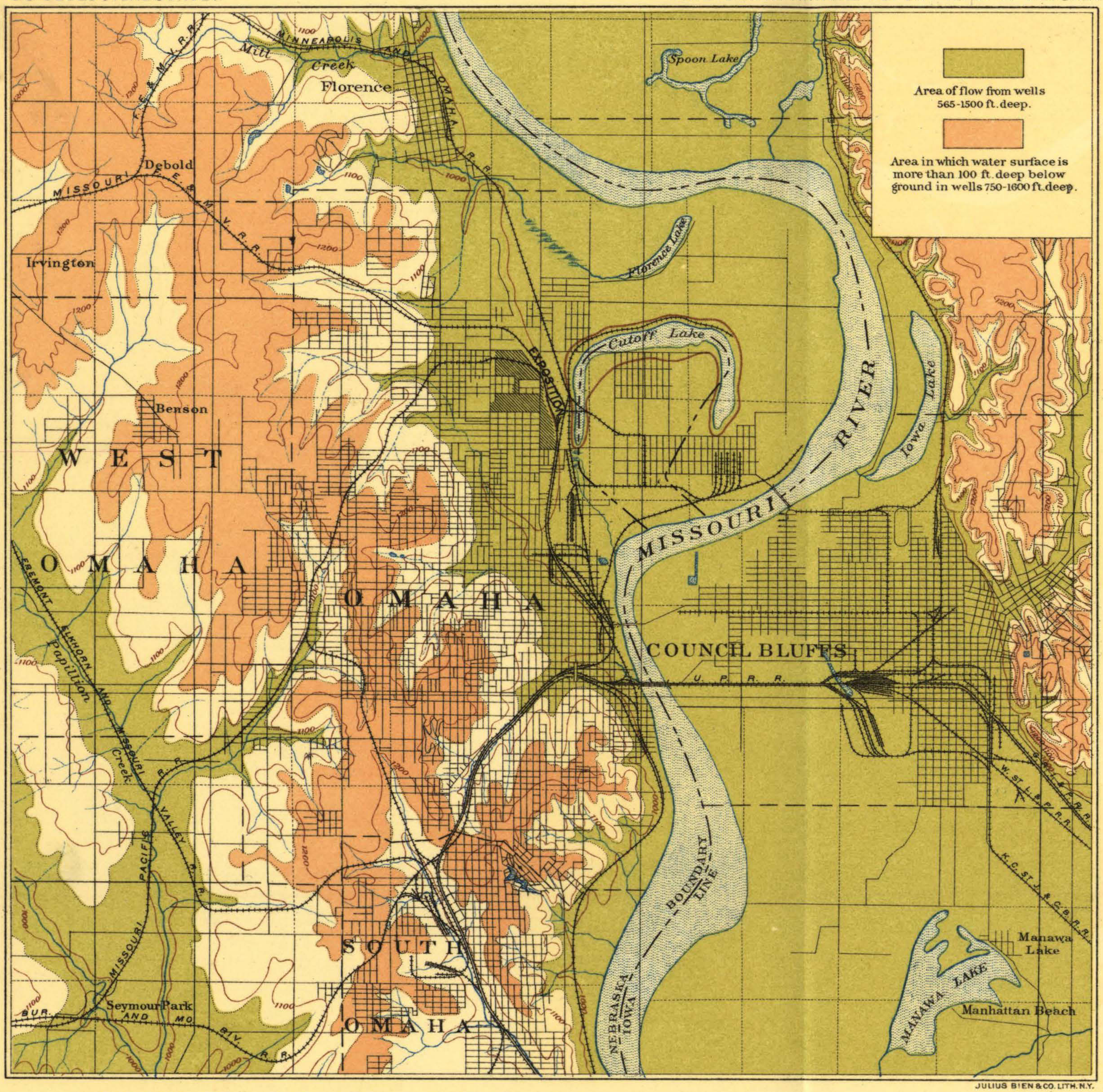
CONTOUR MAP OF UPPER MISSOURI RIVER REGION

SHOWING FACTORS BEARING ON PROSPECTS FOR DEEP UNDERGROUND WATERS

BY N. H. DARTON 1898.

Scale
50 25 0 50 100 150 200 250 MILES.

112



CONTOUR MAP OF OMAHA AND VICINITY SHOWING RELATIONS OF ARTESIAN WATER

BY N. H. DARTON 1898

SCALE

1 ½ 0 1 2 3 4 Miles

numerous small springs at the heads of some of the larger canyons which yield excellent water. Their distribution is shown in Pl. CX. The water is derived mainly from the Gering sands at their contact with the Brule clay.

The Pumpkinseed Valley is excavated entirely in the Brule clay and its lower springs are derived from the alluvial deposits in the valley. This is also the case with springs on Willow Creek and Middle Creek. In the canyons along the north front of the high table-land south of Pumpkinseed Creek there are numerous springs, which yield moderate amounts of water, mainly from the base of the Arikaree formation, and where this deposit is absent, from the base of the Ogallala formation. These springs are known as Gabe spring and Long spring southwest of Harrisburg, and Duggers spring south of Courthouse Rock.

There are a number of springs along the valley of Lawrence Fork, notably one 2 miles south of Redington, which yields a large flow of excellent water. This flow, however, sinks east of Redington and reaches Pumpkinseed Creek under ground.

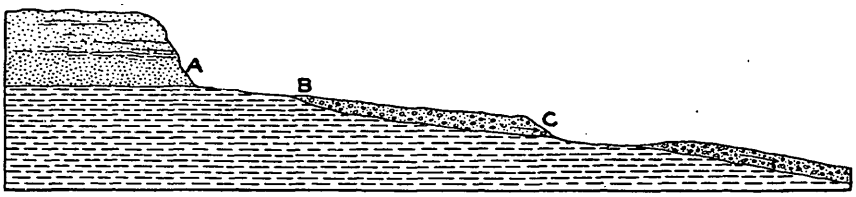


FIG. 230.—Ideal section to illustrate some characteristic features of springs in western Nebraska.

In Lodgepole Valley springs are very rare except at points where the creek itself, having sunk into the alluvial materials in the bottom of the valley, comes out again to flow on the surface for some distance. The best-known spring of this creek is at the "Spring farm" just east of Bronson. Two small springs in Sidney Draw furnish a moderate amount of water.

The springs in this region generally occur under two conditions, which are illustrated in fig. 230. On the left-hand side of the section there is shown the typical spring flowing out of sands, A, at their surface outcrop in a canyon or at the base of high lands. The water gathers from rainfall at a greater or less distance away and sinks underground into permeable beds, through which it travels to emerge as a spring at lower levels. There are many cases, particularly in arid and semiarid regions, where the volume of a rivulet or stream is so small that after running over the surface for some distance the water will sink into the coarse materials which usually lie in the bottom of a valley, as at B. It may then continue as an underflow and emerge in places as a spring of the type shown at C in the middle of the section in fig. 230. This occurs frequently in the region and is the nature of some of the low-level springs above described.

STREAMS.

NORTH PLATTE RIVER.

This stream traverses the central portion of the area and, although it is shallow during the greater portion of the year, carries a relatively large body of water. Its flow is subject to seasonal variations, ranging from a wide, deep torrent in late spring and the first month of summer to a shallow, irregular network of streams flowing among sand bars in the later summer and autumn. It has been estimated that at Gering the North Platte drainage area is 24,340 square miles; at Camp Clarke about 24,830 square miles; and at North Platte 28,517 square miles. The details of river measurements at these three points are given in Water-Supply and Irrigation Paper No. 15, on pages 85, 85, and 86, respectively, and the results of computations of discharge on pages 308 to 310 of the present volume. Reference should also be made to the data given in Part IV of the Eighteenth Annual Report of this Survey on pages 153 to 158, inclusive, and in Bulletin No. 140, on pages 99 to 102.

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

Date.	Maximum.	Minimum.	Mean.
1896.	*Second-feet.*	*Second-feet.*	*Second-feet.*
June 28–30	4,100	3,102	3,508
July 1–31	2,386	977	1,554
August 1–31	1,316	628	924
September 1–30	1,186	738	939
October 1–31	1,290	875	1,008
November 1–8	1,238	706	1,091
1897.			
January	2,404	2,042	2,287
February	2,404	1,567	2,253
March	2,223	450	1,299
April	8,390	1,567	3,649
May	10,540	6,885	8,688
June	11,400	4,520	7,401
July	4,305	930	2,147
August	2,042	580	1,066
September	580	400	492
October	580	350	484
November			*a*500
December			*a*500

a Approximate.

A large volume of the water is taken out of the river at intervals in Scotts Bluff and Cheyenne counties by the various irrigation canals, so that the reports at Gering and Camp Clarke do not indicate the total volume of water which enters the State from the west. It should be borne in mind also that under the bed of the river there is considerable thickness of coarse sand containing an underflow of which the volume is far greater than that flowing on the surface in dry weather.

North Platte River receives a number of minor branches between the mouth of Pumpkinseed Creek and the Wyoming line. They head in the high ridge to the south, and in the edge of the high table-land on the north. With the exception of Horse Creek, their surface waters do not extend to the river, and some of them usually are entirely dry to their heads. There is, however, generally a small underflow through the coarse materials in their beds. The largest volumes of water are from the north, in Dugout, Indian, Red Willow, Winter, Spottedtail, and Sheep creeks. These all head in living springs high up in the canyons, but the waters run only a short distance and sink into the coarse materials, where their volume as underflows is probably not large. Very little water flows out of the ridge extending from Courthouse Rock to the head waters of Kiowa Creek, and except in the heads of a few canyons where there are springs, the valleys are dry and appear to have but scant underflow. Horse Creek carries a moderate volume of water from some high ridges in Wyoming.

PUMPKINSEED CREEK.

The wide valley of Pumpkinseed Creek is traversed by a small stream which heads in the northwest portion of Banner County, in springs and seeps which gather considerable volume in the vicinity of Ashford. Additional supplies are received to the east, but the stream increases in size very gradually. It enters North Platte River near Lapeer. Some gagings made near its mouth were as follows:

	Second-feet.
July 26, 1894	17.1
June 28, 1896	22.2

The stream has numerous branches, but these contribute only surface water during the more rainy portion of the year. They nearly all have underflows of small volume, for their beds consist of gravels and sands into which the water sinks to the "hardpan" floor, and, moving slowly under ground, adds materially to the volume of the underflow of the main creek. The principal affluent is Lawrence Fork, which contains a considerable volume of water in Ts. 17 and 18, R. 52, but this water finally sinks during the summer and flows under ground for 2 miles to join the main creek near Redington. The other branches—Greenwood, Hackberry, and Bighorn creeks, Indian Springs, and Willow Creek—all contain some water in the upper portions of their valleys, but this water sinks into the coarse material of the valleys before it reaches Pumpkinseed Creek. The branches from the north are dry coulées in greater part. They contain water from very small springs in the vicinity of their heads.

LODGEPOLE CREEK.

The waters of Lodgepole Creek rise in Wyoming and, gradually gaining volume, enter Nebraska with a flow which, in August, 1895, was found to be 3.5 cubic feet a second. At about the same time the creek was found to flow 4 cubic feet a second at the north-south line between secs. 34 and 35, T. 15, R. 57. The volume varies greatly from point to point, but there appears to be a good underflow. For portions of its course the entire volume of the stream is diverted into irrigation ditches. In summer the creek becomes perfectly dry from the vicinity of sec. 28, T. 15, R. 54, for about 12 miles, to a point near the south line of sec. 4, T. 14, R. 52, where the water again appears, running $2\frac{1}{4}$ cubic feet a second at first, and then at a dam one-half mile below 4 cubic feet a second. There are in this vicinity many short ditches which take all or the greater portion of the water and leave the creek dry below the dam in the SE. $\frac{1}{4}$ sec. 14, T. 14, R. 51. It continues dry through sec. 13 and nearly through sec. 19, but near the east line of sec. 19 the water again rises to the surface and flows 2 cubic feet a second for a short distance. Then the creek is dry nearly to sec. 36, T. 14, R. 50, where there is a flow of about one-half a second-foot, which is diverted into irrigation ditches.

All these measurements were made in August, 1895, by Mr. Adna Dobson, as given in the first report of the State board of irrigation for 1895 and 1896. A measurement of the Lodgepole made at Kimball by Mr. Youngfelt on June 26, 1896, indicated 4.5 second-feet.

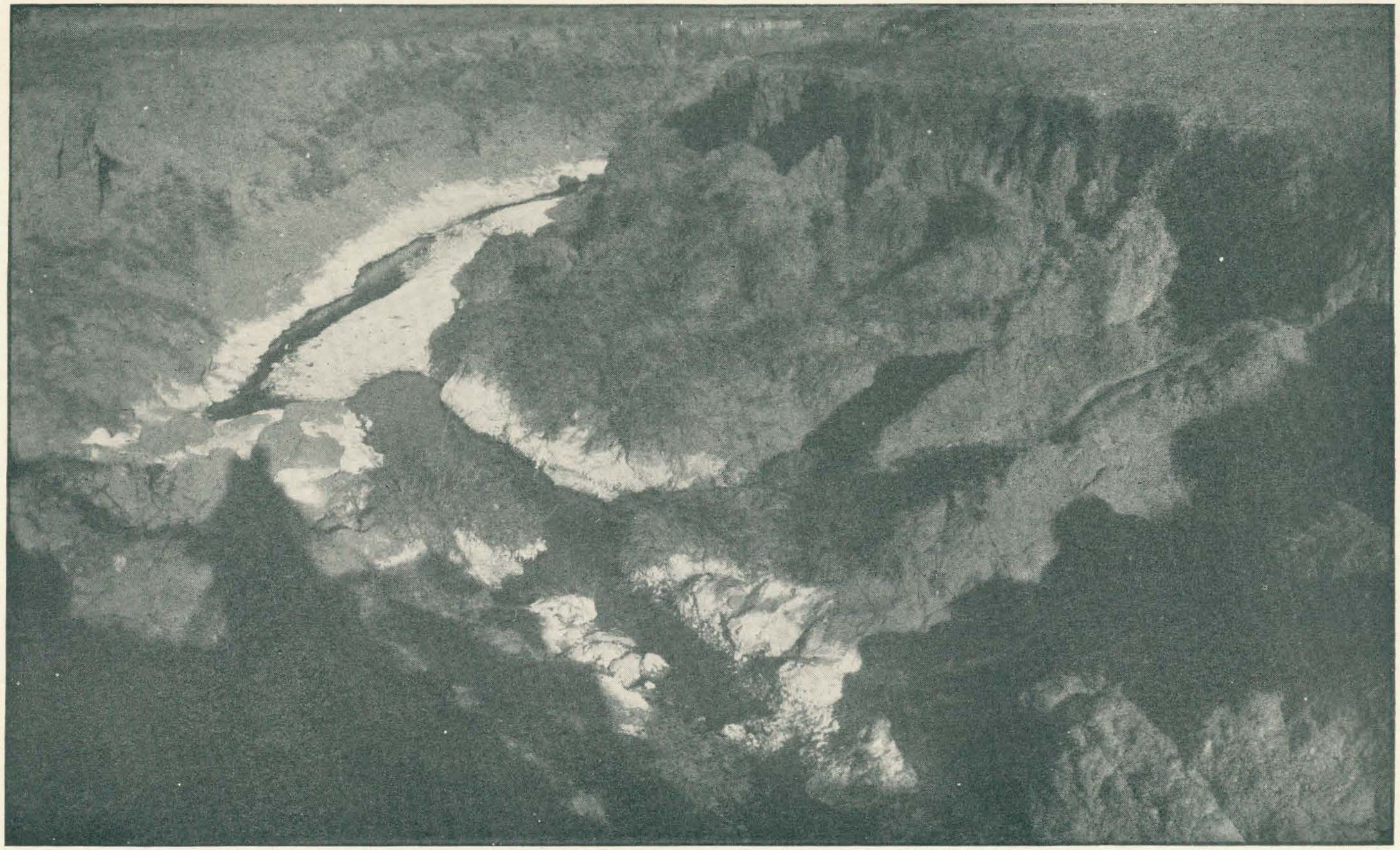
Several tributaries empty into the valley of Lodgepole Creek, but they do not contain flowing waters except in times of freshet. The principal one is Sidney Draw with its two branches, heading in the high table-land far westward in Kimball County, south of Lodgepole Valley. The branches which empty into Lodgepole Creek from the north head in high table-lands a short distance back and descend to the valley as dry coulées with steep declivities. Some contain underflows from springs which ordinarily do not have sufficient volume to reach the surface.

SNAKE CREEK.

Snake Creek is a stream which heads in the southeast corner of Sioux County, mainly among the sand hills, and flows in a very shallow valley over the table-land north of the valley of North Platte River. It receives waters from various springs, but its flow over the surface is intermittent and the volume of water relatively small. Its principal branch is from the north, known as Point of Rocks Creek, which contains a spring of fair size, but flows mainly under ground.

NIOBRARA RIVER.

This stream flows in a relatively shallow depression in the summit of the high table-lands lying between North Platte and White rivers. It enters Nebraska from Wyoming, and is a fine running stream of con-



SPRING AND ITS SALINE DEPOSIT FROM PIERRE SHALE, 10 MILES NORTHWEST OF CHADRON, NEBRASKA.

siderable volume throughout its course. For this reason it was called by the Indians Niobrara, meaning "running water." This translation is still much in use, and the French equivalent, "L'eau qui court," is occasionally heard.

We have only two reports on the volume of the river, one of gaging made by Mr. E. T. Youngfelt, June 23, 1896, at Marsland, where the flow was found to be 4 second-feet, which seems incredibly small, and the other, a measurement made by Prof. L. E. Hicks in range 51, Dawes County, of 98 second-feet on September 4, 1887.

The principal branch which this stream receives in western Nebraska is Whistle Creek, a flowing stream of small volume which heads in Coyote Springs. The other branches are very small and do not have flowing water at the surface.

WHITE RIVER.

The valley, heading in Pine Ridge a short distance east of Harrison and opening diagonally out of the high lands near Crawford, contains the head waters of White River. From its head springs, near Andrews, it is a running stream which gradually increases in volume to the northeast and becomes a prominent river before leaving Nebraska. During the greater part of 1897 a gaging station was maintained at Crawford, Nebraska, the results obtained being given on page 299 of this volume. The following gagings by Mr. E. T. Youngfelt indicate the volume of the White River in early summer and the rate of flow of a number of its branches at various points:

Discharge measurements of White River and some of its branches.[1]

Stream.	Date.	Locality.	Discharge per second.
			Cubic feet.
White River	June 24, 1896	Sec. 23, T. 31 N., R. 53 W	23.30
Do	do	Crawford	30.70
Do	June 25, 1896	Whitney	27.20
Do	June 1, 1891	Chadron	123.00
Soldier Creek	June 24, 1896	Fort Robinson	3.23
White Clay Creek	do	N. line sec. 2, T. 31 N., R. 52 W.	4.00
Fort Robinson Ditch	do	Fort Robinson	.79
Squaw Creek	do	N. line sec. 1, T. 31 N., R. 52 W.	.66
West Ash Creek	June 25, 1896	N. line sec. 25, T. 32 N., R. 51 W.	1.73
East Ash Creek	do	Half mile above mouth	1.09
Little Cottonwood Creek.	do	Sec. 7, T. 32 N., R. 51 W	.10
Big Cottonwood Creek	do	6 miles west of Whitney	.20
Indian Creek	do	Near mouth	.06

[1] Eighteenth Ann. Rept. U. S. Geol. Survey (for 1896-97), Part IV, 1897, p 193.

White River receives numerous branches from the deep canyons in the north face of Pine Ridge between Glen station and Chadron, notably from White Clay, Ash, Indian, and Chadron creeks. Its principal affluent on the north side is Soldier Creek, which heads in T. 32, R. 54, and furnishes a considerable volume of water, in part used in irrigation at Fort Robinson. Little Cottonwood, Big Cottonwood, Lone Tree, and Rush creeks are the principal branches from the north and west. They furnish but small amounts of water and are usually in greater part dry during midsummer.

HAT CREEK BASIN.

Hat Creek and its numerous branches head in deep canyons along the north face of Pine Ridge from Round Top to the Wyoming line. A large amount of water is supplied by the head streams, notably Hat Creek and Sowbelly, Prairie Dog, Monroe, Warbonnet, and Jim creeks, but the amount diminishes rapidly by evaporation as the edge of South Dakota is reached. The branches which head among the low hills north of Pine Ridge contain water only in the rainy portion of the year.

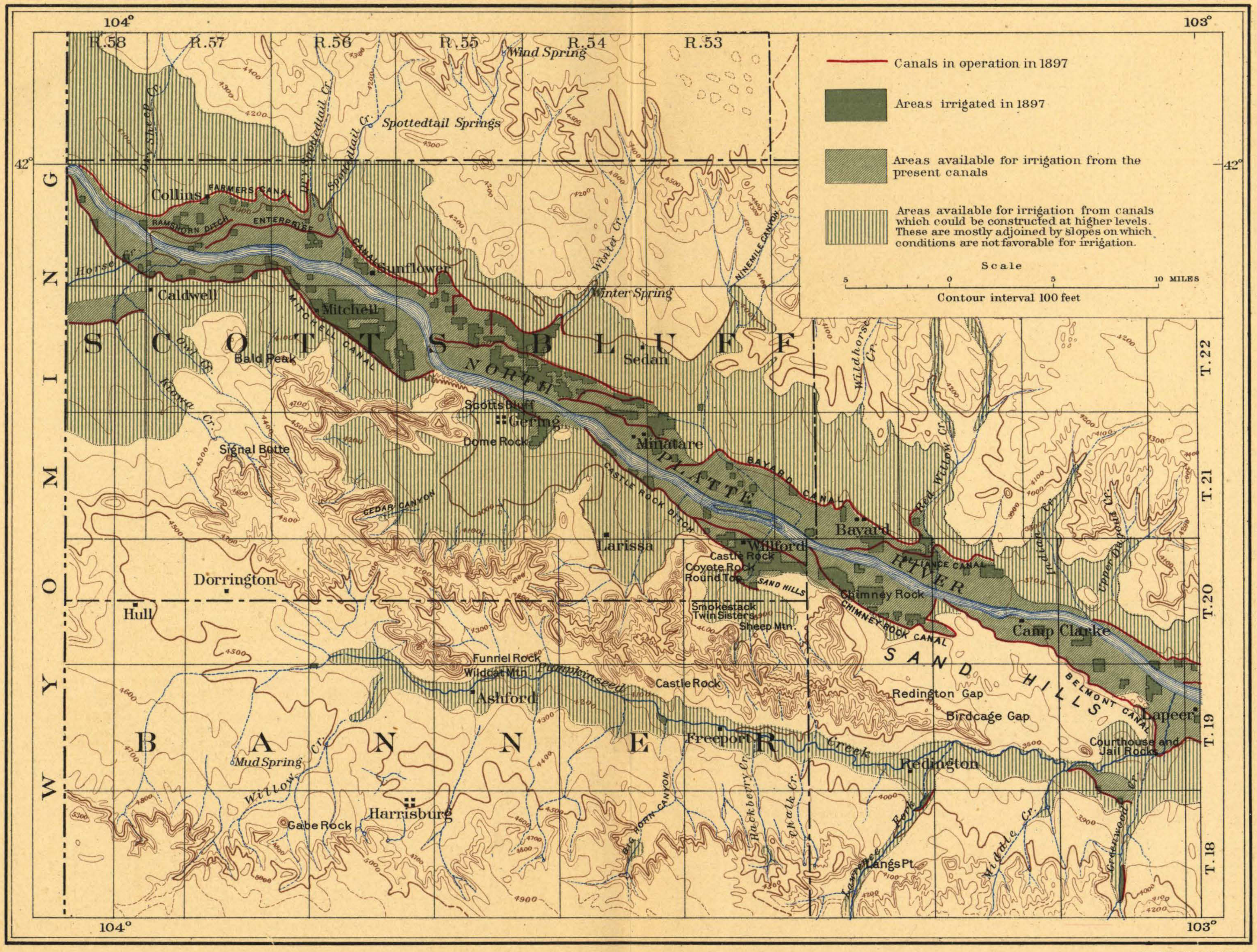
IRRIGATION.

There is in this region considerable acreage under cultivation with the assistance of irrigation. There are extensive canals along the valley of North Platte River, several ditches along White and Niobrara rivers, and local arrangements for irrigation have been made in some of the smaller valleys. The results have been so satisfactory that there is prospect of some extension of irrigation operations. Much of the country is distant from good markets, and during the last few years farm products usually have not sold for profitable prices. The local demands, however, have often been sufficient to yield satisfactory returns to many of the irrigators. In Pls. CXIV and CXV are shown the canals and irrigated and irrigable areas in Nebraska west of the one hundred and third meridian and north of latitude 41° 30′.

NORTH PLATTE VALLEY.

The large volume of water in North Platte River and the wide bottom lands bordered by long zones of gentle slopes afford ideal conditions for irrigation in this valley. The soil is usually thick and rich and, although somewhat alkaline, responds most satisfactorily.

The history of irrigation in the valley dates back to the latter part of 1887, with the organization of the Farmers' Canal Company, in Cheyenne County. Soon thereafter the Winter Creek, Minatare, and Enterprise canals were built, in 1888 and 1889, although the Enterprise canal was not entirely completed until somewhat later. The Minatare canal was begun in February, 1888, and opened August 20, 1888. These canals are all in Cheyenne and Scotts Bluff counties. The Mitchell canal was soon after constructed in Scotts Bluff County on



IRRIGATION MAP OF NEBRASKA, WEST OF THE 103RD MERIDIAN

BY N. H. DARTON 1898

the south side of the river, west of Scotts Bluff. It is about 25 miles in length, 24 feet wide at the bottom, and conveys water to about 20,000 acres of bottom land. Early in 1888 the Castle Rock canal was constructed. It has a width of 18 feet on the bottom for the first 9 miles and then divides into two branches, each about 8 feet wide on the bottom and carrying 3 feet of water. Another large canal was built at Bayard. In 1893 the Ramshorn ditch was built in the western part of Scotts Bluff County. The Farmers canal has a head gate with a front opening 156 feet wide, with 27 individual gates. It is capable of taking an 8-foot head of water. The canal is 60 feet wide at the bottom and carries 8 feet of water. The first mile is completed 60 feet wide on the bottom, and for the remainder of its length its width is 30 feet. A gaging made at its head gate by Mr. E. T. Youngfelt on June 19, 1896, showed a flow of 2.28 cubic feet a second.

The following list comprises all the main canals, but not the many miles of laterals into which they empty:

List of irrigation canals in valley of North Platte River, in Nebraska, west of the one hundred and third meridian.

Name.	Location of intake.				Length.
		Sec.	T.	R.	Miles.
Scotts Bluff County:					
Lawrence canal	Horse Creek	Wyoming			5
Mitchell canal	North Platte River	do			25
Farmers canal	do	19	23	58	15
Ramshorn canal	do	34	23	58	6
Enterprise canal	do	12	23	57	22
Winter canal	do	35	22	56	11
Gering canal	do	7	21	55	5
Minatare canal	do	14	21	55	10
Castle Rock canal	do	19	21	54	15
Bayard canal	do	35	21	54	8
					122
Cheyenne County:					
Bayard canal	do	35	21	54	7
Cnimney Rock canal	do	22	20	53	11
Alliance canal	do	23	20	53	10
Belmont canal	do	34	20	52	15
Browns Creek canal	do	11	19	51	6
					49
Total					171

The Lawrence canal derives its water from Horse Creek in Wyoming, and it is supplemented by one 400-acre storage reservoir 10 feet deep and another covering 180 acres 11 feet deep.

The following estimates of crops raised in the Platte Valley are based on data obtained by Messrs. C. A. Fisher and F. H. Ainsworth during the autumn of 1897. In Scotts Bluff County the area irrigated from North Platte River in 1897 was 16,080 acres, in which wild hay, alfalfa, corn, and wheat were the principal crops. Oats and garden vegetables were also irrigated extensively. In Cheyenne County the area irrigated from North Platte River in 1897 was 4,150 acres, of which hay and alfalfa were the principal products, together with smaller amounts of various cereals and vegetables. The yield per acre of crops under irrigation is somewhat variable. Wheat usually harvests from 30 to 40 bushels an acre; potatoes 150 to 200 bushels, and wild hay 1½ tons. Alfalfa yields 2 tons to the cutting, and is cut three times a season. Near Sunflower post-office there is an extensive orchard under irrigation, which promises to be very successful. It contains about 3,200 trees, many berry bushes, and 5,000 strawberry plants.

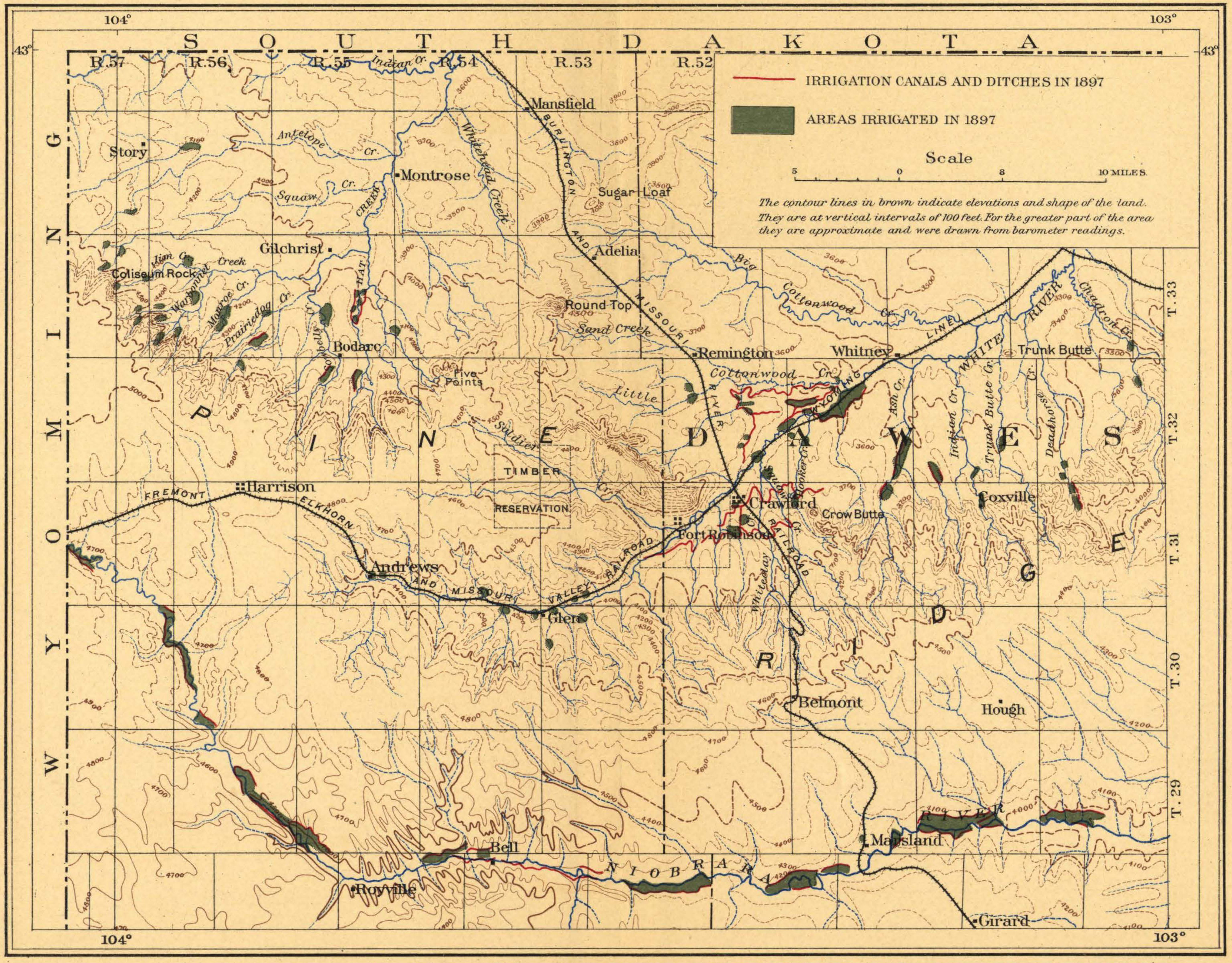
The cost of irrigation was found to vary greatly. Figures were obtained for 7,500 acres in the Platte Valley, which indicate an average cost of 41 cents an acre. The farms are mostly from 80 to 160 acres. The individual cost an acre varied in greater part from 30 to 75 cents. In many cases the water was paid for partly in cash and partly in labor.

PUMPKINSEED VALLEY.

Pumpkinseed Creek is available for irrigation of a small marginal acreage along the greater part of its course, but the waters are used only to a small extent. There is a ditch, known as the Courthouse Rock canal, extending from the west line of range 50 to Greenwood Creek, a distance of 5 miles, and there are several small local ditches and reservoirs at various points, shown in Pl. CXIV. The area of crops is about 90 acres, embracing several hay meadows. Lawrence Fork is used locally for irrigation 2 miles south of Redington, and its excellent water supply would admit of much more extensive use.

NIOBRARA VALLEY.

The waters of Niobrara River are utilized extensively for the irrigation of narrow strips of the bottom lands. There are canals at frequent intervals along its course, which furnish water mainly for hay meadows. Some grain crops are raised, but their acreage is small. The total area under irrigation in 1897 was about 7,015 acres.



IRRIGATION MAP OF NIOBRARA RIVER, WHITE RIVER AND HAT CREEK BASINS IN NEBRASKA WEST OF THE 103RD MERIDIAN

BY N. H. DARTON 1898

JULIUS BIEN & CO. LITH. N.Y.

The following is a list of the canals, compiled from data recently obtained by the State engineer:

List of irrigation ditches along Niobrara River, in Nebraska, west of the one hundred and third meridian.

Name.	Location of intake.			Approximate length.
	Sec.	T.	R.	
Sioux County:				*Miles.*
Bigelow & Seymour ditch	19	31	57	1.75
Warneke's ditch	27	31	57	2.00
Johnson's ditch	36	31	57	.75
Lacota ditch	1	30	57	3.00
Peter Bourett's ditch	29	30	56	2.00
Earnest ditch	9	29	56	4.00
McGinley & Stover upper ditch	23	29	56	3.50
McGinley & Stover lower ditch	25	29	56	3.00
Harris & Neece ditch	3	28	55	10.00
La Belle ditch	6	28	54	2.00
——— ditch	4	28	54	4.00
Irion Bros.' ditch	1	28	54	2.00
Moore's ditch	9	28	53	3.50
Boxbutte County:				
McLaughlin ditch	9	28	52	3.00
Vincent ditch	10	28	52	1.00
Hughes ditch	1	28	52	2.00
Dawes County:				
Snow ditch	35	29	51	1.00
Palmer ditch	36	29	51	5.00
Furman ditch	29	29	50	3.00
Enterprise ditch	28	29	50	3.50
Hatch & Cross ditch	25	29	50	3.00
McMannis & Neeland ditch	29	29	49	2.00
Total	....	....	....	65.00

WHITE RIVER BASIN.

The relatively large volumes of running water in White River and those of its branches which head in the canyons on the north front of Pine Ridge have been utilized at various points for irrigation. Many ditches have been constructed, and there are plans for a more extensive use of the waters. At present about 3,655 acres are under irrigation, in greater part along the main valley.

The following list of ditches is compiled from data obtained by the State engineer during 1897:

List of irrigation ditches in White River Basin, in Nebraska, west of the one hundred and third meridian.

Name.	Location of intake.				Length.
		Sec.	*T.*	*R.*	*Miles.*
Sioux County:					
Lewis ditch	White River	27	31	55	.50
Schwartz-Hughson ditch	do	26	31	55	.25
Tucker's ditch	do	34	31	54	.75
Colville ditch	Kyle Creek	3	30	54	1.00
Diedrichson ditch	White River	1	30	54	.50
Johnson ditch	do	7	30	53	.50
Jacobson ditch	do	32	31	53	.50
Mason ditch	do	32	31	53	.25
Crawford Citizens' ditch	do	23	31	53	1.50
					5.75
Dawes County:					
Crawford Citizens' ditch	do	23	31	53	18.50
Hazleton ditch	White Clay Creek.	13	31	52	1.00
Cooper ditch	do	2	31	52	1.75
Butterworth ditch	White River	3	31	52	.50
Hall's ditch	do	34	32	51	13.00
White River Irrigation Company's ditch.	do	34	32	52	2.00
McFarland's ditch	White Clay Creek.	35	32	52	.75
Harris & Cooper ditch	White River	25	32	52	10.00
Rasher ditch	do	19	32	51	1.00
Welling ditch	do	17	32	51	.50
Harris ditch	do	17	32	51	2.00
McManus ditch	Hooker Creek	7	31	51	1.00
Stewart Brothers' ditch	Little Cottonwood Creek.	8	32	52	1.50
Thomas Stewart ditch	do	8	32	52	.75
Spring Creek ditch	Spring Creek	13	32	52	.75
Spring Creek ditch No. 1	do	18	32	51	1.00
Kusil ditch	Little Cottonwood Creek.	9	32	51	1.00
Mace ditch	West Ash Creek.	2	31	51	1.00
West Ash Creek Irrigation Company's ditch.	do	36	32	51	2.00
Baron ditch	East Ash Creek	32	32	50	.50

List of irrigation ditches in White River Basin, in Nebraska, west of the one hundred and third meridian—Continued.

Name.	Location of intake.				Length.
Dawes County—Continued.		*Sec.*	*T.*	*R.*	*Miles.*
Ox Yoke ditch	East Ash Creek	31	32	50	1.50
James Wilson ditch	Indian Creek	10	31	50	.125
Seegrist ditch	do	3	31	50	.50
Flood ditch	East Fork of Indian Creek.	33	32	50	.75
Smock's ditch	Trunk Butte Creek.	26	32	50	.50
Goff ditch	Dead Horse Creek.	9	31	49	1.00
Norton ditch	do	9	31	49	.75
Woodruff ditch	do	32	32	49	.75
Kemery Ram	do	32	32	49	.50
W. Wilson's ditch	Chadron Creek	12	32	49	.50
H. M. Wilson's ditch	do	12	32	49	.75
Half Diamond	do	1	32	49	1.00
					69.125
Total					74.875

LODGEPOLE VALLEY.

The water of Lodgepole Creek has been utilized for irrigation for several years, and at times practically all the stream has been diverted into the fields. Hay has been the principal crop, but grains and vegetables have also been irrigated to some extent. The average volume of the creek is about 4 cubic feet per second, but along some portion of the valley the waters sink beneath the surface and, traveling under ground for some distance, emerge again in springs. The following facts relating to this valley are taken from notes by Mr. Adna Dobson, made in the summer of 1895.[1]

Commencing from the west, the first ditch is the Hoover, which supplies water for about 50 acres; then come the ditches of S. A. Pierce and L. C. Kinney, which supply water for about 575 acres, mainly of hay lands. In the next 4 miles no more water is taken out, and then comes the head of the Young ditch, which supplies water for about 30 acres, extending to sec. 34, T. 15, R. 57. Five miles lower down is the ditch of Carl Ruttner, which takes water on each side of the creek, the total amount being 4.9 cubic feet a second, which is used for covering about 40 acres. One mile lower down is the beginning of

[1] First Biennial Report of the State Board of Irrigation of the State of Nebraska for 1895 and 1896, prepared by W. R. Akers, Lincoln, 1897, pp. 151-157.

J. J. Kinney's south ditch, which takes all the water in the creek, 3.6 cubic feet a second, for the cultivation of about 140 acres. One-half mile below this is the head of J. J. Kinney's north ditch, into which the entire creek is diverted. The amount of water is 2.1 cubic feet a second for the watering of 190 acres. These ditches are used alternately in order to obtain greater volume. The amount of water in the creek increases rapidly below the head of Mr. Kinney's ditch, and at the east line of sec. 34, one-half mile below, the creek is running about 6 cubic feet a second. Within the next 3 miles is the Hurley, Liley & Polly ditch, which takes 4.5 cubic feet of water a second for the irrigation of 160 acres. Two miles below this is the head of the Hurley & Polly ditch for the irrigation of about 125 acres. One-half mile lower down the valley is the head of the Bay State ditch, which takes 2.5 cubic feet of water a second for 100 acres. In the next 7 miles are the McIntosh, Circle Arrow, and Brady ditches, with only limited supplies of water, the creek becoming practically dry above Mr. Brady's head gate in sec. 28, T. 15, R. 54, and continuing so to a point on sec. 4, T. 14, R. 52, where it again appears. A measurement at the head of Adams ditch, in sec. 31, T. 14, R. 52, showed 2¼ cubic feet a second, which is taken by the Adams ditch for the cultivation of 245 acres, mainly of hay. Next below is Thomas Gunderson's ditch, which has 5 cubic feet of water a second for 100 acres. In sec. 7, T. 14, R. 51, is the ditch of Mr. Hans Christianson, which takes about 1 cubic foot of water a second for 70 acres. One and one-half miles below this is the ditch of Mr. James Mitchell, which takes 3.5 cubic feet a second for 60 acres; and next below is the head of Mr. John Anderson's ditch, for 200 acres. This ditch is used alternately with the Mitchell ditch in order to have a sufficient volume of water. Then comes the very small ditch of Mr. J. A. Shanahan for the irrigation of 2 or 3 acres. The next dam below is for Mr. M. Urback's ditch. Then there is the ditch of N. P. Lingholm, which heads in the SE.¼ sec. 14, T. 14, R. 51, and provides water for 30 acres. It was taking 1.5 cubic feet of water a second at the time of observation. The creek is dry below this through sec. 13 and nearly through sec. 19. Near the east line of sec. 19 the water rises again, and at the head of the Couch ditches, in the SW.¼ sec. 20, T. 14, R. 50, 2 cubic feet a second is available for the irrigation of about 40 acres. Runge's ditches, Nos. 1 and 2, are in secs. 28 and 29, T. 14, R. 50, and provide for about 105 acres. The Ickes ditch comes next, but the amount of water is hardly sufficient to cover more than 100 acres. About one-half cubic foot of water a second passes the Ickes dam, and fills a small pond at the head of the Adams & Tobin ditch, but the supply was inadequate to cover the 180 acres to be irrigated. Below this dam the creek is entirely dry for the next mile, where the water rises again in springs; and at the head of the Trognitz ditch, in sec. 36, T. 14, R. 50, one-half a cubic foot of water a second flows into the ditch and is used for the irrigation of about 34 acres. It is the same ditch that was built by the United States to supply water for Fort Sidney.

The following table gives the acreage of crops irrigated in the Lodgepole Valley west of the one hundred and third meridian in 1896, according to the first report of the State board of irrigation, p. 158:

Acreage of crops irrigated in the Lodgepole Valley west of the one hundred and third meridian in 1896.

	Acres.		Acres.
Alfalfa	317	Barley	20
Native hay	2,160	Rye	2
Corn	80	Potatoes	42
Oats	66	Garden trees, etc	25
Wheat	63		
Millet	57	Total	2,832

HAT CREEK BASIN.

The upper portions of Hat Creek and its numerous branches rising in canyons in the northern slopes of Pine Ridge contain water in sufficient supply for the irrigation of many local areas. These are mainly in the relatively narrow canyons, where only small strips of land are so situated as to be easily watered. The volume of water in most cases is ample and is derived from ever-flowing springs. Nearly all the canyons contain small short canals, which serve for the irrigation of numerous small farms. The total area under irrigation in 1897 was estimated to be 1,860 acres.

The following is a list of the canals according to the plots of the State engineer:

List of irrigation ditches in Hat Creek Basin, Sioux County, Nebraska.

Name.	Location of intake.				Length.
		Sec.	*T.*	*R.*	*Miles.*
Steel ditch	Hat Creek	16	32	55	1.50
Coffee's ditch	do	26	33	55	5.00
Miller ditch	do	23	33	55	.75
Holly's ditch	Boggy Creek	31	33	54	1.00
Old Sowbelly ditch	Sowbelly Creek	7	32	55	2.00
Hall's ditch	do	6	32	55	.50
M. D. Jordan's ditch	do	21	33	55	1.50
Schlitz ditch	Cedar Creek	35	33	56	2.00
Valdeg ditch	Prairie Dog Creek	3	32	56	.50
Zerbst ditch	do	25	33	56	1.00
Big Monroe Creek ditch	Big Monroe Creek	33	33	56	2.00
Biehle ditch		32	33	56	.75
Nolan's ditches No. 1 and No. 2	Warbonnet Creek	23	33	57	1.25
Kay's ditch	do	26	33	57	.75
Daut ditch	do	30	33	56	1.00
——— ditch	do	31	33	56	1.00

List of irrigation ditches in Hat Creek Basin, Sioux County, Nebraska—Continued.

Name.	Location of intake.				Length.
		Sec.	*T.*	*R.*	*Miles.*
Warbonnet ditch	Warbonnet Creek	21	33	56	1.50
Woodruff's ditch	Jim Creek	14	33	57	1.00
Slattery's ditch	do	13	33	57	1.00
Jim Creek ditch	do	8	33	56	.50
Hamlin ditch	Squaw Creek	10	33	57	.50
Dunn's ditch	do	11	33	57	2.00
P. D. Dunn's ditch	do	3	33	57	1.00
Turner's ditch	Antelope Creek	26	34	57	1.50
Story's ditch	do	8	34	56	1.00
Cherry Creek ditch	Cherry Creek	29	33	54	.25
Total					32.75

WINDMILL IRRIGATION.

Several farmers in western Nebraska have experimented with windmill irrigation with encouraging results. There are large supplies of underground waters under the high table-lands, beginning with Pine Ridge and lying in broad expanse between the larger valleys. This is notably the case on the fine table lying between the valleys of Lodgepole Creek and Pumpkinseed Creek. These waters are usually at a depth of over 175 feet, but a large windmill soon raises sufficient water to fill a fair-sized reservoir. About 10 acres seems to be the limit for irrigation from one windmill, but this area will afford sufficient crops for local use. A reservoir is essential for satisfactory irrigation from a pump, but there usually is no difficulty in constructing one in the table-land areas.

CLIMATE.

Western Nebraska has a climate of typical plains character. It is dry and hot in summer, moderately moist in late spring, and cold, but with little snow, in winter. There is considerable variability in the climatic features from year to year, rather more than is found farther south or north, and some local variations from point to point, particularly in rainfall. Records of weather were kept for many years at Sidney in the Lodgepole Valley, and at Fort Robinson on White River, while for shorter periods observations have been made at Alliance, Gering, Hay Springs, Kimball, and Camp Sheridan. In Pl. CXVI there is given a graphic reproduction of precipitation records covering a period of several years at some of the stations above mentioned, compiled from an article on the Rainfall of Nebraska,[1] by C. D. Swezey and G. A. Loveland, together with data for 1896 and 1897, kindly supplied by Mr. Loveland.

[1] University of Nebraska, Bull. Agric. Exper. Stat., Vol. VIII, Article IV, 1896.

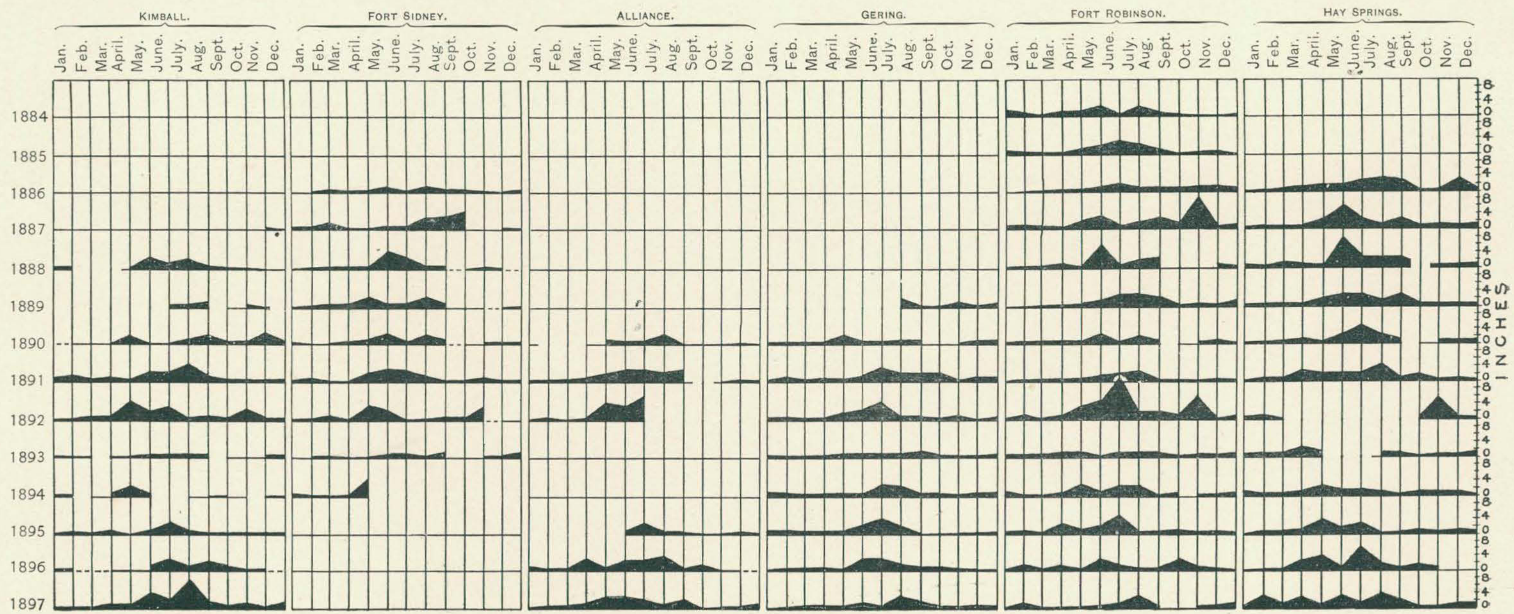


DIAGRAM OF RAINFALL AT LOCALITIES IN WESTERN NEBRASKA, 1884 TO 1897.

- - - No precipitation. —— Trace. The absence of horizontal line indicates that no observations were recorded during a portion of the year.

TIMBER.

The occurrence of timber in this region is restricted to certain localities of relatively limited extent. In the greater part of the plains area there is no timber at all, and the valleys of the Platte and upper Niobrara rivers and Lodgepole Creek do not contain trees. Along the northern escarpment of Pine Ridge, on the slopes of the White River and Hat Creek basins, there is a moderately wide zone of scattered pine forest. It extends from the crest of the ridge down nearly to the foot of the steeper slopes, and the aggregate amount of timber is fairly large. Along the ridge south of North Platte River there was formerly considerable pine, and many of the slopes north of Platte River and south of Pumpkinseed Valley maintained a scattered growth of pine. Some of the canyons in this region contain deciduous trees in small groves, and this is also the case in the many canyons in the northern slopes of Pine Ridge, and at intervals along the banks of White River. The extent of the timber in this region is shown in Pl. CXVII. The principal tree is the Rocky Mountain pine (*Pinus ponderosa*). It attains a diameter of from 1 to 2 feet where the conditions are most favorable, but its growth is somewhat scattering, and deep inroads have been made on the supply by woodcutters. The young pines appear to be thrifty, as they spring up abundantly on most of the slopes, and are growing vigorously. A typical view of the pine and other woods on Pine Ridge is given in Pl. CXVIII, and some further features of the pine growth are shown in Pls. LXXXI and XCIV.

In the region adjoining North Platte River the growth of pines is rather scanty, and nearly all of the larger trees have been or are being cut. This is also the case along the edge of the table-land south of Pumpkinseed Creek.

The deciduous trees of the region comprise mainly cottonwood (*Populus monilifera*), with a moderate proportion of box elder (*Negundium americanum*), and a small variety of other similar trees.

ELEVATIONS.

List of elevations in Nebraska west of the one hundred and third meridian.

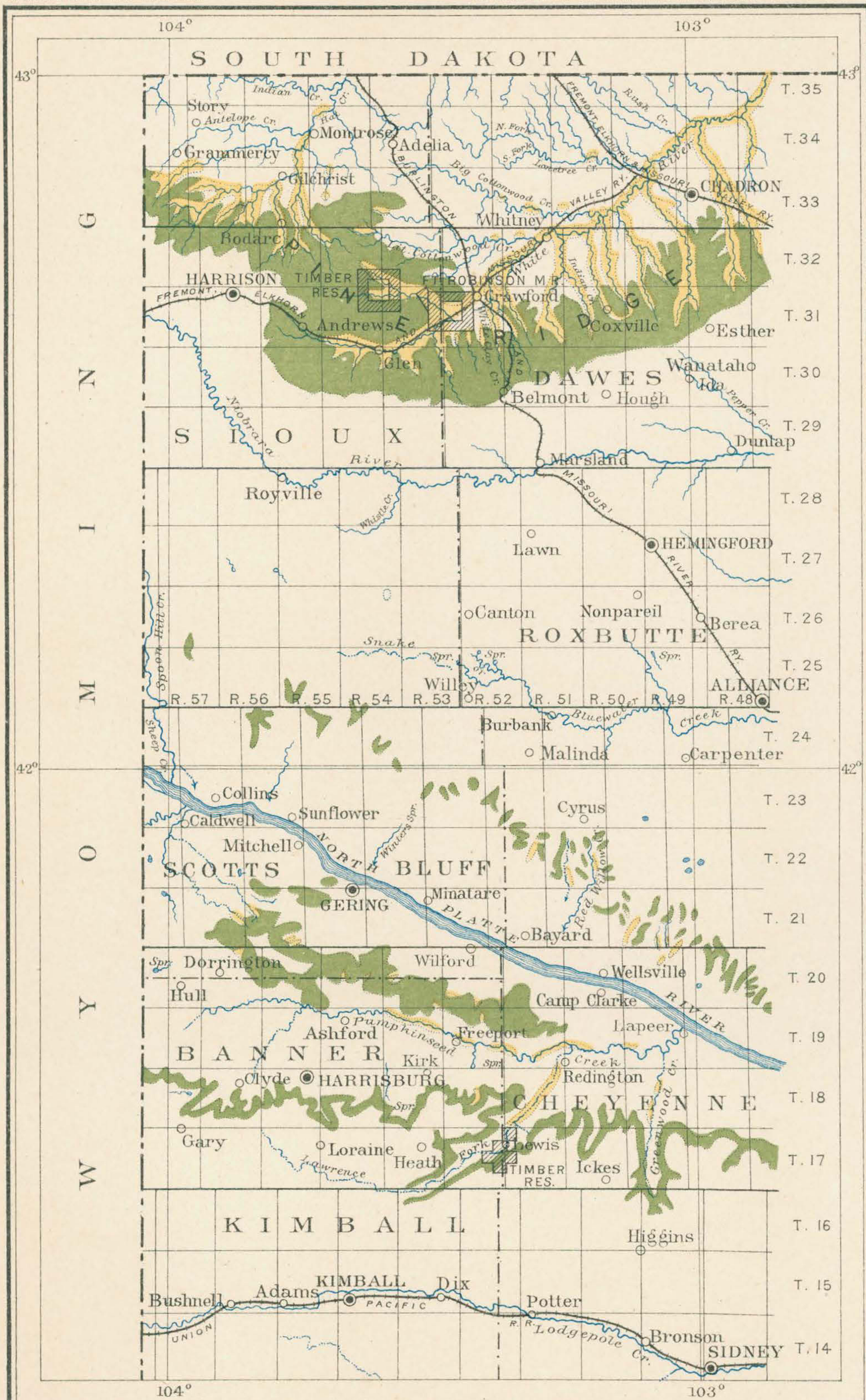
WESTERN CHEYENNE COUNTY.

Locality.	Altitude.	Authority.
	Feet.	
Lapeer	3,638	U. S. G. S. bench mark.
Courthouse Rock	4,100	Do.
Jail Rock	4,002	Do.
Roundhouse Rock	4,255	Do.
Twin Mounds	4,309	Do.
Redington	3,870	Do.
Camp Clarke	3,705	Do.
Springs on Middle Creek	3,830	Do.
Chimney Rock	4,242	Do.
Bird Cage Gap	4,028	Do.
Bayard	3,780	Do.
Redington Gap	4,126	Do.
Cyrus	4,320	Do.
Spring Lakes	4,260	Do.
Duggers Springs	4,030	Do.
Ridge at head of McManigle Canyon	4,520	Do.
Table-land T. 22, R. 50 W	4,200-4,300	Do.
Ickes post-office	4,415	Barometer.
Table at head of Wild Horse Canyon	4,450	U. S. G. S.
Sidney	4,090	Gannett. *a*
Margate siding	4,138	Union Pacific Railroad.
Bronson	4,203	Do.
Herdon siding	4,301	Do.
Potter	4,377	Gannett. *a*
Jacinto siding	4,486	Union Pacific Railroad.

a Dictionary of altitudes in the United States: Bull. U. S. Geol. Survey No. 76, 1891.

KIMBALL COUNTY.

Dix	4,542	Union Pacific Railroad.
Owasco siding	4,616	Do.
Kimball	4,697	Do.
Adams	4,781	Do.
Bushnell siding	4,859	Do.
Smeed siding	4,925	Do.



MAP SHOWING DISTRIBUTION OF TIMBER IN WESTERN NEBRASKA

BY N. H. DARTON

Scale of miles

10 5 0 10 20 30

PINE TIMBER — COTTONWOOD, BOXELDER AND OTHER DECIDUOUS TIMBER

JULIUS BIEN & CO. LITH. N.Y.

List of elevations in Nebraska west of the one hundred and third meridian—Continued.

BANNER COUNTY.

Locality.	Altitude.	Authority.
	Feet.	
Wildcat Mountain	5,038	U. S. G. S.
Hogback Mountain	5,082	Do.
Castle Rock	4,472	Do.
Bighorn Mountain	4,718	Do.
Wrights Gap	4,425	Do.
Gabe Rock	5,006	Do.
Freeport	4,010	Do.
Harrisburg	4,500	Do.
Ashford	4,230	Do.
Mud Springs	4,640	Do.
Willow Springs	4,450	Do.
Funnel Rock	4,502	Do.
Gabe Springs	4,700	Do.
Long Springs	4,700	Do.
Summit of table south of Harrisburg	5,100	Barometer.
Smokestack Rock	4,326	U. S. G. S.
Sheep Mountain	4,507	Do.
Williams Gap	4,420	Do.
Hubbard Gap	4,494	Do.

SCOTTS BLUFF COUNTY.

Scotts Bluff	4,662	U. S. G. S.
Dome Rock	4,560	Do.
Gering	3,902	Do.
Sedan	3,965	Do.
Winter Springs	3,990	Do.
Minatare	3,825	Do.
Sunflower	3,940	Do.
Collins	4,018	Do.
Caldwell	4,050	Do.
Mitchell	4,000	Do.
Larissa	3,960	Do.
Dorrington	4,450	Do.
Intake of Winter canal	3,900	Do.
Intake of Enterprise canal	3,980	Do.
Roubedeau Pass	4,480	Do.
Signal Butte	4,583	Do.
Summit of ridge at head of Cedar Canyon.	4,860	Do.
Mitchell Pass	4,180	Do.
Bald Peak	4,420	Do.
North Platte River at Wyoming line.	4,035	Do.
Castle Rock	4,473	Do.
Steamboat Rock	4,319	Do.
Roundtop Rock	4,479	Do.
Coyote Hill	4,460	Do.

List of elevations in Nebraska west of the one hundred and third meridian—Continued.

SIOUX COUNTY.

Locality.	Altitude.	Authority.
	Feet.	
Snyder's ranch	4,310	U. S. G. S.
Sturdivant's ranch	4,375	Do.
SW. corner of the county	4,050	Do.
NW. corner of the county	4,125	Barometer.
Harrison	4,849	F. E. and M. V. Rwy.
Andrews	4,422	Do.
Glen	4,038	Do.
Adelia	3,725	B. and M. R. R. R.
Mansfield	3,628	Do.
Niobrara River at Wyoming line	4,730	Barometer.
Niobrara River at eastern margin of the county.	4,200	Do.
Niobrara River at Royville	4,457	U. S. G. S.
Niobrara River at mouth of Whistle Creek.	4,280	Do.
Highest sand hill in sec. 17, T. 26, R. 55.	5,100	Do.
Highest sand hill in sec. 21, T. 27, R. 56.	5,020	Do.
Corbin's ranch	4,495	Do.
Mud Springs	4,470	Do.
Coyote Springs	4,520	Do.
McGinley Lakes	4,530	Do.
East Spring	4,525	Do.
Spottedtail Springs	4,120	Do.
Wind Springs	4,460	Do.
Gilchrist	3,900	Barometer.
Montrose	3,750	Do.
Roundtop	4,525	Do.
Coliseum Rock	5,050	Do.
Pine Ridge at Wyoming line, T. 33, R. 57.	5,060	Do.
Pine Ridge, south of Andrews	4,800	Do.
Pine Ridge, south of Glen	4,810	Do.

VIEW OF WOODS IN CHADRON CANYON, DAWES COUNTY, NEBRASKA.

List of elevations in Nebraska west of the one hundred and third meridian—Continued.

DAWES COUNTY.

Locality.	Altitude.	Authority.
	Feet.	
Fort Robinson station	3,755	Gannett. *a*
Crawford	3,674	F. E. & M. V. Rwy.
Whitney	3,404	Do.
Dakota Junction	3,256	Do.
Remington	3,660	B. & M. R. R. R.
Rutland	4,141	Do.
Belmont	4,493	Do.
Marsland	4,156	Do.
Summit of Pine Ridge, near Belmont.	4,600	Barometer
Niobrara River at 103d meridian	3,900	Do.

a Loc. cit.

BOXBUTTE COUNTY.

Hemingford	4,256	B. & M. R. R. R.
Girard	4,365	Do.

INDEX.

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