DEPARTMENT OF THE INTERIOR
Ray Lyman Wilbur, Secretary

U. S. GEOLOGICAL SURVEY
George Otis Smith, Director

Water-Supply Paper 597

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

1928

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UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1929

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - Price 75 cents

CONTENTS

[The letters in parentheses preceding the titles are those used to designate the papers for advance publication]

ILLUSTRATIONS

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES, 1928

N. C. GROVER, Chief Hydraulic Engineer

GEOLOGY OF RESERVOIR AND DAM SITES

By KIRK BRYAN

ENGINEERING GEOLOGY

All engineering structures constitute a load on the earth's crust. If this crust were everywhere of the same character and strength the design of such structures could be much simplified, but the heterogeneity of the materials of the earth's crust and the complexity of their arrangement are notorious, and these geologic conditions enter into most engineering problems. Certain structures, such as bridge piers, dams, tunnels, and heavy buildings, require both for design and construction unusually precise knowledge of the strength, attitude, and water-bearing character of the local rocks. Other structures, such as channel-training works on rivers or coast-protection and harbor works, being intended to guide or restrain natural forces, require an equally precise knowledge of the geologic changes that constantly take place on the earth's surface. Moreover, unusual earth movements and the resulting tremors or earthquakes often endanger the works of man, and in certain localities should be amply guarded against in the design of engineering structures.

It has been well said that the task of the engineer is "to overcome by art the difficulties of Nature." Much of his effort is used in the contest with space, time, and weather or in the ingenious harnessing of sources of power, but in the great construction enterprises already named he contends also with the materials of the earth and the forces that operate on them and thus must solve problems within the field of geology. Many engineers and many great construction enterprises have contributed to geologic knowledge. Whenever an engineer digs a hole for a foundation he is investigating the local geology, and when he erects the simplest building he performs an experiment on the strength of the materials of the earth's crust. Within the limits of his test, and in ordinary construction the limits are narrow, the engineer has learned all the geology that it is necessary for him to know. However, on large undertakings simple procedure and rule of thumb methods derived from such simple tests are inadequate, and elaborate investigations by means of pits, drill holes, loading tests, and so on, are resorted to in order to obtain the necessary information for intelligent design. In an increasing number of undertakings geologists are being called in to give the benefit of their specialized knowledge and of their ability to reduce the number of tests required by locating them in truly significant places. They are needed also to interpret correctly the results obtained.

The responsibilities of a geologist so chosen are very great. However well he may know his own subject, he is handicapped in such duty in proportion as he is ignorant of engineering construction. Little has been published on the application of geology to engineering problems. Most books bearing the title "Engineering geology" are simply college textbooks designed to give engineering students those parts of geology that are most valuable and interesting to them. Exceptions are the very interesting though now somewhat antiquated book by Penning,[1] a recent somewhat sketchy book by Fox,[2] the valuable treatise by De Launay,[3] the third edition of Ries and Watson's textbook,[4] and the highly individual book by Kranz.[4a]

A paper by Lapworth[5] contains much wise observation of geologic conditions in the foundations of dams illustrated with detailed cross sections, but it must be read with the qualification that it deals with British dams constructed in the light of British opinion in favor of deep cut-off walls, usually of puddled clay.

Interesting information will be found in an essay by Dumas[6] and, on certain phases of reservoir problems, in a book by Collet.[7]

The use of geology in engineering is advocated in a number of articles and addresses, but they contain very little information on the

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[1] Penning, W. H., Engineering geology, 164 pp., London, 1880.

[2] Fox, Cyril, Civil engineering geology, London, 1923.

[3] De Launay, L., Traité de géologie et de minéralogie appliquées à l'art de l'ingénieur, 416 pp., 288 figs., Paris, 1922.

[4] Ries, Heinrich, and Watson, T. L., Engineering geology, vii+708 pp., New York, 1925.

[4a] Kranz, W., Die Geologie im Ingenieur-Baufach, 425 pp., 7 pls., 53 figs., Stuttgart, 1927.

[5] Lapworth, Herbert, The geology of dam trenches: Inst. Water Eng. (London) Trans., vol. 16, pp. 25–51; discussion, pp. 51–66, 1911. Reprinted with 1 fig. only, Eng. News, vol. 67, pp. 476–480, 1912.

[6] Dumas, A., Étude théorique et pratique sur les barrages-réservoirs (extrait du Journal de génie civil), 164 pp., 1896.

[7] Collet, L. W., Les lacs, etc., 320 pp., Paris, 1925.

principles involved. Only a few reports on the geology of engineering projects written as a practical guide to construction have been published, and some of these are hidden in engineering documents or in serials not easy of access. In the appended bibliography the papers bearing on the geology of dams, reservoirs, and tunnels in the United States that have come to my attention are given, and brief notes on their scope have been added. A few of the articles were written by engineers, but these contain highly specialized or very detailed geologic information with discussions of the application of this information as to the problems considered. The papers by the late W. O. Crosby and those by Charles P. Berkey are of the highest excellence, and the serious student of engineering geology should digest them thoroughly.

The present paper is offered in the hope that it will be helpful in promoting the application of geology to many irrigation and other engineering projects and that it may guide the geologist charged with the duty of investigating such projects in the presentation of his material.

The infinite variety of possible geologic conditions makes it impracticable to anticipate the type of work that will be necessary for any project to which a geologist may be assigned, but some principles of the application of geology are more or less common to all investigations. A short statement of such of these principles as have been learned in the course of a number of investigations is included herein. The personal element in such work is of large importance, and some remarks on the relation of geologists and engineers have been added.

RESERVOIR SITES

GENERAL REQUISITES

The requisites of a reservoir site are many and exacting; the chief of these are, in a form modified from the statement of Lippincott,[8] (1) a tight basin of ample size; (2) a narrow outlet requiring a relatively small and economical dam, with foundations able to sustain the dam; (3) opportunity for building a safe and ample spillway to dispose of surplus water; (4) available materials of which to construct the dam; (5) assurance that the basin will not fill with mud and sand carried in the water in too short a time; (6) ample and available water supply; (7) use for the stored water or other adequate reason to justify the cost.

It is obvious that a geologist is concerned only with the first five requisites. That the basin must be ample in size is self-evident, and

[8] Lippincott, J. B., Storage of water on Kings River, Calif.: U. S. Geol. Survey Water-Supply Paper 58, p. 25, 1902.

the size is determined by ordinary engineering methods; but the question of its water-tightness can not be answered simply by yes or no, for in spite of leakage some reservoirs are worth their cost. The geologist, therefore, must give this question not only a qualitative but also a quantitative determination to realize his greatest usefulness. He must consider also whether leakage will progressively enlarge the openings and thereby increase and whether it will destroy the stability of the ground.

The size and therefore the cost of the dam required are largely determined by a survey of the site, but the character of the dam and its details are, in many localities, governed by the geology, especially the capacity of the foundations and abutments to transmit water or to sustain weight. These problems require the closest cooperation of geologist and engineer, as the number of engineering devices to overcome natural difficulties continually increases.

Materials of good quality locally available decrease costs, and the geologist should act as a scout to locate and evaluate the rock, gravel, sand, and clay that occur near by. Such qualitative studies are usually inadequate for a final decision as to the usefulness of these materials, and detailed examinations by test pits with laboratory study of samples may be necessary, but these investigations fall within the ordinary field of engineering and do not necessarily require the attention of the geologist, although he may be able to give helpful advice during their progress.

The detritus carried by a stream will lodge in all reservoirs formed by damming a stream valley. On muddy streams the quantity of this material, usually called "silt," may be very large and the reservoir may be filled or "silted" in so short a time as to make its construction inadvisable. Measurement of the "silt" content of a stream [9] falls in the field of engineering, but on preliminary surveys and estimates the geologist may give useful advice and counsel, because the quantity of detritus carried by a stream is a function of the distribution and area of the rocks of the drainage basin. Several examples are described by Collet.[10]

HYDROLOGY OF A RESERVOIR

When a reservoir is filled water escapes from the basin to the adjacent ground. Even concrete-lined reservoirs leak appreciably, and in consequence of these leaks the foundations of a few reservoirs have been undermined with disastrous results.[11] Large reservoirs

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[9] Bryan, Kirk, Silting of reservoirs, studies by engineers [with bibliography]: Nat. Res. Council Researches in Sedimentation in 1925–26, mimeographed, pp. 88–94, 1926.

[10] Collet, L. W., Les lacs, pp. 198–274, Paris, 1925.

[11] Purdue, A. H., Geology and engineering: Resources of Tennessee, vol. 3, pp. 105–109, 1913.

are, of course, unlined, for the cost of lining them is prohibitive. Therefore, unless the leakage to the ground is resisted by natural conditions or is relatively so small as to be of little consequence, the reservoir is a failure. As the leakage must be resisted by the characteristics of the ground, study of a site for a reservoir is a geologic and more particularly a ground-water problem. To solve this problem completely the position and movements of the ground water under natural conditions must be determined, and the effect of filling the basin in producing a new régime in the ground water of the area—by the movement of water from the basin outward to the ground—must be anticipated.

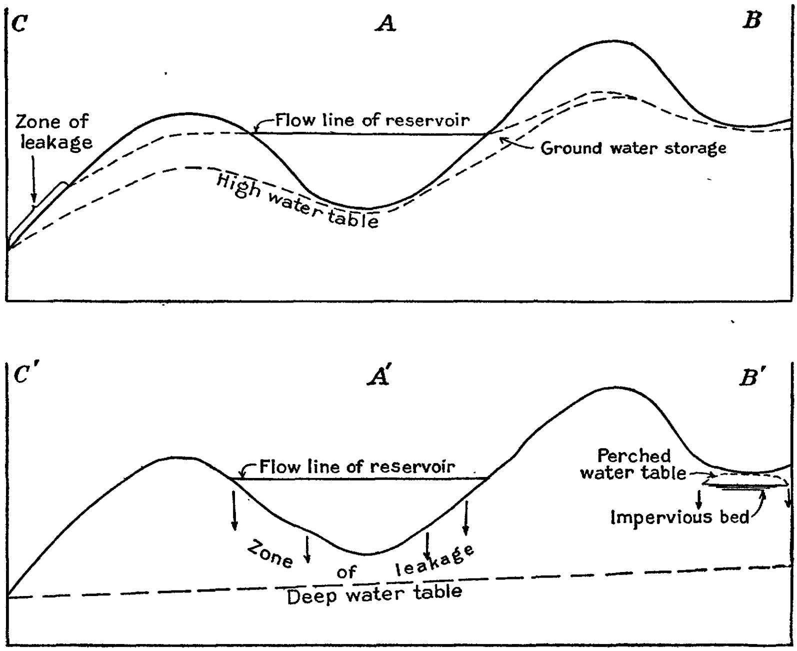

FIGURE 1.—Diagram showing the relation of reservoirs to the water table

RESERVOIRS IN AREAS OF HIGH WATER TABLE

Ordinarily the soils and rocks are saturated with water below a certain depth. The top of this saturated zone is known as the water table. It lies deep beneath hills and comes to the surface at swamps, ponds, and streams. Thus in a general way, under what may be considered normal conditions, the water table has a form approximating the surface topography. In a valley it slopes downstream and from both sides toward the middle of the valley, as suggested in Figure 1, *A*. Such a form is due to the resistance to flow afforded by friction in the interstices of the ground. The gradient of the water table at any place is a function of the size and number of the interstices or openings in the ground and the quantity of water. A steep water table thus indicates tight ground with small interstices or very large quantities of water; conversely, a flat water table indicates large openings in the rocks or very small quantities of water.

If a valley is blocked by a dam, water from the resulting lake will sink into the ground until it meets the inclosing water table. Thereafter a new grade of the water table will be established. If the altitude of the reservoir is below the ground-water divide not only will there be no loss by seepage from the reservoir but there will be an inflow of ground water into the reservoir and an underground storage between the old position and the new position of the water table. The volume of ground that will be newly saturated depends on the water level in the reservoir and on the slope of the water table. The value of this ground-water storage depends on the percentage of pore space and also on the rate at which water will flow in or out of the ground as the water level in the reservoir changes.

In the foregoing discussion nothing has been said about leakage at the dam site. It is obvious, however, that there will exist in the abutments of the dam a high gradient between the water in the reservoir and the level of the ground water just downstream. As this is the place where the new water level is highest with respect to the original level, conditions are here most critical. The abutments of the dam must be practically tight, or serious leakage will occur. As the character of the abutments enters into the problem of building the dam, however, discussion of that topic will be deferred to a later paragraph.

In general, little difficulty is experienced with reservoirs built in areas of high water table when the reservoir occupies a stream valley and the stream is fed by ground water. Under conditions shown at point *C*, Figure 1, leakage is possible from overtopping the ground-water divide at a low point, but it will be moderate if the material of the ridge is fine grained. Where part of the inclosing rim of the reservoir consists of open-textured material, such as basalt, cavernous limestone, or an accumulation of glacial boulders, the ground-water divide is always low also, and thus the low position of the water table, if determined, would speak for caution, but proof of the presence of these open-textured materials makes it certain that large leakage will result. It should be noted that leakage through gypsum or rock salt and to a less extent through limestone will increase by reason of solution of the rock and the removal of débris from caves already formed, but leakage through basalt will be constant or only slightly increased. Leakage through boulders or gravel may, by the removal of sand and similar fine material from the interstices, induce slumping and landslides, with serious consequences. If the openings through which the water leaves the reservoir are not too large, leakage may gradually decrease by reason of the deposition in them of sediment that falls to the floor of the reservoir. The quantity of silt carried by the streams that feed the reservoir and many other factors enter into this contingency. In Bijápur Collectorate, India, the Muchkundi Tank,[12] formed by a masonry dam on schistose rocks, was sealed and made tight after 12 years of silting. In Yorkshire, England,[13] a reservoir formed by a dam 80 feet high leaked 440,000 gallons daily through fissures in the rock of the foundation. After two years of use the fissures were sealed by the deposit of silt and leakage ceased.

A masonry dam [14] across Cedar River, a tributary of Snoqualmie River in Washington, was constructed with its south (left) end resting on "seamy" rock. The north (right) end rested in glacial material. Some leakage through the rock at the south end and around the north end of the dam took place, but large and disastrous leakage occurred through the glacial material that formed the ridge between the two rivers. When the water in the reservoir stood at an altitude of 1,555 feet, springs broke out in Snoqualmie Valley at an altitude of 990 feet. The hydrostatic head was 565 feet, and the distance 6,500 feet, making a gradient of 1 to 11. The emergence of this leakage in Snoqualmie Valley caused slumping of the hillside. The total loss of water was 30,000,000 gallons daily (46.5 second-feet), and since 1914 the reservoir has not been allowed to fill. On account of continuous litigation full descriptions of the materials involved and of tests before and after construction are not available. The glacial materials of the ridge were, however, obviously so coarse grained and porous that it was evident before construction to both geologists and engineers, as set forth by Fowler, that the ridge could not resist the movement of water from the reservoir on a gradient of 1 to 11.

At the Santa Maria Reservoir, in Colorado, leakage takes place through 2 miles of landslide material at the south end of the water body. At Mosca Reservoir,[15] in the same State, leakage through shattered volcanic rock and morainal material has occurred. In the morainal leak the water passed through 1,500 feet of sand and gravel and produced a washout, leaving a ravine 20 feet deep.

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[12] Strange, W. L., Reservoirs with high earthen dams in western India: Inst. Civil Eng. London Proc., vol. 132, p. 137, 1898.

[13] Hill, G. M., discussion of Strange's paper: Idem, p. 208.

[14] Fowler, C. E., Leakage from Cedar Lake Reservoir, Seattle water supply: Eng. News, vol. 73, pp. 112–115, 1915.

[15] Atwood, W. W., Relations of landslides and glacial deposits to reservoir sites in the San Juan Mountains, Colo.: U. S. Geol. Survey Bull. 685, pp. 23–33, 1918.

RESERVOIRS IN AREAS OF DEEP WATER TABLE

The water table lies deep under large areas only where the rocks are notably porous and the openings are large. In such rocks water flows freely at low gradients comparable to the gradients of surface streams. In tighter rocks the gradient of the water table is higher, and only small areas may have a deep water table.

The rocks with large openings are (1) soluble rocks, such as limestone, gypsum, and rock salt, in which caverns form; (2) extrusive basalt with many open cracks, partings between flows, flow breccias, and vesicular and scoriaceous portions; (3) faulted and shattered rocks, usually in small areas; and (4) coarse boulder beds laid down by rivers, by glacial ice, or more rarely by landslide slumping.

In Figure 1 the reservoir *A′* is constructed in an area with a deep water table draining on a flat gradient to valley *C′*. The losses from the reservoir are proportionate to the hydraulic head and the capacity of the rock to transmit water. In the absence of data by which they can be estimated, judgment must be used as to whether the losses will be excessive or not. In one locality part of the bed of a proposed reservoir in extrusive basalt was annually flooded by farmers with water from the spring freshets of near-by creeks. Water 15 feet deep disappeared in six weeks, and as the proposed dam contemplated a depth of 60 feet of water, it seemed likely that the whole content of the reservoir might be lost in say three months. Part of the floor was covered with fine-grained soil which retarded leakage, but with the high velocities engendered by a 60-foot head much of this material would undoubtedly be carried down into the basalt and the rate of leakage would increase. Consequently the project was abandoned.

The Jerome Reservoir, in Idaho, is situated in a depression underlain by several hundred feet of basalt flows. The water table is far below the surface, and leakage through the basalt, though the rock was protected by a cover of soil 10 feet thick in places, was so great as to cause the abandonment of the reservoir. The Hondo Reservoir, in southeastern New Mexico, is situated in a natural depression surrounded by fairly substantial limestone. Below a surface soil the floor is underlain by shale and gypsum, as shown by drill holes, and according to the best information the water table lies about 200 feet below it. After the reservoir was constructed leakage through the cavernous rock beneath it was so rapid as to cause the formation of sinkholes in the soil, and the loss of water was so great that the reservoir was abandoned.

The Deer Flat Reservoir, also known as Lake Lowell, a part of the Boise irrigation project, in Idaho, is situated on an undulating plain between Boise and Snake Rivers. The reservoir is formed by two embankments that close gaps in encircling hills. These embankments are not absolutely tight and allow some seepage at the base. When first filled this reservoir had a relatively large loss of water from the floor and sides, but the loss has gradually diminished, as shown in the following table, the data for which have been supplied by the Bureau of Reclamation:

Losses of water from Deer Flat Reservoir, Idaho, 1909–1921

Year	Maximum area submerged (acres)	Mean area submerged (acres)	Evaporation (acre-feet)	Total loss (acre-feet)	Seepage loss (acre-feet)	Average seepage loss per acre submerged (acre-feet)
1909	2,500	1,355	4,750	57,500	52,850	39.0
1910	3,900	3,002	10,500	93,483	84,983	28.3
1911	6,300	4,459	15,600	150,838	135,238	30.3
1912	7,000	4,625	16,200	85,089	68,889	14.9
1913	8,200	5,250	18,200	89,489	71,089	13.5
1914	8,400	5,337	18,700	82,084	63,384	12.0
1915	8,100	5,123	17,900	67,400	49,500	9.7
1916	6,900	4,820	16,900	43,970	26,141	5.4
1917	7,550	4,500	11,000	32,400	22,138	4.9
1918	9,311	6,171	13,398	54,816	41,418	6.7
1919	9,535	6,019	13,565	44,974	31,409	5.2
1920	9,768	6,388	14,968	62,954	47,986	7.5
1921	9,835	7,279	25,035	66,668	41,633	5.7
Mean	7,485	4,948	15,132	71,666	56,666	[a] 11.4
Total			196,716	931,665	736,658	

[a] The mean of the last column is the result of dividing the mean of the seepage loss by the mean acreage submerged.

The underlying materials consist of horizontal soft sedimentary beds, mostly clay, tuff, and sand of the Payette and possibly the Idaho formation. A few basalt flows are interbedded with the other materials, and on the surface of the plain are discontinuous deposits of gravel. Before the reservoir was built the water table rose under this plain above the level of the adjacent rivers but did not closely approach the surface. The losses of the early years of the reservoir went largely into saturating the underlying beds and raising the water table. The irrigation of surrounding land was begun at the same time and assisted in this process, so that at present the reservoir rests on saturated ground to which it loses only enough water to replace that drawn off by lateral movement to swampy places on the hillsides or to the rivers. Doubtless silting of the bottom of the reservoir has also helped to prevent losses. It is evident that if the underlying materials were more permeable it would require more water to replace that lost by lateral flow. If, for example, the material were a coarse gravel the losses of water might have been so great as to destroy the value of the reservoir.

On South Platte River, in Colorado, several storage reservoirs[16] have been built in natural depressions among sand dunes adjacent

[16] Parshall, R. L., Return of seepage water to the lower South Platte River in Colorado: Colorado Agr. Coll. Exper. Sta. Bull. 279, pp. 58–64, 1922.

to the river. Seepage losses from these reservoirs have been large, but as shown in the table below the loss decreases with age of the reservoir. This fact indicates that the seepage has built up the zone of saturation in the ground to a higher level and thus decreased the gradient of the new water table and consequently the rate of movement of water through the ground. It is also probable that the deposition of silt in the reservoirs has tended to seal the bottoms and thus has cooperated in preventing seepage.

Seepage from reservoirs of the South Platte Valley, Colo., in 1920

Name	Date of construction	Age at time of measurement (years)	Capacity (acre-feet)	Maximum height of dam (feet)	Area at high water (acres)	Loss of water by seepage and evaporation for 12 months (acre-feet) [a]	Percentage of water delivered to reservoir
Jackson Lake	1903	17	35, 400	20	2, 546	10, 610	24
Riverside Reservoir	1909	11	57, 500	25	3, 595	60, 850	46
Prewitt Reservoir	1912	8	32, 800	37	2, 431	34, 990	58

[a] Data sufficient to separate evaporation losses from seepage are not available.

In the investigation of reservoir sites the geologist must guard himself against accepting evidence without analysis. One of the most deceptive conditions is the presence of a perennial stream in the valley that is proposed for use as a reservoir. Is this stream fed by ground water, and does it represent the lowest zone of the local water table? In general, areas of high water table are characterized by many perennial streams, and areas of low water table have feeble surface drainage. As brought out in the investigation of the No. 3 Reservoir of the Carlsbad irrigation project,[17] in New Mexico, Pecos River at the dam site is perched above a low-lying water table. The test well at this point encountered water between 24 and 42 feet, which stood at 24 feet below the surface and 12 feet below the level of the river. Below this wet zone the cavernous rocks were dry to a depth of 72 feet. From this depth to 152 feet water was found, which stood at 72 feet and is probably the main zone of saturation of the region. Pecos River runs above dry rock in a kind of natural flume, which was doubtless formed by the deposition of calcium carbonate from the water of the river in the gravel and cave breccia beneath its bed. Obviously, such a " flume " is limited in capacity, as indicated diagrammatically in Figure 1, *B'*, and if the water level is raised above its sides, any water that spills over may percolate to the deep water table.

[17] Meinzer, O. E., and others, Geology of No. 3 reservoir site of the Carlsbad irrigation project, New Mexico, with respect to water-tightness: U. S. Geol. Survey Water-Supply Paper 580, pp. 1–39, 1926.

If most of the leakage is confined to small areas, building dikes to isolate these areas is a logical step. Such a dike at the McMillan Reservoir, in New Mexico, failed to stop leakage because openings in the gypsum, previously inconspicuous, enlarged and carried off about the same quantity of water as was lost before the dike was built, and because water moved under the dike, which lacked an impervious cut-off. At other reservoirs such attempts have been of doubtful utility. Where, however, leakage takes place through a single definite underground channel, such as the series of caves in limestone that lead from the upstream to the downstream side of an intrenched meander on Black River, N. Y.,[18] the channel can be found and plugged, but such remedies are suitable only where the water pressure is low. The Malad Reservoir,[19] in Idaho, as shown by a contour map of the water table in the alluvium of its floor, leaks in a small area, and excavations in this area show many small cavities along the bedding planes of a limestone. Grouting of this area is advocated, and, if there are not other similar areas, this remedy should convert a now useless dam into a useful property.

Occasionally, also, other factors enter into the problems, as at the Cataract Reservoir and dam for the water supply of Sydney, Australia.[20] Here the reservoir and dam site are underlain at a depth of about 800 feet by valuable coal beds. The prohibition of coal mining under the whole drainage basin or at least under the reservoir site was advocated, but the geologists held that the value of the coal, even at a moderate estimate of the quantity, exceeded the value of the reservoir. They believed, too, that the cover above the coal, consisting largely of sandstone, was sufficiently strong to permit mining not only in the drainage basin but under the reservoir. Under the dam a barrier pillar 1,800 feet wide was specified. However, the wisdom of mining under the reservoir will await its test in the future, when the relative value of the stored water and of the coal may have changed. It may then be feasible as the coal is mined to insert masonry supports for the roof and thus insure that no subsidence and consequent leakage shall take place.

The study of a reservoir site involves large responsibilities for the geologist, because remedial measures against leakage are seldom possible. His conclusions can not be tested save by the expensive method of constructing and filling the reservoir. If he approves

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[18] Stopping underground leakage from power dam: Eng. News-Record, vol. 76, pp. 459–460, 1916.

[19] Stearns, H. T., Porosity of reservoir prevents water storage, Malad Reservoir, Idaho: Eng. News-Record, vol. 96, p. 561, Apr. 8, 1926.

[20] Wade, L. A. B., The construction of the Cataract Dam, Sydney, N. S. W. (abstract): Eng. News, vol. 63, pp. 713–716, 1910. Quotes geologic report by E. J. Pittman and A. A. Atkinson.

the site and after construction the reservoir fails to hold water, the investment is lost; if he condemns the site and no substitute can be found, the project is abortive. In examinations of other types of sites the difficulties that he may point out can by ingenuity and sufficient expenditure be overcome, but as to reservoirs he must bear the responsibility alone. It therefore behooves the geologist charged with such duty to determine the ground-water conditions with exactness, to require the drilling of test wells at critical points, and then to analyze his data with care and in humbleness of spirit.

DAM SITES

GENERAL CONDITIONS

The study of dam sites excites the interest of geologists because of the necessity for precise and detailed work and because funds are usually available for test pits and borings to gain information not obtainable by surface examination. The many devices available to the engineer to overcome difficulties at the site are each limited by various related conditions. Consequently the geologist must be scrupulous to set forth all the facts at his disposal. He should also realize that if adequate funds are available every difficulty can be overcome and that dam sites are abandoned only because the cost of the proposed dam exceeds its probable value. The economic changes of the future may change the ratio of value, and structures now unfeasible may some day be built. The feasibility of a dam is thus an economic problem, and statements as to feasibility are outside the province of a geologist's report, which should be confined to the physical conditions.

A dam consists of an impervious or nearly impervious membrane, supported against the thrust of impounded water.[21] In the ordinary masonry or concrete dam the impervious membrane is a layer of the first few inches or feet of the upstream side of the wall, but in other types of dams the membrane may be a separate structure, and in earth dams no part of the structure may be wholly impervious, but the flow of water is prevented by frictional resistance to movement offered by successive portions of the embankment. The geologist is not concerned with the methods by which the membrane and its supporting structure shall be built except in relation to the geologic difficulties, and he should avoid expressions that give him the appearance of dictating engineering details to the designer. Thus, in a recent geologic report the author, because of unequal bearing power of the north and south halves of the site, strongly recommended an earth

[21] Dillman, G. L., Am. Soc. Civil Eng. Trans., vol. 75, p. 52, 1912. For types of dams see the numerous textbooks.

dam, which could yield unequally without rupture, and condemned a concrete dam. As there was no earth available the designers adopted a flat-decked cellular structure of reinforced concrete, for this type of dam is also flexible. The geologist was therefore left in the embarrassing position of having condemned the type of dam selected, although his warning as to geologic conditions was accepted and met by the design.

The geologist is interested primarily in the load that the dam will form and in the location of the impervious membrane and the depth to which it is to be carried in order to shut off leakage. Masonry and concrete dams, which resist the thrust of the impounded water by their weight or by the strength of a single arch, have narrow bases and impose a large load on each unit area of their foundations. If the rocks seem unsuitable for such a load, the geologist may recommend a wide-base dam instead of a narrow-base dam, but he should avoid expressing an opinion as to whether a dam of rock fill, earth, cellular concrete, or any of the numerous alternatives will best meet the need. The generic terms "wide base" and "narrow base" are the best to use, as they give the designer of the structure no superfluous instructions. Similarly the geologist may specify that the impervious membrane shall be carried through a certain pervious rock into an impervious one, or he may state that a mechanical connection between the impervious or nearly impervious portion of the dam and a certain formation below should be made. The choice of methods whereby the object can be accomplished properly belongs to the engineer, who may use sheet piling, pressure grouting, or a wall of masonry, concrete, or puddled clay.

The geology of dam sites may be considered under the following heads: Foundations; abutments (leakage); spillways; tunnels (bypass, discharge, etc.); materials for construction. This division is quite arbitrary, however, because the factors are so related that in the examination of any one site all must be considered. The cost of construction is also a part of the problem, and intelligent geologic work can be done only in conjunction with the engineer, in whose study of the problem this consideration is prominent. For instance, at a site where large quantities of earth are available and rock suitable for masonry or concrete is absent, relative costs usually indicate that the dam should be an earth structure. As in this type of dam the load per square foot on the foundation is moderate, because of the broad base, the examination of the foundation in this respect may consequently be perfunctory. Yet there are foundations so soft that the weight per unit area even of ordinary earth dams exceeds the bearing power.

FOUNDATIONS OF DAMS

The most common type of dam site lies in a narrow part of a valley where the rock of the abutments of the dam is more or less visible but the bottom of the cross section is covered with the alluvium of the stream. The first question to be answered is the depth of this alluvium. If there are many bedrock outcrops projecting through the alluvium the geologist may hazard an estimate of its average thickness. In general, however, the depth to bedrock can not be predicted with any certainty. The writer has vividly in mind a rocky gorge about 250 feet wide with nearly vertical sides that extend for about half a mile along a small river in the southwestern United States, in which it was proposed to place a low diversion dam. At the head of the gorge bedrock projected from the gravel of the stream channel, and several similar outcrops lay at the lower end of the gorge. It seemed that the stream must be eroding the rock floor, and that the gravel of the channel down to bedrock was removed by each great flood. Considering the size of the stream, 30 feet of gravel appeared to be a liberal estimate, and such a depth would make possible a concrete or masonry dam founded on bedrock. A test drill hole, however, penetrated 81 feet of sand and gravel without reaching rock. Under the prevailing economic conditions this was a prohibitive depth, and consequently a floating or Indian type weir was designed for the site.

Before estimates of cost are made test drill holes are put down at most sites to determine the depth to bedrock, but in reconnaissance surveys a geologist is often called upon to express an opinion, and he must, bearing in mind the hazards of mistakes, weigh carefully the somewhat inadequate data that he may obtain. First, is the stream degrading or aggrading its bed? If it is aggrading the depth of the alluvial fill may be very great, whereas if the stream is still degrading its bed the alluvium over which it runs at ordinary stages is removed in floods, and the stream is said to scour and fill. The depth to which scour and fill can be carried on is a function of the size and velocity of floods and of the quantity of material to be carried through the bedrock channel. It is seldom possible to obtain adequate data to solve the equation indicated above, but by bringing together the results of other lines of reasoning a result of some value can be obtained, as ably demonstrated by Miser [22] in his study of the fill in San Juan Canyon.

In a narrow gorge of a northwestern river it was proposed to set two bridge piers in the channel at the site of a sand bar. The

[22] Miser, H. D., The San Juan Canyon, southeastern Utah, a geographic and hydrographic reconnaissance: U. S. Geol. Survey Water-Supply Paper 538, pp. 58–71, pl. 22, 1924.

geologist was required to predict at what depth rock would be encountered beneath this bar in order that preliminary estimates of cost could be made. The valleys upstream and downstream from this canyon are underlain by 300 feet or more of alluvium, and deep gravel-filled channels are characteristic of rivers in this general region. Investigation showed that the present course of the river in the canyon does not correspond to its ancient course. The shift in position took place by lateral meandering at the level of a terrace 160 to 180 feet above the river. The ancient course is filled with gravel to and perhaps below river level. The newer course is doubtless postglacial. As the site of the bridge piers is in the new course of the river it seemed unlikely that the river had formed a deep channel in so short a time, and the depth to bedrock should, therefore, not exceed the depth of scour and fill. The prediction was made that the depth would not exceed 30 feet, and later test drill holes showed a depth of 29 feet.

Preliminary test drilling for a recently constructed dam indicated a moderate depth to bedrock. However, as the river bed was bared to lay the foundations a narrow cleft or rock channel 70 feet deep was discovered which lay between drill holes only 50 feet apart. This irregularity in the stream bottom was more costly because unexpected. Caution in interpreting the results of drill holes and the use of a greater number to define the bedrock channel are obviously indicated by the experience gained at this dam site.

If the alluvial fill is moderate and the gorge narrow, a masonry dam of gravity or arch section may be considered. Such a dam has a narrow base and places a concentrated load on the foundations. The rock must be able to resist this load. Rocks such as would be considered good building stone ordinarily are entirely strong enough, as their compressive strength exceeds that of the masonry or concrete. However, the joints, bedding planes, and other natural fractures of rocks reduce their strength below that shown in test specimens, and because the effect of these natural weaknesses can not be closely estimated, it is customary to use a large margin of safety.

The presence of clay in the joints or as thin seams along the bedding planes of otherwise sound and strong rocks is a source of danger. Under the increased pressure due to impounding of water in the reservoir, water may be forced into these clay seams and convert them into gliding planes on which movement can take place with little friction. This lubrication of the bedding planes of thin-bedded rocks, such as some sandstones and limestones, will permit the dam to slide forward and rupture. At such sites the rock with clay seams may be removed or percolation through the foundations may be prevented by pressure grouting, or some form of wide-base dam may be used.

Poorly cemented sandstone, porous limestone, tuff, certain breccias, and agglomerate and similar rocks may be massive but are deficient in strength. A single field-loading test of an agglomerate at the site of the proposed Iron Canyon Dam [23] in California indicated that the rock would stand a load of 40 tons to the square foot without signs of failure, but a board of engineers decided that the dam should impose only half as great a load on the rock. Thus they introduced an apparently large factor of safety to provide for the uncertainties arising from a single test on only a portion of the rock and for two other uncertainties due to the fact that the test was made on dry rock, whereas the foundation of the dam would be wet, and that the test occupied only a short time, whereas the dam was expected to stand for many years, during which slow yielding might take place. Following similar reasoning, the engineers who conducted the remarkable field tests of the loosely cemented Dakota sandstone on the site chosen for the new State capitol at Lincoln, Nebr.,[24] showed that the rock would stand more than 60 tons to the square foot, but they decided that 15 tons was a maximum safe load. The architect who designed the footings of the great tower of this building reduced this loading to 12 tons to the square foot.

Field tests are compared to laboratory tests on clay in the account of the investigations of the foundation conditions of a high building at Columbus, Ohio.[25] Tests on cubes showed a compressive strength on the average only 31 per cent as great as that of the material in place. The bearing power of soft clay is much increased when it is kept dry, as indicated by the successful drainage of foundations at Cleveland.[26]

Qualitative data for determining the ability of the natural foundations to stand the load of a high masonry dam at a site where quantitative data are needed are given by La Rue [27] and by Bryan.[28] An examination of the reports mentioned above and a consideration of the following standard table will give a geologist a fair idea of the bearing capacity of the softer rocks and of unconsolidated materials.

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[23] Gault, H. J., and McClure, W. F., Report on Iron Canyon project, California, p. 66, U. S. Recl. Service, 1921. Gault, H. J., Test of bearing capacity of rock at Iron Canyon dam site, California: Reclamation Record, vol. 11, pp. 378–379, 1920; abstract, Eng. News-Record, vol. 85, p. 417, 1920.

[24] Foundation tests for Nebraska State Capitol: Eng. News-Record, vol. 89, pp. 606–609, Oct. 12, 1922. Chambers, R. H., Heavy foundations on sandrock, Nebraska Capitol: Idem, vol. 94, pp. 107–108, 1925.

[25] Waring, R. L., and Morris, C. T., Bearing-power tests on deep caisson foundations: Eng. News-Record, vol. 96, pp. 109–112, 1926.

[26] Betz, F. H., Deep drainage of foundation soil for heavy building: Eng. News-Record, vol. 80, p. 363, 1918.

[27] La Rue, E. C., Water power and flood control of Colorado River below Green River, Utah: U. S. Geol. Survey Water-Supply Paper 556, pp. 20–24, 1925.

[28] Bryan, Kirk, Discussion on geologic setting of rock-fill dam at Lees Ferry, Ariz.: Am. Soc. Civil Eng. Trans., vol. 86, pp. 228–240, 1923.

Safe bearing capacity of rocks and soils

Kind of material	Tons (2,000 pounds to the square foot[a])	
	Minimum load	Maximum load
Rock, the hardest, in thick layers in native bed	200	----------
Rock equal to best ashlar masonry	25	30
Rock equal to best brick masonry	15	20
Rock equal to poor brick masonry	5	10
Clay in thick beds, always dry	6	8
Clay in thick beds, moderately dry	4	6
Clay, soft	1	2
Gravel and coarse sand, well cemented	8	10
Sand, dry, compact, and well cemented	4	6
Sand, clean, dry	2	4
Quicksand, alluvial soil, etc	.5	1

[a] 1 ton to the square foot=138.8 pounds to the square inch, and 1 pound to the square inch=0.072 ton to the square foot. Merriam, Mansfield, American Civil Engineer's Pocket Book, 3d ed., p. 528, 1916.

These data lead, however, only to empiric results. The principles of the yield of sand and clay to load have been ably discussed by Terzaghi,[29] whose work should be studied by all geologists concerned with such problems.

At sites where rocks of unequal bearing capacity occur differential settlement of the dam may result. If, for example, the abutments are of hard rock, and the dam is to rest mainly on the alluvium of the valley, which is not to be excavated, provision must be made for greater settlement of the center of the dam than of the ends. Similarly a valley in horizontal bedded rocks may have walls of hard rock, such as sandstone or limestone, and a floor of shale. The geologic conditions that present such inequalities are numerous, but the devices for providing flexibility in the impervious membrane and in the supporting structure are almost equally numerous and can be most economically planned when the geologic conditions have been closely and accurately defined.

A misinterpretation of geologic conditions during preliminary examination involved additional trouble and expense in building a dam recently completed.[30] What appeared to be a coarse, almost conglomeratic sandstone proved to be a soft sandstone with soft shale layers. The loading was reduced from 15 to 6 tons to the square foot. A cut-off wall 10 feet deep was built, and much grouting was done to prevent percolation through the rock under the dam.

In addition to the bearing capacity of the rock of the foundations, the number and kind of openings in the rock must be considered. If

[29] Terzaghi, Charles, Principles of soil mechanics: Eng. News-Record, vol. 95, seven articles, November and December, 1925.

[30] McEwen, A. B., Combined railway, bridge, and dam built at outlet of Grand Lake, Newfoundland: Eng. News-Record, vol. 99, pp. 128–132, 1927.

there is free communication from the reservoir through these openings uplift pressure[31] on the base of the dam proportional to the depth of water in the reservoir will result. This pressure must be allowed for in the design of the dam. Leakage must also be expected, although the quantity of water lost may be so small as to be negligible. However, if the rock is soluble or contains soluble parts, or if fine material such as sand is eroded from the rock by the flowing water, the leaks may increase, with a resulting loss in water and weakening of the foundation.

For these reasons the impervious portion of a dam is carried to "sound rock," and pressure grouting is employed to cut off leakage. The questions involved in determining what is "sound rock" are discussed on page 22. Pressure grouting is a process by which a material, such as Portland cement mixed thin, is forced into drill holes in a rock to fill cavities and prevent the passage of water. This process is relatively cheap and is remarkably effective under suitable conditions. As ordinarily applied, the grout penetrates and fills all cracks and joint fissures between the drill holes, but does not penetrate the pores of the rock. However, the François system of grouting, recently invented by a Belgian, makes use of a preliminary treatment with chemicals, usually silicate of soda and sulphate of alumina, which facilitate the movement of the grout injected later. By the use of this process[32] cracks and joints in sandstone that were filled with loose sand have been successfully grouted, and gravel beds have been so thoroughly cemented as to cut off the flow of water and make possible excavation by pick and shovel. A shaft[33] was sunk through loose, water-bearing material with ease, and about 80 per cent of the water that would otherwise have entered was excluded from the excavation.[33]

As yet this variation of the process of cement grouting has not become current in the United States, although experiments[34] on cementing gravel have been made with some success. The difficulty of proving that grouting has been successful and the possibility that ungrouted areas may remain have so far weighed heavily against too much dependence on grouting either for reinforcing foundations or for providing adequate cut-off curtains. As usually applied, grouting

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[31] Consult textbooks on dams, also Tests of water pressures under Brule River Dam [Wis.]: Eng. News-Record, vol. 96, p. 275, 1926.

[32] Ball, H. S., The application of cementation to mining: South Wales Inst. Eng. Proc., vol. 36, pp. 517–565, 1921.

[33] Mitton, H. E., The sinking of a colliery in the East Nottinghamshire coal field: Inst. Min. Eng. [England] Trans., vol. 70, pp. 345–367, 1926. See also Blanford, T., The cementation process as applied to mining: Idem, vol. 53, pp. 22–29, 1917, and Horsam, A., and Mawson, T. T., Sinking a shaft by the François cementation process: Idem, vol. 58, pp. 16–28, 1920.

[34] Cartwright, H. H., Tests of grouting gravel in river beds: Eng. News, vol. 69, pp. 979–984, 1913. See also idem, pp. 969–970, and discussion of Estacada Dam cited on p. 19.

is most successful in clean fissures. Thus at the Hales Bar Dam,[35] in Tennessee, where the foundation consists of limestone in which are many caverns, most of them filled with clay, those caverns that were free of clay were successfully grouted by the use of 10,000,000 pounds of Portland cement. The clay in other cavities and caverns, which the grout could not enter, was gradually washed out. Serious leakage through the foundation below this dam then ensued, but recent grouting with hot asphalt appears to have reduced the leakage effectively.[36]

The difficulties of grouting in volcanic breccia and the advisability of using a grouted curtain as a cut-off wall have been discussed in regard to the Estacada Dam, in Oregon.[37] Much more successful grouting was accomplished in the metamorphic rock with clean fractures underlying the Lahontan Dam, in Nevada,[38] and in the sandstone and shale underlying the Olive Bridge Dam, in New York.[39] In these two dams grouting was merely supplemental to cut-off walls that might have prevented dangerous percolation beneath the dam without the additional precaution of grouting.

The geologist should therefore make such observations as will enable him to state the number and spacing of joints and bedding planes and the probability of the existence of cavities and caverns. He should also be able to state whether these openings have been sealed with mineral matter deposited by natural processes, or have been filled with sand or clay, or are so clean and open as to be readily grouted. The likelihood that limestone may be cavernous should be borne in mind, but on the other hand it should be remembered that very large dams [40] of unquestioned stability and water-tightness have been built in this rock with little difficulty. One in southern Spain on Jurassic limestone is 273 feet high and 200 feet long, and another, built for the Baker power plant, in Washington, is 263 feet

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[35] Switzer, J. A., The power development of Hales Bar: Resources of Tennessee, vol. 2, pp. 86–99, 1912. Rock grouting and caisson sinking for the Hales Bar Dam: Eng. News, vol. 70, pp. 949–956, 1913.

[36] Christians, G. W., Asphalt grouting under Hales Bar Dam: Eng. News-Record, vol. 96, pp. 798–802, 1926.

[37] Rands, H. A., Grouted cut-off for the Estacada Dam: Am. Soc. Civil Eng. Trans., vol. 78, pp. 447–482; discussion, pp. 483–546, 1915. See also, on grouting, Wait, B. H., Driving a wet aqueduct tunnel in hard rocks: Eng. News, vol. 63, pp. 660–662, 1911; Angas, W. M., Repairing leaks in a dry dock by grouting: Am. Soc. Civil Eng. Trans., pp. 579–596; discussion, pp. 597–598, 1925; and Dreyer, W., Volcanic formations govern design in Pit River No. 3 hydroelectric development [Calif.]: Eng. News-Record, vol. 96, pp. 144–149, 1926.

[38] Cole, D. W., Making a cut-off wall by grouting fissured rock, Lahontan Dam: Eng. News, vol. 69, pp. 647–651, 1913. See also editorial article, idem, pp. 969–970, and letter of H. A. Rands, idem, p. 1190.

[39] Grouting the Olive Bridge Dam: Eng. Record, vol. 63, pp. 385–386, 1911.

[40] Wegenstein, M. E., High arch type dam built in south Spain: Eng. News-Record, vol. 93, pp. 128–130, 1924. High overflow dam, main unit of Baker power plant [Wash.]: Eng. News-Record, vol. 96, pp. 360–362, 1926. Gowen, C. S., The foundations of the new Croton Dam: Am. Soc. Civil Eng. Trans., vol. 43, pp. 468–542, 1900.

high and 493 feet long and rests on limestone that below river level was pitted with potholes and roughened with ridges. The foundation of the Keokuk Dam across the Mississippi is limestone which was so hard and sound that except for a small cut-off trench it was merely scrubbed to clean it for the reception of the concrete, and pressure grouting was not used. However, many engineers hold that pressure grouting is so cheap that it should always be used at the heel of a dam as an additional factor of safety.

The history of the old Austin Dam, on Colorado River, in Texas, as recounted by Taylor,[41] and the reinvestigation of the old dam and the difficulties in construction of the new dam, as recounted by Mead,[42] should cause hesitation in attempting a large dam in horizontal limestone, especially if the rock is fractured and weathered, unless complete investigation has been made and every precaution taken. Here after the completion of the new dam at least 86 cubic feet of water a second leaked through the zone immediately around the dam and through pervious strata and fissures in the canyon walls at some distance from the dam. Part of this seepage was taking place through clay-filled fissures below the foundations and with undermining of the toe by the overfall of flood waters produced imminent danger of the forward sliding of the dam. A thorough study of the difficulties encountered at this site and the failures induced by measures inadequate to meet these difficulties will enable a competent judgment to be made of the dangers of similar sites in flat-lying, more or less fractured and weathered limestone.

At many dam sites the depth to bedrock in the stream channel is so great that it is impracticable or too expensive to build a masonry dam founded on rock. At such places earth or rock-fill dams are ordinarily used, but multiple-arch dams,[43] flat-decked cellular dams, or sluice-gate sections of masonry have also been built.

The requirement concerning leakage for dams constructed on soft and porous foundations is that percolation of water under the dam shall be so restricted that the velocity of flow will be inadequate to entrain sand or clay and to carry this fine material out from under the dam. Obviously if fine material is carried away from the foundations the leakage will increase, the holes will enlarge, and finally settlement will take place. As a consequence of settlement cracks will open in the dam, and, with the pressure of the water in the reservoir to assist, the structure may collapse.

[41] Taylor, T. U., The Austin Dam: U. S. Geol. Survey Water-Supply Paper 40, 52 pp., 16 pls., 12 figs., 1900.

[42] Mead, D. W., Report on the dam and water-power development at Austin, Tex., 205 pp., privately printed, November, 1917.

[43] Parsons, H. de B., Sherman Island dam and power house: Am. Soc. Civil Eng. Trans., vol. 88, pp. 1257–1292; discussion, pp. 1293–1328, 1925.

The flow under such dams is a function of the height of the dam and the permeability of the material of the foundation. Theoretically the equations representing this function may be solved by the collection of adequate data, and the reader is referred to the interesting attempt at such a solution by Justin,[44] whose paper contains a comprehensive list of successful earth dams and of failures and partial failures of such structures.

In general, the materials under a dam are of irregular permeability and may range from gravel to clay. Cut-off walls or lines of sheet piling or both are used where possible to retard flow, but unless these structures reach bedrock they serve merely as baffles to increase the distance of flow. Similarly, a blanket of clay or concrete connecting with the impervious part of the dam may be built on the reservoir floor upstream from the dam to increase the length of travel. The ratio of the distance of flow (including the blanket, the cut-off wall, and the impervious portion of the dam) to the height of water to be resisted is called the percolation factor.[45] This factor ranges from 5 to 20 in successful dams. The smaller factor is used for gravel, in which there is less danger of the entrainment of material or " piping " under the dam, and the factor of 20 is used for fine material described as " quicksand."

Usually the nature of materials under a river valley is not clear unless test borings can be made. With access to the samples and drill logs thus obtained the geologist can often interpret the data so as to solve some of the problems of earth and rock-fill dams.

At a certain dam site a narrow gorge in granite gneiss, otherwise suitable for dams, was filled to a depth of 83 feet with a swamp deposit which at the surface, in a narrow strip on each side of the stream, formed a quaking bog. The first set of drill holes was interpreted as indicating clay beds at the bottom, resting on the bedrock. Such clay beds would have offered a tight seal for sheet piling either for a cut-off wall or for a cofferdam. The samples from a second set of drill holes were examined by a geologist, who showed that the supposed clay was an impure diatomaceous earth without stability. This material and the overlying muck were so fine grained and unconsolidated and had so high a content of water that excavation of the dam site to bedrock for any type of dam involved the use of slopes of 4 on 1 or flatter. The enormous exca-

[44] Justin, J. D., The design of earth dams: Am. Soc. Civil Eng., vol. 87, pp. 1–61; discussion, pp. 62–141, 1924.

[45] Bligh, W. G., Dams, barrages, and weirs on porous foundations: Eng. News, vol. 64, pp. 708–710, 1910. Lessons from the failure of a weir and sluices on porous foundations: Idem, vol. 69, pp. 266–270, 1913. See, as examples of high dams built on these principles, Henny, D. C., Two earth dams of the United States Reclamation Service: Am. Soc. Civil Eng. Trans., vol. 74, pp. 38–86; discussion, pp. 87–93, 1911.

vation required by the use of these slopes appeared to be too expensive for consideration. The site was abandoned, and a near-by site less favorable topographically was selected.

If it can be shown that an impervious clay bed extends up and down stream for some distance, the impervious part of the dam can be extended to this bed, and the percolation factor may then be considered to be the ratio of the length of this bed to the height of the impounded water. If the alluvial materials are sufficiently well known from test borings, various devices of this type may be used to attain the desired percolation factor with minimum cost. Obviously very close association between geologist and designer is necessary to take cognizance of all the intricacies of the site.

ABUTMENTS OF DAMS

The abutments of dams may be hard or soft rock. In the harder rocks joints, cracks, and bedding planes may form passages through which leakage may take place, but if these cracks are clean they may be grouted under pressure and made water-tight. Abutments of basalt must be regarded with suspicion on account of the many openings that may occur in such rock. These openings may permit leakage, but they are not likely to enlarge, and the stability of the abutment is not menaced by them. Limestone, however, and the still more soluble gypsum and rock salt give rise to large cavities that will, as leakage goes on, increase in size. Obviously if the abutments are broad, these defects are relatively unimportant, whereas if the abutments are narrow ridges, not much wider than a dam, joint cracks and other crevices have more weight as unfavorable factors.

The rock of the abutments that has been exposed to the weather is more or less unsound and should be removed to a depth sufficiently great so that the impervious portion of the dam may rest on "sound rock." The cost of this excavation and the cost of the material placed in it must be estimated by the engineer before construction is begun. Similarly, if the base of the dam or the cut-off structures are to be placed in bedrock, the depth to "sound rock" must be estimated. Unfortunately, this estimate is beset with difficulties. Comparative data on this matter have never been compiled.[46] The geologist is at a disadvantage because of the elasticity of the term "sound rock" and because of the capriciousness of weathering, but he is accustomed to observe the extent and depth of weathering and should be able to assist the engineer in forming a correct judgment as to what depth to "sound rock" to assume. The cut-off wall of one American dam

[46] See, however, Lapworth, H., The geology of dam trenches: Inst. Water Eng. Trans., vol. 16, pp. 25–51; discussion, pp. 51–66, London, 1911.

where it rested on andesite was in places carried 40 feet beyond the "sound rock" line estimated from an examination of drill cores. On the other hand, the recently completed Sennar dam,[47] in Egypt, rests on gabbro that was found to be less weathered than had been anticipated, and a considerable part of the excavation that had been believed to be necessary was saved.

Abutments in unconsolidated rocks present serious problems, for if leakage takes place the stability of the dam may be menaced. An abutment proposed for a dam may be an interfluve between two adjacent lateral tributaries, and this ridge may be as narrow as the proposed dam. The material of the ridge is unlikely to be as compact or self-draining as a properly made earth dam. If, for instance, it is composed of alternating layers of sand and clay, the sand will admit water which will wet the clay and convert it into slippery mud, so that sloughing and landslides will ensue. In general, therefore, abutments in unconsolidated materials should be wide ridges or interfluves between lateral valleys.

If the material of the abutment is fairly uniform, the normal ground-water gradient in like material in the region may be determined. This gradient projected from the flow line of the reservoir through the abutment should fall within its mass with a good margin of safety. Thus in the study of abutments many of the principles of ground-water hydrology heretofore reviewed with respect to reservoirs come into play. There is, however, this difference—the abutment has a small area, which it may be feasible to blanket with impervious material, or leaky places in it may be cut off from the reservoir by dikes, or part of its material may be used to build the dam and be replaced by an extension of the structure. To supply data for a choice between these alternative devices requires of a geologist detailed and penetrating observations.

The importance of these problems may be appreciated from an examination of the history of a well-known American dam. As first proposed, this dam, an earth structure with concrete core wall, was to close a glacial valley at the place where the glacier had deposited its terminal moraine. On the left abutment the quantity of morainal material was small, so the outlet tunnel and spillway were located in andesite on this side. On the right the end of the dam was to rest in the terminal moraine. When excavation for the core wall in this abutment was begun, the glacial till of the moraine was found to be wet and clayey. It started to slip into the excavation to such an extent that the site had to be abandoned. The dam was then built 1,000 feet downstream, where both abutments were in andesite. The cost of the abandoned work and the change of plan was very large,

[47] Sennar Dam on the Blue Nile in Egypt completed: Eng. News-Record, vol. 96, pp. 316–317, 1926.

yet evidence that excavation in this abutment was impracticable existed even before the engineers had dug test pits in which unheeded confirmation was obtained. High above the proposed dam the morainal ridge was marked by landslide topography—sure evidence of not very remote slipping. The cause of this slipping was also patent, for the greater number of the boulders in the glacial till are andesite of the easily weathered local type, and each boulder is surrounded with a shell of clay, which when wet forms an ideal lubricant. The fact that the boulders are partly weathered to clay can be seen in natural exposures and was evident in the test pits. The only advantage of the first site over the second was a slightly smaller yardage, which compared to the costs involved in changing from one site to the other could have been only an inconsiderable saving. If in spite of difficulties the dam had been built as started, the effect of the pressure of the reservoir water on the unstable material of the moraine is difficult to predict in detail but could hardly have been anything but disastrous.

Leakage through abutments is described by Henny [48] in his account of the dams at Cold Springs, Oreg., and Conconully, Wash. The immediate abutments of the Cold Springs Dam consist of basaltic rock of fair quality, but this rock does not extend far into the hills on either side. Seepage through the rock and through the sand and clay beyond the rock is evident but has not been large, as the abutments are wide and the route of travel for the escaping water is very circuitous. Together with seepage through the rock under the dam, which is tied to bedrock by a concrete cut-off wall, the total movement is considerable, though not serious. The visible flow in the creek below the dam ranges from 0.7 to 1.8 cubic feet a second, of which one-fourth may be attributed to losses from the outlet canal. At the Conconully Dam the right or spillway abutment is a narrow ridge of granite and limestone not much wider than the dam and about 600 feet long. A small spring on the downstream side of this ridge had a natural flow of 0.115 cubic foot a second. When the reservoir was filled, the flow from this spring and new springs at other places along the ridge increased gradually to a cubic foot a second, and it decreased as the reservoir was emptied. The spring water is clear, showing that no entrainment of material is taking place, and as the leakage can not affect the stability of the abutment it is of little importance. The loss of water is so slight that no remedial measures have been taken, although the area involved is small enough to make either an earth blanket on the reservoir side of the abutment or pressure grouting of the fissured rock entirely practicable.

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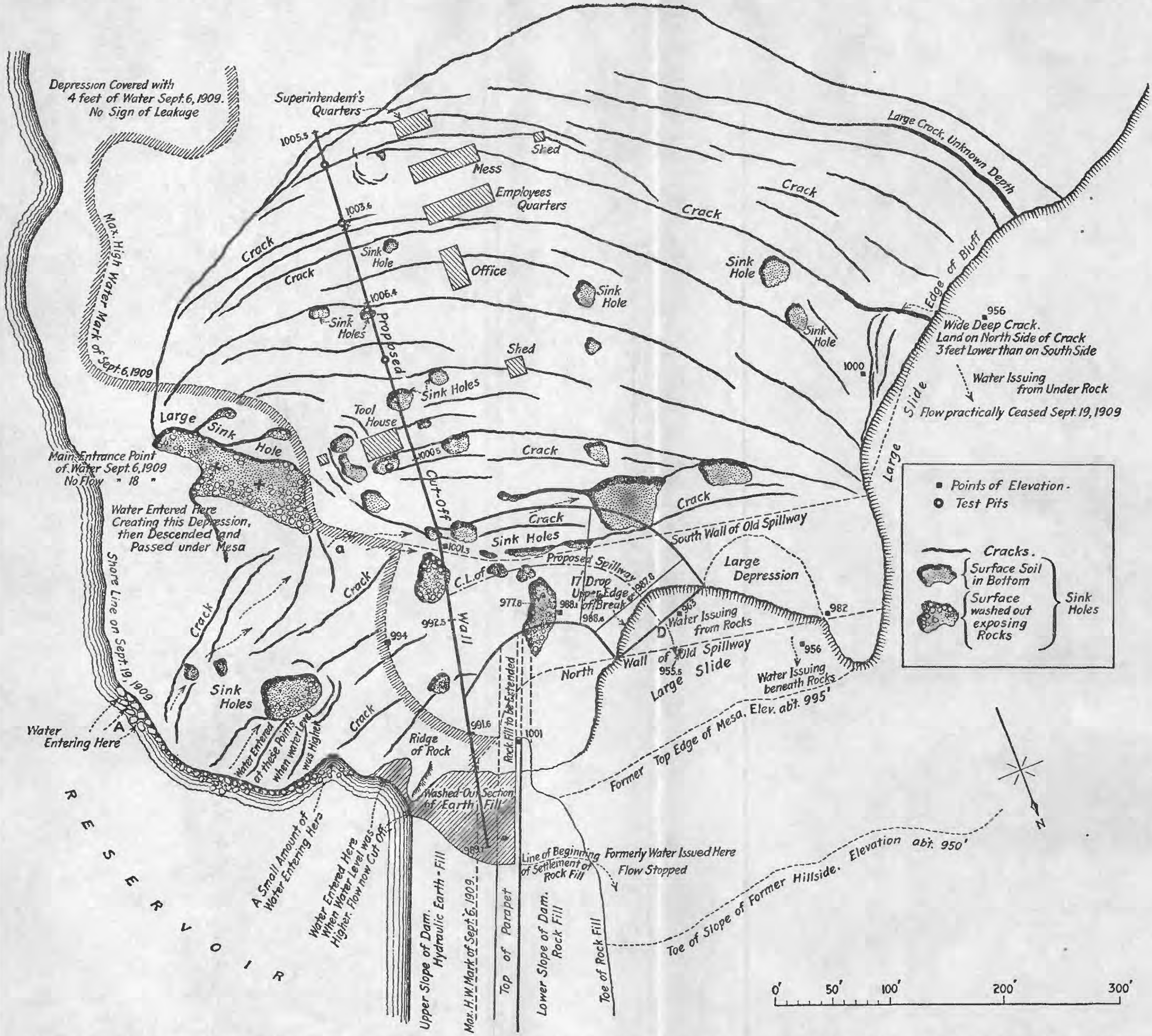
[48] Henny, D. C., Two earth dams of the United States Reclamation Service: Am. Soc. Civil Eng. Trans., vol. 74, pp. 38–86; discussion, pp. 87–93, 1911.



MAP OF SOUTH ZUÑI ABUTMENT OF DAM AT BLACK ROCK, N. MEX., SHOWING HOW SPILLWAY AND END OF DAM WERE UNDERMINED

For complete explanation and additional illustrations, see Engineering News, vol. 62, pp. 597-600, 1909, from which this map is reproduced

The Zuñi Dam [49] at Black Rock, N. Mex., is a rock fill with an earth blanket as the impervious part of the structure. At the dam site 30 feet of basalt lava rests on 40 feet of sand and clay, which rests on " blue clay " 20 feet below the stream grade. The lava caps flat-topped " mesas " on both sides of the narrow canyon. The maximum height of the dam is 70 feet, and the length is 720 feet. The earth blanket is tied to the underlying " blue clay " by a trench filled with puddled clay. A spillway 100 feet wide and 10 feet deep had been excavated in the basalt on the south (left) abutment, which, as shown in Plate 1, had the relatively narrow width of 600 to 800 feet. On September 5, 1909, leaks appeared at the north (right) end of the dam amounting to 124 gallons a minute, and by the next morning this flow had increased to 467 gallons a minute, when it was stopped by blanketing the upstream slope with earth in bags. On the second day, September 6, muddy water was observed issuing from the south (left) end of the dam, and in spite of efforts to stop it the flow increased. The water was passing through cracks in the basalt and carrying away the fine sand that underlay the rock. As the flow increased slips occurred, and soon the spillway was undermined and large sections of the abutment and part of the dam slipped downstream and were carried away. The maximum amount of water discharged through the abutment and around the dam was 5,000 second-feet, but as the level of the reservoir lowered and remedial measures became effective the flow decreased. By September 10 the flow was moderate in amount, and by September 20 it had ceased. The extent of the damage to the abutment and the dam, as it appeared on September 20, is shown in Plate 1. Obviously the flow of water through the cracks in the basalt could take place on low gradients at sufficient velocity to entrain the sand, and even if the abutment had been wider it would have been menaced by this action. As the dam showed no leakage and was damaged only where it rested on the abutment, the failure serves as an excellent example of the fact that a narrow abutment of natural rock may be much weaker than an artificial mound of the same or smaller size.

Beemer [49a] has described succinctly a dam where anticipated leakage was reduced to innocuous quantities.

SPILLWAYS

Some method must be provided by which flood waters may pass a dam. Even if there are works for withdrawing stored water for use, additional waterways must be provided. The necessary capacity of spillways differs according to the size of the reservoir and the

[49] Partial failure through undermining of the Zuñi Dam, N. Mex.: Eng. News, vol. 62, pp. 597–600, 10 figs., 1909.

[49a] Beemer, J. A., Novel solution of Bridgeport Dam (Calif.) spillway problem; Eng. News-Record, vol. 98, pp. 108–110, 1927.

regimen of the stream. There are also various forms of spillways. The so-called overfall type of dam is built so as to pass flood waters over its crest. Other dams have many gates within the body of the structure. The geologist is concerned with the erosive effect at the toe of an overfall dam and with spillways constructed at the side of the dam or at some distance from it. Engineering textbooks cover methods of protection for the toe of an overfall dam rather completely, and the geologist may be able to give very little vital help. At spillway sites, however, the geologist should consider the capacity of the rock to resist wear by falling water. If the site is on one of the abutments of the dam or at some low place in the rim of the reservoir underlain by clay, shale, soft sandstone, or similar material that is easily eroded, a concrete channel must ordinarily be built to convey the water into some natural drainage way. On the other hand, there may be so little water to overflow, or the possibility of a flood great enough to send water through the spillway may be so remote, or the grade may be so gentle that protection of the spillway may cost more than the benefit is worth. It may be cheaper to allow erosion to take place and repair the damage. This choice, however, is to be made on engineering and not on geologic grounds, and the engineer will base his decision on well-understood principles.

A serious problem arises if the only satisfactory place for the spillway is in a narrow abutment and the grade from the crest to the natural drainage way is steep. Here erosive action may weaken the abutment and endanger the structure. Massive igneous rocks will resist the erosive action of clear water, but many jointed consolidated rocks suffer severely. The massive sandstones at the Roosevelt Dam have been so much eroded by the water that falls nearly vertically from the mouths of the spillway tunnels that the cost of repairing the damage and of attempts to prevent further erosion has already reached a large sum. A single flood carried away 10,000 cubic yards of rock from the spillway of the Sweetwater Dam in California,[50] requiring the construction of a concrete apron. At prospective dam sites the geologic report should include a description of the rocks in the proposed spillways and estimates, however rough, of their resistance to erosion, on which the engineer, having in mind all the other factors of the problem, may base a judgment as to the necessity for paving the spillway channels.

At the Sherbourne Lakes Dam, in Montana, a concrete spillway built over one of the abutments was destroyed by soil creep and landsliding of the shale hill above it. Here the damage was caused by too deep a cut in an unstable hill slope. An adequate remedy is not

[50] Schuyler, J. D., Reservoirs for irrigation, 2d ed., p. 226, 1908. See also Hill, R. A., Repairing spillway to Gibraltar Dam: Eng. News-Record, vol. 89, pp. 798–801, 1922; Oram, H. P., Concentrated flow erodes rock below Wilson Dam: Idem, vol. 98, p. 190, 1927.

immediately apparent, and the concrete has been replaced by timber which will form a temporary water channel until movement has ceased.

TUNNELS AT DAM SITES

Tunnels built in connection with dams may be divided by their purposes into three classes—(1) by-pass tunnels for diversion of the stream during construction of the dam, (2) outlet or diversion tunnels for drawing off water for use, (3) spillways. So far as their construction is concerned, these tunnels are like tunnels of any other kind. Only rarely would an abutment be so narrow or weak that the construction of a tunnel might dangerously impair it. The location of these tunnels is, however, subject to many ingenious arrangements by which one tunnel may be made to serve more than one purpose. If, therefore, one abutment has rock more favorable than the other for tunneling, or if construction at one level in preference to another is indicated by the geology, an additional factor is to be considered among the alternative possibilities. The geologist should, therefore, in close association with the engineer, consider all the possible locations for tunnels and describe the rocks with respect to tunneling operations.

TUNNELS IN GENERAL

The geology of tunnels involves problems more familiar to a geologist than other kinds of engineering geology, as his prime duty is to predict from the surface outcrops the position of the rocks at the grade line of the tunnel—that is, to construct a geologic cross section. The work should be of the accuracy demanded in mining operations. However, the same facilities as in mining are seldom available at tunnel sites, for there are generally no extensive excavations near by from which geologic data may be obtained. If, however, the cover is not too great, drilling should be done, and from even a few drill holes skillfully located fairly accurate predictions are possible.

Tunneling, however, is a highly complex art. The use of the proper methods and careful organization have a larger bearing on the cost than the difficulties encountered. For instance, tunnels of large diameter in earth requiring timber for support cost as much as tunnels of the same diameter in hard rock that must be drilled and shot down, but the type of men employed and the organization of the work are wholly different, so if hard rock is encountered unexpectedly in an earth tunnel the cost is much increased. On tunnels of large diameter, therefore, the nature of the material does not enter into the estimates of cost as much as into the plans for procedure. In tunnels of small diameter earth, even if it requires timber, is cheaper to penetrate than rock, and the resistance of the rock to excavation is also a factor in cost. The ease of drilling, position of joints, effect of explosives, and size of pieces also materially affect the cost.

In tunnels of all sizes the characteristics of the rocks that produce disasters are of vital importance, and if they can be controlled the ultimate cost is reduced and human lives may be saved. "Swelling ground" is a name applied to the expansion of the wall rock of a tunnel. This expansion takes place because of the relief of pressure produced by the excavation itself, and this may be the sole cause. However, the absorption of moisture from the air and perhaps other conditions tend to weaken rock newly exposed in the walls of tunnels and cause it to expand. The action is most likely to occur in shale and in the claylike decomposition products of igneous rocks. When such material is encountered the timbers are squeezed and broken, tunnel alinement and shape are lost, and other difficulties arise. As yet the causes of swelling ground are imperfectly known, but the geologist should note that bentonite or any of the minerals characteristic of bentonite [51] are warning signals, and if they occur in material quantity, swelling ground should be anticipated.

Wet ground or sudden rushes of water are expensive or dangerous, or both, and to drive a tunnel below ground-water level in unconsolidated sand, gravel, or clay ordinarily requires complicated apparatus and the use of compressed air to hold out the water. If such wet ground is encountered suddenly, as where a buried river channel crosses the tunnel line, disaster results. Open channels in the crevices of igneous rocks or caverns in limestone produce similar floods. Long tunnels under deep cover may encounter hot springs or sudden inrushes of water from overlying ponds or streams.[52] In some rocks inflow of explosive or noxious gases may occur.

Earth temperatures in tunnels with a thick cover may be high and add to the difficulty of the work. In some localities, as on the Owyhee project, Oregon, observations on the local earth-temperature gradient are available, and the temperature can be closely predicted. In other localities the geologist must, after a review of all the facts available, estimate the probable earth temperature, or if test holes are drilled he may make direct observations.

Fortunately a detailed account of the geologic work by Berkey,[53] which was checked against the results shown by construction, has been published and affords a fairly complete manual for geologic work on tunnels. Many pertinent data are also available in De

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[51] Ross, C. S., and Shannon, E. V., The minerals of bentonite and related clays and their physical properties: Am. Ceramic Soc. Jour., vol. 9, pp. 77–96, 1926.

[52] Kusida, K., Difficulties in long tunnel for Japanese railways: Eng. News-Record, vol. 95, pp. 336–338, 1925.

[53] Berkey, C. P., Geology of the New York City (Catskill) aqueduct: N. Y. State Mus. Bull. 146, 283 pp., 1911.

Launay's textbook,[54] and Ries and Watson [55] have given a good introduction to the subject.

QUALIFICATIONS OF THE GEOLOGIST

The geologist's attitude toward his work and his personality are perhaps larger factors in engineering geology than in other kinds of geologic work. He must inspire confidence in his conclusions, yet he is subject to a rigid verification in which the errors that he may make will be startlingly apparent.

In much geologic work the risk of error is lightly considered. Only the reputation and self-esteem of the geologist are at stake, and he feels that if he is right on the main issue the workers of the future will bring out the whole truth and deal kindly with his minor errors. Geologic work done for engineering projects, however, often concerns the expenditure of large sums of money, and the geologist should feel this responsibility as well as a sense of duty to the engineer whose reputation is also at stake. He should be scrupulously frank in laying before the engineer the nature of the evidence and the basis on which a conclusion has been reached. The science of geology is as yet only partly developed, and in only a few areas has the general geologic structure and history been worked out with the thoroughness that is even now possible. Thus the geologist has an imperfect instrument to work with and may find that in the particular spots selected for engineering structures it is impossible to get adequate evidence. He should therefore assist the engineer in forming a judgment as to the validity of the conclusions indicated by the geologic work. In a certain investigation, for instance, it was proposed to carry a canal across a valley by creating a lake into which the canal would discharge at one end and be led off at the other. A siphon crossing was also possible but required nearly 2 miles more of canal. The cost of the two alternatives was nearly the same, but the lake would afford regulatory storage, which would be an advantage in operation. The abutments of the proposed dam were narrow interfluves between tributary streams and by geologic inference, for there were very few outcrops, were thought to consist of 30 feet of sand resting on clay and therefore likely to leak. By locating the dam half a mile upstream, wider abutments in what appeared to be similar material could be obtained, but greater yardage in the dam and an additional half a mile of canal were required. Although the geologic inference rested on an inadequate basis the engineer decided to test this new site by drilling, which confirmed the prediction as to the composition of the abutment. The new data indicated that with proper precautions a safe structure could be built where the

[54] De Launay, L., op. cit. [55] Ries, Heinrich, and Watson, T. L., op. cit.

abutments were wide, and the engineer abandoned the original site and adopted the new site with its slight additional cost.

As all phases of geologic science may need to be used, the geologist should be broadly trained. Obviously familiarity with the local geology or with geology of the same type is advantageous, but given time a well-trained geologist can master these details, and it is perhaps of greater importance that he should have some knowledge of

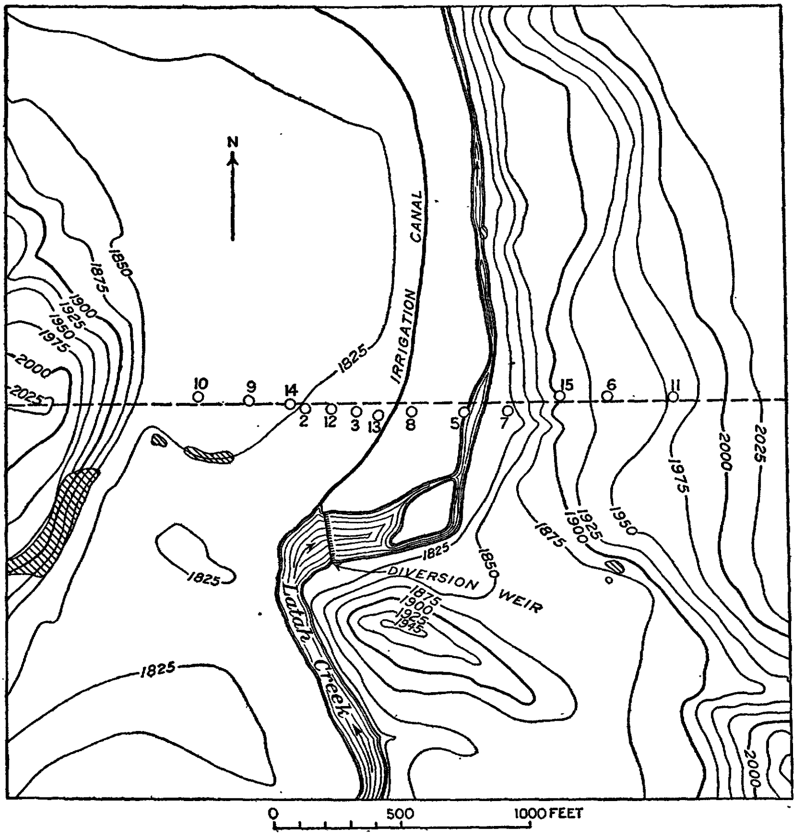

FIGURE 2.—Map showing geology of Latah Creek dam site, Columbia Basin irrigation project, Washington, as interpreted from outcrops and test wells. Diagonal shading indicates outcrops of basalt; the rest of the area is occupied by sand and gravel. Numbered circles indicate drill holes; dashed line, center of proposed dam. See also Figure 3

engineering problems and methods. Above all things, however, the geologist should not allow himself to be diverted to geologic problems, however interesting, that are not involved in the question before him.

A reasonable success in prediction is all that may be expected. What may be deemed to be an unusually close prediction is illustrated in Figure 3. On the map of the site (fig. 2) are shown the

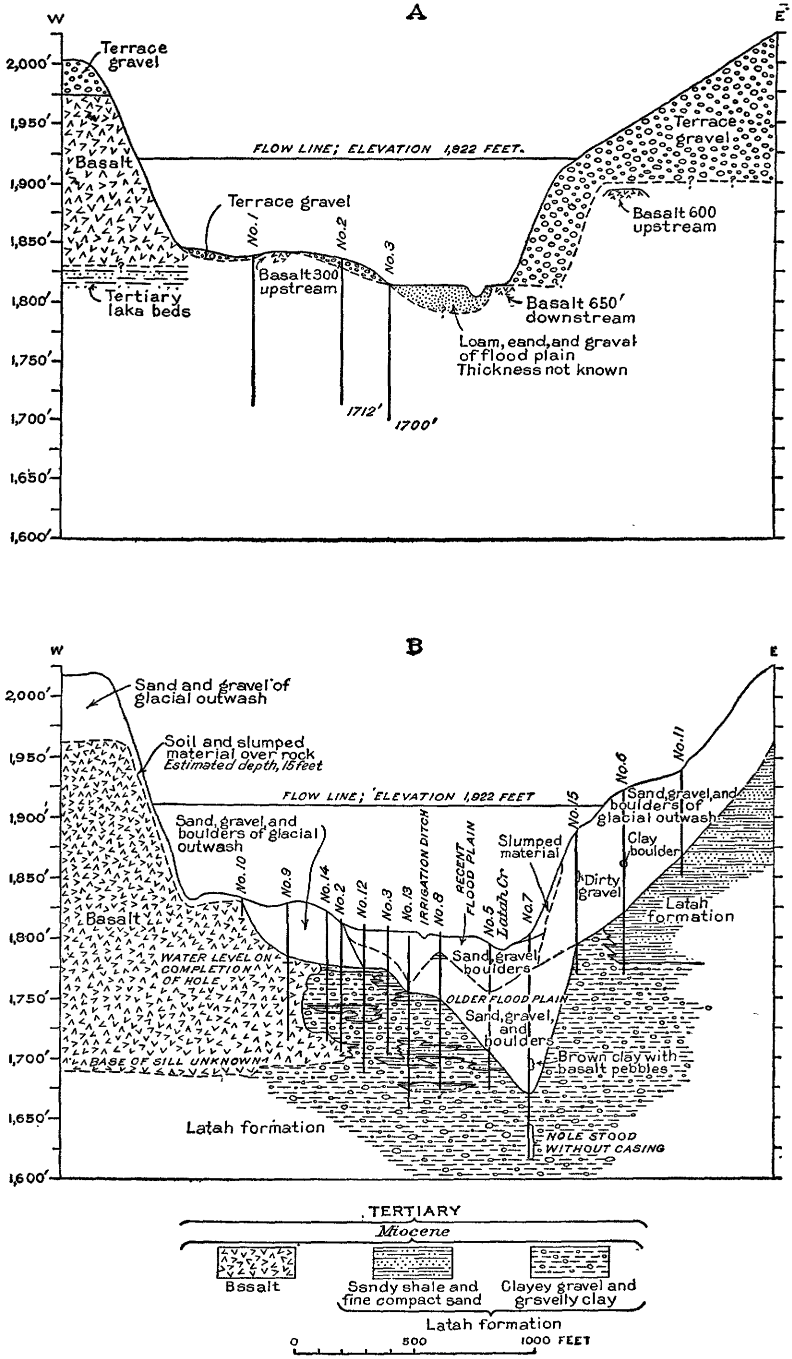

Figure 3.—Geologic cross sections of Latah Creek dam site, Columbia Basin irrigation project, Washington. A, Showing known and inferred relations; B, based on completed examination and results of test drill holes.

outcrops of basalt, and the only other visible materials were sand and gravel of the flood plain and the terraces. In the cross section A, Figure 3, on the center line of the proposed dam is the prediction based on a general study of the geology, as the drill holes 1, 2, and 3, already put in, could not be interpreted. In B, Figure 3, is given the cross section as constructed after the drilling of 13 test holes. The first three holes could then be interpreted, and the conjectured cross section was confirmed except for the depth of the stream channel and the thickness of the sand in the terrace on the right abutment.

RELATIONS OF GEOLOGIST AND ENGINEER

The relations of engineer and geologist should be inspired by mutual confidence. If the engineer feels that the geologist is merely a crack-brained theorist, and the geologist feels that the engineer is merely a stolid-minded fellow who thinks of nothing but figures, little good will come of their association. With mutual consideration, however, they will, by the junction of two divergent points of view, come nearer to the truth of the matter together than by the same amount of independent work.

In general, the geologist bears to an investigation or to a project under construction the relation of a consultant. He should be untrammeled in his survey, but he is responsible to the engineer in charge, and his activities should be so adjusted as to furnish information at the time when it is needed in the engineering work and not necessarily according to a program that will most logically develop the local geologic problems.

On the engineer falls the responsibility for the design of structures and usually also for the cost of the investigation. Unless he confides in the geologist his ideas and tentative decisions as they are formed, the geologic work may be directed into unprofitable fields.

In a certain large project it was proposed to build a dam with many gates across a strait, and the first idea set forth was that this dam should consist of a series of concrete caissons. The water body was about 6,000 feet wide and in places 125 feet deep and had a soft bottom. The prediction of geologic conditions under this extensive body of water was a task to daunt the boldest geologist. However, the engineer in charge and the geologist held a conference, and the engineer proposed a plan to build the structures on dry land on one side of the strait, excavate deep channels to them, and use the material so gained to block the original waterway. As there was excess yardage to compensate for settlement, however large, it is obvious that the geology of the under-water area was of little moment. Had the geologist not been informed of this ingenious device, he would have spent much time in an almost hopeless effort to predict the distribution of rocks in this water-covered area.

The geologist must, therefore, have the confidence of the engineer, but it does not follow that the engineer is bound by the opinions of the geologist, nor can he shift to the geologist the final responsibility for success or failure. If there is doubt in his mind as to the findings of the geologist, he should bring in another or test these findings by additional test pits and borings. At best the real economy in the use of geologists is in reducing the number of actual tests.

In general, the association of geologists with engineering investigations and projects has its principal advantage in directing the attention of the engineer to the detailed characteristics of the rocks and soils with which he must contend. With the accurate description of these materials supplied to him by the geologist and with reasonably accurate predictions of their form and underground extent, he is free to exercise his ingenuity in overcoming the difficulties of construction. To the geologist comes the satisfaction of putting his effort on works of magnitude that will benefit the communities affected, although he will probably report on many more schemes that will never be built than on feasible projects that he will live to see carried out. His best reward comes, however, in the rigid testing of his observations and inferences by means of borings and excavations. Many of his results may have only local value, but others will be of general utility and will be incorporated into the body of geologic knowledge. The principles of the application of geology to the problems of civil engineering are as yet incompletely developed, as indicated by this short sketch, and this field lies open for cultivation by the willing and experienced worker.

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GEOLOGY OF THE OWYHEE IRRIGATION PROJECT, OREGON

By Kirk Bryan

OUTLINE

For many years irrigation by simple diversion has been practiced on the low alluvial lands along Owyhee and Malheur Rivers near their junction with Snake River, in southeastern Oregon. (See fig. 4.) During this period the good soil of higher areas—the so-called bench lands, which lie along both rivers and the adjacent western slopes of the Snake River Valley—has tempted ambitious persons to propose various schemes by which water might be led on to these fertile lands. Small areas have been put under cultivation by pumping water from Snake River, and others in the Malheur Basin by high-level diversion. The major portion of this land, however, requires long canals and diversion from the upper courses of the rivers, and the scale of such work calls for governmental backing. It would be profitless to review all the schemes proposed for the irrigation of these lands, as one has come from each investigation of the problem, differing from the others both in source of water supply and in the position and area of the lands to be irrigated.

As now outlined, the Owyhee project consists of a combined storage and diversion dam at Hole in the Ground, on Owyhee River, and a conduit through rough country involving tunnels and siphons. The conduit divides not far from the reservoir, one branch swinging south to supply the bench lands along Snake River Valley south of the junction with Owyhee River and one branch going north, crossing Owyhee and Malheur Rivers by inverted siphons, to irrigate the discontinuous bench lands adjacent to the lower courses of these streams. The project involves the construction of a dam 390 feet high, at least 14.7 miles of tunnel, and more than 150 miles of main canal. The tentative estimated cost in 1924 was $16,800,000 to be divided as follows: $25 an acre for lands now irrigated by the Owyhee ditch, $117 an acre for lands now served by pumps, and $137 an acre for newly irrigated lands. The settlement of 1,400 to 1,600 families will be required to bring the undeveloped land into use. The

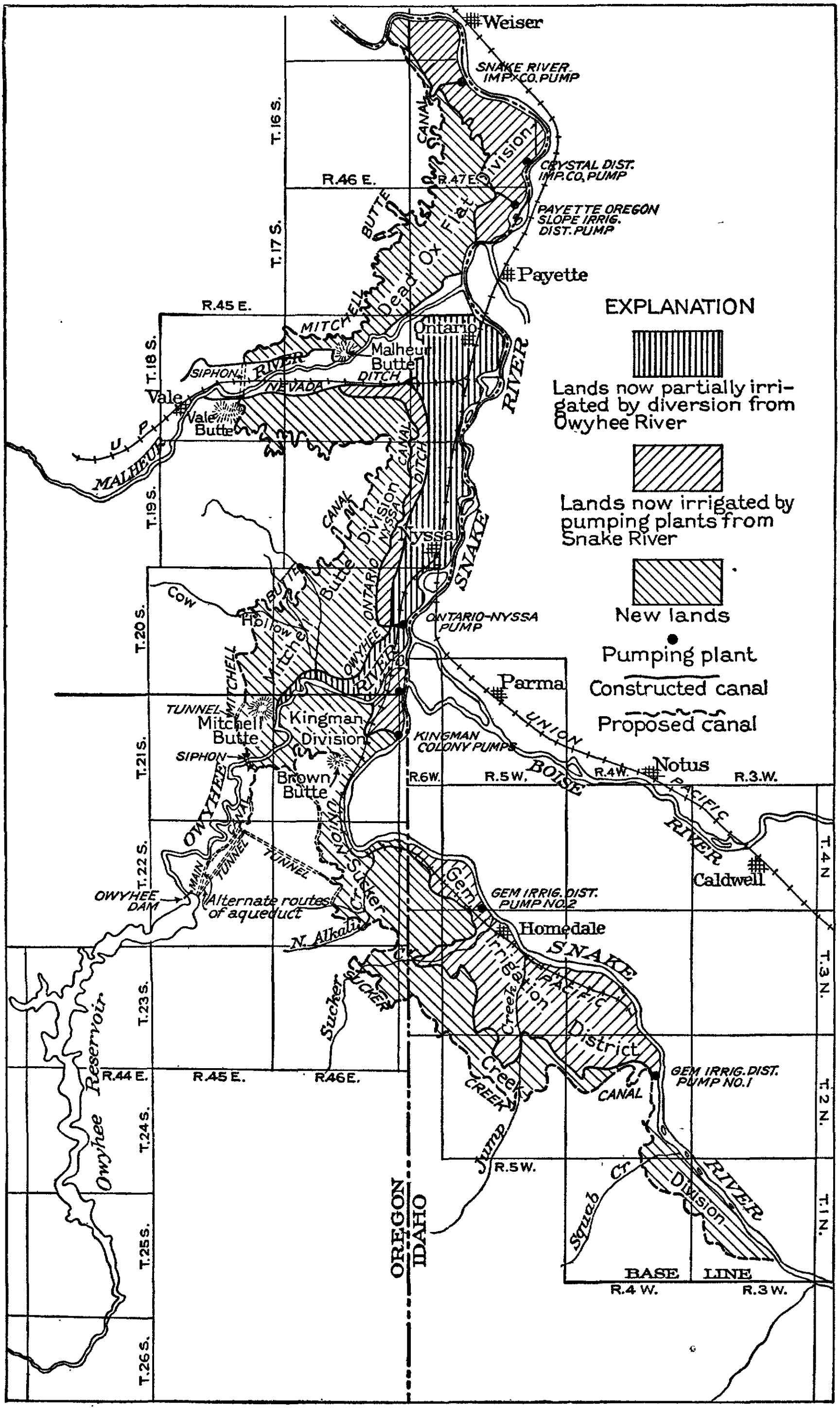


FIGURE 4.—Sketch map showing location of Owyhee irrigation project, Oregon

importance of the project in cost and in prospective benefit to the region is large. The problems of engineering, agriculture, and finance are difficult and interesting. These features are not discussed in this report, which is restricted to the applied geology of the larger engineering structures.

FIELD WORK

At the request of C. E. Weymouth, then chief engineer of the Bureau of Reclamation, I was engaged in field work for eight days, beginning November 26, 1923. One day of this time I spent at the Duncan reservoir site and dam site, three and one-half days at the Diversion reservoir site and dam site, and the remainder of the time in travel and conference. A report on this work, dated December 14, 1923, was made, in which additional field work was recommended. Pursuant to correspondence between the chief engineer, Bureau of Reclamation, and the chief hydraulic engineer, Geological Survey, I arrived in Boise, Idaho, October 1, 1924, and the next day had a conference with J. B. Bond, superintendent of the Boise irrigation project, and R. N. Newell, in charge of field surveys. I arrived at the Bureau of Reclamation camp on the 4th. The following 18 days was spent in field work, and during part of that time I was assisted by B. Coleman Renick, who arrived October 11. Mr. Bond placed an automobile at my disposal. Mr. Newell gave me the facilities of his camp and provided saddle horses. His courtesy and thoughtfulness expedited the work. R. E. Gossett and S. B. Tierney, drill foreman, and other employees of the Bureau of Reclamation were most helpful. The Duncan reservoir site was not reinvestigated in 1924, and as this site is no longer under consideration the statement of December 14, 1923, is not repeated. The results of the work of Mr. Renick on the petrology of the rocks and the order and thickness of the formations are incorporated herein, largely in the phraseology of a manuscript report on these subjects prepared by him. The new formation names Grassy Mountain basalt, Blackjack basalt, and Owyhee basalt, proposed in that manuscript, are herein adopted.

A summary of later geologic work by Warren D. Smith and F. L. Ransome is appended in order to bring up to date the geologic information on the structure of this project.

OWYHEE RIVER

Owyhee River rises in Nevada and flows north and northwest through Idaho into Oregon and thence north to a confluence with Snake River at the Oregon-Idaho boundary. The river and its tributaries flow for most of their courses in canyons cut in the extensive plateaus of southeastern Oregon, a region of deficient rainfall devoted largely to the raising of sheep and cattle. Much of the region is an elevated plateau standing from 3,500 to 4,500 feet above sea level. In Nevada high ranges rise above this level, but in Oregon there are, with the exception of the Stein Mountains, which form a considerable range, only small groups of scattered hills. Most of these hills are, however, dignified by the name of mountains. Parts of the plateau are covered with basalt flows that spread from craters still visible. These flows range in thickness from 25 to 200 feet, and this thin veneer conceals over large areas the complex structure of the underlying rocks.

In general, however, the surface of the plateau appears to be an ancient erosion surface. Rocks of unequal resistance have been more or less reduced to a common level, but successive outpourings of lava and possibly unequal uplift have so complicated the evidence that it may easily be that the surface of the plateau was formed over a long period and in more than one partial erosion cycle.

In this plateau Owyhee River has cut a gorge which is about 500 feet deep near Duncan Ferry and about 2,000 feet deep a few miles from the mouth of the river. (See pl. 2.) In areas of soft rock the gorge widens to a broad valley, and the bottom lands are farmed. In the harder rocks the gorge is narrow and may for miles be too narrow for a road beside the river. The dam sites that were investigated lie in the narrow reaches of the gorge, and the reservoir sites are the broader parts of the valley immediately upstream from them. The recent basalt flows lie above, most of them far above, the proposed flow lines of these reservoirs.

HOLE IN THE GROUND RESERVOIR

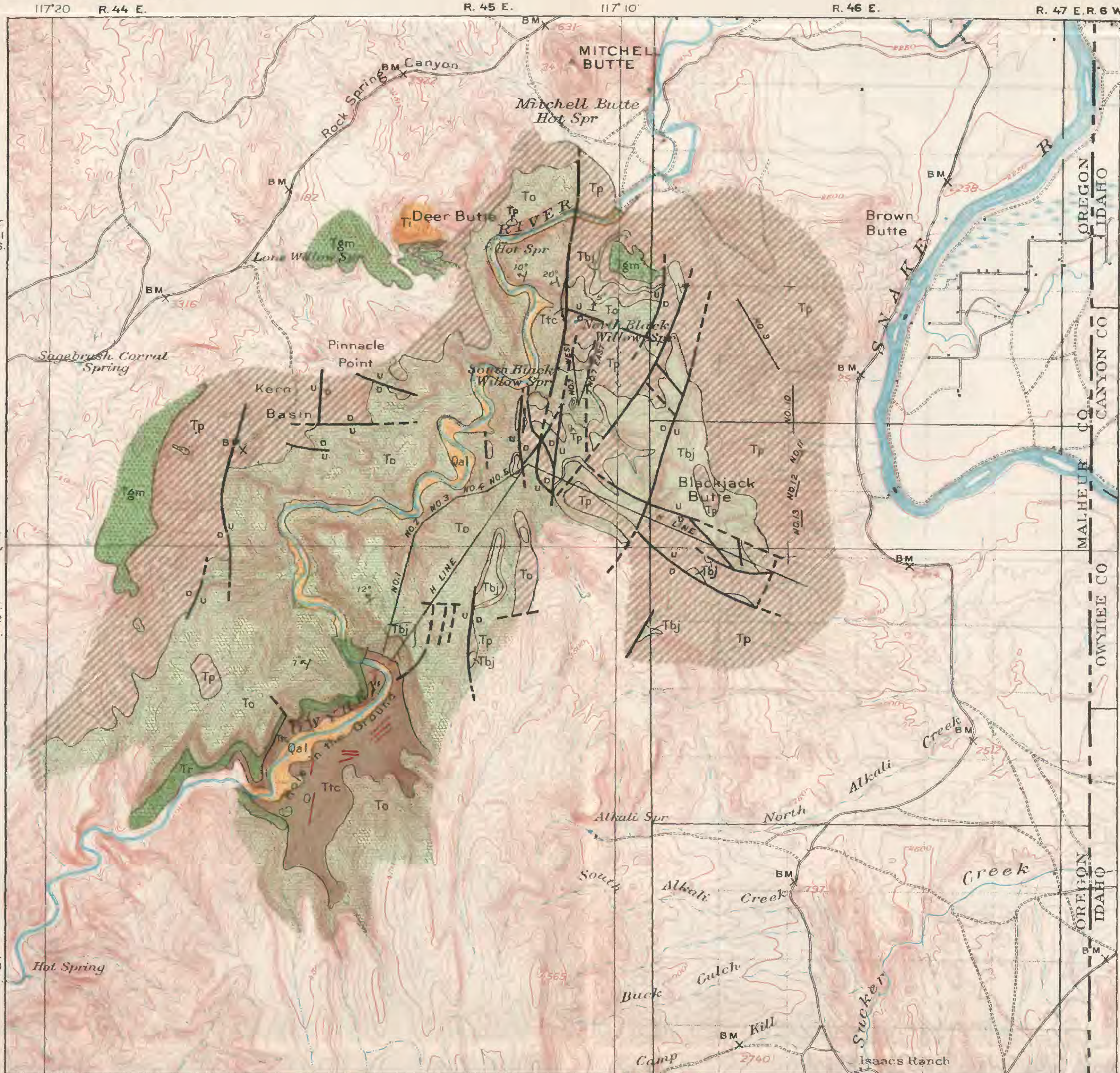
TOPOGRAPHY

In the lower end of a wide part of the Owyhee Canyon, known as Hole in the Ground, it is planned to build a combined storage and diversion dam. For diversion it is necessary to raise the water surface 234 feet, from an altitude of 2,356 feet to 2,590 feet above sea level. On the assumption that the maximum depth of the foundations below water will not exceed 60 feet, diversion will require a dam with a maximum height of 294 feet. If storage is also provided, the dam must raise the water level about 100 feet higher, or to 2,690 feet, and will have a total height of about 394 feet. Even if there are slight modifications in these figures, the dam will be when constructed the highest, or at least one of the highest, in the world.

The dam will stand in a narrow inner gorge known as The Box, whose side walls are precipitous for about 350 feet and above this height flare to normal width. (See pls. 5 and 6.)

PANORAMIC VIEW OF CANYONED COUNTRY NORTH OF OWYHEE DAM SITE, OWYHEE IRRIGATION PROJECT, OREGON

Proposed canal runs through valley in the foreground. Owyhee Gorge in middle ground; Grassy Mountain and Deer Butte in background



Base map from U. S. G. S. topographic map of Mitchell Butte quadrangle

Geology by Kirk Bryan and B. Coleman Renick

GEOLOGIC MAP OF PART OF THE LOWER GORGE OF OWYHEE RIVER, MALHEUR COUNTY, OREG.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

Contour interval 50 feet.

1928

EXPLANATION

SEDIMENTARY ROCKS

QUATERNARY

Recent

Qal — Alluvium

(Gravel, sand, and silt along Owyhee River and its tributaries; mostly derived from volcanic rocks)

TERTIARY OR QUATERNARY

Pliocene or Pleistocene

Ti — Idaho formation

(Sand, silt, ash, and fine conglomerate of fluviatile, lacustrine, and subaerial origin; contains some beds of fresh-water limestone)

TERTIARY

Miocene

Tp — Payette formation

(Sand, silt, volcanic ash, and tuff of fluviatile, lacustrine, and subaerial origin. Locally contains silicified logs and beds of carbonaceous shale. Interbedded with flows of Blackjack basalt east of Owyhee River and intruded by dikes of Grassy Mountain basalt west of Owyhee River)

Miocene (?)

Ttc — Tuffaceous conglomerate

(Conglomerate, sand, ash, and tuff beds underlying the Owyhee basalt and the porphyritic rhyolite. Much weathered)

IGNEOUS ROCKS

TERTIARY

Miocene and Pliocene (?)

Tgm — Grassy Mountain basalt

(Normal olivine basalt, overlying and in part interbedded with upper beds of the Payette formation)

Miocene

Tbj — Blackjack basalt

(A non olivine-bearing, normal augite-hypersthene-labradorite basalt, interbedded with beds in middle of the Payette formation east of Owyhee River.)

To — Owyhee basalt

(Augite-hypersthene basalt; grades from black to red and from dense to scoriaceous and cindery phases; contains a few beds of water-laid tuff; overlies the tuffaceous conglomerate)

Miocene (?)

Tr — Porphyritic rhyolite

(Plagioclase-augite porphyritic glass, including felsite, felsite breccia, pitchstone, and pitchstone agglomerate; overlies the tuffaceous conglomerate)

Basalt dikes

(Intrude the rocks below the Owyhee basalt and represent feeders to the basalt sheet)

U D

Faults

(Known and inferred, U, upthrow; D, downthrow)

7°

Strike and dip

NO. 2 H LINE

Proposed tunnels

Spring

GEOLOGY

The rocks of the area are all of comparatively late geologic age and belong to the great Tertiary sequence that throughout the Northwest is marked by the accumulation of great thicknesses of lava and of almost equal thicknesses of stream and lake deposits. Only part of this series is represented in the area or is related to the proposed engineering structures. The earliest rocks are a group of stream deposits here called the tuffaceous conglomerate; sporadic lava flows, now represented by porphyritic rhyolite, covered the conglomerate in part; flows of basalt, named the Owyhee basalt, then accumulated to a thickness of 1,200 to 1,500 feet; the Payette formation, of fine white tuff and sand with conglomerate and with interbedded basalt flows, was then laid down; after which the Idaho formation, a similar but later set of beds, was deposited. In the following pages each of these formations is described in detail, and the lava flows interbedded with the Payette are given especial treatment.

The geologic map (pl. 3) covers only a few square miles adjacent to the dam, including the tunnel sites. A geologic reconnaissance of the whole reservoir site was made, but the long and arduous task of detailed mapping of this relatively large area was not considered necessary.

TERTIARY SYSTEM

TUFFACEOUS CONGLOMERATE

The oldest rocks within the area studied are of sedimentary origin and crop out in the Hole in the Ground and in a small area near the north end of the region shown on Plate 3. In both localities the beds lie beneath the Owyhee basalt, but in places in the Hole in the Ground a mass of porphyritic rhyolite intervenes between the two formations. The general relations of these formations are shown with diagrammatic clearness in Plate 7. The oldest rocks consist of alternating beds of partly consolidated conglomerate, arkosic sand, and sandy shale of a prevailing buff, light-brown, or green-brown color. Cobbles 6 inches in diameter are common, and a few boulders 1 to 2 feet in diameter were noted. From these sizes the fragments grade down to the size of sand. Most of the pebbles in the conglomeratic beds consist of brown to purple igneous rock and in places give a darker shade to these beds.

The pebbles and rock grains are all much weathered, and in consequence determination of the character of the original rocks which supplied the material is correspondingly difficult. The greater part of the material consists of basalt, andesite, and similar igneous rocks, but fragments of quartzitic arkose and single grains of quartz and feldspar are present. The fine-grained beds are water-laid tuffs. The formation is evidently stream-laid and consists largely of débris derived from a region covered with lava flows and volcanic ash but containing also exposures of rocks of other types. In general, these materials have been only partly lithified, and the formation is not resistant to weathering. In places, however, it stands in small cliffs and produces a picturesque topography of the badland type.

As no fossils were found in these beds, their age can only be approximated. In view of the large amount of weathering to which they were subjected before the overlying rocks were deposited, it seems likely that after their deposition a period of erosion ensued. On this account it may be that the beds are as old as the Clarno formation of the John Day Basin, which ranges in age from upper Eocene to Miocene.

PORPHYRITIC RHYOLITE

GENERAL FORM AND CHARACTER

Cropping out on the west side of Hole in the Ground and forming both sides of The Box is a great sheet of igneous rock. This rock body and correlated outcrops at the south end of Hole in the Ground will be separately described under the name porphyritic rhyolite. These igneous rocks doubtless differ little in age from the associated rocks, although locally they intervene between the tuffaceous conglomerate and the basalts. The porphyritic rhyolite is massive, is marked by strong flow lines, and has the conchoidal fracture and brittleness of lavas of the rhyolite group. The main body is prevailingly red and is speckled with feldspar phenocrysts, but in places in this mass the rock is dark gray or black, and the correlated bodies farther south are wholly black. The absence of noticeable quartz phenocrysts and the glassy character of the groundmass made classification difficult.

The main body and some of the correlated masses are evidently lava flows that were extruded over the slightly eroded surface of the sedimentary rocks already described. There is at least one strictly intrusive mass, and part of the main body may also be intrusive. The detailed structure of the main body throws much light on its origin.

TYPES OF ROCK IN THE MAIN BODY

The main body of the porphyritic rhyolite consists of four unlike phases—red felsite with small quantities of similar black felsite, felsite breccia, pitchstone, and pitchstone agglomerate. In small outcrops or in hand specimens these phases appear to be rocks of quite different origin and might easily be suspected of different chemical composition. However, close inspection shows that there are many gradations between these types, and under the microscope they are almost indistinguishable.

The red felsite is a massive aphanitic rock of a dull red to magenta hue with colorless feldspar phenocrysts. There are also small quantities of black felsite, indistinguishable except for color. Under the microscope the phenocrysts are seen to consist of calcic andesine ($Ab_{45}An_{55}$), and there is in small quantity a mineral of high birefringence that seems to be augite. Many slides show no quartz, but a few crystals were found after diligent search. The groundmass is generally glassy with a considerable amount of microcrystalline calcic feldspar. The andesine feldspar phenocrysts have a length of about 5 millimeters and the augite grains average about 0.01 millimeter.

In hand specimen or after examination of the groundmass alone most geologists would consider this rock a rhyolite. The scarcity of quartz phenocrysts and the presence of andesine feldspar and augite raised the question whether the rock might not be more calcic in its composition than rhyolite, and consequently a partial analysis was made from which a calculation of the norm, by Mr. Renick, fixed the rock in the class rhyolite, as shown in the analysis and tabulation below:

Partial analysis of a composite of several samples of the red porphyritic rhyolite near north end of Hole in the Ground, on lower Owyhee River, Malheur County, Oreg.

[J. G. Fairchild, analyst]

Analysis		Calculated norm	
SiO_2	71.71	Quartz	28.80
Al_2O_3	14.49	Orthoclase	23.91
Fe_2O_3	2.01	Albite	32.49
FeO	.30	Anorthite	10.29
MgO	.25	Diopside	1.08
CaO	2.35	Hypersthene	.10
Na_2O	3.84	Magnetite	.23
K_2O	4.06	Hematite	1.92
TiO_2	.25	Ilmenite	.46
	99.26		99.28

Class I, order 4, rang 2, subrang 3.

The felsite breccia consists of angular fragments of the red felsite embedded in a matrix of similar material. The fragments range from a fraction of an inch to a foot in diameter. In a few places similar fragments of pitchstone occur. The rock was evidently formed by the disruption of cooled and partly cooled portions of the flow that were embedded in a still liquid portion.

The pitchstone is a black or dark-gray rock with a vitreous luster, generally having a conchoidal fracture but in places an uneven fracture as if perlites were present. Strong flow lines, which in many places show minute crumpling and faulting, are conspicuous in weathered surfaces. Under the microscope the pitchstone is seen to contain phenocrysts similar in every respect to those of the red felsite. The glass has alternate light and dark crenulated bands. The light bands have a very minute perlitic texture. A transitional phase between the red felsite and the pitchstone repeats the characters of each. The pitchstone occurs as pseudodikes in the felsite and as blocks in pitchstone agglomerate but is similar in mineralogic character throughout.

The pitchstone agglomerate consists of a matrix of finely comminuted glass, indistinguishable under the microscope from the pitchstone already described, containing angular fragments of pitchstone bounded by conchoidal fracture surfaces and ranging from a fraction of an inch to 3 feet in diameter. The contrast in color between the white tuff-like matrix and the black pitchstone blocks make this a notable rock type. (See pl. 8, *A*.)

FORM AND GROSS STRUCTURE

The main body of the porphyritic felsite, as shown on Plate 3, extends parallel with the general strike of the formations. South of The Box, where it crops out only on the west side of the canyon, the rock forms a wedge decreasing in thickness southward in a distance of a mile from 400 feet to a rounded end about 50 feet thick. It rests everywhere on the tuffaceous conglomerate and is overlain everywhere by white tuff at the base of the Owyhee basalt.

On the east side of the river the mass ends abruptly on a slope having a northeast strike and a dip of 85° NW. Here it abuts against the edges of the nearly horizontal pre-Owyhee sedimentary rocks, and the contact can be traced from a point near the river level vertically up the hillside for about 350 feet. At the top the nearly vertical mass merges into the blanket of pitchstone agglomerate described below. On the other hand, the white tuff bed at the base of the Owyhee basalt passes from the rhyolite to the sedimentary rocks over these contact phases of the rhyolite without a break.

The rhyolite forms both walls of The Box. The height of its upper surface above the river decreases from south to north gradually for half a mile, and then the upper surface slopes downward rather abruptly. The Owyhee basalt forms both banks of the river within a few hundred yards of the lower or north end of The Box.

In gross form the rhyolite is therefore a thick lens increasing from south to north, where its form is obscured by the regional dip that carries the contacts below the surface. Some of the details of these contacts and the distribution of types of rock and minor structural features are shown in Plate 4.

The greater part of this mass consists of the red felsite previously described. This rock is massive and resistant to erosion so that it stands in great bare cliffs, as shown in Plates 5 and 6. It is marked by a well-defined flow structure, which throughout The Box is nearly vertical and generally has a north or northeast trend. Locally there are great sweeping curves by which the strike and dip of the flow structure change rapidly. Part of one of these curves is shown in Plate 9, *A*. In addition to the flow structure there are strong fractures, generally nearly vertical but having diverse trends. Some of these fractures are clean breaks and resemble ordinary joints. Many have sharp walls separated by 2 inches to 10 feet of fault breccia. As shown in Plate 9, *B*, these fractures resemble faults in their clean walls and contained breccia, but there is no evidence of great displacement. Also, as shown on Plate 4, they are relatively numerous near the base of the rhyolite but can not be traced through to the top of the cliffs. A few of these fractures occur at the top of the cliff but can not be traced downward any great distance. In addition to these fractures, there is a minute plating or jointing by which, on weathering, the rock breaks in slabs about half an inch thick. This minute jointing is generally nearly at right angles to the flow structure and is well shown in Plate 9.

RELATIONS OF THE SEVERAL ROCK TYPES

The several rock types of which the rhyolite is composed are mappable as units on a sufficiently large scale. In 1924 a map of the Owyhee dam site, at the south end of The Box, was made under the direction of R. J. Newell on the scale of 40 feet to the inch, with 5-foot contours. On this map, reproduced as Plate 4, the several rock types were plotted, and they were also traced beyond this small area to the limits of outcrop.

The pitchstone conglomerate forms a blanket over the red felsite throughout The Box and ranges in thickness from 10 feet to as much as 100 feet. At the south end, on the east bank of the river, the agglomerate makes a sharp angle and laps around the red felsite in a nearly vertical dikelike mass along the contact with the pre-Owyhee sediments. This dikelike mass, as exposed, is from 20 to 50 feet wide and, as shown on Plates 4 and 6, *B*, splits into dikelike bodies which join the blanket just outside the boundary of the area mapped and inclose a mass of red felsite.

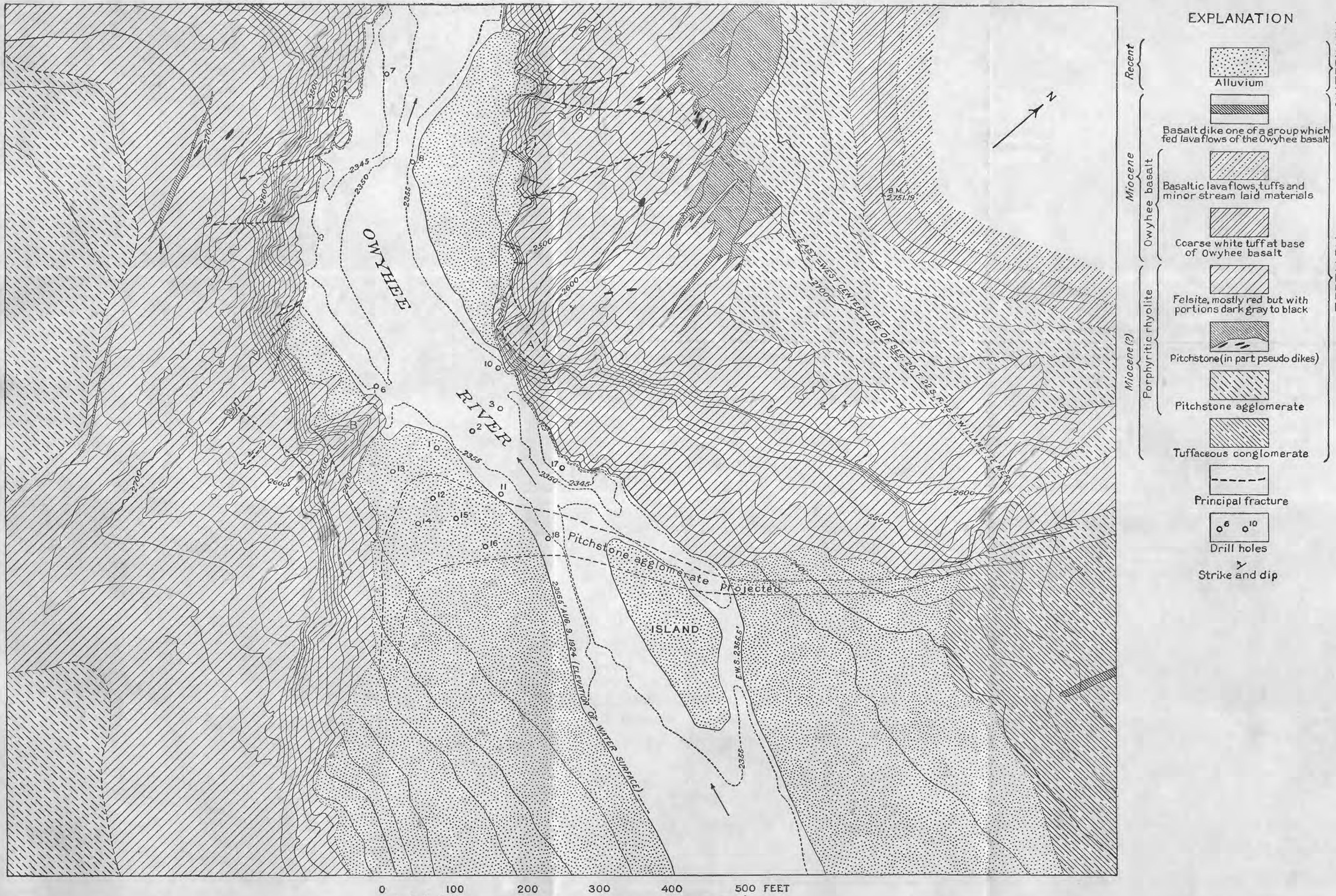
The agglomerate underlies the felsite on the west bank of the river south of The Box, laps around the end of the felsite sheet, and is continuous with the agglomerate at the top previously referred to. At the dam site the existence below the red felsite of this agglomerate was proved in five drill holes, which permit the drawing of tentative boundaries as shown on Plate 4. At the north end of The Box the agglomerate blanket connects with several irregular dikelike masses, which have nearly vertical dips and between which are masses of red felsite. (See pl. 6, *B*.) Although the outcrops are more or less concealed by talus, the presence of these dikelike bodies indicates that the north end of the mass is similar in form to the border on the east side of the river mapped on Plate 4. It may be assumed that here also the red felsite with intervening pitchstone agglomerate rests against the edges of the pre-Owyhee sedimentary rocks.

From the foregoing description it is evident that the pitchstone agglomerate completely incloses the red felsite, conforming to its shape as a glove fits the hand. In places, however, dikelike masses near the more nearly vertical edges of the main mass separate relatively small blocks of the red felsite from the main mass.

The contact between the red felsite and the agglomerate is sharp and distinct, yet in detail transitional. Boundaries can be drawn within 2 or 3 feet of accuracy. The red felsite with its vertical flow lines and its minute jointing extends up to the contact, which is in places minutely irregular, having sharp crenulations of a magnitude of 2 to 3 feet as well as broader irregularities, which are brought out on Plate 4. From an examination in more minute detail along this contact, it is seen that the felsite loses its lithoidal character, pumaceous bands appear, and wedges of the matrix of the agglomerate grade into these bands. In other words, there is no real distinction between the two rocks; there is a rapid but complete transition.

In addition to the pitchstone blocks in the agglomerate there are bodies of pitchstone within the red felsite. These bodies are generally long and narrow and have nearly vertical contacts, so that they appear to be dikes. In general, they lie parallel to and between the plates of the flow structure of the red felsite. They were mapped in detail over the area shown on Plate 4. Many are isolated pseudodikes, but near the north end of the area they unite in a considerable mass, in which smaller bodies of red felsite are completely inclosed.

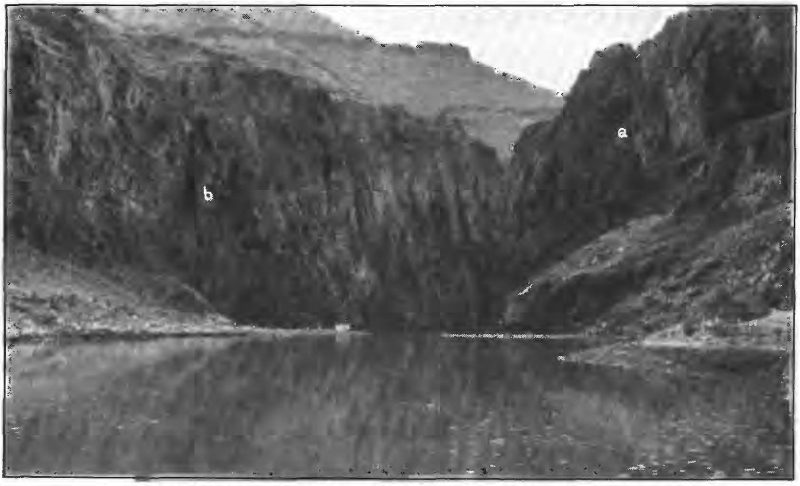
In general, flow structure is not apparent in these pseudodikes. They are massive and do not have the minute jointing of the felsite. Thus they appear to consist of a very different rock, especially as in a few places the pitchstone cuts across the felsite with its well-



MAP SHOWING GEOLOGY OF THE OWYHEE DAM SITE, OWYHEE IRRIGATION PROJECT, OREGON

A. VIEW UPSTREAM, SHOWING THE UPPER END OF THE BOX AND PROBABLE POSITION OF THE DAM

Cliffs in foreground are red felsite; shelf above them pitchstone agglomerate; benched cliffs in background Owyhee basalt



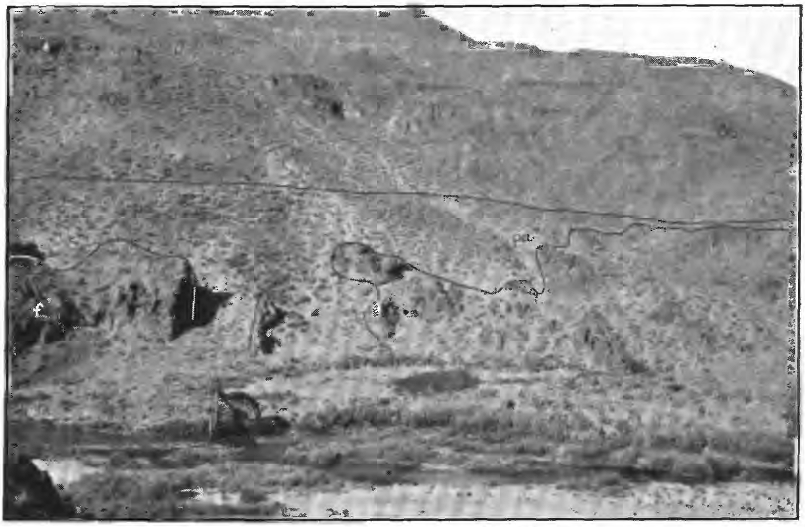
B. VIEW DOWNSTREAM TOWARD ENTRANCE OF THE BOX

Drilling rig on proposed line of dam. Note prominent vertical fracture on the narrow ridges. Points a and b marked A and B on Plate 4

OWYHEE DAM SITE, OWYHEE IRRIGATION PROJECT, OREGON

A. CENTRAL PORTION OF THE BOX

Showing the precipitous walls of felsite and the characteristic joints and fissures



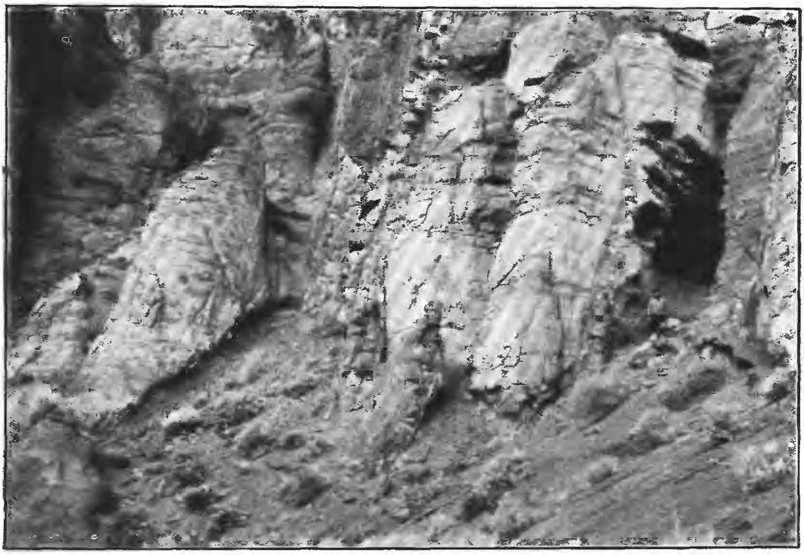
B. LOWER END OF THE BOX

Shows vertical masses of pitchstone agglomerate (pa) in the felsite (f) and the overlying Owyhee basalt (Ob). Water wheel raises water for irrigation of small field downstream

VIEWS OF THE BOX, OWYHEE RIVER, OREGON

A. VIEW UPSTREAM FROM DAM SITE, SHOWING OPEN GORGE

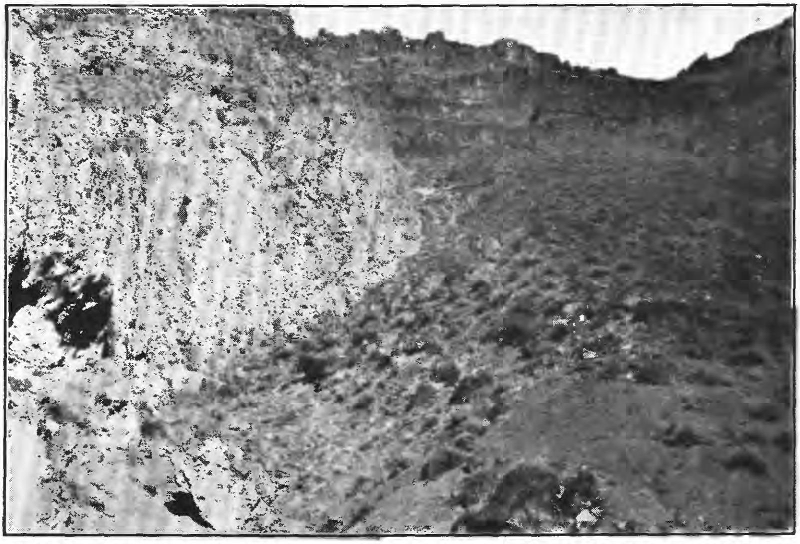
Benched cliffs are flows and tuffs of Owyhee basalt; the slopes largely covered with talus are underlain by tuffaceous conglomerate; that in the middle ground is cut by a network of basalt dikes



B. BASALT DIKES INTRUDED IN TUFFACEOUS CONGLOMERATE

Detail of network of dikes shown in *A*

HOLE IN THE GROUND, OWYHEE RIVER, OREGON



A VERTICAL MASS OF PITCHSTONE AGGLOMERATE THAT FORMS CONTACT ZONE OF PORPHYRITIC RHYOLITE ON EAST SIDE OF RIVER ABOVE THE BOX

Covered slope is occupied by tuffaceous conglomerate overlain by the Owyhee basalt, which forms the benched cliffs in the background

B. PITCHSTONE PSEUDODIKE IN RED FELSITE ON RIGHT ABUTMENT

VIEWS NEAR OWYHEE DAM SITE, OWYHEE IRRIGATION PROJECT, OREGON defined structure. (See pl. 8, *B*.) In these places the pitchstone is evidently younger than the felsite, because it visibly intrudes the felsite and breaks across the preexisting flow structure, but the general parallelism to the plates of the flow structure and the contacts, which are transitional in detail, constitute evidence that the felsite was still warm when the pitchstone dikes came into place.

The pitchstone does not crop out near river level but is confined to the top of the mass. None of the pseudodikes can be traced downward in the cliffs of The Box. These pseudodikes, therefore, were produced by a process that operated only at the top of the rhyolite mass.

South of The Box the felsite breccia crops out at the base of the mass between the pitchstone agglomerate and the red felsite. It ranges in thickness from 10 to 50 feet and grades upward into the massive and unbroken felsite and downward into the pitchstone agglomerate. In a few places the pitchstone agglomerate extends into the breccia in rounded tongues. In other places pieces of red felsite are so common in the agglomerate that there is little distinction between it and the breccia.

INTERPRETATION OF THE KNOWN FACTS

The tongue of rhyolite extending south from The Box is obviously a lava flow; the broad outcrop in which The Box is cut is of less certain origin but is either the upper part of a volcanic neck from which the flow originated or part of a flow. The interpretation to be accepted depends largely on an analysis of the conditions prevailing at the time of eruption, based on the details previously given.

As shown by the microscopic work and by the transitions at contacts, the rocks of all types form parts of a single mass. The red felsite with its oxidized iron and its lithoidal nature acquired these characters and developed its flow structure before it came to place. The generally vertical position of the flow lines, their divergences in strike and dip, and their characteristic sweeping curves indicate that the mass was stiff and almost consolidated when it came to rest. The existence of the felsite breccia at the base of the mass extending from the upper end of The Box southward is confirmatory evidence that the felsite flowed in a nearly consolidated state, for the breccia is made of fragments such as would originate from forward movement of the hardened mass by a push from the point of origin. Similarly, the fracture planes indicate that the mass was so stiff that it was ruptured by movement. The fact that these fractures can not be traced any great distance qualifies the evidence of stiffness and indicates that the rock was viscous in places, and here ruptures either did not form or else were healed as fast as they opened.

The mantle of pitchstone agglomerate that incloses the felsite is a comminuted and more glassy phase, which doubtless was formed by the more rapid cooling of the outside of the mass. The pitchstone fragments are little different from the red felsite except that they do not contain sufficient ferric oxide to make the rock red, and jointing is absent. These fragments have doubtless never been involved in the almost solid flow that is characteristic of the felsite. They are parts of a glassy crust that consolidated sooner than contiguous parts of the felsite. The comminuted glass or tuff of the agglomerate presents a problem, as it does not appear to have been formed wholly by attrition like the felsite breccia. Perhaps there was an explosion of the surface crust of the nearly viscous flow, and almost immediately thereafter the exploded material was dragged along on the top and at the bottom of the almost solid but moving mass. The cause of the explosion may have been confined steam generated by the extrusion of the rhyolite in water, but it seems equally sound to believe that explosions of the crust in the air could produce the phenomena observed.

The pitchstone stringers or pseudodikes are in part at least of later origin than the red felsite, as they are generally parallel to and in places cut the plates of the flow structure. They seem, therefore, to have been the last liquid material in the mass, and they were doubtless squeezed from the almost solid interior through ruptures generally parallel to the flow structure. However, these pseudodikes do not extend into the agglomerate but are cut off almost at right angles by it. There is, perhaps, one exception to this statement, for near the south end of the flow, about a mile from the dam site, two stringers of pitchstone, each about 1 foot thick and 4 feet long, are wholly inclosed within the agglomerate beneath the felsite breccia and red felsite and appear to be intrusive. The presence of the blanket of agglomerate almost at right angles to the pseudodikes of pitchstone implies that locally the agglomerate was formed later than the dikes, else apophyses of pitchstone would extend into the agglomerate. Doubtless as the pitchstone was squeezed out of the interior of the flow it sent out such apophyses, but there was differential movement between the main flow and the agglomerate, which was being dragged on the top as a load. The apophyses were thus broken off in the loose agglomerate and now form an indistinguishable part of it at some distance from their point of origin.

The details of structure can thus be accounted for as sequences of the extrusion of a highly viscous, almost solid flow of rhyolite. It remains to consider whether the broad outcrop of The Box is or is not the upper part of the conduit from which this rhyolite was extruded.

On the east bank of the river the agglomerate abuts against the cut edges of the sedimentary tuffaceous conglomerate. The actual contact can be seen at only one point, and here the laminae of the sedimentary rock are bent down toward the rhyolite mass. The agglomerate and the sedimentary rock adhere, and chunks can be broken out that include the contact, but there is no evidence of change in the sedimentary rock by reason of heat emanating from the rhyolite. If this is an intrusive contact the rhyolite mass must have been almost cold, and what heat it contained must have been dissipated upward through the agglomerate on its border. This postulate is not incompatible with the characteristics of the rhyolite mass as already set forth.

As an alternative it is suggested that the rhyolite flowed into a valley that once existed in the area of The Box and that the former existence of the valley explains the thickening of the mass at this place. If this postulate is true, then the valley wall must have had a slope of 75°, for the present regional dip to the west and north must be subtracted from the 85° slope of the contact, and it is questionable whether the relatively unconsolidated sediments would stand on such a slope 350 feet high. Vertical and nearly vertical cliffs 50 to 75 feet high are common, but the normal erosional slope in the Hole in the Ground is less than 45°. Also, if the peculiar pitchstone agglomerate that forms a sheath over the rhyolite is due to extrusion in water, then the supposed valley, at least 350 feet deep, and the adjacent upland must both have been under water, which seems to be an unlikely hypothesis.

Although the contact of the rhyolite body and the tuffaceous conglomerate seems unusual for an intrusive body, both in form and in the lack of local heat effects, yet the behavior of intrusive bodies at the point where they pass into extrusive bodies is not too well known. Certainly the details of the rhyolite adjacent to this vertical contact indicate stiff flow and moderate temperature similar in all respects to the conditions attending the southern extension of the same mass, whose character as a flow is unquestionable. It also seems reasonable that almost similar conditions should extend for 350 to 400 feet below the throat of a conduit from which such lava might rise.

SIMILAR ROCK BODIES

At the south end of Hole in the Ground, as shown on Plate 3, there are outcrops of similar rock. A thick flow that lies in the same stratigraphic position as the one already described forms a great cliff on the west side of Owyhee River. A part of the same flow forms a similar cliff on the east side and stands at higher altitudes because of the local dip of the rocks to the west. These two bodies have many of the features of the main rhyolite mass but are composed generally of black rather than red felsite.

Below the great flow on the east side of the river is a small mass of black felsite with obscure contacts, which may be a sill. Out on the plain to the north is a small dike of black and vitreous felsite that forms a steep though small hill. This body has nearly vertical contacts with the adjacent flat-lying tuffaceous conglomerate. It is elongated in a northwesterly direction and has a bulbous northwest end. There is an obscure columnar jointing on horizontal planes nearly at right angles to the contacts with the adjacent conglomerate. The body has therefore all the characteristics of a dike or plug that acted as a feeder to sheets of lava now eroded. The tuffaceous conglomerate at the contact is, however, little altered, although there are some bodies of platy vein material, which indicate that hydrothermal waters may have moved along the contact. The petrologic character of this intrusion is obscure and indicates that it may be a more calcic body than the rhyolite. Whether this plug fed the lava sheet a part of which crops out on the south is a question that can not be determined, but the similarity of this rock in gross habit and general appearance to the other bodies of porphyritic felsite leads to the assumption that it belongs to the same group of eruptions.

OWYHEE BASALT

Resting on the tuffaceous conglomerate in the areas where the later rock is exposed lies a great series of lava flows of prevailing basaltic type, reaching a thickness of 1,200 to 1,500 feet, to which the name Owyhee basalt is applied, from their exposures in the Owyhee River gorge. On weathered surfaces these rocks range in color from dark brown and green to red, purple, and yellow; the more brilliant colors are due to beds of cinders and included tuff. As this basalt underlies the Payette formation and is comparatively thick, it is thought to be the approximate equivalent of the Yakima basalt[1] and of similar flows of Miocene age, which underlie the Columbia Plateau of Washington and Oregon. The Yakima and other basalts have generally a somber aspect, as the successive sheets of basalt and rare beds of cinders weather to shades of brown and black. The more brilliant hues of the Owyhee basalt are thus in marked contrast to them, but these colors are best displayed in the Owyhee gorge, and elsewhere the rocks have an aspect more nearly like that of the Yakima.

The major portion of the Owyhee basalt of this area consists of scoriaceous lava and cinders, but the formation includes also massive

[1] Smith, G. O., U. S. Geol. Survey Geol. Atlas, Ellensburg folio (No. 86), 1903.

flows, thin flows, tuff beds, dikes, and sills. Most of the basalt flows are less than 40 feet thick, and nearly all are scoriaceous at the top and bottom. In general the basalt is fine grained and gray on fresh fracture. On microscopic examination it proves to be normal non-olivine-bearing basalt. In part of the area there is, at the top of the formation, a series of flows almost without cinders and 200 feet thick.

The cinder beds consist of the rubbly débris of basaltic eruptions and of flows of the variety called aa. Individual beds are continuous for only short distances, and changes in color are many and capricious. Some beds are markedly lenticular and are evidently buried cinder cones. The cinders consist of rock glass molded around bubbles and may best be likened to a rock froth. In general, the cinder beds are sufficiently consolidated to stand as cliffs, but they weather easily and are covered in many places by a talus of basalt blocks.

The tuff beds are numerous, but not many are continuous. They make only a small part of the whole formation, although they are conspicuous on account of their color. Some are consolidated ash showers, and others are the débris of such showers reworked in streams and ponds. At the base of the Owyhee basalt throughout the area there is a gray-white laminated tuff with grains that reach the size of a pea.

Basalt dikes from 3 to 10 feet wide, many of which pass upward into the Owyhee basalt, occur in the Hole in the Ground, and others were found at various places within the area. (See pl. 7.) All these dikes consist of basalt similar to that of the overlying flows. A few were traced upward and were observed to spread out into sills and flows. Obviously the dikes represent the vents from which the basalt was extruded and demonstrate that this formation was here built up largely by fissure eruptions.

One section of this formation was measured by Mr. Renick, but the lateral variation is so great that the beds can be traced only a small distance, and the section gives only a general idea of the character of the formation. As a summary it may be said that about two-thirds of the whole formation consists of dense or vesicular basalt in the form of flows, sills, and dikes, and about one-third consists of cinders and highly scoriaceous flows, and this part includes the almost negligible tuff beds.

PAYETTE FORMATION

Overlying the Owyhee basalt in the general area there is a deposit consisting largely of fine-grained white sands and shales known as the Payette formation. These sedimentary rocks are interbedded with lava flows, to the older of which the name Blackjack basalt is applied and to the younger the name Grassy Mountain basalt. On the basis of fossil plants collected not many miles from the area here considered, the age of the Payette formation has been determined as Miocene.[2] Above the Payette in this general region are similar beds, known as the Idaho formation, which, on the basis of collections of fossil bones and fresh-water shells, are thought to be of Pliocene or Pleistocene age. It is difficult to distinguish between these formations, and the deposits mapped and described in this report as Payette formation may in places include beds belonging to the Idaho formation.

The two sets of lava flows that in this area are interbedded with the white sands and clays of the Payette formation have large importance in relation to driving tunnels.

The beds of the Payette formation are largely white or light gray and generally fine grained, but pebble beds and conglomerate also occur. The white sands and shales appear to be largely the deposits of river flood plains or of the shallow lakes characteristic of alluvial plains. A few beds are partly consolidated ash of volcanic showers that buried the country and were little worked by streams.

In general the beds are soft, easily eroded, and only sufficiently consolidated to stand as cliffs 30 to 50 feet high. However, the conglomerate and pebble beds are hard and massive and where they occur form conspicuous cliffs and buttes, as in Deer Butte and Mitchell Butte.

The thickness of the Payette beds is not uniform in the area, and the formation thins on approach to the canyon of Owyhee River. Apparently, before or perhaps during the deposition of the Payette, the region was deformed and a ridge was produced in about the position of the present course of Owyhee River. On the west side of the river a section measured by Mr. Renick on the east flank of Grassy Mountain showed 806 feet of sand, sandstone, shale, and tuff to the base of the lava flows that cap the mountain. On the east side of the river the corresponding interval is about 400 feet. Similarly, on the rim of the canyon above Hole in the Ground the westward extensions of the lavas that cap Blackjack Butte rest on the Owyhee basalt with less than 50 feet of shale and sand intervening, and at one point no shale could be found. Four miles to the east, at Blackjack Butte, this interval is about 300 feet. As no lavas of the Blackjack type have been found west of the canyon, the ridge appears to have been an effective barrier to the westward spread of these flows.

[2] Knowlton, F. H., Flora of the Latah formation at Spokane, Wash., and Coeur d'Alene, Idaho: U. S. Geol. Survey Prof. Paper 140, pp. 17–81, 1925.

In the single locality where lava flows from Grassy Mountain have crossed the river nearly 300 feet of sand, shale, and tuff intervene between the base of the Grassy Mountain basalt and the top of the Blackjack basalt.

BLACKJACK BASALT

Blackjack Butte is capped by flows of basalt, named Blackjack basalt, which have a thickness of 350 to 450 feet. These flows decrease in thickness westward and finally are represented on the rim of the canyon of Owyhee River only by a single flow about 50 feet thick. This basalt is interbedded in the middle part of the Payette formation.

The Blackjack basalt is black, brown, and red in the outcrop and generally dark gray on fresh fracture. The rock usually has a banded texture in both vesicular and nonvesicular types. The bands, which are rudely parallel with the top of each flow, are marked by lines of flattened vesicles or narrow wavy openings along which doubtless the volcanic gases were accumulated and expelled. Most of the vesicles are empty, but some are lined with a thin deposit of white amorphous carbonate or a green mineral (chlorite?). In places the sheets of lava are mostly a rubble of vesicular fragments, and here and there the flows are red. Two small cinder cones are attributed to these flows, but most of their material is thought to have risen through fissures. On microscopic examination the Blackjack basalt proved to be very similar to the basalt of the Owyhee flows and without notable peculiarities.

GRASSY MOUNTAIN BASALT

The lava flows of Grassy Mountain, named Grassy Mountain basalt, have a thickness of at least 200 feet. In the base of Deer Butte the total thickness is 172 feet, in three separate flows, and in the only outcrop east of the river the thickness is about 50 feet.

This lava is generally black to greenish black on outcrop, although there are large areas where it is red or purplish. The vesicles are generally filled with white carbonate, but in one outcrop the filling is green. The rock is notable in this area in that it contains olivine phenocrysts and can be distinguished easily from other flows in hand specimens. The Grassy Mountain basalt in part overlies the Payette formation and is in part interbedded in the upper part of the Payette.

IDAHO FORMATION

The Idaho formation, which on the basis of collections of fossil bones and fresh-water shells is thought to be of Pliocene or Pleistocene age, is usually difficult to separate from the underlying Payette formation, of Miocene age, the two formations consisting of similar materials. Some indistinct shells collected by Mr. Renick at Deer Butte give evidence that the Idaho formation is probably present, and the area supposed to be underlain by it has been differentiated on Plate 3. It is possible that the formation is present at other places within the area and that it has been included in the deposits here mapped and described as Payette formation.

QUATERNARY SYSTEM

The alluvium on the banks of Owyhee River and the gravel bars that are found on a few terraces within the canyon are of Quaternary age, but these deposits have not been studied. The larger areas are grouped together on the geologic map.

GEOLOGIC STRUCTURE

The Owyhee basalt and the sedimentary rocks that underlie this great series of flows were once nearly horizontal. The first earth movement recorded in this area is the slight deformation that arched a ridge prior to the deposition of the Payette and Idaho formations. It seems likely that the production of this ridge was only a minor feature of a much larger disturbance by which the Snake River region on the north was carried below the volcanic plateaus on the south. Certainly at Ontario, 30 miles north of this area, the thickness of the Payette and Idaho formations is more than 4,000 feet, as shown by the log of a deep well,[3] and only 8 miles north a well 1,140 feet deep has been drilled without striking the basalt. In the region here considered the deformation was moderate, permitting the accumulation of only some hundreds of feet of sand, conglomerate, clay, and volcanic ash, together with the interbedded lava sheets of the Blackjack and Grassy Mountain flows.

A period of intense dislocation followed, during which the area was broken by faults. These breaks are many and complicated. The principal fault zone trends north and lies just east of the Owyhee gorge. The total displacement is about 1,500 feet, and all the formations west of this fault are tilted to the west. The summation of displacement on faults of smaller throw, both east and west of this main fracture, is such that the higher rocks are carried to lower altitudes both east and west. Thus in approximately the position of the original ridge has been developed a pseudoanticline in which the older rocks are brought near the surface and bordered on each side by younger rocks. This structure also is only one of the minor re-

[3] Washburne, C. W., Gas and oil prospects near Vale, Oreg., and Payette, Idaho: U. S. Geol. Survey Bull. 431, pp. 41–42, 1911.

sults of the greater movement by which the Snake River Basin was carried below the plateaus of southeastern Oregon and southern Idaho.

THE RESERVOIR

The reservoir created by the building of the dam at Hole in the Ground will extend up the canyon about 40 miles, to the vicinity of Watson post office. This long, narrow body of water will have its greatest width in those parts of the canyon where the rocks are soft and the slopes gentle. The only large extension will be in the valley of Dry Creek, which enters Owyhee River some 10 miles above the dam site.

In a hurried reconnaissance made through this reservoir site in 1923 the rock formations were examined with regard to leakage. In the Hole in the Ground the reservoir water will rest wholly against the tuffaceous conglomerate of pre-Owyhee age. The conglomerate is relatively open and porous, though it is so much weathered that on being wet the clayey minerals should expand and close many pore spaces. The beds are cut by many nearly vertical basalt dikes. Although a continuous dike or chain of dikes does not exist, it may be safely assumed that these dikes will force the water to take very intricate courses in moving through the formation. These intricate courses and the frictional resistance to flow through the pores of the rocks will, irrespective of other rocks that may also resist water movement, effectively prevent percolation between the reservoir and Snake River Valley, which lies 7 to 12 miles to the east. At the south end of the Hole in the Ground the water will rest against bodies of rhyolite. This rock is tight in itself and, as previously pointed out, rests on the tuffaceous conglomerate, which will obstruct any leakage that might pass the rhyolite.

Owing to the complicated faulting of the region, the Owyhee basalt forms the floor of the reservoir for 2 miles and the eastern wall for 4 or 5 miles farther south. This formation consists largely of lava flow and is undoubtedly extremely pervious to water. Throughout this area it dips 5°–10° W. As the tuffaceous conglomerate underlies the basalt, this formation must be present to the east, and will here, as farther north, form an effective barrier to movement of water from the reservoir eastward.

Upstream from the last outcrop of the Owyhee basalt, clay, shale, and tuff, with here and there rhyolite dikes and flows, form both sides of the reservoir for a distance of 25 miles. Some of these beds may belong to the Payette formation, but most of them appear to resemble the Mascall, John Day, and Clarno formations of other parts of Oregon. In general, the beds are horizontal or have only low dips. Most of the beds are fine grained and will transmit water only slowly, and the presence of the rhyolite dikes will also interfere with the movement of water. It should be noted also that tributary streams in this part of the Owyhee Canyon have small flows in the dry seasons. These flows are doubtless fed by ground water and indicate that the slope of the water table is toward Owyhee River from both sides. A reservoir built in such a depression of the water table can not leak, for movement out of the reservoir is resisted by the inflow of ground water toward the reservoir.

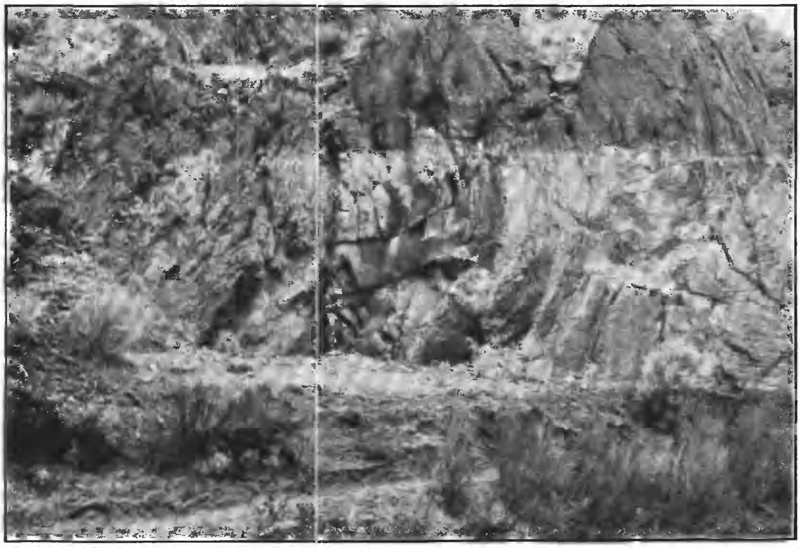
THE DAM SITE

The proposed dam is to be built where the main body of the porphyritic felsite crosses Owyhee River at The Box, the narrow gorge that lies at the north end of the Hole in the Ground. As this dam is to be very high, much consideration must be given to all the facts that relate to its foundation.

The red felsite of The Box has a relatively high crushing strength and is free from pores or large cavities except near its borders or along the fracture system. It is therefore a suitable rock for the foundation of a high masonry dam of either the gravity or the arch type. Its principal disadvantages arise from the fractures and from the peculiar shape of the rock mass with respect to the topography of the gorge.

The fractures are of two types—the minute horizontal sheeting and the nearly vertical fracture system. The horizontal fractures are intensified by weathering, and on exposed surfaces the rock is divided into wavy plates from half an inch to 2 inches thick, as is well shown in Plate 9, *B*, in the lower left corner. These fractures do not appear in the drill cores of test holes and are not open in depth, though they doubtless exist in an incipient form. Although they doubtless slightly lower the strength of the rock, they can have little effect on the proposed structure.

The vertical fracture system consists of fractures that follow nearly vertical planes having several trends. The most extensive of these fractures in the upper part of The Box are shown on Plate 4. The fractures have clean, continuous walls, which in many places are slickensided. Where the walls are separated there are in places open cavities, but in general the space between them, which may be from 2 inches to 10 feet wide, is filled with fragments of rock. In most places the fragments are more or less cemented and form a breccia, but this breccia is obviously inferior to the original rock in strength and resistance to weathering. The breccia also forms channels for the movement of water through the abutments of the dam. The nature of the fractures and the breccia is shown in Plate 9, *B*. In Plate 9, *A*, the dark vertical band is one of these fractures that cuts across the flow structure.

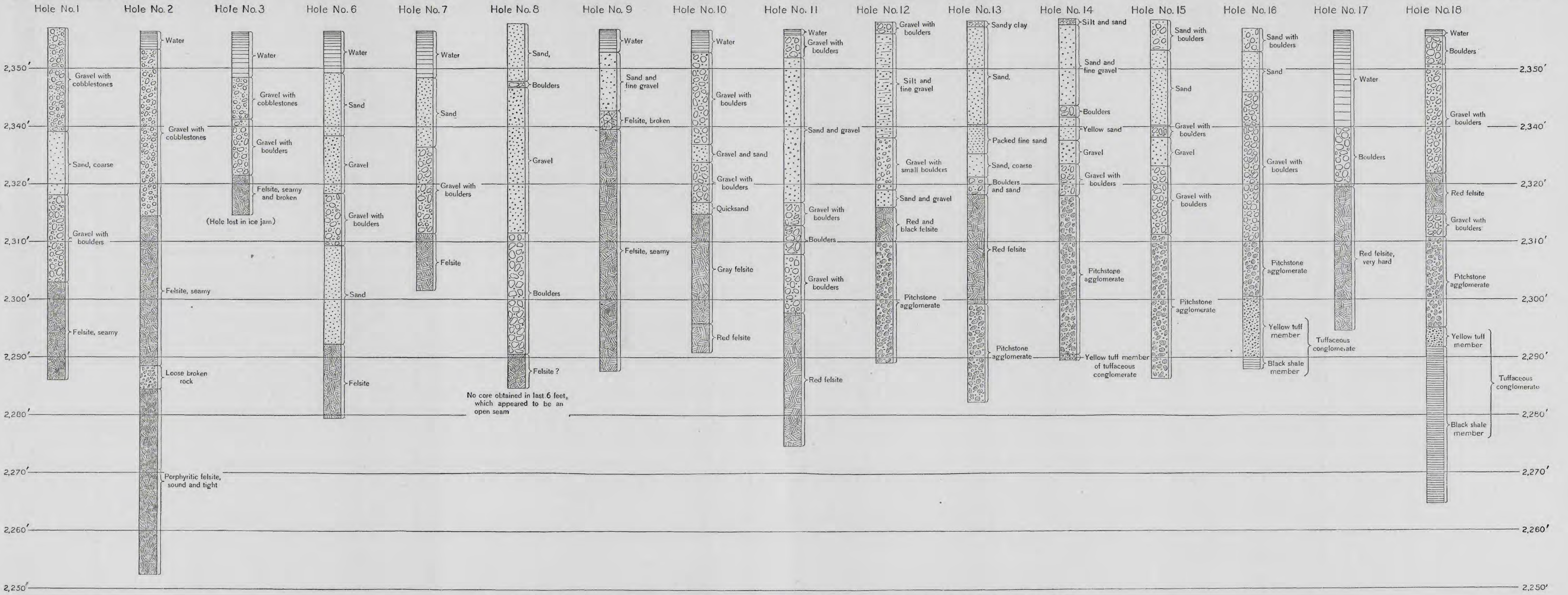


A. CURVED AND NEARLY VERTICAL FLOW STRUCTURE IN RED FELSITE

Note numerous closely spaced horizontal joints, also vertical fracture, which shows as a narrow dark band. The horizontal line at the top of the light-colored zone is a high-water mark

B. VERTICAL FRACTURES IN RED FELSITE

Some are clean breaks; others have a mass of comminuted rock fragments between the walls. Closely spaced horizontal fractures show at the left



MATERIALS ENCOUNTERED IN TEST DRILL HOLES AT OWYHEE DAM SITE, OWYHEE IRRIGATION PROJECT, OREGON

These fractures exist only in the lower parts of the canyon wall and can not be traced through to the top. Therefore they do not weaken the abutment as a whole, nor should leakage on a large scale be feared because of their presence. The fractures are of most consequence in the narrow prongs of rock marked "A" and "B" on Plate 4, where weathering has opened them. (See also pl. 5, *B*.) It seems likely that if the dam is so located that either of these prongs or points serves as a part of the abutment large quantities of rock must be removed in order to clean out these fractures completely and fill them with concrete. It is likely also that pressure grouting should be used in order to seal cracks not readily visible.

The southern boundary of the red felsite mass has a complicated form which has a direct bearing on the details of location of the dam. On the right (east) side of the river the boundary is nearly vertical, on the left (west) side it dips 10°–20° SW., and in the bed of the river the boundary is a warped surface of adjustment between these two divergent planes. The characteristics of this bounding surface where it is concealed by the alluvium of the river were brought out by the test drilling of 1923. The logs of the holes within the area of Plate 4 are shown graphically in Plate 10. Test holes 12, 13, and 15 passed through the red felsite into the pitchstone agglomerate and holes 16 and 18 were continued through the agglomerate and thence into the tuffaceous conglomerate. By the use of this information the trace of the pitchstone agglomerate has been represented on Plate 4 with fair accuracy.

The strength of the pitchstone agglomerate and of the tuffaceous conglomerate is moderate, and these rocks can not be deemed strong enough to support a high masonry dam. The dam should therefore be located far enough within the throat of the gorge to rest wholly on the red felsite, or else additional concrete should be provided so as to lessen the load to the square foot in the part of the base where these soft rocks occur.

As the red felsite tapers toward the south to a feather edge, a decision must be reached as to the thickness necessary to afford adequate support for the dam. The record of drilling shows that the red felsite is not uniform in strength and in places is seamed and fissured. These fissured portions can be much strengthened by pressure grouting, and if thorough grouting is done over the whole base of the dam, a less thickness of felsite can be tolerated than if this device is not used. As the fractures of the felsite are clean-walled breaks, conditions for effective grouting are excellent. An arbitrary decision must be made as to the thickness of felsite that will be tolerated, and I suggest that a thickness of 20 feet thoroughly grouted could be considered equivalent to a thickness of 50 feet ungrouted.

100370°—29——5

If a location well within the throat of the gorge is chosen, there will be ample thickness of felsite, as shown by drill hole No. 2, and these considerations are of no importance.

POSSIBLE LEAKAGE THROUGH ABUTMENTS

In so far as the red felsite forms the abutments no serious leakage need be feared, for the cracks of the rock can transmit only small quantities of water, and as the rock is not soluble this leakage will not increase. As the cracks are clean and free from clay or other disintegration products, they may, if necessary, be readily sealed by pressure grouting.

The left (west) abutment consists wholly of this rock, but in the right (east) abutment the felsite is bounded by a nearly vertical surface against pitchstone agglomerate. The agglomerate, which is in places 50 feet wide, is a porous rock and might transmit water. However, the only place where this water might emerge is at the north end of The Box, about half a mile distant. What path it would travel is problematic, but probably the path would be complicated and indirect. Even if the path were direct, the loss of water through the agglomerate with a hydraulic head of 500 feet to the mile would be moderate, for the material is fine grained. It is so tightly cemented and so compact also that the formation of channels is not to be feared. Similarly, water might travel through the tuffaceous conglomerate and thence into the Owyhee basalt. However, the tuffaceous conglomerate is locally very compact and is cut by a basalt dike very close to its contact with the pitchstone agglomerate. (See pl. 4.) This dike will form an effective barrier to the leakage of water through the conglomerate.

SPILLWAY

If a spillway is planned across one of the abutments, as on the right (east) of the dam site, where, as shown in Plate 4, there is adequate room, then the resistance of the felsite to erosion becomes important. Owing to the intimately jointed and fissured condition of the rock, large quantities of water at high velocity will erode the rock rapidly. This action should be avoided by concreting the spillway or by some other adequate device.

TUNNELS

Under the plans proposed the water is to be distributed by a conduit that will leave the reservoir east of the dam. As the conduit will pass through rough country it will consist in part of tunnels. All these tunnels are shown on Plate 3, except Nos. 6 and 8, which are very short, and No. 14, which is 4,800 feet long and runs west of Mitchell Butte.

The rocks to be encountered have been grouped under four classes, as follows:

1. Tuffaceous conglomerate—a series of stream deposits of greenish-yellow rock traversed by basalt dikes. The formation is compact but not hard and will be easy to drill but will require a slow-acting powder. It will stand well without timber. It is cheap rock to tunnel except for the dikes, which will form obstructions to rapid progress.

2. Owyhee basalt—a series of lava flows with intercalated tuff and stream deposits and about 1,500 feet thick. Some flows are dense, hard rock; others are porous, partly cemented rubble. In general this formation will stand well in tunnels and will require timbering only in weak places; however, the porous layers will require much powder, and a change in methods will be required as the tunnel passes from one member to the next. It is believed that this rock will generally be more expensive to tunnel where inclined than where horizontal or nearly so.

3. The rocks herein designated the Payette formation, but including the Idaho formation, if that is present, consist of a series of fine-grained sediments containing much volcanic ash. The beds are usually white and range from sand to clay. There are hard conglomerates in the formation, but none occur in the tunnel sites. Tunnels in the Payette will be easily dug and will require timber only near the portals and occasional temporary support unless the ground is wet or the material much weathered. Plans should provide, however, for following quickly with the concrete lining, because at least part of the material will slack and weather rapidly.

4. Blackjack basalt—lava flows, which spread out over the area during the time of the deposition of a part of the Payette sediments. This formation ranges in thickness from 50 to 400 feet and lies from 50 to 350 feet above the base of the Payette. The rock is a hard black vesicular basalt. It will be hard to drill and shoot, but the difficulties of working in it will be no greater than those encountered in tunnels in basalt on the Yakima project.

On the basis of existing knowledge of the geology of the region prediction as to the rocks that may be encountered in tunnels is somewhat precarious. However, it is believed that the predictions given herewith are sufficiently accurate for estimating cost. Further information obtained from drill holes may be necessary for construction.

On the line of conduit first proposed, which is called the G line, there are 14 tunnels, numbered from 1 to 14, beginning at the reservoir. The H line would include three tunnels of the G line and two others.

Rocks in tunnels on the G line

	Miles
Tunnel 1:	
Tuffaceous conglomerate	0.4(?)
Owyhee basalt, nearly horizontal	1.45+
	1.85
Tunnel 2: Owyhee basalt, nearly horizontal	.3
Tunnel 3: Owyhee basalt, nearly horizontal	.55
Tunnel 4: Owyhee basalt, nearly horizontal	.45
Tunnel 5:	
Owyhee basalt, nearly horizontal	.55
inclined	.15
	.70
Tunnel 6:	
Blackjack basalt, consolidated cinders	.075
hard block lava	.075
	.15
Tunnel 7, west line:	
Owyhee basalt, inclined, but mostly consolidated cinders	.4
Payette formation	.2
	.6
Tunnel 7, east line:	
Owyhee basalt, inclined, but mostly consolidated cinders; goes through a fault	.55
Payette formation	.1
	.65
Tunnel 8 (in low pass): Payette formation, probably somewhat weathered and may require timbering throughout	.25
Tunnels 9, 10, 11, 12, and 13: Payette formation.	
Tunnel 14 (Mitchell Butte): Payette formation, doubtless weathered and may require timbering.	

Rocks in tunnels on the H line

	Miles
Tunnel 1:	
Tuffaceous conglomerate	0.43 (?)
Owyhee basalt, horizontal	2.95
inclined	.2
	3.58
Tunnel 2:	
Owyhee basalt, horizontal	2.36
inclined	.79
Payette formation	1.12
Blackjack basalt, inclined	.13
	4.4

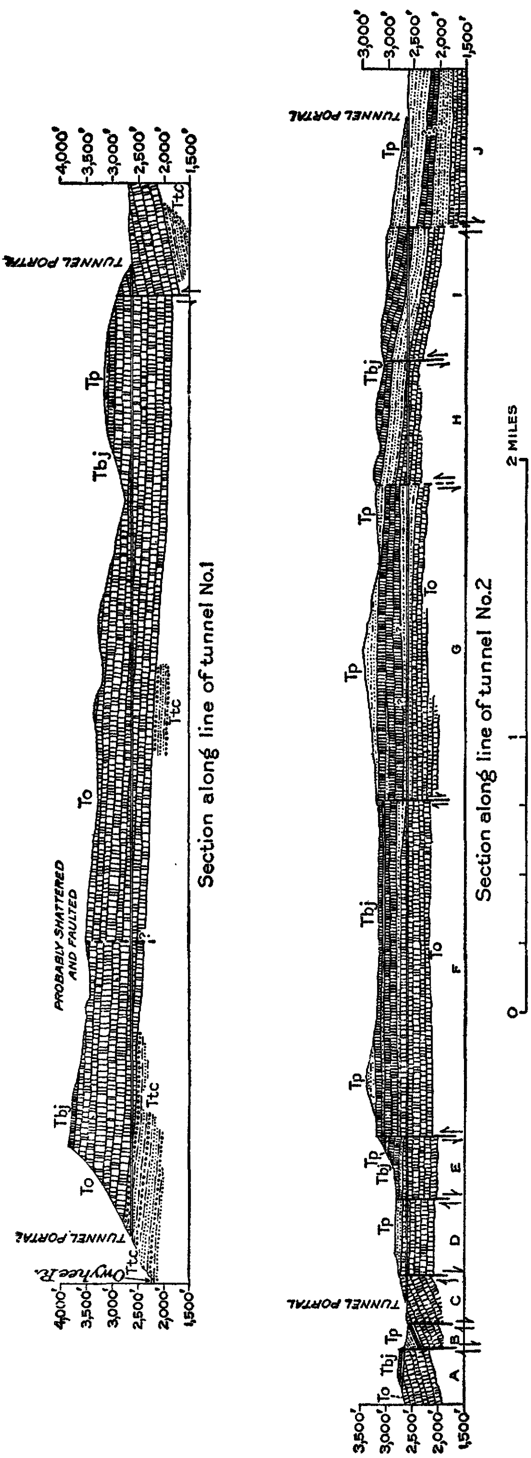


FIGURE 5.—Geologic cross sections on line of tunnels 1 and 2, H line, Owyhee irrigation project, Oregon

Tunnel 2 has the most complicated structure of all listed, and the uncertainties are the greatest. Tunnels 7, 8, and 14 of the G line are used also in this line.

The first ridge penetrated by the first tunnel on both the proposed lines has relatively simple geology, which is shown in the cross section drawn on the line of tunnel 1, H line, given in Figure 5. The gravest uncertainty is the relative amount of tuffaceous conglomerate and of Owyhee basalt that will be encountered. Obviously, if the dip of the rocks is greater than is shown in the section the distance of tuffaceous conglomerate to be traversed is shorter; if the dip is less, conditions are reversed. Although the cost of tunneling in the tuffaceous conglomerate will be less than in the basalt, the cost of drill holes to test the validity of the cross sections as plotted would be so great, on account of the heavy cover, that such tests are doubtless inadvisable.

Tunnel 2 of the H line presents the most complicated geology. The faults are numerous, and the Blackjack basalt increases in thickness from 50 to about 400 feet along the line of the tunnel. The cross section shown in Figure 5 must therefore be considered no more than tentative. The faults are here shown as vertical, but it is certain that most of them are inclined and will be encountered in the tunnel at one side or other of the positions shown. It is impossible, however, without test drilling to improve much on the predictions given in this cross section. As the value of exact knowledge increases with the spread in cost between different classes of material, it becomes an engineering problem to determine whether this tunnel line should be drilled in order to provide more exact data. With such exact data, it might be possible to make part of this tunnel a pressure siphon and hold it for most of its course in the soft Payette formation. Such possibilities present themselves from a consideration of the cross section, but more exact knowledge is necessary before plans can be formulated.

The predictions on the smaller tunnels are considered reasonably accurate, and drilling to verify them is probably not required. Most of these tunnels have a shallow cover, and test holes need not be deep and consequently will not be expensive.

TEMPERATURE IN TUNNELS

The temperature likely to be encountered in a tunnel is always difficult to predict, and no available data are directly applicable to the problem. However, areas that are underlain by volcanic rocks, as this one is, are likely to have high ground temperatures. The presence of hot springs in the area also indicates a high thermal gradient. Data on the known springs are shown below:

Temperature of springs in Owyhee irrigation project, Oregon

Spring		Temperature, °F.	Authority
Name	Location		
Vale Hot Spring	Near Vale	198.5	U. S. Geol. Survey Water-Supply Paper 78.
Vale Natatorium well, 60 feet.	do	199.5	C. E. Van Orstrand.
Vale Sanitarium well, 60 feet.	do	201.6	Do.
Mitchell Butte	Sec. 12, T. 21 S., R. 45 E.	122 to 141	Kirk Bryan.
North Blackwillow	Sec. 26, T. 21 S., R. 45 E.	67	Do.
South Blackwillow	Sec. 35, T. 21 S., R. 45 E.	71	Do.
Hot spring	Sec. 22, T. 21 S., R. 45 E.	Not known; less than 200.	
Do	Sec. 16, T. 23 S., R. 44 E.	do	

All these springs except the Blackwillow Springs are at the bottoms of deep canyons. Apparently, therefore, channels for rising hot water have been established leading to the lowest depressions, and rising hot water is not likely to be encountered in ridges between streams.

In only one deep well in the vicinity have temperature measurements been made. This well was drilled for oil by the Western Pacific Oil Co. Mr. C. E. Van Orstrand, of the United States Geological Survey, made a temperature survey and has furnished the data shown in the following table:

Temperatures in deep well in sec. 19, T. 19 S., R. 44 E., Malheur County, Oreg.

[Western Pacific Oil & Gas Co.'s well No. 1. Measurements by C. E. Van Orstrand]

Depth (feet)	Temperature (°F.)	Depth (feet)	Temperature (°F.)
9	[a] 50	750	96.9
100	61.2	1,000	107.6
250	71.5	1,295	115.4
500	84.6		

[a] Mean annual air temperature at Vale, Oreg.; calculated temperature of ground 59.84°; indicated excess earth temperature of 9.84°.

From these data the temperature gradient is seen to be 1° F. for each 21.9 feet in the relatively flat country southwest of Vale. It seems likely that the ridges on both sides of the Owyhee Canyon, being exposed in the main canyon and its tributaries to loss of temperature, would probably have a smaller gradient for the first 1,500 feet.

However, this high gradient may be assumed as the worst possible condition. The maximum cover on any of the tunnels occurs near the entrance of the first tunnel of the H line leaving Hole in the Ground and amounts to 1,200 feet. On this assumption the maximum earth temperature that may be expected can be calculated from the formula $y=a+bx$, in which x=depth below surface in feet; y=temperature in degrees Fahrenheit at x depth; a=temperature in degrees Fahrenheit at a point just below the surface, as calculated by the method of least squares from the data of the table above; and b=corresponding temperature gradient in degrees per foot. For the well cited $a=59.84$, and $b=0.04575$, as calculated by Mr. Van Orstrand.

The mean air temperature used in the calculations for the well is 50°, as observed at Vale, Oreg., at an altitude of 2,234 feet. The altitude of the high point of tunnel 1 is 3,800 feet, for which the mean annual air temperature may be assumed to be 47°. Therefore, at tunnel 1, $a=56.84$. Then, for point of maximum cover, $x=1{,}200$; $y=56.84+(0.04575\times 1{,}200)=111.7°$ F.

An average temperature gradient in many parts of western United States is about 1° in 50 feet, or $b=0.02$. On the assumption of such a gradient for a minimum, $y=56.84+(0.02\times 1{,}200)=80.8°$ F.

The maximum cover of 1,200 feet exists for only a small part of the tunnel, but long stretches have a cover of 600 feet. For this cover, with the temperature gradient of the well, $y=56.84+(0.04575\times 600)=86.6°$ F.

A review of the foregoing calculations, which unavoidably contain arbitrary assumptions, indicates that the maximum earth temperature to be encountered in tunnel 1 will probably not be less than 81° F. and may be as high as 112° F. for a short distance. Long stretches of this tunnel may have earth temperatures as high as 87°. The shorter tunnels with small depth will obviously not be troubled by high earth temperatures.

The possibility that hot water may be encountered seems slight, because channels of flow have already been established. A consideration of the geologic maps indicates that from each of the bodies of open and porous Owyhee basalt there is generally good opportunity for drainage, and in particular any hot water that may rise into the basalt near tunnel 1 of the H line has good opportunity to escape at elevations lower than the tunnel. In the intimately faulted region south of Blackjack Butte, penetrated by tunnel 2 of the H line, hot water may be entrapped behind blocks of the relatively impervious Payette beds. As drilling in this area is recommended, it is likely that hot water, if any is present, will be discovered in advance of construction.

MATERIALS FOR CONSTRUCTION

The red felsite of The Box can not be quarried as dimension stone but can be obtained in rough blocks. It is hard, impervious, and brittle, will show on test a reasonable crushing strength, and is suitable for rubble masonry or plums. It will crush into angular fragments suitable for concrete.

Any of the basalt ledges above the dam will yield good rock for rubble masonry or for concrete having all the qualities of good trap rock. In selecting a quarry the vesicular and scoriaceous phases of the rock should be avoided.

In The Box and more particularly just above it are bars in the river bed from which gravel can be dredged and used for concrete. The pebbles are formed mostly of volcanic rocks derived from the area upstream, and the largest are 6 inches in diameter. It seems likely, however, that there will be a deficiency in sand in this gravel.

Sand may be obtained by crushing conglomerate and pebbles from beds of the Payette formation. The nearest locality of this rock is at Coyote Butte, and there are large outcrops just south of Deer Butte and at Mitchell Butte. Certain of these gritstones and fine-grained conglomerates could be quarried for use in rough ashlar masonry for the construction of buildings. The rock has a fairly good color and so far as its grain and cement are concerned should be resistant to weather. It will not, however, be easy to work, and its resistance to weather has not been demonstrated by use.

LATER GEOLOGIC WORK

After the submission of the foregoing report, studies of the Owyhee project were continued by the Bureau of Reclamation. In 1927 a large number of test holes were drilled to explore the bedrock within The Box, downstream from the area drilled in 1923 and 1924. Prof. Warren D. Smith was engaged to restudy the geology of the dam and reservoir site, and spent July 26 to August 11 in travel and field work. At the time of his study the dam site at the entrance to The Box had been abandoned, and new locations about 1,000 feet downstream and just outside the area shown on Plate 4 had been adopted.[3a] The principal conclusions and recommendations of his report are as follows:

1. While the geological conditions at this dam site are generally unsatisfactory they are not believed to be irremediable.

2. The chief concern will be in regard to the permeability of the rock formations of this site. As the quantity and duty of the water and the supply in the reservoir are so closely adjusted, large seepage would be fatal to the project.

3. Grouting on an extensive scale will have to be resorted to.

4. No large fault has been definitely located in the immediate vicinity of this site. However, a serious fracture normal to the axis of the proposed dam has been located passing through drill hole A-15.

5. The east abutment of the proposed dam site is much inferior to the western and will call for a great deal of stripping.

[3a] See sketch map in Savage, J. L., Design of the Owyhee irrigation dam: Eng. News-Record, vol. 100, pp. 663-667, 1928.

6. Further drilling along the strike of the main fracture revealed by drill hole A-15 is extremely desirable in order to ascertain its extent and the probability of movement along its plane.

A board of engineers consisting of D. C. Henny, A. J. Wiley, F. A. Banks, and W. H. Walder was convened during the period of Professor Smith's investigation and with his results before it considered the geologic aspects of the problem very fully and recommended that an additional geologic examination be made by Prof. F. L. Ransome. Professor Ransome was accordingly consulted and spent September 14 to 20 in examination of the reservoir and dam site and September 21 and 22 in drawing up a report. As this report recommended additional excavation for obtaining evidence on the existence of the fault mentioned by Professor Smith, he returned in October to inspect these excavations and filed a supplemental report dated October 27, 1927.

In his first report Ransome critically reviewed the previous reports and suggested that the special features of the felsitic rhyolite at The Box and the other rhyolite bodies correlated with it may be accounted for by intrusion of this mass into the tuffaceous conglomerate (tuff of Ransome) before complete cementation of these beds, while they were covered by the water of a shallow lake. "Some of the rhyolite probably broke through the unconsolidated tuff and spread over a part of the lake bottom as a subaqueous lava flow."

Ransome believes that if the tuffaceous beds were wet and unconsolidated and perhaps covered with water it is not difficult to account for the rapid congealing and brecciation of the outer shell of the rhyolite mass. The blunt shouldering aside of some of the tuffs without the injection of tongues or apophyses of rhyolite is also understandable. Ransome believes that deposition of the tuffaceous beds continued after the outbreak of the rhyolite and that fragments of pitchstone were locally mingled with finer material to form the fine white tuff which Bryan considered the base of the Owyhee basalt.

In regard to the more practical aspects of the problem Ransome's statement is appended with slight editorial changes: [4]

Features of the reservoir affecting water retention.—At the lower end of the reservoir, where the water will be deepest, the confining rock will be the prebasaltic tuff. This rock, although soft, is not exceptionally porous, and its porosity is not of a kind to permit any great permanent leakage. Contrary to the impression gained from the reports of my predecessors, the region immediately adjacent to the reservoir is not elaborately faulted, and the faults present are probably advantageous rather than objectionable. The rocks are not composed of soluble material and, being soft, are likely to yield an impervious gouge along any fault fissure. Such gouge would prevent the movement of water along any relatively pervious bed or layer.

[4] Professor Ransome desires it stated that neither of his reports was written with any thought of publication.

The effect of the basaltic dikes in the prebasaltic tuff of the Hole in the Ground section of the reservoir is, I believe, negligible. The dikes are probably no more impervious than the tuff and, even if they were, could not be relied upon as constituting a continuous barrier.

Mr. Bryan raises the question of the permeability of the Columbia River basalt where this formation must be relied upon to retain the water near the mouth of Dry Creek. He disposes effectually of the possibility of leakage to the east and north but leaves unanswered the natural query as to the west and south, where the paths of escape would be down the dip of the flows. It must be admitted that there is a bare possibility of some leakage in these directions, but I can see no probability of serious losses. Examination of the basalt where bare rock is exposed in the bottoms of the ravines showed that the formation is generally hard and fairly tight. There are no visible continuous openings, and any movement of water through the rock would be slow and therefore likely to cease by the clogging of the channels. The distance that the water would have to travel to find an outlet would be many miles, with various possibilities of stoppage on the way. Finally there is a strong suggestion of some rather intricate faulting and tilting, on the lower part of Dry Creek, that would block any water that moved toward an egress in that direction. I do not consider that any considerable or permanent leakage will occur through the Columbia River basalt. Mr. Bryan's characterization of the basalt as "a rock extremely pervious to water" is, in my opinion, too sweepingly condemnatory.

The upper part of the reservoir in the Payette formation can be relied upon as practically tight. Some of the beds are very soft and weather into smooth barren slopes covered with a loose clayey soil that is evidently sticky when wet. It is inconceivable that such beds should permit the escape of any considerable quantity of water.

Although of course absolute certainty is not attainable, I consider that it is reasonably safe to conclude that the proposed reservoir, after the initial absorption, will develop no serious leakage.

Features of the dam site affecting water retention.—The rhyolite against and on which the proposed dam will be constructed is a hard, durable rock, somewhat brittle under blows but by no means fragile. The "pitchstone agglomerate" variety, although much softer as a whole, is, as shown by drill cores and by a cut made at my suggestion, a firmer and much more impervious rock than might be expected from its weathered exposures. As this rock will probably be in contact with the dam only at one end of the structure, near its top, its relative softness is not objectionable. It is not soluble in water and is not likely to develop slipping planes under load when wet.

As exposed in the walls of the gorge at the dam site, the felsitic variety of the rhyolite, as is well brought out in the descriptions and photographs of the earlier geologic reports, is rather conspicuously fissured. A number of structures and processes have contributed to produce this general appearance of fracturing.

The first cause that contributed to the fissuring or jointing of the rhyolite (felsite) was the development of flowage lines or, more accurately, flowage surfaces in a moving viscous mass. Such surfaces give the rock a rough fissility, causing it to split more readily in one direction than in others. The surfaces of flowage run in all directions and in many places are strongly curved. In general, at the dam site the flowage surfaces are more nearly vertical than horizontal and more commonly transverse than parallel to the gorge. As the moving mass passed through increasing degrees of viscosity to the solid state, some of the flowage surfaces probably became actual surfaces of movement between slightly plastic blocks, giving the appearance referred to as slickensides. True slickensiding, however, such as is produced by considerable movement along faults in completely solid rock, appears to be notably absent from the mass. I did not see anywhere any material that could properly be termed "clay gouge," which is a characteristic feature of most large faults.

As the rock cooled it developed internal stresses, which found relief in numerous joints or tight fractures along which there was no appreciable slipping.

The planes of weakness, fractures or joints, developed as here suggested, have been enormously accentuated by weathering, and, although conspicuous in the cliff faces, they become tight and scarcely perceptible fractures when followed for a few feet into the cliff or may even become invisible. Short tunnels run into the cliffs at many places, usually where the rocks looked most fractured at the surface, have invariably entered rock in which the fractures are so minute and the intervening blocks so tightly keyed together as to fulfill all practical requirements as satisfactory abutment or foundation material for a high dam. Such material is generally too impervious to take any grouting.

Cracks of another kind that are conspicuous in parts of the gorge are due to the undercutting of the cliffs by the river, causing slabs or masses of rock to separate from the main mass and tilt or bulge outward toward the river, or to slip downward. The cracks shown on the left in Plate XI of Mr. Bryan's second report [pl. 9, *B*, in this paper] are probably of this character. Such cracks are generally more or less gaping and, if open at the top, may be filled with rubble that has fallen into them, become cemented, and take on something of the appearance of a fault breccia. The filling material, however, shows no trituration due to movement, no crushing or dragging of the fill, and no clay gouge. These features are purely superficial and will disappear when the cliff is cleaned off to provide a proper abutment for the dam.

In a few places fractures were observed of a different character from those heretofore described in this report. The best example of these fissures seen is exposed on the east side of the gorge, practically on the D line of drill holes, where it coincides with a little reentrant in the cliff and with a ravine above. The fissure dips 80°–85° NW. and can be traced in a general N. 35° E. direction up to a point near the 2,625-foot contour, where it appears to end against some transverse flowage structure in the rhyolite. At the river the fissure and its filling are apparently somewhat obscured by cemented débris of superficial character, and, at my suggestion, a short tunnel has been started to provide a more satisfactory exposure. Above the cliff the fissure is readily traceable by its filling of brecciated rhyolite a foot or more wide. At one place there is a zone 7 or 8 feet wide with two or three branches of the breccia-filled fissure. The filling material is shattered and crushed felsite, cemented to a fairly hard and impervious rock. I could recognize no clay gouge and no evidence of recent or extensive movement. The fissure was not recognized on the west side of the river and may end at a feature, presently to be described, which apparently exists in the bottom of the river bed—the so-called "crevice" of the drill records.

The fissure at the D line is probably the result of some settling of the rhyolite mass after its intrusion and solidification, and all movement along it has probably long since ceased. It has no particular significance as regards the proposed construction except that it is probably similar to the "crevice" and may throw some light on the character of that feature.

The records of certain drill holes, particularly A–15, B–1, D–10, and D–11, suggest the presence of a fissure that has been followed by the river in the erosion of that part of its gorge. The testimony supplied by the drilling is somewhat vague, and the cores furnish no satisfactory clue to the nature of the material in the "crevice." The gist of the evidence appears to be that along the line indicated there is comparatively soft, broken rhyolite material that will not core and causes trouble to the drillers.

Examination of the gorge indicated that if there is a fissure coincident with the course of the river at the dam site and if, like most fissures, it has a fairly straight course, it must depart from the gorge in a little ravine on the west side, about 350 feet south of the east end of the Derrick loose-rock dam, or at coordinates S. 12,500 and W. 9,700. The topography suggested that this ravine and the saddle at its head are due to a fissure or fracture zone that is coincident with the course of the gorge above the mouth of the ravine. Examination of the surface at the head of the ravine showed the presence of brecciated material that is probably a fault breccia, and the suggestion is made that a trench be dug across the ravine, approximately on the 2,400-foot contour, with a view to exposing the bedrock and to affording an opportunity of examining the character of the fissure if one is present. Such an examination can be made at relatively slight cost and is likely to yield valuable information that could not otherwise be obtained without sinking a shaft below the river bed and drifting across the "crevice" at the dam site. Presumably the character of the fissure and its filling material, if exposed at the site of the suggested trenching, will not be greatly different from that under the dam site.

No evidence of extensive faulting could be found in the tuffs and lavas south or north of the gorge, such as would indicate the existence of a large or active fault through the gorge, and it is probable that the "crevice," like the northeast fissure at the D line, is a local zone of fracturing due to settling of the rhyolite and has long ceased to be active.

In conclusion, my opinion is that the mass of rhyolite in The Box is of such size and shape, is so situated with relation to surrounding rocks, and has such contact with them as to make any considerable or permanent leakage around, under, or through it extremely improbable. The rhyolite itself is amply strong enough to resist any stresses due to the weight or thrust of a dam of the height proposed, if the dam is properly designed and properly keyed into the rhyolite. The stripping and excavation necessary to fulfill the last requirement is not excessive. Some local grouting may be advisable, but I do not consider that grouting on an extensive or unusual scale will be necessary.

After the exploration of the "crevice" in the gully Ransome made his second visit and in a supplemental report reached the following conclusions:

1. The fault zone uncovered in the trench is the northward continuation of the "crevice" that was encountered in drill holes A–15, B–1, D–10, and D–11 and can be considered as representative of the "crevice" material under the river.

2. The character of the striae and of the wavy grooves along the gouge seams indicates that the displacement along the fault has been of the nature of a nearly horizontal shove of one part of the rhyolite past the other part. This movement, consequently, is not due to a simple settling of the rhyolite on a yielding foundation and may have taken place at a different time from other fissures in the rhyolite.

3. The thinness of the gouge seams and the fact that the solid rhyolite of the walls has not been smoothed and striated indicate that the movement has been moderate—probably not more than 100 feet.

4. The fact that the brittle rhyolite within the fault zone, although shattered, has not been brecciated or ground together, leads to the same conclusion as stated in paragraph 3.

5. The comparative softness of the clay gouge and the lack of cementation of the rhyolite fragments, although not conclusive, at least suggest the possibility that the fault may be younger than other fractures observed in the rhyolite and may be subject to renewed movement.

Ransome therefore recommends that in the design of the dam the presence of a fault along which renewed movement may sometime take place be given due consideration.

A STUDY OF GROUND WATER IN THE POMPERAUG BASIN, CONNECTICUT

WITH SPECIAL REFERENCE TO INTAKE AND DISCHARGE

By Oscar Edward Meinzer and Norah Dowell Stearns

INTRODUCTION

For a number of years the United States Geological Survey has cooperated with the Geological and Natural History Survey of Connecticut in a study of the ground-water resources of that State. A large number of towns have been surveyed, and water-supply papers covering these towns have been published, as shown on Plate 11. The present report covers the ground-water resources of the towns of Bethlehem, Woodbury, and Southbury. It includes also a critical study of the drainage basin of Pomperaug River, which lies chiefly in these three towns. (See pl. 12.) In this study, which is based on observations covering a period of more than three years, an attempt has been made to determine, month by month, what became of the water that fell on the drainage basin as rain or snow and especially to determine for each month the quantity of water that reached the zone of saturation and was added to the ground-water supply and the quantity that was discharged from the zone of saturation as ground-water run-off or by evaporation and transpiration.

The Pomperaug Basin was selected for quantitative study, not because its water resources are intensively developed or especially valuable, but because it presents ground-water conditions that are fairly representative of those throughout the State and because it is a convenient unit for quantitative study, with fewer complications than are found in most areas.

The quantitative study is, in a sense, a by-product of the regular ground-water work in Connecticut. The allotments for carrying on the investigation were small, and the number of observations made were inadequate to yield very accurate results. However, so little work of this kind has been done in the eastern, humid part of the United States and so many problems arise in which it is essential to make estimates of the ground-water recharge in specific areas that it seems worth while to publish the results that were obtained. It is believed also that a presentation of the methods used will be of value to others who may be required to make quantitative studies of ground-water supplies in humid regions.

The investigation was made under the general direction of H. E. Gregory, former superintendent of the Connecticut State Geological and Natural History Survey, and O. E. Meinzer, geologist in charge of the division of ground water in the United States Geological Survey. The general ground-water survey of the basin was made by Arthur J. Ellis, who also had charge of the regular observations that were begun in the summer of 1913 and were continued until about the end of 1916. Special observations were made by Kirk Bryan and H. S. Palmer and by Messrs. Gregory and Meinzer. The water analyses were made by Margaret D. Foster, except that of Nonewaug River, which was made by S. C. Dinsmore. The stream-gaging station at Bennetts Bridge, near the mouth of the Pomperaug, was established by C. H. Pierce, and the gage was read once or twice a day by W. H. Ingram. The three rain gages were read by S. P. Hayes, A. M. Mitchell, and H. M. Canfield, voluntary observers. Weekly measurements of the observation wells were made by Ernest W. and George A. Parkin and later by Ralph Wooden. Thanks are due to the local observers and also to the many owners of wells and springs and other inhabitants of the Pomperaug Basin who furnished information or gave assistance in other ways.

On account of war work and other important duties Mr. Ellis was obliged to postpone his study of the Pomperaug data, and at his untimely death in 1920 the investigation was left incomplete. In 1922 Norah E. Dowell (now Mrs. Stearns) took up the study and spent a few weeks in the Pomperaug Basin. In 1923 H. T. Stearns spent a short time in the basin and completed the geologic map (pl. 12).

The present report was carefully examined by the late H. H. Robinson, superintendent of the Connecticut State Geological and Natural History Survey, and David G. Thompson, both of whom gave much valuable criticism.

GEOGRAPHY

The drainage basin of Pomperaug River is situated in the central part of the western highland of Connecticut. (See pl. 11.) It is about 17 miles in length and 8 miles in maximum width and has an area of about 89 square miles. It comprises nearly all of the towns of Bethlehem and Woodbury, a large part of the town of Southbury, and small parts of the towns of Roxbury, Washington, Morris, Watertown, and Middlebury. (See pl. 12.) It contains the villages of Bethlehem, Woodbury, North Woodbury, Pomperaug, Southbury, and South Britain. The New York, New Haven & Hartford Railroad passes through the southeast corner of the area and has a station at Southbury. Woodbury and North Woodbury are reached by an electric line from Waterbury.

The Pompevaug Basin is one of the rural parts of Connecticut, where the population is relatively small and widely scattered. According to the census of 1920, the town of Bethlehem had 576 inhabitants, the town of Woodbury 1,698, and the town of Southbury 1,238. The density of population was 29 to the square mile in Bethlehem, 47 in Woodbury, and 31 in Southbury. In this, as in many other rural districts in Connecticut, the population is not increasing. From 1910 to 1920 there was a slight increase in Bethlehem and Southbury, but it was more than offset by a decrease of 162 in Woodbury.

Agriculture is the main industry and consists chiefly of general farming and dairying. There are also several small factories in the area. Cultivated fields and orchards are found in the valley bottoms, on the lower and gentler slopes of the hills, and on many of the flat or rounded hilltops. The rocky areas are largely in pasture, and the wet lands produce marsh hay. About a third of the drainage basin consists of woodland.

A meteorologic station has been maintained by the United States Weather Bureau at Waterbury, 10 miles east of this basin, for a period of 38 years. According to the records obtained at this station the mean annual temperature at Waterbury is 48.8° F., the mean annual precipitation 48.81 inches, the average date of the first killing frost October 14, and the average date of the last killing frost April 16.[1] In the Pomperaug Basin there is a long winter season. Spring usually comes so quickly that the snow melts rapidly and sometimes causes strong freshets. It soon gives way to summer, which is a pleasant season except for a few hot waves. Autumn is delightful and often has many weeks of Indian summer, with warm days and cool nights. The winds are prevailingly from the west, except in May and June, when east winds prevail.[2]

TOPOGRAPHY AND DRAINAGE

The Pomperaug Basin consists chiefly of rather rugged uplands, but in the south-central part of the basin there are extensive valley areas. The highest point in the basin, 1,150 feet above sea level, is at its northern extremity, near the village of Morris; the lowest point, only 100 feet above sea level, is at the mouth of Pomperaug River.

Most of the hills are well rounded and are covered with glacial drift. Some of the slopes, however, are very steep and are either entirely bare of soil or so thinly covered that bedrock is exposed at intervals of only a few feet. The valleys trend in a north-south

[1] Climatologic data, 1922 and 1923, United States Weather Bureau.

[2] Summaries of climatological data of the United States, by sections: U. S. Weather Bureau Bull. W, section 105, 1912.

direction. In the south-central part of the basin the valley of Pomperaug River and to some extent the tributary valleys have wide flat bottoms and are bordered by extensive terraces. Both the bottom lands and the terraces are underlain by stratified drift. The terraces generally have smooth surfaces, modified to some extent by kames and kettle holes. In the rest of the basin the valleys are usually narrow and have steep sides.

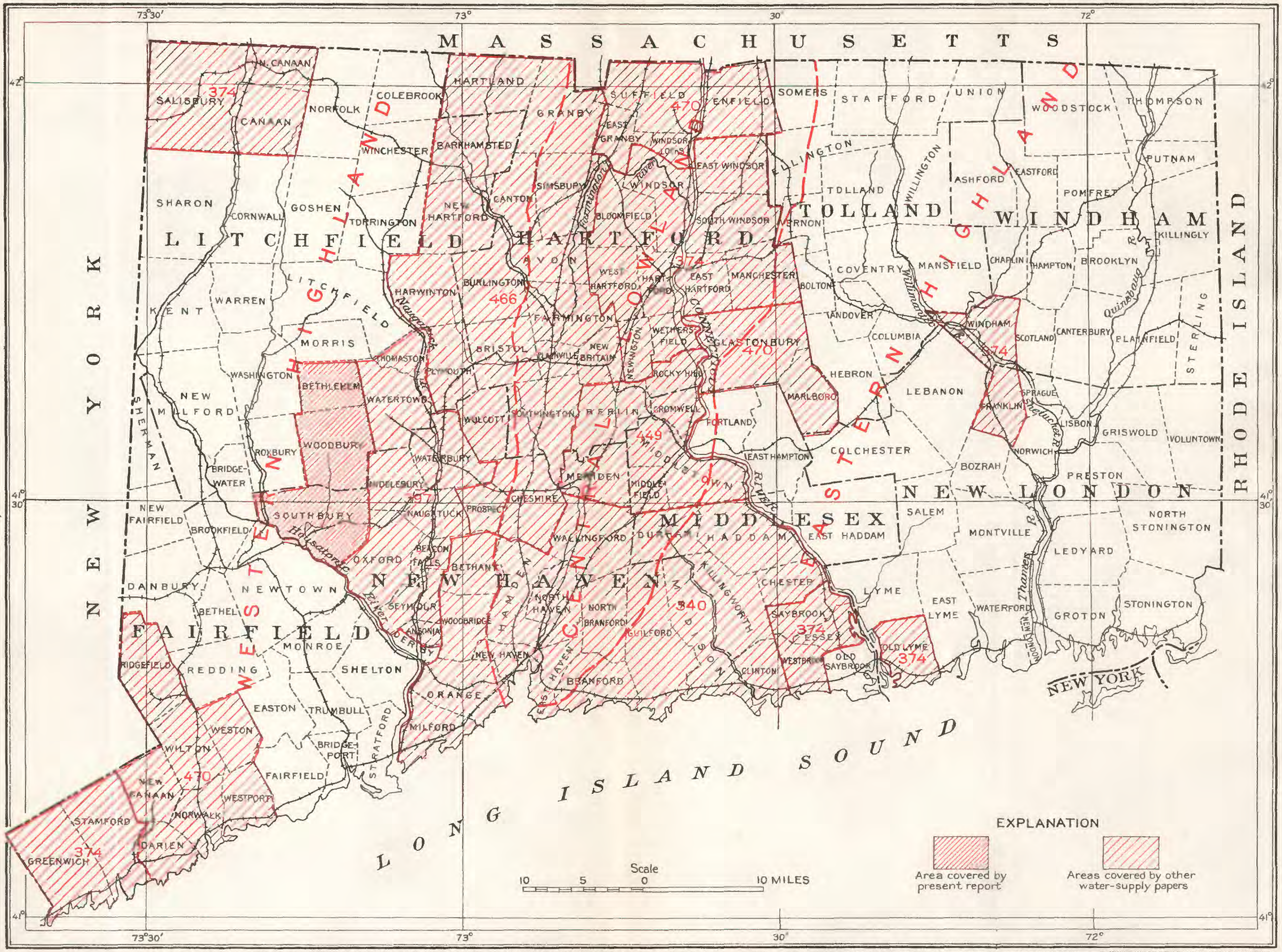
Pomperaug River flows in a generally southward course and discharges into the Housatonic just below Bennetts Bridge. It is formed by the confluence near North Woodbury of Nonewaug River, which drains the northeast quarter of the basin, and Weekeepeemee River, which drains the northwest quarter. (See pls. 12 and 13.)

There has obviously been some derangement of the drainage of Pomperaug River in the lower part of its course and of its tributaries, Hesseky and Transylvania Brooks. These brooks at one time probably formed a single stream that flowed southward. Later the upper part of this stream apparently became impounded by the deposition of glacial drift in the vicinity of the present divide and found an outlet toward the northeast. These changes in drainage are suggested by the abnormal angles that Hesseky Brook makes with the Pomperaug and that the tributaries make with Hesseky Brook, the insignificant divide that at present separates its headwaters from those of Transylvania Brook, the swampy character of its bottom lands, and the lake deposits that underlie its valley. (See pl. 12.) The narrow steep-sided valley of the Pomperaug below South Britain suggests that the river formerly drained directly southward through the low land east of Horse Hill.

Ponds and marshes are found in many parts of the basin. They were produced chiefly by glacial scour or deposition. (See pl. 14.) Long Meadow Pond, the largest pond, is about a mile south of Morris and empties into Weekeepeemee River. Big Meadow Pond lies about 2½ miles east of Bethlehem and empties into Nonewaug River. A small pond lies at the headwaters of Hesseky Brook, and there are a number of others near the villages of Woodbury and Southbury. Marshes are found at the head of Wood Creek, west of Todd Hill, along the course of Weekeepeemee River, south of Bethlehem, and along nearly the whole course of Hesseky Brook. The aggregate area of the ponds in the drainage basin of Pomperaug River is about half a square mile, and that of the marshes is also about half a square mile, not including many small wet tracts where the ground water lies near the surface and gives rise to seeps and springs.

GEOLOGIC SKETCH

The Pomperaug Basin is underlain by ancient crystalline rocks, such as schist, gneiss, granite gneiss, and diorite, except in the south-



MAP OF CONNECTICUT SHOWING PHYSIOGRAPHIC DIVISIONS AND AREAS TREATED IN THE PRESENT AND OTHER DETAILED WATER-SUPPLY PAPERS OF THE UNITED STATES GEOLOGICAL SURVEY

central part, where Triassic trap and sedimentary rocks occur.[3] Spread over these rock formations is a mantle of glacial drift, which is generally thin and in many localities is entirely absent, leaving the rocks exposed. (See pl. 12.)

The ancient crystalline rocks have suffered so many changes that their history is difficult to decipher. In some remote period, probably in early Paleozoic time, sand and mud were deposited in the region, and eventually these materials became consolidated to sandstone and shale.[4] Later there were great mountain-building disturbances, characterized by compression of the earth's crust and intrusion of vast quantities of igneous material. The mashing and intrusion changed the old shale and sandstone into schist and gneiss. Much of the igneous rock also was crushed and converted into gneiss.[5]

During Triassic time the mountains were deeply eroded and much débris was deposited on the lower land. The deposits thus laid down were later consolidated and formed chiefly red sandstone, shale, and conglomerate, but also some dark bituminous shale and green and gray limy shales. In some places in the Connecticut Valley fossil footprints of reptiles and a few reptilian bones have been found in the Triassic rocks. In the Triassic rocks of the Pomperaug Basin remains of fishes and pieces of fossil wood have been found.[6] The Triassic history of the Pomperaug Basin is closely related to that of the central Connecticut lowland. According to one theory the Triassic rocks of this basin were once continuous with those of the greater Triassic area in the Connecticut Valley and were separated from them by erosion; according to another theory the Pomperaug Basin was a separate intermontane valley in which the Triassic sediments were deposited.[7]

The deposition of the Triassic sediments was interrupted throughout the region by eruptions of lava, which spread out in extensive sheets of basalt or trap. These lavas now form the trap ridges of Rattlesnake Hill, French Mountain, Ragland Hill, and Orenaug Hill. (See pls. 12 and 15, *A*.)

Subsequently, probably in Jurassic time, the flat-lying sedimentary rocks and interbedded trap sheets were broken into blocks by a series of faults that in general cut across the area in a northerly direction. Each block was rotated so that its southeast margin was depressed.[8]

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[3] Gregory, H. E., and Robinson, H. H., Preliminary geological map of Connecticut: Connecticut Geol. and Nat. Hist. Survey Bull. 7, 1907.

[4] Rice, W. N., and Gregory, H. E., Manual of the geology of Connecticut: Connecticut State Geol. and Nat. Hist. Survey Bull. 6, pp. 96–100, 1906.

[5] Iden, pp. 79, 109. 110.

[6] Hobbs, W. H., The Newark system of the Pomperaug Valley, Conn.: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 3, pp. 55–56, 161–162, 1901.

[7] Davis, W. M., The structure of the Triassic formation of the Connecticut Valley: U. S. Geol. Survey Seventh Ann. Rept., pp. 461–462, 1888.

[8] Davis, W. M., op. cit., figs. 98, 105; The Triassic formation of Connecticut: U. S. Geol Survey Eighteenth Ann. Rept., pt. 2, pl. 20, 1898. Hobbs, W. H., op. cit.

There is no sedimentary record of the interval between the Triassic period and the glacial epoch, either in the Pomperaug Basin or elsewhere in Connecticut, but erosion took place and left its mark. During the Cretaceous period, as has been shown by Davis,[9] the great block mountains formed by the faulting were almost completely worn away by the streams and a peneplain was developed which extended over the old crystalline rocks as well as the Triassic formations. In later periods, as has been shown by the work of Barrell,[10] the region was uplifted in successive stages and a series of terraces was cut by the sea into the elevated peneplain. Since the uplift the region has been deeply dissected, and only remnants of the original surface remain.

During the Pleistocene epoch the Pomperaug Basin was overridden at least once and probably several times by a thick continental ice sheet. As this ice sheet moved slowly southward it remodeled the topography by scraping away the decayed rock material that had accumulated at the surface, by breaking off and grinding down projecting ledges of rock, and by redepositing the débris. The major features of the topography were left unchanged, but the details were greatly altered. The mantle of residual soil was replaced by glacial drift of two types—unstratified drift, or till, and stratified drift, or glacial outwash. The till, which was deposited directly by the ice, forms a rather thin but irregular and frequently interrupted mantle over the bedrocks throughout the upland portions of the basin. The stratified drift was deposited by the streams that flowed out from the glacial ice and filled the valleys of Pomperaug River and of Hesseky and Transylvania Brooks to a considerable extent. The broad alluvial plains that resulted were later trenched by these streams, but remnants of the original plains remain and form terraces of stratified drift along the valley sides. In a few places silt and clay were deposited in temporary ponds or lakes formed where streams were dammed by the glacial ice and its deposits.

Since the Pleistocene epoch there has been no important change in the topography. Slight erosion has occurred over most of the region, and small amounts of alluvium have been deposited in the valleys. Some swamps have been filled, and some lakes have been changed to swamps by being filled with sediment and vegetation.

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[9] Davis, W. M., U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, pp. 157-159, 1898.

[10] Barrell, Joseph, Piedmont terraces of the Appalachians and their origin: Geol. Soc. America Bull., vol. 24, pp. 688-691, 1913; The piedmont terraces of the northern Appalachians: Am. Jour. Sci., 4th ser., vol. 49, pp. 227-258, 327-362, 407-428, 18 figs., 2 pls., 1920.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES[11]

BEDROCK

PRE-TRIASSIC CRYSTALLINE ROCKS

In most of the Pomperaug Basin the glacial drift is underlain by crystalline rocks of pre-Triassic age, chiefly schist and gneiss. These rocks are so dense that the circulation of water through them is practically restricted to the joints. There are many joints in all these rocks, but in most of them the openings are too narrow, even at the surface, to allow much water to pass. However, the smaller joints are generally connected, either directly or indirectly, with larger ones into which they may drain. The joint openings in these rocks diminish rapidly in size from the surface downward, and most of them disappear entirely within a few hundred feet of the surface. Water-bearing fissures at greater depths are rare.

In the openings of this intricate system of joints ground water is stored in relatively small quantities and generally moves very sluggishly, if at all. Thus, although these rocks generally yield from 1 to several gallons a minute to drilled wells of moderate depth, they are not effective in transmitting much water any great distance, and it is safe to assume that they form a nearly impervious bottom, through which only small quantities of water escape from the Pomperaug Basin.

TRIASSIC ROCKS

The Triassic rocks, it is believed, underlie most parts of the valleys of Pomperaug River and Hesseky and Transylvania Brooks and the islandlike upland between these valleys. (See pl. 12.) They include sedimentary rocks and interbedded trap rocks. The sedimentary rocks consist chiefly of arkosic conglomerate and sandstone but include also some shale and limestone. The trap rocks, being the most resistant, have been etched into strong relief and form the prominent range of hills that extends from Woodbury to South Britain. Sandstone and conglomerate flank the outcrops of trap and probably underlie most of the valley lowlands, although they crop out in only a few places.

The sedimentary rocks are in general hard and dense. They are somewhat porous, but their pore spaces are so small that they yield little or no water from these spaces. Like the crystalline rocks, they are broken by numerous joints, which become tighter and less numerous with depth. The shale is generally less permeable than the sandstone, but it also is traversed by water-bearing joints. The trap rocks are as a rule even denser than the sedimentary rocks, but in some places they yield meager supplies of water from joints.

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[11] For a more detailed discussion of water in the rocks of Connecticut see Gregory, H. E., and Ellis, E. E., Underground water resources of Connecticut: U. S. Geol. Survey Water-Supply Paper 232, 1919.

FAULTS

The rocks underlying the Pomperaug Basin are broken by many faults,[12] but it is believed that the fault fissures do not form water conduits large enough to allow ground water to escape in any considerable amounts, and there is no evidence of deep-seated waters appearing as springs. (See pp. 85–89.)

GLACIAL DRIFT

TILL

The till forms a mantle over the bedrock of most of the Pomperaug Basin. (See pls. 12 and 17, *A*.) It is an ice-laid deposit composed

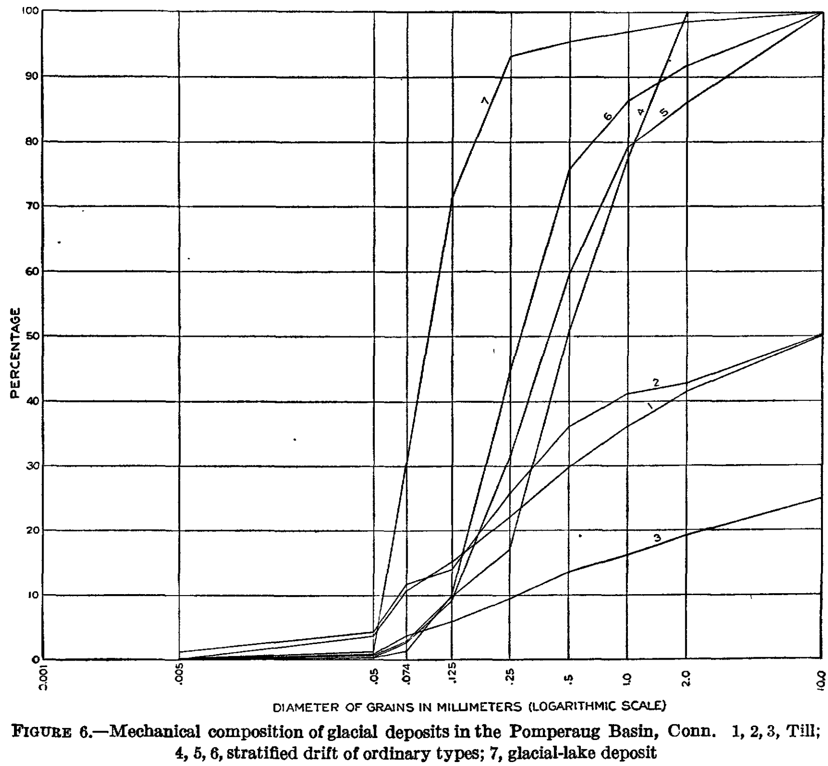


FIGURE 6.—Mechanical composition of glacial deposits in the Pomperaug Basin, Conn. 1, 2, 3, Till; 4, 5, 6, stratified drift of ordinary types; 7, glacial-lake deposit

of a matrix of the pulverized and granulated fragments of the rocks over which the ice sheet passed and of larger pieces of the same rocks embedded in the matrix. Its color in general is blue-gray, but near the surface, where the iron-bearing constituents of the matrix have been weathered, it is yellow or brown, and where the material is in large part derived from the red Triassic rocks it is reddish brown to

[12] Davis, W. M., op. cit. Hobbs, W. H., op. cit.

red. The boulders are very abundant and are scattered over the fields and exposed in the banks of cuts.

Some of the till, especially that part below the weathered zone, is very tough, as is indicated by the term "hardpan" often applied to it. The toughness of the till is due in part to the presence of clay, in part to its having been thoroughly compacted by the great weight of the ice sheets, and in part to the interlocking of the sharp, angular grains. It seems probable that the more soluble constituents of the matrix have to some extent been dissolved by the ground water and have been redeposited in such a way as to cement the particles together.

The relative amounts of the different sizes of material in till and in stratified drift as determined by mechanical analyses are shown in the following table and in Figure 6. The material smaller than 1 centimeter in diameter was tested practically according to the methods used by the United States Bureau of Soils.[13] The amounts of material larger than 1 centimeter in diameter were estimated in the field. The results shown in the table were calculated as percentages, including the coarse material, for which estimates were made.

Mechanical analyses of glacial deposits, Pomperaug Basin

[Analyzed by Norah E. Dowell]

Material	Diameter (millimeters)	Till			Stratified drift			
		1	2	3	4	5	6	7
Gravel to boulders [a]	Larger than 10	50.0	50.0	75.0	0	0	0	0
Gravel	10–2	8.7	4.7	5.9	0	13.8	7.3	1.5
Fine gravel	2–1	5.2	3.0	2.9	22.2	6.9	6.3	1.7
Coarse sand	1–0.5	6.4	6.1	2.7	26.9	19.4	10.8	1.6
Medium sand	0.5–0.25	7.7	10.3	4.0	33.9	28.2	31.0	2.0
Fine sand	0.25–0.125	7.0	9.5	3.7	13.5	22.6	35.2	21.9
Very fine sand	0.125–0.074	4.2	4.8	2.1	2.2	6.4	6.8	40.3
	0.074–0.05	7.0	7.4	2.9	1.0	2.2	2.3	29.9
Silt	0.05–0.005	3.8	2.9	.8	.3	.4	.3	1.0
Clay	Less than 0.005	.0	1.3	.0	.1	.1	.0	.1
Effective size [b] millimeters		.07	.07	.27	.13	.13	.13	.06
Uniformity coefficient [c]					4.9	3.8	2.8	1.9
Porosity per cent		16.3	15.8	8.7	31.8	37.1	38.5	41.9

[a] Estimated in field.

[b] The term "effective size" is here used to mean the diameter of grain which is just too large to pass through a sieve that allows 10 per cent of the material, by weight, to pass through (Meinzer, O. E., Outline of ground-water hydrology: U. S. Geol. Survey Water-Supply Paper 494, p. 45, 1923).

[c] The uniformity coefficient is the quotient of the diameter of a grain that is just too large to pass through a sieve that allows 60 per cent of the material, by weight, to pass through, divided by the diameter of a grain that is just too large to pass through a sieve that allows 10 per cent of the material, by weight, to pass through (Meinzer, O. E., op. cit., p. 45).

Samples 1 and 3 represent till derived chiefly from the gneiss and schist. Sample 2 represents till derived chiefly from Triassic sandstone, shale, and trap. There is no great difference in the mechanical analysis due to this difference in composition, except that No. 2 has a larger percentage of clay and No. 3 a larger percentage of boulders and pebbles.

[13] U. S. Dept. Agr. Bur. Soils Bull. 84, 1912.

The porosity was obtained in the laboratory by adding measured quantities of water to definite volumes of the material. The average porosity of the three samples of till is 13.6 per cent. In 1915 six samples of till were tested in the field by the senior author for porosity by adding measured quantities of water to definite volumes of the material. These tests gave porosities ranging from 21 to 11.5 per cent and averaging 14.7 per cent after corrections had been made for material of large size.

In most places the till yields only small supplies of water, but locally bodies of stratified sand and gravel within the till yield water freely. The till is of great value for domestic supplies because it is widely distributed and at most places will yield to inexpensive dug wells enough water for family uses. The till is also the reservoir which feeds most of the small springs that provide gravity supplies for many farms. Furthermore, it holds the water supplied by precipitation and yields it slowly to the streams, thus maintaining a perennial flow in streams that would otherwise be dry much of the time.

STRATIFIED DRIFT

In contrast with the till, which was laid down directly by the ice, the stratified drift is a water-laid deposit. (See pls. 17, *B*, and 18.) It consists of material that was derived chiefly from the ice but was well washed and sorted by the water that issued from the melting ice sheet. The stratified drift consists of beds laid one upon another in an intricate and irregular way. Some of the beds consist of clay, some of fine sand, some of coarse sand, others of gravel, and still others of cobbles, but the sands are the most abundant. The material of each bed is rather uniform in size, but there may be a great difference between adjacent lenses. In general the finer materials form more extensive beds than the coarser. Some of the beds of clay and silt, though only an inch or two thick, have a horizontal extent of hundreds of feet, whereas lenses of gravel may be 2 or 3 feet thick and yet not extend over 10 feet horizontally. The sand lenses are composed almost entirely of quartz grains, but in the gravel lenses there are pebbles of many kinds of rocks. The clay beds consist of true clay, thin flakes of mica, and minute particles of quartz and feldspar. All the deposits contain iron, which gives them brown colors.

The physical character of four samples of stratified drift is shown in the table on page 81 and in Figure 6. The mechanical analyses were made in the same way as those of the samples of till. Samples 4, 5, and 6 represent some of the finer material that was laid down by running water. All three samples consist of relatively well assorted material. Almost all the material is included within two or three sizes, whereas in the till there is a wider diversity of sizes, even exclusive of the boulders and cobbles that were taken out before the analyses were made. The strata of coarser stratified drift are also well assorted. Sample 7 is a very fine, well-assorted sand that was presumably deposited in a glacial lake.

The average porosity of samples 4, 5, and 6 is 35.8 per cent, and the porosity of sample 7 is 41.9. Field tests of porosity of eight samples of glacial outwash made by the senior author in 1915 gave results ranging from 18 to 37.6 per cent and averaging 28 per cent. One of these was a glacial-lake deposit with a porosity of 36 per cent, and another a recent stream deposit with a porosity of 48 per cent. As both the till and the stratified drift are variable even within short distances, a considerable range in mechanical composition and porosity is to be expected, even in deposits of the same class.

The best water-bearing material in the basin is the coarser stratified drift found in the valley of Pomperaug River and to some extent in the tributary valleys. These porous deposits of clean sand and gravel will yield water in large quantities to properly constructed wells, and their supplies are readily replenished when the rains come. They are valuable for obtaining large supplies from wells for municipal and industrial uses.

CIRCULATION OF GROUND WATER

The ground water in the Pomperaug Basin is virtually all derived from the rain and snow that fall on the drainage area. On the steep slopes the water runs off rapidly and relatively little enters the ground, but on the more gentle slopes and on the flat areas a larger portion of the precipitation is absorbed by the soil. Some of the water sinks through the pores of the unconsolidated material until it reaches the water table or the relatively impervious bedrock, and thence it moves laterally. Except in the stratified drift, however, lateral movement does not take place over great distances, largely because the unconsolidated materials occur in discontinuous areas interrupted by ledges of bedrock which cause the water to return to the surface.

Throughout most of the Pomperaug Basin the water table, or upper surface of the zone of saturation, is not far below the land surface, and in many places it appears virtually at the surface in springs, marshes, and seepage areas. Over a large part of the basin it is so near the surface that much of the ground water is dissipated through direct evaporation and through absorption by the roots of trees and other vegetation. The water table is commonly nearer the surface on the till-covered hills than in the stratified drift of the valleys, because the till, owing to its lower porosity and permeability, becomes saturated more quickly than the stratified drift. The greatest depth to ground water is found in the terraces underlain by the permeable stratified drift, in which the water table is nearly on a level with the streams.

WATER SUPPLIES

WELLS

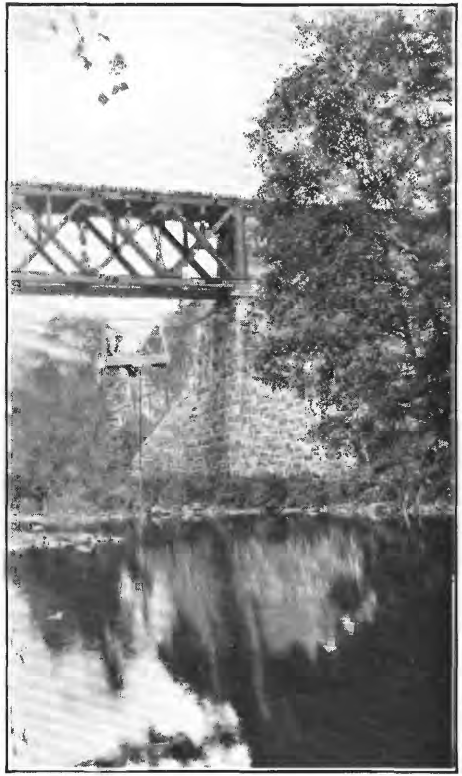
Practically all the domestic water supplies in the Pomperaug Basin are drawn from the glacial drift. Only a few wells penetrate bedrock, and these may draw water from the rock or from the overlying glacial drift. In the present investigation information was obtained in regard to about 160 wells in the area.

Most of the wells end in till, which underlies about nine-tenths of the area. These are nearly all dug wells, about 3 feet in diameter and curbed with stone. As a rule they furnish supplies of water adequate for domestic use, but if the well is unfavorably situated, as on a slope where the water drains quickly away, the supply may be inadequate or the well may be dry during summer droughts. Many of the wells investigated were reported to fail in dry seasons. Most of these are very shallow and fail because they are above the water table at its low stages or because they are on slopes where the ground water drains away completely.

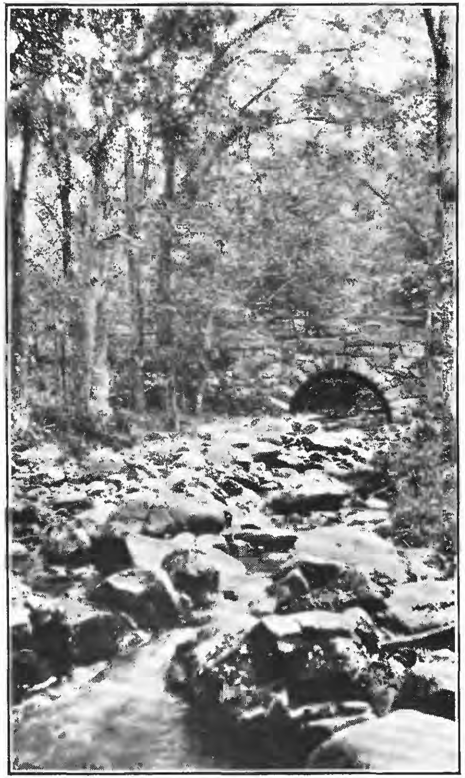
Most of the dug wells are between 15 and 30 feet deep. The deepest dug well examined was 40 feet deep, and the shallowest was only 7 feet. Many of the wells have either hand pumps or chain and sucker pumps, but some have only a rope and bucket equipment.

In parts of the valley bottoms of Pomperaug River and of Transylvania Brook and in the vicinity of North Woodbury the wells draw their supplies from the stratified drift. Most of these wells are dug wells, about 3 feet in diameter and curbed with stone, like the dug wells in till.

Only a few water supplies are obtained from drilled wells. These are of only moderate depth and obtain their water either from jointed bedrock or from the glacial drift overlying the rock. In Bethlehem the well of Homer Weldron was drilled in the bottom of a dug well 20 feet deep and ended in rock at a depth of 200 feet. However, the drilled hole has been abandoned, and only the dug well is used. In Southbury two drilled wells were reported, one, 25 feet deep, owned by Charles Hine and the other, 75 feet deep, owned by Mr. Hickock. Both of these wells are reported to end in sand and gravel. The Hickock well is said to have a good yield. In Woodbury three drilled wells were reported. The well of F. E. Warner is said to end in rock and to yield a supply of hard water. The well of C. B. Dakin, 3 inches in diameter and 296 feet deep, is reported to have passed through a few feet of drift and the rest of the distance through schist. It yields an unfailing supply. The well of C. M. Rowley is 60 feet deep and draws water from glacial materials.

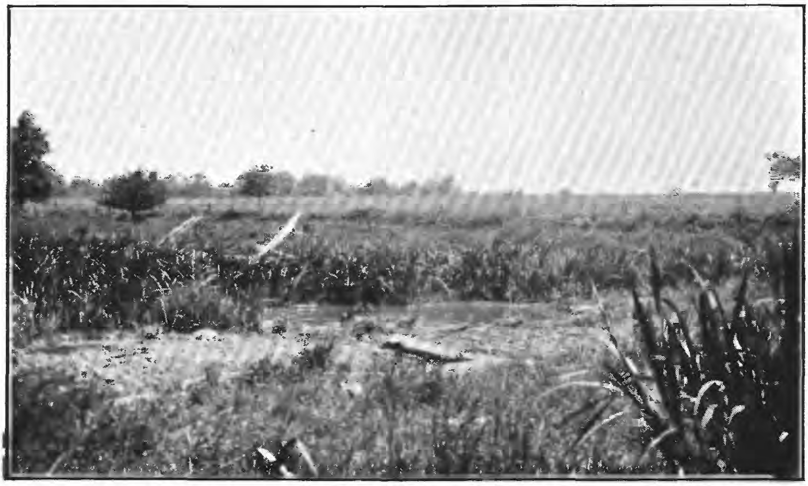


A. GAGING STATION ON POMPERAUG RIVER AT BENNETTS BRIDGE, CONNECTICUT



B. NONEWAUG RIVER 1½ MILES NORTH OF MINORTOWN, CONN.

A typical stream bed in till



A. MARSH ON TOP OF HILL AT THE HEAD OF SPRUCE BROOK, 2 MILES EAST OF ROXBURY FALLS, CONN.

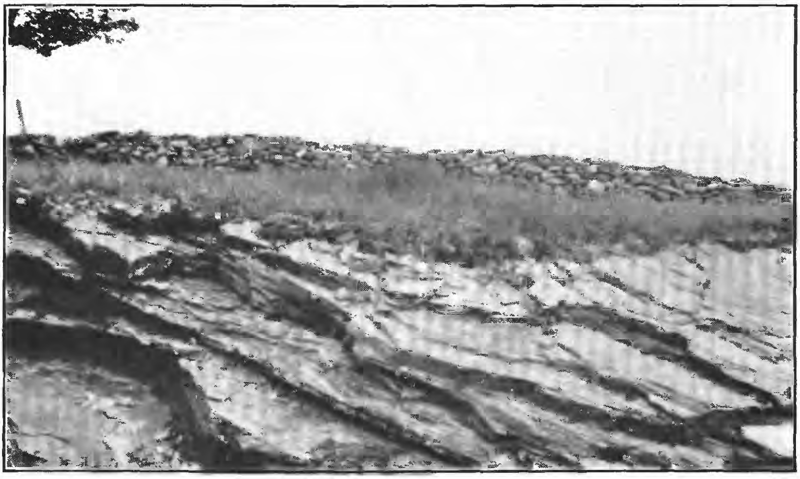
B. MARSH IN A ROCK-SCOURED BASIN, OR TARN, ON SOUTH SIDE OF FLAT HILL, WEST OF SOUTH BRITAIN, CONN.

A. TRAP RIDGES OF RATTLESNAKE HILL, NEAR SOUTH BRITAIN, CONN.

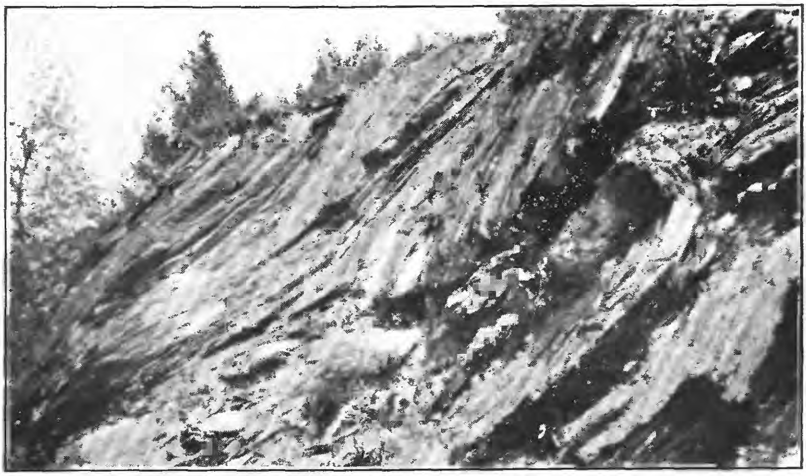
View across Pomperaug Valley from Georges Hill

B. ROADSIDE SPRING NEAR MINORTOWN, CONN.

Shows vegetation typical of localities where the water table is very near the surface



A

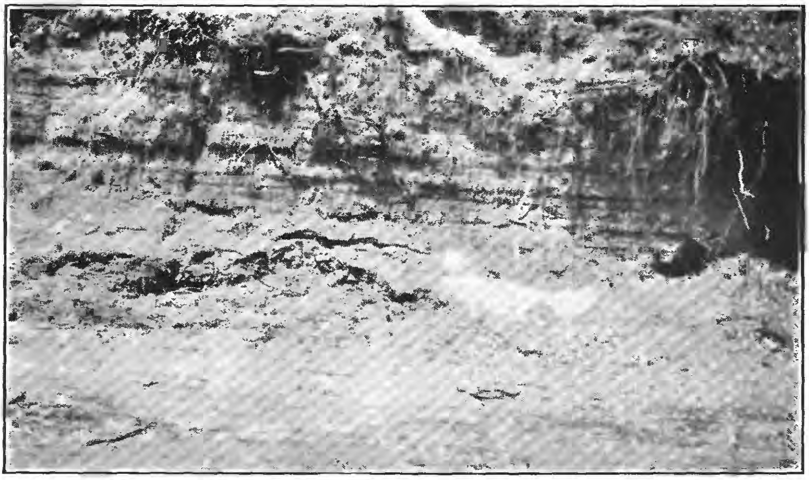


B

SCHIST SHOWING JOINTS AND PARTING PLANES IN WHICH GROUND WATER CIRCULATES

A. TILL 1 MILE NORTH OF SOUTHBURY CENTER, CONN.

The till is an unstratified glacial deposit that yields water in moderate amounts and supplies most of the domestic wells in the Pomperaug Basin



B. STRATIFIED GLACIAL-LAKE DEPOSIT ABOUT 1 MILE SOUTHEAST OF SOUTH BRITAIN, CONN.

Chiefly very fine sand. Material of this type yields practically no water to wells

A. STRATIFIED DRIFT NORTH OF NORTH WOODBURY, CONN.

Yields abundant supplies of water to wells

B. DISTORTED STRATIFIED DRIFT OVERLAIN BY TILL, MINORTOWN, CONN.

SPRINGS

In the present investigation records were obtained in regard to 74 springs in the Pomperaug Basin. Springs are very numerous, especially in the area of crystalline rocks, and many of them are used for domestic purposes. Some of the springs are in their natural condition, but many of them have been improved by enlarging and walling up the spring basins and building covers or small houses over them. The water from many of the springs flows by gravity through pipe lines to the houses and barns. Many of these houses have modern plumbing with toilet and laundry facilities, and some have hydrants with water under considerable pressure. Many watering troughs along the road are supplied by water piped from springs on the hillsides, and a few roadside springs have been enlarged and partly walled or covered. Plate 15, *B*, shows a roadside spring that is only slightly improved.

The abundance of springs in the Pomperaug Basin is probably due to the fact that the bedrock is exposed or lies very near the surface in so many places, expecially on the hillsides. In some places the water seeps out over large areas; in others the flow is more concentrated. Many of the hills have a north-south elongation with gently rounded tops, but steep east and west sides. The glacial drift is relatively thick on the tops of these hills, but the bedrock is likely to crop out on the steep sides, and here springs are commonly found. This mode of occurrence gives a linear arrangement to many of the springs. Other springs occur at the foot of slopes or along the streams.

No evidence was found that any of the springs are due to the rise of deep-seated water through fault fissures. In the following table are listed all the springs for which records of temperature were obtained. Most of the observations were made by H. T. Stearns in 1923. The observed temperatures of spring waters range from 47° to 62° F. Some of these temperatures are considerably above the mean annual air temperature of the area (49° F.), but examination of the springs made it evident that the relatively high temperatures were due not to the deep source of the water but rather to very shallow sources affected by the summer temperatures or to heating of the water after it seeped from the ground.

Records of springs in the Pomperaug Basin for which temperature was obtained

No. on map	Owner	Improvement	Temperature (°F.)	Flow (gallons per minute)	Date of measurement of temperature and flow	Remarks
S 1		Barrel and 1-inch pipe to house.	47	2	June 12, 1923	
S 2			54	½		
S 3	C. E. Beardsley	Stone casing and wooden curb.	49	20	June 28, 1923	See analysis, 3, p. 87.
S 4	James Hunt			1		Never fails; very little fluctuation.
S 5		Spring house, barrel, and pipe.	49	2	June 13, 1923	
S 6			46 52		Spring Fall	Never fails and never freezes in winter.
S 7		Horse tank	52	3–5	June 6, 1923	Two springs.
S 8			52	3	June 8, 1923	
S 9		1-inch pipe to house	47	2	June 13, 1923	Not in use.
S 10		Piped	60	8		
S 11		Horse tank	60			
S 12			55			Affected by rain.
S 13		Horse tank	57		June 6, 1923	Two springs.
S 14		Dug and cased	53	2	June 7, 1923	
S 15		Wooden spring house	52	6	June 2, 1923	Stock.
S 16	G. Sypher	Concrete basin	56–58		June 29, 1923	See analysis 4, p. 87.
S 17		Spring house. Piped to house.	55	Small	May 31, 1923	
S 18	J. R. Gilson	Spring house. Piped to house and barn. Depth 8 feet, diameter 7–8 feet.	51, 50	3, 8	June 2, 1923	Two springs. Never fail. Domestic and stock.
S 19		Spring house	54	4	do	
S 20		Shed	52	4		
S 21	Eugene Kerner	Enlarged. Pumped to house through tank.	49	15–20	June 27, 1923	See analysis 1, p. 87.
S 22		Walled and covered. Piped to house.	54	4–5	June 4, 1923	
S 23	Henry Shortt	Dug and walled; depth 2 feet, diameter 2 feet. Spring house.	47	4–5	June 28, 1923	See analysis 10, p. 87.
S 24	Geo. L. Curtis	Piped to house and barn	54	2–3	do	See analysis 8, p. 87.
S 25	Southbury Inn	Enlarged in the form of a well 20 feet deep.	58		June 21, 1923	
S 26		Wooden trough	51	5–6	June 1, 1923	Stock.
S 27			62		do	
S 28			50	2	1913	Constant flow.
S 29		Barrel	57	3	do	
S 30		Concrete box 6 by 2 feet	47	5–10	June 25, 1923	

MUNICIPAL SUPPLY

A private corporation supplies water to the Orenaug fire district, which comprises most of the villages of Woodbury and North Woodbury. In 1922 it was reported that about 700 inhabitants were served. The water flows by gravity from two reservoirs formed by the impounding of two branches of South Brook, south of Woodbury. One is a supply reservoir with a capacity of 800,000 gallons; the other is a storage reservoir with a capacity of 11,000,000 gallons.

QUALITY OF WATER

The chemical character of the ground water in the Pomperaug Basin is indicated by the analyses given in the following table. The wells and springs from which the samples were taken are shown on Plate 12. In general the analyses indicate that the ground water of this basin is similar to that of other parts of Connecticut where analyses have been made of water derived from till and stratified drift.

The amount of total solids in the samples analyzed is low, ranging from 40 to 106 parts per million. The waters are relatively soft, having a hardness ranging from 21 to 73 parts per million.

Analyses of ground water in the Pomperaug Basin

[Samples collected June 27 to 29, 1923. Analyzed by Margaret D. Foster. Parts per million]

Litchfield County

	1	2	3	4	5
Silica (SiO_2)	20	9.5	12	19	21
Iron (Fe)	.12	.08	.08	.12	.09
Calcium (Ca)	6.8	4.1	6.0	7.0	23
Magnesium (Mg)	2.4	2.6	1.6	2.8	3.8
Sodium and potassium (Na+K)	5.1	2.4	3.4	4.9	2.4
Bicarbonate radicle (HCO_3)	31	21	23	37	73
Sulphate radicle (SO_4)	6.7	7.7	8.0	6.6	12
Chloride radicle (Cl)	2.0	1.2	1.2	1.8	2.0
Nitrate radicle (NO_3)	.47	.13	1.3	.15	.78
Total dissolved solids at 180° C	58	40	46	61	106
Total hardness as $CaCO_3$ (calculated)	27	21	22	29	73

1. Spring at Woodbury; owned by Eugene Kerner. Water from till. Map No. S 21.
2. Dug well about 15 feet deep at Minortown; owned by L. S. Darrow. Water from stratified drift. Map No. W 30.
3. Spring at Bethlehem; owned by C. E. Beardsley. Water from till. Map No. S 3.
4. Spring at Woodbury; owned by G. Sypher. Water from till. Map No. S 16.
5. Dug well about 30 feet deep, at Woodbury; owned by W. M. Stiles. Water from till. Map No. W 25.

New Haven County

	6	7	8	9	10
Silica (SiO_2)	22	20	14	9.3	18
Iron (Fe)	.15	.12	.09	.24	.09
Calcium (Ca)	16	12	16	8.6	17
Magnesium (Mg)	6.2	4.7	2.3	3.7	2.4
Sodium and potassium (Na+K)	5.0	5.0	3.1	3.8	4.2
Bicarbonate radicle (HCO_3)	68	34	53	23	53
Sulphate radicle (SO_4)	12	8.9	8.5	10	7.2
Chloride radicle (Cl)	2.9	14	1.0	2.3	3.2
Nitrate radicle (NO_3)	.85	1.1	.48	13	4.4
Total dissolved solids at 180° C	101	99	75	62	84
Total hardness as $CaCO_3$ (calculated)	65	49	49	37	52

6. Dug well about 15 feet deep at White Oaks; owned by L. B. Holmes. Water from stratified drift. Map No. W 33.
7. Dug well 35 feet deep at Southbury; owned by Wm. Olson. Water from stratified drift. Map No. W 32.
8. Hillside spring at South Britain; owned by Geo. Curtis. Water from till. Map No. S 24.
9. Dug well about 25 feet deep at South Britain; owned by Charles Luff. Water from till. Map No. W 31.
10. Spring at Southbury; owned by Henry Shortt. Water from till. Map No. S 23.

The analysis of a composite sample of the water of Nonewaug River is given below. Samples were taken daily from July 11 to December 31, 1915, with the exception of August 20, October 11–12 and 14–18, and December 11, 13–20, and 31. For record of the discharge of Nonewaug River during this period see pages 103–104.

Analysis of composite sample of water from Nonewaug River at Alder Swamp bridge

[S. C. Dinsmore, analyst]

	Parts per million
Silica (SiO_2)	30
Iron (Fe)	.19
Aluminum (Al)	.15
Calcium (Ca)	5.1
Magnesium (Mg)	2.4
Sodium (Na)	8.2
Potassium (K)	1.8
Carbonate radicle (CO_3)	.0
Bicarbonate radicle (HCO_3)	37
Sulphate radicle (SO_4)	8.8
Chloride radicle (Cl)	2.6
Nitrate radicle (NO_3)	.38
Total solids at 180°C	79
Total hardness as $CaCO_3$ (calculated)	23

This analysis shows the river water to be very similar to the ground waters that have the smaller quantities of dissolved solids. According to tests of the daily samples made to determine the chloride, carbonate, and bicarbonate radicles, the chloride ranged during the period from 1.6 to 3.6 parts per million; the bicarbonate ranged from 11 to 47 parts per million; and the carbonate was reported absent except on 36 days, when the highest found was 15 parts per million.

INVENTORY OF THE WATER RESOURCES

GENERAL CONDITIONS

CIRCULATION

The source of the water in the Pomperaug drainage basin is essentially the precipitation—chiefly rain and snow—on the basin. This water may be temporarily stored, but it is eventually disposed of by evaporation and run-off. A part of it is intercepted by trees and other vegetation, from which it evaporates and is returned to the atmosphere without reaching the ground; a part is evaporated directly from the surface of the ground; a part flows directly into the streams and ponds and runs off, except a small amount that is lost by evaporation; a part percolates into the ground and becomes soil moisture, or penetrates to the water table, where it enters the zone of saturation and is called ground water. The soil moisture may be absorbed and transpired by plants or may be evaporated directly from the soil. The water in the zone of saturation may be transpired by plants or may evaporate where it comes near the surface, or it may seep into the ponds and streams eventually and be carried out of the basin by Pomperaug River as run-off.

It is believed that practically no water is lost by deep percolation out of the Pomperaug drainage basin and that practically no water enters the basin from deep-seated sources. (See below.) Therefore except as there is no increase or decrease in surface or subsurface storage within a given period, the difference between the amount of precipitation in the basin during the period and the amount of stream flow out of the basin is approximately the amount that is evaporated, directly or through the agency of plants.

STORAGE

The water that falls as rain or snow may be stored on the surface or below the surface. Surface storage includes the water that is held in the ponds and reservoirs, and for the purposes of this investigation it includes also the water in the streams. Moreover, surface storage includes the considerable quantities of water that accumulate on the surface in winter as ice or snow. The subsurface storage consists of the soil moisture, in the zone of aeration, and of the ground water, in the zone of saturation. The storage creates an interval of variable duration between the falling of the water as rain or snow and its exit from the basin by evaporation or as run-off, and it thereby greatly complicates the problem of determining what ultimately becomes of the water that falls as rain or snow.

PERCOLATION INTO OR OUT OF THE BASIN

Before an inventory of the water supply in the Pomperaug drainage basin was undertaken a careful investigation was made to determine whether there is any percolation into or out of the basin. It is recognized that the rocks in this basin have been faulted and that the fault fissures may carry water and bring it to the surface in the form of springs. However, no indication was found that any water comes from a deep-seated or distant source outside of the drainage basin. There are no thermal springs, and all the field evidence indicates that the fault openings are small and, like other joints in the bedrock, carry only small quantities of water, at shallow depths and through short distances. It is reasonably certain that the water discharged by springs in this basin is practically all supplied by precipitation on the basin.

Further, it is believed that there is practically no percolation of ground water out of the drainage basin by underflow through openings in the bedrock or through glacial drift. The borders of the drainage basin are in most places high areas underlain by bedrock. In the few places where there seemed to be a possibility of percolation out of the basin an inspection of the local conditions has led to the belief that percolation does not occur. For the purpose of this study, therefore, it may be assumed that there is no percolation into or out of the drainage basin.

PERIOD COVERED BY THE INVESTIGATION

In the present investigation records of precipitation, run-off, and water levels in wells were obtained during a period extending from the summer of 1913 to about the end of 1916. These records, with others, were used to estimate the amount of water that fell on the basin during the period and the rate at which it was disposed of by the different processes of circulation and storage. The daily, monthly, and annual records were analyzed. For making annual estimates it was advantageous to consider a year as extending from October 1 to September 30, chiefly because on October 1 the amount of water in storage is usually about at a minimum and there are usually fewer complications in estimating the storage than at other times during the year. On October 1 the ground water, the soil moisture, and the water in surface streams are usually near the minimum and there is no snow storage to complicate the problem, as there might be on January 1. The period covered by this investigation therefore covers three complete years—October 1, 1913, to September 30, 1916, and all annual averages are based on records of these three years.

PRECIPITATION

RECORDS OF PRECIPITATION

The United States Weather Bureau maintains no regular stations within the Pomperaug drainage basin but has maintained a station at Waterbury, about 10 miles east of this basin, for many years, including the entire period covered by this investigation. From July, 1913, to December, 1916, rain gages were maintained by the United States Geological Survey in Bethlehem, North Woodbury, and South Britain, and records of precipitation at these stations were obtained through the cooperation of public-spirited citizens who served without remuneration. The observations in Bethlehem were made by Samuel P. Hayes, those in North Woodbury by Asahel M. Mitchell, and those in South Britain by Henry M. Canfield. The assistance of these voluntary observers is gratefully acknowledged. The following table gives the daily and monthly records at each of the three stations:

Precipitation, in inches, in the Pomperaug Basin, July, 1913, to December, 1916

Bethlehem

Day	July	Aug.	Sept.	Oct.	Nov.	Dec.	Day	July	Aug.	Sept.	Oct.	Nov.	Dec.
1913							1913						
1	0	0	0	0	------	0	16	0	0	0	0	0	0
2	0	.14	0	2.17	------	0	17	0	0	0	0	.34	0
3	0	0	0	0	------	0	18	0	.02	.51	0	0	0
4	0	0	0	0	0.07	0	19	.25	0	.13	0	0	0
5	0	0	.20	0	0	0	20	0	0	.26	.54	.24	0
6	0	0	0	0	0	0	21	.05	0	.15	.42	0	0
7	0	.76	.01	0	0	.37	22	0	0	.54	0	0	.36
8	0	0	1.02	0	0	.77	23	0	.35	0	0	0	0
9	0	0	0	0	.43	0	24	.07	0	0	0	0	0
10	.23	0	0	.04	.54	0	25	.06	0	0	2.41	0	0
11	0	.03	0	0	0	0	26	0	0	0	2.49	0	.69
12	0	0	0	1.06	0	0	27	0	0	0	.92	0	0
13	1.22	0	0	0	0	0	28	0	0	0	.01	0	0
14	.22	.05	0	0	0	0	29	1.03	.46	0	0	.46	0
15	0	0	0	0	.12	0	30	0	1.09	0	0	------	0
							31	0	0	------	0	------	0
								3.13	2.90	2.82	10.06	[a] 2.20	2.19

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1914												
1	------	------	------	0	0	0	0	0	------	0	0	0
2	------	------	------	.24	0	.56	1.17	0	------	0	.17	0
3	------	------	------	0	0	0	0	.12	------	0	0	0
4	------	------	------	0	0	0	0	0	------	0	0	0
5	------	------	------	0	.43	.84	0	0	------	0	0	0
6	------	------	------	0	1.20	0	0	0	------	0	0	0
7	------	------	------	.19	0	0	.84	.03	------	0	0	0
8	------	------	------	.10	0	0	.23	0	------	0	0	.50
9	------	------	------	.72	.07	.09	0	0	------	0	.33	0
10	------	------	------	0	.11	0	0	0	------	0	0	0
11	------	------	------	0	0	0	.03	.71	------	0	0	0
12	------	------	------	.12	.55	0	.10	.49	------	0	0	0
13	------	------	------	0	.74	0	0	0	------	0	0	0
14	------	------	------	0	0	0	0	0	------	0	0	1.30
15	------	------	------	0	0	0	1.27	0	------	0	0	0
16	------	------	------	.76	0	.36	.03	0	------	.35	2.00	0
17	------	------	------	.02	0	0	0	0	------	2.66	.20	0
18	------	------	------	0	0	0	0	.25	------	.11	0	0
19	------	------	------	0	0	0	0	.15	------	.45	0	0
20	------	------	------	0	0	.61	0	.05	------	0	.44	.24
21	------	------	------	.75	0	0	0	.25	------	0	0	0
22	------	------	------	0	0	.28	2.8	1.11	------	0	0	.36
23	------	------	------	0	0	.08	0	0	------	0	0	0
24	------	------	------	0	0	0	.21	0	------	0	0	0
25	------	------	------	0	0	.08	0	0	------	0	0	.01
26	------	------	------	1.12	0	0	0	0	------	0	0	0
27	------	------	------	.25	0	0	0	0	------	0	0	0
28	------	------	------	.02	0	.28	.30	0	------	0	0	0
29	------	------	------	.02	0	.17	1.20	.25	------	0	0	0
30	------	------	------	.06	0	0	.04	.08	------	0	0	.41
31	------	------	------	------	.17	------	.03	0	------	0	------	0
	------	------	------	4.37	3.27	3.35	5.73	3.49	0.33	3.57	3.14	2.82
1915												
1	0	0.82	0	0	0.39	0	2.00	0	0	0	0	0
2	0	1.01	0	0	0	0	.10	0	0	.75	0	0
3	.05	.13	0	0	.05	0	.29	.25	0	.08	0	0
4	0	.05	0	.09	0	0	0	.07	0	0	0	0
5	0	0	0	0	.43	0	.58	3.10	0	0	0	0
6	0	.60	0	0	.05	0	0	.04	0	.22	.16	0
7	1.29	0	0	.13	0	.04	0	.25	0	0	0	0
8	0	0	0	0	.35	0	.12	.13	0	.88	0	0
9	0	0	0	0	0	0	0	.38	0	0	.15	0
10	0	0	0	0	0	0	0	.78	0	0	0	0

[a] Record not quite complete.

Precipitation, in inches, in the Pomperaug Basin, July, 1913, to December, 1916—Continued

Bethlehem—Continued

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1915												
11	0	0	0	.33	0	0	0	0	0	0	0	0
12	0	0	0	.81	0	.22	.08	0	0	0	0	0
13	1.41	0	0	0	.48	0	.01	0	0	0	0	0
14	0	0	0	0	0	0	0	.72	0	0	0	.75
15	0	.15	0	0	0	0	0	0	0	.10	.74	0
16	0	.47	0	0	0	.58	0	0	0	0	0	0
17	0	0	0	0	0	.18	.04	0	0	0	0	0
18	1.09	0	0	0	0	.02	0	0	.50	0	0	1.36
19	1.15	0	0	0	0	0	0	0	.20	0	0	.12
20	0	0	0	0	0	0	.27	0	0	0	.95	0
21	0	0	0	0	0	.28	.02	0	0	.34	0	0
22	0	0	0	0	1.02	0	.23	.56	3.50	0	0	0
23	0	0	0	.31	.10	.30	0	.52	0	0	0	0
24	1.12	0	0	0	0	0	0	0	0	0	0	.02
25	0	2.29	0	0	.27	0	0	.61	0	0	0	0
26	.08	.19	.02	0	0	.20	0	0	0	0	0	.86
27	0	0	0	0	.26	0	.35	0	.23	.43	.15	0
28	0	0	0	0	0	.07	0	0	0	0	0	0
29	0	------	0	.09	0	0	.60	.22	0	0	0	0
30	0	------	0	0	0	0	0	.22	0	0	.16	.21
31	0	------	0	------	0	------	.01	.02	------	0	------	0
	6.19	5.71	.02	1.76	3.40	1.89	4.70	7.87	4.53	2.80	2.31	3.32
1916												
1	0	0	0	0	0	0	0	0	0	0	0	1.60
2	.43	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	.15	.55	0	0	.25	.35	0	0	0	0	0	0
5	0	0	0	.11	0	0	.75	0	0	0	0	0
6	0	0	0	0	0	.60	0	0	0	0	.60	0
7	.04	0	0	0	0	0	0	1.23	0	0	0	0
8	0	0	.30	0	0	.40	0	0	0	0	0	0
9	0	0	0	0	.41	.05	0	.68	0	0	0	0
10	0	0	.67	.23	0	0	.35	0	0	0	0	0
11	.50	0	.04	0	0	0	0	.52	0	0	0	0
12	0	0	0	0	0	0	.25	0	0	0	0	0
13	0	.85	0	.16	0	0	.47	0	0	0	0	0
14	.14	0	0	0	0	0	.98	0	0	.30	0	0
15	0	0	0	.77	.45	0	0	0	0	0	0	.82
16	0	0	.85	0	.07	.48	0	0	1.36	.03	0	0
17	0	0	0	0	1.21	1.20	0	0	0	0	0	0
18	0	0	0	0	.10	0	0	0	0	0	0	0
19	0	0	0	.10	0	.25	0	0	.56	0	0	0
20	0	0	0	0	0	0	0	0	0	1.06	0	0
21	0	0	0	0	0	.32	.23	0	0	0	0	0
22	0	0	0	.60	0	.10	0	0	0	0	0	0
23	0	0	.33	0	0	0	0	0	0	0	0	1.49
24	0	0	0	0	.16	0	.09	1.13	0	0	1.44	0
25	0	.80	0	0	0	.40	0	0	0	0	0	0
26	0	1.40	0	0	0	0	.61	0	0	.04	0	0
27	0	0	0	0	0	0	0	.09	0	0	0	0
28	.06	0	0	.04	0	0	0	.55	0	0	0	0
29	0	0	0	0	1.07	0	0	0	0	0	0	.49
30	0	------	.34	0	0	0	0	0	1.52	0	0	0
31	0	------	0	------	.57	------	0	0	------	0	------	0
	1.32	3.60	2.53	2.01	4.29	4.15	3.73	4.20	3.44	1.43	2.04	4.40

Precipitation, in inches, in the Pomperaug Basin, July, 1913, to December, 1916—Continued

North Woodbury

Day	July	Aug.	Sept.	Oct.	Nov.	Dec.	Day	July	Aug.	Sept.	Oct.	Nov.	Dec.
1913							1913						
1	0	0	0	0	0	0	16	0	0	0	------	0	0
2	0	.15	.01	2.05	0	0	17	0	0	Tr.	0	.65	0
3	.01	Tr.	Tr.	.04	0	0	18	.14	0	.58	0	0	0
4	0	0	0	0	.06	0	19	.03	------	.06	------	0	0
5	0	0	.46	0	0	0	20	0	------	.29	.42	.24	Tr.
6	.05	0	0	0	0	0	21	.01	------	.13	.35	0	.44
7	0	.79	Tr.	0	0	.14	22	0	------	.74	0	0	0
8	0	0	.44	Tr.	0	.77	23	0	------	.58	0	0	.79
9	.05	0	.24	.03	.46	0	24	0	------	0	0	0	0
10	.23	Tr.	0	0	1.08	0	25	.01	------	0	2.80	0	0
11	0	.03	0	0	0	0	26	0	------	0	2.00	0	.34
12	0	0	0	1.04	0	0	27	0	------	0	.90	0	.24
13	.63	0	0	0	0	0	28	0	.56	0	0	0	0
14	.07	.03	0	0	0	0	29	.57	.50	0	.03	.56	0
15	0	0	0	0	0	0	30	0	1.13	0	0	0	0
							31	0	0	------	0	------	0
								1.80	------	3.53	[a] 9.66	3.05	2.72

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1914												
1	0	1.33	0	0	0	0	0	0	------	0	0	------
2	0	0	3.87	.31	0	.25	1.27	0	------	0	0	------
3	0	0	0	Tr.	0	0	.27	.06	------	0	0	------
4	.16	0	0	0	0	0	.01	.31	------	0	0	------
5	.21	0	0	0	.44	.85	0	.05	------	0	0	------
6	0	0	0	0	1.47	0	0	0	------	0	0	------
7	0	[b] .30	([b])	0	0	.06	.67	0	------	0	0	------
8	0	0	0	.21	0	0	.19	0	------	0	0	------
9	0	0	0	.72	.12	0	0	0	------	0	0	------
10	0	0	0	0	.03	0	0	0	------	0	0	------
11	0	0	0	0	0	0	0	.32	------	0	0	------
12	0	0	0	.15	.59	0	.19	1.54	------	0	0	------
13	0	0	0	0	.54	0	.02	.02	------	0	0	------
14	0	([b])	0	0	0	0	0	0	------	0	0	------
15	0	0	.03	0	0	0	1.18	0	------	0	0	------
16	0	[b] .51	0	.83	0	.33	0	0	------	.30	2.50	------
17	[b] .34	0	0	.02	0	0	0	0	------	2.38	0	------
18	0	0	.16	0	0	0	.09	0	------	.07	0	------
19	0	0	.50	0	0	0	0	.28	------	.51	0	------
20	0	0	0	0	0	.61	0	.35	------	0	[b] .87	------
21	.50	0	0	.50	0	0	0	.13	------	0	0	------
22	0	0	0	.02	0	.31	.25	.30	------	0	0	------
23	0	0	0	0	0	.10	.21	0	------	0	0	------
24	0	0	0	0	0	0	0	0	------	0	0	------
25	.83	0	0	0	0	.06	0	0	------	0	0	------
26	0	0	.12	1.22	0	0	0	0	------	0	0	------
27	0	0	0	.29	0	0	0	0	------	0	0	------
28	.08	0	.42	0	0	.07	.58	0	------	0	0	------
29	0	------	.41	0	0	.19	.87	.21	------	0	0	------
30	.03	------	.12	.08	0	0	.06	.09	------	.05	0	------
31	0	------	0	------	0	------	.05	0	------	0	------	------
	2.15	------	5.63	4.35	3.19	2.83	5.91	3.66	------	3.31	3.37	------
1915												
1	0	2.00	------	0	0.36	0	2.00	0	0	0	0	0
2	0	0	------	0	0	0	0	.05	0	.82	0	0
3	0	0	------	0	.03	0	.18	.21	0	0	0	0
4	0	0	------	0	0	0	.17	.07	0	0	0	0
5	0	0	------	0	.35	0	.03	3.10	0	0	.12	0

[a] Record not quite complete. [b] Snow.

Precipitation, in inches, in the Pomperaug Basin, July, 1913, to December, 1916—Continued

North Woodbury—Continued

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1915												
6	0	1.06	------	0.09	0.06	0	0.46	0	0	0.22	0	0
7	1.31	0	------	.21	0	0	0	.50	.11	0	0	0
8	0	0	------	0	.28	0	.60	.14	0	.83	0	0
9	0	0	------	0	0	.07	1.20	.40	0	.06	.17	.09
10	0	0	------	0	0	0	0	.63	0	0	0	0
11	0	0	------	.20	0	0	0	0	0	0	0	------
12	.29	0	------	.62	.45	.12	.10	0	0	0	0	------
13	1.60	0	------	0	.05	0	0	.90	.14	0	0	------
14	0	0	------	0	0	0	.04	0	.22	0	0	------
15	0	.15	------	0	0	0	0	0	0	.09	0	------
16	0	.28	------	0	0	.65	0	0	0	0	.73	------
17	0	0	------	0	0	.20	0	.02	0	0	0	------
18	.91	0	------	0	0	0	0	------	------	0	0	2.00
19	1.10	0	------	0	0	0	.06	------	------	0	0	0
20	0	0	------	0	0	0	.22	------	.69	0	0	0
21	0	0	------	0	0	.36	.06	------	1.60	.30	1.32	0
22	0	0	------	0	1.25	0	.39	------	0	0	0	0
23	0	0	------	.29	.10	.36	0	------	0	0	.10	0
24	1.00	0	------	0	0	.03	0	------	0	0	0	.09
25	0	2.00	------	0	.25	0	0	------	0	0	0	0
26	0	.21	------	0	0	.06	0	------	0	0	0	.98
27	0	0	------	0	.19	0	.23	------	.18	.29	0	0
28	0	0	------	0	0	.16	0	1.51	0	0	.06	0
29	0	------	------	.05	0	0	.57	.37	0	0	.15	0
30	0	------	------	.13	0	0	0	.19	0	0	0	0
31	0	------	------	------	0	------	0	0	------	0	------	0
	6.21	5.70	------	1.59	3.27	2.01	6.31	------	------	2.61	2.65	------
1916												
1	0	0.22	0	0	0	0	0	0	0	0	0.16	0
2	------	------	0	0	0	0	0	0	0	0	0	0
3	.65	------	0	0	0	0	.60	0	0	0	0	0
4	0	------	0	.07	.22	.24	0	0	0	0	0	0
5	------	------	0	0	0	0	0	0	0	0	0	.04
6	.20	------	0	0	0	0	0	0	0	0	.39	0
7	0	------	0	.10	0	0	0	0	0	0	0	0
8	0	------	0	0	.47	0	0	0	0	0	0	0
9	0	------	0	0	0	.50	0	1.29	0	0	0	0
10	0	------	.50	.40	0	0	.71	.69	0	.11	0	.43
11	.45	------	0	0	0	.06	0	------	0	0	0	0
12	0	------	0	0	0	.22	0	.06	0	0	0	0
13	.19	------	0	0	0	0	0	0	0	0	0	.90
14	0	------	0	0	0	0	1.24	0	0	.25	0	0
15	0	------	0	.92	0	0	0	0	0	0	0	0
16	0	------	0	0	.30	0	0	0	1.21	0	0	.13
17	0	------	0	0	1.35	1.36	0	0	0	0	0	0
18	0	------	0	.09	0	0	0	0	0	0	.12	0
19	0	------	0	0	0	0	0	0	.86	0	0	0
20	0	------	0	.11	0	.46	0	0	0	.96	0	0
21	0	------	0	0	0	.26	.30	0	0	.03	0	.12
22	0	------	0	0	0	0	0	0	0	0	0	0
23	.03	------	0	.47	.50	0	0	0	0	0	1.44	1.18
24	0	------	0	0	.06	.56	0	1.00	.20	0	0	0
25	0	------	0	0	0	0	0	0	0	0	0	0
26	0	------	0	0	0	0	.80	0	0	0	0	0
27	0	------	0	0	0	0	.55	.15	0	0	0	0
28	.10	------	0	0	.50	0	.35	0	0	0	0	.50
29	0	------	0	.09	.39	0	0	.82	0	0	0	0
30	0	------	.42	0	0	0	0	0	1.45	0	.82	0
31	0	------	0	------	.02	------	0	0	------	0	------	------
	------	(c)	.92	2.25	3.81	3.66	4.55	------	3.72	1.35	2.93	[a] 3.30

[a] Record not quite complete.

[c] Number of light snows. Heavy rain last of month.

Precipitation, in inches, in the Pomperaug Basin, July, 1913, to December, 1916—Continued

South Britain

Day	1913				1914				1915			
	July	Aug.	Sept.	Oct.	May	June	July	Aug.	Aug.	Sept.	Oct.	Nov.
1	0	0	0	2.05	1.12	0	Tr.	0	0	0	0	0
2	0	.33	0	.06	.52	0	1.52	0	.02	0	.75	0
3	0	0	0	0	0	0	.04	.04	.70	0	.05	0
4	0	0	.07	0	0	.08	0	.17	.30	0	0	0
5	0	0	.02	0	0	.69	0	.04	.24	0	Tr.	.07
6	0	0	0	0	0	0	.48	0	0	0	.15	0
7	0	.92	1.17	0	0	0	.12	0	.47	.13	0	0
8	0	Tr.	0	0	0	.04	.04	0	.07	0	.90	0
9	.11	0	0	.05	.10	0	.01	0	.38	0	0	.11
10	.18	0	0	0	.05	0	0	.01	.17	0	0	0
11	0	0	0	.02	0	0	0	.29	0	0	0	0
12	0	0	.26	1.05	.60	0	.35	.29	0	0	0	0
13	.62	0	0	0	.42	0	0	0	.68	.10	0	.03
14	.04	.08	0	0	0	0	0	0	0	.03	0	0
15	0	0	0	0	.02	0	.86	0	0	0	.16	.84
16	0	0	0	0	0	.39	.02	0	0	0	.03	.11
17	0	0	0	0	0	0	.02	0	0	0	0	0
18	.08	0	.49	0	0	0	.10	.02	0	0	0	0
19	.02	.73	.11	.11	0	0	0	.27	0	.36	0	Tr.
20	0	0	.35	.06	0	.47	0	1.39	0	0	0	1.16
21	.13	0	.16	.02	0	.02	0	.52	0	0	.21	0
22	0	0	1.15	0	0	.60	0	.45	.84	.89	0	0
23	0	.22	.23	0	0	.01	.02	0	.54	0	0	0
24	Tr.	0	0	0	0	Tr.	.19	0	0	0	0	.02
25	.13	0	0	0	0	.04	0	0	.71	0	Tr.	0
26	0	.06	0	2.65	0	0	0	0	0	0	Tr.	0
27	0	0	Tr.	1.12	.05	0	0	0	0	.13	.23	.05
28	0	0	Tr.	1.05	0	.26	.42	0	0	0	Tr.	0
29	.67	.29	0	0	0	.37	.52	.36	.51	0	0	.09
30	0	1.63	0	0	.05	-------	.07	.11	.14	0	0	0
31	0	0	-------	.04	.02	-------	.27	-------	0	-------	0	-------
	1.98	4.26	4.01	8.28	2.95	[a]2.97	5.05	[a]3.96	5.77	1.64	2.48	2.48

[a] Record not quite complete.

Summaries of the monthly and annual precipitation at each station in the Pomperaug Basin and at the Waterbury station are given in the tables below. The average for these stations for each month, including the Waterbury station, is taken to be the precipitation in the Pomperaug Basin during that month. As the whole record for Waterbury to 1923 covers a period of 38 years, the average monthly and average annual precipitation at that station is nearly the actual average or so-called normal. It is also doubtless nearly the normal for the Pomperaug Basin and is therefore used in computing the departures from normal given in the tables.

Normal monthly and annual precipitation at Waterbury, in inches

October	4.15	May	3.95
November	3.75	June	3.20
December	4.29	July	4.68
January	4.23	August	4.48
February	3.97	September	3.86
March	4.43		
April	3.82	Annual	48.81

Monthly precipitation, in inches, in the Pomperaug Basin and at Waterbury, July, 1913, to December, 1916

Month	Bethlehem	North Woodbury	South Britain	Waterbury	Average [a]	Departure from normal [b]
1913						
July	3.13	1.80	1.98	1.36	2.07	−2.61
August	2.90	(c)	4.26	2.93	3.35	−1.13
September	2.82	3.53	4.01	3.37	3.43	−.43
October	10.06	9.66	8.28	8.83	9.21	+5.06
November	2.20	3.05		2.92	2.72	−1.03
December	2.19	2.72		2.84	2.58	−1.71
1914						
January		2.15		3.87	3.01	−1.22
February		(c)		3.10	3.10	−.87
March		5.93		6.09	6.01	+1.58
April	4.37	4.35		3.87	4.20	+.38
May	3.27	3.19	2.95	2.81	3.06	−.89
June	3.35	2.83	2.97	3.29	3.11	−.09
July	5.73	5.91	5.05	6.04	5.68	+1.00
August	3.49	3.66	3.96	3.55	3.67	−.81
September	.33			.29	.31	−3.55
October	3.57	3.31		3.18	3.35	−.80
November	3.14	1.37		2.98	2.50	−1.25
December	2.82			5.38	4.10	−.19
1915						
January	6.19	6.21		7.08	6.49	+2.26
February	5.71	5.70		5.49	5.63	+1.66
March	.02			.17	.10	−4.33
April	1.76	1.59		2.30	1.88	−1 94
May	3.40	3.27		2.78	3.15	−.80
June	1.89	2.01		1.73	1.88	−1.32
July	4.70	6.31		6.30	5.77	+1.09
August	7.87	(c)	5.77	7.82	7.87	+3 39
September	4.53	(c)	1.64	1.15	2.56	−1.30
October	2.80	2.61	2.48	2.55	2.61	−1.54
November	2.31	2.65	2.48	2.58	2.51	−1.24
December	3.32	(c)		6.37	4.86	+.57
1916						
January	1.32	(c)		1.05	1.48	−2.75
February	3.60	(c)		5.88	4.77	+.80
March	2.53	.92		3.84	2.43	−2.00
April	2.01	2.25		2.34	2.20	−1.62
May	4.29	3.81		3.40	3.83	−.12
June	4.15	3.66		5.01	4.27	+1.07
July	3.73	4.55		5.19	4.49	−.19
August	4.20	(c)		5.08	4.67	+.19
September	3.44	3.72		2.97	3.38	−.48
October	1.43	1.35		1.10	1.29	−2.86
November	2.04	2.93		2.98	2.65	−1.10
December	4.40	3.30		2.87	3.52	−.77

[a] Including Waterbury.
[b] The normal is that for Waterbury, based on a record of 38 years at that station.
[c] Record not quite complete.

Annual precipitation, in inches, in the Pomperaug Basin for the period of three years, October 1, 1913, to September 30, 1916

	Average [a]	Departure from normal
October, 1913, to September, 1914	46.66	−2.15
October, 1914, to September, 1915	45.28	−3.53
October, 1915, to September, 1916	41.50	−7.31

[a] Based on the monthly averages given in the preceding table.

DISTRIBUTION OF PRECIPITATION

The daily precipitation in the Pomperaug Basin, based on the averages for the three stations in the basin, is shown diagrammatically in Plate 19, and the monthly precipitation, as given in the preceding tables, is shown in Figure 7. The long-term monthly averages for Waterbury show a notably even distribution of precipitation through-

DIAGRAM SHOWING PRECIPITATION, TOTAL RUN-OFF, GROUND-WATER RUN-OFF, TEMPERATURE, AND FLUCTUATION OF THE WATER TABLE IN THE POMPERAUG BASIN, JULY, 1913, TO DECEMBER, 1916

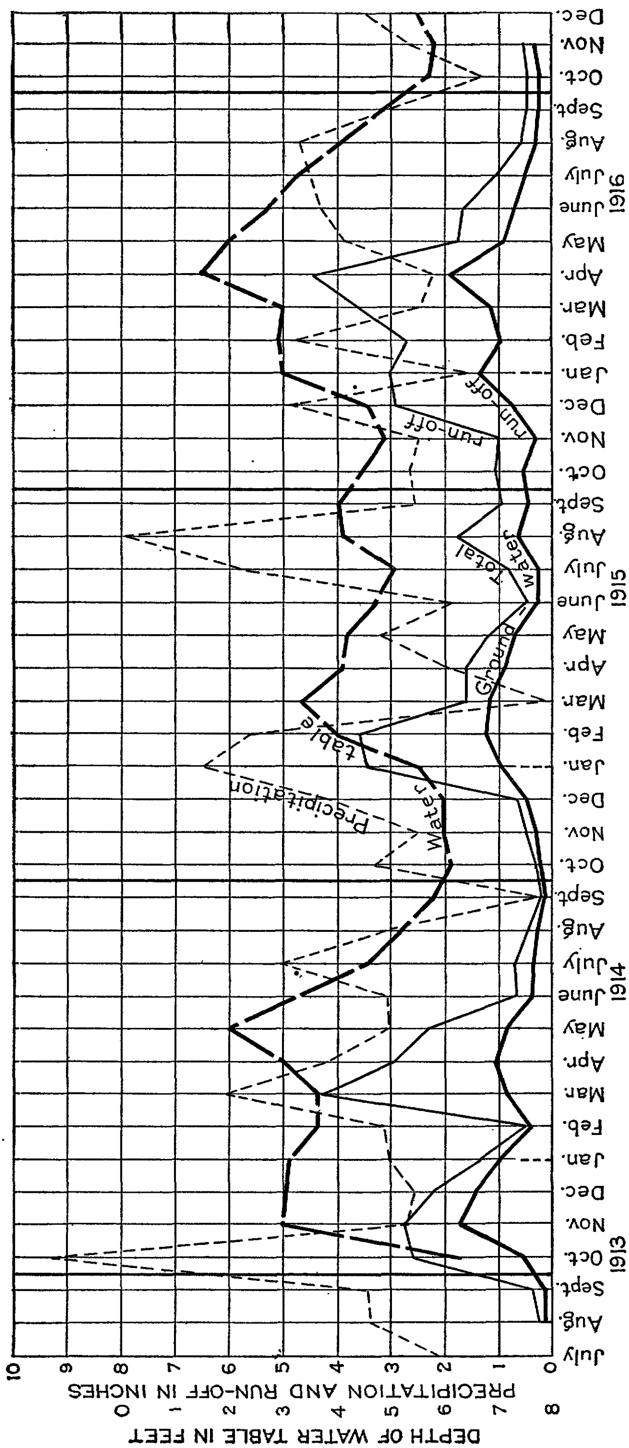


FIGURE 7.—Monthly precipitation, total run-off, ground-water run-off, and stage of the water table in the Pomperaug Basin, Conn., July, 1913, to December, 1916

out the year, which indicates that there are no definite rainy or dry seasons, as, for example, in California. There is, however, a great variation from month to month in the precipitation, as is shown in Figure 7.

A comparison of the daily precipitation at the three stations in the Pomperaug Basin shows a wide variation on certain days. These local differences indicate that the average of the three stations is not always representative of the amount of precipitation in the basin. This conclusion is in accord with results obtained by Marston [14] on local variations in precipitation in the vicinity of Boston, Mass.

SNOWFALL

The snowfall at Waterbury in the three winters under investigation is shown in the following table:

Snowfall at Waterbury, 1913–1916

Month	Inches (unmelted)			Percentage of total precipitation [a]		
	1913–14	1914–15	1915–16	1913–14	1914–15	1915–16
November	2.0	3.0	0.5	7	10	2
December	4.0	6.0	35.0	14	11	55
January	9.0	11.0	1.2	23	16	11
February	26.5	2.0	24.0	85	4	41
March	6.0	Trace.	39.0	10	0	[b] 100
April	Trace.	10.0	6.0	0	43	26
	47.5	32.0	105.7			

[a] Based on the assumption that 10 inches of snow, when melted, produced 1 inch of water.
[b] Calculated value is 102 per cent.

In the Pomperaug Basin during December, January, and February the average daily temperature is below freezing on most days, and the ground is generally frozen; consequently, the conditions are favorable for snow storage. However, in any of these months there may be warm days with rains and extensive thaws. All the snow may disappear and the ground may be bare for considerable periods. From December to February the number of days at Waterbury that had average temperatures below freezing amounted to 55 out of 90 in the winter of 1913–14, 50 out of 90 in 1914–15, and 61 out of 91 in 1915–16. In each winter there were two of these three months in which more than half the days had average temperatures below freezing. November of each year had very few days that averaged below freezing. March was variable, having only 7 such days in 1915, 11 in 1914, and 22 in 1916. Even when the mean daily temperature is below freezing the temperature during a part of the day may be well above the freezing point. Moreover, the recorded temperatures are those of the air in a place sheltered from the sun, whereas much of the snow is subjected to the direct rays of the sun. However, the water that results from the thawing on days when the mean temperature is below

[14] Marston, F. A., The distribution of intense rainfall and some other factors in the design of storm-water drains: Am. Soc. Civil Eng. Proc., vol. 50, pp. 19–46, 543–558, 1924.

freezing is largely refrozen before it has percolated far. Even in the coldest weather there is a slight loss of snow by direct evaporation.

Number of days with average temperature below freezing at Waterbury, 1913–1916.

Month	1913–14	1914–15	1915–16	Month	1913–14	1914–15	1915–16
November	1	6	1	March	11	7	22
December	10	21	24	April	0	0	0
January	22	17	15				
February	23	12	22		67	63	84

TOTAL RUN-OFF

RECORDS OF RUN-OFF

POMPERAUG RIVER

In connection with this investigation a gaging station was maintained on Pomperaug River at Bennetts Bridge, near its mouth, from July 30, 1913, to December 15, 1916, with some interruptions, especially in winter. (See pl. 13, *A*.) In the following tables are given the results of current-meter measurements made to establish the relation between gage height and discharge, also the daily, monthly, and annual discharge of the river as determined from daily gage heights according to the standard methods of the United States Geological Survey. (See also pl. 19 and fig. 7.)

POMPERAUG RIVER AT BENNETTS BRIDGE, CONN.[15]

LOCATION.—About one-fifth mile above confluence of the Pomperaug with Housatonic River, a quarter of a mile north of Bennetts Bridge, New Haven County, and 1 mile east of Sandy Hook railroad station.

DRAINAGE AREA.—89.3 square miles (measured on topographic maps).

RECORDS AVAILABLE.—July 30, 1913, to December 15, 1916, when station was discontinued.

GAGE.—Inclined staff in three parts, attached to rock ledge and to tree on right bank; read by W. H. Ingram.

DISCHARGE MEASUREMENTS.—Made from cable at gage or by wading.

CHANNEL CONTROL.—Channel irregular; bed covered with gravel and boulders. Control is formed by large rocks about 100 feet below the gage, sharply defined.

EXTREMES OF DISCHARGE.—1913–1916: Maximum stage recorded, 7.4 feet March 2, 1914 (discharge, 2,520 second-feet); minimum stage recorded, 0.68 foot September 20, 1914 (discharge, 7.7 second-feet).

ICE.—Stage-discharge relation affected by ice which forms on control and river below the gage.

REGULATION.—Operation of power plants at South Britain, 2½ miles above the station, causes a small diurnal fluctuation at low stages.

ACCURACY.—Control has been changed by obstructions at various times in previous years. Rating curve well defined below 400 second-feet; above that the curve for 1915 and 1916 is parallel to 1913 and 1914 curves. Gage read to quarter-tenths twice daily except in winter, when it was read once a day. Daily discharge ascertained by applying mean daily gage height to rating table. Records good.

[15] U. S. Geol. Survey Water-Supply Papers 351, pp. 107-108; 381, pp. 114-116; 401, pp. 102-104; 431, pp. 119-121; 451, p. 111.

Discharge measurements of Pomperaug River at Bennetts Bridge, 1913–1916

Date	Gage height	Discharge	Date	Gage height	Discharge	Date	Gage height	Discharge
1913	*Feet*	*Sec.-ft.*	1914	*Feet*	*Sec.-ft.*	1915	*Feet*	*Sec.-ft*
July 31	1.10	15.6	Jan. 14	[a] 2.90	21.6	Mar. 3	2.42	202
Oct. 16	1.59	39.7	Jan. 27	[a] 2.40	53.8	Apr. 10	2.06	126
Oct. 17	1.58	39.2	Mar. 2	6.80	2,080	Do	2.07	129
Do	1.58	38.6	Do	6.33	1,750	June 22	1.23	33.2
Oct. 27	4.71	801	Aug. 16	1.22	25.7	Dec. 21	[a] 2.74	223
Oct. 28	3.80	482	Do	1.22	25.3			
Do	3.78	472	Sept. 11	1.10	20.3	1916		
Oct. 29	3.46	382	Nov. 3	[b] 2.68	24.2	Jan. 22	[a] 3.11	161
Do	3.44	380	Nov. 18	[b] 3.05	60.6	Mar. 27	2.80	295
Do	3.44	381	Dec. 19	[b] 3.48	[a] 93.9	Do	2.86	318
Oct. 31	3.00	276				Aug. 17	1.26	385
Nov. 3	2.66	237						

[a] Stage-discharge relation affected by ice.
[b] Stage-discharge relation affected by temporary dam below the gage.

Daily discharge, in second-feet, of Pomperaug River at Bennetts Bridge, July 30, 1913, to December 15, 1916

Day	July	Aug.	Sept.	Day	July	Aug.	Sept.	Day	July	Aug.	Sept.
1913				1913				1913			
1		17	24	11		18	21	21		21	29
2		18	22	12		18	21	22		19	56
3		17	21	13		17	22	23		22	83
4		16	20	14		18	20	24		19	39
5		16	21	15		19	20	25		20	32
6		15	20	16		20	20	26		18	28
7		18	21	17		18	24	27		18	28
8		20	37	18		20	22	28		19	24
9		18	34	19		23	22	29		19	23
10		17	26	20		23	27	30	16	39	23
								31	16	30	

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1913–14												
1	24	250	180	125			250	200	62	41	36	24
2	190	230	166	109		1,730	385	170	74	144	32	23
3	109	210	158	118		610	280	149	59	95	31	22
4	58	200	146	130		550	230	144	81	62	35	22
5	43	190	143	143		430	200	325	133	48	32	20
6	38	170	136	109		355	190	550	73	41	31	19
7	34	162	152	105		250	180	370	54	51	28	18
8	35	152	310	107		190	200	250	57	95	25	20
9	34	355	210	113		190	400	240	48	67	24	19
10	32	460	180	124		156	260	220	50	47	27	19
11	32	290	180	107		138	230	190	57	42	67	18
12	92	250	162			118	210	270	46	51	47	18
13	92	230	150			106	190	385	40	41	35	17
14	54	230	154			120	166	290	31	35	31	18
15	43	220	154			180	156	230	35	101	30	14
16	40	210	136			300	370	190	47	97	26	14
17	35	260	136			370	250	170	48	64	26	13
18	34	240	130			310	190	159	32	60	24	14
19	34	210	113			250	170	139	30	44	26	14
20	48	250	99			180	170	133	57	38	49	7.7
21	115	220	112			128	230	127	43	34	45	16
22	64	200	170			134	200	113	49	31	97	14
23	43	190	158			127	170	102	56	36	47	18
24	46	170	430			138	149	94	45	35	36	16
25	760	166	230			170	138	85	38	31	30	11
26	1,520	158	290			290	400	78	35	29	28	12
27	1,040	148	210			400	355	73	32	28	25	
28	520	141	154			760	270	68	31	31	26	
29	385	220	143			760	250	58	35	63	28	
30	310	200	132			490	230	45	42	56	28	
31	270		130			290		35		45	26	

Daily discharge, in second-feet, of Pomperaug River at Bennetts Bridge, July 30, 1913, to December 15, 1916—Continued

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1914–15												
1	------	22	45	------	------	272	70	148	54	195	21	71
2	------	22	40	------	------	231	71	110	49	104	27	64
3	------	26	40	------	------	209	76	97	46	76	32	55
4	------	26	35	------	------	155	66	85	43	55	246	52
5	------	22	35	------	------	151	107	114	40	50	392	50
6	------	22	35	------	------	166	144	112	39	93	184	50
7	------	19	45	------	------	163	189	91	37	53	203	49
8	------	19	40	------	------	159	159	104	43	71	141	50
9	------	26	45	------	------	134	144	104	40	257	193	49
10	------	22	45	------	------	134	128	82	37	101	355	42
11	------	22	45	------	------	127	182	70	32	70	189	36
12	------	22	------	------	------	122	420	64	33	60	137	35
13	------	22	------	------	------	120	224	98	30	52	235	40
14	------	26	------	------	------	114	176	91	29	55	159	44
15	------	26	------	------	------	114	153	71	28	50	118	39
16	------	112	------	------	------	114	135	61	46	32	103	35
17	105	91	------	------	------	106	127	66	42	36	84	32
18	66	55	------	------	------	97	118	77	38	31	76	36
19	55	50	------	------	------	93	110	63	34	34	65	36
20	50	66	------	------	------	97	104	56	32	30	61	37
21	35	66	------	------	------	93	93	56	37	36	54	355
22	30	55	------	------	------	96	89	213	32	46	120	280
23	30	45	------	------	------	107	107	159	31	37	211	155
24	26	45	------	------	------	106	120	112	40	32	112	97
25	26	45	------	------	------	96	101	127	30	27	182	84
26	26	45	------	------	------	91	93	101	29	28	141	75
27	26	55	------	------	------	85	89	118	28	30	85	80
28	22	55	------	------	------	78	80	85	29	24	72	65
29	22	45	------	------	------	87	85	72	27	44	78	58
30	22	45	------	------	------	77	89	58	26	40	117	55
31	26	------	------	------	------	72	------	56	------	31	96	------
1915–16												
1	48	54	72	220	257	282	1,100	135	109	62	48	33
2	78	54	67	245	220	232	1,050	126	87	57	42	29
3	112	51	65	232	208	208	800	118	84	144	40	27
4	84	48	58	175	220	197	605	126	106	115	38	27
5	77	51	56	197	197	175	470	118	100	83	36	28
6	89	51	56	605	175	165	380	115	164	72	36	23
7	77	47	51	270	208	154	350	110	103	64	36	25
8	197	47	47	245	165	154	308	109	135	54	45	25
9	165	48	47	220	154	154	350	154	118	61	97	25
10	106	50	47	208	154	154	365	110	115	96	61	22
11	87	47	47	197	144	144	320	101	115	92	96	20
12	77	47	47	197	135	135	295	87	126	92	66	20
13	70	46	47	208	126	165	282	79	96	87	50	20
14	67	45	47	220	118	154	440	75	83	232	41	21
15	74	60	47	197	118	135	410	95	75	106	37	22
16	65	97	47	175	118	135	295	112	75	79	33	106
17	61	71	56	175	118	154	270	500	470	68	35	41
18	57	61	154	175	118	154	258	258	258	67	32	33
19	54	88	535	165	118	118	220	175	220	57	30	61
20	62	257	270	165	110	118	197	135	245	51	28	44
21	78	135	245	154	110	110	197	116	154	51	27	33
22	70	112	197	154	103	106	220	106	154	54	27	30
23	61	97	175	154	103	106	258	144	116	55	27	30
24	56	89	175	154	103	106	220	154	101	50	61	30
25	55	84	175	208	103	103	197	126	118	47	41	29
26	52	79	2,010	270	1,520	115	175	103	175	91	33	27
27	82	72	680	425	570	295	164	91	110	126	32	26
28	78	74	500	410	380	605	164	112	96	115	41	24
29	70	75	425	282	320	950	164	175	83	71	62	25
30	61	78	320	245	------	1,730	144	144	70	58	41	175
31	57	------	220	245	------	1,270	------	144	------	55	34	------

1913: Gage read twice daily at about 7 a. m. and 6 p. m. Discharge determined from a rating curve well defined below 2,600 second-feet.

1913–14: Discharge determined from a rating curve well defined below 2,600 second-feet. Mean discharge Sept. 27–30 estimated at 12 second-feet; Jan. 12–31, 95 second-feet; Mar. 1, 152 second-feet. Discharge during winter determined from discharge measurements and climatic records.

1914–15: Discharge determined as follows: Oct. 17 to Dec. 11 from a rating curve not well defined; Mar. 1 to Sept. 30 from a well-defined rating curve. No estimates of discharge determined for the winter. For the period Oct. 1–16, on account of uncertainty as to backwater, no estimates have been made.

1915–16: Stage-discharge relation affected by ice Dec. 6–25, Jan. 8–24, and Feb. 12–25. Discharge ascertained from gage heights corrected for backwater by means of two discharge measurements, observer's notes, and weather records.

Daily discharge, in second-feet, of Pomperaug River at Bennetts Bridge, July 30, 1913, to December 15, 1916—Continued

Day	Oct.	Nov.	Dec.	Day	Oct.	Nov.	Dec.	Day	Oct.	Nov.	Dec.
1916				1916				1916			
1	61	30	118	11	23	31	52	21	60	29	
2	43	30	78	12	23	29	72	22	44	30	
3	36	29	64	13	25	29	103	23	38	39	
4	32	28	57	14	27	30	67	24	33	258	
5	30	32	56	15	30	29	60	25	31	83	
6	29	52	52	16	28	29		26	30	57	
7	28	38	47	17	26	32		27	29	47	
8	27	34	42	18	24	31		28	28	46	
9	25	33	43	19	41	28		29	28	43	
10	25	32	70	20	95	27		30	28	78	
								31	28		

Monthly discharge of Pomperaug River at Bennetts Bridge, August, 1913, to November, 1916

[Drainage area, 89.3 square miles]

Month	Discharge in second-feet				Run-off (depth in inches on drainage area)
	Maximum	Minimum	Mean	Per square mile	
1913					
August	39	15	19.7	0.221	0.25
September	83	20	27.7	.310	.35
October	1,520	24	199	2.23	2.57
November	460	141	219	2.45	2.73
December	430	99	173	1.94	2.24
1914					
January			[a] 103	1.15	1.33
February			[a] 49.9	.559	.58
March	1,730	106	[a] 335	3.75	4.32
April	400	138	236	2.64	2.94
May	550	35	182	2.04	2.35
June	133	30	50.7	.568	.63
July	144	28	54.3	.608	.70
August	97	24	34.8	.390	.45
September	24	7.7	[a] 16.3	.183	.20
October	105	[a] 12	[a] 24.5		[a] .31
November	112	19	40.6	.455	.51
December			[a] 48.5		.62
1915					
March	272	72	125	1.40	1.61
April	420	66	128	1.43	1.60
May	213	56	94.2	1.05	1.21
June	54	26	36.0	3.40	.45
July	257	24	60.6	.678	.78
August	392	21	138	1.55	1.79
September	355	32	73.5	.823	.92
October	197	48	78.3	.877	1.01
November	257	45	73.8	.826	.92
December	2,010	47	225	2.52	2.90
1916					
January	605	154	232	2.60	3.00
February	1,520	103	224	2.51	2.71
March	1,730	106	283	3.17	3.66
April	1,100	144	356	3.99	4.45
May	500	75	137	1.53	1.76
June	470	70	135	1.51	1.68
July	232	47	81.0	.907	1.05
August	97	27	43.6	.488	.56
September	175	20	36.0	.403	.45
October	95	23	34.0	.381	.44
November	258	27	44.8	.502	.56
December 1–15	118	42	65.4	.732	.41

[a] Estimated.

Annual discharge of Pomperaug River at Bennetts Bridge

Period	Discharge in second-feet				Run-off (depth in inches on drainage area)
	Maximum	Minimum	Mean	Per square mile	
October, 1913, to September, 1914	1,730	7.7	140	1.57	21.04
October, 1914, to September, 1915					16.79
October, 1915, to September, 1916	2,010	20	159	1.78	24.15
3-year period, October, 1913, to September, 1916	[a] 2,010	[a] 7.7			[b] 20.66
Entire period, July 30, 1913, to Dec. 15, 1916	[a] 2,010	[a] 7.7			

[a] No record for January and February, 1915. [b] Annual average.

NONEWAUG RIVER

A gaging station was maintained on Nonewaug River at Alder Swamp Bridge, near its mouth, from July 13 to December 31, 1915. The results of current-meter measurements and the daily discharge in second-feet for the period are given in the following table. (See also fig. 10.) The record is discussed on pages 108–113.

NONEWAUG RIVER AT ALDER SWAMP BRIDGE

LOCATION.—Short distance above Alder Swamp Bridge.
DRAINAGE AREA.—About 25 square miles.
RECORDS AVAILABLE.—July 13 to December 31, 1915.
GAGE.—Staff gage nailed to tree.
EXTREMES OF DISCHARGE.—Maximum, 300 second-feet on December 26; minimum, 6.0 second-feet on August 2.

Discharge measurements of Nonewaug River at Alder Swamp Bridge

Date	Gage height	Discharge
	Feet	*Sec. ft.*
July 9, noon	1.11	66.02
July 10, 9.30 a. m	.68	27.37
July 12, 10 a. m	.46	14.30
July 14, noon	.40	11.26

Daily discharge, in second-feet, of Nonewaug River at Alder Swamp Bridge, July to December, 1915

Day	July	Aug.	Sept.	Oct.	Nov.	Dec.
1		6.6	18.9	11.3	13.5	17.8
2		6.0	14.3	40.1	12.9	17.1
3		7.0	11.3	28.8	12.9	17.1
4		7.5	8.8	28.8	11.3	17.1
5		173.5	7.8	28.8	13.5	17.1
6		54.0	8.4	27.4	12.9	17.1
7		82.5	8.0	26.0	11.8	13.5
8		50.8	8.0	123.5	11.3	14.0
9		[a] 122.0	7.8	54.0	21.6	14.3
10		97.0	7.8	39.2	12.3	14.3
11		57.0	7.8	34.1	11.8	14.3
12		122.0	8.0	22.3	11.3	11.8
13	12.3	150.0	8.8	20.0	12.3	Obstructed by snow.
14	10.9	54.0	9.0		11.8	
15	9.5	34.1	8.8		34.1	
16	8.8	30.9	8.8		27.4	
17	8.4	27.4	8.4		20.0	
18	8.0	22.3	9.5		15.9	
19	7.5	18.3	9.5	13.5	21.6	
20	8.4	14.3	9.0	15.4	214.7	
21	[b] 9.8	11.8	12.9	24.8	39.2	77.9
22	13.5	10.5	129.3	17.8	30.0	54.0
23	9.5	76.6	32.0	14.8	24.2	50.9
24	7.8	54.0	18.9	14.3	20.5	49.0
25	7.0	45.0	16.5	14.0	19.5	42.6
26	6.3	36.9	14.8	12.9	19.5	300.0
27	7.0	23.7	14.0	33.0	19.5	181.0
28	6.8	21.0	14.0	20.5	20.0	76.8
29	13.5	19.5	12.9	17.1	20.5	101.0
30	8.4	34.1	11.8	15.9	20.0	79.0
31	7.0	27.4		14.3		Reading stopped.

[a] 70.5 second-feet before rain.
[b] 7.8 second-feet 2 hours before rain.

DISTRIBUTION OF RUN-OFF

The daily discharge of surface water from the Pomperaug Basin for the period August 1, 1913, to December 15, 1916, is shown by means of a curve in Plate 19. Two features of the run-off are conspicuous—sharp peaks, coinciding with heavy rainfall or, in winter, often with high temperatures and rapid thaws; and general seasonal fluctuation, the high run-off normally occurring in winter and spring and the low run-off in summer and fall.

The monthly run-off from the Pomperaug Basin from August, 1913, to November, 1916, in relation to the monthly precipitation, is shown in Figure 7; and the average monthly run-off, in relation to the average monthly precipitation for the same period, is shown in Figure 8. During the summer the run-off is small in comparison to the precipitation, but during some winter months it is greater than the precipitation. In the summer much of the rainfall is evaporated directly or used by plants, and very little reaches the streams. In the winter a large part of the precipitation falls as snow and may remain on the ground from one month to another. When the accumulated snow melts it may produce a monthly run-off that is greater than the precipitation for that month. This is clearly shown by the records for March, 1915, when the run-off was 1.61 inches but the precipitation as recorded was only 0.10 inch, and for April, 1916, when the run-off was 4.45 inches and the precipitation only 2.20 inches. It

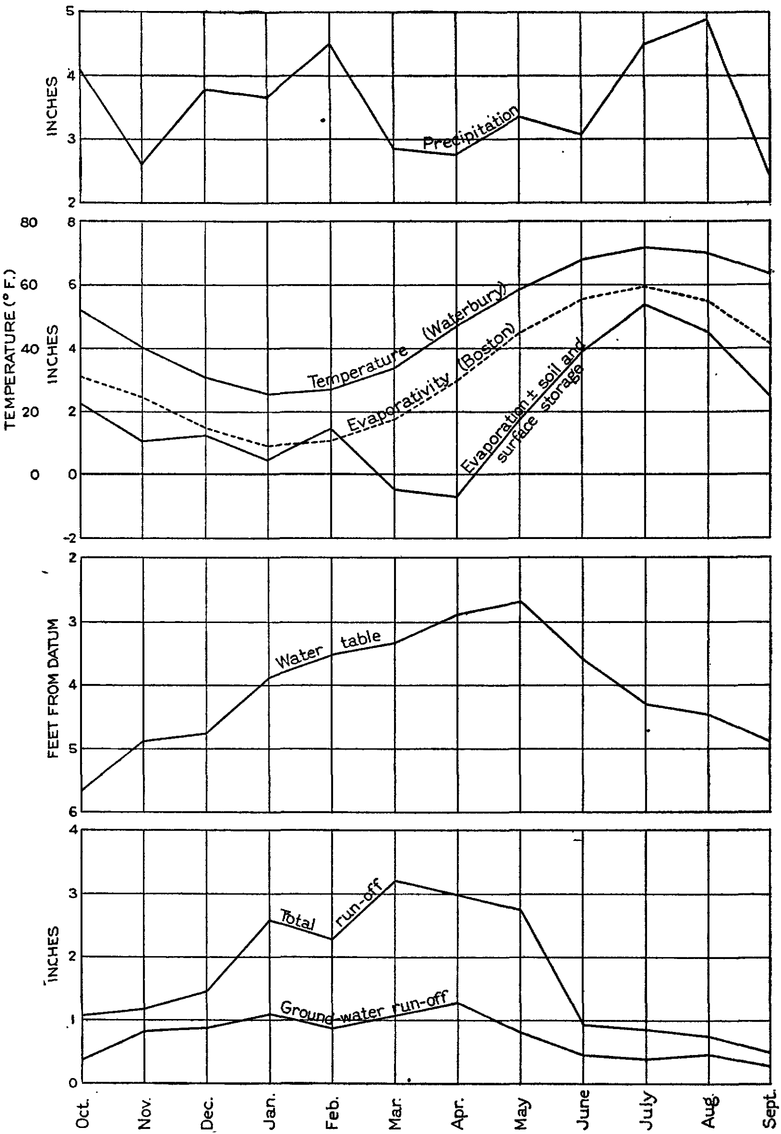


FIGURE 8.—Average monthly weather and water conditions in the Pomperaug Basin, Conn., August, 1913, to December, 1916. The precipitation curve is based on the monthly averages for the Pomperaug Basin during the period, not the Waterbury normal

sometimes happens that heavy precipitation occurs near the end of a month, producing disproportionately high run-off in the following month. In October, 1913, the precipitation was abnormally high, and there were very heavy rains in the last week of the month; the precipitation in November was low, but as a result of the October rains the run-off in November exceeded the precipitation.

In the year October, 1913, to September, 1914, the annual precipitation was 46.66 inches, which was only slightly below normal, and the run-off was 21.04 inches. At the beginning of this water year, in October, 1913, dry conditions evidently prevailed. The water table was low, the soil was probably dry, and the run-off was low. The heavy precipitation of October supplied soil moisture, raised the water table, and caused a high run-off. However, at the end of the water year, in September, 1914, dry conditions again prevailed, the soil moisture was depleted, and the water table receded to about the level it had in the preceding autumn. This year therefore approximated average conditions, and the run-off is probably not very far from the average annual run-off from the basin. The discharge records for January and February were, however, unsatisfactory because of the effects of backwater produced by ice, and the estimates for these two months may be somewhat low.

In the year October, 1914, to September, 1915, the precipitation was 45.28 inches and the run-off only 16.79 inches. Several conditions tended to make the run-off relatively low. Dry conditions prevailed at the beginning of the water year, but at the end of the year, in September, 1915, there was relatively abundant soil moisture and the water table averaged about 1.7 feet higher than in the preceding October. Some of the precipitation was evidently stored as soil moisture or as ground water, and there was correspondingly less run-off in proportion to the precipitation than in the preceding water year. Further, the very dry spring of 1915, especially in March, reduced the amount of annual run-off below normal, as spring is the season of usual heavy run-off. March and April in both 1914 and 1916 had high run-off. Moreover, in July and August, 1915, there was heavy precipitation, but it was well distributed and produced little run-off. This precipitation, together with that in September, left the soil moist and the ground-water supply replenished at the end of September. All these conditions resulted in a low run-off during the year in spite of nearly normal precipitation.

In the year October, 1915, to September, 1916, the precipitation was only 41.5 inches, whereas the run-off was 24.15 inches—the highest of the three years under investigation. The year began with moist soil and a high water table, and hence there was relatively large run-off in spite of the rather small precipitation. At the end of the water year, in September, 1916, the usual dry conditions prevailed. However, for several of the winter months the precipitation at Waterbury was much heavier than that recorded at some of the stations in the Pomperaug Basin, which suggests that there were either larger local differences in precipitation than would be expected in winter or else considerable errors due to the difficulties in obtaining measurements of snowfall and of converting these into depth of water. The actual precipitation on the basin was probably greater than is indicated by the average of the available records.

It should be recognized that for the entire period both precipitation and run-off data may have rather large percentages of error because not enough precipitation stations were maintained to make the average results entirely representative and because of interruptions in the discharge records, especially in the winter, when ice in the river interfered with accurate work.

GROUND-WATER RUN-OFF

GENERAL CONDITIONS

The run-off from the Pomperaug Basin shown in the preceding tables consists of direct run-off and ground-water run-off. The direct run-off is the water that reaches the streams by flowing over the surface; the ground-water run-off is the water that reaches the streams by traveling underground, first forming a portion of the ground-water supply in the zone of saturation and later seeping out along the stream channels. After a rain the direct run-off reaches the streams quickly, and nearly all of it is discharged from the basin within a few days. That part of the rain which becomes ground water, however, reaches the streams much later and during a longer period because of its retardation in its underground course. Thus the soil and the underlying deposits act as a reservoir, receiving a part of the water from rains and snows and yielding it slowly and gradually to the streams. Consequently, there is generally a small but steady stream flow throughout the summer, when very little of the precipitation reaches the ground water and when for considerable periods there is virtually no direct run-off.

METHOD OF ESTIMATING GROUND-WATER RUN-OFF

An effort was made to determine the quantity of ground water that percolates into the streams and is carried out of the basin by Pomperaug River. The general method applied is that used by Houk [16] in his investigations of flood control in Ohio. It is based on the facts that the direct run-off from any rain is nearly all carried out of the basin within a few days of the time it falls and that in the later part of any protracted period of fair weather the water discharged by the trunk stream is nearly all ground water.

[16] Houk, I. E., Rainfall and run-off in Miami Valley, State of Ohio: Miami Conservancy District Tech. Repts., pt. 8, 1921.

Curves were drawn by Houk [17] showing both total and ground-water run-off from the drainage basin of Mad River above Wright, Ohio, for the period 1915 to 1919. (See fig. 9.) The curves showing ground-water run-off were drawn so as to pass through the low points only of the hydrograph for total run-off. They are very smooth, and the resulting estimates of ground-water run-off seem to be conservative.

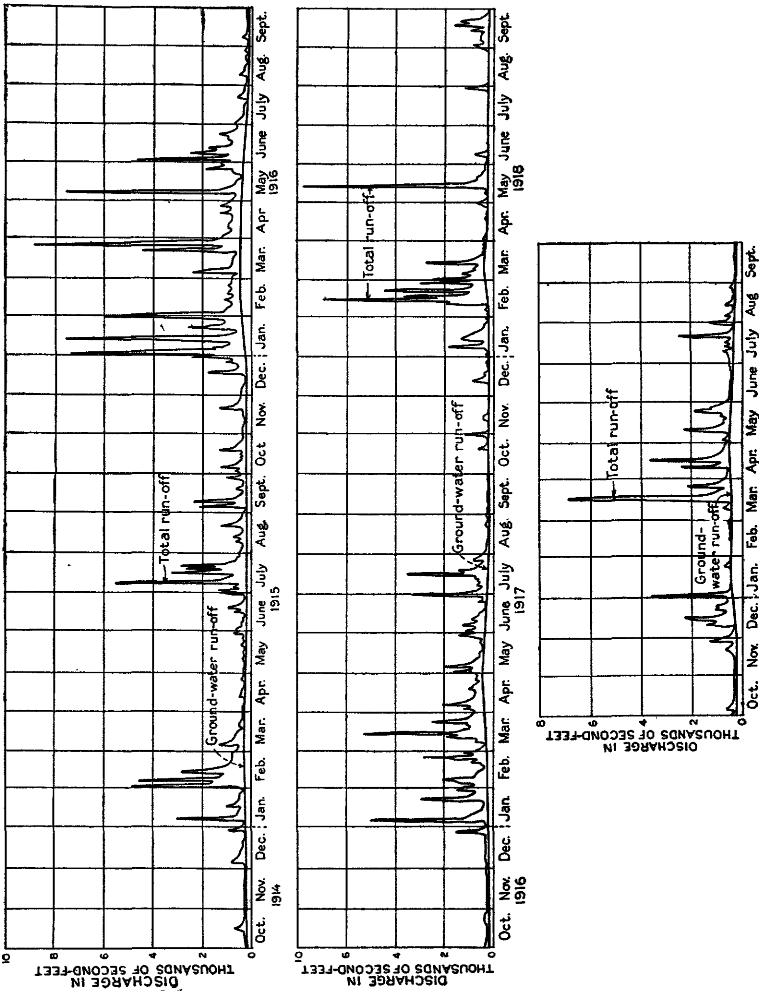


FIGURE 9.—Total and ground-water run-off from the drainage basin of Mad River above Wright, Ohio, 1915 to 1919. (After Houk)

The diagrams in Plate 19 and Figure 10 show that the crest of a flood reaches the mouth of the Pomperaug very promptly after the rain that causes it. Generally the crest reaches the mouth of the Nonewaug on the same day that the rain occurs and the mouth of the Pomperaug on the same or the following day. Special observa-

[17] Houk, I. E., op. cit.

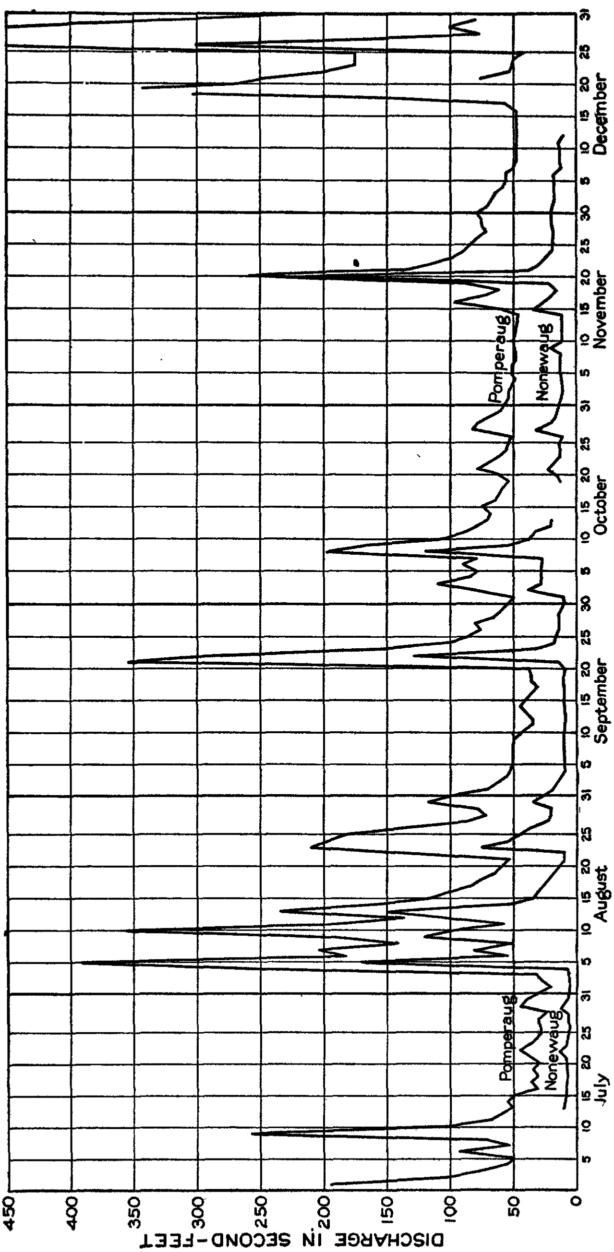


FIGURE 10.—Hydrographs of Pomperaug River at Bennetts Bridge and of Nonewaug River at Alder Swamp Bridge, Conn., July to December, 1915, showing the brief interval that elapses between the crests of floods at the two stations

tions were made of the flood that resulted from the rain on July 8, 1915. On that day there was only a slight rain at the Bethlehem station, but at North Woodbury about 0.60 inch of rain fell early in the forenoon and about 1.20 inches during the afternoon—mostly during the middle of the afternoon. No rain fell at North Woodbury after 7 p. m. The crest of the flood reached the Alder Swamp Bridge, on Nonewaug River, some time in the evening of July 8, and the river had subsided somewhat by the morning of July 9. The Pomperaug at Bennetts Bridge had not yet felt any effects of the rain when the gage was read on the evening of July 8, but it had risen slightly by the morning of July 9, and it reached its crest about the evening of July 9, about one day after the crest had passed the Alder Swamp Bridge. The Nonewaug was nearly though not entirely back to its pre-storm condition by the morning of July 10, about a day and a half after it had been at its highest stage; the Pomperaug had subsided nearly to normal by July 11, within two days after it had been at its highest stage.

At noon July 9, when the Nonewaug was still in flood, it was flowing at the Alder Swamp gaging station at an average velocity of fully 1½ feet a second, or 24 miles a day; at noon July 14, when it was again at a low stage, it was flowing at an average rate of fully 9 inches a second, or about 12 miles a day. The cross-section area of the stream at this point is more or less normal, indicating that the velocities given can be taken as a rough measure of the rate at which the water moves toward its exit from the basin.

Rough calculations indicate that the entire volume of water in the Pomperaug and its tributaries at a given stage, exclusive of a few of the largest ponds, is only equal to the volume that is discharged by the stream in a short period—probably not more than two days. The large ponds, which have considerable storage capacity, introduce some uncertainty. However, it is a matter of common observation that at all stages of the Pomperaug its water is drawn from numerous brooks, draining all parts of the basin, and that the ponds do not notably increase the flow of the streams on which they are situated. No rain of sufficient consequence to have much effect on the streams occurred until July 20, when the volume of water in the Pomperaug and its tributaries was not very much less than on July 11, although practically no direct run-off had been received in this period of 10 days. Evidently from July 11 to 20 the discharge recorded at Bennetts Bridge was only a little greater than the discharge of ground water into the Pomperaug River system. Similar analysis of other storms and succeeding periods of fair weather will give approximately the ground-water run-off for those periods.

The total run-off as measured at the gaging station near the mouth of Pomperaug River was plotted in second-feet by days for the period from October 1, 1913, to December 15, 1916. (See pl. 19.) On this diagram was drawn a ground-water run-off curve, in general connecting the troughs of the total run-off curve. The drawing of the ground-water run-off curve was a somewhat arbitrary process in several respects:

1. Although most of the direct run-off from a given storm is discharged within a day or two after the storm, a good many days probably elapse before the last of the direct run-off has passed under Bennetts Bridge. Thus although it is certain that within a few days after a storm the ground-water run-off curve approaches close to the total run-off curve, yet no data are available for determining just how close it approaches on a given day or just where the two virtually come together. In general it was assumed that during the parts of the year when there was no snow the direct run-off was discharged from the basin within a week after a rainstorm.

2. There is uncertainty as to the amount of ground-water run-off during the flood stage of a stream, and the longer the stream is kept at an abnormal stage by successive rains at short intervals the greater becomes the uncertainty. During the flood stage the discharge of ground water is probably checked because the water levels of the streams are likely to be higher than the adjacent water table. However, periods of flood run-off are commonly also periods of ground-water recharge, when the water table is built up. Hence the discharge of ground water is usually greater after a flood stage than it was before the flood, and accordingly the curve showing ground-water run-off was brought up somewhat to meet the descending curve that shows total run-off.

3. In winter and early spring the situation is complicated by the snowfall, the uncertainty as to when the snow melts, and the protracted periods of heavy discharge due in part to direct run-off but in part also to a high stage of the water table and the resulting large discharge of ground water. For this season a study as detailed as possible was made of the daily weather conditions to determine the periods of melting snow, and then about the same rule was applied as for the parts of the year when there was no snow.

Thus, in November, 1913, the ground-water run-off was computed to be 1.73 inches, which is nearly the monthly maximum for the period covered by the investigation. The ground-water run-off curve for that month was controlled by two troughs of the total run-off curve, one of which reached its lowest point on November 8 and the other on November 28. The low point of the first trough occurred at the end of a period of 11 days with virtually no precipitation at any station; the low point of the second at the end of a period of 8 days. The conclusion can therefore not be avoided that the ground-water run-off curve should approach close to the total run-off curve on these dates and should have approximately the position and form shown in Plate 19. As only 2 inches of snow (unmelted) fell during the month there can be no appreciable error due to the inclusion of melted snow with the ground-water run-off. In like manner the position of the ground-water run-off curve in December is approximately determined by the troughs of November 28 and December 20.

For a month such as April, 1914, there is more uncertainty as to the position of the ground-water run-off curve, because there was no period of more than four or five days between rainstorms that affected the run-off, and because some run-off may have been produced by the melting of snow. For such a month the position of the curve was determined by projecting the downward-trending segments of the total run-off curve, giving these projections as nearly as possible the form that is characteristic of the parts of the curve that represent long intervals of fair weather.

An attempt was made to estimate the proportion of daily run-off that is derived from ground water by comparing the chemical composition of the stream water each day with that of average well water. The gaging station on Nonewaug River (see p. 103) was established in part for this purpose, and daily samples were taken, with slight interruptions, during the period in which a record of daily discharge was obtained, July 13 to December 30, 1915. For comparison one sample was taken from each of 14 wells in the vicinity.

The constituents chosen for this experiment were the chloride radicle (Cl), the bicarbonate radicle (HCO_3), and the carbonate radicle (CO_3), because of the simple volumetric methods that could be used in determining the quantities of these radicles in the samples of well water and in the daily samples taken from Nonewaug River.

The method proved to be inapplicable in the Pomperaug Basin, at least for these constituents, because of the small amounts of each that occur in the average well water—hardly more than in the direct run-off. Thus the chloride in the 14 samples of well water averaged 3.7 parts per million. Two of the samples contained 12 and 14 parts per million, which may have been due to pollution. If these two are disregarded the chloride in the remaining 12 samples averaged only 2.1 parts per million. On the other hand, the chloride in the stream water ranged from 1.6 to 3.6 parts per million and averaged 2.6 parts. Thus, also, the bicarbonate in the 14 samples of well water averaged 50 parts per million, whereas in the daily samples of stream water it ranged from 11 to 47 parts and averaged 37 parts.

Changes in the stage of the stream generally produced small changes in both chloride and bicarbonate concentration, but they were altogether too small to be useful in estimating the quantity of ground-water run-off. In the first part of the period the chloride content regularly decreased in high stages and increased in low stages, suggesting that the ground water received by Nonewaug River contained slightly more chloride than was normal for the direct run-off. Later in the period, however, the chloride content showed a tendency to increase slightly in high stages and to decrease in low stages, as if the ground water received by the stream in that part of the period contained a little less chloride than was normal for the direct run-off. The bicarbonate evidently occurred in somewhat greater amount in the average ground water than in the direct run-off, for it generally increased in low stages and decreased in high stages. However, any differences that may have existed between the average ground water and the average direct run-off, in respect to concentration of either constituent, were so small and variable that they produced only slight and erratic changes in the concentration of the mixture from which the daily samples were taken.

ESTIMATES OF GROUND-WATER RUN-OFF

The curve in Plate 19 that shows ground-water run-off is probably as accurate as can be drawn with the available data, but greater accuracy would have been possible if more gaging stations had been maintained. A check on the accuracy of this curve is found in the closeness with which it follows the trend of the curve that shows the fluctuation of the water table. (See pl. 19 and pp. 127–129.) From the curve showing the ground-water run-off were obtained the monthly and annual ground-water run-off as given in the following table. (See also figs. 7 and 8.)

Estimated ground-water run-off and direct run-off, in inches, from the Pomperaug Basin, August, 1913, to November, 1916

Month	Total run-off	Ground-water run-off	Direct run-off	Month	Total run-off	Ground-water run-off	Direct run-off
1913				1915			
August	0.25	0.13	0.12	March	1.61	1.19	0.42
September	.35	.17	.18	April	1.60	.90	.70
October	2.57	.52	2.05	May	1.21	.67	.54
November	2.73	1.73	1.00	June	.45	.28	.17
December	2.24	1.42	.82	July	.78	.24	.54
				August	1.79	.60	1.19
1914				September	.92	.44	.48
January	1.33	[a] 1.00	[a].33	October	1.01	.55	.46
February	.58	[a].40	[a].18	November	.92	.36	.56
March	4.32	.86	3.46	December	2.90	.73	2.17
April	2.94	1.03	1.91				
May	2.35	.85	1.50	1916			
June	.63	.39	.24	January	3.00	1.34	1.66
July	.70	.38	.32	February	2.71	.99	1.72
August	.45	.29	.16	March	3.66	1.16	2.50
September	.20	.18	.02	April	4.45	1.90	2.55
October	.31	.22	.09	May	1.76	.89	.87
November	.51	.34	.17	June	1.68	.69	.99
December	[a].62	[a].50	[a].12	July	1.05	.54	.51
				August	.56	.29	.27
1915				September	.45	.25	.20
January	[b] 3.41	[a].95	[a]2.46	October	.44	.25	.19
February	[b] 3.58	[a] 1.20	[a] 2.38	November	.56	.32	.24

[a] Estimated on inadequate data.
[b] Run-off from drainage basin of Farmington River, above New Boston, Mass., area 92.7 square miles (Water-Supply Paper 401, p. 95). No records available for the Pomperaug Basin.

Estimated annual ground-water run-off, in inches, from the Pomperaug Basin, 1913–1916

October, 1913–September, 1914	9.05
October, 1914–September, 1915	7.53
October, 1915–September, 1916	9.69
Average	8.76

DISTRIBUTION OF GROUND-WATER RUN-OFF

During a period usually lasting from about November or December until about April or May the ground-water flow is large and generally reaches a maximum for the year. During this period evaporation is low and the demands of plant life are nearly zero; hence a large part of the water that falls as rain or snow is added to the soil moisture or percolates into the ground-water reservoir when the ground is not frozen. The water table generally rises and stands high during this period. Because of the high head of the ground water the flow of the springs is increased and the amount of ground-water run-off is large. Beginning about April or May, however, the amount of direct evaporation and the demands of plant life increase and the water table begins to lower. With decreased amount of ground water there is decreased head and hence decreased ground-water flow. Throughout the summer the ground-water run-off is usually small, and unless there are exceptionally heavy or persistent rains it decreases as the season advances.

Ground-water run-off in Pomperaug Basin in relation to precipitation and to total run-off

Month	Precipitation (inches)	Total run-off		Ground-water run-off		
		Inches	Per cent of precipitation	Inches	Per cent of precipitation	Per cent of total run-off
1913						
August	3.35	0.25	7	0.13	4	52
September	3.43	.35	10	.17	5	49
October	9.21	2.57	28	.52	6	20
November	2.72	2.73	100	1.73	64	63
December	2.58	2.24	87	1.42	55	63
1914						
January	3.01	1.33	44	[a] 1.00	33	75
February	3.10	.58	19	[a] .40	13	69
March	6.01	4.32	72	.86	14	20
April	4.20	2.94	70	1.03	25	35
May	3.06	2.35	77	.85	28	36
June	3.11	.63	20	.39	13	62
July	5.68	.70	12	.38	7	54
August	3.67	.45	12	.29	8	64
September	.31	.20	6	.18	6	90
October	3.35	.31	9	.22	7	71
November	2.50	.51	20	.34	14	67
December	4.10	[a] .62	15	[a] .50	12	81

[a] Estimated.

Ground-water run-off in Pomperaug Basin in relation to precipitation and to total run-off—Continued

Month	Precipitation (inches)	Total run-off		Ground-water run-off		
		Inches	Per cent of precipitation	Inches	Per cent of precipitation	Per cent of total run-off
1915						
January	6.49	[b] 3.41	53	[a] .95	15	28
February	5.63	[b] 3.58	54	[a] 1.20	21	34
March	.10	1.61	---------	1.19	1,200	74
April	1.88	1.60	85	.90	48	56
May	3.15	1.21	38	.67	21	55
June	1.88	.45	24	.28	15	62
July	5.77	.78	14	.24	4	31
August	7.87	1.79	2	.60	8	34
September	2.56	.92	36	.44	17	48
October	2.61	1.01	39	.55	21	54
November	2.51	.92	37	.36	14	39
December	4.86	2.90	60	.73	15	25
1916						
January	1.48	3.00	203	1.34	91	45
February	4.77	2.71	57	.99	21	37
March	2.43	3.66	151	1.16	48	32
April	2.20	4.45	202	1.90	86	43
May	3.83	1.76	46	.89	23	51
June	4.27	1.68	39	.69	16	41
July	4.49	1.05	23	.54	12	51
August	4.67	.56	12	.29	6	52
September	3.38	.45	13	.25	7	56
October	1.29	.44	34	.25	19	57
November	2.65	.56	21	.32	12	57

[a] Estimated. [b] Run-off from drainage basin of Farmington River above New Boston, Mass.

Average monthly ground-water run-off in Pomperaug Basin in relation to precipitation and to total run-off, August, 1913, to December, 1916

Month	Precipitation (inches)	Total run-off		Ground-water run-off		
		Inches	Per cent of precipitation	Inches	Per cent of precipitation	Per cent of total run-off
October	4.12	1.08	26	.39	9	36
November	2.60	1.18	45	.69	27	59
December	3.77	1.92	38	.88	23	46
January	3.66	2.58	70	1.10	30	43
February	4.50	2.29	51	.86	19	38
March	2.85	3.20	112	1.07	38	33
April	2.76	3.00	109	1.28	46	43
May	3.35	1.77	53	.80	24	45
June	3.09	.92	30	.45	15	49
July	4.50	.84	19	.39	9	46
August	4.89	.76	16	.33	7	43
September	2.42	.48	20	.26	11	54

Annual ground-water run-off in Pomperaug Basin in relation to precipitation and to total run-off

Month	Precipitation (inches)	Total run-off		Ground-water run-off		
		Inches	Per cent of precipitation	Inches	Per cent of precipitation	Per cent of total run-off
October, 1913, to September, 1914	46.66	21.04	45	9.05	19	43
October, 1914, to September, 1915	45.28	16.79	37	7.53	17	45
October, 1915, to September, 1916	41.50	24.15	58	9.69	23	40
Three-year average	44.48	20.66	46	8.76	20	42

In the drainage basin of Miami River above Dayton, Ohio, according to Houk,[18] in a period of 26 years, from 1894 to 1919, the annual precipitation ranged from about 24 to more than 46 inches, the total annual run-off from less than 4 to more than 24 inches, and the annual ground-water run-off from about 2 to 7 inches. (See fig. 11.) These data indicate how widely the ground-water run-off may vary from year to year, both in actual amount and in percentage of total run-off. They show that short-time records may be misleading because the few years which they cover may occur in an exceptionally wet or in an exceptionally dry period or may be abnormal in other respects.

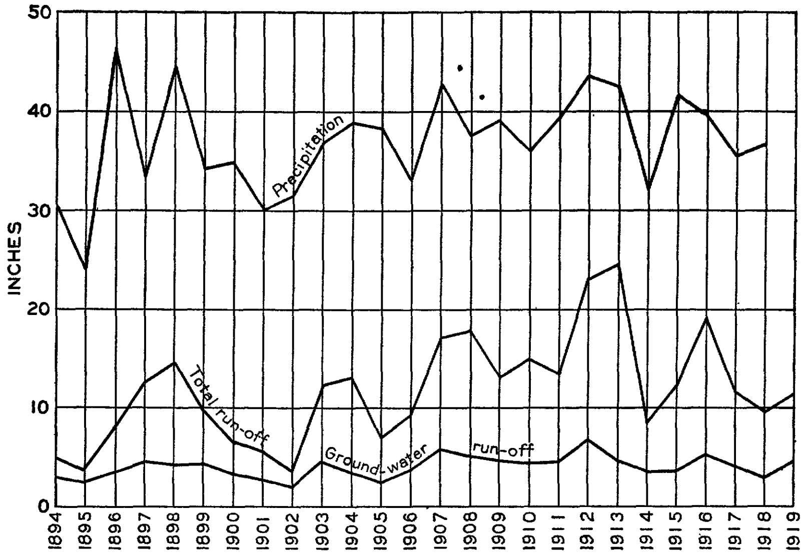


FIGURE 11.—Precipitation, total run-off, and ground-water run-off in the drainage basin of Miami River above Dayton, Ohio, 1894 to 1919. (After Houk)

FLUCTUATION OF THE WATER TABLE AND ITS RELATION TO GROUND-WATER STORAGE

RECORDS OF WATER LEVELS IN WELLS

Weekly measurements of depth to the water level were made on a number of selected wells during the period from October, 1913, to December, 1916, in order to obtain data on the fluctuation of the water table. These measurements were made chiefly by Ernest W. and George A. Parkin and Ralph Wooden, all of North Woodbury. Their faithful and careful work was of much value in the investigation and is much appreciated. The location of the wells is shown on Plate 12, and the records are given in the following tables.

Originally there were 29 wells under observation, but measurements in some of these were discontinued before the end of the investi-

[18] Houk, I. E., op. cit., p. 166.

gation. Nearly complete data for the period are available for 22 wells, of which 11 are in till and 11 in stratified drift.

Records of observation wells in the Pomperaug Basin

No.	Owner	Topographic position	Depth (feet)	Water-bearing material	Remarks
W 1	Ed. Smith	Flat	34.2	Stratified drift	Cement curb. 2-bucket rig. Water used to some extent.
W 2	Frank Chatfield	do	27.9	do	2-bucket rig. Water used to some extent. Dry every summer.
W 3	F. A. Dillingham	do	36.8	do	Observations discontinued after April, 1914.
W 4	Lant. Bennett	Slope	28.5	do	Used for washing only.
W 5		do	25+	do	Observations discontinued after August, 1914.
W 6	William Morris	Flat	16.9	do	Considerable water used.
W 7	——— Russell	Slope	28.7	Till with thin cover of stratified drift.	Not used in 1915.
W 8	Thomas Sullivan	do	30.2	do	Considerable water used.
W 9	Charles Beardsley	Flat	22.8	Stratified drift	Used in 1915. Observations discontinued October, 1913.
W 10	Henry M. Canfield	Slope	33.3	do	Not used in 1915. Records incomplete.
W 11	James Fleming	do	23.0	Till	Considerable water used.
W 12	Pine Tree House	Flat	22.5	Stratified drift	Not used in 1915. Observations discontinued in April, 1914, but resumed in July, 1915.
W 13	V. Markham	do	18.0	Till	Not used in 1915.
W 14	Oliver Towles	do	20.5	Stratified drift	2-bucket rig. Considerable water used.
W 15	S. L. Capewell	do	28.0	Till	2-bucket rig.
W 16	G. W. Drakley	do	20.6	Stratified drift	Do.
W 17		Foot of hill	24.8	Till	2-bucket rig. Observations discontinued in November, 1913, but resumed in August, 1914.
W 18	T. Comber	Flat at foot of hill.	12.9	Stratified drift	2-bucket rig.
W 19	Herbert Someset	Top of hill	22.6	Till with thin cover of stratified drift.	Do.
W 20	Old Lodge	Flat at foot of hill near river.	10.4	Stratified drift	2-bucket rig. Not used in 1915.
W 21	Edward Crane	Flat	22.9	do	Two-bucket rig. Used in 1915.
W 22	John Minor	do	41.4	do	2-bucket rig.
W 23	F. C. Parkin	Slope	26.2	Till with thin cover of stratified drift; red sandstone at bottom.	2-bucket rig and house pump.
W 24	——— Chatfield	do	25.5	Till	Pump.
W 25	W. C. Stiles	Flat	24.2	do	Windlass. Water used for drinking.
W 26	——— Baten	do	29.8	Stratified drift	Observations discontinued in October, 1913.
W 27	——— Kiel	Foot of hill	32.1	Till	Observations discontinued in April, 1914.
W 28	F. Gilbert	Slope	27.4	do	2-bucket rig.
W 29	J. Cassidy	Flat	34.5	Till with thin cover of stratified drift.	Records incomplete.

Weekly records of the depth, in feet, to the water level in the observation wells

[Records of wells 3, 5, 9, 12, 17, 26, and 27, which were under observation for only a short time, are omitted from this table]

	1	2	4	6	7	8	10	11	13	14	15	16	18	19	20	21	22	23	24	25	28	29
1913																						
Oct. 4	32.4	25.9	27.5	16.8	27.5	27.7	30.35	19.7	17.65	18.5	23.8	19.4	11.5	20.12	9.6	20.7	34.15	25.1	22.9	18.95	24.95	
Oct. 11	32.4	26.0	27.45	16.4	27.5	27.8	30.5	19.4	17.5	18.45		19.4	11.7	20.3	10.0	20.95	34.3	24.85	23.45	18.8	25.0	
Oct. 18	32.45	26.0	27.45	16.3	27.6	27.95	30.6	19.2	17.1	18.4	20.1	19.0	11.8	20.2	10.0	21.0	34.3	24.9	23.5	18.4	24.9	
Oct. 25	32.5	25.8	26.4	13.0	27.6	28.15	30.95	19.2	16.55	18.4	20.2	19.0	9.7	20.2	7.1	21.0	34.1	24.2	23.15		24.7	
Oct. 26																		20.2				
Oct. 27																		14.65				
Oct. 30																		14.1				
Nov. 1	29.95	24.4	25.85	9.1	25.6	27.6	30.4	18.2	9.2	17.8	22.95	13.55			7.55	17.9		14.65	21.25	18.7	16.9	
Nov. 8	29.1	24.45	25.2	9.4	25.45	27.8	30.2	18.3	9.45	16.85	21.45	15.55	10.4	19.65	7.7	18.25	24.05	16.65	19.4	18.4	18.1	
Nov. 15	28.5	24.1	25.6		30.15	26.5	30.2	18.0	9.2	16.2	21.25		10.6	19.9	8.1	18.15	33.65	16.0	16.5	18.5	17.5	
Nov. 22	28.1	24.45	24.65	9.15	24.8	26.6	30.05	17.9	9.15	16.0	21.85	19.4	10.55	18.15	7.95	18.3	33.9	16.5	19.1	18.8	17.55	
Nov. 29	26.8	24.1	24.5	9.4	24.65	26.5	30.1	18.0	9.6	16.2	20.5	19.1	10.1	18.5	7.85	18.7	34.1	16.15	19.1	18.75	17.1	
Dec. 6	26.5	24.15	24.55	9.9	24.5		29.9	18.2	9.4		20.6	17.6	10.85	18.3	7.0	18.6	33.5	16.8	19.4	18.4	18.7	
Dec. 13	26.3	24.1	24.5	9.95	24.5	26.9	29.9	18.0	9.3	16.3	20.4	17.6	10.7	18.2	7.0	17.5	33.4	17.6	19.5	18.5	18.3	
Dec. 20	26.7	24.1	24.6	10.2	24.8	27.15	29.9	18.1	9.4	16.3	20.5	17.9	11.4	18.4	7.2	17.8	33.3	18.1	19.7	18.75	18.8	
Dec. 27	26.4	23.9	24.65	9.6	24.35	27.1	29.9	18.1	8.8	16.4	20.7	17.5	10.8	18.05	7.0	17.7	33.4	18.15	19.8	18.4	18.0	
1914																						
Jan. 3	26.15	23.9	24.35	9.45	24.4	26.9	29.85	18.15	9.4	16.2	20.6	17.4	11.2	18.3	7.2	17.9	33.4	18.0	19.9	18.5	18.4	
Jan. 10	25.9	24.0	24.4	9.55	24.1		29.75	18.0	9.6	16.25	20.55	17.95	11.0	18.3	7.3	17.95	33.6	17.55	19.5	18.55	18.9	31.35
Jan. 17	26.1	24.3	24.6	10.0	24.4	26.8	29.8	18.1	10.0	16.4	20.9	18.15	11.2	18.5	7.15	18.1	33.4	17.6	19.7	18.6	20.0	
Jan. 24	26.6	24.3	25.0	10.9	24.4	26.6	29.8	18.3	9.6	16.45	21.3	18.35	11.3	18.85	7.3	18.4	33.8	19.3	20.0	18.1	20.3	31.2
Jan. 31	26.7	24.1	24.7	11.2	24.6	26.6	29.4	18.6	9.7	16.6	21.4	18.3	11.3	18.8	7.5	18.1	33.2	19.5	20.2	18.4	19.6	
Feb. 7	26.1	24.0	24.6	9.8	25.0	26.4	29.6	18.5	9.4	16.5	21.5	18.4	11.1	18.6	7.0	17.9	32.9	21.3	20.1	18.4	18.3	
Feb. 21	26.1	24.15	25.4	9.4	25.5	27.2	29.8	18.1	10.6	16.6	22.0	18.5	11.0	18.5	7.6	18.3	33.15	21.8	19.6	18.5	18.9	
Feb. 28	26.3	24.3	25.5	9.5	24.4	27.1	29.6	18.4	10.2	16.4	22.3	18.8	10.7	18.5	7.8	18.8	33.2	21.8	20.1	18.6	18.14	
Mar. 7	27.0	24.0	25.0	10.0	24.3	27.35	29.7	18.8	9.9	16.6	22.4	17.9	10.4	18.0	6.7	17.4	32.5	19.7	19.95	18.7	19.5	
Mar. 14	26.6	24.1	25.0	12.5	25.3	27.3	29.75	18.6	9.6	16.6	22.7	18.0	10.65	18.2	7.2	18.0	32.1	21.0	20.8	18.4	18.45	
Mar. 21	26.1	23.9	24.8	11.8	25.3	27.3	29.7	18.7	9.4	16.5	22.9	17.8	10.4	18.05	6.9	17.7	32.3	21.3	20.7	18.5	17.9	
Mar. 28	26.0	23.8	24.6	11.1	25.5	26.7	29.7	18.3	9.3	16.6	22.9	18.0	10.6	18.0	7.0	17.8	32.4	21.1	20.1	18.3	17.6	
Apr. 4	25.9	23.7	24.75	11.25	25.2	26.6	29.65	18.3	9.05	16.3	23.0	17.2	10.2	17.8	7.0	17.85	32.6	22.45	20.3	18.4	17.35	
Apr. 11	26.0	23.6	24.3	10.85	24.9	26.6	29.75	18.25	8.8	16.3	23.0	16.85	10.0	17.7	6.8	17.4	32.5	21.7	20.1	18.4	17.3	
Apr. 18	26.1	23.5	24.0	9.75	24.6	26.3	29.6	17.9	8.95	16.0	22.55	16.35	10.0	17.6	6.65	17.25	32.4	19.85	19.1	18.3	17.3	31.1
Apr. 25	25.9	23.75	23.9	9.8	24.1	26.2	29.6	17.85	9.2	15.85	22.25	16.65	10.2	17.8	6.9	17.2	32.3	18.45	18.5	18.2	18.0	31.1
May 2	25.55	23.5	23.6	9.2	23.65	26.5	27.6	17.6	9.4	15.65	21.8	16.1	10.2	17.6	6.2	16.5	32.5	16.6	17.7	17.6	17.2	31.1
May 9	25.3	23.35	23.3	9.75	23.25	25.9	29.6	17.8	8.6	15.6	21.4	15.3	10.45	17.4	5.9	15.9	32.3	14.3	17.1	17.4	16.8	31.0
May 16	25.1	23.4	22.9	8.6	22.95	25.65	29.5	17.5	8.85	15.2	21.45	15.85	10.05	17.55	5.6	15.65	32.5	13.8	16.7	17.5	16.9	31.05
May 23	24.95	23.65	23.0	9.5	22.95	25.5	29.6	17.8	9.45	15.6	20.0	16.95	10.5	17.9	6.6	17.05	32.5	14.35	26.85	18.75	18.6	31.15
May 30	25.15	23.6	23.15	9.3	23.45	25.55	29.7	17.9	10.0	15.65	19.95	17.85	10.9	18.1				16.0	18.1	18.4	18.8	31.15
June 6	25.5	23.9	25.6	9.4	23.3	25.6	29.6	18.0	10.85	15.5	20.1	18.4	10.95	18.0	6.5	17.0	32.4	18.2	19.1	18.1	18.5	31.1
June 13	25.1	24.0	25.5	11.2	23.2	25.7	29.6	18.6	11.4	15.4	19.9	18.7	11.4	18.7	7.0	17.7	32.4	18.6	19.5	18.3	22.7	31.2
June 20	25.9	24.0	24.3	12.3	23.3	25.6	29.7	18.8	12.2	16.4	20.2	18.75	10.6	18.95	7.7	18.1	32.4	19.9	19.95	18.45	22.2	31.2

June 27	26.4	24.3	24.5	12.85	23.3	25.5	29.7	19.1	12.4	16.1	20.6	19.0	11.1	19.0	7.6	18.4	32.45	20.6	20.1	18.4	23.2	31.2
July 1	26.7	24.5	24.7	13.4	26.1	26.5	29.75	18.5	13.0	16.8	21.4	18.9	11.2	19.6	7.6	18.2	34.5	21.4	20.45	18.4	23.1	31.3
July 11	26.9	24.5	25.1	13.8	25.9	26.45	29.8	18.9	13.2	17.3	21.3	19.0	12.0	19.4	8.0	19.0	34.5	22.1	20.8	18.45	23.65	31.3
July 18	27.8	24.5	25.3	13.8	25.35	26.5	29.85	19.2	13.3	17.3	21.55	19.0	11.4	19.35	8.1	19.2	34.55	22.7	21.0	18.5	23.85	31.3
July 25	28.5	24.7	25.6	13.9	25.4	26.5	29.75	19.4	13.3	17.5	21.7	19.1	11.45	-------	-------	-------	-------	23.3	21.2	18.5	-------	31.3
Aug. 1	29.3	24.7	25.9	14.5	-------	26.7	30.0	19.6	13.9	17.6	21.95	19.2	11.4	19.4	8.7	19.75	33.0	23.75	21.2	18.4	23.8	31.0
Aug. 8	30.4	25.0	26.1	15.0	25.9	27.2	30.2	20.0	14.5	17.8	22.45	19.4	11.8	19.6	9.0	19.9	33.3	23.8	21.3	18.6	24.3	31.1
Aug. 15	30.7	24.9	26.3	-------	25.7	-------	30.1	20.1	14.7	17.7	22.55	19.3	11.9	19.45	9.0	20.0	33.2	23.75	21.6	18.5	24.6	31.1
Aug. 22	31.2	25.0	26.4	15.4	26.1	25.7	29.7	20.1	14.8	17.4	22.8	19.4	11.9	19.4	9.2	20.1	32.8	23.6	21.75	18.5	24.4	31.1
Aug. 29	32.9	25.0	26.6	15.7	26.4	27.6	30.25	20.0	14.7	17.7	22.9	19.5	11.7	19.2	9.8	20.4	33.3	23.7	22.0	18.6	24.0	31.45
Sept. 5	32.2	25.5	26.5	15.55	27.9	26.3	30.65	20.2	15.0	17.9	22.7	19.6	11.8	19.6	9.8	20.5	33.5	23.65	22.05	18.7	24.45	31.5
Sept. 12	32.3	25.4	26.6	15.5	27.7	27.8	-------	20.4	15.15	18.00	23.45	19.65	12.05	19.65	10.0	20.9	32.75	23.9	22.15	19.0	24.25	31.2
Sept. 19	32.5	25.6	26.7	16.5	26.8	28.1	30.9	20.5	15.55	18.2	23.5	19.9	12.7	19.8	10.2	21.0	33.5	24.25	22.3	19.2	24.95	32.6
Sept. 26	32.3	25.7	27.5	15.85	26.85	28.1	29.7	20.7	15.9	18.7	23.9	20.0	12.65	20.3	10.3	21.55	33.7	24.65	22.5	19.3	25.0	32.0
Oct. 3	33.2	27.9	27.5	16.2	26.8	28.1	29.1	20.5	16.25	18.3	23.8	20.5	12.5	20.6	10.0	21.7	33.25	24.7	22.9	19.6	25.5	31.8
Oct. 10	33.5	27.9	27.0	16.0	26.9	28.1	29.0	21.0	16.0	18.5	24.15	20.0	12.7	20.0	10.0	21.3	33.7	25.1	22.5	19.2	25.6	31.7
Oct. 17	33.1	27.9	26.7	16.0	26.9	27.4	28.2	20.6	15.9	18.6	24.0	20.0	12.2	19.5	9.8	20.9	33.5	25.7	22.7	19.0	25.5	31.2
Oct. 24	33.0	26.9	26.7	16.0	26.9	28.2	29.1	20.5	16.0	18.3	24.2	19.7	12.3	19.0	9.6	20.5	33.2	25.7	22.5	18.8	25.4	31.1
Oct. 31	33.0	26.8	26.6	16.0	25.7	28.2	30.1	20.7	16.3	18.3	24.4	19.3	12.3	19.5	10.2	20.2	33.0	25.5	22.6	18.6	25.55	31.0
Nov. 7	33.0	26.85	26.6	16.2	25.5	28.2	30.5	20.7	16.5	18.2	24.5	19.2	12.4	18.9	9.9	20.0	29.9	25.4	22.7	18.7	25.6	31.3
Nov. 14	33.2	26.5	26.9	16.5	25.7	28.0	30.5	20.9	16.6	18.2	24.7	19.5	12.4	19.2	9.9	20.0	30.2	25.7	22.8	18.6	25.7	31.6
Nov. 21	33.1	26.5	26.3	16.2	25.7	28.0	30.1	20.7	16.6	18.1	24.7	19.2	12.2	19.9	9.7	20.3	30.1	25.7	22.3	18.5	25.7	31.5
Nov. 28	33.0	26.6	26.3	16.1	25.7	28.1	30.0	20.8	16.2	18.0	24.9	19.7	12.55	19.1	9.75	20.1	30.5	25.3	22.0	18.7	25.25	31.3
Dec. 6	33.0	26.4	26.9	16.15	25.2	28.7	30.0	20.9	16.25	18.1	24.7	19.1	12.7	19.1	10.4	20.0	30.3	24.7	22.4	18.6	25.1	31.1
Dec. 12	33.1	26.4	26.1	16.4	25.5	28.05	30.0	20.3	16.0	18.3	24.3	19.3	12.1	19.9	9.4	20.3	30.1	24.4	23.1	18.2	25.6	31.6
Dec. 19	33.2	26.0	26.0	16.3	25.5	28.0	-------	20.0	16.25	18.1	24.3	19.0	11.9	19.7	9.2	20.3	30.0	23.4	23.0	18.4	25.4	-------
Dec. 26	33.2	25.9	26.0	16.3	25.1	28.0	-------	20.05	16.2	18.0	24.65	19.0	11.7	19.8	9.1	20.3	30.0	22.6	23.4	18.4	25.2	-------
1915																						
Jan. 2	33.3	25.7	26.05	16.1	25.2	28.0	-------	20.0	16.2	18.0	24.3	19.0	11.1	19.8	9.1	20.3	30.2	22.6	23.1	18.2	25.2	-------
Jan. 9	33.1	25.2	26.0	16.0	25.0	28.05	-------	20.0	16.1	18.0	24.2	19.0	10.6	19.4	9.05	20.2	30.0	22.6	23.9	18.2	25.1	-------
Jan. 16	33.0	25.5	26.0	16.0	25.0	27.85	-------	19.9	16.1	17.9	24.1	19.0	10.4	19.1	8.7	20.0	29.8	21.7	23.4	18.2	25.0	-------
Jan. 23	29.9	25.6	26.0	15.9	24.9	27.7	-------	19.7	16.0	17.8	24.1	18.7	9.2	19.1	8.3	20.0	29.7	18.65	23.1	18.2	25.0	-------
Jan. 30	29.9	25.4	26.0	15.7	24.7	27.7	-------	19.7	16.7	17.7	24.0	18.0	9.2	19.1	8.0	19.7	29.5	18.05	20.7	18.0	-------	-------
Feb. 6	29.7	25.4	25.8	15.6	24.45	27.5	-------	19.6	16.2	17.4	23.8	18.0	9.2	19.0	8.05	19.4	29.5	17.8	20.1	18.0	-------	-------
Feb. 13	29.7	25.6	25.8	-------	25.6	27.7	-------	20.2	9.0	17.2	23.5	18.0	9.0	19.0	8.0	19.1	29.4	18.15	20.0	18.0	-------	-------
Feb. 20	29.7	25.7	25.5	-------	25.8	27.5	-------	20.4	9.0	17.0	23.4	18.0	9.2	18.9	8.0	19.1	29.9	18.7	20.0	18.05	-------	-------
Feb. 27	29.5	25.7	25.2	-------	25.8	27.1	-------	20.2	9.0	17.0	23.0	18.2	9.0	18.6	8.0	19.0	29.7	18.6	19.8	18.0	18.4	-------
Mar. 6	25.1	23.5	22.9	-------	24.6	26.55	-------	20.2	9.15	15.5	23.4	18.2	10.7	17.95	5.7	15.7	29.6	17.9	19.05	18.3	17.4	-------
Mar. 13	25.1	23.2	22.9	-------	24.6	26.5	30.0	20.2	9.1	15.4	23.7	18.2	10.7	17.95	5.7	15.6	29.4	17.75	18.9	18.1	-------	-------
Mar. 20	25.4	23.2	22.9	-------	24.9	26.85	-------	20.4	9.1	15.4	23.7	18.7	10.6	17.95	5.7	15.6	29.9	18.2	19.2	18.1	-------	-------
Mar. 27	25.7	23.1	22.9	-------	24.9	26.8	-------	20.6	9.2	15.4	23.9	18.9	10.9	17.9	5.7	15.7	29.95	19.9	19.0	18.1	-------	-------
Apr. 3	25.65	24.3	24.25	-------	25.4	25.7	-------	21.4	10.0	16.6	20.2	18.6	10.6	19.6	6.9	17.9	29.9	20.8	21.7	18.4	-------	-------
Apr. 10	25.6	24.2	24.2	-------	25.4	25.9	-------	21.0	10.0	16.2	20.4	18.8	10.9	19.6	6.9	17.9	29.4	21.6	21.7	18.0	-------	-------
Apr. 17	25.9	24.4	24.9	-------	25.55	25.9	-------	21.5	10.0	16.4	20.6	18.8	10.9	19.6	6.95	17.6	29.5	21.7	21.7	18.6	-------	-------
Apr. 24	26.9	24.4	24.6	-------	25.6	25.9	-------	21.5	10.0	16.4	20.8	16.7	10.9	19.95	6.9	17.9	29.8	20.9	20.5	18.6	-------	-------
May 1	26.45	24.3	24.95	-------	25.8	25.9	-------	21.5	10.4	16.4	20.9	16.8	10.95	19.9	6.95	17.7	29.7	21.7	20.9	18.7	-------	-------
May 8	26.1	24.0	24.7	-------	25.5	25.8	-------	21.3	10.2	16.2	20.9	16.6	10.7	19.5	6.7	17.6	29.5	20.6	20.9	18.6	-------	-------
May 15	26.5	24.4	24.7	-------	25.55	25.8	-------	21.4	10.6	16.4	20.9	16.9	10.9	19.7	6.7	17.6	29.8	20.8	20.7	18.6	-------	-------
May 22	26.4	24.6	24.7	-------	25.4	25.8	-------	21.6	10.4	16.7	20.9	16.9	10.9	19.7	6.4	17.6	29.9	21.0	20.9	18.5	-------	-------
May 29	28.35	24.6	24.9	-------	25.6	27.65	-------	19.9	9.7	17.0	23.0	18.75	11.2	18.1	7.9	18.85	33.25	21.45	20.5	18.5	-------	-------

Weekly records of the depth, in feet, to the water level in the observation wells—Continued

	1	2	4	6	7	8	10	11	13	14	15	16	18	19	20	21	22	23	24	25	28	29
1915																						
June 6	29.3	24.5	25.4	------	25.4	28.0	------	20.5	10.4	17.4	23.3	18.8	11.6	18.6	8.4	18.9	33.6	22.1	20.6	18.7	------	------
June 13	29.6	24.7	25.1	------	24.5	28.0	------	20.5	10.8	17.6	23.4	18.9	11.7	18.4	8.4	18.8	33.7	22.3	20.9	18.6	------	------
June 20	29.4	25.0	25.2	------	25.1	27.9	------	20.5	10.8	17.9	23.8	18.95	11.9	18.7	8.8	18.95	33.8	22.8	20.95	18.6	------	------
June 26	30.05	25.0	25.55	14.5	25.9	28.0	31.0	21.0	12.0	17.4	23.4	19.2	12.35	19.0	9.0	19.9	33.8	23.3	21.0	18.5	23.15	31.1
July 3	30.4	24.95	25.0	14.6	25.9	28.6	31.2	21.4	12.5	18.7	23.0	19.0	11.7	19.2	8.6	19.8	33.7	23.5	20.05	18.4	23.2	31.4
July 10	30.9	24.9	25.8	14.7	26.1	28.3	31.5	21.0	11.9	17.45	23.9	18.3	11.25	18.5	8.2	19.4	33.75	23.8	21.1	18.5	22.75	31.3
July 17	31.1	25.0	25.9	14.2	26.2	28.2	31.0	20.9	11.2	18.1	23.6	18.4	12.6	18.5	9.2	19.8	31.5	23.6	21.0	19.6	22.7	31.9
July 24	31.55	25.2	26.0	13.8	26.3	28.3	31.8	21.0	12.0	17.8	23.9	18.9	12.2	18.85	9.2	20.0	34.0	23.3	21.4	18.6	21.7	31.5
July 31	31.45	25.2	26.1	13.9	26.2	28.4	31.9	21.4	12.0	17.6	23.9	18.95	12.4	18.9	9.6	20.0	34.1	23.0	21.6	18.7	21.8	31.6
Aug. 7	31.1	25.0	26.0	12.8	25.4	27.5	31.4	20.3	11.6	17.2	23.4	18.05	12.1	18.4	8.3	20.0	34.0	22.4	21.0	18.6	20.9	30.9
Aug. 14	31.0	25.2	26.2	12.8	25.1	27.6	31.6	20.3	11.2	17.4	23.3	18.0	12.1	18.5	8.4	20.1	32.9	22.0	21.05	18.6	20.7	30.4
Aug. 21	30.8	25.1	26.0	12.1	25.0	27.0	31.1	20.0	11.0	17.1	23.05	17.6	12.0	18.3	8.1	20.0	31.9	19.6	20.4	18.7	20.4	30.1
Aug. 28	30.9	24.6	26.5	12.7	25.0	27.3	------	20.1	11.2	17.15	23.3	17.85	12.1	18.3	8.6	20.4	31.0	18.3	20.4	18.3	20.6	30.7
Sept. 4	30.8	24.7	26.6	12.7	25.2	27.6	------	20.3	11.2	17.2	23.1	17.7	12.4	18.5	8.6	20.4	31.1	18.5	20.1	18.3	20.4	30.2
Sept. 11	30.3	24.6	26.7	13.0	25.3	27.8	------	20.1	11.3	17.3	23.0	17.6	12.4	18.5	8.4	20.5	31.2	18.8	21.0	18.4	20.5	30.3
Sept. 18	30.0	24.4	26.8	13.0	25.2	27.7	------	20.0	11.1	17.6	23.3	17.3	12.2	18.5	8.9	20.7	31.0	19.2	21.0	18.6	20.7	30.5
Sept. 25	30.0	24.5	26.9	12.9	25.2	27.8	------	20.3	11.0	17.6	23.4	17.2	12.3	18.4	8.9	20.5	30.8	19.8	20.9	18.5	20.6	30.4
Oct. 2	29.9	24.5	26.7	12.85	25.4	27.7	------	20.2	10.6	17.2	23.5	17.1	12.1	18.5	8.4	20.3	30.7	21.2	20.8	18.5	20.3	30.1
Oct. 9	29.6	24.4	26.8	12.6	25.4	28.1	------	20.4	10.5	17.2	23.3	17.1	12.1	18.5	8.4	20.5	30.3	20.8	20.7	18.6	20.4	30.0
Oct. 19	29.2	24.7	25.8	15.4	26.3	28.2	------	20.0	11.1	17.3	22.2	18.6	11.4	18.7	8.8	19.7	34.1	21.3	21.1	18.7	22.8	31.8
Oct. 23	29.5	24.7	25.8	15.65	26.4	28.3	------	20.9	11.1	17.3	22.1	18.8	11.4	18.9	8.85	19.7	34.0	21.4	21.0	18.7	22.8	31.9
Oct. 30	29.65	24.6	25.9	15.7	26.3	28.1	------	20.8	11.25	17.2	22.2	18.8	11.2	18.9	8.7	19.6	34.0	21.2	20.95	18.5	22.7	31.7
Nov. 6	30.2	24.75	26.1	15.75	26.3	28.2	------	21.0	11.3	17.2	22.2	18.9	11.3	18.9	8.7	19.8	34.0	21.35	21.1	18.5	22.9	31.9
Nov. 13	30.65	24.95	26.3	16.0	26.5	28.3	------	21.1	11.4	17.3	22.5	18.9	11.45	19.0	9.0	20.0	34.0	21.9	21.2	18.6	23.0	32.0
Nov. 20	30.8	24.8	26.5	16.0	26.6	28.6	------	21.1	11.15	17.4	22.6	19.1	10.6	18.7	8.6	19.8	34.0	22.0	21.1	18.6	23.0	32.1
Nov. 27	31.3	24.8	26.45	16.0	26.5	28.4	------	21.0	10.6	17.2	22.6	19.1	11.0	18.3	8.75	19.8	34.15	22.6	21.3	18.5	22.1	32.2
Dec. 4	31.4	24.6	26.5	16.0	26.6	28.45	------	20.6	10.75	17.3	23.0	19.15	11.2	18.3	8.9	19.85	34.1	22.7	21.4	18.6	20.45	32.3
Dec. 13	31.5	25.0	26.7	16.1	26.65	28.5	------	20.9	11.0	17.4	23.2	19.2	11.45	18.4	9.1	20.0	34.3	22.7	21.7	18.6	20.7	34.3
Dec. 20	31.6	24.9	26.8	15.75	26.8	28.6	------	21.0	10.4	17.1	23.2	18.0	10.0	17.8	8.2	19.5	34.3	22.3	21.0	17.4	18.7	32.4
Dec. 25	31.5	24.6	26.5	13.3	26.1	28.6	------	20.4	10.0	16.8	23.2	18.0	10.5	18.0	8.25	19.1	34.2	21.6	21.2	18.6	17.5	32.3
1916																						
Jan. 1	29.7	23.7	25.35	10.55	25.3	28.0	------	20.0	9.2	16.3	23.0	16.35	9.8	17.6	7.3	17.9	34.0	15.8	19.8	18.5	16.7	32.1
Jan. 8	28.65	23.5	25.0	9.9	25.0	27.5	------	19.8	9.3	16.0	22.5	16.1	9.95	17.6	7.2	17.85	34.0	15.2	19.2	18.35	17.0	32.0
Jan. 17	27.8	23.6	24.65	9.6	24.8	27.3	------	19.8	9.6	15.9	22.1	16.4	10.2	17.8	6.8	17.5	33.8	15.1	18.9	18.3	17.6	32.0
Jan. 22	27.0	23.7	24.4	9.8	24.8	27.2	------	19.7	------	16.0	21.7	17.2	10.4	18.0	6.65	17.4	33.8	16.0	19.0	18.0	18.5	32.3
Jan. 29	25.9	23.45	23.8	9.75	24.65	27.2	------	19.6	------	15.85	21.5	16.8	9.8	17.5	5.9	16.2	33.5	15.9	18.5	18.3	17.2	31.9
Feb. 7	25.1	23.6	23.7	10.0	24.35	27.1	------	19.5	------	15.8	21.0	16.85	10.15	17.8	6.25	19.7	33.4	17.0	18.7	18.3	17.6	31.8
Feb. 12	24.9	23.7	23.9	10.25	24.25	27.2	------	19.6	------	15.9	20.8	17.4	10.4	18.0	6.5	16.85	33.0	17.6	19.2	18.3	18.4	31.5
Feb. 21	24.8	24.0	24.0	10.5	24.5	27.3	------	19.7	------	16.1	20.7	17.9	10.6	18.1	6.7	17.15	33.1	18.5	19.4	18.3	19.1	31.7
Feb. 28	24.2	23.1	23.4	8.7	24.0	27.1	------	19.5	------	15.55	21.0	15.1	9.35	16.9	5.6	15.7	33.15	12.5	17.85	18.3	17.2	31.6
Mar. 4	24.3	23.2	23.0	8.4	23.8	26.5	------	19.4	------	15.35	20.4	16.1	10.0	17.8	6.1	16.4	33.0	14.5	17.8	18.3	17.4	31.5
Mar. 13	21.4	23.4	23.3	8.45	23.8	26.8	------	19.5	------	15.7	20.0	17.3	10.6	18.2	6.5	17.3	33.0	17.35	18.35	18.4	19.0	31.2
Mar. 20	24.8	23.7	23.6	8.9	24.15	26.85	------	19.6	------	16.1	20.4	17.7	10.6	19.2	6.6	17.3	32.7	18.5	19.4	18.3	19.2	31.4

Mar. 27	24.8	23.8	23.85	9.4	24.3	27.0	--------	19.8	--------	16.0	20.5	18.0	10.7	18.2	6.9	17.5	32.8	18.7	19.55	18.3	19.8	31.3
Apr. 1	22.85	22.6	19.8	8.3	23.1	25.6	--------	19.15	--------	14.8	19.8	12.8	8.4	16.55	4.35	13.0	22.7	11.0	14.2	16.5	16.4	31.0
Apr. 8	23.1	22.7	20.7	8.3	22.45	23.9	--------	19.0	--------	14.15	18.25	14.15	9.6	17.6	5.1	14.6	32.15	13.85	14.4	17.3	17.0	30.6
Apr. 15	23.3	22.8	20.9	8.3	21.9	24.1	--------	18.8	--------	14.2	17.7	15.0	9.5	17.7	5.2	15.2	31.8	15.0	15.0	17.3	17.0	30.5
Apr. 24	23.35	23.1	21.4	8.3	21.75	23.7	--------	19.1	--------	14.5	17.3	15.9	10.1	17.8	5.5	15.9	31.55	15.1	16.0	18.0	17.8	30.2
May 1	23.5	23.3	21.7	8.4	21.8	23.9	--------	18.7	--------	14.75	17.4	16.8	10.3	18.9	5.8	16.0	31.8	15.6	16.9	18.3	18.5	29.9
May 8	23.7	23.35	22.2	8.4	22.2	24.2	--------	18.6	--------	15.2	17.8	17.4	10.6	17.9	6.1	16.6	31.85	16.3	17.7	18.3	19.3	29.8
May 13	24.1	23.6	23.65	8.9	22.6	24.3	--------	18.7	10.4	15.6	18.3	17.9	10.9	18.0	6.5	17.1	31.8	17.2	18.5	18.4	20.3	29.6
May 21	24.1	23.6	23.0	8.75	22.9	24.45	--------	18.6	9.95	15.8	18.4	18.0	10.55	17.9	6.6	17.3	31.8	18.0	18.8	18.4	19.1	29.5
May 29	24.4	23.75	23.3	9.3	23.1	24.6	--------	18.6	10.2	15.9	17.8	18.2	10.85	17.9	7.0	17.7	32.0	--------	19.2	18.4	18.7	29.35
June 3	24.7	23.9	23.6	9.7	23.3	24.6	--------	18.7	10.35	16.0	19.0	18.5	10.85	18.0	7.3	18.2	32.0	--------	19.4	18.3	18.7	29.5
June 10	25.0	24.1	24.0	10.3	23.8	24.8	--------	18.7	10.6	16.2	19.2	18.6	10.8	18.0	7.2	18.2	32.2	19.3	19.6	18.4	20.1	29.4
June 19	25.3	23.95	24.3	9.7	24.0	25.0	--------	18.8	10.7	16.4	19.5	18.6	10.4	18.1	7.4	18.3	32.3	19.8	19.7	18.4	20.7	29.7
June 26	25.5	24.1	24.4	9.9	24.0	25.3	--------	19.0	10.2	16.5	19.9	18.5	10.7	18.0	7.4	18.7	32.7	20.4	19.9	18.5	19.7	29.6
July 1	25.8	24.1	24.5	10.3	24.1	25.2	--------	18.9	10.5	16.6	19.9	18.7	11.0	18.2	7.6	18.6	32.5	20.0	20.0	18.4	20.6	29.65
July 8	26.1	24.25	24.65	10.1	24.3	25.1	--------	19.5	11.0	16.65	20.25	18.8	11.1	18.6	7.7	18.8	32.5	20.3	20.0	18.4	21.8	29.6
Aug. 1	27.6	24.2	25.15	10.3	24.5	25.2	--------	19.6	11.3	16.8	20.6	18.5	11.0	18.8	7.9	19.0	32.7	21.2	20.5	18.2	22.8	30.1
Aug. 5	27.9	24.4	25.3	11.1	24.8	25.2	28.0	19.8	11.6	16.8	20.9	18.8	11.6	19.0	8.2	19.4	32.9	21.3	20.7	18.4	22.9	30.3
Aug. 12	28.3	24.5	25.4	11.4	24.8	25.4	28.0	19.9	11.8	17.2	21.5	18.8	11.4	19.0	8.4	19.5	33.0	22.3	20.9	18.6	23.0	30.4
Aug. 19	28.7	24.4	25.55	12.1	24.9	25.3	28.0	20.2	12.0	17.1	21.0	18.9	11.75	19.1	8.8	19.7	33.2	22.4	21.0	18.4	23.1	30.25
Aug. 26	29.3	24.5	25.9	13.0	25.25	25.8	28.0	20.3	12.6	17.1	21.4	19.35	11.8	19.4	9.0	20.4	33.5	22.5	21.1	18.4	23.4	30.45
Sept. 2	29.7	24.7	25.8	13.7	25.5	25.9	28.2	20.4	12.8	17.3	21.4	19.0	11.8	19.5	9.0	20.0	33.4	21.9	21.2	18.6	23.7	30.6
Sept. 9	29.8	24.85	26.0	14.0	25.45	25.8	28.3	20.35	13.45	17.3	21.6	19.1	11.9	19.35	9.4	20.1	33.3	22.25	21.4	18.6	23.6	30.8
Sept. 16	30.4	25.0	26.2	14.5	25.7	26.4	28.4	20.7	13.9	17.6	21.8	19.2	12.0	19.5	9.4	20.4	33.4	22.9	21.4	18.5	23.9	30.4
Sept. 23	31.0	25.0	26.35	14.9	25.8	26.5	28.55	20.8	14.3	17.8	22.1	19.1	11.75	19.8	9.6	20.5	33.6	23.3	21.6	18.4	24.0	30.7
Sept. 30	31.5	25.0	26.5	15.1	25.9	26.6	28.5	20.9	14.6	17.7	22.3	19.35	11.45	19.7	9.35	20.55	33.75	23.9	21.65	18.6	24.2	31.2
Oct. 7	32.0	25.4	26.55	15.6	26.15	27.3	28.65	21.3	15.0	18.0	22.75	19.4	11.9	19.95	9.65	20.7	34.3	24.5	21.9	18.6	24.75	32.8
Oct. 14	32.0	25.2	26.6	15.4	26.0	27.0	28.55	21.7	14.7	17.8	22.55	19.3	11.8	20.5	9.7	20.6	33.6	25.1	22.0	18.4	24.3	33.2
Oct. 21	31.9	25.3	26.6	15.6	25.9	27.1	--------	20.7	15.0	17.9	23.0	19.1	11.55	19.8	9.6	20.6	33.8	25.4	22.0	18.8	24.3	31.35
Oct. 28	31.9	25.4	26.7	16.0	26.2	27.25	28.8	20.8	14.6	17.9	23.0	19.3	11.8	20.2	9.9	20.9	34.0	25.7	22.5	18.7	25.1	31.65
Nov. 4	32.0	25.5	26.9	16.4	26.4	27.4	28.8	20.7	14.5	18.0	23.2	19.35	11.9	20.0	--------	20.7	34.1	25.4	22.2	18.8	24.7	31.8
Nov. 11	32.7	25.6	26.9	16.3	26.4	27.6	28.9	20.9	14.2	17.9	23.4	19.4	11.8	20.1	10.0	20.7	34.3	25.6	22.35	18.8	24.8	32.0
Nov. 18	25.6	27.1	26.9	16.5	26.55	27.7	29.2	20.9	14.2	18.1	23.6	19.5	11.8	20.1	--------	20.9	34.4	25.5	22.5	18.9	24.75	32.1
Nov. 25	31.95	25.5	27.4	16.4	26.5	27.6	29.0	20.8	13.8	17.9	23.7	19.25	11.3	20.0	9.6	20.75	34.0	24.7	22.5	18.8	24.8	32.0
Dec. 2	31.9	25.6	27.3	16.3	26.4	27.8	29.1	20.6	13.1	17.8	24.0	19.1	11.4	20.0	9.6	20.7	34.3	25.5	22.7	18.9	24.0	32.0
Dec. 9	31.9	25.6	27.3	15.7	26.2	28.0	29.1	20.3	12.4	17.9	24.1	18.95	11.5	18.8	9.6	20.6	34.3	24.4	22.8	18.7	24.7	32.2
Dec. 17	32.0	25.5	27.3	15.4	26.3	28.0	29.25	20.4	11.9	17.8	24.2	19.0	11.4	19.5	9.6	20.6	34.8	25.5	23.1	18.7	24.9	32.3
Dec. 24	32.0	25.6	27.0	14.7	26.1	28.0	29.1	20.2	11.3	17.7	24.6	18.0	10.8	19.0	9.0	20.4	34.6	24.8	22.4	18.7	--------	--------
Dec. 30	31.8	25.4	26.8	13.2	25.6	28.2	29.4	20.0	10.7	17.6	24.2	18.0	11.1	18.3	9.3	20.3	34.7	24.0	23.1	18.6	23.9	32.5

INTERPRETATION OF THE RECORDS

As a rule the fluctuations in the observation wells were of the same general character, although each well has individual characteristics. The chief factors in the variations in fluctuation seem to be the depth of the well, or, more precisely, the depth to the water table; the location of the well, whether on a flat area, on a hill slope, or near the foot of a hill; and the kind of water-bearing material, whether till or stratified drift. The wells in stratified drift are on a flat area, whereas the wells in till are on hill slopes or at the foot of hills, and almost all the wells in stratified drift are deeper than those in till; therefore it is difficult to separate the factors that influence any individual well.

In general the shallow wells show greater range in fluctuation than the deep wells, and the wells on hill slopes or at the foot of hills show wider fluctuations and greater flashiness than those on plains. The same amount of water will cause a greater rise of the water level in till than in stratified drift, but the rise and subsequent fall in stratified drift will probably occur more quickly because the water moves through stratified drift more rapidly than through till. In other words, after a rain some of which percolates to the water table the wells in till will show a greater but perhaps less prompt rise than the wells in stratified drift.

When the ground is frozen and there is not much recharge the water table on hilltops and slopes declines, but because of the general movement of the ground water toward the valleys the water table in the lowlands may remain stationary or even rise during the same period of frozen ground. Thus in upland-till wells the water level is likely to decline during prolonged periods of severe winter weather, whereas in the stratified-drift wells, which are on the lowlands, the water table is much less likely to decline. This difference in the behavior of till and stratified-drift wells occurred during the winter of 1913–14, as is shown in Figure 12.

The fluctuation of the water table during the period from October, 1913, to December, 1916, is shown in Plate 19 by means of a composite curve based on the averages of the weekly measurements recorded in the preceding table. In constructing this curve the highest water level in each well during the period was used as the zero datum for that well, and the fluctuations of the water level in that well were expressed in depths below this datum. This method allowed a fair comparison of the fluctuations of the water levels in the wells. The altitude of the wells above sea level was not determined. As about 90 per cent of the drainage basin is covered by till and only about 10 per cent by stratified drift, the average figures for the wells in till were given a relative value of 90 and those for the wells in stratified drift were given a relative value of 10. The curve based on this weighted

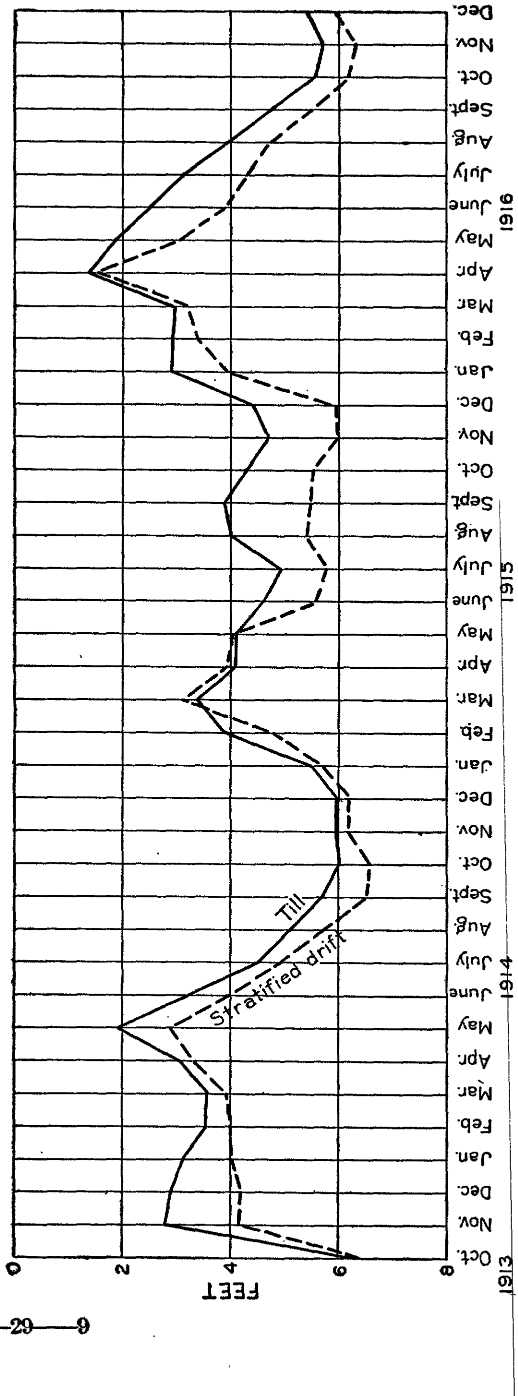


FIGURE 12.—Fluctuation of water table in till and in stratified drift in the Pomperaug Basin, Conn., by months, October, 1913, to December, 1916

average is regarded as showing average conditions for the entire drainage basin.

The following table gives the average monthly depths to the water level in the wells in till and in stratified drift and the weighted average of these two for the period covered by the investigation. (See also fig. 8.)

Average stage of the water table in the Pomperaug Basin, October, 1913, to December, 1916, as indicated by the position of the water levels in the observation wells

[Figures indicate feet below the highest water levels in these wells during the period]

Month	Till	Stratified drift	Weighted average	Month	Till	Stratified drift	Weighted average
1913				1915			
October	6.34	6.35	6.34	May	4.14	4.07	4.13
November	2.81	4.17	2.95	June	4.63	5.55	4.72
December	2.86	4.21	3.00	July	4.94	5.76	5.02
				August	3.97	5.41	4.11
1914				September	3.84	5.44	4.00
January	3.06	4.03	3.16	October	4.32	5.55	4.44
February	3.58	4.04	3.63	November	4.72	6.04	4.85
March	3.57	3.93	3.61	December	4.41	5.97	4.57
April	3.06	3.50	3.10				
May	1.89	2.89	1.99	1916			
June	3.22	3.97	3.30	January	2.87	3.91	2.97
July	4.55	4.90	4.59	February	2.86	3.41	2.92
August	5.10	5.72	5.16	March	2.94	3.22	2.97
September	5.73	6.50	5.81	April	1.42	1.49	1.43
October	6.04	6.59	6.10	May	1.84	3.05	1.96
November	5.97	6.15	5.99	June	2.55	3.91	2.69
December	5.92	6.17	5.95	July	[a] 3.13	[a] 4.27	3.24
				August	3.99	4.73	4.06
1915				September	4.76	5.54	4.84
January	5.49	5.70	5.51	October	5.64	6.16	5.69
February	3.88	4.75	3.97	November	5.72	6.33	5.77
March	3.39	3.11	3.36	December	5.43	5.98	5.49
April	4.09	3.94	4.08				

[a] Only 2 sets of records.

FLUCTUATION OF THE WATER TABLE IN RELATION TO PRECIPITATION AND OTHER WEATHER CONDITIONS

The fluctuations of the water table, as shown by fluctuations of the water levels in the wells, indicate a seasonal emptying and refilling of the ground-water reservoir. The filling of the ground-water reservoir occurs when water derived from rain or snow percolates into the zone of saturation. The discharge of ground water is effected chiefly through ground-water run-off and through evaporation, including transpiration.

The water table usually begins to rise in the fall, as soon as evaporation and plant growth become slight, and it rises rapidly whenever there is a heavy rain or when the snow melts on ground that is not frozen. There may also be a retardation in the rate of ground-water discharge due to lower temperature, and hence greater viscosity of the ground water at the points of discharge, but this effect is probably slight. There is considerable variation from one year to another in the time when the principal recharge takes place, owing to differences in snow and frost conditions as well as to irregularities in precipitation.

However, in early spring the water table usually reaches its highest stage for the year. As soon as the weather becomes warm and plant growth becomes active the water table begins to decline unless this is prevented by unusually heavy rains. All through the summer soil evaporation and the demands of vegetation are so great that but little water percolates to the zone of saturation, whereas ground-water run-off continues and water is also discharged from the zone of saturation by soil evaporation and transpiration. Hence the water table usually declines persistently throughout the summer and reaches its lowest stage in the fall. During the summer only exceptionally heavy or prolonged rains cause any considerable rise in the ground-water level.

A detailed study of the fluctuations of the water table shows some interesting facts regarding the filling and emptying of the ground-water reservoir during the period of observation. The rains of October, 1913, amounted to 9.21 inches, which was 5.06 inches above normal, whereas the demands of soil evaporation and plant growth so late in the season were doubtless low. The direct run-off during the month was high, and there was a large addition to the supply of soil moisture, but a large part of the rain also entered the zone of saturation. About October 11 the water table began to rise slightly, then more rapidly, and from October 25 to November 1 the rise amounted to about 3 feet. Most of the replenishing was accomplished in this last week of October, as the water table rose only half a foot higher by November 15 and no higher during December. A slight lowering of the water table occurred during January and February, 1914, and a rise of 1.8 feet during April and the first part of May. The highest stage of the water table was reached about May 16. The growing period, or period of depletion, then began, and the water table declined steadily, reaching its lowest stage for 1914 and for the entire period of the investigation in the first part of October—following a drought of several weeks at the end of the growing period. At this low stage the water table averaged about 4½ feet below the high stage of May, showing a considerable emptying of the ground-water reservoir.

The rains in the middle of October, 1914, checked the depleting process and caused a slight rise of the water table. However, from that time until the later part of December the water table remained nearly stationary. More rapid replenishment began in January, 1915, and continued practically without interruption until early in March, the total rise being about 3 feet. The large rise during the middle of the winter was due to high temperature and heavy precipitation, partly in the form of warm rains, which took the frost out of the ground and thus allowed the water to reach the zone of saturation. On account of the exceptionally dry spring, especially in March, the water table began to decline unusually early, and by the middle of April it was about 1 foot below its high stage early in March. Owing to rains later in the season, however, the decline was not nearly so great in the summer of 1915 as it had been in the summer of 1914, and in August, when there is usually severe depletion, there was actually a rise of about 1 foot due to excessive and protracted rains following the abundant rainfall of July. This higher level was fairly well maintained throughout the rest of August, all of September, and the early part of October. Then followed a few weeks of deficient rainfall during which the water table descended nearly a foot. Thus in 1915 the water table reached two low stages—one at the end of July and another in November or December—but at neither time did it go to nearly as low a level as in the fall of 1913 and the fall of 1914. At the low stage in November, 1915, the water table stood less than 2 feet below its high stage of March. The water year October, 1914, to September, 1915, closed with more than the usual amount of water in storage.

The replenishing period began about the middle of December, 1915. The water table rose quickly as a result of heavy precipitation, and by January 8, 1916, it had risen about 2 feet. Throughout January, February, and March the water table fluctuated somewhat but maintained a high level. This was a winter of heavy snowfall, with temperatures below normal in February and especially in the first three weeks of March, resulting in large snow storage. The rapid and large rise of the water table during the last week in March was due to unseasonably high temperatures which melted the snow and took the frost out of the ground, thus permitting water to reach the zone of saturation. This rise, occuring at a time when the water table already stood high, brought the water table by April 8 to the highest point it reached during the entire period covered by the investigation. Depletion began early in April, and except for a temporary rise during a rainy period in the later part of May the water table continued to descend until the middle of November, when it was about 4.8 feet below the high point of the preceding April. In the low stage of November, 1916, the water table stood lower than it had in the low stage of 1915 and at about the same level as in the low stage of 1914, but not quite so low as in October, 1913, when the observations were begun.

Thus, in spite of somewhat deficient precipitation during the period of investigation, the supply of ground water was not depleted—that is, the quantity of water stored in the zone of saturation at the end of the period was fully as great as the quantity stored at the beginning of the period.

The decline from the high stage in the spring to the low stage in the fall, representing depletion of the ground-water supply, was 4.5

feet in 1914, 1.85 feet in 1915, and 4.8 feet in 1916. The depletion was probably nearest to the normal in 1914. The rise of the water table from fall to spring, representing replenishment of the ground-water supply, was 4.8 feet in 1913–14, 3.1 feet in 1914–15, and 3.85 feet in 1915–16. For the 3-year period the average decline of the water table from spring to fall was 3.72 feet, and the average rise from fall to spring was 3.92 feet, the small difference between average decline and average rise being due to the fact that the water table stood a little higher at the end of the period than at the beginning.

FLUCTUATION OF THE WATER TABLE IN RELATION TO GROUND-WATER RUN-OFF

As shown in Plate 19 and Figure 7, the ground-water run-off fluctuates with the water table. Almost without exception, when the water table rises the ground-water run-off increases, and when the water table declines the ground-water run-off decreases. However, in the summer the decrease in ground-water run-off is disproportionately great (see fig. 8), because much of the ground-water that appears at or near the surface evaporates instead of being carried away by the river.

In Figure 13 an effort is made to establish a ground-water rating curve for the Pomperaug drainage basin. Numbers indicate months of the year in which observations were made, "1" standing for January, "2" for February, etc. A dot represents a set of observations made in the period from October to April, when evaporation is at a minimum; a cross represents a set of observations made in the period from May to September, when there is active evaporation of ground water. This rating curve, based only on observations when evaporation was not great, doubtless lies to the right of the broken line and is approximately represented by the continuous line. It is comparable to the rating curves that are developed in gaging surface streams, the coordinates being (1) the average depth, in feet, of the water levels in the observation wells below the zero datum for each well, and (2) the ground-water run-off, in second-feet, as determined from the curve in Plate 19. The average depth of the water levels, or average stage of the water table, was as a rule determined once a week by measurements of the observation wells. Hence, the dots and crosses in Figure 13 show the weekly positions of the water table plotted against the corresponding ground-water run-off.

It is evident from the data presented in Figure 13 that from May to September evaporation of ground water is a process which is very effective in reducing the amount of ground-water run-off. Thus, with the water table at the same altitude the ground-water run-off will be much less in August than in January because in August a part of the ground water that is returned to the surface or near to the surface is disposed of by evaporation. Hence, it is not feasible to make a single rating curve that will be applicable in all seasons. If, however, only the months are considered in which not much evaporation takes place a curve can be drawn that will represent approximately the ground-water run-off during these months. Thus, in drawing the rating

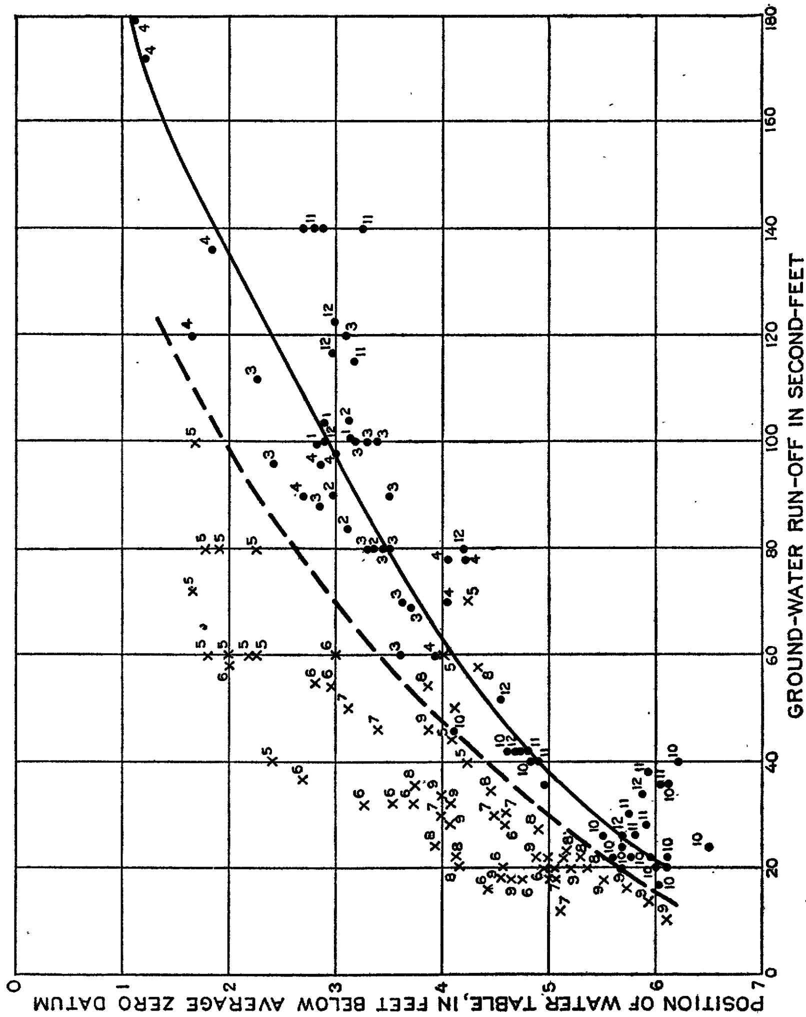


FIGURE 13.—Rate of ground-water run-off in relation to stage of water table in the Pomperaug Basin, Conn., based on water-level data given in the table on pages 117-121 and ground-water run-off as shown in Plate 19. (See p. 127)

curve shown by the continuous line in Figure 13, only the observations from October to April (represented by dots), were taken into consideration, and some allowance had to be made for evaporation in the early part of October. Although the dots are not perfectly alined, they fall into about as narrow a zone as could be expected with the imperfect data that were used. This curve probably represents somewhat less than the total ground-water discharge in the summer, because the roots of plants and the soil capillaries do not wait for the water to appear at the surface but pump it up from some depth. Further research is required to determine the characteristic type of ground-water rating curves.

Considerable interest attaches to the question what is the "point of zero flow," or how much farther the water table would have to descend below the low stages reached in the fall of 1913 and the fall of 1914 before stream flow would cease. As the water table comes near this point the ground-water run-off approaches zero, and therefore the actual arrival of the water table at the point of zero flow would be indefinitely delayed were it not for the fact that evaporation of ground water would continue and might easily carry the water table below this point—a condition that is common in arid regions. Meager ground-water run-off would probably continue in certain localities long after most parts of the basin had ceased to contribute to the stream flow. The inference from this line of reasoning is that a small amount of water would continue to flow in the principal streams of the Pomperaug River system even after a much more protracted drought than any that occurred in 1913 or 1914.

Even after ground-water run-off from a given area ceases there generally remains a supply of ground water that is stored in the zone of saturation, somewhat as a supply of surface water remains in a reservoir after there is no more water to go over the spillway. This water can be recovered by wells. Usually in times of severe drought many dug wells fail. In some localities the ground-water reservoir may at such times actually be drained except for the water in the crevices of the bedrock, and no remedy is available except to drill into the rock. Commonly, however, the trouble is due merely to the fact that the well is not deep enough to extend to the water table at its lowest stages, and the flow into the well can be restored by digging the well a little deeper.

CHANGES IN GROUND-WATER STORAGE REPRESENTED BY FLUCTUATIONS OF THE WATER TABLE

The changes in the quantities of water held in storage in the zone of saturation can be calculated from the fluctuations in the water table if the average specific yield of the glacial materials in the belt of fluctuation is known. For example, if a material whose specific yield is 20 per cent were saturated and then allowed to drain it would yield a volume of water equal to one-fifth of the volume of the material. Obviously, if in such material the water table declines 5 inches the quantity of water removed from the zone of saturation during the decline amounts to a layer of water 1 inch deep.

No direct data are available regarding the specific yield of the water-bearing materials in the Pomperaug Basin. However, the specific yield is equal to the porosity minus the specific retention, and the specific retention approximates the moisture equivalent expressed in percentage by volume. These terms have been defined as follows:[19]

The *specific yield* of a rock or soil, with respect to water, is the ratio of (1) the volume of water which, after being saturated, it will yield by gravity to (2) its own volume.

The *specific retention* of a rock or soil, with respect to water, is the ratio of (1) the volume of water which, after being saturated, it will retain against the pull of gravity to (2) its own volume.

The *moisture equivalent* of a soil is the ratio of (1) the weight of water which the soil, after saturation, will retain against a centrifugal force 1,000 times the force of gravity to (2) the weight of the soil when dry. It can also be expressed as the ratio of (1) the volume of water retained under the specified conditions to (2) its own volume.

The moisture equivalent by weight can be roughly calculated from the mechanical analyses according to the following formula developed by Briggs and Shantz:[20]

Moisture equivalent $= 1.84\ (0.01\ \text{sand} + 0.12\ \text{silt} + 0.57\ \text{clay})$.

The percentages of sand, silt, and clay in three samples of till and three samples of ordinary stratified drift in the Pomperaug Basin are given in the table on page 81. The material larger than sand is considered as having a moisture equivalent of 0. The moisture equivalents by weight are changed to moisture equivalents by volume by multiplying by the specific gravity of the materials.

The average porosity of the samples of till is 14 per cent, and that of the samples of stratified drift is 36 per cent (p. 81). The calculated average moisture equivalent (by volume) of the till is 3.4 per cent, and that of the stratified drift is 3 per cent. If these are used as specific retentions the specific yield of the till is 10.6 per cent and that of the stratified drift 33 per cent. As about 90 per cent of the basin is covered with till and 10 per cent with stratified drift the average specific yield of the glacial materials in the Pomperaug Basin is computed to be 12.8 per cent.

The monthly increase or decrease in the quantity of water stored in the zone of saturation was determined by obtaining from Plate 19 the rise or decline of the water table between the first and last day of each month, and multiplying this rise or decline by 12.8 per cent, the computed average specific yield. The results are given in the tables on pages 143–144.

[19] Meinzer, O. E., Outline of ground-water hydrology, with definitions: U. S. Geol. Survey Water-Supply Paper 494, pp. 25, 28–29, 1924. See also Meinzer, O. E., Occurrence of ground water in the United States, with a discussion of principles: U. S. Geol. Survey Water-Supply Paper 489, pp. 50–63, 1924.

[20] Briggs, L. J., and Shantz, H. L., The wilting coefficient for different plants and its indirect determination: U. S. Dept. Agr. Bur. Plant Industry Bull. 230, 1912.

EVAPORATIVITY

RECORDS OF EVAPORATIVITY

No records of evaporativity, or evaporation from a free water surface, are available for the Pomperaug Basin. The averages for Boston, Mass., as computed by Fitzgerald,[21] are given in the following table and are shown graphically in Figure 8. These averages are based on observed rates of evaporation from Chestnut Hill Reservoir, at Boston, corrected and supplemented by a formula which Fitzgerald derived from other observations and experiments.

Average evaporativity

Month	Precipitation [a] (inches)	Evaporativity		Month	Precipitation [a] (inches)	Evaporativity	
		Inches [b]	Per cent of precipitation [c]			Inches [b]	Per cent of precipitation [c]
October	4.15	3.16	76	May	3.95	4.46	113
November	3.75	2.25	60	June	3.20	5.54	173
December	4.29	1.51	35	July	4.68	5.98	128
January	4.23	.96	23	August	4.48	5.50	123
February	3.97	1.05	26	September	3.86	4.12	107
March	4.43	1.70	38				
April	3.82	2.97	78		48.81	39.20	80

[a] Waterbury normal, based on record covering 38 years.
[b] Evaporation at Boston, Mass.
[c] On the assumption that the evaporativity is the same in the Pomperaug Basin as at Boston.

RECORDS OF DAILY TEMPERATURE

It is not necessary here to discuss the various weather conditions that control the rate of evaporation from a free water surface. One of the most influential of these conditions is the temperature of the air that comes into contact with the water, and hence the temperature may be taken as a more or less reliable indication of the rate of evaporation. The maximum and minimum daily temperature and the average monthly and annual temperature at Waterbury, as recorded by the United States Weather Bureau during the period covered by this investigation, are given in the following tables. The average daily temperature at Waterbury is shown on Plate 19, and the average monthly temperature in relation to evaporation and evaporativity is shown in Figure 14.

[21] Fitzgerald, Desmond, Evaporation: Am. Soc. Civil Eng. Trans., vol. 15, pp. 581-646, 1886; corrected in vol. 17, p. 275, 1892.

Daily maximum and minimum temperatures for Waterbury, Conn., July, 1913, to December, 1916 [a]

Month		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1913																																
July	Max	97	90	92	92	93	92	82	83	80	84	82	81	87	83	82	84	85	79	90	88	86	89	87	79	82	83	86	86	94	97	91
	Min	66	73	61	60	66	72	54	45	53	62	53	46	64	63	51	55	52	62	60	65	57	52	60	66	62	48	53	59	70	65	65
August	Max	83	89	91	83	83	85	84	85	88	94	84	80	73	80	83	92	96	96	83	82	79	77	83	83	79	82	79	85	77	85	85
	Min	64	64	55	60	51	54	62	58	66	72	53	49	55	56	49	58	62	70	64	49	47	47	54	54	54	44	64	55	66	65	55
September	Max	85	88	83	86	68	78	69	84	78	72	72	71	74	66	68	71	72	80	70	62	69	71	70	70	78	78	70	70	77	70	----
	Min	65	68	65	68	57	57	56	66	50	39	41	48	48	39	33	38	45	63	55	53	59	61	43	40	42	49	51	36	47	46	----
October	Max	63	61	70	72	80	74	66	69	74	79	68	67	58	62	63	67	74	66	61	63	63	60	60	60	64	63	65	71	69	59	49
	Min	52	51	45	51	56	56	60	62	64	64	61	53	36	39	43	51	46	46	51	52	43	32	30	42	58	52	51	46	45	43	30
November	Max	49	55	57	57	51	65	65	61	63	55	40	49	55	51	46	39	45	58	58	70	64	60	69	50	44	50	44	36	39	43	----
	Min	25	34	31	45	32	26	28	33	51	37	24	30	34	39	38	32	32	30	44	51	52	49	46	32	23	33	24	29	34	34	----
December	Max	46	51	54	49	52	52	54	52	36	39	38	38	50	54	49	45	57	46	41	45	51	43	40	47	43	36	33	30	35	37	40
	Min	32	35	41	35	40	38	34	25	20	20	26	17	22	24	27	27	25	30	18	22	28	34	28	34	30	32	17	11	14	14	16
1914																																
January	Max	35	29	32	33	45	38	38	37	42	39	34	30	18	13	24	36	39	32	31	36	34	36	36	47	43	27	40	55	51	55	46
	Min	18	16	25	30	32	12	19	30	14	34	27	14	−6	−10	8	14	28	11	11	27	29	10	1	28	15	11	14	36	34	39	30
February	Max	42	38	50	53	45	34	44	44	23	33	28	12	21	27	27	15	24	28	30	28	28	34	32	19	29	42	46	46	----	----	----
	Min	34	24	23	38	25	20	20	22	10	15	9	−10	−6	13	5	−11	0	−7	23	16	13	−7	12	0	−5	−5	9	11	----	----	----
March	Max	44	46	44	42	45	39	40	42	33	35	32	35	37	42	57	54	55	45	36	31	32	38	42	46	51	64	72	66	40	36	60
	Min	33	25	27	28	25	31	29	29	24	19	19	14	13	14	34	28	32	30	24	17	12	22	18	22	22	38	45	35	34	30	32
April	Max	58	52	45	45	43	48	47	63	59	50	52	61	56	56	54	39	63	76	83	63	55	69	69	65	60	46	54	59	59	51	----
	Min	27	41	33	21	31	23	37	38	35	27	31	39	25	22	35	34	34	32	49	52	42	38	34	29	42	38	41	46	50	39	----
May	Max	60	66	74	69	61	74	76	71	70	78	75	73	47	68	67	72	72	80	84	87	82	84	75	74	76	91	94	85	82	80	84
	Min	31	31	40	42	49	48	42	49	46	44	49	46	39	41	39	39	40	40	46	48	54	50	58	45	45	62	70	63	55	45	49
June	Max	82	75	78	75	72	74	83	89	70	86	90	87	84	79	79	69	76	76	68	71	75	68	73	90	92	88	78	69	77	74	----
	Min	56	48	43	58	51	42	44	64	54	55	55	56	56	53	55	51	42	48	52	44	44	57	37	60	67	61	58	59	55	54	----
July	Max	77	75	69	80	76	75	65	83	81	78	79	91	88	79	78	84	88	90	83	80	79	81	77	82	82	88	87	78	76	67	73
	Min	46	58	54	57	57	57	55	59	63	61	65	63	68	60	63	69	76	71	61	49	56	55	53	61	63	64	57	58	53	55	54
August	Max	85	85	81	76	74	81	84	94	93	91	81	77	83	79	85	84	87	80	92	85	83	85	85	84	79	78	78	71	65	81	85
	Min	57	57	61	61	60	60	64	66	64	67	71	68	61	60	65	54	63	59	68	69	66	66	54	67	51	51	53	62	61	60	54
September	Max	87	92	87	81	80	78	74	76	67	72	67	72	78	78	81	88	92	92	82	87	95	97	93	88	78	62	69	62	65	68	----
	Min	56	70	65	63	49	48	62	54	40	39	45	41	39	39	39	40	44	46	59	44	52	53	56	59	55	45	40	34	28	48	----
October	Max	67	78	84	83	81	72	64	79	77	79	83	76	70	62	64	64	67	71	65	73	80	77	67	58	57	62	56	53	56	54	55
	Min	46	34	38	42	50	48	50	52	50	55	62	48	49	40	43	59	60	48	49	43	40	47	39	41	42	41	35	23	39	40	34
November	Max	73	65	58	71	66	51	52	56	45	41	54	51	62	58	45	62	48	32	34	38	34	48	35	36	48	57	58	46	50	47	----
	Min	35	44	37	37	35	37	29	40	32	22	27	29	29	38	32	43	32	84	26	32	22	20	20	15	28	38	42	22	20	30	----
December	Max	62	64	62	52	38	34	33	33	33	40	42	38	35	51	32	29	29	29	39	42	32	37	26	22	25	13	21	36	32	45	42
	Min	36	38	48	32	32	27	29	29	27	27	27	22	17	32	9	11	11	6	15	25	24	24	13	8	9	−4	−9	8	16	32	20
1915																																
January	Max	33	30	28	31	39	42	57	47	37	35	32	37	44	43	46	47	45	55	56	45	37	31	41	48	33	37	35	36	35	21	23
	Min	11	20	18	11	7	26	40	30	22	20	14	29	34	22	34	29	30	43	45	32	25	15	20	23	26	25	28	30	10	4	6
February	Max	40	32	19	33	31	53	48	37	52	28	39	49	43	41	51	51	37	41	45	55	53	51	51	58	53	39	29	32	----	----	----
	Min	22	11	10	17	10	30	33	26	23	8	12	34	24	27	36	37	30	16	20	23	23	22	34	41	38	25	14	16	----	----	----

March	Max	37	44	39	45	45	39	47	48	43	44	46	42	51	49	48	49	43	41	50	51	45	50	50	57	59	54	41	51	44	37	48
	Min	19	24	19	13	28	28	29	29	22	25	27	21	20	26	21	22	22	22	20	26	28	30	33	29	29	33	16	29	28	18	21
April	Max	50	50	46	50	49	51	52	68	70	70	62	66	61	63	68	69	64	72	80	77	69	63	73	74	92	84	92	89	74	68	----
	Min	31	25	27	27	23	37	32	33	37	44	49	49	35	32	32	33	45	46	50	50	41	31	44	45	50	44	54	46	44	48	----
May	Max	62	61	64	60	67	71	72	74	72	69	73	73	70	68	70	63	50	62	66	71	66	76	67	63	77	69	62	72	73	63	80
	Min	41	39	44	41	44	47	41	55	56	41	45	56	44	41	45	35	44	39	35	38	49	49	53	47	44	54	36	46	43	37	35
June	Max	84	75	67	74	75	75	81	75	81	75	74	82	78	90	83	77	80	85	77	76	79	70	66	73	78	80	80	83	86	78	----
	Min	45	47	43	45	47	54	60	59	54	53	51	59	48	58	60	62	62	59	64	61	52	49	55	51	46	55	49	49	53	61	----
July	Max	79	76	83	85	76	77	78	73	81	84	84	71	86	88	90	84	90	87	88	81	80	73	80	79	85	85	83	86	86	87	89
	Min	65	62	59	64	65	56	50	63	56	53	56	60	53	60	59	64	70	64	64	64	60	60	52	58	52	57	61	55	60	62	71
August	Max	89	84	79	71	75	65	80	83	85	82	85	80	89	88	85	89	84	71	76	83	79	77	85	86	83	78	69	74	66	73	72
	Min	67	70	59	56	56	57	58	61	63	57	57	59	69	65	62	64	66	48	48	50	56	57	65	60	67	54	47	48	54	57	55
September	Max	75	85	90	88	82	80	75	83	95	90	88	83	84	91	93	94	92	82	76	82	72	64	70	71	73	68	66	66	72	75	----
	Min	49	49	50	57	65	65	62	69	68	68	56	60	64	68	68	70	66	63	61	53	60	45	36	45	44	48	43	40	41	38	----
October	Max	68	52	68	71	66	60	62	60	60	61	64	75	77	74	80	68	76	74	73	66	78	70	56	54	59	64	69	63	65	60	60
	Min	41	46	37	42	51	50	41	48	37	34	29	41	42	52	64	51	37	43	52	60	59	40	38	31	27	36	50	34	39	44	40
November	Max	69	68	51	48	48	51	55	62	62	51	55	61	59	51	52	45	43	45	58	58	50	44	38	40	48	54	51	56	49	43	----
	Min	45	50	40	28	38	33	26	27	39	30	33	42	32	27	43	31	27	25	30	38	38	30	22	31	24	24	28	33	33	28	----
December	Max	39	39	37	35	36	32	32	33	39	32	27	36	31	32	26	32	31	51	38	34	34	34	39	42	49	54	37	39	35	30	31
	Min	20	27	24	19	20	23	27	19	24	16	16	12	18	25	15	16	17	31	30	25	17	10	14	29	25	27	19	32	25	18	10
1916																																
January	Max	39	36	37	33	41	50	27	25	31	40	46	42	45	39	21	33	32	19	24	36	53	56	55	42	55	61	67	63	46	35	50
	Min	16	28	29	14	27	26	16	7	6	20	34	26	26	11	3	18	11	5	10	17	35	36	31	24	29	41	49	45	19	24	34
February	Max	54	41	30	26	35	44	40	23	35	32	28	22	22	17	29	32	40	38	34	22	21	39	38	36	42	42	33	25	29	----	----
	Min	40	24	22	5	12	25	22	10	18	18	11	18	15	−8	−13	3	27	26	6	−1	−3	−5	27	24	29	30	16	7	9	----	----
March	Max	32	27	33	28	32	22	39	39	29	41	40	35	45	39	35	25	26	19	31	29	38	37	36	38	54	66	58	55	48	63	68
	Min	10	17	13	14	15	7	17	28	16	19	10	4	28	22	18	12	5	2	14	11	24	24	18	13	28	23	29	33	38	39	32
April	Max	63	56	55	45	57	55	50	44	40	54	61	55	50	49	58	70	64	53	60	63	63	61	49	55	60	57	54	49	70	71	----
	Min	37	41	33	33	34	33	31	30	30	30	27	41	42	39	35	31	42	41	38	44	43	41	40	41	40	43	41	38	37	40	----
May	Max	69	72	67	69	69	74	71	75	65	64	79	75	73	69	56	56	56	56	56	67	76	67	57	70	84	80	76	68	83	76	73
	Min	44	45	47	48	48	53	48	44	51	40	51	49	44	40	45	50	49	44	36	40	42	42	43	50	57	51	47	35	59	60	57
June	Max	75	80	74	75	76	77	73	59	58	55	59	76	77	71	68	69	67	81	72	74	72	71	73	76	71	81	80	83	80	80	----
	Min	43	44	54	50	49	49	54	54	54	47	49	54	54	54	53	50	61	60	56	54	45	48	47	51	56	54	61	65	57	56	----
July	Max	83	84	84	73	68	85	89	91	82	74	81	92	91	81	77	80	83	87	87	89	85	85	83	79	78	77	87	80	77	80	93
	Min	49	55	63	57	57	52	56	63	65	64	67	70	71	68	56	55	67	70	61	69	70	70	70	68	70	70	71	63	49	60	68
August	Max	88	80	83	84	82	94	90	95	87	74	73	87	80	79	84	83	89	87	88	89	93	96	91	81	86	84	85	69	77	83	85
	Min	62	54	63	65	69	72	69	73	80	69	59	63	57	50	50	57	63	57	58	57	55	68	66	65	52	60	63	55	44	53	54
September	Max	88	80	72	77	80	80	82	92	78	80	75	76	83	92	78	73	72	74	69	75	75	74	71	70	66	73	85	78	77	68	----
	Min	51	67	42	55	58	56	63	71	60	45	45	41	54	50	68	58	39	41	47	37	44	52	63	48	45	42	53	57	68	46	----
October	Max	69	72	77	72	80	81	78	84	84	73	64	68	66	59	62	69	65	55	58	69	68	59	60	62	62	62	56	63	63	66	63
	Min	32	35	35	46	40	57	54	42	60	34	32	34	43	38	30	50	49	28	40	57	54	34	34	32	53	53	29	33	32	53	47
November	Max	63	62	55	55	50	56	57	60	67	62	50	48	46	59	37	36	38	44	50	50	40	42	55	58	38	32	52	50	60	57	----
	Min	52	37	33	30	38	32	26	32	39	43	38	26	36	32	24	21	23	31	23	27	21	14	26	38	27	18	32	29	40	43	----
December	Max	43	45	47	52	56	53	45	46	45	42	39	36	33	31	28	22	26	26	28	32	36	40	38	32	38	25	33	43	37	22	25
	Min	32	32	27	38	48	40	34	32	30	25	21	32	24	19	19	18	11	4	20	9	24	32	29	20	24	15	17	33	21	13	12

[a] From U. S. Weather Bureau records.

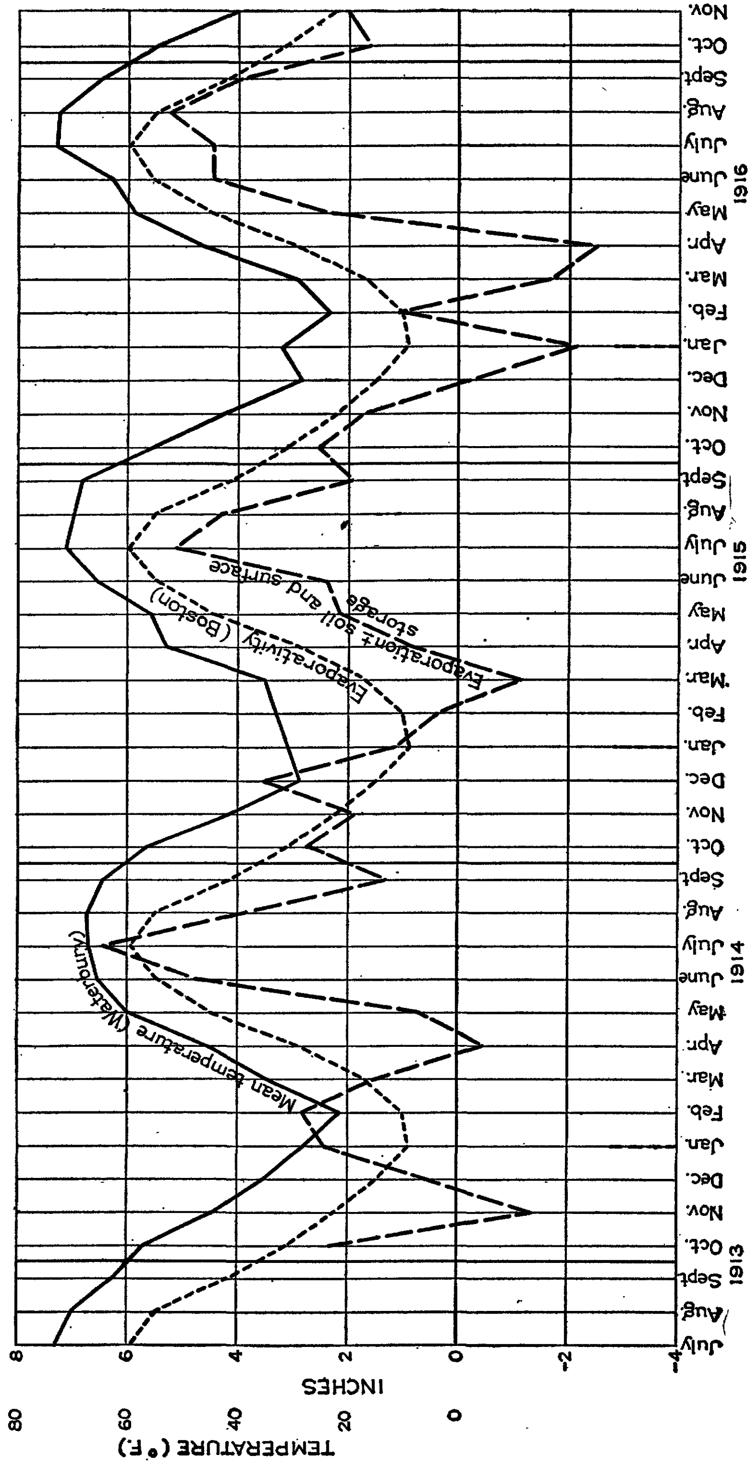


FIGURE 14.—Monthly temperature, evaporativity, and evaporation plus or minus changes in soil and surface storage in the Pomperaug Basin, Conn., July, 1913, to November, 1916

Average monthly and annual temperatures at Waterbury, July, 1913, to December, 1916, and normal temperatures at the same station (°F.)

	1913	1913–14	1914–15	1915–16	1916	Normal
October		57.2	56.8	54.6	54.5	52.2
November		44.0	40.6	42.4	41.0	40.6
December		35.4	28.8	28.5	30.6	31.0
January		28.0	31.2	32.2		25.5
February		21.8	33.0	23.5		26.7
March		35.2	35.4	28.8		33.5
April		46.0	53.2	46.8		47.0
May		60.9	55.9	58.6		58.1
June		65.4	65.8	62.8		67.6
July	73.0	69.4	71.1	73.0		71.7
August	70.7	71.8	69.0	72.6		69.6
September	62.4	64.0	68.0	64.6		63.2
Annual		49.9	50.9	49.0		48.8

RELATION OF EVAPORATIVITY TO PRECIPITATION

The evaporativity has a great seasonal fluctuation, ranging each year from a very slow rate in winter to a rapid rate in summer, but the differences in evaporativity from day to day or from month to month are not so great and erratic as the corresponding differences in precipitation. Moreover, for the same month in successive years the range of evaporativity is not nearly so great as the range in precipitation.

If the records for evaporativity at Boston can be regarded as approximately correct for the Pomperaug Basin, it follows that the evaporation from a free water surface in this basin is slightly less than the precipitation, although it may be greater in certain dry years. In general, the evaporation from a free water surface is greater than the precipitation during the summer and less than the precipitation during the winter, but occasionally there are summer months in which the precipitation is in excess of the evaporation.

EVAPORATION

TOTAL EVAPORATION

It is believed that the Pomperaug Basin does not lose any notable quantity of water by subterranean percolation. If this is true practically all the water that falls on the basin as rain or snow ultimately either evaporates or escapes through Pomperaug River. During any given period, however, some of the water may be stored as snow or ice, as surface water in ponds and streams, as soil moisture, or as ground water in the zone of saturation; on the other hand, water may be drawn from storage in the melting of snow and ice, the shrinking of ponds and the dwindling of streams, the drying out of the soil, or the lowering of the water table. Obviously, therefore, for any month, year, or other designated period, the total evaporation is about equal to the precipitation minus the total run-off and minus the net increase in storage, or to the precipitation minus the total run-off and plus the net decrease in storage.

The table on page 143 shows the difference between the precipitation and the total run-off minus any increase in ground-water storage or plus any decrease in ground-water storage for each month and year covered by the investigation. As no definite data were obtained concerning increase and decrease in the other forms of storage no allowances could be made for them. Thus this table shows the monthly and annual evaporation without corrections for changes in surface and soil storage. Even without these corrections the figures show in general the variations in monthly evaporation from one season to another. (See also fig. 14.) However, they are too large to represent evaporation alone in months when the soil became wetter (usually in late fall but also in occasional months of excessive rainfall in other seasons) and in months when snow accumulated on the ground. On the other hand, they are too small to represent all of the evaporation in months when the soil moisture was depleted (as in most months of late spring and in some months of summer and early fall) and in months when the snow that fell earlier in the winter disappeared. In some spring months the loss in snow storage is counterbalanced by increase in soil storage.

In the annual estimates the correction for increase or decrease in storage would be relatively much smaller, and in the 3-year average it would be still smaller. In other words, the figures given in this table show approximately the annual evaporation in the successive years, and the figure given for the annual average is a closer approximation to the average annual evaporation during the period of the investigation.

The evaporation opportunity is the actual evaporation expressed as a percentage of the evaporativity—that is, of the evaporation that would occur from a free water surface. If the average annual evaporativity at Boston represents fairly the evaporativity in the Pomperaug Basin during the years covered by the investigation the evaporation opportunity was about 64 per cent in the year ending September, 1914, about 64 per cent in the year ending September, 1915, and about 50 per cent in the year ending September, 1916—an average of about 59 per cent for these three years. If the run-off records for the first of these years and the precipitation records for the third year are a little too low, as is suspected, the actual evaporation opportunity may have been a little less than computed in the first year and a little more in the third year.

The records seem to indicate that in midsummer, when plant growth is most active, the evaporation opportunity is not far from 100 per cent. According to the records, average evaporativity and average evaporation both reach their maximum in July, when the average evaporativity is given as 5.98 inches and the average evaporation plus or minus storage is given as 5.34 inches. As July is usually a month when soil moisture is depleted, rather than increased, this figure for evaporation is apparently not too large.

Studies of relative amounts of precipitation, run-off, and evaporation have recently been made by Houk [22] in the drainage basin of Miami River above Dayton, Ohio, and by Bates and Henry [23] in the Wagonwheel Gap area, Colo. The average annual results derived from these investigations are given in the following table for comparison with the results obtained in the Pomperaug Basin. The records for the Miami Basin cover a period of 25 years, and those for Wagonwheel Gap 7 years, whereas those of the Pomperaug Basin cover only 3 years.

Comparison of average annual precipitation, run-off, and evaporation in the Pomperaug drainage basin, Conn., the Miami drainage basin above Dayton, Ohio, and drainage basin A of the Wagonwheel Gap area, Colo.

		Pomperaug	Miami	Wagonwheel Gap
Length of record	years	3	25	7
Precipitation	inches	44.48	37.07	21.00
Run-off	do	19.53	11.87	6.08
Evaporation [a]	do	23.20	25.20	14.92
	percentage of precipitation	52	68	71

[a] For the Miami Basin and the Wagonwheel Gap area this figure is precipitation minus run-off; for the Pomperaug Basin it is precipitation minus run-off and ground-water storage. (See table, p. 144.)

In the Miami Basin the precipitation is considerably less than in the Pomperaug Basin, but the evaporation appears from the data available to be slightly greater, leaving much less water to be carried off by the streams. In the Wagonwheel Gap area the precipitation is notably less, hence there is less water available either for evaporation or for discharge by the streams, but the proportion of evaporation to precipitation is greater.

Evaporation proceeds in two ways—by transpiration, or the evaporation from the pores or stomata of plants, and by evaporation that takes place without the agency of plants. Transpiration is limited to the growing season, which in the Pomperaug Basin extends from about April to October. Quantitative studies of transpiration have been made by numerous investigators, but most of these studies have been concerned primarily with irrigation and with the water requirement of plants. The results have commonly been expressed in pounds of water required to produce a pound of dry matter. The rate of transpiration depends upon many factors, such as temperature,

[22] Houk, I. E., Rainfall and run-off in the Miami Valley: Miami Conservancy District Tech. Repts., pt. 8, 1921.

[23] Bates, C. G., and Henry, A. J., Stream-flow experiment at Wagonwheel Gap, Colo.: Monthly Weather Rev. Suppl. 17, 1922.

humidity, wind velocity, light, soil moisture, and kind of vegetation. The subject is summarized as follows by Meyer:[24]

For tentative purposes the following normal seasonal transpiration may be used as a base value in estimating water losses for the north-central portion of the United States: 9 to 10 inches for grains, grasses, and agricultural crops; 8 to 12 inches for deciduous trees; 6 to 8 inches for small trees and brush; 4 to 6 inches for coniferous trees. These quantities represent inches depth of water over the entire area occupied by the given form of vegetation.

Only a very general estimate can be made of the rate of transpiration in the Pomperaug Basin. About 32 per cent of the basin is wooded, and most of the woodland is in small deciduous trees and brush. On the basis of Meyer's figures 9 inches seems a conservative estimate of the average amount of transpiration from both the wooded and the nonwooded areas.

If the total evaporation in the Pomperaug Basin was about 23 inches a year during the three years covered by the investigation and the transpiration was about 9 inches, it follows that about 14 inches a year was evaporated in other ways—chiefly from the moisture in the soil, but in part from the rain and snow intercepted by trees and other plants, in part from rain and snow lying on the surface of the ground, and in part from the water of ponds and streams.

EVAPORATION OF WATER DERIVED FROM THE ZONE OF SATURATION

Part of the water evaporated from the soil or transpired from plants is derived from the zone of saturation and hence from the supply of ground water. The amount of this ground-water evaporation was estimated in the following manner:

From November to April, each year, when the temperature is low, plant life nearly dormant, and the ground frozen much of the time, only small quantities of ground water are lost by evaporation. Moreover, no feasible method was available for estimating these small quantities. Therefore, the ground-water evaporation during these months was considered negligible.

Estimates of monthly ground-water evaporation for the period from May to October each year were computed from the monthly ground-water recharge, change in ground-water storage during the month, and monthly ground-water run-off. These quantities are given in the summary table on page 143. The methods of obtaining ground-water run-off and changes in ground-water storage are explained on pages 107 to 113 and 129 and 130; the methods of estimating the ground-water recharge on pages 140 and 141. For any month during the period from May to October in which there was a decrease in the

[24] Meyer, A. F., The elements of hydrology, p. 262, New York, John Wiley & Sons, 1917.

amount of ground water in storage, the recharge plus the net withdrawal from storage gives the total discharge of ground water, and this total discharge minus the ground-water run-off gives the ground-water evaporation. For example, in May, 1914, the recharge was estimated to be 1.84 inches, the net withdrawal from storage 0.08 inch, and the ground-water run-off 0.85 inch. Therefore, the total discharge of ground-water during the month was computed to be 1.92 inches and the ground-water evaporation 1.07 inches. In June, 1914, there was no recharge or, more precisely, the amount of recharge was so small that it was regarded as negligible. In the same month the net withdrawal from storage was 2.30 inches and the ground-water run-off was 0.39 inch. The total discharge of ground water was therefore taken to be 2.30 inches, and the ground-water evaporation 1.91 inches.

For certain months during the evaporation period in which there was considerable recharge no method was available for estimating the recharge independently of the ground-water evaporation (p. 141). Hence, there was no way of computing the ground-water evaporation. For these exceptional months the best that could be done was to obtain the average ground-water evaporation for corresponding months in other years and to assume that this average represented the evaporation for this month. Thus the ground-water evaporation could not be computed for October, 1913, and October, 1914, but it was computed to be 0.87 inch in October, 1915, and 0.82 inch in October, 1916, and therefore the somewhat unsatisfactory assumption was made that the ground-water evaporation in October, 1913, and October, 1914, was the average of these two figures, or 0.85 inch. The only other months for which averages from other years had to be used were May, August, and September, 1915.

The average annual ground-water evaporation for the three years covered by the investigation, according to the computations that were made, was 6.21 inches, or about 27 per cent of the total evaporation. This includes transpiration of trees and other plants that feed upon water from the zone of saturation and also evaporation from soil in low places where the soil is kept moist by rising ground water. It also includes evaporation from springs, seepage areas, and streams.

The table on page 144 shows that although the total evaporation, like the evaporativity, does not reach its maximum until July, the ground-water evaporation reaches its maximum in June. The table also indicates that the ground-water evaporation amounts to about 66 per cent of the total in May and to about 36 per cent of the total in June, whereas for the entire year it amounts to only 27 per cent of the total. Although these monthly averages are believed to be subject to large errors they are probably correct in showing that the ground-water evaporation is relatively large in the first part of the evaporation season, when the water table stands high.

GROUND-WATER RECHARGE

It remains to consider the quantity and distribution of the ground-water recharge—that is, the water that percolates down to the water table and enters the zone of saturation.

There was some recharge in every month or nearly every month from October to May in each year covered by this investigation, as is shown by the fact that in every one of these months, with a few possible exceptions, the water table either rose or else declined only moderately—not enough to provide the amount of ground water that was disposed of by run-off and evaporation. The monthly recharge varied greatly in amount, however, being largest in months in which there was heavy rainfall or in which much snow melted and least in months with meager precipitation or with frozen ground and accumulating snow.

During the summer months (June to September) the consumption of water by plants and the evaporation from the soil are so great that not much of the rain escapes to the water table except at times of especially heavy rainfall. As is shown in Plate 19, most ordinary summer rains have no noticeable effect on the water table. In August, 1915, when the water table rose conspicuously, there was obviously heavy recharge, and some recharge is also indicated by the water-level data in July and August, 1914, July and September, 1915, and June and July, 1916.

The monthly recharge was computed as follows: For the period from November to April, when ground-water evaporation is regarded as negligible, the recharge in any month is equal to the ground-water run-off plus the net increase in ground-water storage as indicated by the rise of the water table, or minus the net decrease in ground-water storage as indicated by decline of the water table. In most of these months there was a rise in the water table and hence some storage to be added to the run-off. The greater part of the recharge occurs during this cold period, when the problem is not seriously complicated by evaporation.

In the remaining months of the year, when evaporation has to be taken into account, the simple method used for the colder months is not applicable. For these months it was necessary to compute the recharge, so far as possible, directly from the fluctuations of the water table. The regular decline of the water table in some months shows that there was little or no recharge in these months, and hence in making the computations recharge in these months was regarded as zero. In those summer months in which the water levels were appreciably affected by precipitation the amount of recharge was estimated, if possible, directly from the water-table curve in Plate 19. For example, in August, 1914, the water table declined gradually until at least August 15, but between the measurements made on the 15th and those made on the 22d there were several rains which not only stopped the decline but raised the water table 0.18 foot. The recharge between these dates was estimated not on the rise of the water table, but on the vertical interval between the level at which it stood on August 22 and the level at which it would have stood if the gradual decline prior to August 15 had continued until August 22. This interval is about 0.3 foot and represents a recharge of about 0.45 inch. After August 22 the water table resumed its decline and no further allowance was made for recharge in this part of the month.

In a few of the summer months with large recharge it was impossible to make a satisfactory estimate of recharge by inspection of the water-table curve in Plate 19. These months were October, 1913, October, 1914, and May, August, and September, 1915. For these months average figures for ground-water evaporation were used, as explained on page 143, and the recharge was then computed as the sum of ground-water run-off and ground-water evaporation plus or minus change in storage. The estimates of recharge for these months are in error to the extent that the quantities used for ground-water evaporation are inaccurate.

According to the methods of computation explained above, the annual ground-water recharge during the three years ranged from 14.04 to 16.84 inches and averaged 15.57 inches, or 35 per cent of the precipitation.

It was not practicable to make an inventory of the water in the stratified drift as distinct from that in the entire basin. However, as the stratified drift yields water more freely than the till, large ground-water developments in this region are generally made by sinking wells in the stratified drift, and hence it is of practical importance to have information on the rate of recharge in deposits of this kind. The data given in the table on page 124 show that the fluctuations of the water table in the stratified drift are comparable in magnitude to those in the till. As the specific yield of the stratified drift is much greater than that of the till, it is obvious that the fluctuations of the water table in the stratified drift represent much greater quantities of ground water than the average fluctuations for the entire basin, as shown in the summary table on page 143. Much of this water comes from precipitation on the areas of stratified drift, but some comes as surface or ground water from adjacent areas that are underlain by till.

SUMMARY

The water in the drainage basin of Pomperaug River is nearly all derived from precipitation—that is, from the rain and snow which fall on the basin. It is nearly all disposed of as run-off or by evaporation—that is, it is either carried out of the basin by Pomperaug River or else is evaporated directly or through the agency of plants. In the three full years covered by this investigation, October, 1913, to September, 1916, according to the data that were obtained, the precipitation averaged 44.48 inches, the run-off 20.66 inches, and the evaporation 23.20 inches a year (plus or minus a slight unknown difference in stream and soil storage). Moreover, there was during the 3-year period a net increase in ground-water storage (that is, in the quantity of water stored in the zone of saturation) which amounted to 1.85 inches, or an average of 0.61 inch a year, as is shown by the higher position of the water table at the end than at the beginning of the period.

During the 3-year period the ground-water recharge, or quantity of water that percolated from the surface to the water table and entered the zone of saturation, averaged 15.58 inches a year. Of this amount, an average of 8.76 inches seeped into Pomperaug River and its tributaries and was carried out of the basin by the river, 6.21 inches evaporated either directly or through the agency of plants, and 0.61 inch remained in storage in the zone of saturation.

According to these results, in the 3-year period the total run-off amounted to about 46½ per cent and the total evaporation to about 52 per cent of the precipitation, about 1½ per cent of the precipitation being stored in the zone of saturation. The ground-water recharge amounted to about 35 per cent of the precipitation, of which somewhat more than half was disposed of as run-off and somewhat less than half by evaporation. More precisely, the ground-water run-off amounted to about 19½ per cent of the precipitation, the ground-water evaporation to about 14 per cent, and the net increase in ground-water storage to about 1½ per cent.

There was no marked seasonal distribution of the precipitation but a very pronounced seasonal distribution of the evaporation. Consequently, each year was divided into a replenishing and a depleting season. In the replenishing season, from late fall to early spring, an average of approximately 7 inches of water was stored in the zone of saturation, over and above the withdrawals as run-off and by evaporation; in the depleting season, from late spring to early fall, nearly a like average amount was withdrawn from storage, in addition to the contributions that were occasionally received by the zone of saturation during this season. Most of the water withdrawn from storage during the depleting season was utilized by the vegetation or otherwise evaporated; only a small part ran off through Pomperaug River. In any long period of years the average seasonal depletion will, of course, be very nearly equal to the average seasonal replenishment.

In the following tables are given a summary of the monthly and annual inventories of the water supply of this basin during the period covered by the investigation:

Inventory of the water supply of the Pomperaug Basin, July, 1913, to December, 1916, in depth in inches over the drainage area

	Precipitation	Increase or decrease of ground water in storage	Ground-water run-off	Ground-water recharge	Ground-water evaporation	Total run-off	Total evaporation plus increase or minus decrease in surface and soil storage	Principal changes in surface and soil storage or other conditions that make the figures given in last column greater or less than total evaporation
1913								
July	2.07	--------	--------	--------	--------	--------	--------	
August	3.35	--------	0.13	--------	--------	0.25	--------	
September	3.43	--------	.17	--------	--------	.35	--------	
October	9.21	+4.30	.52	5.67	[a] 0.85	2.57	2.34	Increase in stream and soil storage.
November	2.72	+1.38	1.73	3.11	([b])	2.73	−1.39	Decrease in soil storage.
December	2.58	−.23	1.42	1.19	([b])	2.24	.57	
1914								
January	3.01	−.77	[c] 1.00	.23	([b])	1.33	2.45	Estimate of total run-off probably too low.
February	3.10	−.31	[c] .40	.09	([b])	.58	2.83	Increase in snow storage; estimate of total run-off probably too low.
March	6.01	+.23	.86	1.09	([b])	4.32	1.46	
April	4.20	+1.69	1.03	2.72	([b])	2.94	−.43	Decrease in snow storage.
May	3.06	−.08	.85	[d] 1.84	1.07	2.35	.79	Decrease in soil and stream storage.
June	3.11	−2.30	.39	([e])	1.91	.63	4.78	
July	5.68	−1.46	.38	[d] .45	1.53	.70	6.44	
August	3.67	−.77	.29	[d] .45	.93	.45	3.99	
September	.31	−1.23	.18	([e])	1.05	.20	1.34	Decrease in soil storage.
October	3.35	+.31	.22	1.38	[a] .85	31	2.73	Increase in soil storage.
November	2.50	+.15	.34	.49	([b])	.51	1.84	
December	4.10	−.08	[c] .50	.42	([b])	[c] .62	3.56	Increase in soil storage and perhaps in snow storage; estimate of total run-off may be too low.
1915								
January	6.49	+2.00	[c] .95	2.95	([b])	[c] 3.41	1.08	
February	5.63	+1.69	[c] 1.20	2.89	([b])	[c] 3.58	.36	
March	.10	−.38	1.19	.81	([b])	1.61	−1.13	Decrease in stream and snow storage.
April	1.88	−.614	.90	.29	([b])	1.60	.89	
May	3.15	−.23	.67	1.61	[a] 1 17	1.21	2.17	
June	1.88	−1.00	.28	([e])	.72	.45	2.43	
July	5.77	−.15	.24	[d] .60	.51	.78	5.14	
August	7.87	+1.84	.60	3.34	[a] .90	1.79	4.24	
September	2.56	−.31	.44	1.05	[a] .93	.92	1.95	Decrease in soil storage.
October	2.61	−.92	.55	[d] .50	.87	1.01	2.52	
November	2.51	−.15	.36	.21	([b])	.92	1.74	
December	4.86	+2.30	.73	3.03	([b])	2.90	−.34	Records for precipitation probably too low.
1916								
January	1.48	+.61	1.34	1.95	([b])	3.00	−2.13	Decrease in snow storage.
February	4.77	+1.00	.99	1.99	([b])	2.71	1.06	Increase in snow storage; records for precipitation probably too low.
March	2.43	+.38	1.16	1.54	([b])	3.66	−1.61	Decrease in snow storage; records for precipitation probably too low.
April	2.20	+.31	1.90	2.21	([b])	4.45	−2.56	Decrease in snow storage.
May	3.83	−.31	.89	[d] 1.84	1.26	1.76	2.38	
June	4.27	−1.84	.69	[d] .40	1.55	1.68	4.43	
July	4.49	−1.00	.54	[d] .40	.86	1.05	4.44	
August	4.67	−1.15	.29	([e])	.86	.56	5.26	
September	3.38	−1.06	.25	([e])	.81	.45	3.99	
October	1.29	−.77	.25	[d] .30	.82	.44	1.62	
November	2.65	+.08	.32	.40	([b])	.56	2.01	Increase in soil storage.
December	3.52	+.84	--------	--------	([b])	--------	--------	

[a] Unsatisfactory estimate based on average of corresponding months in other years.
[b] Ground-water evaporation is regarded as negligible.
[c] Estimated on inadequate data.
[d] Estimated from irregularity in water-table curve in Plate 19.
[e] Ground-water recharge was apparently negligible in amount.

Inventory of the average monthly water conditions in the Pomperaug Basin, July, 1913, to December, 1916, in depth in inches over the drainage area

[Based on all data in the preceding table]

Month	Precipitation [a]	Increase or decrease of ground water in storage	Ground-water run-off	Ground-water recharge	Ground-water evaporation	Total run-off	Total evaporation plus increase or minus decrease in surface and soil storage
October	4.12	+0.73	0.39	1.96	0.85	1.08	2.36
November	2.60	+.33	.69	1.05		1.18	1.05
December	3.77	+.71	.88	1.55		1.92	1.26
January	3.66	+.61	1.10	1.71		2.58	.47
February	4.50	+.79	.86	1.66		2.29	1.42
March	2.85	+.08	1.07	1.15		3.20	−.43
April	2.76	+.46	1.28	1.74		3.00	−.70
May	3.35	−.21	.80	1.76	1.17	1.77	1.78
June	3.09	−1.71	.45	.13	1.39	.92	3.88
July	4.50	−.87	.39	.48	.96	.84	5.34
August	4.89	−.03	.33	1.27	.90	.76	4.50
September	2.42	−.87	.26	.35	.93	.48	2.43

[a] Based on monthly precipitation during the period; not Waterbury normal.

Inventory of the annual water supply of the Pomperaug Basin, October, 1913, to September, 1916, in depth in inches over the drainage area

[Based on all data in the preceding table]

Month	Precipitation	Increase or decrease of ground water in storage	Ground-water run-off	Ground-water recharge	Ground-water evaporation	Total run-off	Total evaporation plus increase or minus decrease in surface and soil storage
October, 1913, to September, 1914	46.66	+0.45	9.05	16.84	7.34	21.04	25.17
October, 1914, to September, 1915	45.28	+3.23	7.53	15.83	5.07	16.79	25.26
October, 1915, to September, 1916	41.50	−1.83	9.69	14.07	6.21	24.15	19.18
Average	44.48	+.61	8.76	15.58	6.21	20.66	23.20

DISCUSSION OF METHODS AND RESULTS

In arid regions so many quantitative investigations of ground-water supplies have been made that the methods of work are relatively well understood. In humid regions, however, much less quantitative work has been done, the methods that are employed in arid regions are largely inapplicable, and the problem of making quantitative estimates is inherently more difficult. The method used in this investigation is a composite of several available methods and has doubtless led to more reliable results than could have been obtained by the application of any single method. The observations made, however, were not adequate in number nor sufficiently refined to lead to very accurate results, and the period of observation was too short to give average conditions. With the same general method much more accurate results can be obtained if sufficient funds and time are available to make more numerous and more detailed observations.

The precipitation records show that many of the rains and snows are local or vary in intensity within short distances, and that an accurate measure of the quantity of water that falls upon an area so large as the Pomperaug Basin can not be obtained from three rain gages, even though they are well distributed and there are no gaps in the records. Where so few gages are used the daily records are the most likely to be unrepresentative, but even the monthly and annual records may show considerably more or less precipitation than the true average for the basin. It should be noted, however, that with the method that was used the records of precipitation do not enter directly into the ground-water estimates.

In such an investigation the record of total run-off, as determined by the gaging station near the mouth of the trunk stream, is very important, and more money should be spent than was available for the station at Bennetts Bridge, to make this record accurate and complete. Instead of a staff gage read by a local observer once or twice a day, an automatic gage, or water-stage recorder, should be installed. In winter, when the relation of discharge to stage is disturbed by ice in the river, a sufficient number of current-meter measurements should be made to obtain a complete and reliable record.

In this investigation the estimates of ground-water run-off were based on the discharge of the Pomperaug at Bennetts Bridge—that is, on the discharge during the periods between rains, when there was virtually no direct run-off left in the stream system. Much better results could be obtained by basing the estimates on periods beginning as soon after rains as all of the direct run-off has reached the streams. With this method the ground-water run-off during any particular day would be the total run-off minus the decrease in stream storage. The decrease in stream storage could be estimated by maintaining gages at several points on the trunk stream and on selected tributaries and making surveys of the stream system showing the approximate water areas of different parts of the system at different gage heights. Calculations show that in a drainage basin which is not larger than the Pomperaug the total quantity of water stored in the stream system at any time is rather small compared with the rate of discharge and hence that errors in the measurement of decrease in storage will introduce relatively small errors in the estimates of ground-water run-off. The proposed method would have the advantage over the method used in this investigation in that the record would cover a much larger part of each period between rains and that the entire process would be one of observation and measurement without the intangible feature of the present method. It would not be necessary to make current-meter measurements to develop rating curves at the subsidiary stations, as only change in storage, indicated by change in gage-height, is involved, not rate of discharge.

Records should be obtained in regard to snow storage and soil storage. The precipitation records should show whether the precipitation occurred as rain or snow, and there should be a record of the days when the snow contributed to the direct run-off, when it did not thaw sufficiently to contribute to the run-off, when the ground was virtually free of snow, and when the ground was frozen. Soil storage is an important item in the monthly inventory and could be estimated on the first of each month by making a number of moisture determinations of soil samples collected in fairly typical locations. Large numbers of moisture determinations are made in connection with dry-farming and irrigation investigations, and some are now made in the laboratories of the Geological Survey in connection with hydrologic investigations.

There should be a larger number of observation wells, they should be more widely distributed over the basin, and so far as possible they should be equipped with automatic water-stage recorders. Much more work should be done to determine the specific yield of the different kinds of material in which the water table occurs, because the specific yield is a factor in the estimates of ground-water recharge and ground-water evaporation. In recent investigations it has been found feasible to obtain columns of the undisturbed materials and to make direct tests of the specific yield of these materials in their natural state. The columns are taken directly above the water table at a low stage.

Records of evaporation from a free water surface should be obtained for the entire period covered by the investigation. Work could also be done in determining transpiration and soil evaporation by tank experiments and from daily fluctuations of the water table shown by water-stage recorders over wells. Indeed, with the methods that have been outlined, the accuracy of the results in a quantitative study of the water resources of an area will be largely a function of the funds and time available for making the investigation.

PROBLEMS OF THE SOFT-WATER SUPPLY OF THE DAKOTA SANDSTONE, WITH SPECIAL REFERENCE TO THE CONDITIONS AT CANTON, SOUTH DAKOTA

By Oscar E. Meinzer

INTRODUCTION

The Dakota sandstone, which is recognized as the basal formation of the Upper Cretaceous rock series, underlies most of North Dakota, South Dakota, and Nebraska, the western parts of Minnesota, Iowa, and Kansas, and considerable parts of several States farther west and southwest. In most of the area that it occupies it is deeply covered by younger formations, but it appears at the surface in widely separated localities. It is exposed in the bluffs of Missouri and Big Sioux Rivers in the vicinity of Sioux City, Iowa, where it is identified by the fossils that it contains, especially the fossil leaves. Over wide areas, however, it is known only from drilling operations, which rarely produce any fossils. In sinking deep wells in most parts of South Dakota the drill, after penetrating the surficial deposits, passes through several hundred feet of strata that consist chiefly of soft shale, and then through alternating beds of sandstone and shale that range in aggregate thickness from less than a hundred to a few hundred feet. It is generally assumed that the first distinct sandstone stratum encountered by the drill marks the top of the Dakota sandstone and that the entire succession of alternating shales and sandstones belongs to this formation, though it is recognized that the lowest strata may belong to the Lakota sandstone or to some other formation of the Lower Cretaceous series.[1]

The water supplies from different parts of the Dakota sandstone differ greatly in their chemical character—that is, in the kinds and amounts of mineral matter that they hold in solution. They differ from place to place and in successive strata in the same place. In a broad sense the waters of the Dakota sandstone may be grouped in two main classes—hard water and soft water. In general, in North

[1] Darton, N. H., Geology and underground waters of South Dakota: U. S. Geol. Survey Water-Supply Paper 227, p. 41, 1909.

Dakota, South Dakota, and Minnesota the soft water occurs in the upper part and the hard water in the lower part of the Dakota sandstone. This relation was first determined in 1895 by Shepard,[2] who

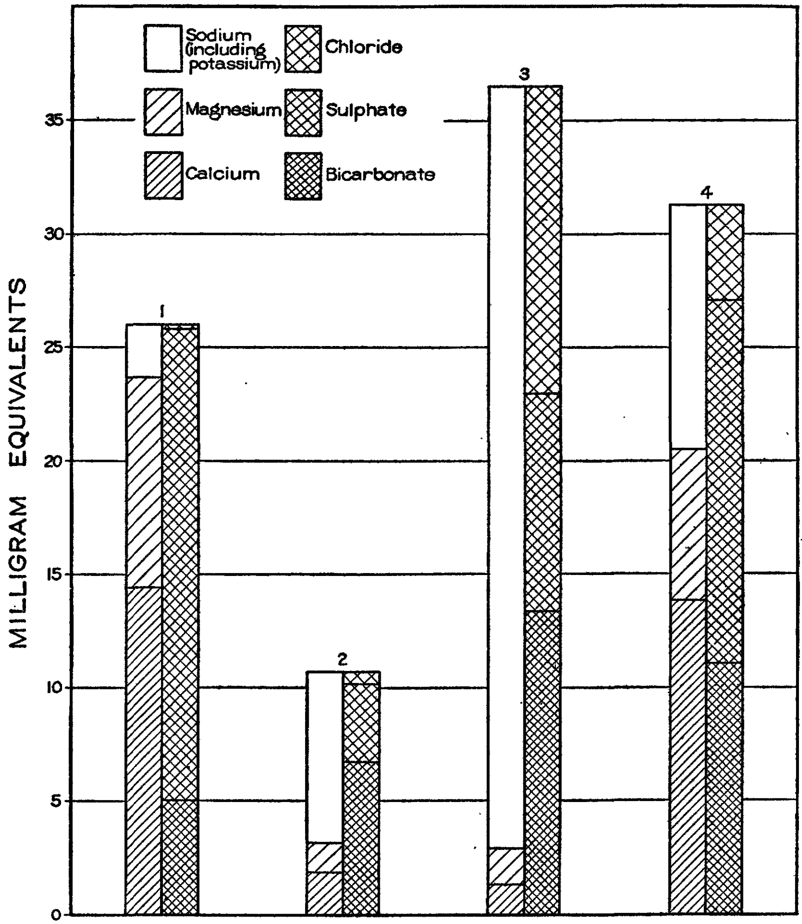


FIGURE 15.—Diagram showing chemical composition of water from the Dakota sandstone and from the terrace gravel at Canton, S. Dak. 1, Water from terrace gravel at Canton (average of 2 analyses on p. 161); 2, water from Dakota sandstone at Canton (average of A, E, G, and H on p. 161); 3, water from "first flow" of Dakota sandstone (average given on p. 149); 4, water from "second flow" of Dakota sandstone (average given on p. 149)

made analyses of 10 samples of water from the "first flow" and of 10 samples from the "second flow" of the Dakota sandstone in South Dakota, with the results shown in the following table and graphically represented in Figure 15.

[2] Shepard, J. H., The artesian waters of South Dakota: South Dakota Agr. Coll. and Exper. Sta. Bull. 41, 1895.

Average content of dissolved mineral matter in the two types of water from the Dakota sandstone in South Dakota

[Determined from analyses by J. H. Shepard. Parts per million]

	"First flow"	"Second flow"
Calcium (Ca)	27	279
Magnesium (Mg)	20	79
Sodium (Na)	773	249
Sulphate radicle (SO_4)	465	770
Chloride (Cl)	480	145
Total solids	2,261	2,019

Investigations in southwestern Minnesota in 1907 showed that the two types of water found in South Dakota occur also in the Dakota sandstone in Minnesota.[3] It was found that there are several soft-water and several hard-water strata here and that their relations are somewhat complicated, but that the principal soft-water strata

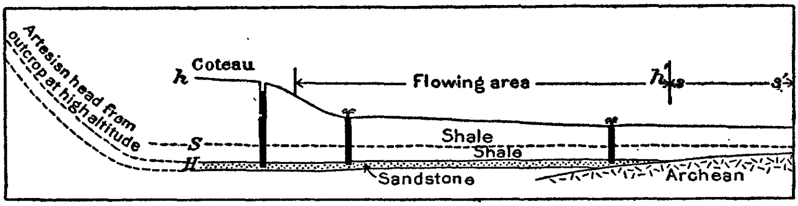


FIGURE 16.—Diagrammatic section through southwestern Minnesota showing the relation of stratigraphy and structure to the geographic distribution of hard and soft water in the Dakota sandstone

occur in the upper part and the principal hard-water strata in the lower part of the formation. The recent work of Simpson and Riffenburg[4] has shown that in North Dakota also the Dakota sandstone contains the two kinds of water and that in general the soft water occurs in the upper part and the hard water in the lower part of the formation.

Over large areas in southwestern Minnesota where the basal granite occurs relatively near the surface the lower strata of sandstone are cut off, but the upper strata lap over the granite and yield soft water.[5] (See fig. 16.) These conditions seem to give the clue to the conditions at Canton, S. Dak. Darton[6] has shown that in a con-

[3] Hall, C. W., Meinzer, O. E., and Fuller, M. L., Geology and underground waters of southern Minnesota: U. S. Geol. Survey Water-Supply Paper 256, pp. 68–74, pl. 4, 1911. See also the county reports in this paper.

[4] Simpson, H. E., and Riffenburg, H. B., Geology and ground-water resources of North Dakota: U. S. Geol. Survey Water-Supply Paper 598 (in press). See also Riffenburg, H. B., Chemical character of ground waters of the northern Great Plains: U. S. Geol. Survey Water-Supply Paper 560, pp. 50–51, 1925; Meinzer, O. E., and Hard, H. A., The artesian-water supply of the Dakota sandstone in North Dakota, with special reference to the Edgeley quadrangle: U. S. Geol. Survey Water-Supply Paper 520, pp. 79–80, 1925.

[5] Hall, C. W., Meinzer, O. E., and Fuller, M. L., op. cit., pp. 54, 55, 68–73. See also county reports and pl. 4.

[6] Darton, N. H., op. cit., p. 41, pl. 11.

siderable part of southeastern South Dakota where the Sioux quartzite is relatively near the surface it cuts off the Dakota sandstone, but that the Benton shale, which lies next above the sandstone, overlaps upon the quartzite throughout a wide belt. Although no certain correlations can be made, it appears that in the vicinity of Canton the quartzite occurs at such an altitude that it cuts off the lower part of the Dakota sandstone but not the uppermost stratum, which contains soft water.

The Dakota sandstone extends far eastward from South Dakota and Nebraska and occurs as a thin and somewhat interrupted formation throughout much of the western halves of Minnesota and Iowa. However, practically no soft-water wells have until recently been known in the Dakota sandstone in Iowa or in adjacent parts of South Dakota or Minnesota, and it has been a question how far southeast soft water may be found in this formation. The most southeasterly point at which soft water was reported by Shepard [7] was at Iroquois, S. Dak., about 100 miles northwest of Canton. In the ground-water survey of southern Minnesota careful attention was given to the southward extension of the soft-water horizons, but no soft-water wells were found near the southern margin of the State. In the ground-water survey of Iowa no samples of really soft water were obtained from the Dakota sandstone.[8] It is therefore a matter of considerable economic significance that soft water has been found in the vicinity of Canton. It is still uncertain to what extent soft-water supplies can be found in the Dakota sandstone of western Iowa and adjacent parts of Minnesota, South Dakota, and Nebraska. Many wells have been drilled without finding soft water, and it appears that where the Dakota sandstone rests as a thin and interrupted formation upon rocks of the Paleozoic systems, which yield hard water,[9] the prospects of finding soft water are not so good as where the Dakota sandstone rests on relatively impermeable rocks, such as the granite and quartzite. However, the soft-water strata where they have been found in Minnesota are thin and do not yield water freely, and hence a driller might easily drill through them without finding the soft water or without separating it from the hard water of other horizons. It is, therefore, very desirable that in future deep drilling in this region the drillers should keep this problem in mind and make an effort to obtain an unadulterated sample of water from each water-bearing stratum that is penetrated in order to find the soft water wherever it occurs.

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[7] Shepard, J. H., op. cit., pp. 21, 66.

[8] Norton, W. H., Underground water resources of Iowa: U. S. Geol. Survey Water-Supply Paper 293, pp. 142–177, 1912.

[9] Hall, C. W., Meinzer, O. E., and Fuller, M. L., op. cit., pp. 74–75. Norton, W. H., and others, op. cit., pp. 139–183 and county reports.

The conditions at Canton were brought to the attention of the Geological Survey on account of the trouble caused by sand in the city wells, which are pumped much harder than the farm wells that end in the same soft-water stratum of the Dakota sandstone. This is not a new or uncommon problem. In the work in northwestern Iowa in 1906 and in southwestern Minnesota in 1907, it was found that in these areas and in adjacent parts of South Dakota most of the drilled wells ended in sand belonging to the glacial drift or the Dakota sandstone, that in many localities these wells had given so much trouble that nearly all had been abandoned, and that the successful finishing of wells in sand was one of the most difficult problems in connection with water supplies in the region. Therefore the entire problem was investigated in the field and laboratory. As a result practical advice was given that has in large measure been followed by the drillers and has resulted in general improvement in the methods used in finishing wells in sand. This advice consisted essentially in recommending wells of larger diameter than the 2-inch "tubulars"; driving the casing to the proper depth; having the metal screen (where one is required) attached tightly to the bottom of the casing and of small enough diameter so that it can be removed when it becomes clogged without pulling the casing; developing a natural screen or an artificial gravel screen; and installing a pump that is independent of the casing. In regard to gravel screens, the following statement was made:[10]

> Glacial deposits and to some extent also Cretaceous strata are poorly sorted, fine sand and coarser grit generally being more or less mixed together. When a well is to be finished in one of these deposits it should be pumped for a protracted period in such a manner as to remove the fine silt and leave a natural screen of coarser material. This frequently makes it possible to finish the well without a screen where otherwise one would have been required, but it should be done even where a screen is inserted. Proper treatment in this respect requires patience and skill, but it undoubtedly results in superior wells.
>
> The process of developing a natural screen is sometimes supplemented by introducing into the well a quantity of gravel or crushed tile of the proper coarseness. This method has proved successful with drillers who are willing to devote sufficient time and effort to it and often makes it possible to finish a well without putting in an ordinary screen.

Although the trend among drillers has been in the direction of better methods of finishing wells, in ways such as are indicated above, the sand problem still presents many difficulties, and there is still much room for improvement in developing and applying effective methods.

The present report is in no sense a treatise on the quality of water or the methods of finishing wells in the Dakota sandstone. It is

[10] U. S. Geol. Survey Water-Supply Paper 256, pp. 82–87, 1911; Water-Supply Paper 293, pp. 190–195, 1912.

essentially a by-product of the study that was made as a basis for a recommendation to the United States Office of Indian Affairs in regard to drilling a well at the Asylum for Insane Indians, near Canton. The report presents data as to the occurrence of soft water in an area where its existence has not until recently been known and calls attention to the possibilities of finding it in other localities in this general region in which at present only hard water is known. Furthermore, the report presents, almost for the first time in hydrologic literature, detailed information as to the performance of wells in a sand whose physical and hydrologic properties were determined in the laboratory. It is hoped that this contribution to hydrology will be of service especially to the water-well drillers of the Northwest in improving the water supplies of that region. The writer considers the drillers his colaborers, for they have contributed generously not only to this investigation but to virtually all the ground-water investigations that have been made by the Geological Survey.

GENERAL CONDITIONS AT CANTON, S. DAK.

GEOLOGY

The city of Canton, the seat of Lincoln County, is on the west side of Big Sioux River, which here forms the boundary between South Dakota and Iowa. (See fig. 17.)

The area about Canton is underlain at a depth of a few hundred feet by the Sioux quartzite, which is the hard pink rock exposed at Sioux Falls. This is a very ancient rock belonging to the Algonkian system. Above the Sioux quartzite is a thin series of sandstone and shale of Cretaceous age. The sandstone is believed to be an upper member of the Dakota sandstone, and the overlying shale is probably a part of the Benton shale.[11]

The Cretaceous strata are completely buried under glacial deposits of several kinds. Old glacial drift apparently underlies all of this region and belongs chiefly to what is known as the Kansan drift sheet but may include still older drift known as the Nebraskan drift sheet. Throughout Lincoln County, however, except along Big Sioux River and in the southeastern part of the county, the Kansan drift sheet is overlain by much younger drift that is known as the Wisconsin drift sheet. East of the river, in Iowa, the Wisconsin drift is absent, but great deposits of buff wind-blown silty material, called loess, rest on the Kansan drift and largely cover it. This is, in part at least, the reason why the bluffs on the east side

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[11] Wilder, F. A., Geology of Lyon and Sioux Counties: Iowa Geol. Survey Ann. Rept., vol. 10, pp. 96–117, 1900.

of the river are so much higher than those on the west side. Loess occurs also on the west side of the river on the upland a few miles south of Canton. Along the Big Sioux there are extensive deposits of gravel that were laid down by the river in the last glacial stage.

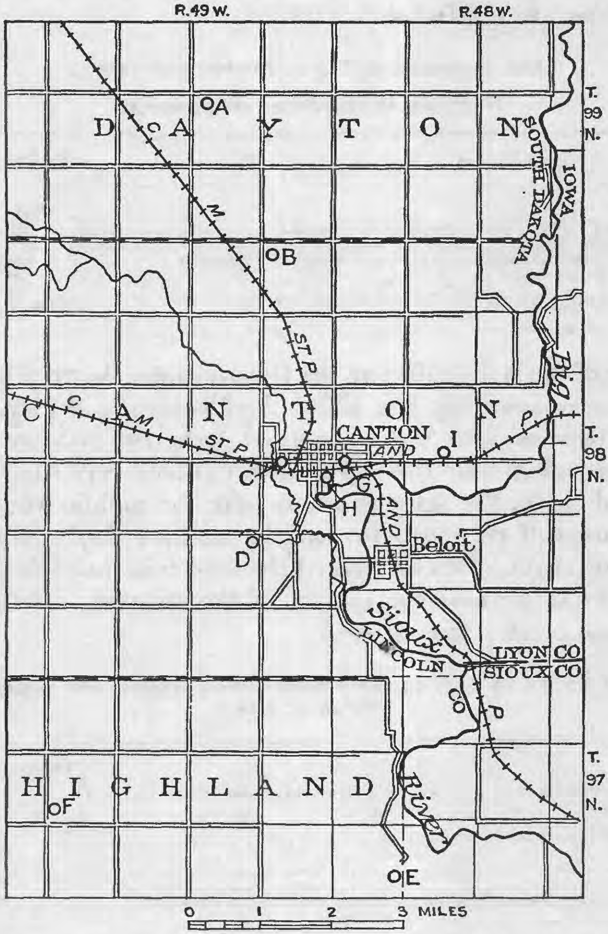


Figure 17.—Map of the vicinity of Canton, S. Dak., showing location of soft-water wells. The letters give the designations of the wells used in the table and text

After the river had deposited this gravel it cut its channel somewhat deeper, and hence the gravel now occurs chiefly under benches or terraces that lie somewhat above the bottom lands.[12]

The materials penetrated in drilled well 1 of the Canton waterworks were reported by Mr. Norman Harrison, the driller, as shown

[12] Carman, J. E., The Pleistocene geology of northwestern Iowa: Iowa Geol. Survey Ann. Rept., vol. 26, pp. 294–307, 1917. The information regarding the glacial drift was obtained chiefly from Carman's paper.

below. This report was given from memory, however, and Mr. Harrison emphasized the fact that it is very inaccurate as to the thickness and depth of the different materials. Apparently the "blue clay" is glacial drift; the "gray and bluish shale," "brown rock," and "blue muck" belong to the Benton shale; and the "sandstone" belongs to the Dakota sandstone.

Log of drilled well 1 at Canton waterworks

[Depths and thicknesses given are approximate]

	Thickness	Depth
	Feet	*Feet*
Clean "river-bed" gravel, water bearing in lower part	20	20
Blue clay, containing some pebbles and boulders	40	60
Gray and bluish shale, containing no pebbles but some slaty streaks	140(?)	200(?)
Brown rock, somewhat hard	30	230(?)
Blue muck	40	270+
Sandstone, water bearing	32 or 34	306

The log of the well drilled at the United States Asylum for Insane Indians, as reported by Mr. E. C. Archibald, the driller, is given below. Three samples were submitted from the 252-foot "shale." The sample taken near the top is bluish pebbly clay that is doubtless glacial drift; the samples taken near the middle and near the bottom consist of very uniform and fine-grained clay or shale, probably Benton shale. Two samples of the sandstone, one taken near the top and the other near the bottom of the stratum, consist of fine, even-grained sand. (See p. 163.)

Log of well drilled in 1926 at the United States Asylum for Insane Indians, Canton, S. Dak.

	Thickness	Depth
	Feet	*Feet*
Soil and subsoil	5	5
Gravel	30	35
Shale [a]	252	287
Sandstone [b]	33	320
Shale	2	322

[a] See description of samples given above.   [b] See description of samples, pp. 162-165.

GROUND WATER

Most of the farms in the vicinity of Canton obtain their water supplies from wells that end in the glacial drift. No investigation was made of these wells. Most of them apparently yield enough water for farm use, but on some farms it has been difficult to obtain satisfactory wells. The water is hard but is used for drinking and cooking as well as for watering livestock.

The city of Canton has for many years obtained its public water supply from large dug wells in the terrace gravel that occurs along Bix Sioux River. The supply for the United States asylum near Canton has also been obtained from this gravel. The gravel yields water in considerable quantity, but the water is hard and otherwise highly mineralized.

On several farms in the vicinity of Canton wells have been drilled to the Dakota sandstone in order to obtain the relatively soft water that occurs in this sandstone. These wells have been drilled within the last 15 years, according to Mr. Harrison, who put down most of them. In 1920 a successful soft-water well was drilled by Mr. Harrison and Mr. E. E. Adair at the electric plant in Canton. A little later five wells were drilled by the same drillers for the city of Canton, but these wells have given much trouble under the heavy pumping to which they have been subjected. Recently a well was drilled at the United States asylum by Mr. E. C. Archibald.

WATER IN THE TERRACE GRAVEL

DUG WELLS OF THE CANTON WATERWORKS

The oldest pumping plant and well field of the waterworks of the city of Canton are on Dakota Street, between the railroad station and the river. (See fig. 18.) An old abandoned well, 8 feet in diameter, is situated at the foot of Dakota Street, about 40 feet from the river bank and only a few feet above the level to which the river is impounded. It is understood that this well was abandoned because of pollution from the river; it is so situated that it could easily have been polluted by river water. Later a number of well points were driven on the low ground on the east side of Dakota Street, but it seems that these became clogged and incrusted and hence failed to yield as much water as was required. Wells were then dug on ground somewhat higher and somewhat farther from the river. Two dug wells are at present equipped to furnish water to the waterworks, one on Dakota Street and the other on Bartlett Street, and these two wells furnished the entire supply to the city waterworks until recently, when the soft-water wells were drilled. (See p. 159.) No accurate information is available as to the consumption of water from the city waterworks, but it probably ranges between 150,000 and 300,000 gallons a day, and this was the approximate range of daily pumpage from the two wells before the soft-water wells were drilled.

The Dakota Street well is at the corner of Ninth Street, about 500 feet from the river and nearly midway between the river and the railroad station. It is on a terrace fully 10 feet above the abandoned well near the river. It is about 20 feet in diameter and about 30 feet deep and is cased with brick. The water level in the well stands about 20 feet below the surface when it has not been lowered by pumping. This well has in recent years supplied a large part of the city water.

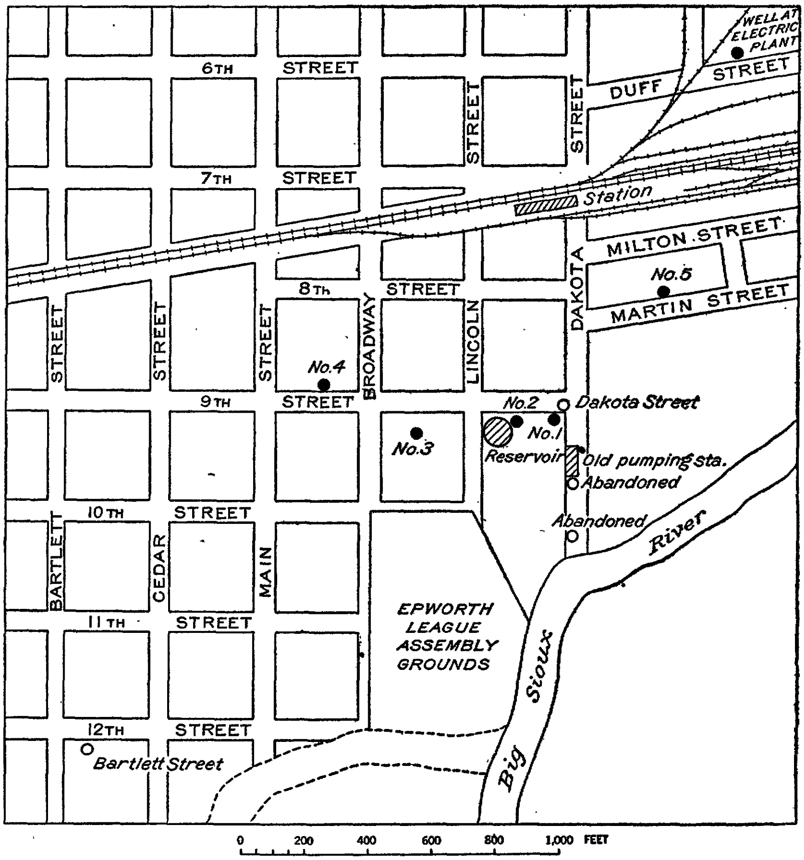


FIGURE 18.—Map of a part of the city of Canton, S. Dak., showing location of the city wells and of the well at the electric plant. Open circles indicate dug wells that end in terrace gravel; solid black circles indicate drilled wells that end in Dakota sandstone. Dashed line indicates abandoned channel of Big Sioux River

The Bartlett Street well is on a small knoll about a third of a mile southwest of the Dakota Street well, at the corner of Twelfth Street. It is 400 feet from an abandoned channel of the river and considerably farther from the present channel. It is about 12 feet in diameter and 35 feet deep and is reported to yield 120,000 gallons a day.

Before the soft-water wells were drilled these two dug wells were barely adequate to supply the city waterworks, but the supply could easily have been increased by sinking more wells into the water-bearing gravel. The principal objection to the dug wells was, however, the poor quality of their water, both as to bacterial pollution and as to mineralization. It is practically certain that neither of these wells is polluted by the river, and any bacterial pollution could probably be completely overcome. The hardness of the water and its high content of mineral matter, however, constitute a detriment that can not be wholly remedied.

The table on page 161 gives an analysis of the hard-water supply of Canton. The sample was collected by Dr. H. R. Hummer, superintendent of the United States Asylum for Insane Indians, in October, 1925, presumably from the Dakota Street well. The water was clear when it was received in the laboratory.

DUG WELLS AT THE UNITED STATES ASYLUM FOR INSANE INDIANS

The United States Asylum for Insane Indians is about a mile east of Canton, in the SE. ¼ sec. 18, T. 98 N., R. 48 W. The two dug wells that furnished the water supply up to 1926 are near the southwest corner of the asylum grounds, not far from the road. They are on a low terrace of Big Sioux River. The water is lifted by an electrically driven pump from the wells to an elevated tank with a capacity of about 30,000 gallons, which is on the high ground to the north, where the asylum buildings are situated.

The following information was furnished by Doctor Hummer:

> The wells are 24 feet deep and end in gravel. The water level normally stands about 21 feet below the surface. The wells are pumped simultaneously at a combined rate of about 5,000 gallons an hour, or 80 gallons a minute. With this rate of pumping the water level is drawn down about 1¾ feet, but it is restored virtually to its normal position within 15 minutes after pumping ceases. The wells have never failed to supply water at this rate of pumping. The daily consumption amounts to about 15,000 gallons.

A sample of the water was collected by Doctor Hummer in October, 1925. The analysis, given in the table on page 161, shows that this water, like that from the shallow wells of the city waterworks, contains very large quantities of calcium and magnesium, chiefly as sulphates. These constituents render the water very hard and unsatisfactory for washing and also cause it to deposit excessive amounts of scale in steam boilers. The raw water can, of course, be improved for washing and boiler use by application of soda ash or other treatment. One favorable feature of this water for washing and general use is its very low content of iron.

WATER IN THE DAKOTA SANDSTONE

WELLS DRILLED INTO THE SANDSTONE

The wells drilled to the Dakota sandstone in or near Canton in regard to which definite information was obtained are shown on Figure 17 and are listed in the following table. Apparently they do not differ greatly in the altitude at which they end, most of the differences in depth being due to surface irregularities. A few other soft-water wells were reported in this general area, some of them on the east side of the river, in Iowa.

Wells in or near Canton, S. Dak., that end in Dakota sandstone

Map designation (fig. 17)	Owner	Location	Diameter	Depth
			Inches	*Feet*
A	M. B. Kennedy	NW. ¼ sec. 28, T. 99 N., R. 49 W	3	[a] 362
B	M. L. Syverund	NW. ¼ sec. 2, T. 98 N., R. 49 W	3	[a] 442
C	Norman Harrison (Holsey Place)	NW. ¼ sec. 23, T. 98 N., R. 49 W.; on south side of Fifth Street, about 300 feet east of Beaver Creek.	3	[a] 316
D	Irving Seapy	NE. ¼ sec. 27, T. 98 N., R. 49 W	3	[a] 323
E	Newton Hill Farm, C. B. Kennedy estate.	SE. ¼ sec. 13, T. 97 N., R. 49 W	3	[a] 502
F	Ernest Wendt estate	SW. ¼ sec. 8, T. 97 N., R. 49 W		[a] 530
G	Northern States Power Co	NW. ¼ sec. 24, T. 98 N., R. 49 W.; Duff Street between Kimball Street and Milwaukee Avenue.	8	301
H	City waterworks:			
	No. 1	Southwest corner Dakota and Ninth Streets.	8	306
	No. 2	130 feet west of well 1	8	300+
	No. 3	300 feet west of well 2, on south side of Ninth Street between Lincoln Street and Broadway.	8	[b] 316
	No. 4	300 feet northwest of well 3, on north side of Ninth Street between Broadway and Main Street.	8	321
	No. 5	North side of Martin Street, east of Dakota Street, 300 feet south of railroad and 500 feet northeast of well 1.	12	311
I	United States Asylum for Insane Indians.	SE. ¼ sec. 18, T. 98 N., R. 48 W	6	322

[a] The depths given are based on the memory of the driller and may be somewhat inaccurate.
[b] Later deepened to about 329 feet. (See p. 160.)

So far as information was obtained, the private farm wells (A to F) yield enough water for farm use and have proved generally satisfactory, except well F, which gave trouble with sand and has been abandoned. These wells were drilled with hydraulic percussion or so-called jetting rigs. The hole was usually drilled to the sandstone, and then a 3-inch casing was inserted and was driven down so as to be seated in the sandstone. A somewhat smaller hole was then drilled into the sandstone to a depth of 7 to 16 feet below the bottom of the casing, no attempt being made to drill to the bottom of the sandstone. The well was then cleaned out, and a cylinder pump, attached to an independent pump pipe, was installed. The water generally rises 200 feet or more above the bottom of the well by artesian pressure, and the cylinder is usually placed 50 or 60 feet below the water level in the well.

Information in regard to the well at the electric-light plant, now owned by the Northern States Power Co., was obtained largely from Mr. G. G. Dokken, the manager. This well, the location of which is shown in Figure 18, was drilled in 1920, after the existence of soft water had been demonstrated. The casing was driven down into the sandstone to shut out the overlying soft material, and it extends within about 6 feet of the bottom of the well. The water is reported to have risen by artesian pressure to a level about 100 feet below the surface. A 3¾-inch single-acting cylinder pump was inserted at the end of a 4-inch pipe. It was first placed about 280 feet below the surface, but on account of trouble with sand it was later raised to a level only about 200 feet below the surface. Since this change was made there has been no serious trouble with sand, and the well is regarded as a success. The well was formerly pumped at about 20 gallons a minute during a large part of each day and apparently never failed to supply water at this rate of pumping. Mr. Dokken estimated that on many days the pumpage exceeded 15,000 gallons. It is said that after the city wells were drilled the pump in this well ran more heavily, presumably on account of a lowering of the water level.

It was some time after the well at the electric-light plant was completed that the city of Canton drilled similar wells to provide soft water for the public supply. The log of well 1 is given on page 154; other information in regard to the five city wells is given in the foregoing table. These wells were presumably drilled and cased to the sandstone and were then drilled with a somewhat smaller diameter for a depth of 30 to 34 feet through the entire bed of sandstone and to a hard rock that was believed to be the Sioux quartzite. Double-acting deep-well cylinder pumps were installed in all the wells; their capacities were as follows: Nos. 1 and 2, about 55 gallons a minute each; Nos. 3 and 4, about 30 gallons a minute each; No. 5, about 135 gallons a minute. These wells have not given satisfactory service. They have not produced the relatively large quantities of water required for the public supply, and with the large pumps that were used they have caused much trouble and expense on account of the fine sand that is drawn into the wells. This sand either settles at the bottom and clogs the well or else is lifted with the water and damages the pump. Considerable improvement was effected by work done on the wells in the later part of 1925 and in January, 1926. Mr. William Tank, the mayor, reported that after this work had been done wells 1, 3, and 5 were in service, were producing, respectively, about 35, 30, and 50 gallons a minute, and were furnishing the entire public supply of about 150,000 gallons a day. (See p. 167.)

Information as to the height to which the water normally rose in the city wells is indefinite and conflicting. According to the driller the water in well 1 at first rose within 65 feet of the surface. In a memorandum furnished by Mr. Tank June 12, 1925, he stated that at that time the water level in well 4 was about 175 feet below the surface and the cylinder about 265 feet below the surface; also that the water level in well 5 was about 150 feet below the surface and the cylinder 275 feet below the surface. On September 29, 1925, the water level in well 3, according to a measurement by Mr. Tank, was 162 feet below the surface; at the time of this measurement wells 1 and 4 were being pumped and there may still have been a slight drawdown in well 3 due to withdrawal of water from this well. The available information, although not conclusive, indicates that considerable lowering of the head has resulted in the vicinity of these wells owing to the heavy pumpage from them during the period since they were drilled.

In 1926 the United States Office of Indian Affairs had a soft-water well drilled at the Asylum for Insane Indians near Canton. (See fig. 17 and tables on pp. 154 and 158.) According to Mr. Archibald, the driller, the stratum of sandstone was struck in this well at a depth of 287 feet and was found to be 33 feet thick and to rest on shale. The water level was about 90 feet below the surface. The well was cased to a depth of 290 feet and was successfully pumped at 25 gallons a minute. This rate of pumping, however, was reported to produce a drawdown in the water level of about 220 feet.

Work done on city well 3 in September, 1925, indicated that this well had not been drilled to the quartzite; its original depth was reported to be 316 feet, but during the cleaning operations in 1925 the hole was carried at least to 329 feet, the cuttings at that depth being a soft, shaly rock. It is improbable that the quartzite is even approximately level over any large area; moreover, the sandstone stratum encountered in these wells does not have the usual character of a shore deposit. Hence, there are independent reasons for expecting that in some places in the vicinity of Canton other sedimentary beds—some of them possibly water-bearing—may be found between the recognized soft-water stratum and the Sioux quartzite. The water prospects have obviously not been fully tested in any well that has not reached the quartzite.

CHEMICAL CHARACTER OF THE WATER

Samples of water were collected by Doctor Hummer in October, 1925, from four of the wells drilled to the Dakota sandstone; in November, 1926, from the new well at the asylum; and in August, 1927, again from the new well. The first sample from the asylum well was too small for complete analysis. All these samples, as also the two from the terrace gravel, were analyzed in the Geological Survey, and the results are given in the following table:

Analyses of water from wells in or near Canton, S. Dak.

[Analyst, Margaret D. Foster. Parts per million]

	Terrace gravel		Dakota sandstone					
	City water-works (dug well on Dakota Street)	U. S. Asylum for Insane Indians (2 dug wells)	M. B. Kennedy (A, fig. 17)	Newton Hill Farm (E, fig. 17)	Electric plant (G, fig. 17)	City well No. 1 (H, fig. 17)	U. S. Asylum for Insane Indians (I, fig. 17)	
							First sample [a]	Second sample [b]
Silica (SiO_2)	26	25	11	16	9.6	9.4	----------	15
Iron (Fe)	.06	.07	.57	.38	1.0	.48	----------	4.1
Calcium (Ca)	312	267	45	42	38	30	----------	62
Magnesium (Mg)	118	108	18	17	17	13	----------	27
Sodium and potassium (Na+K)	57	48	97	211	181	194	----------	[c] 185
Carbonate radicle (CO_3)	0	0	0	0	0	0	24	0
Bicarbonate radicle (HCO_3)	325	283	361	405	429	432	205	361
Sulphate radicle (SO_4)	1,067	931	81	263	163	164	329	306
Chloride radicle (Cl)	3.8	7.0	5.5	22	14	15	36	32
Nitrate radicle (NO_3)	1.2	0	7.7	.10	25	10	----------	.27
Total dissolved solids at 180° C	1,752	1,512	449	776	659	666	[d] 700–800	824
Hardness as $CaCO_3$ (calculated)	1,264	1,110	186	175	164	128	[e] 191	266

[a] Incomplete analysis of small sample collected in November, 1926.
[b] Analysis of sample collected in August, 1927. The comparatively large quantity of iron probably comes from the sand that was in the sample when received. Dissolved iron almost always separates by the time the sample is received in the laboratory. Therefore, it is customary to determine the iron in the sediment and to add it to the very small amount that is in solution when the water is received. It is probable that a sample of the water free from sediment would have a much smaller quantity of iron.
[c] Sodium, 164; potassium, 21.
[d] Estimated.
[e] Determined by soap method.

The samples from the Dakota sandstone obviously represent water of the same general character, although the water from the M. B. Kennedy well is notably lower in sodium and potassium and in sulphate and chloride than the average, whereas the water from the Newton Hill well is relatively high in all these constituents. The water from the asylum well is relatively high in most of the constituents and is somewhat harder than the other sandstone waters.

The Dakota sandstone water is notably different from that in the gravel in its content of mineral matter and hence in its chemical behavior. (See fig. 15.) The gravel water contains large quantities of calcium and magnesium, which make it hard, whereas the sandstone water is low in these constituents and hence relatively soft. The large amount of magnesium and sodium sulphates in the gravel water makes it somewhat objectionable for drinking and cooking. The sandstone water is therefore much better for drinking, for domestic uses, and for use in steam boilers. The gravel water is, however, superior in containing only a negligible amount of iron, whereas the sandstone water contains an appreciable amount of iron, which is objectionable for toilet and laundry uses.

The water from the well at the electric plant, according to Mr. Dokken, is very satisfactory for boiler use. Before this well was drilled great trouble was experienced with scale in the boilers, and attempts to soften the water were not entirely successful. The soft water cleaned off the scale and is said to form practically no scale at all. It has no serious tendency to cause foaming. Much water from this well was formerly sold to the people of Canton, who filled their cisterns with it and used it for washing.

The soft water at Canton is less highly mineralized and of better quality for nearly all uses than most of the soft water that is obtained from the Dakota sandstone in other areas. Thus the average of 10 samples of other soft waters from South Dakota, shown on page 149, compares unfavorably with the Canton soft water in showing a much higher content of the sodium salts, especially sodium chloride, which renders much of the soft water in other areas distinctly salty.

PHYSICAL PROPERTIES OF THE WATER-BEARING SANDSTONE

The stratum of sandstone that yields the soft water in the vicinity of Canton is about 30 to 34 feet thick and consists of fine but clean quartz sand that is sufficiently consolidated to form a soft, friable rock. Some of the physical properties of four samples of the material, as determined in the Geological Survey, are given in the table below. The two samples from the asylum well were tested by A. M. Piper according to standard methods; [13] the other two had previously been partially examined by Norah D. Stearns. Some of the sand from sample 4 is shown, greatly magnified, in Plate 20.

[13] Stearns, N. D., Laboratory tests of physical properties of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 596, pp. 124–149, 1927.

Laboratory tests of physical properties of the water-bearing stratum of the Dakota sandstone at Canton, S. Dak.

	1	2	3	4
Mechanical analysis: [a]				
Fine gravel (larger than 1 mm.)	1.2	0.3	2.8	2.0
Coarse sand (1 to 0.5 mm.)	2.0	.5	2.2	.8
Medium sand (0.5 to 0.25 mm.)	1.8	.4	3.3	1.1
Fine sand (0.25 to 0.1 mm.)	89.0	81.9	41.3	36.7
Very fine sand (0.1 to 0.05 mm.)	[b] 6.0	16.9	48.6	56.5
Silt and clay (smaller than 0.05 mm.)			1.8	2.9
	100.0	100.0	100.0	100.0
Moisture equivalent: [c]				
Per cent by weight			2.5	2.4
Per cent by volume			3.9	3.6
Porosity (per cent of total volume)			[d] 42.1	[d] 44.3
Permeability coefficient [e]		57	81	69

[a] The actual sizes of the sieves used, as determined by the U. S. Bureau of Standards, are as follows: 1.00, 0.59, 0.26, and 0.09 millimeter. About 25.4 millimeters is equal to 1 inch.
[b] Nearly all very fine sand—that is, more than 0.05 millimeter in diameter.
[c] The moisture equivalent is the moisture that remains in the sample after it has been saturated and then subjected to a centrifugal force 1,000 times the force of gravity, expressed as a percentage of the dry weight of the sample or as a percentage of the volume of the sample.
[d] The samples were obtained from well drillings and are not volumetric. The volume was determined in the laboratory after the sample had been compacted as much as possible by shaking and tamping.
[e] The permeability coefficient of a water-bearing material is the quantity of water, in gallons a day, that will flow through a cross-section area of 1 square foot of the material under a hydraulic gradient of 100 per cent.

1. Sample sent to the Geological Survey by William Tank, mayor, in June, 1925, and described as "a sample of the sand pumped out with the water."
2. Sample from the well of Norman Harrison (C in table on p. 158), collected by him when he drilled the well.
3. Sample from upper part of sandstone stratum in the asylum well, collected by E. C. Archibald, driller.
4. Sample from lower part of sandstone stratum in asylum well, collected by E. C. Archibald.

The sandstone is sufficiently consolidated so that the well remains open in it without casing, yet it is so feebly cemented that the drillings come up as incoherent sand and not as chips of sandstone. Under the microscope the drillings are seen to consist of separate quartz grains that are not cemented to one another, and there is no evidence of any cementing material. (See pl. 20.) On the other hand, many of the grains have a mottled appearance indicating that they have been etched by the solvent action of the water. In the wells that are pumped hard there has been rather persistent trouble due to sand rising with the water. According to Mr. Archibald, the upper 3 feet of the stratum in the asylum well consists of soft sand, but the rest is in general a rather firm sandstone. Even under pumping with great drawdown it yielded very little sand.

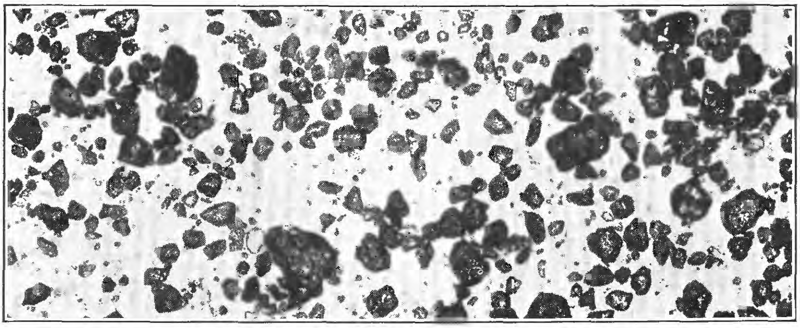
The samples analyzed consist essentially of fine to very fine sand, with only small amounts of medium and coarse sand and fine gravel (more than 0.25 millimeter in diameter) and only small amounts of silt or clay (less than 0.05 millimeter in diameter). In samples 2, 3, and 4 the 10 per cent size—that is, the size that is just larger than the finest 10 per cent by weight—is between 0.1 and 0.05 millimeter. It is believed that samples 2, 3, and 4 are fairly representative of the material as it occurs in the earth and that the fine material has not been washed out to any great extent in taking the samples. This can not, however, be definitely asserted.

In Plate 20, *B*, the largest grains shown are about 0.2 millimeter, or less than a hundredth part of an inch, in average diameter; the bulk of the material falls into the classes described as fine sand (0.25 to 0.1 millimeter) and very fine sand (0.1 to 0.05 millimeter); the smallest grains showing definite boundaries—those less than a fifth of an inch in diameter in the photograph—are classed as silt; and the swarms of minute particles are classed as clay. The smallest particles shown in the photograph are close to the maximum size of material that has Brownian movements. Though the silt and clay particles are very numerous they are so small that they do not form any large part of the material—not enough to fill much of the interstitial space or to prevent the sample from having the appearance of clean sand. Some of the largest grains are well rounded, but others have sharp angles; the smaller particles are angular or subangular.

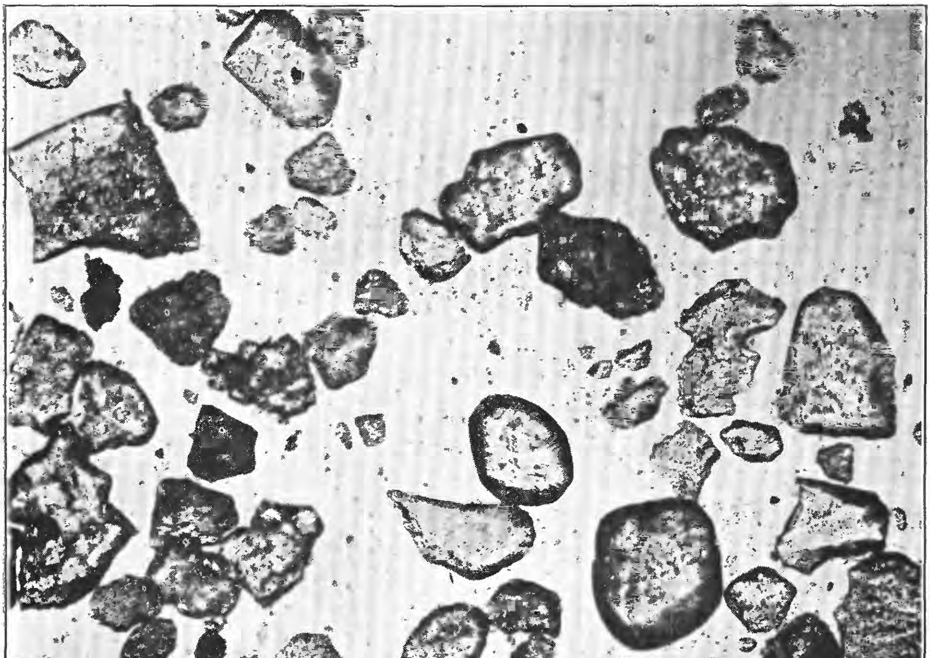
The high porosity, or large amount of void space, as determined in the two samples from the asylum well (Nos. 3 and 4) is due to the scarcity of silt and clay and the general uniformity in size of grain. The fine material does not form a large enough part of the total volume to reduce the porosity appreciably by occupying the void spaces.

In each of the two samples from the asylum well the moisture equivalent is less than 4 per cent of the total volume of the sample. This remarkably low moisture equivalent for so fine a sand is evidently due chiefly to the scarcity of the very fine material, which is the most effective in holding moisture against centrifugal force or the force of gravity. The moisture equivalent of a material is often taken as a rough measure of the specific retention, or quantity of water that is held by the material against the pull of gravity; and the porosity minus the moisture equivalent is often taken as a rough measure of the specific yield, or quantity of water that is free to drain out of the material. If this assumption is permissible for these samples, the material of the soft-water stratum at Canton has a high specific yield.

Tests of permeability were made on samples 2, 3, and 4, but it should be understood that if the samples differ in compactness and texture from the material in its natural condition the results of the permeability tests may be misleading. These three samples did not differ much in permeability, and their average permeability coefficient was 69. This means that 69 gallons of water would percolate in a day through each square foot of the material under a hydraulic



A



B

SAND FROM THE SOFT-WATER STRATUM PENETRATED IN THE WELL OF THE UNITED STATES ASYLUM FOR INSANE INDIANS, CANTON, S. DAK.

A, Enlarged about 35 diameters; *B*, enlarged about 100 diameters

gradient of 100 per cent. Originally the hydraulic gradient of the Dakota sandstone in the southeastern part of South Dakota was approximately 10 feet to the mile in a general easterly direction,[14] but there is no information as to the present gradient in the vicinity of Canton. If the water-bearing stratum is 33 feet thick and has a hydraulic gradient of 10 feet to the mile and a permeability of 69, about 23,000 gallons a day percolates laterally through each mile of width of the stratum. Accordingly, a well or group of wells would have to draw from a distance of half a mile in each direction to yield a supply of 23,000 gallons a day, or from a distance of 6½ miles to yield 300,000 gallons a day.

Further computations indicate that if the permeability of the sandstone is as great as is indicated by the tests, water can be drawn to the Canton city wells at a rate of 300,000 gallons a day, but that this is nearly the maximum possible inflow.[15] The available data as to the performance of the wells indicate that the actual permeability in the compact sandstone may be less than that obtained in the laboratory, and hence that the supply perennially available at Canton may be less than has been computed. The plain lesson from these considerations is that while the city should develop its soft-water supply so far as practicable, it should keep its hard-water wells in repair and in sanitary condition so that they can be drawn upon whenever it may be necessary. Measurements of depth to the water level should be made from time to time in one of the wells, under similar pumping conditions in all the wells, in order to obtain information as to a progressive lowering in head. As the asylum well is 1½ miles from the city wells there will be no serious interference between it and the city wells. Unless mechanical difficulties develop in that well, a supply of as much as 15,000 gallons a day will doubtless be perennially available at the asylum.

METHODS OF FINISHING WELLS

The small size of grain and slight coherence of the Dakota sandstone make it difficult to finish a well in this sandstone, especially a well that is to be subjected to heavy pumping. The more rapidly a well is pumped the farther the water level in it is lowered and the greater the pressure of the water into the well becomes. With increased pressure the velocity of the water percolating into the well is increased and hence also the tendency for the water to dislodge the fine grains of sand and to carry them into the well. The character of the water-bearing material in the soft-water stratum at Can-

[14] Darton, N. H., Geology and underground waters of South Dakota: U. S. Geol. Survey Water-Supply Paper 227, pl. 11, 1909.

[15] Slichter, C. S., Theoretical investigation of the motion of ground water: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 2, pp. 358–363, 1899.

ton is such that, even with the most skillful work in developing and finishing the wells, it is not to be expected that a large supply can be pumped from one well without causing trouble with sand.

The trouble with the city wells was first brought to the attention of the Geological Survey by Mr. Tank. In a letter of June 12, 1925, he described the conditions, in part, as follows:

About the time the pumps were started to operate the four wells (Nos. 1, 2, 3, 4) furnished about 30 gallons of water a minute, but this water contained a large quantity of fine sand or sandstone, the abrasive quality of which was such that it destroyed the pump leathers and valves in a week and cut out the brass cylinders in about six months. Two men are kept at work almost continuously changing the leathers and grinding the valves and at times installing a new cylinder; also cleaning out the well chamber below the casing, which fills up with sand. This work has been carried on with the expectation that eventually the sloughing off of the sandstone surrounding the well would clear itself and that the abrasive action of the sand would thus be eliminated. However, this has not been the case, for we are still bothered with the sand. * * *

The four wells thus failing to supply a sufficient amount of water, a well with 12-inch casing was sunk (No. 5) and was equipped with a pump of the same type but much larger. The same conditions were found at the bottom of this well; in fact, the conditions were much worse than in the other four.

In response to Mr. Tank's letter the following statement of advice was prepared:

This is very fine sand in which to develop a well of considerable yield. If the undisturbed material in the sand bed includes coarser sand, it might be possible to get a satisfactory yield by developing a natural strainer by pumping out the fine sand; otherwise, the only hope appears to be in developing a gravel strainer by inserting gravel into the well. A metal strainer fine enough to keep out this sand will not give satisfactory results, and not much improvement can be expected by changing the position of the cylinder.

I suggest undertaking to develop well No. 5 by the following procedure: Put in a 6-inch casing with about 30 feet of coarse strainer or perforated casing at the bottom. This will leave an annular space between the 6-inch casing and the 12-inch casing at the bottom of about 3 inches. Insert fine clean gravel into this annular space and withdraw water and sand from the 6-inch casing until the water clears. Presumably, as sand enters the well and is withdrawn, the gravel will settle down and more gravel should be added at the top. The best device for cleaning out wells and developing gravel strainers is an air lift, but with a low-water level this might not be an economical way of lifting the water after the wells are put into service. It might be advisable first to use as large a bailer as can be advantageously operated. If this gives promising results it might be well to use an air compressor, or possibly, for the sake of economy, endeavor to complete the cleaning process with the pumps now at hand. If this method of finishing the well proves successful, the cleaning out process should be continued until the water clears with as large a discharge as possible. When the well is put into service it should not be pumped more rapidly than perhaps half the rate at which it furnished clear water at the end of the cleaning process. It is understood that in well No. 5, as in the others, the casing extends only to the top of the sand bed, about 30 feet from the bottom. The strainer or perforated casing at the bottom of the proposed 6-inch casing should extend to the bottom of the well.

At the time the field work was done at Canton, in September, 1925, wells 1 and 4 were in service, wells 2 and 5 were idle and said to be in bad condition, and well 3 was being cleaned out. Well 1 was yielding little or no sand and was giving fairly satisfactory service, but well 4 was bringing up fine bluish sand and was not giving satisfactory service. According to Mr. Harrison, the driller, well 1 was thoroughly cleaned out by means of an air compressor under the direction of the engineer in charge. He stated that the air lift was used for over a month, that occasionally back pressure was applied by means of the compressor, and that eventually the water cleared up under the air lift and yielded about 50 gallons a minute without bringing up sand. Mr. Harrison further stated that the air lift was not used on the other wells and very little effort was made to clean them out before putting them in service.

Mr. Archibald was employed by the city of Canton in the fall of 1925 to finish the wells, if possible, in a more satisfactory manner. He began work soon after the writer's visit to Canton. In a letter of January 26, 1926, Mr. Tank furnished the following information in regard to work done on wells 1, 3, 4, and 5:

In general we proceeded to remove the pump pipe, clean out the well thoroughly by use of hydraulic drills to what is supposed to be granite [Sioux quartzite] lying below the sandstone stratum. After cleaning out the well throughly we inserted in the uncased portion of the well from 30 to 40 feet of perforated and slotted pipes ranging from 4 to 5 inches in diameter. We then proceeded to pump the water out of these wells as long as the condition of the plungers permitted this to be done. Immediately upon the wearing out of the plungers we replaced the cup leathers and ground the valves and started to pump again. By this procedure we removed from these wells a considerable portion of the finer sand and left the coarser sand surrounding the slots in the newly inserted casing and thereby retaining the sand from coming in the casing. Nos. 1, 3, and 5 are doing exceptionally well and are furnishing, respectively, 35, 30, and 50 gallons a minute. No. 4 is still giving considerable trouble. We have had soft water for a period of eight weeks continuously without having been compelled to use any of the hard-water wells except once during a fire. We are using now about 150,000 gallons daily, and it is furnished by three wells.

In a letter of February 13, 1926, Mr. Archibald stated that the wells were greatly improved but were not yet finished to his satisfaction. He stated that the casings did not extend down to the sandstone and that the shale had caved and filled the wells and that it was still doing so. In his opinion further casing was necessary to shut out this fine material effectively.

The considerations above set forth seem to lead to the following conclusions: The water-bearing sandstone is sufficiently firm and coherent so that wells of small yield can often be finished successfully in it as rock wells—that is, with the holes left uncased and without strainers of any kind where they extend through the sandstone. In such wells care should be taken to seat the casing in firm sandstone and when the well is put into service to operate the pump slowly enough so that the sand grains will not be carried into the well. In some places the material is probably so incoherent that wells of this type will not be successful even at slow rates of pumping, and even the most successful wells may in time accumulate sand that will have to be cleaned out. The water-bearing stratum does not contain enough coarse material to be adapted for developing a natural strainer merely by the process of cleaning out the fine sand. Better results should be obtained and a more stable well assured by inserting fine gravel in the manner described above. But in whatever manner a well is finished in such material it should not be subjected to too heavy pumping. When it is put into service it should be pumped at a slower rate than the rate at which it produced water while it was being developed.

CONTRACT FOR DRILLING WELL AT THE UNITED STATES ASYLUM FOR INSANE INDIANS

Within certain limitations, the ground water belongs to the owner of the land under which it lies, and when he has a well drilled to it he pays the driller for effective service in developing a natural resource to which he already has legal title. Wells are commonly drilled at a certain price per foot. In localities where the prospects for obtaining successful wells are known to be good the driller may guarantee a water supply, but in localities where there has not been much drilling or where it is known that there are considerable chances of failure the driller usually guarantees only to make the hole. Well drilling involves many uncertainties, and even without a guaranty as to water the driller assumes much financial hazard. Unless he has ample financial backing and can obtain adequate extra pay for such a guaranty, he should not assume the extra hazard that it involves in territory where the ground-water conditions are uncertain.

If the water is obtained from hard rocks, the driller may have performed his entire duty when he has sunk the hole to the required depth. If, however, the water occurs in beds of sand or other incoherent material the driller's work is not complete when he has made the hole but only when he has, so far as possible, developed or finished the well in such a manner that it will yield a water supply without inflow of sand, silt, or clay and will remain in good condition for a period of years. The process of developing or finishing the well requires quite as much skill as the process of making the hole, and, if properly done, it may consume much time. A reliable driller will not leave a well in an unfinished condition or in a condition that will cause trouble in the future. However, if he is paid only at a certain rate per foot for making the hole, he can hardly afford to spend much time in developing the well, and if he does so he is at a great disadvantage with his less scrupulous competitors. In localities where wells end in sand it is therefore desirable to devise a form of contract that will give the driller adequate reward for skillful work in finishing a well without requiring him to assume undue hazards. Such a form of contract will also be advantageous to the persons for whom the wells are drilled, for it will tend to give them the services of skillful drillers on competitive terms.

The problem of a proper form of contract confronted the United States Office of Indian Affairs when it asked for bids for drilling the well at the asylum at Canton. The following specifications are essentially as they were prepared by the Geological Survey with a view to meeting the conditions outlined above:

Specifications for one well to be sunk at the Asylum for Insane Indians, Canton, S. Dak., into the sandrock that bears soft water:

The bidder shall furnish all equipment and labor necessary properly to construct and finish the well and shall furnish the casing and strainer and any other material or element that may be required to construct the well in a workmanlike manner. He shall case the well from top to bottom with 8-inch standard casing or pipe. [Diameter was later specified to be 6 inches.] He shall so construct the well at the bottom as to shut off and seal the well from any water entering from above the soft-water sandrock. He shall also construct the well in the soft-water sandrock at the bottom in such a manner that it will furnish at least 15,000 gallons of water in 24 hours without interference or trouble from sand or any other cause during a pumping test of at least two days' duration. He shall commence sinking the well within a reasonable period after the approval of his contract, shall continue operations without any unnecessary delay until the well is finished, and shall complete the well by November 1, 1926. When the well is completed with the above-mentioned guaranty as to yield and freedom from interference by sand or from other trouble, he shall receive full payment at the rate of $—— per foot of well drilled.

It is understood that the well shall be drilled to a maximum depth of 350 feet, if necessary, unless the hard Sioux quartzite, or "Sioux Falls granite," is struck before that depth is reached. It is further understood that in case it is impossible, on account of the absence or unsatisfactory character of the sandrock, to fulfill the above-mentioned guaranty, the contractor shall be paid at the rate of one-half of the above-mentioned price per foot drilled.

Because of the guaranty of "15,000 gallons in 24 hours without interference or trouble from sand or any other cause during a pumping test of at least two days' duration," the contract was attractive only to skillful drillers, and it gave the successful bidder a strong inducement and a proper reward for doing his best work. On the other hand, by specifying half price if the driller should not succeed in fulfilling the guaranty, he was protected from assuming an excessive hazard. In general, Government contracts for drilling wells have been very exacting in their requirements, and this has resulted in discouraging bidders and in making the bids excessively high. It is believed that an equitable and reasonable contract is to the interest of the Government in procuring the services of skillful and reliable drillers at moderate prices.

The advantages of this form of contract could, of course, have been obtained with specifications of other kinds. For example, the driller might be paid a certain price per foot for making the hole and an additional sum for fulfilling the guaranty. This would not be very different in effect from the actual specifications but would have the disadvantage of requiring a more complicated bid and of being a more radical departure in form from the usual contracts.

The successful bidder for the contract for the asylum well was Mr. E. C. Archibald, Council Bluffs, Iowa, whose bid of $5 a foot was the lowest submitted. As the well stood the prescribed test, the driller received the full price, which, for a total depth of 322 feet, amounted to $1,610.

GEOLOGY AND WATER RESOURCES OF THE UPPER McKENZIE VALLEY, OREGON

By Harold T. Stearns

INTRODUCTION

It was the writer's good fortune in the summer of 1926 to be assigned to the investigation of numerous dam and reservoir sites in western Oregon. During this investigation trips were made to many out-of-the-way places. One of these was a trip by pack train up McKenzie River to its source, made in the company of B. E. Jones, chief of the power division, conservation branch, United States Geological Survey, with Arthur Belknap as packer. The writer is indebted to Mr. Jones for arranging the details of the trip and to Mr. Belknap for much information given freely from his intimate knowledge of the valley. Mr. Belknap's father pioneered this region, and it is for him that many of the important features are named. The writer is indebted also to F. F. Henshaw, district engineer, United States Geological Survey, who furnished many records of stream flow.

GEOGRAPHY AND CLIMATE

McKenzie River, famous for its large trout and beautiful scenery, rises in Linn County, Oreg. Its source is Clear Lake, which lies in the Cascade Range, about 8 miles west of Santiam Pass and about the same distance from Mount Washington, on the summit of the range. McKenzie River flows south about 15 miles, then west about 70 miles to its confluence with Willamette River, near Eugene. (See fig. 19.) The east-west stretch of the valley of the McKenzie is traversed by the State highway from Eugene to Bend and is readily accessible by automobile. The settlement of Belknap Springs lies near the elbow of the river, 2 miles northeast of the highway and 60 miles by road from Eugene. The part of the valley north of Belknap Springs is little known. It has been traversed by forest rangers, hunters, and fishermen, but so far as the writer is aware it has not heretofore been described. This upper valley of the McKenzie, with its hidden falls, unique volcanic features, and remarkable springs, is the subject of this paper. As the five-day reconnaissance in the valley was made for another purpose, these observations are not complete; they are given largely to call attention to this region as a promising field for additional geologic work.

The climate of the area described is similar to that of much of the western slope of the Cascade Range. The cool summer nights make it an ideal location for summer resorts, and the number of these resorts has increased rapidly since the opening of the State highway

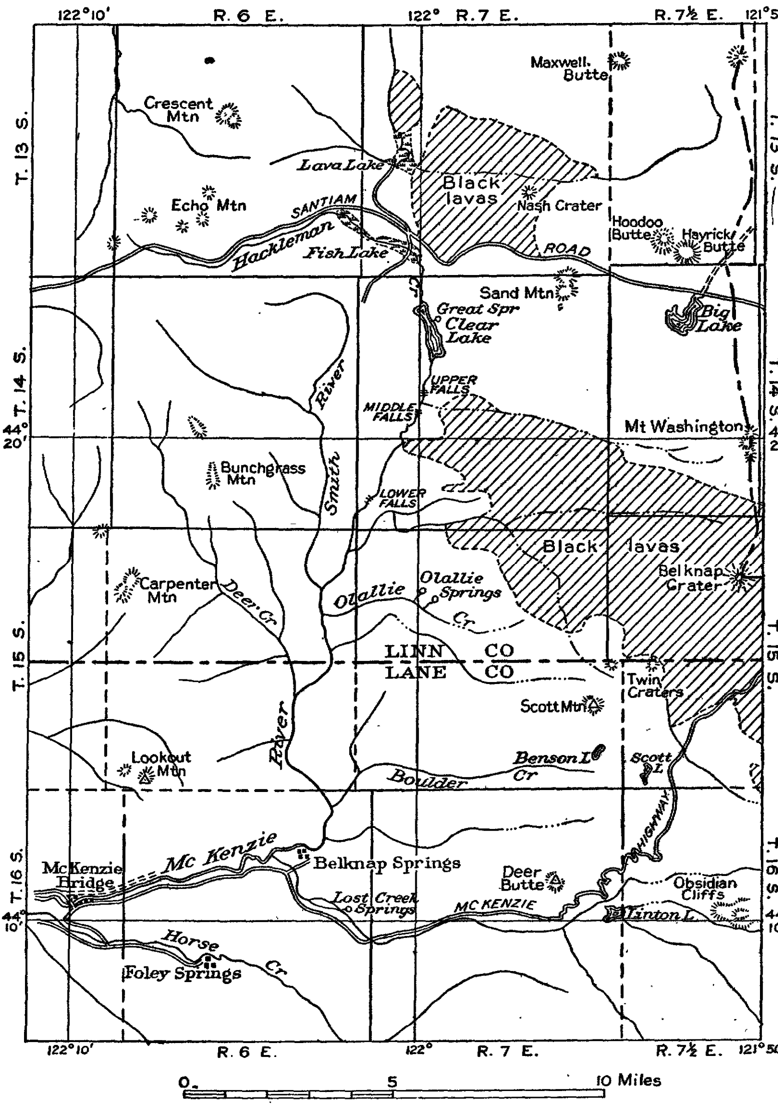


FIGURE 19.—Map of the upper McKenzie River region, Oregon

over McKenzie Pass. No Weather Bureau station is now maintained in the valley, but during the 12 years 1902 to 1913, observations were taken at McKenzie Bridge. The highest temperature recorded during that period was 108° F., and the lowest 0° F. The mean temperatures for 1902 to 1913 are given in the table below. McKenzie Bridge is 1,400 feet above sea level, and the altitude increases rapidly upstream, hence the maximum and minimum temperatures for the area around Clear Lake are considerably lower than those at McKenzie Bridge.

Average temperature (°F.) at McKenzie Bridge, Oreg., 1902–1913

Month	Mean	Mean maximum	Mean minimum	Month	Mean	Mean maximum	Mean minimum
January	34.5	42.8	26.3	August	63.2	84.2	42.3
February	38.7	49.6	27.8	September	57.7	76.0	39.4
March	42.8	55.9	29.6	October	51.3	66.9	35.6
April	48.5	64.1	33.0	November	41.9	52.2	31.6
May	53.4	68.8	37.9	December	36.0	44.9	28.1
June	58.8	75.4	42.3				
July	65.0	84.8	45.3	Annual	49.3	62.1	34.9

The annual precipitation in the form of rain and snow at McKenzie Bridge amounts to about 70 inches. The precipitation in the upper McKenzie Valley is probably not very different in amount, though during some years it may be as much as 90 inches. The luxuriant forest of magnificent cedars and firs, the long strips of gray moss hanging from the branches of the trees, and the soft green moss which covers the ground beneath constitute mute evidence of the humidity. The available records of precipitation are given in the following tables:

Precipitation, in inches, at McKenzie Bridge, Oreg., 1902–1913

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1902	------	11.64	------	7.39	6.13	0.94	2.80	0.05	1.47	2.70	16.11	15.30	------
1903	15.00	3.95	5.88	3.18	2.97	2.31	.77	1.64	3.02	4.13	15.34	6.34	64.53
1904	12.04	18.59	15.23	5.00	2.64	1.31	2.62	.34	.53	4.43	5.59	13.90	82.22
1905	5.24	2.27	8.60	1.91	5.65	2.32	.52	.18	4.26	7.73	6.29	8.15	53.12
1906	7.45	8.40	3.31	2.89	4.67	5.57	.00	.20	4.08	6.83	14.94	8.99	67.33
1907	12.81	12.28	6.78	8.26	2.90	4.35	.50	2.79	2.60	2.03	10.76	20.05	86.11
1908	6.21	5.26	8.82	3.56	5.50	2.58	.55	2.11	.76	10.49	5.47	7.14	58.45
1909	15.75	11.07	4.62	1.66	4.03	.71	2.64	.10	3.57	5.46	21.14	6.27	77.02
1910	7.73	11.31	5.06	2.58	4.14	2.73	.00	.08	1.11	5.79	18.17	7.07	65.77
1911	5.67	4.51	2.60	3.23	5.91	.89	.09	.05	6.34	2.82	13.19	7.19	52.49
1912	17.12	11.38	4.44	5.35	5.71	4.94	.92	3.87	2.98	7.10	10.13	11.08	85.02
1913	13.04	3.15	10.54	3.64	3.63	6.53	1.43	.97	3.02	7.46	9.95	------	------
Mean	10.73	8.65	6.90	4.05	4.49	2.93	1.07	1.03	2.81	5.58	12.26	10.13	70.63

Precipitation, in inches, at Clear Lake, Oreg., 1913–1915

Month	1913	1914	1915	Month	1913	1914	1915
January	12.41	15.84	7.21	August	0.81	0.00	------
February	2.07	7.35	7.27	September	3.77	8.56	------
March	10.42	4.09	3.82	October	7.31	6.58	------
April	3.78	4.46	3.08	November	10.97	6.15	------
May	4.23	2.42	7.02	December	4.67	2.95	------
June	6.25	2.85	1.05				
July	1.13	.53	------	Annual	67.75	61.78	------

GEOLOGY AND PHYSIOGRAPHY

GENERAL FEATURES

The only previous geologic work in this area was done by Hodge,[1] who cites Clear Lake and some of the other features near Santiam Pass as proof of the existence of a buried valley tributary to the valley of Santiam River, which lies north of the McKenzie Valley. The entire area around the upper McKenzie is occupied by basaltic lava flows that issued from numerous vents on the summit of the Cascade Range from the late Tertiary to geologically recent time. Many of the flows are so new as to be nearly bare of vegetation.

Between Belknap Springs and Olallie Creek McKenzie River flows in a relatively wide canyon carved in the older basalt, which may correspond to the Columbia River basalt, but from Olallie Creek upstream (see pl. 21) the canyon narrows and is bordered on the east by a thickly forested bench of intracanyon basalt. At Lower Falls and for several miles upstream this bench is about half a mile wide and terminates in a vertical cliff about 500 feet high facing McKenzie River. From the height and steepness of this cliff, which has been formed entirely by erosion, one would suppose that the river occupies a narrow V-shaped gorge in the bottom of the canyon. However, upon descending the dim foot trail to Lower Falls one finds a nearly level valley floor about an eighth of a mile wide. The floor is formed by a flow of olivine basalt that partly fills the gorge. A shallow channel, in places 5 feet deep, has been eroded in this floor. The west wall of the canyon is densely forested and rises less steeply than the east wall but to a greater height. This west wall is much older than the eastern one and is the original wall of the valley of the ancestral McKenzie River.

It is evident that after a wide V-shaped canyon had been carved it was filled to a depth of about 650 feet with numerous intracanyon basalt flows. After this epoch of lava filling the river carved a new canyon about 500 feet deep, leaving remnants of the lava fill as a high bench on the east side. Into this later canyon came the flows of olivine basalt that caused Lower, Middle, and Upper Falls, and Clear Lake. The relations of these valleys and flows are shown in Plate 21 and Figure 20.

The lava that forms the valley floor above Lower Falls is of the pahoehoe type, with relatively smooth surface, satiny or shiny crust, and ropy structure. It is full of lava tubes and joints, and the lava domes and other features of the original surface are well preserved. It is of geologically recent origin and may have flowed into the valley within the last thousand years.

[1] Hodge, E T., Mount Multnomah, pp. 21, 114, Eugene, Oregon Univ., 1925.

About 200 feet downstream from Lower Falls and on the west bank of the river there is a vertical tree mold in this flow 12 feet deep and 2 feet in diameter. Others were found in the same area. Tree molds of this type indicate that shells of lava froze around the tree trunks before the wood completely burned away. These molds are all within 25 feet of the margin of the flow, where the lava was sluggish and partly cooled. Tree molds are rarely preserved in the middle of a lava flow because subsequent movement tilts them over or fills them with lava.

This lava flow entered McKenzie Valley from the east in sec. 29, T. 14 S., R. 7 E., or about 1½ miles above Lower Falls, in the form of a great cascade a quarter of a mile wide, which spread to form a large fan of lava on the valley floor, similar in shape to an alluvial fan.

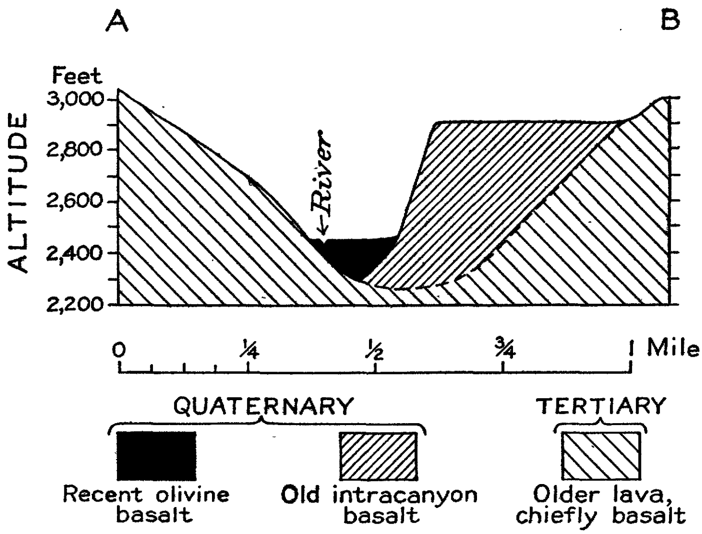


FIGURE 20.—Geologic section of the McKenzie Valley near Lower Falls, Oreg.

(See pl. 21.) The flow came from the crest of the Cascade Range near Belknap Crater. (See fig. 19.) It is chiefly of the clinkery type of basalt, or aa lava, with the bristling, jagged surface and jumbled blocks produced by the granulation of a stiff, overcooled fluid on the point of solidifying. The lava entering the canyon apparently changed from the pahoehoe to the aa type during the last phases of the eruption. Another large, thick flow of aa lava enters McKenzie Valley from the east in secs. 17 and 20, T. 14 S., R. 7 E. (See pl. 21.) This flow caused the Upper and Middle Falls. The lava flows about Clear Lake are considered in connection with the lake, on pages 176 and 177.

In the face of the nearly vertical cliff in the intracanyon lava on the east side of the valley at Lower Falls are exposed numerous nearly horizontal lava beds, and about half a mile above the falls there is a large lava tube or cave in the cliff through which an ancient river of lava flowed.

LOWER FALLS

The Lower Falls of McKenzie River is in the NE. ¼ sec. 31, T. 14 S., R. 7 E. It is 60 feet high and is due to the tumbling of the river over the east edge of the last basalt flow where it is in contact with the older intracanyon flows that form the bench on the east side of the valley. At the time of the writer's visit, in September, 1926, Lower Falls was dry. It generally flows only in the spring, for during the rest of the year the water sinks into the permeable lava in the valley floor about 1½ miles upstream, in the northern part of sec. 30, T. 14 S., R. 7 E., flows underground for this distance of 1½ miles, and gushes out as a huge spring in the plunge pool at the foot of the falls. In September, 1926, considerable water issued also a few feet above the surface of the pool. (See pl. 22, *A*.) It is estimated that a total of 350 second-feet of water issued as springs at Lower Falls at the time it was visited.

MIDDLE FALLS

Middle Falls is in the NE. ¼ sec. 20, T. 14 S., R. 7 E. The river at this place makes a magnificent leap from a lava cliff 70 feet high. (See pl. 22, *B*.) A few springs issue from crevices at the base of the cliff, and the cavernous condition of the basalt back of the falls suggests that perhaps in flood stages of the river there are even larger springs.

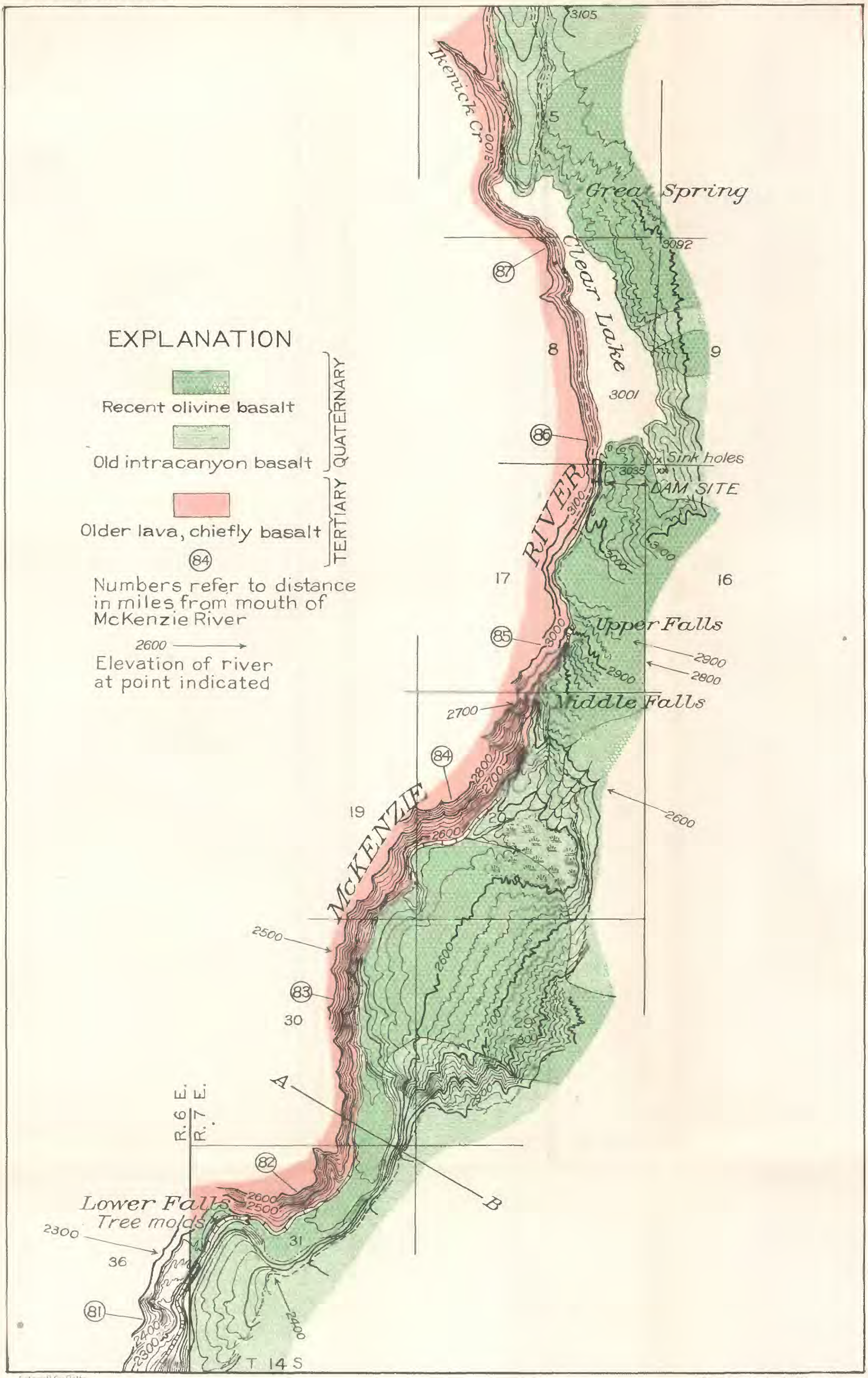
UPPER FALLS

Upper Falls is the grandest cataract on McKenzie River. Here the river makes one great leap of 100 feet over a lava dam and then tumbles in a series of beautiful cascades another 40 feet. (See pl. 23, *A*.) The falls is in the SE. ¼ sec. 17, T. 14 S., R. 7 E., at an altitude of 2,900 feet.

CLEAR LAKE

Clear Lake lies at the head of McKenzie River in secs. 5 and 8, T. 14 S., R. 7 E. It is about a quarter of a mile wide and 1¼ miles long and occupies a narrow valley. (See pl. 21.) It is reported to have a maximum depth of 172 feet. Its waters are extremely clear and of an exquisite green color. During the writer's visit the riotous colors of the autumn foliage were reflected along its shores, and from the northwest side there could be seen framed in the foliage the reflection of the snow-clad slopes and peak of Mount Washington.

The west shore of the lake is a relatively steep soil-covered slope which supports a growth of giant firs and pines. The east shore rises gently; much of it is covered with rough aa lava of the younger flows,



Geology by H. T. Stearns

GEOLOGIC MAP OF THE UPPER McKENZIE VALLEY, OREGON

0 1 2 Miles

Contour interval 20 feet

A. SPRINGS AT THE BASE OF LOWER FALLS, McKENZIE RIVER, OREG., SEPTEMBER 4, 1926

B. MIDDLE FALLS, McKENZIE RIVER, SEPTEMBER 4, 1926

A. UPPER FALLS AND CASCADES OF McKENZIE RIVER, OREG., SEPTEMBER 4, 1926

B. SUBMERGED UPRIGHT TREE TRUNK IN CLEAR LAKE, OREG., SEPTEMBER 5, 1926 in places bare of vegetation. North of the lake are older basalt flows, which are correlated with the old intracanyon basalt that forms the high bench on the east side of the river at Lower Falls. These bury a valley in still older basalt.

The basin occupied by Clear Lake was formed by a flow of relatively late olivine aa lava that entered the east side of McKenzie Valley near the present outlet of the lake and piled up against the west wall of the valley in the form of a great dam nearly 200 feet high. This lava flow was not traced to its source, but it probably originated at or near Belknap Crater. (See fig. 19.)

At the time the lava entered the valley a forest bordered McKenzie River at this place, for a submerged but still upright forest is visible in the shallow northern part of the lake. The tree trunks, many of them 2 to 3 feet in diameter and 40 feet high, were particularly noticeable during the dry summer of 1926, when the tops of many of them projected a few inches above the water. They have remained erect because the water is not agitated by violent storms or strong currents. Plate 23, *B*, is a view taken from a boat of one of these upright trunks in the clear water. It appears like a tree ghost in the picture, for the lower part (beneath the water) seems to fade away in the reflection of the sky above the living trees that stand on the far shore of the lake.

It is evident that the water of the lake has never stood appreciably lower than it does now, because all the trees rotted off at about the present lake level. They are thoroughly water-logged and are found to be tough when cut with a knife. Around the base of the trees is a laminated deposit of white ooze that may consist of diatoms. The same material covers the entire bottom of the lake and probably gives the water its green color. The trunks are in an excellent state of preservation, and there is no reason to doubt that they will stand much longer, as they are protected by the deposit of ooze, which increases in thickness each year.

The presence of the submerged forest and the fact that the lava dam at the outlet of the lake has been only slightly eroded by McKenzie River are conclusive evidence that the lake was formed in recent geologic time. At first thought these upright submerged trees seem to indicate a very recent date for the eruption that dammed the lake, but the vegetation on this flow indicates that the trees in the water must have been submerged at least 300 years. The lava dam supports a thick forest, and pine trees 3 feet in circumference lie wasting away on the surface. The dead trees must have been rotting at least 100 years and were probably over 200 years old when they died. An allowance must be made also for the time that elapsed between the eruption of the lava and the beginning of the tree growth. If measurements could be made of the rate of deposition of the ooze and of its thickness at the base of the trees, they would be of service in determining the date of the submergence. But evidence does not seem to be available to establish the age of the lava flow at the outlet further than that it is post-Pleistocene and is more than 300 years old. It is apparent, however, that the nearly barren flows on the east shore of the lake and on the adjacent slopes of the Cascade Range were extruded many years later than the lava at the outlet.

The hydrologic relations of Clear Lake are described on page 184.

WATER RESOURCES

McKENZIE RIVER

The drainage area tributary to McKenzie River above McKenzie Bridge is about 343 square miles, including the basin of Lava Lake, north of Clear Lake, which probably drains into Clear Lake and McKenzie River through underground channels. Without the Lava Lake drainage the area is only about 289 square miles. These areas are estimated from the United States Forest Service map of the Santiam National Forest. All the upper part of the drainage basin is covered with permeable basalt, which obliterates many old divides and has no visible surface run-off even during the wettest months; hence it is difficult to determine the boundaries of the drainage basin.

A gaging station has been maintained on upper McKenzie River at McKenzie Bridge since August 8, 1910, and one was maintained at the outlet of Clear Lake from June 20, 1912, to July 31, 1915. The following stream-flow records for these stations have been furnished by F. F. Henshaw, district engineer, United States Geological Survey, Portland, Oreg. Daily records for these stations have been published by the United States Geological Survey in the reports on surface water supply for the years prior to 1924.

M'KENZIE RIVER AT CLEAR LAKE, OREG.

Location.—In sec. 8, T. 14 S., R. 7 E., at the outlet of Clear Lake in Linn County, about 20 miles northeast of McKenzie Bridge, the nearest post office.

Drainage area.—90 square miles.

Records available.—June 20, 1912, to July 31, 1915.

Gage.—A float gage in the lake and a vertical staff at the outlet, the latter for checking only.

Discharge measurements.—Made from a suspension footbridge at the outlet.

Channel and control.—Closely compacted volcanic sand and gravel bound together with fine silt. Timber bulkheads on each side. Practically permanent.

Extremes of discharge.—1912–1915: Maximum stage recorded, 10.69 feet May 27 and June 3, 1913 (discharge, 1,130 second-feet); minimum stage recorded, 7.53 feet September 23, 1915 (discharge, 165 second-feet).

Ice.—Stage-discharge relation unaffected by ice.

Diversion.—None.

Regulation.—None.

Cooperation.—Gage-height record furnished by the Oregon Electric Railway Co.

Monthly discharge, in second-feet, of McKenzie River at Clear Lake, Oreg., for the years ending September 30, 1912–1915

Month	Maximum	Minimum	Mean
1912			
June 20–30	577	484	532
July	475	371	415
August	371	298	327
September	337	258	308
1912–13			
October	305	230	255
November	980	303	542
December	395	332	352
January	472	328	397
February	323	272	296
March	419	288	326
April	715	445	643
May	1,130	553	869
June	1,130	745	892
July	745	424	544
August	423	337	384
September	347	276	309
The year	1,130	230	484
1913–14			
October	366	269	328
November	364	307	343
December	374	283	335
January	475	281	410
February	442	323	373
March	727	409	640
April	902	487	677
May	649	491	576
June	484	382	432
July	377	270	322
August	268	223	244
September	300	215	248
The year	902	215	411
1914–15			
October	328	256	288
November	319	292	304
December	292	209	236
January	242	209	231
February	283	242	268
March	460	266	320
April	645	414	541
May	472	361	403
June	448	288	353
July	281	201	234

M'KENZIE RIVER AT M'KENZIE BRIDGE, OREG.

Location.—In sec. 14, T. 16 S., R. 5 E., at highway bridge at McKenzie Bridge, Lane County.

Drainage area.—343 square miles of Lava Lake drainage is considered a part of McKenzie River drainage; otherwise 289 square miles.

Records available.—August 8, 1910, to September 30, 1926, with some breaks.

Gage.—Vertical staff attached to right abutment of highway bridge at McKenzie Bridge. Gages at Paradise Ranger station, 2 miles upstream, and at Hayes ranch, half a mile upstream, have been used at times.

Discharge measurements.—Made from cable three-eighths of a mile above the ranger station.

Channel and control.—Rocky and gravelly; fairly permanent, except in extreme floods.

Extremes of discharge.—1910–1926: Maximum stage recorded, 8.3 feet on January 6, 1923, determined by leveling to high-water marks (discharge from extension of rating curve, 18,000 second-feet); minimum discharge, 890 second-feet, October 13 to 26, 1924.

Ice.—Stage-discharge relation unaffected by ice.

Diversions.—None.

Regulation.—None.

Monthly discharge, in second-feet, of McKenzie River at McKenzie Bridge, Oreg., for the years ending September 30, 1911–1926

Month	Maximum	Minimum	Mean
1910–11			
October 13–21	1,120	1,060	1,080
November	3,300	1,060	1,730
December	3,600	1,490	2,020
January	1,650	1,250	1,430
February	1,480	1,250	1,330
March	1,740	1,180	1,390
April	1,740	1,480	1,570
May 1–26	2,620	1,560	1,930
1911–12			
November 6–30	3,320	1,050	1,680
December	1,570	1,290	1,420
January	6,170	1,290	2,520
February	4,620	2,000	2,640
March	2,270	1,470	1,660
April	1,770	1,470	1,540
May	2,540	1,770	2,020
June	2,220	1,770	1,880
July	1,770	1,380	1,480
August	1,380	1,270	1,340
September	1,570	1,190	1,300
1913			
January			[a]1,610
February	1,770	1,380	1,470
March	4,620	1,380	1,780
April			[a]2,630
May	2,840		[a]2,640
June	2,860	2,030	2,370
July	2,220	1,530	1,830
August	1,530	1,360	1,450
September	1,490	1,240	1,310
1913–14			
October	1,960	1,210	1,390
November			[a]1,500
December	1,760	1,280	1,430
January	2,870	1,570	1,980
February	2,690	1,490	1,710
March	2,780	1,660	2,170
April	2,920	1,600	2,030
May	1,900	1,530	1,750
June	1,690	1,390	1,510
July	1,390	1,210	1,290
August	1,210	1,090	1,150
September	1,330	1,080	1,170
The year	2,920	1,080	1,590
1915			
April	2,000	1,450	1,690
May	1,860	1,360	1,550
June	1,580	1,250	1,390
July	1,240	1,120	1,180
August	1,110	1,010	1,060
September	1,010	960	977
1915–16			
October	966	924	947
November	4,410	924	1,760
December	2,920		2,050
January	1,880	1,270	1,430
February	5,260	1,360	2,650
March	3,320	1,720	2,200
April	2,760	2,130	2,330
May	3,240	2,260	2,510
June	3,080	2,260	2,660
July	2,840	1,860	2,320
August	1,830	1,520	1,640
September	1,620	1,360	1,460
The year	5,260	924	1,990
1917			
April	2,880	1,670	2,110
May	2,880	2,050	2,430
June	3,450	2,380	2,880
1917—Continued			
July	2,750	1,900	2,330
August	1,850	1,580	1,660
September	1,580		1,500
1917–18			
October 17–31	1,340	1,260	1,280
November	4,260	1,190	1,350
December 1–15	3,450	1,580	1,990
January			
February			
March 12–31	2,430	1,630	1,990
April	2,210	1,900	1,980
May	2,100	1,630	1,800
June	1,630	1,390	1,510
July	1,390	1,320	1,360
August	1,320	1,180	1,250
September	1,180	1,140	1,170
1918–19			
October	1,250	1,110	1,150
November	1,460	1,110	1,220
December	2,100	1,140	1,340
January	4,400	1,180	1,900
February	2,430	1,630	1,830
March	2,000	1,460	1,670
April	3,060	1,900	2,420
May	3,060	2,210	2,430
June	2,320	1,680	1,990
July	1,630	1,390	1,500
August	1,460	1,250	1,320
September	1,250	1,180	1,210
The year	4,400	1,110	1,660
1919–20			
October		1,110	1,200
November	2,550	1,460	1,750
December	2,800	1,460	1,920
January	6,440		2,200
February	2,210	1,320	1,600
March	1,630	1,320	1,410
April	1,810	1,460	1,640
May	2,000		1,780
June	1,720	1,390	1,480
July	1,390		1,330
August	1,250	1,180	1,200
September	1,810	1,110	1,310
The year	6,440	1,110	1,570
1920–21			
October	2,670	1,540	1,780
November	3,340	1,320	2,100
December	8,600	1,720	2,610
January	6,550	1,810	2,730
February	2,240	1,810	2,610
March	3,780	1,900	2,370
April	3,060	1,900	2,250
May	2,670	2,210	2,500
June	2,550	1,900	2,250
July	1,900	1,540	1,640
August	1,540	1,390	1,490
September	1,540	1,320	1,390
The year	8,600	1,320	2,140
1921–22			
October	1,460	1,250	1,300
May	3,360	1,860	2,570
June	3,530	1,990	2,740
July	1,860		1,610
August			1,270
September	1,170		1,100

[a] Estimated by comparison with Clear Lake record.

Monthly discharge, in second-feet, of McKenzie River at McKenzie Bridge, Oreg., for the years ending September 30, 1911–1926—Continued

Month	Maximum	Minimum	Mean
1922–23			
October	1,080	962	1,000
November	1,050	962	984
December 1–13	....	944	965
April 7–30	2,410	2,130	2,310
May	4,240	2,130	2,560
June	2,410	1,800	2,060
July	1,800	1,500	1,590
August	1,500	1,350	1,430
September	1,320	1,170	1,230
1923–24			
October	....	1,170	1,250
November	2,410	1,120	1,280
December	3,880	....	2,190
January	3,880	1,610	2,070
February	4,600	1,990	2,750
March	1,990	1,390	1,660
April	1,610	1,500	1,570
May	1,610	1,270	1,440
June	1,280	1,150	1,210
July	1,170	1,050	1,100
August	1,050	980	1,000
September	1,020	908	963
The year	4,600	908	1,540
1924–25			
October	1,860	890	971
November	3,860	1,350	2,050
December	2,550	1,470	1,730
January	5,370	1,590	2,440
February	7,420	1,840	3,370
March	1,840	1,550	1,680
April	2,550	1,590	1,890
May	2,430	1,840	1,960
June	1,840	1,430	1,650
July	1,430	1,310	1,390
August	1,310	1,160	1,210
September	1,190	1,100	1,140
The year	7,420	890	1,780
1925–26			
October	1,100	1,050	1,070
November	1,200	1,030	1,100
December 1–16	1,430	1,170	1,260
May 19–31	1,270	1,200	1,240
June	1,200	1,070	1,120
July	1,070	983	1,020
August	1,050	962	979
September	1,060	934	963

Miscellaneous discharge measurements of upper McKenzie River

Date	Locality	Discharge (second-feet)
Sept. 12, 1913	1½ miles below Clear Lake and about ½ mile below Middle Falls, in sec. 20, T. 14 S., R. 7 E.	642
Oct. 20, 1913	do	686
Aug. 8, 1924	Trail bridge ½ mile below outlet of Clear Lake, in the NE. ¼ sec. 17, T. 14 S., R. 7 E.	172

SPRINGS

BELKNAP HOT SPRINGS

The Belknap Hot Springs issue from several vents in coarse consolidated conglomerate of unknown age on the north bank of McKenzie River near the point where the river turns westward, in sec. 11, T. 16 S., R. 6 E. A small cold spring issues a short distance upstream from the hot springs. At the main vent the temperature of the water on September 4, 1925, was 180° F., and the discharge was about 50 gallons a minute. At two other vents on the same day the temperature was 174° and 147° F. The total discharge of all the hot springs is about 75 gallons a minute of mineralized water. A part of the hot water is conducted in pipes through the water of the river and cooled sufficiently in this way for use in the natatorium. The remainder is carried across the river in a wooden flume and used for baths. A hotel and several cottages for campers are located on the south bank of the river.

LOST CREEK SPRINGS

Lost Creek Springs issue in sec. 19, T. 16 S., R. 7 E., in a pool of clear water at the terminal margin of a flow of rough aa basalt. Lost Creek originates in these springs and after flowing 2 miles northwest joins McKenzie River about a mile below Belknap Hot Springs. White Branch, its only tributary, joins it about three-quarters of a mile below the springs. White Branch is fed by Collier Glacier, on the summit of the Cascade Range, and carries considerable water during the period when the ice is thawing, but at other times its flow is small. A measurement of this creek at the foot of the glacier on September 10, 1912, gave a discharge of only 2.2 second-feet, and on September 7, 1926, it was less than 1 second-foot. The large spring pool at the head of Lost Creek had a temperature of 42° F. on September 7, 1926. Discharge measurements of Lost Creek are given below.

Miscellaneous discharge measurements of Lost Creek, Oreg.

Date	Locality	Gage height (feet)	Discharge (second-feet)
Oct. 10, 1910	Highway bridge, near mouth, in NE. ¼ sec. 15, T. 16 S., R. 6 E.		201
Mar. 11, 1911	do	0.79	191
July 20, 1911	do	1.69	339
Nov. 18, 1911	do	1.60	259
Sept. 11, 1912	White Branch of Lost Creek near mouth		57
Sept. 12, 1912	Sec. 13, T. 16 S., R. 6 E.		243
Sept. 26, 1915	Highway bridge, near mouth, in NE. ¼ sec. 15, T. 16 S., R. 6 E.	.80	184

During the summer of 1926, B. E. Jones, of the United States Geological Survey, maintained a station on Lost Creek in connection with power studies. The flow during this period is given in the following table:

Discharge, in second-feet, of Lost Creek at highway bridge, near mouth, in NE. ¼ sec. 15, T. 16 S., R. 6 E., in 1926

Month	Maximum	Minimum	Mean
June 26–31	235	227	231
July	238	204	226
August	214	186	200
September	199	163	180
October	193	163	171
November 1–27	257	170	200

It is safe to assume that the minimum flow during September, October, and November consisted only of water discharged by the large springs at the head of Lost Creek, for during the low-water periods in these months there is practically no surface water entering the creek. Thus the group of springs at the head of the creek discharged at least 160 second-feet during the summer of 1926, a year when the discharge of streams of the region was the lowest on record.

The aa lava from which the springs issue fills the former valley of Lost Creek. It is reported that Lost Lake, also known as Linton Lake, in sec. 13, T. 16 S., R. 7 E., about 6 miles to the east, is the source of the water of the springs. This lake was not visited, but it is believed that a good part of the spring water is derived from permeable basalt to the northeast of the lake. These basalt flows occupy and in places obliterate a long, broad subdrained glaciated valley.

OLALLIE SPRINGS

Olallie Creek rises in springs in old basalt in sec. 8, T. 15 S., R. 7 E., and flows southwestward for a distance of 1½ miles to McKenzie River. The creek heads in two short tributaries, each of which occupies a narrow ravine in the lava. The north fork is only two-fifths of a mile long and has its source in two large springs that issue about 20 feet above the bed of the creek. The temperature of the water of the upper and larger spring on September 3, 1926, was 40° F. These springs come from cavernous aa clinker at the contact of two basaltic lava flows that appear to occupy and partly fill a former wide canyon. Minor springs issue at the edge of the creek near by and contribute to its flow. The south fork of Olallie Creek has its source less than a quarter of a mile from the confluence with the other fork, in a large spring in the bed of the channel.

Discharge measurements of Olallie Creek, Oreg.

Date	Locality	Discharge (second-feet)
May 13, 1924	600 feet above the mouth, in the SW. ¼ sec. 12, T. 15 S., R. 6 E.	165
Aug. 12, 1924	do	197
July 20, 1926	Just below the confluence of the two forks	135
Sept. 6, 1926	do	139

The flow of 139 second-feet on September 6, 1926, was derived entirely from springs rising within an area of 1 square mile in the headwaters of this creek. It appears, therefore, from the few measurements available that the discharge of these springs is considerably over 100 second-feet throughout the summer.

GREAT SPRING

Great Spring issues quietly in a pool of green water from a nook in the margin of a fresh flow of aa basalt about 200 feet from the northeast shore of Clear Lake, in the SW. ¼ SE. ¼ sec. 5, T. 14 S., R. 7 E. On September 5, 1926, it had a temperature of 39° F. and a discharge of about 30 second-feet. The water flows westward into Clear Lake.

The exact source of the spring is unknown, but the fresh lava flow from which it issues apparently buries a creek that was formerly tributary to McKenzie River. The water is evidently derived from precipitation that has percolated through the extremely permeable basalts to the east and has gathered as an underground stream in this lava-filled valley.

CLEAR LAKE

SOURCE OF THE WATER

The physiographic relations of Clear Lake have been described on page 176. During the late summer and fall this lake has no surface tributaries except Great Spring and Ikenick Creek, a small creek tributary to the northwest end of the lake. The total flow of these two creeks does not exceed 35 second-feet during the fall, yet the discharge from Clear Lake is considerably more. Measurements made at the gaging station on McKenzie River at the outlet of this lake are given on page 179. The minimum discharge recorded at this station was 165 second-feet on September 28, 1915. If not more than 35 second-feet was entering the lake from Great Spring and Ikenick Creek, 130 second-feet must have been discharged from springs in the bottom of the lake. As the discharge at that time was abnormally low, it is probable that 200 second-feet or more is the usual increment from springs in the bottom of the lake. The lake is therefore a great spring pool where an underground river finds its way to the surface. It is probable that the drainage from Lava Lake, to the north, forms part of this subterranean flow into Clear Lake and McKenzie River. The temperature of the lake was measured in several places on September 6, 1926, and found to range from 50° to 52° F. The wide difference between the temperature of the lake water and that of Great Spring is probably due largely to the warming of the lake water by the sun.

Clear Lake occupies a part of the ancestral valley of McKenzie River. This valley can not be traced in the area north of the lake, as that area is covered by lava flows. Observations indicate that the ancient McKenzie River carved out a wide and deep canyon with many tributaries on the slope of the Cascade Range, but the numerous lava flows have completely buried all traces of the former stream pattern. The lava is chiefly permeable basalt, and it is through the cavities and interstices in this lava that the ground water flows. Hence many of the former streams continued to flow in practically the same channels but beneath the surface. As the part of the valley now occupied by Clear Lake was not filled with lava, it became the exit for the subterranean McKenzie River, and the lava dam at the outlet caused the formation of a lake instead of the usually relatively small spring pool.

LEAKS

During the examination of Clear Lake as a possible reservoir site the writer was attracted to its southeast corner by the great quantities of driftwood lodged there. As the wind rarely blows from the northwest at this lake it was surmised that the driftwood was carried by a lake current.

Close inspection revealed a muddy channel 30 feet wide, filled with driftwood, which leads southeastward. During slightly higher stages of the lake the channel is evidently submerged. In its first 200 feet the channel contained numerous small springs which had a temperature of 40° F. on September 5, 1926, and a discharge of about 8 second-feet. About 300 feet from the lake the channel ended abruptly against the margin of the aa lava flow that dammed the valley, and the entire flow of the springs cascaded into a sink hole partly filled with driftwood. The hole is about 10 feet in diameter and 3 feet deep, with a distinct funnel shape. Numerous holes of similar shape filled with water were found near by. These holes apparently constitute leaks only during high stages of the lake. Because of these leaks it was considered not feasible to make a storage reservoir of the lake. Further evidence of leakage through the lava dam is afforded by the net gain in the flow of McKenzie River 1½ miles below the outlet. (See p. 187.)

QUANTITY OF GROUND WATER

The flow of McKenzie River at McKenzie Bridge during the low-water periods is derived chiefly from spring flow above the gaging station. Besides Olallie and Lost Creeks, which are spring fed, nine small surface streams enter McKenzie River above McKenzie Bridge during the low-water periods; these are Smith River and Anderson, Deer, Frissell, Boulder, Scott, Kink, Bobby, Payne, and Carmen Creeks. The last four are short and unimportant. Deer Creek, on August 30, 1912, had a discharge at its mouth, in sec. 26, T. 15 S., R. 6 E., of 19.9 second-feet. The discharge of Smith River at its mouth, in sec. 11, T. 15 S., R. 6 E., on August 26, 1912, was 20.6 second-feet, and on June 26, 1913, 154 second-feet. During August and September this river rarely flows more than 25 second-feet. The discharge of Anderson Creek is about 20 second-feet during periods of low water; it is reported to have its source in a spring. The total flow of all the other tributaries during low-water periods probably does not exceed 50 second-feet, and part of this amount is reported to come from springs not far from the river. The source of the water in Deer Creek and Smith River during low-water periods is unknown, but the water is probably not chiefly derived from springs. Hence, in any calculation of the amount of ground water entering McKenzie River, at least 40 second-feet should be deducted for the flow of Smith River and Deer Creek, and a total of about 100 second-feet for all tributaries discharging other than spring water. The minimum flow on record of McKenzie River at McKenzie Bridge was 890 second-feet, in October, 1924. On the assumption that 100 second-feet was contributed to the river during this month by the surface tributaries, 790 second-feet was discharged by springs above the gaging station.

The available records of minimum discharge of McKenzie River at McKenzie Bridge for the low-water months of August, September, and October are given in the following table:

Minimum discharge, in second-feet, of McKenzie River at McKenzie Bridge, Oreg., for August, September, and October, 1910 to 1926

Year	August	September	October	Year	August	September	October
1910			[a] 1,060	1919	1,250	1,180	1,110
1912	1,270	1,190		1920	1,180	1,110	1,540
1913	1,360	1,240	1,210	1921	1,390	1,320	1,250
1914	1,090	1,080		1922			962
1915	1,010	960	924	1923	1,350	1,170	1,170
1916	1,520	1,360		1924	980	908	890
1917	1,580		1,260	1925	1,160	1,110	1,050
1918	1,180	1,140	1,110	1926	962	934	

[a] Oct. 13–21.

The average minimum flow during the 14 years for which low-water records are available is 1,077 second-feet. The average direct run-off at the lowest stages of the river is almost certainly not over 150 second-feet. Hence, the average discharge from springs above McKenzie Bridge at the lowest stages is at least 925 second-feet. How much more is contributed by springs during periods of high water can not be ascertained from existing data. The writer estimates from miscellaneous measurements that at least 520 second-feet of the flow from springs at low stages is contributed from the four largest spring groups, in approximately the amounts given in the table below. These amounts are slightly greater than was observed in 1926 because that was an unusually dry year.

Average low-water flow of large springs tributary to upper McKenzie River, Oreg.

	Second-feet
Clear Lake	160
Great Spring	30
Olallie Springs	150
Lost Creek Springs	180
	520

The flow on September 12, 1913, at the outlet of Clear Lake, according to the daily-discharge records,[2] was 319 second-feet. A measurement of McKenzie River made on the same day 1½ miles

[2] U. S. Geol. Survey Water-Supply Paper 362, p. 147, 1917.

below Clear Lake and about half a mile below Middle Falls, in sec. 20, T. 14 S., R. 7 E., showed a flow of 642 second-feet. No surface streams enter the river between these two points, hence the net gain in 1½ miles of the McKenzie channel on this date was 323 second-feet. Only a very small part of this inflow can be seen as springs entering from the bank of the river. The remainder must therefore issue as springs in the bed of the river. Most of this inflow is believed to be leakage from Clear Lake that finds its way through the natural lava dam at its outlet. Considerable water issues as small springs at the base of Lower Falls. An analysis of the low-water discharge of McKenzie River above McKenzie Bridge is given below. These quantities are only approximate because of the lack of sufficient data for a more refined analysis, but they show in a general way the source of the low-water flow.

Sources of the low-water flow of McKenzie River above McKenzie Bridge, Oreg.

	Second-feet
Approximate direct run-off	150
Discharge of Clear Lake and of Great, Olallie, and Lost Creek Springs	520
Spring inflow in 1½ miles of channel below Clear Lake	325
Other spring inflow	82
	1,077

Complete records of precipitation and run-off are available for comparison for the hydrographic years ending September 30, 1912, and September 30, 1914. During the year ending September 30, 1912, a total precipitation of 79.91 inches was recorded at McKenzie Bridge. The run-off for 1912 at McKenzie Bridge was 1,160,000 acre-feet, which is equivalent to a run-off of 63.40 inches for the drainage basin of 343 square miles above the gaging station. During the year ending September 30, 1914, a total precipitation of 69.05 inches was recorded at Clear Lake, in the upper part of the drainage basin. The run-off for 1914 at McKenzie Bridge was 1,150,000 acre-feet, which is equivalent to a run-off of 62.86 inches. Thus the records for these two years indicate that a large proportion of the annual precipitation in the drainage basin appears as run-off.

It is estimated that at least 670,000 acre-feet was discharged from springs within the basin during each of these years. This flow from springs is equivalent to an intake of 36.62 inches over the entire drainage area, or nearly 60 per cent of the annual run-off and about 50 per cent of the annual precipitation. As springs of McKenzie Valley are practically all fed from the lava beds on the east side of the McKenzie drainage basin it is very probable that at least 75 per cent of the precipitation on these recent lava beds finds its way to the water table.

100370°—29——13

SUMMARY

Two epochs of lava filling with the resulting formation of lakes, waterfalls, subterranean streams, and large springs are the outstanding features in the geologic development of the upper McKenzie River Valley. The presence of an upright submerged forest in the bottom of Clear Lake, which was ponded by a lava flow, is proof that the volcanic action at that point was relatively recent. Other lava flows in the valley may be still younger.

The run-off for the drainage basin for the year ending September 30, 1912, was 63.40 inches, and that for the year ending September 30, 1914, was 62.86 inches. From an analysis of the stream-flow records it appears that the flow from springs is equivalent to an intake of 36.63 inches over the entire drainage area, or nearly 60 per cent of the annual run-off, about 50 per cent of the total annual precipitation, and about 75 per cent of the annual precipitation over the intake area of permeable basalt that supplies the springs. It is estimated that the flow from springs in the upper McKenzie Valley is about 925 second-feet, or about 670,000 acre-feet a year. Of this amount about 520 second-feet rises in four spring groups. All these springs issue from basalt, and three of them discharge about 150 second-feet each. The size of the springs is evidence of the remarkable permeability of the basaltic flows of this region.

Visible leaks on the southeast shore of Clear Lake indicate that this lake is unfit for use as a storage reservoir.

SURFACE WATER SUPPLY OF THE SACRAMENTO RIVER BASIN, CALIFORNIA, 1895–1927

By H. D. McGlashan

INTRODUCTION

The measurement of the flow of the streams in California was begun by the State engineer in 1878, in accordance with the law requiring him "to investigate the problems of the irrigation of the plains, the condition and capacity of the great drainage lines of the State, and the improvement of the navigation of rivers." The work was restricted to a few localities in the Sacramento and San Joaquin River Basins, the principal station being on the Sacramento at Collinsville.

The State engineer's office was discontinued in 1884, and practically no further stream studies were made in California until 1894, when engineers of the United States Geological Survey made a few measurements of streams in the semiarid parts of the State. The following year the Geological Survey established a station on Sacramento River at Jellys Ferry, 12 miles above Red Bluff, and since that time it has gradually extended the work, as funds were made available, until it now has available records of flow at a large number of points on California streams.

The records to June 30, 1912, for the Sacramento River Basin were published in Water-Supply Paper 298. Subsequent records are contained in the annual series of water-supply papers as follows:

	Water-Supply Paper		Water-Supply Paper		Water Supply Paper
1912	331	1917	461	1923	571
1913	361	1918	481	1924	591
1914	391	1919–20	511	1925	611
1915	411	1921	531	1926	631
1916	441	1922	551	1927	651

Although a few of these papers are out of print, most of them can be bought from the Superintendent of Documents, Government Printing Office, Washington, D. C., or they may be consulted at the Geological Survey offices at 303 Customhouse, San Francisco, and 600 Federal Building, Los Angeles, and at the public libraries in the principal cities.

The records are summarized in this paper to make them readily available for reference. For detailed information of daily discharge, run-off in acre-feet, and station descriptions giving full information regarding location and equipment of station and other pertinent information, reference should be made to the above-mentioned water-supply papers or to the files at the Geological Survey offices.

COOPERATION AND ACKNOWLEDGMENTS

Cooperation in stream measurements between the United States Geological Survey and the State of California was first provided for by the State legislature in an act approved March 16, 1903. Similar acts continued the cooperation until April 22, 1909, when an act placing cooperation between the State of California and the United States Geological Survey on a permanent basis was approved. This act provided as follows:

> The department of engineering is hereby empowered to carry on topographic surveys and investigations into matters pertaining to the water resources of the State along the lines of hydrography, hydro-economics, and the use and distribution of water for agricultural purposes, and to that end, where possible and to the best interests of the State, shall enter into contracts for cooperation with the different departments of the Federal Government in such amounts as may be an equitable and necessary division of the work. The State engineer, with the consent of the governor, may maintain and continue such investigations where there is available money not covered by cooperation contract. For the permanent maintenance of said surveys and investigations there is hereby continuously appropriated out of the general fund of the State treasury for each and every fiscal year, commencing with the date upon which this act becomes effective, the sum of $30,000.

Of this sum, $9,000 was allotted annually to investigations of water resources. To supplement this fund and the Federal appropriation, the State Conservation Commission, State Board of Control (water powers), State Water Commission, and later the Department of Public Works through the divisions of engineering and irrigation and water rights have allotted additional money.

The State budget for 1928 and 1929 groups all State cooperation with the Geological Survey for investigation of water resources and provides a fund of $25,000 a year for the biennium. This cooperation is disbursed by the division of engineering and irrigation, Department of Public Works, through Edward Hyatt, jr., State engineer.

The earliest stream gaging work in the State was carried on under the direction of William Ham. Hall, State engineer, by C. E. Grunsky, who continued in charge until the State engineer's department was abolished. Work by the United States Geological Survey was begun in 1894, under the direction of F. H. Newell, chief hydrographer, by Arthur P. Davis and Joseph B. Lippincott. On the establishment of the United States Reclamation Service, in 1902, Mr. Lippincott became supervising engineer for California, and the field work was continued under his direction by Willian B. Clapp and Samuel G. Bennett, until the separation of the Reclamation Service from the Geological Survey in 1906, when Mr. Clapp became district engineer. On Mr. Clapp's death in December, 1911, H. D. McGlashan was appointed district engineer.

Much cooperation and many records have been furnished by other Federal bureaus, counties, municipalities, irrigation districts, permittees and licensees of the Federal Power Commission, private companies, and individuals, to whom credit is given in the annual series of water-supply papers.

TOPOGRAPHY

California is traversed on the east and west by two approximately parallel ranges of mountains—the Sierra Nevada and the Coast Range—which converge at Mount Shasta on the north and at Tehachapi on the south and inclose the largest body of farming land in the State, the area often spoken of as the Great Valley of California. This valley is a gently sloping and practically unbroken plain, about 400 miles long and ranging in width from a few miles to 80 miles, with an average width of 40 miles. The total area of the valley proper is 15,700 square miles, or 10,048,000 acres; including mountains and minor valleys it comprises more than 58,000 square miles.

On the east side the valley has since the beginning of Cretaceous time been bordered by the Sierra Nevada; on the west side diastrophic processes have gradually built up the barrier of the Coast Ranges, changing the depression from a gulf of the sea to a lake and from a lake to a drained valley. From the beginning of the Cretaceous period the Great Valley has been the depository of enormous masses removed by erosion from the rising land on the east, and to a less degree also of the débris from the Coast Ranges.[1]

The northern portion of the Great Valley is drained by Sacramento River; the southern portion is drained by the San Joaquin. The two rivers unite at the head of Suisun Bay, from which they pass through San Pablo and San Francisco Bay and the Golden Gate to the Pacific Ocean.

The area drained by the Sacramento is divisible, according to elevation, into three parts—(1) the central region, known as the Sacramento Valley, whose general altitude is less than 500 feet above sea level; (2) the foothill region, made up of hills and ridges ranging in altitude from 500 to 2,300 feet and traversed by ravines and canyons of moderate depth; (3) the mountain region, in which altitudes exceed 2,300 feet above sea level.

Sacramento Valley, which is by far the most important area in the drainage basin, lies along the lower course of Sacramento River for a

[1] Lindgren, Waldemar, Tertiary gravels of the Sierra Nevada, California: U. S. Geol. Survey Prof. Paper 73, p. 15, 1911.

distance of about 150 miles northward from its mouth. The altitude of the valley ranges from about 300 feet above sea level at Red Bluff to only a few feet at the mouth of the river. Except for Marysville Buttes, in its center, its slope is gentle and uniform, ranging from approximately 4 feet to the mile in the north to less than 6 inches to the mile in the south.

The monotonous surface of the alluvial plains of the Sacramento Valley is scarcely broken by any recognizable relief; the lowest depressions are covered with swamp grass and tule, among which are tortuous sloughs and sheets of standing water, widening in flood times to vast lakes. The only sharply salient features are the river banks of sand and clay, from a few feet to 20 feet high. The valley floor is the gently sloping surface of a Pleistocene lake bottom, only recently drained by constructive processes. The rivers are at their base level and in their sluggish course deposit the loads of sand and clay brought down from the mountains, corrade their banks, and endeavor to establish new and changing channels.[2]

The total area of Sacramento Valley is about 4,250 square miles, including 2,510 square miles of high lands not subject to overflow but requiring irrigation for successful farming; 450 square miles of lower lands, overflowed occasionally; 1,250 square miles of low lands, overflowed periodically and submerged for a considerable period of the year; and 38 square miles of perennial stream surface.[3] It is thus evident that about 40 per cent of the valley suffers from floods and about 60 per cent from drought. The valley as a whole suffers from an excess of water at one season and a deficiency at another. The problem of remedying these defects embraces three distinct phases—the preservation and improvement of navigation, the reclamation of swamp and overflowed lands, and the development of irrigation for all the higher lands.

The floods occur in winter or early spring. The largest floods for which there are stream-flow records were those of 1904, 1906, and 1909.

From the rim of the valley there is a gentle rise across the zone of low-lying foothills and a steeper rise up the mountain side to the divide on the summit of the encircling ranges. The eastern watershed ranges in altitude from 10,000 feet in the south to 6,000 feet in the north; the western watershed ranges from 4,000 feet in the south to 9,000 in the north; and the northern from 4,000 to 8,000 feet, exclusive of Mount Shasta, which rises 14,161 feet above sea level.

The mountain ranges surrounding the basin belong to the Cordilleran system. The Sierra Nevada has an average width of approximately 70 miles from the rim of the valley to the crest of the range, which lies only a few miles west of the eastern boundary of the State. The range terminates in the Warner Mountains, in the northeastern part of the State, a region presenting evidence of recent volcanic action. Vast beds of lava cover the western slope of the

[2] Lindgren, Waldemar, op. cit., p. 17.
[3] California Com. Pub. Works Rept., 1894, p. 28.

range, and many cones, craters, ash deposits, and lakes exist in the vicinity of Mount Shasta and Lassen Peak, which are themselves the cones of extinct volcanoes. The Coast Range has an average width of 35 miles from the rim of the valley to the crest, which lies inland from the shore at a distance ranging from 30 miles at the south to nearly 100 miles at the north, where the range takes the name Trinity Mountains.

DRAINAGE

THE MAIN STREAM

The mountain torrent that forms the head of Sacramento River issues from a small lake (unnamed on the map) lying 6,600 feet above sea level on Mount Eddy, one of the peaks of the Trinity Mountains. About 8 miles east of this lake, or 12 miles by the course of the stream, it receives Wagon Valley Creek, which is fed by springs emerging from the lava beds at the southwest base of Mount Shasta, springs that are frequently referred to as the source of the Sacramento. At a point 370 miles south of its junction with Wagon Valley Creek the river unites with the San Joaquin and enters Suisun Bay, 50 miles from San Francisco.

The river is joined by numerous tributaries from the east and west. Those coming from the Sierra Nevada flow almost southwest; those from the Coast Range flow in a general easterly direction. The broad western slope of the Sierra furnishes by far the larger part of the drainage and all the important tributaries. Most of the streams from the Coast Range do not reach the Sacramento directly but become lost "in the intricate plexus of sloughs which meander through the tule lands bordering the main river. On the east, also, only the larger tributaries reach the Sacramento by a definite channel, and often that becomes an exceedingly tortuous one." [4]

Of the total fall of the river—6,600 feet from source to sea level—5,913 feet occurs in the 56 miles above the mouth of Pit River and 447 feet more in the 67 miles between Pit River and Red Bluff, leaving only 240 feet of fall for the remaining 250 miles of the course. The distribution of the fall is indicated by the following table of distances and elevations:

[4] Ransome, F. L., The Great Valley of California: California Univ. Dept. Geology Bull., vol. 1, p. 379, 1896.

Distances and elevations along Sacramento River from source to mouth

	Distance	Elevation above sea level	Distance between points	Fall between points	Fall per mile
	Miles	*Feet*	*Miles*	*Feet*	*Feet*
Source	0	6,600			
Wagon Valley Creek (mouth)	12	3,400	12	3,200	266
Delta	40	1,000	28	2,400	86
Mouth of Pit River	56	687	16	313	20
Redding (bridge above)	76	500	20	187	9
Red Bluff	123	240	47	260	5.5
Tehama	140	190	17	50	3
Stony Creek (mouth)	177	140	37	50	1.3
Junction with San Joaquin River	370	0	193	149	.8

Above the mouth of Pit River the Sacramento is a comparatively small stream, flowing swiftly in a well-defined channel; below the Pit it is larger, and at Red Bluff, where it enters Sacramento Valley, it becomes a sluggish stream of small slope. It is navigable to Red Bluff, 250 miles above its mouth.

Below the mouth of Stony Creek, throughout a large part of its course, the Sacramento occupies a ridge 5 to 20 feet higher than the troughs of the nearly parallel flood basins on each side, which are 2 to 7 miles from the river. The channel capacity throughout this distance is less than one-third that necessary to carry ordinary floods.

The large overflow area on the west side of the Sacramento is divided into two basins—Colusa Basin on the north and Yolo Basin on the south—by a ridge of detritus brought down by Cache Creek. The flood area on the east side of the river is divided into four basins—called, from north to south, Butte, Sutter, American, and Sacramento—by Marysville Buttes and Feather and American Rivers. The total area of these large flood basins is about 900 square miles.

The following data in regard to the area and capacity of these basins are taken from the Report of the Commissioner of Public Works to the Governor of California for 1904:[5]

Colusa Basin is 50 miles long, from 2 to 7 miles wide, and has a capacity of 690,000 acre-feet at flood stage. It discharges into the Sacramento above Knights Landing through Sycamore Slough.

Yolo Basin is 40 miles long, 7 miles in average width, and its capacity at flood stage is 1,115,000 acre-feet. It discharges through Cache Slough into Steamboat Slough and thence into the Sacramento near the foot of Grand Island, about 25 miles above the head of Suisun Bay.

[5] For detailed information regarding flood-control works see "Sacramento flood control project, revised plans," submitted to the reclamation board by W. F. McClure, State engineer, February 10, 1925.

Butte Basin is north of Marysville Buttes and its area varies from 30 to 150 square miles, depending on the river stage; its capacity at flood stage is 450,000 acre-feet. It discharges through Butte Slough into Sutter Basin.

Sutter Basin is south of Marysville Buttes and north of Feather River. Its area is 138 square miles, and its flood-stage capacity is 895,000 acre-feet. It discharges into Sacramento River through sloughs above the mouth of Feather River.

American Basin is south of Feather River and north of the American. Its area is 110 square miles, and its capacity at flood stage is 571,000 acre-feet. It discharges into the Sacramento north of the city of Sacramento, but owing to its great depth it is never free from water.

Sacramento Basin is a narrow strip south of American River, extending from the city of Sacramento to Walnut Grove. It is filled by overflow from Mokelumne River or the Sacramento, but not so frequently as the other basins are filled.

Many islands have been formed in the delta region between the lower courses of the Sacramento and the San Joaquin. Several sloughs carry the water of one river to the other among the islands, especially at higher river stages. The islands range in size from 1,600 to 43,000 acres and are very fertile.

THE TRIBUTARIES

PIT RIVER

Pit River is formed near Alturas, in Modoc County, by the union of its North and South Forks. The South Fork rises on the western slope of Warner Mountains, about halfway between Warren and Eagle Peaks, at an altitude of 8,000 feet above sea level, flows southwestward 10 miles, westward about 10 miles, and northward 16 miles through a swampy meadow to its junction with the North Fork. The North Fork flows southward from a point about half a mile south of Goose Lake but normally receives no overflow from that body of water. As overflow has, however, been recorded,[6] and as it is possible that water from the lake may reach the river by underground channels in the porous lavas which characterize this section, the area tributary to the lake is considered a part of the Pit River Basin. The principal direct tributaries of the North Fork of the Pit—Swedrengen, Joseph, and Parker Creeks—rise on the western slopes of the Warner Mountains, 6,000 feet above sea level, and flow westward, descending 1,200 feet in courses that measure less than 12 miles.

From Alturas the Pit takes a general southwesterly course to its junction with the Sacramento about 12 miles north of Redding.

[6] Waring, G. A., Geology and water resources of a portion of south-central Oregon: U. S. Geol. Survey Water-Supply Paper 220, p. 38, 1908. See also U. S. Geol. Survey Water-Supply Paper 295, p. 40, 1912.

The total fall between the head of the South Fork and the mouth of the main stream is about 7,300 feet, of which 3,550 feet occurs on the South Fork in the first 18 miles of its course.

Physically the Pit Basin is not tributary to the larger Sacramento Basin but is really its upper extension under a different name. It comprises about 7,000 square miles, equal to about 23 per cent of the total area of the Sacramento River Basin. The greater part of the Pit Basin exceeds 4,000 feet in altitude and consists chiefly of barren lava beds in the north and numerous small, flat, marshy meadow valleys in the south. The area contains also many volcanic buttes and peaks, of which Mount Shasta (14,161 feet above sea level) and Lassen Peak (10,437 feet above sea level) are the most important, but these peaks are on the Pit Basin divide and are shared in common with the upper Sacramento and Feather River Basins, respectively.

About 50 per cent of the Pit Basin is devoid of forests, the timberless area lying chiefly in the northern and eastern parts. There are two well-forested areas in the basin—one south of Pit River and north of Lassen Peak, and the other north of Pit River and south of Mount Shasta, extending westward from Fall River to the upper Sacramento River and including the McCloud Basin. All the public land in the forested areas is included in national forests.

The principal tributaries of Pit River are McCloud River, Squaw Creek, and Fall River, from the north, and Burney, Hat, Beaver, Ash, and West Valley Creeks from the south. McCloud and Fall Rivers are the largest, each having a minimum flow of 1,200 to 1,500 second-feet. Hat and Burney Creeks have a minimum flow of less than 100 second-feet. Goose Lake, though topographically tributary to the Pit Basin, has discharged water to it only once since 1869; it is said to have overflowed in 1881 for more than two hours during a severe storm from the north.

McCloud River drains an area comprising 649 square miles, lying just east of the upper Sacramento Basin. The river rises in large springs southeast of Mount Shasta, but its main water supply comes directly from the southern and eastern slopes of Mount Shasta through Squaw, Mud, Cold, and Ash Creeks, its tributaries. The river flows southward, is about 60 miles long, and falls more than 4,000 feet. It discharges into Pit River about 4 miles east of the confluence of the Pit with the Sacramento.

The precipitation in Pit River Basin is very unevenly distributed. In the upper eastern part of the basin it is only about 10 inches annually and occurs largely as snow, which at moderate altitudes soon melts. In the western and northwestern parts, however, the mean annual precipitation may reach 75 inches, according to altitude and occurs principally as rain except on the upper slopes of Mount Shasta, Lassen Peak, and other high peaks. In the McCloud Basin it is seldom less than 40 inches and occasionally reaches 100 inches. Practically all the precipitation is confined to the rainy season—from November to April of each year.

The valleys of the Pit Basin are used chiefly for meadow lands and the growing of stock feed. Some of them are flooded artificially for the raising of wild hay. The uplands are used only for domestic pasturage and for general stock raising, which is carried on extensively.

Numerous reservoir sites on the upper reaches of the Pit and its tributaries have been surveyed by the United States Bureau of Reclamation. A reservoir at the Big Valley site, near Bieber, would store more water than the river furnishes at this point. Warm Spring Reservoir, at Canby, would also have a large storage capacity.

The basin also affords exceptional opportunities for power development, especially below Fall River Mills, which is about halfway between the source and mouth of the Pit. The installed capacity of power plants on Pit River and tributaries is about 210,000 horsepower.

Many perennial springs issue from crevices in the lava beds and some of them discharge several hundred second-feet. Fall River is fed by large springs about 10 miles above its mouth, which discharge approximately 1,500 second-feet. Hat and Burney Creeks are fed largely by springs, and McCloud River draws heavily from numerous large springs on the southern slope of Mount Shasta. Most of the smaller tributaries are also spring fed.

COTTONWOOD CREEK

Cottonwood Creek has three principal forks—North, Middle, and South Forks. North Fork rises in Bully Choop Mountain, which reaches an altitude of 7,073 feet above sea level. It is about 20 miles long, drains an area of 112 square miles, and has a total fall of about 4,200 feet. It unites with Middle Fork a short distance below Gas Point. Middle Fork is about 30 miles long, has a fall of 5,900 feet, and drains an area of 261 square miles. South Fork rises in the Yolla Bolly Mountains, which reach an altitude of about 6,000 feet above sea level, and unites with the main creek a few miles west of the town of Cottonwood; it is about 45 miles long, drains an area of 395 square miles, and has a fall of 4,600 feet. The main creek flows eastward and empties into the Sacramento about 5 miles east of the town of Cottonwood and opposite the mouth of Battle Creek. The total drainage area is 929 square miles.

The crest of the Coast Range, which forms the western boundary of the basin for a distance of about 50 miles, ranges in altitude from 6,000 to 8,000 feet above sea level. From the crest toward the east, the basin slopes rapidly to the foothills around the north end of the Sacramento Valley, and is regularly furrowed by numerous drainage ways. About two-thirds of the area is more than 1,000 feet above sea level.

The basin is well timbered, but at the lower altitudes the growth is more or less scrubby. The upper part of the basins of Middle and South Forks is included in the Trinity National Forest.

The mean annual precipitation ranges from 25 inches in the lower part, where it occurs as rainfall, to more than 50 inches along the crest of the Coast Range, where much of it occurs as snow.

Some irrigation is carried on in this basin, especially in the northern part along the North Fork.

STONY CREEK

Stony Creek drains an area on the eastern slope of the Coast Range, north of the Cache Creek Basin and south of the basin of Thomas Creek, which lies between it and the Cottonwood Creek Basin on the north. The total drainage area comprises about 828 square miles, of which about 600 square miles is embraced in an irregular parallelogram, 10 to 15 miles wide, that touches the crest of the range for a distance of 50 or 60 miles. The creek rises in the south end of this area and flows northward along its eastern border about 35 miles, then northeastward about 15 miles, and finally southeastward to its junction with the Sacramento near St. John. The creek is about 90 miles long, and its fall is 4,000 to 5,000 feet.

The principal tributaries of Stony Creek are Little Stony Creek from the south end of the area, Briscoe Creek from its middle, Grindstone Creek from its north end, and North Fork, which enters the main creek about 10 miles northwest of Orland.

The drainage basin of Stony Creek is somewhat peculiar, topographically and geologically. The main stream lies wholly in sedimentary rocks; the tributaries from the west come from the granitic crest of the range and have heavy gradients. At various points in the basin the streams intersect conglomerate ridges which, because of their resistance to erosion, have produced favorable sites for dams and reservoirs. The basin ranges in altitude from a few hundred feet in the valley to 6,000 feet or more at the summit of the range.

The basin is covered with a good growth of grass and dense brush at the lower altitudes and heavy, commercially valuable timber on the mountain summits. About three-fourths of the upper basin is included in a national forest.

The mean annual precipitation ranges from 18 inches in the valley to 40 inches or more on the mountain summits, where more or less of it occurs as snowfall. The heaviest floods occur during the winter.

Water is stored in East Park Reservoir, on Little Stony Creek, for irrigation use on the Orland project, United States Bureau of Reclamation. Additional storage for this project is now under construction at the Stony Gorge site.

FEATHER RIVER AND ITS TRIBUTARIES

THE MAIN STREAM

Feather River heads on the crest of the Sierra and takes a general southwesterly course to its junction with the Sacramento about 30 miles south of Marysville and about 15 miles northwest of Sacramento. It is about 175 miles long and its drainage area comprises approximately 6,590 square miles, lying on the western slope of the Sierra Nevada, south of the Pit River Basin and north of the American River Basin.

The basin is roughly triangular in shape and is naturally subdivided into three other comparatively large basins—North Fork Basin at the north and west, with a total drainage of about 2,220 square miles; Middle Fork Basin, in the center and at the east, with a total drainage area of about 1,340 square miles; and Yuba Basin at the south, with a total drainage area of more that 1,300 square miles

The drainage basin of the North Fork, here regarded as the continuation of the main stream, includes the eastern part of Butte, the greater part of Plumas, and the southwestern corner of Lassen Counties. In length the North Fork Basin does not exceed 75 miles, and its width in Plumas County is about 65 miles.

The Middle Fork Basin is long but comparatively narrow except at its east end, where it broadens and includes Sierra Valley, a large meadow valley at an altitude 5,000 feet above sea level. Beckwith Pass, which opens into this valley from the east, is the lowest pass in the Sierra Nevada, its altitude being about 5,200 feet above sea level. Sierra Valley and the surrounding country are very dry in the summer. The greatest altitude in the Middle Fork Basin is about 8,500 feet. The Middle Fork unites with the North Fork in Butte County, about 6 miles northeast of Oroville.

Above Prattville are two small basins of almost equal size, the eastern being drained by Hamilton Branch and the western by North Fork. The eastern basin ranges in altitude from 4,300 to 7,500 feet, has an area of 230 square miles, and includes the East Arm of Big Meadows and the large level area called Mountain Meadows. The western basin has an area of 245 square miles, ranges in altitude from 4,300 to 10,000 feet, and includes the West Arm of Big Meadows and the higher country about Lassen Peak. Hamilton Branch unites with North Fork about 3 miles east of Prattville, at the lower end of Big Meadows.

The greater part of the Feather River Basin is rough and mountainous, and the slopes are deeply trenched by numerous stream channels. The rocks in the southern and eastern parts of the basin are principally granite; at the lower altitudes some porous and deeply eroded slate and lava are also found. The northern part of the basin is characterized by cones, craters, deposits of volcanic ash, and lakes, which indicate recent volcanic activity. The soil of the basin is porous, absorbs moisture readily, and serves to equalize the stream flow. The numerous meadows and valleys that exist in different parts of the area also help to maintain a steady flow in the streams during the dry season.

The basin is well forested. At the lower altitudes the growth consists for the most part of brush and scrubby timber. The mountain sides, except around the summits of the highest peaks, like Lassen, are covered with merchantable timber. About two-thirds of the entire basin, 4,300 square miles in round numbers, is inclosed in national forests, which include all the upper part of the basin except Sierra Valley on Middle Fork, the meadows around Prattville on North Fork, and a few other very small valleys.

The mean annual precipitation in the Feather Basin is about 30 inches in the foothill belt and increases toward the mountain summits. It ranges from 40 to 60 inches in the North and Middle Fork Basins at the north and east, and from 40 to 75 inches in the Yuba Basin at the south. In the winter much of it occurs as snowfall which does not disappear from the summits until summer.

Very little irrigation is practiced in the Feather Basin, though some water is diverted for use in the small valleys and in the Sacramento Valley below the foothills. Considerable water is used for mining and power.

The basin affords many excellent storage sites, especially on the North and Middle Forks. Surveys of a large number of reservoir sites in this area have been made by the United States Bureau of Reclamation and many others have been made by private companies.

The basin has many large springs, especially in the lava districts, which supply a more or less steady flow throughout the year. Many perennial springs are found in the Yuba Basin. The Feather Basin also contains many small glacial lakes, chiefly in Yuba and North Fork Basins.

Lake Almanor Reservoir (Big Meadows) was completed in 1914 to a capacity of 300,000 acre-feet. In 1926 the dam was raised, increasing the capacity to 1,300,000 acre-feet. The Butte Valley Reservoir has a capacity of 50,000 acre-feet.

The installed capacity of power plants on the North Fork of Feather River is more than 200,000 horsepower, and the ultimate development is estimated at 1,000,000 horsepower. The power resources of the Middle Fork of Feather River are important but undeveloped.

YUBA RIVER

Yuba River rises near the crest on the western slope of the high Sierra and flows southwestward to its junction with Feather River at Marysville. The total length of the stream is about 90 miles. Its basin lies south of the Middle Fork of Feather River Basin, west of the Truckee River Basin, and north of the American and Bear River Basins, is chiefly in Yuba, Sierra, and Nevada Counties, and is one of the principal subdivisions of the Feather River Basin. It has an area of more than 1,300 square miles and is triangular in shape, the base of the triangle lying along the crest of the Sierra. Its extreme length from the mouth of Yuba River to the crest of the Sierra is about 70 miles, and its greatest width is about 35 miles. The river is formed by three principal forks—Middle, North, and South. The Middle Fork, which is considered the continuation of the main stream, rises in Sierra and Nevada Counties on the west and south slopes of Weber Peak and takes a general southwesterly course. It receives the North Fork in Yuba County, in the northeastern part of T. 17 N., R. 7 E., and the South Fork in Nevada County, in the southwestern part of T. 17 N., R. 7 E.

The topography of the Yuba Basin is rugged and mountainous. From the edge of the Sacramento Valley the surface rises gently through the foothills and then more abruptly through rounded and broken mountains to the crest of the Sierra, which along the Yuba-Truckee divide has a mean altitude of about 8,000 feet and a few peaks exceeding 9,000 feet. The streams have cut deep canyons which head well up in the mountains. Slate and kindred rocks, much eroded, are found in the lower western part of the basin; in the higher eastern part the rocks are granite and lava. A stratum of serpentine traverses the basin parallel to the crest but at a considerable distance from it.

The soil is deep in most places and supports a hardy growth of brush and timber, especially along the sides of the canyons. The North Fork Basin has at present the best forest cover, and that of South Fork the poorest, but this difference is the result of lumbering operations. All the upper part of the Yuba Basin, more than 800 square miles, is now included in a national forest.

The mean annual precipitation ranges from 18 inches at Marysville to about 70 inches near the mountain crest. In the upper and central parts of the basin the precipitation ranges from 50 to 70 inches and occurs principally as snow, which remains on the ground all winter and well into the summer. The North and South Fork Basins probably receive the largest precipitation.

Little irrigation is practiced in the Yuba River Basin, but the main stream could undoubtedly be used for irrigating a part of the Sacramento Valley.

Several storage sites have been developed in the Yuba River Basin, including numerous small lakes near the headwaters of the South Fork. Stored water was originally used in hydraulic mining. At present the water is used for irrigation along the foothill fruit belt and for the development of power.

The principal power developments on Yuba River are those of the Pacific Gas & Electric Co. at the Colgate and Bullards Bar plants, about 12 miles above the gaging station at Smartsville, and those using water from Lake Spaulding on the South Fork of Yuba River.

Perennial springs are found in different parts of the Yuba River Basin, particularly along the North Fork. At the higher altitudes in the South Fork Basin are many small glacial lakes, and here also are many rounded, denuded summits and glacial valleys.

The channel of Yuba River for many miles above its mouth has been filled with enormous quantities of tailings from hydraulic mining. The depth of this débris is about 7 feet at the mouth; about 26 feet at Daguerre Point, 11 miles above the mouth; and about 84 feet in The Narrows, 18 miles above the mouth. A débris storage dam has been built at Bullards Bar and is used jointly for storing débris from hydraulic mining and for the development of power.

INDIAN CREEK

Indian Creek rises in the Sierra divide and flows westward to its junction with North Fork of Feather River. The stream is about 50 miles long and its drainage area, comprising 733 square miles,[7] is much greater than that of North Fork above the junction of the two streams. The basin is in the northeastern part of Plumas County, north of Middle Fork of Feather River and east of the upper part of North Fork. For about 45 miles it lies along the Sierra divide, which separates it from Honey Lake drainage basin at the east. The principal tributaries are Squaw, Red, Clover, Little Grizzly, and Spanish Creeks from the south and Light and Wolf Creeks from the north.

Practically all of the Indian Creek Basin has an altitude exceeding 5,000 feet, and much of it is a lava formation 6,000 to 7,000 feet in altitude. The entire basin is included in a national forest except a few meadows, of which Indian and American Valleys are the largest.

The mean annual precipitation is between 40 and 45 inches, and a large part of it occurs as snowfall. During the winter the streams freeze over occasionally.

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[7] U. S. Recl. Service Fourth Ann. Rept., p. 93, 1906.

The basin affords several good storage reservoir sites. Opportunities for power development are also good. With the available fall, the flow of the streams is sufficient to generate at least 20,000 horsepower continuously, and by utilizing storage 60,000 horsepower could be developed.

BEAR RIVER

Bear River drains a narrow strip on the western slope of the Sierra below an altitude of 5,500 feet. The basin is about 60 miles long and not more than 10 miles wide and lies south of the Yuba River Basin and north of the American River Basin. Its total area is less than 300 square miles.

The river rises in the extreme northeastern part of the basin near Emigrant Gap and flows southwestward to its junction with Feather River about 15 miles south of Marysville. It is the boundary line between Nevada and Placer Counties and closely parallels the Bear-American divide, which is 1 to 2 miles south of it. Its principal tributaries are Steep Hollow Creek, Greenhorn River, and Wolf Creek, all from the north.

The Bear River Basin has very little forest, except on a small area in the upper part. The mean annual precipitation ranges from 21 inches in the valley to 52 inches at the source of the river, where much of it occurs as snow that soon disappears.

Some irrigation is practiced in this basin. Storage is not feasible, and the minimum flow of the streams is not sufficient to develop much power. Water diverted from Lake Spaulding, after passing through the Drum power plant, is discharged into Bear River. Bear River Canal diverts water near Colfax for power; this water is afterward used for irrigation in the foothill area near Auburn.

AMERICAN RIVER

American River drains the area lying on the western slope of the Sierra, south of the Bear and Yuba River Basins west of Lake Tahoe and the Truckee River Basin, and north of the Consumnes and Mokelumne River Basins. The area is triangular in shape, about 80 miles long, and has a maximum width of 50 miles along the crest of the Sierra, and its total area is about 2,000 square miles.

American River is formed by the union of its three principal forks and flows southwestward about 110 miles to its junction with the Sacramento just above the city of Sacramento. North and Middle Forks are about 60 miles long, with a fall of nearly 8,000 feet and drain areas measuring, respectively, 349 and 640 square miles. South Fork, about 60 miles long, falls nearly 9,000 feet and drains an area of 861 square miles. North and Middle Forks unite near Auburn, about 20 miles above the mouth of South Fork, which is only a few miles above Folsom. Each of the forks has many other forks, branches, and tributaries.

Almost half of the American drainage basin exceeds 5,000 feet in altitude and probably one-third of it ranges from 6,000 to 9,000 feet. The rocks of the upper part are chiefly granites, which have yielded to glacial and erosional action to such an extent as to form many regular ridges and drainage channels.

The lower portions of the basin are barren or sparsely timbered, but the higher portions support a good growth of timber. All the upper part of the basin, amounting to considerably more than half of the total, is included in a national forest.

The mean annual precipitation ranges from 21 inches in the Sacramento Valley to probably 60 inches near the summit of the Sierra, where it occurs as snow which does not disappear till summer. In the foothill region it ranges from 25 to 30 inches and in the central region from 45 to 55 inches. It is probably somewhat greater in the northern than in the southern part of the basin. At the higher altitudes there is much snow and ice during the winter.

Some water is diverted from the American for irrigation, particularly in the Sacramento Valley. Considerable storage is feasible, particularly on Middle and South Forks.

The upper part of the American Basin shows evidence of glaciation, which has left many small lakes, some of which have been dammed and used for storage in connection with mining.

The installed capacity of the two power plants on South Fork of American River is 46,000 horsepower. The storage developed for these plants amounts to 32,000 acre-feet. The storage and power developments on the North and Middle Forks are small.

CACHE CREEK

The Cache Creek drainage basin lies on the eastern slope of the Coast Range in Lake, Colusa, and Yolo Counties, immediately south and west of the south end of the Stony Creek Basin and north of the Putah Creek Basin. The upper part of the area, comprising about 824 square miles, lies in the central part of Lake County, south of the divide separating the Eel River and Cache Creek Basins. It is roughly rectangular in shape, and contains Clear Lake in its center. From Lake County the basin extends southeastward to the Sacramento Valley as a strip about 50 miles long and 10 miles wide. The total area of the basin is 1,290 square miles.

Cache Creek is the only known outlet of Clear Lake. The lake is very irregular in shape and has an area of 65 square miles and an altitude of 1,325 feet at mean level. Its length is 20 miles and its greatest width 7 miles. The upper part, or main lake, has a maximum depth of 35 feet, but the lower neck has a few small areas as much as

50 feet in depth. The drainage area tributary to the lake is about 417 square miles, chiefly toward the south and west. The principal creeks flowing into the lake are Scotts, Middle, and Clover from the west, and Doba, Kelsey, and Cole [8] from the south. They are torrential during the rainy season, but are practically dry in the summer.

From the lake Cache Creek flows southeastward to the Yolo Basin and ultimately into Sacramento River through sloughs. Its total length is about 80 miles.

The largest and most important tributary of Cache Creek is the North Fork, which drains 250 square miles in the eastern part of Lake County. The only other important tributary is Bear Creek, which drains the western part of Colusa County. These creeks are very small in the summer, but rarely become dry. All the tributaries are torrential during the rainy season.

The upper part of the Cache Creek drainage basin in Lake County is mountainous and very rugged. Some of the peaks reach an altitude of 6,000 feet above sea level, and their slopes, as well as those of the lower ranges, are very steep. About 5 miles below the outlet the creek enters Cache Creek Canyon, in which it flows for 25 miles on an average grade of 35 feet to the mile. In some places the canyon walls are vertical cliffs 300 feet high. Below the canyon the creek enters Capay Valley, from 1 to 3 miles wide and 20 miles long, through which it winds for a distance of nearly 30 miles before entering the Sacramento Valley.

On the northern slope of the ranges around Clear Lake are fine belts of fir, oak, and pine. Elsewhere on the high ranges the vegetation consists of a dense growth of greasewood and chaparral. A strip along the northern edge of the basin is included in a national forest.

The mean annual precipitation ranges from 17 inches in the Sacramento Valley to 40 inches or more on the mountainous summits in Lake County, where much of it occurs as snowfall in the winter.

The upper part of this basin contains springs, a number of which, especially in the North Fork Basin, have medicinal properties that attract many visitors.

PUTAH CREEK

The Putah Creek Basin lies on the eastern slope of the Coast Range south of the Cache Creek Basin and north of Napa Valley. It includes the southern part of Lake County, the northern half of Napa County, and small parts of Yolo and Solano Counties. The basin is rather long from northwest to southeast and comparatively narrow, being about 20 miles wide at the north and less than 10 miles at the east. It has a total area of about 810 square miles.

[8] Cole Creek is not named on Punnett's map of Lake County or on the sketch map accompanying Water-Supply Paper 45 (Pl. I).

Putah Creek rises in the northwestern corner of the basin in the St. Helena Range and flows southeastward into the Yolo Basin near Davis, and thence into Sacramento River through Cache Slough. The total length of the creek is about 80 miles. It has numerous tributaries which have a heavy flood discharge in the winter but are practically dry during the summer. The chief tributaries are Soda Creek from the north and Pope Creek from the west.

The topography of the Putah Creek Basin is very rugged. Much of the upper basin is rough and precipitous. The underlying rock is an impervious slate and serpentine with only a thin soil covering. There is very little tilled land in the basin except below the foothills. Altitudes range from about 100 feet in the valley to about 5,000 feet on the mountain summits.

The lower parts of the basin are comparatively barren of timber, though they support a considerable growth of grass and brush which extends down as far as the foothills. At moderate altitudes timber grows scatteringly, and the mountain summits are covered by a fairly heavy timber growth.

The mean annual precipitation varies widely in the different parts of the basin. Along the foothills it averages about 28 inches, in the central part about 40 inches, and along the crest of the divide, where some of it occurs as snowfall in the winter, about 65 inches. Helen Mine, on the northern slope of Mount St. Helena, receives almost 100 inches annually.

Below the foothills is a large area of rich irrigable land, which could be supplied with water from Putah Creek. Some of this land is already irrigated and has been proved to be susceptible of the highest state of cultivation.

At least two good reservoir sites exist on the main stream, one near Winters and the other near Guenoc.

STREAM FLOW

GAGING STATIONS

The following list comprises the gaging stations that have been maintained in the Sacramento River Basin. The stations are arranged in downstream order, tributaries being indicated by indention. A dash after the last date in a line indicates that the station was being maintained September 30, 1927.

Sacramento River at Castella, Calif., 1910–1922.
Sacramento River at Antler, Calif., 1910–11, 1919–
Sacramento River at Kennett, Calif., 1925–
Sacramento River near Red Bluff, Calif., 1895–
Sacramento River at Butte City, Calif., 1921–
Sacramento River at Colusa, Calif., 1921–
Sacramento River at Knights Landing, Calif., 1921–

Sacramento River at Verona, Calif., 1926–
Sacramento River at Collinsville, Calif., 1878–1885.
Pit River near Canby, Calif., 1904–5.
Pit River near Bieber, Calif., 1904–1908, 1914, 1921–1926.
Pit River at Fall River Mills, Calif., 1921–
Pit River near Pecks Bridge, Calif., 1922–1924.
Pit River at Lindsay Flat, Calif., 1922–1927.
Pit River at Big Bend, Calif., 1910–
Pit River near Ydalpom, Calif., 1910–
South Fork of Pit River near Ivy, Calif., 1904–5.
West Valley Creek near Likely, Calif., 1904–5.
Pine Creek near Alturas, Calif., 1918–
Ash Creek at Adin, Calif., 1904–5.
Fall River at Fall River Mills, Calif., 1912–13.
Bear Creek near Dana, Calif., 1921–1926.
Hat Creek near Hat Creek, Calif., 1926–
Hat Creek at Hawkins ranch, Calif., 1911–1913.
Hat Creek at Wilcox ranch, near Cassel, Calif., 1921–22.
Hat Creek at Hat Creek, Calif., 1910–1913.
Hat Creek near Carbon, Calif., 1921–22.
Rising River near Cassel, Calif., 1911–1913, 1921–22.
Burney Creek above Burney, Calif., 1921–22.
Burney Creek near Burney, Calif., 1911–1913, 1921.
Burney Creek at Burney Falls, Calif., 1921–22.
Kosk Creek near Big Bend, Calif., 1910–1915.
Montgomery Creek at Montgomery Creek, Calif., 1911–1913.
Squaw Creek near Ydalpom, Calif., 1911–1913.
McCloud River near Gregory, Calif., 1902–1908.
McCloud River at Baird, Calif., 1911–
Clear Creek near Shasta, Calif., 1911–1913.
Cow Creek at Millville, Calif., 1911–1913.
Clover Creek at Millville, Calif., 1911–1913.
Little Cow Creek near Palo Cedro, Calif., 1911–1913.
Bear Creek near Millville, Calif., 1911–1913.
North Fork of Cottonwood Creek near Ono, Calif., 1919.
North Fork of Cottonwood Creek at Ono, Calif., 1907–1913.
Moon Creek near Ono, Calif., 1919.
Mill Creek near Los Molinos, Calif., 1911.
Thomas Creek at Paskenta, Calif., 1920–
Deer Creek near Vina, Calif., 1911–1915, 1920–
Stony Creek near Fruto, Calif., 1901–1912.
Stony Creek near Stonyford, Calif., 1913–1914, 1918–
Stony Creek near Elk Creek, Calif., 1919–
Stony Creek near Orland, Calif., 1919–
Little Stony Creek near Lodoga, Calif., 1908–
North Fork of Feather River above Prattville, Calif., 1905–1907.
North Fork of Feather River near Prattville, Calif., 1905–
North Fork of Feather River at Big Bar, Calif., 1911–
North Fork of Feather River at Big Bend, Calif., 1905–1910.
Feather River at Oroville, Calif., 1902–
Feather River at Nicolaus, Calif., 1921–
Hamilton Branch of Feather River near Prattville, Calif., 1905–1907.
Butt Creek at Butte Valley, Calif., 1905–1921.

- Sacramento River Basin—Continued.
  - Feather River Basin—Continued.
    - Indian Creek near Crescent Mills, Calif., 1906–1918.
      - Spanish Creek at Keddie, Calif., 1911–
    - Middle Fork of Feather River near Clio, Calif., 1925–
    - Middle Fork of Feather River at Sloat, Calif., 1911–
    - Middle Fork of Feather River near Nelson Point, Calif., 1924–
    - Middle Fork of Feather River near Oroville, Calif., 1911–
      - Grizzly Creek near Portola, Calif., 1906, 1925–
      - South Fork of Feather River at Enterprise, Calif., 1911–
        - Palermo Land & Water Co.'s canal at Enterprise, Calif., 1911–
    - Middle Fork of Yuba River at Milton, Calif., 1926–
    - Middle Fork of Yuba River near North San Juan, Calif., 1900, 1911–
    - Yuba River at Smartsville, Calif., 1903–
    - Yuba River at Parks Bar Bridge, Calif., 1900.
      - Oregon Creek near North San Juan, Calif., 1911–
      - North Fork of Yuba River near Sierra City, Calif., 1924–
      - North Fork of Yuba River at Goodyear Bar, Calif., 1910–
      - North Fork of Yuba River near North San Juan, Calif., 1900.
        - North Fork of North Fork of Yuba River at Downieville, Calif., 1910–1926.
        - Rock Creek at Goodyear Bar, Calif., 1910–
        - Goodyear Creek at Goodyear Bar, Calif., 1910–
      - Canyon Creek above Jackson Creek, Calif., 1926–
      - Canyon Creek below Bowman Lake, Calif., 1926–
        - Jackson Creek at mouth, Calif., 1926–
      - Bear River near Colfax, Calif., 1911–1913, 1915–1917.
      - Bear River at Van Trent, Calif., 1904–
        - Bear River Canal near Colfax, Calif., 1912–
  - North Fork of American River near Colfax, Calif., 1911–
  - American River at Fairoaks, Calif., 1904–
    - Middle Fork of American River near East Auburn, Calif., 1911–
      - Rubicon River at Rubicon Springs, Calif., 1910–1914.
      - Rubicon River near Quintette, Calif., 1909–1914.
        - Little Rubicon River near Rubicon Springs, Calif., 1910–11.
        - Little South Fork of Rubicon River at South Fork sawmill, near Quintette, Calif., 1910–1914.
        - Little South Fork of Rubicon River below Gerle Creek, near Quintette, Calif., 1910–1914.
        - Little South Fork of Rubicon River at mouth, near Quintette, Calif., 1909–1911.
          - Gerle Creek near Rubicon Springs, Calif., 1910–1912.
            - Little South Fork ditch at sawmill, near Quintette, Calif., 1910–1913.
        - Pilot Creek near Quintette, Calif, 1910–1914.
        - Pilot Creek ditch near Quintette, Calif, 1910–1914.
    - South Fork of American River below Silver Fork, at Kyburz, Calif., 1906.
    - South Fork of American River at Kyburz, Calif., 1906–7, 1923–24.
    - South Fork of American River near Kyburz, Calif., 1907, 1922–
    - South Fork of American River near Camino, Calif., 1922–

Sacramento River Basin—Continued.
American River Basin—Continued.
South Fork of American River near Placerville, Calif., 1911–1920.
Echo Lake flume near Vade, Calif., 1923–
Medley Lakes outlet near Vade, Calif., 1923–
Silver Lake outlet near Kirkwood, Calif., 1922–
Silver Fork of South Fork of American River near Kyburz, Calif., 1924–
Twin Lakes outlet and spillway near Kirkwood, Calif., 1922–
El Dorado Canal near Kyburz, Calif., 1922–
Alder Creek near Whitehall, Calif., 1922–
Plum Creek near Riverton, Calif., 1922–
Silver Creek at Union Valley, Calif., 1921–
Silver Creek near Placerville, Calif., 1922–
South Fork of Silver Creek at Ice House, Calif., 1922, 1924–
Finnon reservoir outlet near Placerville, Calif., 1922–
Western States Gas & Electric Co.'s flume near Camino, Calif., 1922–
Cache Creek at Lower Lake, Calif., 1901–1915.
Cache Creek at Yolo, Calif., 1903–
Putah Creek near Guenoc, Calif., 1904–1906.
Putah Creek at Winters, Calif., 1905–

MAXIMUM AND MINIMUM DISCHARGES

Maximum and minimum discharges recorded at stations in the Sacramento River Basin, California

Station	Period of record	Drainage area	Maximum discharge				Minimum discharge
			Date	Gage height	Discharge	Discharge per square mile	
		Sq. mi.		*Feet*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
Alder Creek near Whitehall	1922–1927	22.8	Feb. 6, 1925	4.95	715	31	0.1
American River at Fairoaks	1904–1927	1,910	Mar. 19, 1907	30.4	119,000	62	3.6
Middle Fork of American River near East Auburn	1911–1927	628	Feb. 6, 1925	25.0	36,300	58	23
North Fork of American River near Colfax	1911–1927		Jan. 1, 1914	16.0	23,000		15
South Fork of American River near Kyburz	1922–1927		May 16, 1927	6.57	3,220		.4
South Fork of American River near Camino	1922–1927		Feb. 6, 1925	19.0	18,000		3.7
South Fork of American River near Placerville	1911–1920		Jan. 25, 1914	19.0	15,000		49
Butt Creek at Butte Valley	1905–1921	73	Jan. 16, 1909		[a] 1,640	22	7
Bear Creek near Dana	1921–1926		Feb. 6, 1925	6.0	562		0
Bear River at Van Trent	1904–1927	263	Jan. 14, 1909	18.9	29,600	113	.7
Cache Creek near Lower Lake	1901–1915	500	Feb. 20, 1909	13.8	4,340	8.7	0
Cache Creek at Yolo	1903–1927	1,230	Feb. 2, 1915	27.8	21,100	17	0
North Fork of Cottonwood Creek at Ono	1907–1913	52	Dec. 31, 1913	9.0	4,180	80	1
Deer Creek near Vina	{1911–1915 1920–1927}		Dec. 31, 1913	11.0	6,920		60
Feather River at Oroville	1902–1927	3,640	Mar. 19, 1907	30.2	187,000	51	[b] 402
North Fork of Feather River at Big Bar	1911–1927		Jan. 1, 1914		[a] 35,000		[a] 423
North Fork of Feather River near Prattville	1905–1927	506	Mar. 19, 1907	16.2	10,000	20	[c] 0
Middle Fork of Feather River near Nelson Point	1923–1927		Feb. 22, 1927	10.98	12,300		36
Middle Fork of Feather River near Oroville	1911–1927	1,340	Dec. 31, 1913	18.0	34,200	26	100

[a] Mean daily discharge.
[b] Power regulation.
[c] Storage at Lake Almanor began in March, 1914.

Maximum and minimum discharges recorded at stations in the Sacramento River Basin, California—Continued

Station	Period of record	Drainage area	Maximum discharge				Minimum discharge
			Date	Gage height	Discharge	Discharge per square mile	
		Sq. mi.		*Feet*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
Middle Fork of Feather River at Sloat	1910–1927	795	Feb. 22, 1927	10.1	11,700	15	22
South Fork of Feather River at Enterprise	1911–1927	130	Feb. 25, 1917	12.05	10,600	82	.2
Goodyear Creek at Goodyear Bar	1910–1927	12.2	Feb. 21, 1927	7.4	1,580	130	1.2
Indian Creek near Crescent Mills	1906–1918	740	Mar. 19, 1907	20.2	11,700	16	12
Kosk Creek near Big Bend	1910–1915	51.9	May 11, 1915	8.0	2,920	56	19
Little Stony Creek near Lodoga	1907–1927	102	Feb. 2, 1909	11.8	7,060	69	[d] 0
McCloud River at Baird	1910–1927	665	Feb. 2, 1917	14.3	27,600	42	740
Medley Lakes outlet near Vade	1922–1927		June 21, 1925	2.86	146		0
Oregon Creek near North San Juan	1910–1927		Feb. 20, 1927	9.0	5,050		1.0
Pine Creek near Alturas	1918–1927	31	Mar. 29, 1919	3.2	147	4.7	2.3
Pit River near Bieber	1904–1908, 1914, 1921–1926	2,950	Mar. 19, 1907	16.4	27,500	9.3	0
Pit River at Big Bend	1910–1927	4,920	Apr. 29, 1917	5.39	13,600	2.8	[e] 644
Pit River at Fall River Mills	1921–1927	4,150	Apr. 4, 1922	5.96	7,330	1.8	[f] 12
Pit River near Ydalpom	1910–1927	5,260	Dec. 31, 1913	18.2	47,000	8.9	[e] 1,000
Plum Creek near Riverton	1922–1927	7.0	Feb. 6, 1925	3.70	500	71	.1
Putah Creek at Winters	1905–1927	654	Dec. 31, 1913	39.0	60,000	92	0
Rock Creek at Goodyear Bar	1910–1927	10.8	do	7.0	820	76	.3
Sacramento River at Antler	1910–1911, 1919–1927	461	Nov. 30, 1926	17.0	28,200	61	110
Sacramento River at Castella	1910–1922	257	Jan. 2, 1914	13.7	16,000	62	
Sacramento River near Red Bluff	1895–1927	9,300	Feb. 3, 1909	35.2	278,000	30	2,640
Silver Creek near Placerville	1921–1927		Feb. 6, 1925	12.0	7,330		10
South Fork of Silver Creek at Ice House	1924–1927		May 16, 1927	3.92	800		.5
Silver Fork of South Fork of American River near Kyburz	1924–1927		Feb. 6, 1925	5.25	2,350		[g] 7.5
Silver Lake outlet near Kirkwood	1922–1927		May 16, 1927	3.94	313		.1
Spanish Creek at Keddie	1911–1927		Dec. 31, 1913	10.0	9,450		9
Stony Creek near Elk Creek	1919–1927	298	Jan. 21, 1921	7.8	10,200	34	0
Stony Creek near Fruto	1901–1912	601	Feb. 2, 1909	16.3	36,000	60	.5
Stony Creek near Orland	1920–1927	636	Jan. 30, 1921	10.3	19,500	31	0
Thomas Creek at Paskenta	1921–1927		Feb. 20, 1927	9.1	11,500		0
Twin Lakes outlet near Kirkwood	1922–1927		June 13, 1927	1.93	172		.2
Yuba River at Smartsville	1903–1927	1,220	Jan. 15, 1909	28.3	111,000	91	[b] 71
Middle Fork of Yuba River near North San Juan	1910–1927		Feb. 21, 1927	14.0	21,900		21
North Fork of Yuba River at Goodyear Bar	1910–1927	214	May 11, 1915	11.5	12,600	59	80
North Fork of North Fork of Yuba River at Downieville	1910–1926	71.2	do	8.0	6,760	95	10

[b] Power regulation.
[d] Storage at East Park Reservoir.
[e] Regulation at Pit No. 3 Reservoir.
[f] Fall River diverted through Pit River No. 1 plant.
[g] Storage at Silver and Twin Lakes.

DEFICIENCY IN DISCHARGE

Days of deficiency in discharge of Sacramento River near Red Bluff, Calif., during the years ending September 30, 1896–1927

[Drainage area, 9,300 square miles]

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column															
	1896	1897	1898	1899	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911
3,300	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
3,400	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
3,600	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
3,800	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
4,000	----	----	----	----	----	----	----	22	----	----	----	----	----	----	----	----
4,200	----	----	----	----	1	17	29	73	----	----	----	----	----	----	----	----
4,500	----	----	----	----	46	47	30	86	33	----	----	----	----	----	----	----
5,000	----	----	83	130	103	88	101	107	36	50	36	----	59	14	50	5
5,500	19	63	114	188	124	126	136	124	69	73	79	12	76	65	87	92
6,000	125	104	167	202	144	146	166	137	78	88	144	86	112	120	110	119
6,500	166	127	241	222	155	157	186	147	93	100	161	121	159	148	141	145
7,000	175	136	277	243	158	166	193	153	98	103	172	132	167	161	158	157
7,500	183	145	296	257	163	171	200	156	111	119	177	147	173	172	169	168
8,000	191	155	306	278	166	176	205	170	128	136	182	158	182	180	179	180
9,000	197	183	316	295	181	194	212	189	155	156	188	169	201	191	189	194
10,000	207	197	332	310	209	212	223	197	177	185	197	178	214	202	208	203
11,000	219	211	342	320	235	238	232	208	202	209	206	184	242	209	221	210
12,000	231	219	348	325	257	251	235	217	214	217	212	192	263	216	236	220
14,000	248	236	353	338	290	281	253	253	233	247	234	220	301	235	264	241
16,000	260	250	357	343	309	301	269	268	240	275	245	238	319	241	283	258
18,000	275	273	360	348	320	317	282	292	245	288	261	255	331	252	299	278
20,000	293	287	360	350	326	321	295	308	248	297	283	264	337	269	312	299
25,000	314	325	364	353	342	335	322	326	267	310	309	289	345	298	333	315
30,000	330	339	364	356	345	344	327	337	278	324	322	306	351	307	339	334
35,000	339	345	364	358	348	347	330	345	289	336	331	314	357	313	347	346
40,000	340	349	365	359	351	350	337	349	303	344	338	333	360	322	359	349
50,000	347	357	----	362	355	354	342	354	323	353	350	343	365	330	362	356
60,000	353	359	----	363	360	357	347	357	332	358	357	349	365	340	363	362
75,000	357	362	----	364	362	360	354	361	343	364	361	353	365	347	363	364
100,000	361	365	----	365	364	364	358	363	359	364	363	357	366	353	365	364
150,000	366	----	----	----	365	365	363	365	365	365	365	365	----	362	----	365
200,000	----	----	----	----	----	----	365	----	366	----	----	----	----	364	----	----
Over 200,000	----	----	----	----	----	----	----	----	----	----	----	----	----	365	----	----

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column															
	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927
3,300	----	----	----	----	----	----	----	----	3	----	----	9	139	13	86	1
3,400	----	----	----	----	----	----	----	----	54	----	----	23	150	35	97	9
3,600	----	----	----	----	----	----	11	----	83	6	4	56	157	69	103	24
3,800	----	----	----	----	----	----	45	13	92	6	37	62	161	93	110	70
4,000	----	----	----	----	----	----	73	25	100	11	65	74	168	109	122	102
4,200	----	----	----	----	----	27	76	74	151	90	88	91	262	117	163	119
4,500	2	20	7	----	----	49	139	96	176	112	130	125	316	124	200	126
5,000	42	77	40	4	47	81	166	150	255	126	164	161	336	148	241	135
5,500	132	111	101	62	101	139	212	188	276	134	192	176	342	169	251	146
6,000	178	130	118	109	126	164	236	204	286	140	204	192	349	185	256	153
6,500	188	148	134	142	139	186	255	208	304	147	214	217	352	198	265	157
7,000	192	168	146	155	154	221	260	217	315	151	220	242	354	205	272	164
7,500	208	188	155	163	165	230	269	226	328	155	224	261	357	215	278	169
8,000	223	196	162	173	175	235	281	235	336	156	228	278	358	225	289	183
9,000	236	220	173	188	182	249	299	248	342	160	236	300	360	233	305	197
10,000	263	232	184	199	207	267	305	257	346	169	244	315	361	249	310	205
11,000	280	253	188	206	217	280	313	261	350	172	262	326	361	269	316	210
12,000	300	284	195	215	220	288	322	264	353	190	274	332	361	281	322	213
14,000	327	314	210	221	240	309	332	277	356	219	296	344	363	297	329	233
16,000	336	333	234	235	258	321	338	293	359	234	322	349	363	304	333	205

Days of deficiency in discharge of Sacramento River near Red Bluff, Calif., during the years ending September 30, 1896–1927—Continued

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column															
	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1025	1926	1927
18,000	345	347	246	242	274	333	345	301	361	244	335	355	364	311	336	272
20,000	351	351	259	254	288	342	354	321	363	254	345	356	365	324	340	286
25,000	359	359	284	299	313	351	359	343	364	298	356	360	365	339	348	312
30,000	362	359	320	316	328	359	363	351	366	322	359	363	365	346	353	323
35,000	364	361	327	324	338	361	364	358	----	337	362	364	365	350	355	332
40,000	365	361	332	333	346	362	364	358	----	344	364	365	365	352	359	337
50,000	365	362	342	343	355	362	364	359	----	352	365	----	366	355	363	347
60,000	366	365	345	352	358	363	365	362	----	359	----	----	----	357	363	353
75,000	----	----	351	359	363	363	----	363	----	363	----	----	----	352	364	359
100,000	----	----	355	363	366	364	----	364	----	364	----	----	----	364	365	364
150,000	----	----	363	364	----	364	----	365	----	365	----	----	----	365	----	365
200,000	----	----	365	364	----	365	----	----	----	----	----	----	----	----	----	----
Over 200,000	----	----	----	365	----	----	----	----	----	----	----	----	----	----	----	----

Days of deficiency in discharge of Pit River at Big Bend, Calif., during the years ending September 30, 1912–1927

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column															
	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927
2,050	----	----	----	----	----	----	----	----	1	----	----	36	162	136	191	120
2,100	----	----	----	----	----	----	----	----	19	1	----	73	168	170	208	134
2,150	----	----	----	----	----	----	----	2	109	6	----	105	206	208	224	145
2,200	----	----	----	----	----	----	----	2	109	12	----	105	206	208	241	154
2,250	----	----	----	----	----	----	9	30	135	33	64	150	284	219	253	164
2,300	----	----	----	----	----	----	68	100	161	109	136	190	324	235	269	169
2,350	----	----	----	----	----	----	68	100	161	112	136	223	338	235	276	175
2,400	----	----	----	----	----	----	68	100	161	114	142	223	338	245	288	185
2,450	----	----	----	----	----	----	113	136	277	128	223	250	345	257	295	191
2,500	----	3	----	----	----	1	113	136	277	128	223	269	347	257	296	197
2,600	----	32	10	26	7	5	161	222	312	139	245	287	350	287	314	207
2,700	59	69	74	60	88	91	161	222	312	139	247	306	354	299	320	212
2,800	59	95	116	99	102	138	259	248	335	149	251	313	357	305	326	220
2,900	92	156	155	165	137	186	259	248	335	151	254	330	358	312	329	226
3,000	92	185	165	212	161	224	299	254	341	156	262	338	359	322	336	235
3,100	177	247	179	230	182	233	322	263	347	177	273	347	360	327	337	243
3,200	244	281	192	235	213	246	322	263	347	177	275	351	361	330	341	252
3,300	244	285	195	236	218	247	330	272	352	189	283	255	362	332	342	256
3,400	307	288	200	237	223	249	330	272	352	189	284	356	362	334	346	260
3,500	307	291	205	243	228	256	338	286	359	214	292	359	363	337	352	265
3,600	324	300	207	249	234	264	338	298	359	237	296	364	364	339	353	269
3,800	351	314	215	257	251	278	342	306	362	253	299	365	365	343	356	273
4,000	355	325	226	269	260	283	348	309	363	260	304	----	366	345	359	276
4,500	359	346	242	318	283	296	356	324	365	289	318	----	----	352	362	300
5,000	366	356	256	354	293	303	360	340	366	311	332	----	----	356	365	322
5,500	----	358	271	364	313	311	362	347	----	320	337	----	----	359	----	336
6,000	----	359	283	365	323	324	364	350	----	334	341	----	----	361	----	341
6,500	----	362	300	----	331	327	365	353	----	347	345	----	----	361	----	348
7,000	----	362	319	----	334	329	----	354	----	353	353	----	----	362	----	356
8,000	----	365	343	----	352	336	----	361	----	362	362	----	----	365	----	363
9,000	----	----	353	----	359	342	----	365	----	365	365	----	----	----	----	365
10,000	----	----	359	----	363	350	----	----	----	----	----	----	----	----	----	----
12,000	----	----	365	----	366	358	----	----	----	----	----	----	----	----	----	----
14,000	----	----	----	----	----	365	----	----	----	----	----	----	----	----	----	----

Days of deficiency in discharge of Feather River at Oroville, Calif., during the years ending September 30, 1903–1927

[Drainage area, 3,640 square miles]

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column												
	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915
800													
900										12	4		
1,000									1	34	29	9	
1,100								10	7	68	64	31	
1,200	20		3	4				23	21	86	90	32	
1,300	20		37	62		34	23	34	44	108	101	38	
1,400	20		53	85		51	35	63	64	127	109	43	
1,500	33		60	96		51	46	73	72	146	121	50	
1,600	55	6	66	103		52	59	91	85	170	133	58	
1,800	87	47	78	103	3	91	106	107	113	189	161	104	9
2,000	104	74	88	129	67	120	124	119	128	191	172	138	27
2,500	132	99	117	150	109	153	151	145	150	216	195	158	121
3,000	143	110	153	166	123	162	163	162	166	238	242	170	161
3,500	174	161	176	169	131	167	171	169	174	264	255	176	191
4,000	196	181	183	171	135	176	175	176	181	283	268	177	201
5,000	238	208	201	182	150	205	182	194	192	318	282	182	214
6,000	254	219	214	195	170	235	187	220	208	324	291	186	221
7,000	274	225	229	212	188	268	190	246	219	331	297	199	232
8,000	290	229	253	218	201	292	195	261	224	344	304	212	239
9,000	295	234	279	221	208	320	202	276	234	354	315	218	249
10,000	301	238	307	230	215	343	205	282	240	363	333	224	260
12,000	314	242	329	243	236	355	236	296	253	364	350	236	282
15,000	331	254	340	274	253	364	288	333	262	365	363	253	309
20,000	353	282	354	327	279	366	339	358	300	366	365	305	343
30,000	361	330	364	353	339		351	364	343			347	353
40,000	362	340	364	357	351		355	365	360			354	359
50,000	363	347	364	360	355		356		363			358	360
60,000	363	354	364	363	359		358		363			359	361
80,000	364	359	365	364	361		362		365			362	363
100,000	365	365		365	362		362					364	365
150,000		366			364		365					365	
200,000					365								

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column											
	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927
800									11			
900									56			
1,000					2	1			100			
1,100					5	2		3	128	1		
1,200			1		16	5	3	11	140	6		
1,300			3		31	8	11	13	156	13	2	
1,400			10		42	13	18	21	184	25	6	1
1,500	1		36		73	19	36	21	214	34	11	11
1,600	1		67	4	86	30	67	36	227	50	44	19
1,800	7		124	31	127	77	102	90	300	127	98	53
2,000	118	2	166	94	190	89	128	124	320	173	210	109
2,500	155	103	242	182	259	108	173	151	345	206	239	150
3,000	168	181	273	232	275	128	195	167	356	225	249	165
3,500	180	218	287	243	284	134	207	199	358	236	255	175
4,000	191	226	294	251	300	141	217	226	359	249	258	184
5,000	205	245	304	268	312	152	226	268	362	268	274	201
6,000	219	261	310	286	325	167	243	292	362	306	305	224
7,000	237	272	318	299	349	180	253	316	363	318	324	237
8,000	242	275	331	310	359	192	266	336	363	339	336	248
9,000	245	281	341	313	362	212	276	346	363	349	339	261

Days of deficiency in discharge of Feather River at Oroville, Calif., during the years ending September 30, 1903–1927—Continued

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column											
	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927
10,000	255	292	345	318	362	239	288	348	363	353	345	289
12,000	268	312	349	327	363	284	308	357	364	359	350	305
15,000	305	328	352	346	364	331	314	362	364	360	355	327
20,000	354	345	362	362	365	356	331	365	364	360	356	344
30,000	360	356	363	363	366	361	358	------	365	362	359	357
40,000	364	362	365	364	------	363	365	------	366	362	362	361
50,000	366	363	------	364	------	363	------	------	------	363	364	363
60,000	------	364	------	365	------	363	------	------	------	364	365	363
80,000	------	364	------	------	------	365	------	------	------	365	------	364
100,000	------	365	------	------	------	------	------	------	------	------	------	364
150,000	------	------	------	------	------	------	------	------	------	------	------	365
200,000	------	------	------	------	------	------	------	------	------	------	------	------

NOTE—Regulation at Lake Almanor Reservoir began March, 1914.

Days of deficiency in discharge of Yuba River at Smartsville, Calif., during the years ending September 30, 1904–1927

[Drainage area, 1,220 square miles]

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column											
	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915
150	------	------	------	------	------	------	------	------	------	------	------	------
200	------	------	------	------	------	------	------	------	------	------	------	------
300	------	------	------	------	------	------	24	------	25	70	35	8
400	------	------	------	20	68	39	69	33	60	84	75	81
500	26	55	82	48	114	87	92	83	130	125	115	118
600	70	70	125	100	138	116	105	110	173	138	124	150
800	99	87	155	118	155	145	134	139	193	160	145	174
1,000	112	110	163	122	163	161	146	150	218	185	158	191
1,200	114	142	165	126	168	168	154	158	237	206	165	200
1,400	120	167	167	132	171	173	161	165	249	227	172	205
1,600	139	174	169	134	177	176	164	168	271	250	177	209
1,800	171	178	171	137	191	177	168	168	286	162	180	212
2,000	187	184	174	141	199	178	172	176	290	273	186	214
2,500	206	187	189	154	221	180	180	184	307	285	193	216
3,000	216	202	197	169	257	183	191	196	314	288	207	224
3,500	222	209	202	180	276	187	216	203	318	289	214	237
4,000	225	226	206	187	289	190	229	207	323	296	222	246
5,000	233	263	222	203	329	214	258	219	330	314	259	262
6,000	237	297	241	226	349	250	282	230	340	330	283	280
7,000	249	323	258	249	360	276	306	251	356	350	292	310
8,000	260	342	273	274	364	294	326	275	366	356	304	327
10,000	293	357	301	314	366	320	347	308	------	365	328	345
12,000	319	360	327	330	------	340	352	330	------	------	345	348
15,000	346	361	343	341	------	349	358	347	------	------	354	354
20,000	352	365	356	352	------	353	361	360	------	------	361	359
30,000	359	------	361	357	------	359	363	363	------	------	363	363
40,000	362	------	363	359	------	360	365	365	------	------	364	363
50,000	363	------	365	360	------	362	------	------	------	------	365	365
60,000	366	------	------	362	------	362	------	------	------	------	------	------
75,000	------	------	------	362	------	363	------	------	------	------	------	------
100,000	------	------	------	365	------	363	------	------	------	------	------	------
125,000	------	------	------	------	------	365	------	------	------	------	------	------

Days of deficiency in discharge of Yuba River at Smartsville, Calif., during the years ending September 30, 1904–1927—Continued

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column											
	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927
150	......	......	......	......	21	......	......	......	56	3	19	......
200	......	......	36	44	63	5	......	......	89	15	27	9
300	27	45	98	72	118	42	50	19	124	37	100	62
400	85	74	166	103	142	64	78	67	179	73	157	96
500	113	99	203	133	166	85	105	89	208	96	185	104
600	124	121	217	170	193	105	126	115	241	118	196	113
800	134	129	224	193	231	119	148	130	279	144	218	123
1,000	154	150	230	214	241	122	180	138	309	178	228	141
1,200	161	165	235	223	247	128	185	143	326	192	231	152
1,400	169	175	248	230	251	130	190	154	339	202	234	160
1,600	172	199	254	235	255	133	193	169	348	208	236	163
1,800	176	211	258	238	268	135	195	189	350	216	241	165
2,000	177	212	264	243	271	136	200	206	354	219	253	166
2,500	190	220	278	248	287	139	212	247	363	235	264	175
3,000	197	240	286	258	296	145	221	268	364	255	285	186
3,500	207	251	300	266	310	158	226	282	364	269	305	197
4,000	215	264	312	279	317	175	244	295	364	288	311	204
5,000	223	279	339	296	349	221	265	315	364	307	329	234
6,000	230	294	352	308	355	273	272	327	365	330	341	256
7,000	251	309	357	335	360	310	290	344	365	341	346	283
8,000	290	327	359	346	362	333	294	351	365	348	352	305
10,000	335	346	363	354	364	354	321	358	366	359	357	324
12,000	352	351	363	361	364	359	338	361	......	360	358	338
15,000	355	358	365	362	365	363	354	362	......	360	359	348
20,000	363	362	......	363	366	364	364	364	......	362	364	358
30,000	366	364	......	365	......	365	365	365	......	363	365	364
40,000	......	365	......	......	......	......	......	......	......	365	......	364
50,000	......	......	......	......	......	......	......	......	......	......	......	365
60,000	......	......	......	......	......	......	......	......	......	......	......	......
75,000	......	......	......	......	......	......	......	......	......	......	......	......
100,000	......	......	......	......	......	......	......	......	......	......	......	......
125,000	......	......	......	......	......	......	......	......	......	......	......	......

Days of deficiency in discharge of Bear River near Van Trent, Calif., during the years ending September 30, 1905–1927

[Drainage area, 263 square miles]

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column											
	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916
5	......	......	......	......	......	......	......	......	......	......	......	......
10	......	7	......	......	......	......	......	20	6	......	......	......
20	7	81	15	......	2	24	......	90	81	11	......	......
35	69	147	58	61	43	95	61	128	124	32	1	......
50	88	163	101	139	134	132	128	161	143	43	13	1
100	98	180	149	162	176	175	199	229	187	81	72	13
150	146	187	156	180	214	191	212	248	254	142	109	84
200	164	191	161	197	236	202	223	284	289	190	149	138
250	192	196	181	220	244	216	236	321	310	207	182	166
300	203	200	191	239	248	220	242	329	324	225	204	192
400	234	215	215	293	258	247	255	350	346	241	239	234
500	264	234	226	308	279	272	272	357	353	251	254	253
600	283	253	234	327	291	309	274	359	356	261	267	262
700	305	269	243	344	294	323	276	361	358	277	288	266
800	314	277	255	347	302	335	284	363	360	293	304	275
1,000	331	295	282	355	309	344	311	365	360	314	312	283
1,200	345	307	297	359	315	346	319	366	360	319	319	286
1,400	352	317	303	361	320	349	327	......	363	327	325	298
1,600	352	323	316	362	330	355	331	......	363	332	330	310
1,800	353	327	321	364	336	357	334	......	363	335	334	315

Days of deficiency in discharge of Bear River near Van Trent, Calif., during the years ending September 30, 1905–1927—Continued

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column											
	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916
2,000	354	333	327	364	339	358	335	------	364	336	339	323
2,500	360	342	339	366	343	359	341	------	364	343	345	330
3,000	361	348	345	------	350	362	350	------	364	345	348	339
3,500	361	350	345	------	350	364	351	------	364	347	353	346
4,000	361	351	347	------	354	364	353	------	365	350	355	348
5,000	364	355	349	------	356	364	356	------	------	354	358	355
6,000	364	356	355	------	357	364	358	------	------	357	363	356
7,000	365	359	356	------	357	364	358	------	------	358	363	361
8,000	------	359	358	------	358	364	359	------	------	358	363	361
10,000	------	361	359	------	360	365	360	------	------	360	364	364
15,000	------	363	363	------	363	------	364	------	------	364	365	365
20,000	------	365	363	------	363	------	364	------	------	365	------	366
25,000	------	------	363	------	364	------	365	------	------	------	------	------
30,000	------	------	365	------	365	------	------	------	------	------	------	------

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column										
	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927
5	------	22	9	49	13	------	------	140	5	------	5
10	------	47	72	91	34	4	7	140	13	3	9
20	60	110	96	156	101	109	40	161	40	67	56
35	76	191	108	197	114	144	84	243	69	172	86
50	81	213	132	208	124	155	101	310	93	188	112
100	90	241	183	274	144	180	133	353	187	242	159
150	145	266	203	303	167	203	145	362	222	250	207
200	187	295	244	327	180	212	169	362	235	257	224
250	207	309	254	333	196	224	182	364	253	268	237
300	227	310	272	339	204	228	205	364	256	274	241
400	253	323	281	345	219	237	233	365	274	302	254
500	277	329	282	349	230	248	248	365	285	320	268
600	294	336	293	351	241	259	266	365	298	327	279
700	308	341	302	352	252	272	292	365	314	332	294
800	323	346	307	357	266	279	309	366	321	336	308
1,000	336	354	335	358	281	303	323	------	337	337	320
1,200	343	356	342	360	302	327	337	------	351	339	329
1,400	349	358	344	360	321	335	344	------	356	343	353
1,600	351	359	348	360	332	342	348	------	358	346	339
1,800	353	360	352	361	342	345	351	------	360	350	342
2,000	354	362	355	362	346	350	355	------	360	352	345
2,500	355	362	359	364	353	353	357	------	360	356	346
3,000	358	364	360	365	355	353	357	------	362	359	347
3,500	358	364	362	365	359	355	360	------	363	360	353
4,000	359	364	362	365	359	357	360	------	363	361	353
5,000	361	365	362	365	361	359	363	------	364	364	357
6,000	361	------	362	365	362	361	364	------	364	365	358
7,000	361	------	362	366	363	362	364	------	364	------	359
80,00	362	------	363	------	363	362	364	------	364	------	361
10,000	364	------	364	------	363	364	364	------	364	------	361
15,000	365	------	364	------	365	364	364	------	365	------	364
20,000	------	------	365	------	------	365	364	------	------	------	364
25,000	------	------	------	------	------	------	365	------	------	------	365
30,000	------	------	------	------	------	------	------	------	------	------	------

Days of deficiency in discharge of American River at Fairoaks, Calif., during the years ending September 30, 1906–1927

[Drainage area, 1,910 square miles]

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column										
	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916
100	-	-	8	6	-	-	10	2	4	-	-
150	39	-	42	21	-	-	13	5	18	1	-
200	62	-	51	42	33	-	42	52	53	8	23
300	92	25	56	70	63	16	45	81	73	66	85
400	107	33	65	101	72	71	133	104	93	97	102
600	138	64	73	119	108	115	159	146	126	133	128
800	146	79	130	138	140	140	194	176	139	153	144
1,000	152	97	154	142	146	145	219	190	146	172	150
1,200	153	113	163	156	148	148	232	216	151	183	154
1,500	161	125	178	167	157	158	242	240	158	189	160
2,000	165	136	220	172	163	165	273	262	165	195	167
2,500	179	148	245	177	168	171	285	277	171	203	173
3,000	186	160	272	178	173	174	309	286	175	214	182
3,500	195	172	295	181	181	177	312	292	183	222	189
4,000	197	176	311	182	195	188	317	297	192	236	193
5,000	201	188	339	192	206	198	326	311	205	252	204
6,000	206	191	356	220	228	206	336	330	217	273	215
7,000	219	204	364	239	247	211	341	341	243	292	220
8,000	229	228	365	269	267	216	354	352	274	298	238
9,000	239	244	366	281	299	234	359	359	290	308	262
10,000	251	261	-	298	323	241	364	361	305	314	282
12,000	278	276	-	329	341	259	366	365	327	330	319
14,000	305	310	-	338	350	286	-	-	345	343	345
16,000	318	327	-	342	353	305	-	-	350	351	356
20,000	345	347	-	347	359	331	-	-	355	355	363
25,000	358	351	-	350	362	355	-	-	356	360	364
30,000	360	354	-	355	362	359	-	-	358	362	365
40,000	363	358	-	360	363	363	-	-	361	364	366
50,000	365	359	-	361	365	363	-	-	363	365	-
60,000	-	360	-	361	-	363	-	-	365	-	-
75,000	-	362	-	362	-	365	-	-	-	-	-
100,000	-	364	-	365	-	-	-	-	-	-	-
125,000	-	365	-	-	-	-	-	-	-	-	-

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column										
	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927
100	1	49	-	1	-	-	-	93	6	-	-
150	7	81	50	59	7	-	-	102	21	12	-
200	13	97	72	112	14	2	-	108	28	49	12
300	38	156	85	135	51	47	33	118	64	87	34
400	56	194	105	146	62	71	53	137	85	105	87
600	93	205	128	191	92	111	96	223	113	195	109
800	120	213	178	225	111	123	117	258	130	217	115
1,000	135	219	200	233	118	129	129	285	147	225	123
1,200	150	225	220	240	119	146	134	300	169	234	137
1,500	165	234	228	245	123	179	141	313	186	237	149
2,000	207	252	240	254	132	194	147	339	204	247	170
2,500	215	265	244	270	142	200	157	354	211	255	176
3,000	224	277	247	278	152	208	187	361	216	283	187
3,500	240	286	254	287	166	220	226	363	223	308	198
4,000	248	295	266	294	176	233	254	363	231	317	202
5,000	266	313	281	310	210	245	270	364	259	329	214
6,000	277	322	295	331	240	257	288	365	280	337	238
7,000	285	332	305	342	273	278	298	365	296	347	263
8,000	294	344	314	352	299	285	312	365	306	351	283
9,000	308	356	322	356	312	299	327	365	318	355	300

Days of deficiency in discharge of American River at Fairoaks, Calif., during the years ending September 30, 1906–1927—Continued

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column										
	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927
10,000	320	360	339	360	341	303	332	365	330	359	310
12,000	337	364	351	365	355	321	353	366	346	360	326
14,000	349	365	357	365	361	331	358	------	353	362	336
16,000	357	------	361	365	363	339	361	------	359	363	346
20,000	360	------	364	366	364	353	362	------	362	364	356
25,000	363	------	364	------	364	365	364	------	363	365	361
30,000	364	------	364	------	364	------	365	------	364	------	362
40,000	365	------	364	------	365	------	------	------	364	------	363
50,000	------	------	365	------	------	------	------	------	364	------	365
60,000	------	------	------	------	------	------	------	------	364	------	------
75,000	------	------	------	------	------	------	------	------	365	------	------
100,000	------	------	------	------	------	------	------	------	------	------	------
125,000	------	------	------	------	------	------	------	------	------	------	------

Days of deficiency in discharge of Cache Creek at Yolo, Calif., during the years ending September 30, 1904–1927

[Drainage area, 1,230 square miles]

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column											
	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915
0	50	8	94	55	60	94	82	111	242	236	82	22
5	50	21	104	66	84	110	97	136	255	246	91	37
10	50	23	104	71	96	118	130	156	273	250	99	47
20	50	26	106	79	114	122	151	162	276	268	124	52
35	50	31	109	84	122	128	166	164	277	277	136	64
50	71	33	114	97	138	130	170	168	283	282	142	96
75	93	51	122	102	174	136	174	171	290	289	148	119
100	102	77	128	102	187	143	180	184	302	302	150	129
150	117	110	146	108	193	155	188	192	323	308	161	153
200	126	155	163	119	211	163	193	204	334	315	184	175
250	164	165	171	125	219	172	220	208	341	323	186	181
300	181	171	181	139	225	181	231	215	346	326	187	192
400	205	183	193	158	238	192	245	228	352	338	191	212
500	220	199	197	176	252	201	256	243	360	348	207	216
600	228	210	206	187	264	213	266	253	364	354	214	223
700	239	216	211	195	276	220	288	257	365	355	218	227
800	243	222	220	203	290	229	307	271	365	356	221	230
1,000	250	234	244	223	307	239	340	296	366	357	238	240
1,200	258	260	264	241	326	247	351	309	------	358	247	245
1,400	265	276	276	255	345	254	356	323	------	358	256	258
1,700	273	310	287	283	351	263	358	335	------	361	269	273
2,000	282	322	308	299	354	270	360	342	------	362	286	284
2,500	302	348	325	311	358	279	361	349	------	364	293	297
3,000	316	354	337	322	361	286	363	351	------	364	302	306
4,000	330	358	348	335	364	307	364	354	------	365	320	323
5,000	350	360	353	343	365	316	365	357	------	------	330	334
6,000	355	362	358	352	365	328	------	358	------	------	337	343
8,000	360	362	361	358	366	347	------	361	------	------	346	358
10,000	363	364	363	358	------	356	------	361	------	------	353	361
15,000	366	365	364	364	------	362	------	364	------	------	361	363
20,000	------	------	365	365	------	364	------	365	------	------	365	365
25,000	------	------	------	------	------	365	------	------	------	------	------	------

Days of deficiency in discharge of Cache Creek at Yolo, Calif., during the years ending September 30, 1904–1927—Continued

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column											
	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927
0	39	97	122	169	363	180	230	192	300	175	235	173
5	95	123	149	182	363	183	230	204	338	180	237	178
10	138	132	166	250	363	187	234	214	338	184	237	181
20	152	163	257	277	363	199	240	220	339	196	248	184
35	177	196	309	284	363	211	258	226	348	213	269	189
50	187	216	317	287	363	221	268	233	353	221	272	192
75	201	237	324	291	363	229	276	240	358	236	280	195
100	203	242	328	293	363	239	282	253	360	246	285	215
150	207	275	334	298	364	243	294	264	362	267	301	223
200	209	286	341	302	364	253	302	290	362	276	311	235
250	212	298	350	308	364	262	312	313	363	287	314	239
300	214	322	353	310	364	272	320	324	363	290	316	243
400	225	335	357	325	364	292	336	334	364	300	322	252
500	237	346	360	333	364	299	339	339	364	306	326	264
600	240	351	361	339	365	304	344	346	365	310	328	268
700	244	352	363	344	365	305	347	349	366	318	331	272
800	248	354	363	347	365	308	348	355	------	324	334	274
1,000	256	356	365	354	366	311	353	357	------	328	341	280
1,200	268	358	------	356	------	317	356	358	------	333	344	282
1,400	277	360	------	359	------	319	357	360	------	337	346	286
1,700	283	360	------	359	------	322	359	363	------	343	348	294
2,000	297	361	------	362	------	327	361	364	------	347	350	299
2,500	317	361	------	362	------	340	361	365	------	358	354	303
3,000	334	362	------	363	------	348	364	------	------	361	354	315
4,000	353	362	------	364	------	355	364	------	------	362	359	344
5,000	356	362	------	364	------	357	365	------	------	362	361	351
6,000	359	364	------	364	------	360	------	------	------	363	363	354
8,000	363	364	------	365	------	362	------	------	------	364	363	358
10,000	364	364	------	------	------	364	------	------	------	364	365	360
15,000	365	364	------	------	------	365	------	------	------	365	------	365
20,000	366	365	------	------	------	------	------	------	------	------	------	------
25,000	------	------	------	------	------	------	------	------	------	------	------	------

Days of deficiency in discharge of Putah Creek at Winters, Calif., during the years ending September 30, 1906–1927

[Drainage area, 1,230 square miles]

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column										
	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916
0	------	------	------	------	------	?	38	92	57	------	------
5	------	------	51	52	45	?	99	130	57	------	------
10	44	11	94	97	86	128	120	140	121	61	51
20	115	87	118	136	137	148	175	161	130	92	123
35	178	145	178	156	161	188	234	181	148	124	153
50	187	155	197	164	176	207	261	206	163	147	161
75	189	164	217	192	190	221	293	233	172	156	170
100	191	169	230	202	204	229	317	263	188	170	188
150	203	202	259	233	236	235	335	301	208	194	215
200	206	214	276	241	251	240	340	321	221	205	234
250	221	222	288	246	270	257	346	330	235	211	242
300	242	229	295	250	284	262	348	336	243	224	249
400	260	240	309	259	304	273	351	344	257	249	260
500	274	249	322	267	318	284	356	347	269	261	269
600	284	267	330	271	326	292	358	350	276	268	276
700	290	273	335	278	332	298	359	351	283	276	281
800	294	281	336	284	333	303	361	352	293	286	289
1,000	301	293	340	294	345	313	361	356	300	298	294
1,200	309	304	343	296	347	322	362	356	305	303	304
1,400	315	310	344	299	349	326	364	357	310	311	310

Days of deficiency in discharge of Putah Creek at Winters, Calif., during the years ending September 30, 1906–1927—Continued

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first column										
	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916
1,700	323	321	348	307	354	331	364	357	318	315	317
2,000	329	333	354	311	356	335	364	358	322	319	327
2,500	334	338	357	316	359	341	365	358	330	324	337
3,000	341	340	360	324	360	344	365	359	332	331	342
4,000	347	345	362	334	362	352	365	362	337	342	348
5,000	352	349	364	341	363	354	366	362	341	346	355
6,000	357	352	364	346	363	354	-----	362	343	354	356
8,000	361	353	364	351	363	357	-----	364	351	356	360
10,000	361	360	365	354	363	360	-----	365	353	358	360
15,000	362	362	366	358	365	363	-----	-----	356	363	363
20,000	363	362	-----	362	-----	363	-----	-----	362	364	363
30,000	365	365	-----	365	-----	365	-----	-----	363	364	364
40,000	-----	-----	-----	-----	-----	-----	-----	-----	365	365	365
50,000	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	366

Discharge in second-feet	Number of days when discharge was equal to or less than that shown in first colnum										
	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927
0	-----	86	120	178	112	155	114	208	94	120	69
5	78	190	174	194	138	184	123	273	113	150	116
10	95	212	185	202	148	184	130	283	118	159	131
20	168	251	204	270	158	200	150	296	131	220	147
35	177	269	227	283	164	219	167	316	145	237	156
50	182	277	239	289	172	229	184	329	153	246	162
75	205	285	253	301	188	251	201	342	167	250	177
100	227	297	261	320	201	263	211	348	190	256	185
150	260	306	285	338	209	276	233	353	206	275	197
200	275	318	295	343	222	286	253	356	233	292	216
250	298	324	302	351	228	292	266	357	262	300	229
300	309	328	304	355	232	297	274	359	280	304	237
400	323	332	309	357	260	315	297	360	299	312	253
500	329	337	317	359	276	322	308	361	311	319	266
600	334	342	324	359	286	325	314	362	320	321	276
700	337	346	329	360	305	332	325	362	326	323	285
800	341	349	331	361	311	336	332	363	331	327	293
1,000	346	351	335	363	319	338	340	364	336	334	308
1,200	347	358	340	363	324	342	343	364	341	338	320
1,400	351	359	342	364	330	347	348	364	343	340	324
1,700	353	360	345	364	334	349	349	365	349	342	329
2,000	355	362	350	364	341	350	352	365	350	346	336
2,500	356	364	354	365	344	354	355	365	352	348	343
3,000	356	364	355	366	346	355	361	365	354	349	345
4,000	360	365	358	-----	353	355	361	365	357	354	347
5,000	361	-----	359	-----	355	359	361	365	358	354	351
6,000	362	-----	359	-----	356	361	361	365	359	355	354
8,000	362	-----	361	-----	359	365	362	365	361	359	359
10,000	363	-----	361	-----	361	-----	363	365	362	362	360
15,000	363	-----	363	-----	362	-----	364	366	363	363	362
20,000	363	-----	364	-----	363	-----	364	-----	364	365	365
30,000	364	-----	365	-----	365	-----	365	-----	365	-----	-----
40,000	365	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
50,000	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

MONTHLY-DISCHARGE RECORDS

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.

Sacramento River at Castella

[Drainage area, 257 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	-------	385	552	472	648	1,550	2,060	1,630	1,030	362	238	223	-------
1911–12	253	253	239	637	464	610	751	1,610	770	297	216	274	532
1912–13	208	599	358	402	541	639	1,390	1,290	518	236	206	200	548
1913–14	200	321	590	2,050	1,480	2,090	2,460	2,050	970	376	238	218	1,090
1914–15	290	197	223	367	1,890	2,060	2,820	2,520	1,650	626	299	257	1,090
1915–16	249	296	826	546	2,090	2,700	1,790	1,250	798	462	230	208	949
1916–17	217	246	323	241	799	459	967	937	447	189	141	118	420
1917–18	-------	-------	-------	-------	-------	971	-------	-------	-------	-------	-------	-------	-------
1918–19	-------	-------	-------	739	1,170	-------	-------	-------	-------	115	115	118	-------
1919–20	-------	-------	-------	239	219	411	671	587	297	152	111	118	-------
1920–21	184	1,030	668	1,210	1,210	1,880	1,490	1,490	830	295	198	197	888
1921–22	183	208	306	318	496	650	1,200	1,610	597	193	143	143	504
Av.	223	393	454	656	1,000	1,270	1,560	1,500	791	300	194	189	753

Sacramento River at Antler

[Drainage area, 461 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	-------	-------	1,080	1,660	2,090	3,680	3,080	2,210	1,800	430	245	245	-------
1911–12	278	310	289	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
1918–19	-------	-------	-------	-------	-------	-------	-------	2,150	579	274	212	225	-------
1919–20	247	239	570	362	334	859	1,660	1,000	380	212	153	156	514
1920–21	233	2,700	2,600	4,020	3,310	3,730	2,430	2,290	1,200	341	247	232	1,940
1921–22	232	264	620	586	1,760	1,650	2,150	2,300	807	263	207	163	911
1922–23	317	426	708	863	768	832	2,530	1,290	500	255	181	184	736
1923–24	228	216	241	346	905	320	290	184	137	111	110	114	264
1924–25	389	1,210	885	801	5,170	1,880	4,320	1,880	692	302	222	416	1,480
1925–26	407	521	752	655	3,210	1,230	2,750	776	357	209	183	196	918
1926–27	227	4,050	2,710	2,020	4,750	2,250	3,280	1,720	835	296	210	210	1,850
Av.	284	1,100	1,050	1,260	2,480	1,830	2,500	1,580	729	269	197	214	1,080

Sacramento River at Kennett

[Drainage area, 6,600 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1925–26	-------	-------	4,050	3,850	15,300	6,470	8,660	4,360	3,210	2,880	2,720	2,7[illegible]	-------
1926–27	3,170	10,500	10,700	11,100	24,000	13,700	17,100	8,900	5,790	3,950	3,350	3,350	9,530

Sacramento River near Red Bluff[a]

[Drainage area, 9,300 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1894–95	-------	-------	-------	-------	-------	-------	-------	24,500	11,300	7,200	5,760	6,190	-------
1895–96	5,580	5,810	7,330	45,300	14,400	22,100	23,600	27,900	13,300	7,230	5,910	5,710	15,300
1896–97	5,840	11,000	20,800	14,400	35,700	21,600	22,600	18,700	8,050	6,340	5,610	5,480	14,300
1897–98	5,750	6,270	8,240	6,130	12,500	9,600	6,820	6,630	6,670	4,900	4,570	4,570	6,890
1898–99	4,850	4,980	4,980	13,800	7,100	21,100	11,000	7,330	6,660	4,970	4,560	4,550	7,990
1899–1900	5,580	14,800	14,600	29,600	11,500	23,300	12,200	9,840	5,970	4,770	4,380	4,550	11,880
1900–1901	6,840	8,560	15,800	21,000	34,200	20,600	11,000	10,100	6,080	4,900	4,420	4,480	12,000
1901–2	4,750	8,170	12,400	5,860	69,200	27,000	21,600	17,300	9,380	5,440	4,890	4,210	15,500
1902–3	5,170	18,900	17,000	25,100	16,600	31,200	18,300	10,300	6,240	4,820	4,160	4,020	13,500
1903–4	4,570	21,400	12,500	10,700	46,200	73,300	38,800	24,500	11,900	8,160	5,990	6,220	22,000
1904–5	10,900	8,800	13,600	31,500	26,400	30,700	18,200	12,300	8,140	5,740	4,960	4,770	14,700
1905–6	4,860	5,310	5,760	20,400	23,800	42,300	25,900	19,000	17,600	8,060	5,970	5,680	15,400
1906–7	5,540	6,200	15,000	21,500	45,400	55,700	32,200	15,500	12,200	7,550	6,260	5,830	19,100
1907–8	5,870	6,200	11,600	21,000	23,200	15,000	11,900	10,700	7,560	5,570	4,830	4,710	10,700
1908–9	5,230	6,060	6,370	72,900	63,900	25,500	19,500	13,800	9,890	6,840	5,710	5,560	20,100
1909–10	6,250	12,300	16,100	16,200	21,800	28,900	16,000	9,310	6,280	5,320	4,860	4,940	12,400
1910–11	5,170	6,510	10,200	17,100	23,800	33,300	24,900	16,200	10,700	6,550	5,380	5,170	13,700
1911–12	5,410	5,520	5,550	11,800	10,100	14,900	11,500	15,600	8,820	5,620	4,810	5,620	8,770
1912–13	5,000	9,910	8,410	17,500	10,800	11,400	16,600	11,700	7,180	5,540	4,880	4,460	9,440
1913–14	4,540	7,390	15,700	66,100	35,500	24,700	27,600	15,700	10,300	6,720	5,350	5,200	18,700
1914–15	5,910	5,750	7,800	20,000	56,500	28,200	26,500	27,300	12,400	7,030	5,410	5,080	17,100
1915–16	5,160	5,920	15,700	26,500	39,500	28,900	16,700	11,000	7,950	6,680	5,080	4,960	14,400
1916–17	5,230	5,630	8,350	7,780	20,200	12,400	21,900	13,100	7,390	4,950	4,400	4,330	9,550
1917–18	4,390	5,110	6,710	5,800	10,300	17,200	12,700	6,510	4,560	3,790	3,700	4,450	7,080
1918–19	5,680	5,650	5,890	13,400	29,200	21,800	17,500	9,420	5,150	4,290	3,950	4,040	10,400
1919–20	4,460	4,260	5,760	4,910	4,780	8,380	11,300	5,870	4,170	3,590	3,370	3,440	5,380
1920–21	4,060	20,600	25,200	34,300	28,000	25,600	15,200	11,800	7,550	4,800	4,100	4,070	15,400
1921–22	4,320	4,740	8,700	6,810	17,100	14,100	17,500	13,500	7,040	4,290	3,820	3,710	8,730
1922–23	4,560	5,580	10,400	10,800	7,730	6,630	14,400	6,910	5,150	3,920	3,460	3,620	6,910
1923–24	4,170	4,080	4,260	4,750	8,680	4,430	4,010	3,250	2,970	2,900	2,900	2,960	4,100
1924–25	3,900	7,260	7,120	7,300	44,800	12,600	21,000	10,300	6,200	3,650	3,490	3,770	10,700
1925–26	4,020	4,480	5,470	6,860	28,400	8,670	13,500	5,980	3,760	3,190	3,120	3,090	7,390
1926–27	3,720	14,300	18,900	19,300	46,200	21,700	24,800	11,800	6,890	4,480	3,780	3,770	14,700
Av.	5,230	8,360	11,000	19,900	27,300	23,200	18,400	13,000	8,040	5,450	4,660	4,640	12,300

[a] Previous to February, 1902, station was maintained at Jellys Ferry, 12 miles above Red Bluff.

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
Sacramento River at Butte City													
1920–21	-------	-------	-------	-------	-------	-------	-------	-------	6, 760	3, 780	2, 990	3, 150	-------
1921–22	-------	-------	-------	-------	-------	-------	-------	-------	-------	3, 230	2, 660	2, 890	-------
1922–23	4, 740	-------	-------	-------	-------	-------	-------	-------	-------	3, 260	2, 710	3, 330	-------
1923–24	4, 410	4, 310	4, 590	5, 070	-------	-------	-------	-------	1, 780	1, 670	1, 790	2, 300	-------
1924–25	3, 630	9, 550	7, 980	7, 810	-------	-------	-------	-------	-------	2, 560	2, 230	2, 840	-------
1925–26	4, 070	4, 920	6, 160	-------	-------	-------	-------	-------	2, 440	1, 710	1, 530	2, 420	-------
1926–27	3, 680	-------	-------	-------	-------	-------	-------	-------	-------	3, 430	2, 460	3, 000	-------
Sacramento River at Colusa													
1920–21	-------	-------	-------	-------	-------	-------	-------	11, 100	6, 930	3, 720	2, 720	2, 860	-------
1921–22	4, 030	-------	-------	-------	-------	-------	-------	-------	-------	2, 930	2, 350	2, 680	-------
1922–23	4, 620	-------	-------	-------	-------	-------	-------	-------	-------	3, 170	2, 490	3, 240	-------
1923–24	4, 560	4, 470	4, 650	5, 080	-------	-------	-------	-------	1, 720	1, 620	1, 750	2, 250	-------
1924–25	3, 700	7, 570	7, 860	8, 260	-------	-------	-------	-------	-------	2, 470	2, 110	2, 750	-------
1925–26	4, 010	4, 640	5, 990	-------	-------	-------	-------	-------	2, 090	1, 390	1, 230	2, 250	-------
1926–27	3, 680	-------	-------	-------	-------	-------	-------	-------	-------	3, 140	2, 130	2, 780	-------
Sacramento River at Knights Landing													
1920–21	-------	-------	-------	-------	-------	-------	13, 100	10, 700	-------	-------	-------	-------	-------
1921–22	3, 930	-------	-------	-------	-------	-------	-------	-------	-------	3, 120	2, 520	3, 350	-------
1922–23	5, 380	-------	-------	-------	-------	-------	-------	-------	-------	3, 110	2, 410	3, 670	-------
1923–24	4, 720	4, 510	4, 800	5, 280	-------	-------	-------	-------	1, 390	1, 090	1, 490	2, 310	-------
1924–25	3, 740	7, 460	8, 550	8, 950	-------	-------	-------	-------	-------	2, 470	2, 140	3, 270	-------
1925–26	4, 470	4, 850	6, 130	-------	-------	-------	-------	-------	2, 330	1, 390	1, 480	3, 110	-------
1926–27	4, 010	-------	-------	-------	-------	-------	-------	-------	-------	3, 160	2, 340	3, 320	-------
Sacramento River at Verona													
1925–26	-------	-------	-------	-------	-------	-------	-------	12, 780	3, 745	1, 994	2, 101	4, 523	-------
1926–27	6, 034	-------	-------	-------	-------	-------	-------	-------	15, 900	5, 110	3, 520	4, 850	-------
Sacramento River at Collinsville [b] [Drainage area, 26,200 square miles]													
1878–79	-------	8, 000	9, 000	12, 000	30, 000	110, 000	110, 000	75, 000	45, 000	16, 000	8, 500	6, 500	-------
1879–80	8, 000	7, 500	27, 000	28, 000	21, 000	22, 000	95, 000	135, 000	110, 000	53, 000	18, 000	9, 000	44, 500
1880–81	4, 500	7, 000	20, 000	95, 000	115, 000	77, 000	90, 000	70, 000	25, 000	14, 000	8, 000	6, 500	44, 600
1881–82	7, 000	8, 200	16, 000	24, 000	22, 000	55, 000	90, 000	92, 000	74, 000	17, 000	8, 000	6, 500	35, 000
1882–83	10, 000	14, 000	11, 000	12, 000	17, 000	21, 000	73, 000	80, 000	32, 000	12, 000	7, 000	6, 500	24, 600
1883–84	7, 000	7, 500	7, 400	12, 000	24, 000	80, 000	105, 000	111, 000	90, 000	31, 000	12, 000	7, 500	41, 200
1884–85	8, 000	7, 000	31, 000	90, 000	52, 000	30, 000	29, 000	23, 000	14, 000	6, 500	5, 500	5, 200	25, 100
Pit River near Canby [Drainage area, 1,500 square miles]													
1903–4	-------	-------	-------	135	2, 140	4, 210	1, 680	2, 080	594	135	43	15	-------
1904–5	91	131	188	443	533	479	510	165	151	61. 7	6. 4	5. 6	230
1905–6	45. 4	92. 2	118	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

[b] Data taken from "Physical data and statistics of California," by William Ham. Hall, State engineer, 1886.

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

Pit River near Bieber

[Drainage area, 2,950 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1903–4	-------	-------	-------	238	3,950	7,590	4,210	3,440	542	83	33	16	-------
1904–5	105	165	304	1,040	1,080	1,100	950	166	103	51.8	9.85	1.23	423
1905–6	15.4	91	210	1,280	1,930	4,640	2,590	948	544	251	50.8	23.8	1,050
1906–7	44.5	-------	-------	710	4,190	6,940	2,970	1,130	2,160	323	71.7	51.5	-------
1907–8	113	307	799	861	339	322	77.6	83.3	85.6	68.3	9.3	4.8	256
1913–14	-------	-------	-------	3,500	1,830	2,370	1,440	323	192	75.0	32.6	-------	-------
1921–22	30.6	76.4	103	168	458	1,310	2,890	750	62.9	19.7	5.65	5.17	487
1922–23	7.97	47.6	175	405	373	327	155	12.7	15.9	54.1	15.9	1.05	131
1923–24	48.6	68.0	165	225	665	107	112	14.3	11.7	0	0	0	116
1924–25	6.85	65.5	47.6	510	1,380	267	100	57.4	125	29.2	4.71	5.47	209
1925–26	41.6	103	225	182	979	360	91.1	31.6	15.7	6.74	4.25	.11	165

Pit River at Fall River Mills

[Drainage area, 4,150 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1921–22	1,340	1,400	1,460	1,450	1,600	2,770	4,700	2,520	1,520	1,350	1,310	1,220	1,890
1922–23	-------	-------	-------	-------	-------	404	229	106	140	132	136	131	-------
1923–24	158	144	210	156	586	199	294	148	181	122	116	133	202
1924–25	134	141	163	411	1,530	320	169	107	211	89.9	66.4	81.3	277
1925–26	114	186	272	249	1,050	425	210	108	91.4	69.2	59.5	64.6	236
1926–27	75.5	159	259	383	1,610	1,770	1,740	458	314	171	106	116	589

Pit River near Pecks Bridge

[Drainage area, 4,620 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1921–22	-------	-------	-------	-------	-------	-------	-------	3,550	2,400	2,110	2,040	2,010	-------
1922–23	2,130	2,190	2,400	2,650	2,500	2,490	2,440	2,150	2,120	1,990	1,910	1,990	2,250
1923–24	2,120	2,110	2,130	2,100	2,560	2,130	2,040	1,740	1,700	1,740	-------	-------	-------

Pit River at Lindsay Flat

[Drainage area, 4,860 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1922–23	-------	2,150	2,350	2,650	2,480	2,460	2,450	2,130	2,007	1,940	1,860	1,940	-------
1923–24	2,040	2,080	2,090	2,050	2,570	2,110	2,030	1,820	1,780	1,750	1,750	1,770	1,990
1924–25	1,840	1,940	1,920	2,140	3,980	2,340	2,340	2,070	1,880	1,330	98.9	80.8	1,820
1925–26 [c]	96.2	101	138	129	1,270	784	904	70.3	62.2	50.5	45.2	42.2	300
1926–27 [c]	48.4	58.1	71.9	92.9	955	872	1,970	552	-------	-------	-------	-------	-------

d Formerly known as Henderson.

Flow through Pit No. 3 power house at Lindsay Flat

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1925–26	1,793	1,878	1,917	1,795	1,954	1,633	1,448	1,756	1,702	1,700	1,669	1,697	1,744
1926–27	1,770	1,900	2,100	2,100	2,880	3,180	2,300	2,530	2,270	1,920	1,730	1,730	2,200

Pit River at Big Bend [d]

[Drainage area, 4,920 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	-------	-------	3,820	3,530	5,290	8,260	7,380	5,130	3,760	3,220	2,990	2,970	-------
1911–12	3,020	3,190	3,100	3,530	3,400	3,490	3,360	3,690	3,010	2,910	2,710	2,700	3,170
1912–13	2,780	3,030	3,000	2,930	3,090	3,940	4,950	3,490	2,870	2,830	2,760	2,560	3,180
1913–14	2,610	2,710	3,040	7,680	5,840	7,080	6,250	4,280	3,370	2,950	2,840	2,810	4,280
1914–15	2,910	2,900	2,880	2,900	4,550	4,230	4,390	4,370	3,160	2,820	2,560	2,620	3,350
1915–16	2,680	2,880	3,200	3,230	7,290	6,640	5,050	3,850	3,510	2,940	2,660	2,610	3,860
1916–17	2,840	2,920	2,900	2,750	3,570	4,380	10,300	5,540	3,450	2,800	2,650	2,650	3,890
1917–18	2,630	2,780	2,850	2,750	2,970	3,920	3,500	2,670	2,400	2,330	2,310	2,430	2,790
1918–19	2,600	2,600	2,590	2,850	4,140	4,460	5,430	3,120	2,410	2,290	2,240	2,280	3,070
1919–20	2,390	2,440	2,500	2,440	2,500	2,900	3,180	2,320	2,150	2,150	2,140	2,150	2,440
1920–21	2,270	2,880	3,360	5,020	5,600	6,000	4,140	3,580	3,030	2,440	2,250	2,250	3,560
1921–22	2,330	2,440	2,430	2,380	2,730	4,110	6,280	4,290	2,800	2,310	2,240	2,220	3,040
1922–23	2,250	2,320	2,580	2,850	2,590	2,590	2,790	2,340	2,270	2,080	1,970	2,070	2,390
1923–24	2,190	2,210	2,260	2,200	2,770	2,250	2,140	1,850	1,810	1,850	1,840	1,900	2,100
1924–25	2,030	2,140	2,080	2,380	4,740	2,770	2,840	2,410	2,140	1,610	1,860	1,810	2,380
1925–26	2,000	2,180	2,250	2,070	3,680	2,640	2,520	1,940	1,790	1,750	1,770	1,760	2,190
1926–27	1,850	2,060	2,370	2,520	4,940	5,230	5,340	3,650	2,790	2,200	1,930	1,990	3,060
Av.	2,460	2,600	2,780	3,180	4,100	4,410	4,700	3,440	2,750	2,440	2,340	2,340	3,050

[c] To obtain the total flow of Pit River for 1925 to 1927 the flow through Pit River No. 3 power house should be added.

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

Pit River near Ydalpom

[Drainage area, 5,260 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	------	------	5,090	5,410	8,420	12,200	10,600	6,600	4,500	3,550	3,150	3,080	------
1911–12	3,170	3,300	3,220	4,760	4,560	5,270	4,440	5,270	3,680	3,140	2,880	3,000	3,890
1912–13	2,810	3,730	3,820	5,490	4,550	5,560	6,980	4,680	3,470	3,170	2,960	2,740	4,160
1913–14	2,740	3,470	4,600	17,500	10,500	9,910	10,100	5,530	4,150	3,470	2,860	2,800	6,450
1914–15	3,060	3,120	3,480	5,420	12,400	7,910	7,380	7,640	4,130	3,200	2,830	2,740	5,230
1915–16	2,800	3,320	5,030	7,680	14,600	10,400	6,580	4,450	3,830	3,350	2,750	2,740	5,590
1916–17	2,920	3,080	3,660	3,240	7,340	6,180	13,300	6,490	3,870	2,910	2,750	2,820	4,850
1917–18	2,780	3,100	3,650	3,330	4,800	7,830	4,870	3,500	2,570	2,470	2,450	2,600	3,660
1918–19	2,990	2,930	2,860	4,570	9,590	8,440	7,750	4,100	2,810	2,430	2,290	2,360	4,390
1919–20	2,570	2,510	3,380	2,690	2,680	3,930	5,550	2,850	2,340	2,270	2,200	2,190	2,930
1920–21	2,490	5,460	7,980	9,720	10,700	8,890	5,830	4,450	3,410	2,780	2,500	2,480	5,530
1921–22	2,530	2,700	3,400	2,930	5,990	7,220	8,690	6,170	3,990	2,770	2,480	2,480	4,260
1922–23	2,650	3,110	3,330	3,810	3,340	3,280	5,000	3,310	2,750	2,430	2,170	2,250	3,120
1923–24	------	------	------	------	------	------	------	2,000	1,920	1,920	1,900	1,940	------
1924–25	2,150	2,810	2,510	3,200	11,700	4,690	5,780	3,550	2,790	1,870	2,020	2,050	3,700
1925–26	2,200	2,460	2,700	2,610	7,590	3,620	3,700	2,400	2,010	1,900	1,840	1,850	2,870
1926–27	1,970	3,780	4,030	5,460	12,300	8,450	8,890	4,930	3,310	2,450	2,160	2,120	4,930
Av	2,660	3,260	3,920	5,490	8,190	7,110	7,220	4,580	3,270	2,710	2,480	2,480	4,370

South Fork of Pit River near Ivy

[Drainage area, 91 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1903–4	------	------	------	30	76	82	90	372	234	85	46	35	------
1904–5	47	41	39	38	44	66	90	150	120	34	25	15	59.1
1905–6	14	20	30	------	------	------	------	------	------	------	------	------	------

West Valley Creek near Likely

[Drainage area, 140 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1903–4	------	------	------	20	100	70	75	115	50	20	20	12	------
1904–5	20	20	30	23.5	23.6	32	31.2	24.8	29.3	16.8	14.3	18.7	23.7
1905–6	14.4	16.1	25	------	------	------	------	------	------	------	------	------	------

Pine Creek near Alturas

[Drainage area, 31 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1917–18	------	------	------	------	------	------	------	------	19.8	------	------	------	------
1918–19	5.90	6.37	5.23	5.62	6.98	23.9	22.5	41.0	23.2	11.6	8.87	8.32	14.2
1919–20	9.32	9.98	9.63	9.71	9.09	13.0	22.2	38.6	34.0	15.7	11.3	9.38	16.0
1920–21	9.32	12.2	18.8	17.6	19.9	19.6	22.7	49.8	66.9	30.4	15.9	13.7	24.7
1921–22	12.8	12.7	12.4	10.4	10.8	20.2	25.3	42.9	44.0	16.5	11.9	9.75	19.2
1922–23	9.82	10.8	11.0	12.2	11.0	11.3	13.1	23.0	26.7	21.7	14.1	11.8	14.7
1923–24	15.5	14.0	13.6	13.1	15.2	13.0	24.6	36.4	15.8	9.08	7.31	6.45	15.3
1924–25	7.43	8.50	10.6	11.4	13.6	11.9	22.2	45.4	40.2	21.5	13.5	13.1	18.3
1925–26	13.9	14.2	17.6	15.0	18.0	15.5	29.2	37.5	23.2	12.5	11.0	10.6	18.2
1926–27	12.7	11.8	11.8	12.0	20.8	18.1	25.4	51.1	59.2	31.0	18.4	15.1	23.9
Av	10.7	11.2	12.3	11.9	13.9	16.3	23.0	40.6	35.3	18.9	12.5	10.9	18.3

Ash Creek at Adin

[Drainage area, 260 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1903–4	------	------	------	------	------	------	550	505	75.8	39.8	30.1	33.2	------
1904–5	31.6	31.8	55.5	107	158	214	176	56.7	32.8	15.5	20.5	27.2	77.2
1905–6	31.1	37.5	34.0	------	------	------	------	------	------	------	------	------	------

Fall River at Fall River Mills

[Drainage area, 600 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1911–12	------	------	------	------	1,460	1,470	1,480	1,480	1,440	1,430	1,430	1,470	------
1912–13	1,420	1,460	1,440	1,380	1,430	1,410	1,450	1,500	1,370	1,360	1,330	1,280	1,400

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

Bear Creek near Dana

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1921–22	0.72	1.29	2.90	4.16	6.68	36.2	90.5	277	62.8	3.20	0.92	0.40	40.9
1922–23	1.35	2.52	3.85	1.50	1.50	9.50	109	86.6	18.1	3.04	1.22	.04	19.9
1923–24	.65	.96	1.10	2.24	23.0	1.47	5.72	.10	0	0	0	0	2.84
1924–25	0	11.7	0	10.8	148	67.8	148	71.1	14.2	0	0	0	38.4
1925–26	0	.93	10.7	2.00	54.5	62.6	65.9	8.64	------	------	------	------	------

Hat Creek near Hat Creek

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1925–26	------	------	------	------	------	------	------	------	------	------	91.7	90.5	------
1926–27	93.6	114	115	108	112	116	124	181	197	137	107	106	126

Hat Creek at Hawkins ranch

[Drainage area, 265 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	------	------	------	------	------	------	------	------	------	------	------	184	------
1911–12	207	213	198	193	184	178	178	183	197	174	170	206	190
1912–13	202	205	157	146	133	137	146	181	176	125	------	------	------

Hat Creek at Wilcox ranch, near Cassel

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1921–22	129	136	121	118	118	113	125	162	211	121	116	117	132

Hat Creek at Hat Creek

[Drainage area, 326 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	------	144	163	149	144	137	153	116	194	167	79.4	109	------
1911–12	158	164	161	170	160	153	129	117	128	85.8	86.3	132	137
1912–13	139	149	134	131	128	126	131	103	108	76.8	83.4	55.3	114

Hat Creek at Carbon

[Drainage area, 384 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1921–22	530	560	590	547	563	582	548	475	543	479	477	471	530

Rising River near Cassel

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	------	------	------	------	------	------	------	------	------	------	------	462	------
1911–12	446	420	412	400	374	352	332	329	362	364	370	418	328
1912–13	447	432	381	349	326	306	298	292	344	349	340	335	350
1920–21	------	------	------	------	------	------	297	294	306	296	283	282	------
1921–22	290	300	309	297	294	306	302	272	306	304	309	287	298

Burney Creek above Burney

[Drainage area, 44 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1921–22	11.0	13.0	16.5	15.8	17.8	17.2	52.4	223	79.4	15.5	11.6	10.3	40.5
1922–23	12.6	------	------	------	------	------	------	------	------	------	------	------	------

Burney Creek near Burney

[Drainage area, 92 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	------	------	------	------	------	------	------	------	------	------	------	18.8	------
1911–12	23.1	24.3	21.5	31.7	54.8	54.7	62.1	98.3	42.3	16.7	14.6	17.7	38.4
1912–13	17.9	47.9	37.5	44.9	25.4	38.1	124	142	57.2	28.4	------	------	------
1920–21	------	------	------	------	------	------	179	171	51.5	17.2	15.3	14.6	------
1921–22	16.5	18.9	------	------	------	------	------	------	------	------	------	------	------

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

Burney Creek at Burney Falls

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1920–21	-------	-------	-------	-------	-------	-------	274	242	174	165	159	152	-------
1921–22	148	148	149	148	177	251	205	303	200	160	154	152	183
1922–23	149	149	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

Kosk Creek near Big Bend[d]

[Drainage area, 51.9 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	30.9	55.1	253	-------	-------	-------	1,020	625	230	88.9	51.8	42.2	-------
1911–12	33.5	33.0	30.3	-------	-------	-------	221	378	174	69.9	40.7	40.2	-------
1912–13	39.2	103	91.0	111	177	181	469	322	121	73.1	51.1	34.4	147
1914–15	47.2	27.9	20.9	93.7	691	635	828	868	211	87.0	56.5	37.4	297

Montgomery Creek at Montgomery Creek

[Drainage area, 42 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	20.4	-------
1911–12	21.7	21.7	21.4	66.9	53.3	63.2	58.7	76.8	47.7	24.8	18.9	23.3	41.5
1912–13	18.8	51.6	42.8	56.3	58.1	61.8	128	94.1	45.2	26.5	17.9	14.4	51.1

Squaw Creek near Ydalpom

[Drainage area, 112 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1911–12	-------	42.0	38.0	491	351	621	359	499	211	67.7	30.1	48.2	-------
1912–13	39.9	263	266	963	404	365	510	224	119	44.0	-------	-------	-------

McCloud River near Gregory

[Drainage area, 608 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1902–3	1,350	2,830	2,570	2,880	2,040	3,740	2,810	1,910	1,540	1,370	1,320	1,300	2,140
1903–4	1,320	3,430	1,830	1,650	6,000	9,390	5,470	3,760	2,220	1,750	1,570	1,510	3,320
1904–5	2,700	1,640	1,840	3,890	3.280	4,070	2,490	2,110	1,600	1,490	1,400	1,370	2,320
1905–6	1,370	1,350	1,370	2,540	2,600	4,180	3,110	3,080	3,480	1,690	1,480	1,400	2,300
1906–7	1,380	1,400	2,070	2,880	5,510	6,000	4,100	2,290	1,840	1,550	1,440	1,400	2,660
1907–8	1,380	1,370	1,660	2,300	2,280	2,150	2,170	1,880	1,570	-------	-------	-------	-------

McCloud River at Baird

[Drainage area, 665 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	-------	-------	-------	2,160	3,160	3,800	4,060	3,260	2,440	1,650	1,450	1,390	-------
1911–12	1,380	1,350	1,290	2,230	1,800	2,250	1,910	2,930	1,770	1,340	1,260	1,260	1,730
1912–13	1,210	1,910	1,590	2,450	1,880	1,740	2,640	2,430	1,550	1,290	1,200	1,150	1,750
1913–14	1,150	1,370	2,030	7,200	4,420	3,500	5,020	3,000	2,120	1,650	1,430	1,280	2,840
1914–15	1,340	1,280	1,300	2,020	6,870	4,410	4,570	5,290	2,400	1,790	1,540	1,460	2,830
1915–16	1,430	1,430	2,620	3,280	6,110	4,880	3,490	2,470	1,870	1,700	1,470	1,390	2,670
1916–17	1,390	1,400	1,650	1,460	3,330	2,030	2,560	2,070	1,530	1,220	1,090	1,090	1,720
1917–18	1,080	1,110	1,310	1,170	1,850	2,970	2,290	1,370	1,080	981	965	967	1,430
1918–19	985	1,030	1,040	2,030	3,750	2,340	2,710	1,780	1,210	1,070	990	982	1,640
1919–20	977	927	1,070	986	950	1,310	2,010	1,280	1,030	935	893	868	1,100
1920–21	913	3,370	3,260	4,440	3,770	4,010	2,910	2,300	1,650	1,270	1,120	1,060	2,500
1921–22	1,030	1,040	1,330	1,250	2,430	2,260	2,700	2,690	1,660	1,170	1,060	1,030	1,630
1922–23	1,020	1,060	1,250	1,380	1,250	1,220	2,660	1,550	1,150	992	936	923	1,280
1923–24	940	852	880	888	1,450	918	890	818	776	766	758	753	888
1924–25	879	1,340	1,110	1,210	5,120	2,120	3,840	2,070	1,460	1,120	1,000	1,030	1,830
1925–26	913	898	968	850	3,770	1,380	2,010	1,180	967	866	850	842	1,270
1926–27	836	2,710	3,070	2,560	5,680	2,930	4,630	2,590	1,690	1,240	1,070	1,000	2,480
Av.	1,090	1,440	1,610	2,210	3,390	2,590	2,990	2,300	1,550	1,240	1,120	1,090	1,850

[d] Formerly known as Henderson.

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

Clear Creek near Shasta

[Drainage area, 182 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	14. 1	-------
1911–12	10. 0	10. 0	21. 4	267	168	391	388	509	271	98. 7	48. 3	65. 8	187
1912–13	48. 8	173	157	406	336	242	459	238	86. 0	40. 9	24. 7	23. 4	185

Cow Creek at Millville

[Drainage area, 185 square miles]

1910–11	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	69. 6	-------
1911–12	87. 7	103	102	290	139	263	154	263	141	67. 2	53. 5	130	150
1912–13	82. 2	225	166	473	136	169	411	351	122	65. 4	43. 5	42. 8	191
1913–14	36. 3	-------	-------	-------	528	130	-------	-------	-------	-------	-------	-------	-------

Clover Creek at Millville

[Drainage area, 48 square miles]

1910–11	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	9. 1	-------
1911–12	15. 6	17. 1	19. 5	91. 4	55. 1	107	43. 6	63. 1	22. 3	7. 5	3. 0	28. 0	39. 4
1912–13	9. 63	127	89. 8	198	47. 7	58. 3	87. 4	55. 0	21. 9	9. 19	4. 9	4. 7	59. 6

Little Cow Creek at Palo Cedro

[Drainage area, 148 square miles]

1910–11	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	8. 48	-------
1911–12	15. 8	22. 1	22. 7	315	226	352	119	215	49. 4	5. 89	3. 39	18. 5	114
1912–13	10. 1	294	222	635	139	268	231	114	41. 6	17. 5	6. 0	7. 5	166

Bear Creek near Millville

[Drainage area, 106 square miles]

1910–11	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	39. 8	-------
1911–12	56. 9	62. 5	59. 2	135	64. 4	167	81. 0	78. 3	26. 2	5. 78	2. 00	82. 0	68. 4
1912–13	8. 4	215	58. 7	190	75. 2	87. 7	168	40. 3	27. 6	10. 3	5. 7	5. 2	74. 1

North Fork of Cottonwood Creek near Ono

[Drainage area, 12.0 square miles]

1918–19	-------	-------	-------	-------	66. 1	57. 4	51. 5	25. 6	13. 2	6. 14	4. 08	4. 69	-------
1919–20	5. 13	4. 94	10. 7	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

North Fork of Cottonwood Creek at Ono

[Drainage area, 52 square miles]

1907–8	-------	11. 4	125	254	361	189	142	91. 2	26. 8	6. 5	3. 6	4. 8	-------
1908–9	10. 5	17. 2	27. 5	907	1, 000	453	360	153	49. 9	12. 0	5. 08	7. 68	250
1909–10	20. 6	66. 9	157	139	231	374	231	105	32	10. 3	4. 26	5. 91	115
1910–11	27. 3	29. 7	69. 6	167	236	508	309	171	66. 7	17. 9	6. 33	7. 50	135
1911–12	13. 5	14. 2	16. 9	150	109	182	224	263	133	37. 9	12. 5	23. 2	98. 2
1912–13	13. 5	86. 4	60. 9	158	131	88. 8	151	71. 1	29. 5	6. 82	1. 24	1. 15	66. 2

Moon Creek near Ono

[Drainage area, 9.6 square miles]

1918–19	-------	-------	-------	-------	49. 4	56. 5	53. 6	34. 0	15. 7	7. 20	3. 60	2. 36	-------
1919–20	6. 09	7. 58	12. 0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

Mill Creek near Los Molinos

[Drainage area, 173 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	-------	-------	-------	-------	-------	-------	-------	633	686	332	168	143	-------
1911–12	135	132	129	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

Thomas Creek at Paskenta

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1920–21	3.34	1,460	1,160	1,300	890	884	500	357	109	-------	-------	0.33	-------
1921–22	3.20	18.1	301	403	433	322	983	656	80.0	18.2	1.92	.15	267
1922–23	18.2	85.9	517	462	277	166	594	183	96.2	9.16	6.24	4.16	201
1923–24	11.8	16.4	38.2	59.7	312	48.9	45.3	18.2	1.41	0	0	0	44.9
1924–25	47.5	200	354	308	1,630	522	847	693	130	43.8	14.9	25.0	392
1925–26	30.0	45.9	117	142	1,100	370	523	112	27.0	6.12	1.06	.32	200
1926–27	7.61	367	649	513	1,690	962	832	473	152	30.5	8.28	4.98	466

Deer Creek near Vina

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1911–12	-------	135	130	217	173	300	204	318	158	106	96	147	-------
1912–13	103	173	139	354	176	221	530	404	187	117	100	93.4	217
1913–14	92.5	161	635	1,820	1,020	697	928	614	273	155	121	115	551
1914–15	120	123	157	471	1,280	659	808	1,080	339	147	115	106	445
1919–20	-------	-------	-------	-------	-------	-------	395	254	109	83.3	78.1	78.6	-------
1920–21	91.9	625	683	1,240	706	672	542	489	271	132	104	101	470
1921–22	121	118	334	255	777	514	600	799	475	156	112	101	360
1922–23	102	198	620	336	210	192	422	203	129	84.2	79.9	94.3	223
1923–24	94.3	83.2	91.1	98.8	267	154	127	77.2	66.1	63.3	65.5	64.3	104
1924–25	78.5	121	176	129	838	287	491	224	121	77.4	67.2	71.7	219
1925–26	78.7	112	139	195	651	239	700	166	84.9	66.8	63.0	64.4	209
1926–27	79.1	465	264	427	1,270	548	657	393	172	104	86.6	81.4	372
Av---	96.1	210	306	504	670	408	534	418	199	108	90.7	93.2	317

Stony Creek near Fruto

[Drainage area, 601 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1900–1	-------	-------	-------	-------	2,230	857	362	350	66.4	7.4	4.1	34.0	-------
1901–2	130	159	474	129	4,800	2,780	1,720	743	211	3.0	2.4	8.2	930
1902–3	159	1,830	1,350	1,610	1,290	1,880	1,080	336	15.1	6.2	8.7	5.9	798
1903–4	16.4	696	535	335	3,990	4,460	1,600	715	165	34.1	13.5	18.8	1,050
1904–5	167	70.7	453	2,420	1,470	2,050	870	675	206	35.4	12.4	13.7	704
1905–6	16.3	27.1	68.1	2,200	1,540	2,500	1,280	610	495	127	32.6	17.3	743
1906–7	29.0	61.4	582	2,020	3,310	4,430	1,640	450	236	47.1	15.0	19.0	1,070
1907–8	30.0	44.0	597	1,140	1,680	993	525	364	186	47.6	14.8	6.83	469
1908–9	34.0	88.2	192	6,360	5,480	1,300	966	488	145	41.0	15.9	12.8	1,260
1909–10	47.4	370	651	840	964	1,910	733	240	73.8	11.0	.82	1.43	487
1910–11	8.68	46.1	346	949	734	4,000	1,330	557	450	119	161	126	736
1911–12	91.2	32.5	22.0	182	173	270	289	484	182	169	128	74.8	175
Av---	66.3	311	479	1,650	2,310	2,290	1,030	501	203	54.0	34.1	28.2	766

Stony Creek near Stonyford

[Drainage area, 97 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1912–13	-------	-------	-------	-------	-------	-------	201	165	87	44	29	22	-------
1913–14	21.0	58.0	391	1,590	810	434	401	232	130	60.2	40.2	30.8	348
1914–15	32.0	36.4	45.1	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
1918–19	-------	-------	60.6	202	591	367	290	201	87.6	54.2	48.9	46.6	-------
1919–20	44.2	49.0	88.6	30.3	25.9	69.9	176	83.0	53.0	32.4	23.0	23.0	58.2
1920–21	34.4	379	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
1921–22	49.0	45.3	69.5	66.8	321	150	317	272	138	59.3	44.4	37.0	129
1922–23	47.9	109	286	220	136	103	233	114	66.3	43.5	29.9	28.4	118
1923–24	29.7	30.8	34.7	56.8	126	35.3	43.3	29.0	17.5	14.0	14.5	14.0	36.8
1924–25	32.6	73.2	146	137	883	246	387	427	142	66.5	47.5	43.0	214
1925–26	41.0	36.7	48.4	67.5	635	156	344	97.2	49.9	35.8	28.2	23.2	126
1926–27	30.7	252	349	332	1,130	377	400	195	106	57.8	47.7	42.4	270
Av---	36.2	107	152	300	518	215	279	182	87.7	46.8	35.3	31.0	162

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

Stony Creek near Elk Creek

[Drainage area, 298 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1918–19	-------	-------	-------	-------	-------	-------	-------	186	225	255	230	149	-------
1919–20	28.4	34.0	59.1	28.6	22.6	41.8	63.5	102	126	112	82.5	30.1	61.1
1920–21	20.0	377	897	1,390	1,010	473	252	190	163	233	225	178	449
1921–22	67.5	51.2	61.9	46.4	379	220	378	284	208	281	252	232	203
1922–23	90.2	167	291	154	31.2	57.6	307	181	202	244	223	158	176
1923–24	26.7	30.0	30.7	33.7	79.7	12.0	83.4	102	54.0	.13	.53	.23	37.5
1924–25	13.1	61.1	120	40.8	1,070	273	541	543	201	265	257	162	290
1925–26	53.0	28.3	27.5	84.8	915	93.5	679	152	246	234	186	106	228
1926–27	21.9	242	532	340	2,480	492	481	192	196	280	255	199	461
Av.	40.1	124	252	265	748	208	348	215	180	212	190	135	238

Stony Creek near Orland

[Drainage area, 636 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1919–20	-------	-------	-------	29.2	31.6	67.1	219	108	83.5	75.6	48.8	16.0	-------
1920–21	6.13	719	1,340	2,900	1,700	828	407	365	221	218	201	168	752
1921–22	41.4	18.2	118	91.9	750	404	751	588	258	229	208	191	300
1922–23	56.5	197	502	392	179	147	461	238	206	212	192	148	245
1923–24	15.5	18.5	40.2	52.4	180	23.8	87.7	73.9	28.8	2.08	.43	0	43.0
1924–25	0	73.7	237	219	2,920	595	1,070	1,220	314	256	223	154	590
1925–26	49.7	28.9	42.2	248	1,860	295	1,120	225	227	194	149	89.8	365
1926–27	10.4	451	928	563	4,250	1,150	826	418	224	227	195	161	759
Av.	25.7	215	458	562	1,480	439	618	404	195	177	152	116	436

Little Stony Creek near Lodoga

[Drainage area, 102 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1907–8	-------	-------	-------	155	322	113	42.2	28.4	8.6	3.3	3.0	1.0	-------
1908–9	0.0	0.4	17.8	1,320	896	279	164	37.7	13.7	4.9	2.4	1.02	225
1909–10	.65	11.1	57.5	101	80.7	170	60.5	13.2	3.20	1.48	.44	0	41.5
1910–11	-------	-------	4.24	174	180	952	125	49.1	28.7	16.7	14.1	10.0	-------
1911–12	5.3	2.8	6.5	22.3	13.8	46.5	24.6	47.4	16.9	1.87	0	3.33	16.0
1912–13	.48	10.7	18.1	129	39.5	25.0	39.8	20.9	6.2	0	0	2.5	24.3
1913–14	1.32	10.3	248	1,170	409	149	108	40.2	13.3	1.63	.118	0	179
1914–15	1.13	1.48	16.3	270	859	249	147	102	32.1	9.89	1.49	.03	136
1915–16	0	0	111	442	218	167	70.0	29.2	16.4	2.73	6.77	8.90	89.3
1916–17	1.42	0	23.1	43.9	278	99.1	93.3	34.5	11.9	0	0	0	47.1
1917–18	2.00	1.00	5.05	5.45	76.5	114	66.1	19.4	2.15	0	0	3.27	24.2
1918–19	1.52	6.43	16.6	83.9	219	125	52.7	25.4	10.4	.48	0	0	44.0
1919–20	.58	.06	15.3	11.8	0	24.0	60.8	22.6	.20	0	0	0	11.3
1920–21	.25	95.7	281	477	191	102	77.9	24.4	13.4	3.39	0	0	105
1921–22	0	.65	33.4	29.9	276	100	81.7	53.3	9.50	.10	0	0	47.1
1922–23	.18	19.2	130	96.2	61.8	35.4	67.4	15.5	4.67	0	0	4.27	36.2
1923–24	0	0	.32	12.8	21.6	14.3	4.92	.81	0	0	0	0	4.51
1924–25	0	1.9	55.7	47.7	401	60.4	94.6	93.2	26.4	5.0	.2	0	63.1
1925–26	0	3.2	7.0	47.0	312	29.7	186	29.0	2.1	0	0	0	49.2
1926–27	0	83.5	186	136	552	113	98.9	29.2	9.83	1.03	0	0	97.7
Av.	.82	13.8	64.9	239	270	148	75.9	35.8	11.5	2.62	1.43	1.72	68.9

North Fork of Feather River above Prattville

[Drainage area, 245 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1904–5	-------	-------	-------	-------	-------	-------	-------	-------	-------	436	365	341	-------
1905–6	338	332	326	442	553	668	923	1,360	1,200	730	471	404	646
1906–7	373	404	506	428	974	1,290	1,450	1,490	1,150	-------	-------	-------	-------

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

North Fork of Feather River near Prattville

[Drainage area, 506 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1904-5	------	------	------	------	------	------	------	------	------	759	668	639	------
1905-6	628	622	594	936	1,220	1,590	2,200	2,780	2,180	1,210	794	685	1,290
1906-7	676	696	894	814	2,300	2,800	3,290	3,230	2,650	1,280	951	826	1,700
1907-8	794	758	939	917	809	1,140	1,500	1,500	1,110	723	635	610	953
1908-9	632	647	612	2,550	1,310	1,380	2,120	2,580	1,950	1,010	800	734	1,360
1909-10	731	1,200	1,010	844	908	2,160	1,780	1,250	768	662	602	623	1,040
1910-11	625	696	908	------	------	------	2,990	3,040	2,630	1,210	855	790	------
1911-12	791	623	597	672	697	764	792	1,130	930	572	561	584	727
1912-13	605	705	604	585	591	664	1,680	1,510	978	685	586	554	812
1913-14	577	636	605	1,250	957	[a]1,450	1,510	1,950	1,660	787	1,100	1,180	1,140
1914-15	1,210	1,320	1,640	1,090	956	638	449	2,230	1,950	983	1,100	1,280	1,240
1915-16	1,340	1,370	771	1,340	1,590	1,380	1,000	1,170	928	1,070	1,420	1,590	1,250
1916-17	1,550	1,320	867	1,130	791	342	435	1,160	478	1,200	1,740	1,870	1,080
1917-18	1,960	1,550	1,010	821	434	178	97.5	100	402	865	1,130	817	784
1918-19	1,280	1,330	1,370	547	130	44.3	82.9	762	862	1,100	1,260	1,340	847
1919-20	1,420	1,240	1,030	627	426	46.9	17.5	12.9	445	1,140	1,130	877	703
1920-21	988	491	214	356	895	270	1,190	2,500	1,390	1,510	1,200	1,150	1,010
1921-22	1,090	745	848	692	382	1,080	351	1,910	1,300	917	936	975	941
1922-23	862	1,060	1,530	913	775	249	27.5	84.8	469	956	1,230	1,060	769
1923-24	1,040	1,020	726	633	294	349	269	403	798	897	421	416	607
1924-25	999	837	708	701	128	199	220	86.0	651	1,030	982	971	630
1925-26	731	743	595	465	604	244	151	461	831	1,130	1,370	1,360	724
1926-27	959	649	191	166	35.0	28.7	33.9	43.4	79.2	827	1,080	986	426
Av.	977	921	830	859	773	809	1,010	1,360	1,160	979	980	953	945

North Fork of Feather River at Big Bar

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910-11	------	------	------	------	------	6,170	12,200	10,700	7,690	2,650	1,500	1,190	------
1911-12	1,210	1,350	1,330	1,900	1,910	2,140	2,460	3,610	2,550	1,170	964	1,090	1,810
1912-13	980	------	------	------	1,500	------	5,430	5,370	2,760	------	975	859	------
1913-14	885	1,200	2,040	9,500	6,070	7,510	9,580	7,320	3,710	1,680	1,540	1,580	4,370
1914-15	1,700	1,930	2,250	2,110	4,960	3,990	5,330	10,000	4,410	1,980	1,510	1,510	3,470
1915-16	1,540	1,780	1,930	3,360	7,630	8,670	9,080	------	3,410	2,270	1,950	1,900	------
1916-17	1,950	1,980	2,340	1,930	4,360	3,140	7,430	6,680	3,760	2,170	2,270	2,180	3,340
1917-18	2,200	2,050	1,840	1,500	2,080	3,490	4,140	2,050	1,130	1,310	1,490	1,320	2,050
1918-19	1,860	1,980	2,000	1,510	3,260	2,650	6,080	4,390	1,790	1,740	1,740	1,810	2,560
1919-20	1,840	1,670	1,730	1,250	1,050	2,080	3,310	2,890	1,370	1,540	1,400	1,130	1,770
1920-21	1,330	3,530	2,950	4,790	4,570	5,660	------	------	3,240	2,440	1,750	1,440	------
1921-22	1,490	1,120	1,550	1,580	2,350	3,470	5,910	12,500	5,540	1,780	1,330	1,270	3,330
1922-23	1,370	1,890	3,220	2,670	2,240	2,580	4,140	2,920	1,870	1,540	1,630	1,410	2,290
1923-24	1,430	1,360	1,120	1,170	2,110	1,010	1,230	838	664	723	819	852	1,110
1924-25	1,170	1,380	1,250	1,370	4,860	2,480	3,250	2,600	1,590	1,280	1,290	1,360	1,970
1925-26	1,270	1,260	1,600	1,380	4,400	2,790	5,500	2,430	1,420	1,640	1,750	1,700	2,240
1926-27	1,360	3,590	2,420	2,280	7,790	5,200	5,700	4,130	2,760	1,880	1,890	2,010	3,380
Av.	1,470	1,870	1,970	2,550	3,820	3,940	5,670	5,230	2,920	1,740	1,520	1,450	2,590

North Fork of Feather River at Big Bend

[Drainage area, 1,940 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1904-5	------	------	------	------	------	------	------	------	------	------	1,080	1,030	------
1905-6	1,060	1,120	1,150	6,490	5,150	9,680	9,910	9,430	7,570	2,980	1,540	1,310	4,780
1906-7	1,240	1,610	4,070	3,510	12,900	18,300	13,800	9,330	6,250	2,700	1,720	1,470	6,410
1907-8	1,520	1,580	2,980	3,770	2,990	4,590	5,660	5,130	3,700	1,590	1,010	987	2,960
1908-9	1,190	1,310	1,300	------	------	------	------	------	------	1,820	1,290	1,200	------
1909-10	1,480	3,230	3,620	2,990	3,560	9,000	7,060	4,000	1,580	1,160	973	998	3,300
1910-11	1,010	1,280	2,240	------	------	------	------	------	------	------	------	------	------

[a] Storage at Lake Almanor began in March, 1914.

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

Feather River at Oroville

[Drainage area, 3,640 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1901–2	--------	--------	--------	1,980	16,800	9,970	16,700	10,700	5,650	2,190	1,410	1,200	--------
1902–3	1,420	3,530	5,890	7,390	5,240	11,900	18,900	9,430	4,270	2,280	1,810	1,590	6,140
1903–4	1,770	19,700	4,180	3,430	28,000	39,800	24,700	18,600	7,880	3,050	2,010	2,260	12,900
1904–5	4,290	2,750	6,230	10,400	10,200	14,300	10,100	7,630	4,220	1,810	1,350	1,270	6,210
1905–6	1,280	1,320	1,390	14,500	11,100	21,600	19,200	17,500	13,800	5,240	2,490	1,970	9,280
1906–7	1,920	2,410	7,070	7,130	21,500	36,900	29,500	23,400	15,200	6,000	2,650	1,900	13,000
1907–8	1,850	1,780	6,060	6,610	6,380	7,250	9,210	8,170	5,310	2,320	1,510	1,250	4,810
1908–9	1,650	1,750	1,910	39,900	18,400	13,400	15,900	14,000	9,060	3,270	1,800	1,821	10,200
1909–10	1,960	5,750	8,140	6,750	7,970	17,900	12,600	6,850	2,620	1,600	1,350	1,170	6,220
1910–11	1,200	1,860	3,400	8,960	10,200	15,800	30,100	22,100	15,600	3,870	1,650	1,310	9,670
1911–12	1,330	1,560	1,430	3,420	2,730	4,000	4,190	8,270	4,300	1,180	969	1,180	2,880
1912–13	1,010	2,810	1,740	3,370	2,660	3,660	10,600	10,000	4,060	1,650	1,170	1,010	3,690
1913–14	1,030	1,740	6,880	30,000	17,500	19,700	22,400	16,300	7,150	2,380	1,830	1,840	10,700
1914–15	2,060	2,380	3,030	4,570	16,800	11,000	14,900	27,200	8,900	3,130	2,150	2,090	8,130
1915–16	2,050	2,400	4,210	11,000	19,200	24,300	22,500	13,700	5,890	3,040	2,340	2,270	9,360
1916–17	2,610	2,660	4,820	3,060	12,100	6,820	19,100	15,300	7,280	2,760	2,360	2,240	6,700
1917–18	2,170	2,150	2,330	1,790	3,450	8,780	10,300	4,620	1,860	1,560	1,640	1,620	3,520
1918–19	2,270	2,530	2,510	2,560	9,150	6,420	14,100	9,510	2,760	1,990	1,900	1,820	4,750
1919–20	2,010	1,810	2,360	1,730	1,800	4,130	7,180	5,960	2,310	1,800	1,550	1,270	2,830
1920–21	1,580	9,190	8,300	13,200	10,100	14,700	11,700	13,300	6,650	2,810	1,860	1,650	7,900
1921–22	1,610	1,630	3,100	3,000	6,990	7,280	14,000	25,100	11,100	2,690	1,730	1,560	6,640
1922–23	1,650	2,380	6,240	5,040	3,630	4,930	9,430	6,270	3,050	1,890	1,710	1,590	3,990
1923–24	1,710	1,620	1,510	1,640	4,670	1,560	2,150	1,250	924	852	956	992	1,640
1924–25	1,510	2,110	2,210	2,410	14,100	5,090	7,710	5,580	2,730	1,770	1,670	1,710	3,970
1925–26	1,690	1,940	2,150	2,390	10,800	5,570	14,100	4,170	1,930	1,840	1,820	1,860	4,120
1926–27	1,720	7,250	4,310	5,280	24,700	10,900	14,200	9,800	4,630	2,110	1,860	1,790	7,240
Av.	1,810	3,480	4,060	7,750	11,400	12,600	14,800	12,100	6,120	2,500	1,750	1,620	6,660

Feather River at Nicolaus

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1920–21	--------	--------	--------	--------	--------	--------	--------	--------	--------	2,090	748	811	--------
1921–22	--------	--------	--------	--------	--------	--------	--------	--------	--------	2,940	786	827	--------
1922–23	2,000	--------	--------	--------	--------	--------	--------	--------	--------	1,800	847	1,210	--------
1923–24	2,050	1,870	1,880	--------	--------	--------	--------	--------	114	28.9	9.9	352	--------
1924–25	1,520	2,780	4,060	4,350	--------	--------	--------	--------	--------	--------	543	824	--------
1925–26	1,720	2,230	3,220	--------	--------	--------	--------	--------	966	405	396	1,010	--------
1926–27	1,780	--------	--------	--------	--------	--------	--------	--------	--------	1,610	709	1,030	--------

Hamilton Branch of Feather River near Prattville

[Drainage area, 230 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1904–5	--------	--------	--------	--------	--------	--------	--------	--------	--------	219	211	202	--------
1905–6	191	182	171	333	575	757	1,030	1,290	846	347	254	231	517
1906–7	212	218	343	282	1,220	1,340	1,710	1,460	877	--------	--------	--------	--------

Butt Creek at Butte Valley

[Drainage area, 73 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1904–5	--------	--------	--------	--------	--------	--------	--------	--------	--------	47.2	33.6	32.0	--------
1905–6	32.0	33.3	58.8	221	141	287	360	320	220	69.3	45.9	44.9	153
1906–7	42.6	48.7	90.2	95.1	312	367	500	343	186	67.1	43.8	39.6	178
1907–8	37.9	41.8	97.8	76.5	62.6	113	173	132	64.6	30.4	24.5	26.7	73.4
1908–9	27.1	28.2	29.5	460	178	159	280	233	104	40.8	33.0	32.1	134
1909–10	42.1	83.9	91.0	65.5	72.9	221	165	65.0	30.9	26.3	26.3	26.2	76.3
1910–11	26.4	34.7	52.7	--------	--------	--------	353	404	--------	--------	34.9	32.4	--------
1911–12	32.5	38.9	29.3	69.5	55.4	69.1	79.0	120	60	25.6	23.9	34.9	53.2
1912–13	35.3	57.3	49.8	101	61.1	78.4	209	176	64.1	35.4	30.9	29.3	77.3
1913–14	30.2	43.7	54.5	212	142	278	387	321	134	68.6	49.3	46.8	147
1914–15	51.8	49.5	57.7	52.0	128	185	345	336	164	61.4	44.8	38.2	126
1915–16	39.8	48.4	82.5	155	159	258	339	337	165	61.5	44.8	38.2	144
1916–17	44.5	53.9	64.5	63.8	110	103	270	234	126	39.7	29.2	25.3	96.6
1917–18	23.7	30.1	38.4	30.5	54.2	116	181	87.9	25.3	13.7	12.4	20.8	52.8
1918–19	21.9	24.6	24.6	32.5	70.8	73.8	247	163	31.6	13.9	11.4	12.7	60.4
1919–20	15.0	17.3	46.3	34.5	28.5	56.7	133	111	29.8	12.3	8.42	9.93	41.9
1920–21	19.6	89.6	78.0	140	117	240	260	--------	--------	--------	--------	--------	--------
Av.	32.6	45.2	59.1	121	113	174	268	226	100	40.9	31.1	30.6	101

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

Indian Creek near Crescent Mills

[Drainage area, 740 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1905–6	-------	-------	-------	868	824	2,000	2,550	1,790	1,010	226	53.1	57.9	-------
1906–7	94.8	132	534	504	2,210	2,930	3,860	2,110	1,000	241	91.3	88.9	1,150
1907–8	114	139	384	478	363	989	1,030	661	306	72.4	15.1	22.7	381
1908–9	58.8	94.4	124	2,910	1,380	1,200	2,540	2,020	962	240	35.3	36.9	967
1909–10	101	356	484	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
1911–12	78.0	121	111	164	174	255	284	590	178	43.7	15.1	37.3	171
1912–13	49.5	135	116	145	201	298	1,090	679	225	85.4	44.9	33.5	258
1913–14	44.2	103	205	2,070	1,370	3,000	3,660	1,930	518	116	29.2	42.8	1,090
1914–15	74.8	94.0	121	178	779	923	1,320	1,750	320	75.9	26.5	33.2	472
1915–16	40.7	83.7	227	512	1,530	2,810	3,050	1,360	544	144	38.1	42.6	861
1916–17	81.3	119	205	140	712	582	2,710	1,900	674	121	30.4	30.9	605
1917–18	38.2	77.5	117	116	235	813	-------	-------	-------	-------	-------	-------	-------
Av.	70.5	132	239	735	889	1,440	2,210	1,480	574	137	37.9	42.7	662

Spanish Creek at Keddie

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1911–12	-------	77.2	79.6	157	110	196	186	313	154	45.5	24.8	46.9	-------
1912–13	49.3	90.5	83.9	120	120	200	479	380	134	55.7	47	28.5	149
1913–14	34.8	73.4	423	1,760	1,160	847	1,000	649	207	36.1	43.3	42.5	520
1914–15	56.4	63.8	83.9	118	1,060	685	748	1,430	267	82.4	40.4	38.9	385
1915–16	48.5	73.5	270	617	981	1,260	1,230	592	297	75.5	65.0	65.0	462
1916–17	70.0	127	177	176	564	461	1,440	793	287	139	60.2	42.2	359
1917–18	42.9	60.0	107	72.0	204	617	572	213	58.7	24.9	19.9	55.5	170
1918–19	68.1	66.7	78.1	120	667	479	758	392	77.8	29.6	20.0	24.9	228
1919–20	47.9	54.7	76.1	73.9	79.0	212	373	202	-------	-------	-------	-------	-------
1920–21	-------	-------	-------	-------	-------	967	623	568	250	59.0	25.0	30.0	-------
1921–22	45.9	123	242	191	472	564	929	1,100	465	119	41.8	27.5	359
1922–23	41.8	168	281	232	166	239	427	256	116	36.6	24.4	38.6	169
1923–24	59.8	61.5	74.8	90.2	269	80.3	90.9	29.9	11.2	9.31	10.1	16.2	66.0
1924–25	50.0	89.8	84.7	98.9	499	215	320	197	59.8	22.5	20.4	32.3	138
1925–26	55.3	69.3	70.1	103	630	320	828	235	49.3	18.2	11.9	20.1	197
1926–27	51.8	375	174	246	1,200	604	777	509	241	62.6	26.5	37.1	352
Av.	51.6	105	154	278	545	497	674	491	178	54.4	32.0	36.4	273

Middle Fork of Feather River near Clio

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1925–26	22.0	38.0	50.3	102	389	290	367	110	17.1	13.6	9.18	14.6	116
1926–27	21.1	143	152	218	1,710	922	1,210	534	191	50.1	23.6	32.2	433

Middle Fork of Feather River at Sloat[f]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	-------	-------	-------	-------	-------	-------	-------	-------	-------	438	146	77.1	-------
1911–12	90.0	136	137	216	259	215	261	591	332	66.6	48.4	59.9	201
1912–13	51.8	174	88.5	213	127	347	882	626	291	69.5	63.4	48.1	248
1913–14	48.0	76.4	423	2,580	2,750	3,740	2,670	1,740	733	199	75.5	62.2	1,250
1914–15	74.5	78.0	91.4	103	516	1,090	1,100	1,460	472	126	58.5	53.1	434
1915–16	57.9	74.2	187	328	1,560	3,620	2,680	1,260	706	249	79.0	64.9	903
1916–17	76.8	100	260	143	448	938	2,070	1,440	839	189	75.0	53.8	551
1917–18	54.4	69.9	114	97.0	248	955	1,440	543	182	54.5	43.3	68.8	322
1918–19	99.1	126	118	153	627	981	2,030	979	187	63.8	51.8	41.0	452
1919–20	53.8	60.0	190	128	196	425	835	650	300	125	31.3	31.9	252
1920–21	52.5	449	314	896	788	1,620	869	851	606	154	64.3	55.0	555
1921–22	64.4	73.5	131	161	404	397	3,490	3,290	1,230	232	89.8	60.7	800
1922–23	64.0	139	476	503	300	1,060	1,490	911	484	138	54.6	55.5	473
1923–24	72.2	79.4	88.7	131	300	116	199	120	38.4	27.9	24.0	25.9	101
1924–25	54.2	99.0	101	170	1,200	545	660	541	198	61.1	48.9	50.4	304
1925–26	64.7	81.0	113	173	786	574	1,000	427	91.8	46.3	36.9	41.0	282
1926–27	48.2	369	310	413	2,480	1,450	1,950	1,090	667	165	58.7	64.0	741
Av.	64.2	137	196	400	812	1,130	1,480	1,030	460	141	61.7	53.7	492

Middle Fork of Feather River near Nelson Point

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1923–24	-------	-------	-------	128	366	175	288	182	76.9	48.8	39.4	44.9	-------
1924–25	94.0	189	184	239	1,530	695	1,010	819	289	112	85.7	89.7	436
1925–26	104	122	155	218	883	744	1,510	614	159	87.6	69.9	66.6	390
1926–27	84.1	535	458	585	2,830	1,750	2,420	1,710	972	248	131	120	971

[f] Station maintained at Cromberg previous to December, 1913

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

Middle Fork of Feather River near Oroville

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1911–12	-------	437	358	769	857	1,240	1,470	3,040	1,300	367	215	264	-------
1912–13	237	834	495	938	815	1,200	3,710	4,020	1,260	433	263	193	1,200
1913–14	187	483	1,650	8,720	5,720	7,470	7,590	5,730	2,160	678	322	270	3,400
1914–15	326	341	430	894	4,440	3,920	5,730	8,090	2,630	729	354	269	2,330
1915–16	262	381	1,130	2,810	5,850	8,150	7,740	4,790	2,360	831	358	287	2,900
1916–17	383	532	1,430	707	2,980	3,020	6,720	5,830	3,290	700	300	223	2,160
1917–18	207	270	511	379	1,130	3,130	4,490	2,040	641	258	161	278	1,120
1918–19	414	496	449	655	3,060	2,830	6,250	4,030	798	328	196	173	1,630
1919–20	227	220	575	423	610	1,730	3,270	2,950	848	302	157	139	955
1920–21	303	2,780	2,840	4,710	3,490	5,840	4,360	4,390	2,090	586	300	248	2,660
1921–22	254	331	823	903	2,440	2,400	6,700	9,420	4,830	890	368	257	2,460
1922–23	304	547	2,140	1,800	1,160	2,190	4,440	3,090	1,220	473	239	243	1,490
1923–24	278	253	332	395	1,590	540	857	392	176	122	110	105	424
1924–25	255	480	582	765	5,070	2,140	3,400	2,480	1,010	372	242	259	1,390
1925–26	289	440	571	756	3,660	2,330	5,110	1,580	508	247	173	161	1,300
1926–27	250	2,270	1,590	2,140	8,580	5,160	6,350	4,720	2,080	561	284	226	2,800
Av.	278	693	994	1,740	3,220	3,330	4,890	4,160	1,700	492	253	225	1,880

Grizzly Creek near Portola[a]

[Drainage area, 51 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1905–6	-------	-------	-------	40.0	110	153	474	323	101	11.9	0.73	0.51	-------
1925–26	0.92	2.25	2.03	9.16	29.9	78.0	89.6	25.8	1.10	.34	.36	.55	19.9
1926–27	.63	22.4	21.6	26.4	109	151	185	103	23.3	2.46	.45	.7	53.4

South Fork of Feather River at Enterprise

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1911–12	-------	38.0	34.4	131	140	286	332	572	168	9.70	1.40	12.5	-------
1912–13	15.5	143	60.9	205	154	217	702	754	166	14.7	1.50	1.24	203
1913–14	1.17	72.0	492	2,120	1,210	906	1,070	758	246	37.8	2.68	2.00	574
1914–15	18.3	28.1	68.6	231	1,130	762	1,190	1,840	403	77.6	15.0	2.47	476
1915–16	4.26	41.7	223	839	1,210	1,260	1,220	766	285	56.2	6.32	6.82	491
1916–17	44.1	53.1	248	148	947	451	1,130	873	383	33.5	.82	.53	354
1917–18	1.15	19.7	80.3	58.0	229	522	684	268	23.7	.80	.68	20.7	158
1918–19	34.2	58.6	59.4	104	841	469	944	616	77.5	2.89	.87	.73	263
1919–20	8.7	20.4	148	76.5	110	372	836	602	117	3.90	1.7	19.6	193
1920–21	66.2	993	815	1,130	580	1,060	786	714	247	23.2	2.68	5.00	535
1921–22	8.61	26.1	170	171	682	549	786	1,500	706	62.6	3.56	2.50	387
1922–23	14.4	61.0	481	316	216	273	840	445	90.6	9.34	.80	5.00	229
1923–24	7.84	4.33	18.7	43.4	430	69.6	137	12.3	1.0	1.0	1.0	1.0	58.8
1924–25	11.1	67.5	94.5	103	1,450	424	775	494	94.8	11.3	11.2	16.8	287
1925–26	12.7	32.1	46.4	128	796	226	937	173	18.5	1.60	1.21	1.68	192
1926–27	28.0	388	267	331	1,700	877	1,000	658	223	26.1	20.3	4.87	450
Av.	18.4	128	207	383	739	545	836	690	203	23.3	4.48	6.46	323

Palermo Land & Water Co.'s canal at Enterprise

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1911–12	-------	23.9	17.0	13.9	16.5	15.7	19.9	29.4	38.3	35.9	23.5	20.4	-------
1912–13	21.0	14.8	15.7	13.8	21.2	20.4	21.8	32.3	35.0	38.5	27.2	20.4	23.5
1913–14	19.3	10.6	10.5	1.23	13.4	20.1	21.0	33.5	35.1	38.3	32.8	27.9	22.0
1914–15	24.2	18.3	14.5	14.9	11.4	14.2	17.6	17.3	35.3	37.8	37.6	32.9	23.1
1915–16	30.6	21.7	16.9	6.99	9.74	9.97	18.0	31.5	33.8	36.1	35.8	29.7	23.4
1916–17	17.9	15.4	9.49	6.81	16.7	17.7	17.2	31.9	37.5	38.9	33.4	26.9	22.4
1917–18	24.2	19.3	9.45	10.1	17.9	12.7	20.6	35.4	38.8	23.8	16.6	16.7	20.4
1918–19	19.1	14.4	12.0	12.6	9.87	13.7	23.1	32.0	36.9	28.8	18.2	18.3	20.0
1919–20	20.8	16.0	12.0	12.4	11.6	14.3	5.33	28.6	36.6	28.3	16.4	15.9	18.2
1920–21	18.4	14.0	7.90	5.23	6.31	8.21	19.9	30.3	34.7	38.4	28.2	24.0	19.7
1921–22	22.8	17.5	9.34	12.3	7.89	10.9	16.6	28.7	34.4	39.8	33.8	24.2	21.6
1922–23	21.8	11.6	10.6	9.44	13.3	16.1	18.4	33.0	36.8	37.3	25.6	21.6	21.3
1923–24	28.7	21.9	14.4	12.1	9.59	14.0	22.6	34.2	16.9	10.6	15.7	10.1	17.6
1924–25	13.4	10.3	10.5	15.7	6.21	18.2	18.1	28.2	33.7	35.6	37.6	32.6	21.8
1925–26	20.0	16.0	12.5	12.6	10.4	16.9	13.9	29.4	37.1	31.7	30.0	26.7	21.5
1926–27	16.1	13.9	10.5	10.8	10.5	9.90	12.6	21.0	23.2	31.3	36.2	34.4	19.3
Av.	21.2	16.2	12.1	10.7	12.0	14.6	17.9	29.8	34.0	33.2	28.0	23.9	21.1

[a] Station maintained near Beckwith during 1905–6.

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

Middle Fork of Yuba River at Milton

[Drainage area, 51 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1925–26	-------	-------	-------	19.5	47.0	134	347	206	26.6	3.45	1.57	1.55	-------
1926–27	3.21	70.7	67.6	96.2	158	160	274	572	473	58.2	7.23	4.27	161

Middle Fork of Yuba River near North San Juan

[Drainage area, 206 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1899–1900	-------	-------	-------	-------	-------	-------	-------	-------	-------	128	74.1	66.9	-------
1910–11	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	108	73.3	-------
1911–12	98.1	110	89.4	217	173	292	371	928	520	112	52.3	65.5	253
1912–13	59.8	238	143	280	283	330	942	1,060	366	117	66.5	46.9	328
1913–14	42.1	128	605	2,290	1,220	989	1,320	1,490	714	190	63.0	46.4	756
1914–15	71.5	68.5	96.5	274	1,120	782	1,210	2,670	892	171	67.1	50.1	617
1915–16	48.5	83.4	274	896	1,550	1,640	1,630	1,380	842	226	70.0	57.0	721
1916–17	76.6	106	316	196	921	449	1,520	1,400	1,110	180	61.0	48.1	527
1917–18	45.7	55.5	93.5	77.4	286	719	1,020	678	248	50.2	37.6	73.7	282
1918–19	101	128	110	178	969	671	1,490	1,270	204	70.2	43.8	38.4	434
1919–20	57.1	55.5	173	94.7	104	416	870	897	297	80.6	35.9	34.8	260
1920–21	90.4	650	725	1,010	761	1,280	1,010	1,150	682	133	52.9	45.6	632
1921–22	46.9	58.6	210	207	776	680	1,160	2,640	1,850	239	68.8	43.8	663
1922–23	62.8	131	758	421	338	395	1,230	1,310	598	165	53.8	55.2	460
1923–24	65.7	54.5	78.4	88.9	334	116	315	180	45.3	25.7	23.5	24.9	111
1924–25	62.1	149	279	300	1,740	565	1,170	966	344	86.8	51.1	50.8	470
1925–26	62.1	83.8	123	209	903	481	1,210	477	121	45.4	29.0	30.1	309
1926–27	63.8	779	346	587	2,940	1,160	1,650	1,450	920	173	51.4	43.5	830
Av.	65.9	180	276	458	901	685	1,130	1,250	610	129	56.1	49.7	478

Yuba River at Smartsville

[Drainage area, 1,220 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1902–3	-------	-------	-------	-------	-------	-------	-------	-------	2,910	897	516	479	-------
1903–4	550	4,890	2,010	1,830	14,800	15,400	10,700	10,600	4,970	1,260	591	732	5,690
1904–5	1,880	1,070	2,350	4,900	5,010	7,110	6,750	6,070	3,100	782	471	429	3,330
1905–6	453	474	566	7,560	4,970	12,000	8,770	10,800	10,000	3,350	744	520	5,020
1906–7	403	757	4,130	4,990	14,100	17,300	13,100	8,750	6,750	3,060	736	505	6,220
1907–8	517	472	1,590	3,380	2,230	3,590	4,800	5,200	3,180	705	350	329	2,200
1908–9	521	478	764	23,000	9,740	5,330	7,340	8,450	6,520	1,360	605	431	5,380
1909–10	543	5,010	6,550	4,520	4,390	8,170	7,900	4,690	1,280	525	328	383	3,690
1910–11	388	653	1,400	7,840	6,840	8,680	10,900	8,560	9,490	2,590	607	453	4,870
1911–12	476	619	499	1,310	973	1,920	2,280	6,020	3,300	543	318	378	1,560
1912–13	351	1,570	713	2,060	1,470	1,840	5,540	6,670	1,910	507	291	230	1,930
1913–14	225	545	2,610	11,500	3,140	4,320	7,910	9,810	5,220	1,280	472	326	3,960
1914–15	412	401	666	1,610	7,770	5,050	7,280	12,700	4,400	785	404	318	3,450
1915–16	298	482	1,830	5,520	8,830	9,520	9,310	7,900	5,640	1,270	408	341	4,260
1916–17	488	670	2,610	1,510	6,510	3,630	7,760	7,300	6,540	1,040	311	266	3,190
1917–18	251	307	615	446	2,130	4,310	5,180	3,540	1,250	313	176	485	1,580
1918–19	594	728	630	1,200	6,360	4,090	6,230	7,390	1,260	333	202	180	2,410
1919–20	288	276	1,070	555	784	2,790	5,010	4,720	1,700	390	167	161	1,490
1920–21	569	4,230	5,190	6,570	4,770	7,060	5,990	7,150	4,720	821	351	256	3,970
1921–22	314	430	1,790	1,830	5,590	4,100	6,390	12,600	10,200	1,420	486	279	3,770
1922–23	342	873	4,610	2,580	1,890	2,160	6,290	6,140	3,100	1,090	429	379	2,490
1923–24	460	337	521	614	1,780	783	1,490	745	182	149	98.1	232	610
1924–25	456	795	1,590	1,560	9,240	3,240	5,680	5,790	1,670	637	335	275	2,560
1925–26	287	433	725	866	6,860	2,850	6,780	2,960	985	280	244	150	1,910
1926–27	362	4,610	2,830	3,290	12,800	6,280	9,570	7,930	5,140	868	336	273	4,450
Av.	476	1,300	1,990	4,210	5,960	5,900	7,040	7,190	4,220	1,050	399	352	3,330

Yuba River at Parks Bar Bridge

[Drainage area, 1,230 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1899–1900	-------	-------	-------	-------	-------	-------	-------	-------	-------	716	506	494	-------

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

Oregon Creek near North San Juan

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	3.3	-------
1911–12	5.4	13.5	6.6	67.7	36.8	84.1	63.9	107	22.1	5.7	2.5	3.9	35.0
1912–13	4.8	45.5	15.7	63.1	61.8	74.5	227	90.5	17.3	6.19	2.87	2.43	50.7
1913–14	3.11	14.0	146	692	336	163	146	53.1	21.5	7.47	3.10	3.83	132
1914–15	6.56	7.93	11.6	45.7	338	213	214	353	54.6	15.9	7.61	7.23	105
1915–16	8.56	18.4	63.5	267	453	359	182	66.9	19.4	8.53	5.79	5.78	120
1916–17	8.00	18.5	70.2	55.4	273	126	333	105	22.4	7.77	4.98	3.75	84.1
1917–18	3.04	4.90	9.02	6.15	49.3	175	129	23.8	5.72	2.99	2.40	7.26	34.7
1918–19	10.0	19.3	17.6	41.4	296	218	266	65.5	11.7	4.21	3.00	3.71	78.0
1919–20	7.58	10.5	39.8	22.0	23.7	147	275	72.4	14.0	4.40	1.95	2.63	51.7
1920–21	14.7	192	284	352	309	375	198	116	39.4	10.9	2.70	3.29	157
1921–22	8.14	15.6	79.5	84.4	298	263	351	353	90.1	15.8	4.51	2.48	129
1922–23	9.57	32.3	226	105	76.1	72.8	184	48.6	20.6	7.41	3.22	6.02	65.9
1923–24	12.0	16.2	22.9	23.5	71.0	11.9	35.4	8.40	2.27	1.73	1.64	1.65	17.1
1924–25	8.29	25.4	59.5	76.6	360	77.7	147	47.7	21.9	5.38	2.84	3.39	67.4
1925–26	6.38	13.6	18.0	33.3	201	59.2	141	27.7	7.37	1.91	1.27	1.61	41.4
1926–27	5.90	112	44.1	128	558	188	250	80.3	24.8	5.83	2.50	2.47	113
Av.	7.63	35.0	69.6	129	234	163	196	101	24.7	7.01	3.30	3.81	80.1

North Fork of Yuba River near Sierra City

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1923–24	-------	-------	-------	50.9	91.1	67.8	226	171	52.0	39.3	34.1	33.2	-------
1924–25	53.3	92.4	77.5	93.9	386	193	486	702	284	65.9	56.0	55.7	211
1925–26	64.3	69.7	77.9	72.2	175	225	576	402	102	52.9	41.4	30.5	157
1926–27	47.9	235	184	198	377	368	540	961	871	205	72.2	63.7	342

North Fork of Yuba River at Goodyear Bar

[Drainage area, 214 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	-------	214	482	725	596	975	2,160	2,260	3,330	982	301	303	-------
1911–12	186	191	151	214	221	278	432	1,390	1,060	236	147	144	388
1912–13	130	287	163	212	272	326	1,000	1,740	832	271	158	125	461
1913–14	116	185	506	1,680	995	1,350	2,070	2,900	1,750	540	221	171	1,040
1914–15	195	174	175	233	706	718	1,460	2,860	1,710	423	198	146	748
1915–16	131	152	322	443	996	1,570	1,970	2,230	1,930	570	246	179	893
1916–17	202	190	364	214	572	549	1,400	1,930	2,090	492	224	167	697
1917–18	135	146	196	174	353	643	1,250	1,110	488	174	118	176	413
1918–19	222	224	195	217	707	626	1,680	2,230	570	225	147	133	597
1919–20	148	132	204	201	193	446	858	1,480	644	230	124	120	401
1920–21	169	814	662	935	783	1,280	1,360	1,860	1,510	462	260	170	855
1921–22	143	168	247	318	452	562	1,120	3,140	3,100	665	279	176	865
1922–23	196	232	538	468	397	513	1,090	1,810	1,000	452	265	204	598
1923–24	193	141	144	165	376	206	458	318	139	96.0	80.6	80.0	199
1924–25	155	212	256	296	1,400	653	1,260	1,440	577	226	164	143	559
1925–26	152	173	217	211	720	622	1,370	747	270	141	109	99.2	399
1926–27	126	735	465	556	1,790	1,140	1,560	2,160	1,780	451	222	171	921
Av.	162	257	311	427	678	733	1,320	1,860	1,340	390	192	153	627

North Fork of Yuba River near North San Juan

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1899–1900	-------	-------	-------	-------	-------	-------	-------	-------	-------	458	313	290	-------

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

North Fork of North Fork of Yuba River at Downieville

[Drainage area, 71.2 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	-------	78.4	173	260	247	403	858	864	1,140	323	122	78.0	-------
1911–12	72.6	67.0	49.4	82.8	93.1	122	193	516	351	93.9	43.1	47.5	**144**
1912–13	43.4	110	57.9	67.9	110	137	410	646	308	111	60.4	44.4	**176**
1913–14	40.9	65.6	230	652	309	480	759	927	444	122	67.9	50.0	**346**
1914–15	57.8	57.9	57.7	78.4	253	286	598	1,200	554	144	87.7	68.0	**287**
1915–16	54.6	65.7	100	116	335	692	868	869	662	186	71.7	58.8	**339**
1916–17	65.2	68.9	119	62.8	258	239	753	859	824	199	82.2	60.0	**298**
1917–18	54.7	59.9	67.5	61.0	114	214	434	342	112	53.7	42.5	65.5	**135**
1918–19	146	68.4	65.4	79.3	251	244	877	997	227	95.1	50.9	30.1	**257**
1919–20	39.4	34.6	74.3	58.4	76.6	194	401	707	273	86.2	54.4	39.5	**170**
1920–21	77.8	611	416	475	290	675	631	788	540	162	80.3	57.3	**401**
1921–22	57.6	62.7	88.5	128	180	250	546	1,490	1,140	262	94.3	65.9	**365**
1922–23	73.0	76.8	205	187	141	181	402	535	305	123	74.6	57.4	**197**
1923–24	56.1	38.6	44.6	50.8	139	75.3	150	109	45.0	26.9	19.1	19.6	**64.1**
1924–25	59.5	67.5	72.6	85.4	246	211	550	264	73.3	52.0	45.0	37.3	**146**
1925–26	40.3	103	109	118	534	290	451	482	195	84.6	56.3	56.5	**207**
Av.	62.6	102	121	160	224	293	555	725	450	133	65.8	52.2	**235**

Rock Creek at Goodyear Bar

[Drainage area, 10.8 square miles]

1910–11	-------	4.99	12.8	102	53.8	50.2	218	95.2	38.6	3.14	0.70	1.03	-------
1911–12	1.85	3.41	2.07	8.17	5.28	13.8	20.4	52.5	10.0	1.58	.56	1.33	**10.1**
1912–13	1.43	8.95	4.17	10.0	11.4	16.2	71.9	61.3	7.56	1.51	.80	.77	**16.3**
1913–14	1.11	4.97	36.5	175	87.4	70.7	83.6	43.9	11.3	1.60	1.00	1.00	**43.0**
1914–15	1.69	1.26	1.36	12.4	83.9	56.4	87.9	139	18.6	2.49	1.00	1.00	**33.5**
1915–16	.87	2.30	25.3	57.5	110	118	95.8	54.1	11.1	2.58	1.35	1.38	**39.9**
1916–17	2.74	4.29	24.8	7.59	65.3	48.2	118	85.4	25.8	1.88	.99	1.07	**31.8**
1917–18	1.24	2.99	3.47	3.07	16.7	65.1	83.7	25.0	2.40	.52	.38	2.99	**17.2**
1918–19	3.27	6.86	4.59	9.00	66.6	49.3	104	44.5	3.23	1.02	.70	1.05	**24.1**
1919–20	3.10	4.03	8.83	5.92	6.04	35.7	76.1	47.7	5.89	1.12	.70	1.08	**16.4**
1920–21	4.03	52.1	58.1	85.2	59.7	91.8	62.9	50.1	9.92	1.07	.58	.76	**39.6**
1921–22	1.41	2.67	14.2	14.2	46.2	54.8	78.3	135	61.8	5.97	1.92	1.00	**34.7**
1922–23	3.52	8.39	46.7	33.6	22.5	26.6	67.4	35.9	7.87	3.21	.75	1.24	**21.5**
1923–24	2.69	2.12	2.39	5.31	23.4	6.76	-12.2	1.78	.86	.23	.24	.28	**4.76**
1924–25	7.98	5.92	10.5	16.3	108	50.4	71.2	30.7	11.3	1.60	1.22	1.19	**25.7**
1925–26	2.20	4.14	7.67	10.9	60.2	25.2	52.6	9.50	1.92	.48	.50	.57	**14.3**
1926–27	2.71	45.5	25.6	35.7	135	70.9	89.9	46.2	10.4	2.63	.61	.74	**38.0**
Av.	2.62	9.70	17.0	34.8	56.6	50.0	82.0	56.3	14.0	1.92	.82	1.09	**25.7**

Goodyear Creek at Goodyear Bar

[Drainage area, 12.2 square miles]

1910–11	-------	9.8	32.2	146	175	354	236	154	62.5	10.0	5.2	5.0	-------
1911–12	5.0	7.1	5.0	14.9	16.9	32.7	48.7	81.3	20.8	6.2	4.5	4.7	**20.7**
1912–13	4.9	17.6	7.8	17.2	32.7	34.8	110	87.7	20.0	6.8	5.0	4.1	**28.9**
1913–14	4.18	12.4	58.5	206	110	131	138	74.6	16.1	4.81	2.26	2.0	**63.2**
1914–15	3.11	2.65	3.61	13.7	85.3	81.2	130	166	34.9	10.5	6.34	3.97	**44.9**
1915–16	4.69	8.09	34.1	63.1	149	175	156	92.9	23.4	9.28	4.27	3.91	**59.9**
1916–17	6.39	10.8	36.2	16.7	81.7	82.2	173	133	45.9	10.6	4.71	4.20	**50.1**
1917–18	3.87	7.00	10.8	8.19	33.5	97.6	130	46.6	8.07	3.08	2.08	5.91	**29.6**
1918–19	10.3	14.5	8.97	16.1	106	82.2	175	82.1	10.8	7.55	6.06	5.37	**43.1**
1919–20	6.32	8.00	19.2	15.2	14.3	61.7	114	72.5	12.4	4.94	3.00	4.07	**28.0**
1920–21	8.16	85.2	85.1	125	86.4	138	105	84.5	26.5	6.84	4.84	5.33	**63.3**
1921–22	8.35	10.4	22.0	17.6	42.5	46.3	95.7	187	80.4	12	6	6	**44.5**
1922–23	8.52	17.1	61.0	48.8	39.2	54.8	106	43.0	16.9	7.32	5.09	5.17	**34.4**
1923–24	3.81	6.23	7.56	11.5	34.0	9.18	23.8	4.52	3.14	2.46	1.84	3.23	**9.14**
1924–25	11.9	12.2	20.7	29.0	150	61.4	90.7	47.4	17.3	6.16	6.78	6.62	**37.5**
1925–26	7.87	18.8	20.8	18.6	79.6	47.0	75.7	20.4	7.63	4.42	3.23	3.69	**25.2**
1926–27	8.61	65.7	33.4	49.1	209	109	135	73.6	20.0	8.48	4.68	2.95	**58.8**
Av.	6.62	18.4	27.5	48.0	85.0	94.0	120	85.4	25.1	7.14	4.46	4.48	**40.1**

Canyon Creek above Jackson Creek

1925–26	-------	-------	-------	28.2	58.4	75.0	208	151	31.5	14.3	13.7	13.2	-------
1926–27	10.4	136	50.6	67.9	134	83.7	148	306	321	52.4	49.1	42.7	**116**

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

Canyon Creek below Bowman Lake

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1925–26	-------	-------	-------	44.1	124	152	321	217	-------	-------	14.6	14.3	-------
1926–27	-------	-------	-------	-------	98.5	166	246	198	7.79	5.87	4.80	2.70	-------

Jackson Creek at mouth

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1925–26	-------	-------	-------	-------	16.4	29.6	67.7	22.6	4.56	9.70	1.94	1.09	-------
1926–27	1.46	12.7	13.1	18.3	40.7	32.0	53.6	85.5	39.5	7.37	3.00	3.80	25.8

Bear River near Colfax

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1911–12	-------	62.2	30.3	131	63.2	118	151	251	130	9.13	10.1	31.4	-------
1912–13	12.7	120	65.7	287	201	127	478	195	35.1	0	0	0	126
1914–15	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	79.2	-------
1915–16	71.8	126	255	1,090	1,350	1,110	283	165	159	109	102	89.7	407
1916–17	121	135	-------	-------	943	458	618	292	98.0	-------	-------	-------	-------

Bear River at Van Trent

[Drainage area, 263 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1904–5	-------	217	421	888	861	1,040	564	596	193	37.1	38.1	37.3	-------
1905–6	32.2	23.8	39.8	2,320	1,200	3,000	1,180	737	608	113	26.5	26.1	776
1906–7	26.7	90.7	1,310	1,300	2,810	4,450	1,300	404	282	84.7	39.7	38.0	1,010
1907–8	44.5	51.0	363	731	535	553	316	280	142	40.8	30.0	31.8	260
1908–9	52.1	54.2	145	4,820	2,160	748	409	166	88.7	46.8	37.2	40.0	731
1909–10	53.6	269	979	914	709	788	302	117	48.4	24.5	21.0	22.7	354
1910–11	35.5	46.2	105	3,600	1,580	1,910	726	278	124	45.4	40.8	34.4	710
1911–12	50.2	65.8	34.9	210	118	286	262	297	71.0	15.2	13.1	22.2	121
1912–13	27.0	177	123	490	148	203	346	139	49.2	27.6	17.9	17.6	147
1913–14	21.7	73.7	834	3,820	2,010	813	581	283	168	143	143	166	750
1914–15	179	179	184	481	3,190	813	609	1,740	331	149	58.2	120	653
1915–16	137	171	959	3,320	2,870	1,740	581	350	259	198	152	139	902
1916–17	165	185	726	400	1,910	834	893	377	167	42.6	18.4	40.5	470
1917–18	19.7	35.2	40.8	35.4	395	950	361	165	82.7	10.2	10.4	29.8	177
1918–19	44.3	197	198	172	2,350	1,230	670	206	70.2	26.3	10.4	7.9	418
1919–20	16.9	18.4	136	54.0	62.3	538	542	128	83.2	7.77	10.0	7.20	134
1920–21	25.1	541	1,740	2,130	1,450	1,120	381	215	106	32.6	11.4	15.5	645
1921–22	23.5	23.1	441	360	2,700	1,570	1,020	564	187	40.5	13.6	18.7	565
1922–23	51.4	173	1,670	1,130	658	472	1,150	329	224	93.6	47.7	34.0	503
1923–24	38.0	27.0	38.2	56.9	97.8	55.6	51.3	5.38	6.9	2.9	2.8	2.77	31.9
1924–25	27.3	42.1	141	95.4	1,630	664	857	290	154	91.7	65.0	31.2	331
1925–26	28.0	34.5	56.6	164	1,670	312	1,130	263	31.7	18.8	63.7	48.2	307
1926–27	19.2	556	149	665	3,660	786	1,480	93.0	52.4	77.2	79.5	123	621
Av.	50.8	142	471	1,220	1,510	1,080	683	349	153	59.5	41.3	45.8	483

Bear River Canal near Colfax

[Drainage area, 257 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1911–12	-------	-------	-------	29.1	29.7	19.9	29.3	45.8	50.5	50.3	51.9	42.0	-------
1912–13	30.6	-------	-------	-------	-------	-------	-------	72.9	66.3	61.6	60.1	57.8	-------
1913–14	-------	-------	-------	-------	-------	-------	31.8	69.8	79.2	104	93.1	89.7	-------
1914–15	55.0	48.9	55.2	59.0	28.1	54.9	79.6	58.4	80.2	103	75.3	82.8	65.3
1915–16	88.7	63.4	49.2	28.8	21.9	0	27.2	90.5	154	185	166	129	83.8
1916–17	67.9	36.1	95.1	157	171	212	173	213	235	173	177	172	157
1917–18	197	161	119	82.2	143	101	232	236	226	162	167	137	164
1918–19	199	238	243	175	186	225	251	266	233	168	176	138	208
1919–20	95.9	92.6	130	157	134	219	238	259	209	236	243	205	185
1920–21	153	257	252	249	193	251	267	275	256	230	237	223	237
1921–22	221	203	155	116	211	257	170	276	273	236	245	277	220
1922–23	241	171	137	1.8	3.9	192	236	275	261	228	238	256	188
1923–24	255	206	126	85.2	171	102	74.4	190	203	231	212	93.7	163
1924–25	40.1	105	281	257	265	251	286	278	285	285	257	246	236
1925–26	185	155	133	136	79.0	43.9	169	262	286	296	300	294	196
1926–27	222	104	188	240	129	109	252	261	300	296	293	300	225
Av.	147	142	151	127	126	146	168	196	200	190	187	171	179

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

North Fork of American River near Colfax

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	------	------	------	------	------	------	------	------	------	------	------	100	------
1911–12	95.3	104	83.8	197	188	393	643	1,330	736	141	70.5	------	------
1912–13	------	------	152	382	401	532	1,330	1,370	496	153	82.6	60.8	------
1913–14	55.7	113	------	------	------	1,650	1,980	2,120	1,090	261	84.6	65.4	------
1914–15	81.9	75.8	125	325	1,900	1,330	1,900	3,420	1,600	281	91.1	73.1	925
1915–16	64.1	77.8	287	1,400	2,250	2,770	2,290	1,870	1,200	264	78.4	69.2	1,050
1916–17	85.4	107	583	332	1,720	1,050	2,130	2,100	1,470	246	84.8	66.2	823
1917–18	50.3	62.3	103	88.4	355	1,130	1,550	1,060	365	87.1	55.1	103	417
1918–19	172	182	172	205	1,440	1,220	2,080	1,790	330	99.4	74.9	57.3	645
1919–20	51.4	47.8	197	122	136	722	1,330	1,180	423	102	56.9	51.6	368
1920–21	99.0	623	957	1,450	1,230	1,860	1,540	1,600	985	191	72.0	62.3	887
1921–22	59.7	61.8	311	359	1,530	1,270	1,750	3,300	1,990	298	81.1	66.9	918
1922–23	72.5	230	1,350	776	696	804	1,910	1,800	838	264	60.3	71.7	739
1923–24	81.8	62.8	72.8	102	465	181	508	268	32.0	22.1	21.9	24.3	152
1924–25	61.3	210	347	354	2,250	992	1,980	1,640	608	155	75.1	57.7	715
1925–26	58.2	75.8	144	245	1,110	786	1,520	623	167	63.0	46.0	45.1	401
1926–27	53.8	847	487	834	3,250	1,370	2,710	1,980	1,210	226	76.9	61.6	1,070
Av.	76.2	192	358	478	1,260	1,130	1,700	1,720	846	178	69.5	64.8	701

American River at Fairoaks

[Drainage area, 1,910 square miles]

1904–5	------	------	1,000	3,270	4,230	6,150	6,880	6,120	3,010	695	270	138	------
1905–6	147	194	254	7,260	5,930	14,200	12,100	15,100	16,000	6,340	1,020	419	6,580
1906–7	298	563	3,970	4,150	14,800	24,700	15,600	12,200	11,100	5,510	1,500	813	7,930
1907–8	693	821	1,790	2,600	1,960	3,290	4,490	4,590	2,600	870	200	123	2,000
1908–9	384	441	576	24,300	15,500	6,460	7,990	9,510	7,650	2,310	607	287	6,330
1909–10	511	4,590	7,670	8,520	5,240	10,500	10,500	7,950	2,260	516	213	201	4,900
1910–11	342	538	1,600	13,900	10,600	13,000	15,100	14,500	17,700	3,200	459	304	7,600
1911–12	350	430	400	1,130	800	1,920	2,870	6,840	4,470	830	209	330	1,740
1912–13	243	1,470	599	1,570	1,290	1,750	6,040	7,210	2,550	614	283	154	1,980
1913–14	155	487	2,150	17,100	7,010	8,110	9,420	11,700	6,590	2,110	451	191	5,460
1914–15	332	375	681	1,550	9,210	4,650	8,510	15,500	8,030	1,770	391	225	4,230
1915–16	217	378	1,310	7,740	10,200	13,100	11,800	9,870	6,710	1,970	340	220	5,300
1916–17	626	651	2,010	1,590	7,330	4,470	9,230	10,300	8,920	1,680	372	198	3,910
1917–18	185	181	520	284	2,230	5,090	7,400	5,000	1,940	322	69.9	415	1,960
1918–19	940	805	778	677	6,500	5,110	9,440	9,660	1,610	269	139	134	2,980
1919–20	159	151	688	633	650	3,870	6,070	7,140	2,720	547	178	157	1,920
1920–21	564	2,560	4,420	7,700	5,680	8,690	7,260	8,570	6,240	1,240	326	246	4,450
1921–22	399	785	2,210	1,910	6,690	5,500	8,190	16,600	11,300	1,600	358	264	4,620
1922–23	499	1,030	6,490	4,360	3,160	3,550	9,510	9,960	4,680	1,580	351	377	3,800
1923–24	646	468	470	619	2,000	879	2,000	1,490	206	26.8	15.8	24.4	731
1924–25	234	965	1,610	1,520	10,900	5,180	10,200	9,810	4,340	1,080	324	283	3,810
1925–26	438	542	893	793	4,660	3,150	7,980	3,210	812	247	168	206	1,900
1926–27	353	2,920	2,250	3,620	13,900	7,170	12,200	9,780	6,930	1,240	381	329	5,010
Av.	396	970	1,930	5,080	6,540	6,980	8,730	9,240	6,020	1,590	375	263	4,050

Middle Fork of American River near East Auburn

1911–12	------	141	148	326	340	757	1,090	3,820	1,960	298	97.3	146	------
1912–13	95.9	557	308	921	517	550	3,530	4,970	1,490	367	187	75.4	1,130
1913–14	69.8	180	966	7,680	3,470	2,390	6,770	5,600	3,400	897	150	68.8	2,630
1914–15	73.0	91.9	321	801	6,120	4,770	4,550	9,560	3,170	471	203	94.4	2,490
1915–16	50.9	173	795	1,910	3,910	5,370	5,270	4,270	2,830	747	175	101	2,130
1916–17	222	243	874	452	2,140	1,700	4,420	4,660	3,840	664	163	92.5	1,610
1917–18	84.0	125	226	200	643	1,830	3,170	2,510	1,160	153	67.2	164	860
1918–19	337	326	286	306	2,210	1,850	5,230	3,760	665	151	73.2	63.2	1,260
1919–20	93.0	85.8	348	260	286	1,350	2,900	3,380	1,110	191	64.8	55.4	845
1920–21	195	1,190	1,440	2,430	2,050	3,520	3,250	3,680	2,560	485	111	79.6	1,750
1921–22	90.2	106	409	496	1,820	2,040	3,610	7,260	4,600	637	125	80	1,770
1922–23	200	406	2,610	1,590	1,270	1,870	3,840	4,230	1,810	724	145	114	1,570
1923–24	201	108	136	222	840	353	1,010	738	108	43.2	30.0	25.4	315
1924–25	122	357	627	596	3,610	1,900	3,960	3,560	1,580	429	120	90.1	1,390
1925–26	128	161	319	279	1,570	1,570	3,150	1,340	366	89.4	43.4	37.3	746
1926–27	75.7	1,230	790	1,440	5,150	2,840	5,080	4,470	2,960	581	137	88.5	2,040
Av.	136	343	663	1,240	2,250	2,170	3,800	4,240	2,100	433	118	86.0	1,500

Monthly discharge, in second-feet, at station in the Sacramento River Basin, Calif.—Continued

Rubicon River at Rubicon Springs

[Drainage area, 31.6 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1909–10	-------	-------	-------	-------	68.3	157	258	388	138	44.7	3.5	13.1	-------
1910–11	1.0	44.8	78.7	47.3	43.9	65.0	210	446	861	280	41.2	6.1	-------
1911–12	4.7	10.4	5.89	9.97	12.0	20.6	71.1	343	362	83.5	12.2	16.1	-------
1912–13	3.9	52.3	11.3	13.9	32.4	49.3	181	431	227	77.8	21.7	3.7	92.3
1913–14	1.4	7.95	33.6	118	75	124	-------	-------	-------	-------	-------	-------	-------

Rubicon River near Quintette

[Drainage area, 198 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1909–10	-------	-------	968	554	428	1,130	1,880	1,400	469	102	17.2	21.2	-------
1910–11	20.5	137	431	601	591	881	1,880	2,330	3,230	783	127	37.7	-------
1911–12	32.4	46.1	38.1	68.0	119	256	512	1,700	1,020	247	57.2	74.0	-------
1912–13	18.4	306	105	98.5	208	325	1,110	1,910	748	216	64.1	18.3	428
1913–14	9.5	54	296	1,180	749	1,240	1,870	2,770	-------	-------	-------	-------	-------

Little Rubicon River near Rubicon Springs

[Drainage area, 7 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910–11	-------	10.2	40.5	21.9	27.6	21.3	52.6	98.3	208	47.7	4.0	-------	-------

Little South Fork of Rubicon River at South Fork sawmill, near Quintette

[Drainage area, 16.6 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1909–10	-------	-------	-------	-------	55.3	105	161	99.5	18.3	1.58	0	0.41	-------
1910–11	1.77	6.85	25.9	58.4	63.0	67.0	179	265	274	29.6	3.4	1.1	-------
1911–12	2.7	4.3	8.2	9.2	11.5	14.6	48.2	169	77.8	5.5	1.0	3.7	-------
1912–13	1.9	25.7	9.6	8.5	17.5	25.7	102	164	50.7	9.15	2.43	1.5	34.9
1913–14	1.03	5.0	41.6	70.9	44.9	115	179	225	89.4	-------	-------	-------	-------

Little South Fork of Rubicon River below Gerle Creek, near Quintette

[Drainage area, 49.6 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1909–10	-------	-------	-------	-------	116	352	452	257	30.4	5.2	4.9	6.0	-------
1910–11	9.4	14.1	90.5	137	195	226	541	752	682	56.6	8.8	15.1	-------
1911–12	15.3	21.8	22.5	11.7	17.4	39.5	125	440	172	24.0	22.6	5.3	-------
1912–13	4.4	62.2	13.1	13.9	46.7	77.5	276	437	93.3	11.1	5.2	4.0	87.1
1913–14	3.89	4.5	68.3	176	116	360	488	659	-------	-------	-------	-------	-------

Little South Fork of Rubicon River at mouth, near Quintette

[Drainage area, 57.8 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1909–10	-------	-------	260	204	158	380	476	292	49.6	5.9	3.9	7.4	-------
1910–11	12.0	15.2	120	191	248	298	692	841	736	103	39.7	18.0	-------
1911–12	12.8	24.3	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

Little South Fork ditch at sawmill, near Quintette

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1909–10	-------	-------	-------	-------	-------	-------	-------	-------	-------	7.4	11.8	12.8	-------
1910–11	10.4	0.24	0	0	0	0	0	0	0	9.5	12.7	10.1	-------
1911–12	9.52	10.7	-------	-------	-------	-------	-------	-------	-------	14.3	18.2	22.0	-------
1912–13	17.0	0	0	0	0	0	0	0	5.0	15.3	21.4	17.8	-------
1913–14	9.66	1.33	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

Gerle Creek near Rubicon Springs

[Drainage area, 9 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1909–10	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	17.8	18.1	-------
1910–11	19.5	5.2	25.4	18.0	31.8	35.4	72.3	88.5	107	5.69	21.2	15.0	-------
1911–12	15.5	16.1	18.1	3.2	2.5	3.8	3.0	-------	37.7	12.9	28.0	-------	-------

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

Pilot Creek near Quintette

[Drainage area, 18.7 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1909-10	-------	-------	-------	-------	-------	156	105	29.8	8.9	7	7	8.1	-------
1910-11	7.7	4.9	9.2	123	98.4	127	246	117	45.9	11	6	5.7	-------
1911-12	10.6	15.1	8.5	18.6	8.1	9.2	30.5	63.6	16.5	10.9	9.9	15.1	-------
1912-13	11.3	12.7	8.6	19.6	18.0	23.7	86.7	37.3	13.4	9.1	9.3	5.5	21.2
1913-14	4.5	6.0	31.7	267	132	-------	-------	-------	-------	-------	-------	-------	-------

Pilot Creek ditch near Quintette

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1909-10	-------	-------	-------	-------	-------	11.8	6.6	12.8	11.9	8.8	8.9	12.3	-------
1910-11	13.1	6.2	7.6	2.6	0	0	0	0	5.2	10.5	8.1	10.9	-------
1911-12	12.2	12.1	3.56	1.64	7.44	10.5	10.7	13.5	13.7	14.4	14.5	16.3	-------
1912-13	12.0	7.8	5.8	0	0	2.1	7.4	9.2	12.1	14.0	18.5	17.0	8.9
1913-14	11.4	10.2	10.7	18.5	-------	-------	-------	-------	-------	-------	-------	-------	-------

South Fork of American River below Silver Fork, at Kyburz

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1905-6	-------	-------	-------	-------	-------	385	810	1,830	2,870	1,480	-------	-------	-------

South Fork of American River at Kyburz

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1905-6	-------	-------	-------	-------	-------	-------	-------	625	1,240	770	180	42.0	-------
1906-7	32.8	23.2	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
1922-23	-------	-------	-------	-------	-------	-------	-------	736	446	133	37.8	90.2	-------
1923-24	34.4	22.7	37.9	31.4	60.0	35.3	158	228	59.5	35.4	6.36	1.13	59.1

South Fork of American River near Kyburz

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1906-7	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	55.3	-------
1907-8	34.0	41.2	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
1922-23	33.4	22.5	87.3	82.0	83.1	247	741	1,580	906	301	30.5	55.0	348
1923-24	52.5	56.7	20.8	9.28	18.1	2.48	172	265	.76	.62	.70	.54	50.0
1924-25	8.28	23.8	31.7	19.1	295	342	904	1,560	1,050	187	9.08	1.10	369
1925-26	4.77	5.65	28.4	11.3	16.1	169	662	601	107	6.35	.58	.56	135
1926-27	2.50	127	73.7	126	304	461	861	1,580	1,480	258	2.81	8.95	439

South Fork of American River near Camino

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1922-23	-------	90.6	833	564	521	927	2,390	3,280	1,640	497	28.2	54.3	-------
1923-24	69.5	25.3	29.1	98.3	337	146	620	572	13.8	8.73	11.7	12.3	161
1924-25	41.4	224	334	305	1,830	1,260	2,940	3,360	1,990	407	62.9	33.3	1,060
1925-26	59.5	73.4	171	126	532	831	1,950	1,210	259	37.2	11.8	12.6	437
1926-27	16.1	475	349	605	2,120	1,790	3,030	3,370	2,820	509	68.6	62.3	1,260

South Fork of American River near Placerville

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1910-11	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	110	-------
1911-12	119	161	145	323	247	516	779	2,710	2,190	361	90.6	136	648
1912-13	91.2	365	196	355	384	518	1,840	2,900	1,210	328	124	72.3	699
1913-14	81.8	152	355	3,650	2,200	2,520	3,410	4,650	3,220	1,040	186	88.8	1,790
1914-15	146	147	212	408	1,820	1,500	2,910	4,360	3,560	905	168	106	1,350
1915-16	95.8	133	348	1,560	2,360	3,460	4,300	3,910	3,170	883	188	105	1,700
1916-17	339	260	736	494	1,770	1,310	3,010	4,020	4,480	901	154	112	1,460
1917-18	99.4	98.0	152	139	469	1,460	2,650	2,610	1,490	141	63.3	153	793
1918-19	296	264	213	228	1,410	1,390	3,080	4,070	754	123	91.8	85.7	996
1919-20	111	91.3	300	218	230	1,130	1,890	3,220	1,390	293	-------	-------	-------
Av.	153	186	295	808	1,210	1,530	2,650	3,610	2,380	553	133	108	1,180

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

Echo Lake flume near Vade

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1922–23	------	------	------	------	------	------	------	------	------	------	------	7.2	------
1923–24	------	------	------	------	------	------	------	------	5.90	2.28	5.57	.01	------
1924–25	------	------	------	------	------	------	------	------	------	------	------	------	------
1925–26	------	------	------	------	------	------	------	------	------	------	8.65	.02	------
1926–27	------	------	------	------	------	------	------	------	------	.43	15.0	9.35	------

Medley Lakes outlet near Vade

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1922–23	24.6	------	------	------	------	------	------	------	26.4	2.90	19.0	55.1	------
1923–24	8.25	0.74	6.62	4.0	0.5	1.0	3.05	6.14	38.2	35.4	1.25	.1	8.80
1924–25	.52	------	------	------	------	------	------	------	64.9	49.3	45.1	54.8	------
1925–26	5.21	------	------	------	------	------	------	13.7	35.6	88.2	3.82	0	------
1926–27	.21	2.91	1.03	.4	5	52	12	25	36.5	43.8	42.9	60.8	23.6

Silver Lake outlet near Kirkwood

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1922–23	26.8	19.9	------	------	------	------	46.0	164	95.5	25.6	7.55	0.16	------
1923–24	.20	.20	5.15	28.0	10.6	0.10	.20	56.6	5.11	28.7	25.1	1.18	13.6
1925–26	39.8	7.74	7.77	1.39	.20	.18	84.1	85.4	24.7	15.1	38.4	3.89	25.9
1926–27	.24	5.40	6.99	24.6	28.0	28.0	36.8	179	202	20.8	42.3	30.1	50.3

Silver Fork of South Fork of American River near Kyburz

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1923–24	------	------	------	------	------	------	------	------	------	------	------	56.5	------
1924–25	42.3	63.1	70.5	75.9	213	230	540	772	462	129	60.9	29.7	224
1925–26	59.1	57.2	57.7	66.8	42.9	145	405	314	133	49.3	114	118	130
1926–27	65.9	106	82.0	114	204	267	507	780	644	159	74.9	76.3	256

Twin Lakes outlet and spillway (combined) near Kirkwood

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1922–23	1.47	1.36	1.20	4.30	4.30	5.01	29.3	126	134	86.5	13.8	1.69	34.2
1923–24	21.4	9.41	1.54	.2	.20	.60	1.00	1.00	10.10	.20	40.2	48.9	11.2
1924–25	28.2	17.1	7.39	7.46	.20	.25	.79	.82	130	54.7	40.4	2.08	24.2
1925–26	7.79	33.0	25.4	45.1	2.54	.57	1.93	63.8	53.7	15.7	63.8	98.8	34.5
1926–27	54.2	28.2	10.1	2.12	.40	.58	.57	46.8	154	61.2	8.88	22.6	32.5

El Dorado Canal near Kyburz

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1922–23	40.9	36.7	33.4	39.9	36.5	40.3	0	20.7	49.5	52.3	53.5	51.6	38.0
1923–24	29.5	1.3	38.1	67.5	104	74.1	115	124	98.7	79.4	76.9	54.7	71.8
1924–25	43.1	85.6	79.1	104	88.2	87.4	93.8	109	134	150	137	108	102
1925–26	93.1	84.2	78.7	85.2	83.2	110	130	108	148	152	137	128	112
1926–27	77.1	66.3	81.4	82.4	85.9	88.4	97.4	116	138	148	146	147	106

Alder Creek near Whitehall

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1922–23	1.44	2.27	47.9	36.5	22.1	53.7	147	94.7	25.6	4.54	0.88	0.75	36.5
1923–24	1.04	1.00	1.10	3.30	17.1	5.22	14.7	5.06	.55	.19	.11	.13	4.05
1924–25	.69	7.38	13.3	16.0	95.6	80.4	162	98.4	23.2	4.20	.95	.41	41.4
1925–26	.79	1.62	2.34	5.32	22.9	47.7	97.9	19.2	3.23	.67	.25	.21	16.7
1926–27	.37	18.8	24.9	29.0	103	118	171	115	30.0	4.06	1.21	.49	50.8

Plum Creek near Riverton

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1922–23	------	1.8	52.1	18.3	16.2	17.4	45.3	6.50	1.60	0.5	0.3	0.75	------
1923–24	0.45	.50	1.78	2.00	6.57	.92	2.17	.47	.22	.11	.15	.23	1.27
1924–25	.60	2.11	5.77	3.55	39.3	18.1	42.7	9.65	3.17	.72	.26	.21	10.3
1925–26	.48	.78	1.05	2.31	17.9	7.57	18.3	2.35	.65	.21	.18	.20	4.21
1926–27	.26	8.08	3.96	13.3	54.9	24.2	44.7	7.79	1.75	.47	.26	.26	13.0

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

Silver Creek at Union Valley

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1924–25	12.4	72.6	90.0	100	570	340	649	825	420	78.7	11.6	7.88	262
1925–26	20.9	37.9	64.2	63.5	128	282	528	280	49.7	6.67	3.20	2.79	122
1926–27	6.33	131	112	156	373	390	676	846	644	97.0	11.6	6.97	286

Silver Creek near Placerville

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1921–22	-------	-------	-------	152	223	310	868	2,250	1,350	214	70.2	54.2	-------
1922–23	54.2	88.3	401	291	251	466	1,130	1,330	631	226	60.2	51.8	416
1923–24	80.0	54.1	56.7	74.7	237	143	362	280	49.1	17.6	12.4	12.8	114
1924–25	40.7	141	211	201	976	684	1,300	1,390	750	191	47.5	38.7	493
1925–26	62.5	89.4	148	118	297	496	928	485	116	31.3	22.0	19.7	233
1926–27	28.9	297	242	381	1,040	896	1,330	1,450	1,110	258	60.7	37.7	589

South Fork of Silver Creek at Ice House

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1921–22	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	9.6	3.0	-------
1924–25	3.61	23	30	32.8	91.7	83.4	207	383	232	63.7	6.82	2.46	96.5
1925–26	7.39	8.27	20.5	10.1	18.7	73.7	199	147	39.2	3.30	.63	.53	44.0
1926–27	1.13	35.7	29.1	39.4	70.4	79.3	165	348	345	77.9	9.66	1.76	100

Finnon reservoir outlet near Placerville

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1922–23	3.30	4.06	10.2	6.58	7.32	6.35	8.95	7.85	3.04	4.26	4.20	2.75	5.73
1923–24	4.40	4.69	5.07	5.55	3.53	5.66	4.89	4.19	1.94	.07	1.34	1.67	3.59
1924–25	1.10	3.92	3.22	.59	10.6	5.33	8.02	3.65	3.97	3.21	3.19	3.33	4.11
1925–26	3.86	4.53	4.88	4.89	7.93	4.58	7.43	4.42	8.95	.14	0	0	4.26
1926–27	3.51	2.53	4.43	2.92	13.1	5.37	7.72	3.77	5.88	2.39	.19	7.65	4.88

Western States Gas & Electric Co.'s flume near Camino

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1922–23	-------	104	105	104	105	105	105	105	106	106	101	104	-------
1923–24	107	106	105	102	107	107	107	108	83.6	42.0	38.8	41.2	87.7
1924–25	51.7	58.4	74.3	93.0	107	65.5	24.0	84.3	106	116	111	108	83.3
1925–26	113	109	106	109	108	106	105	105	110	106	87.4	90.7	105
1926–27	86.5	87.4	103	104	105	104	107	105	110	107	102	102	102

Cache Creek at Lower Lake

[Drainage area, 500 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1900–1901	-------	-------	-------	460	722	832	587	461	330	213	126	55.4	-------
1901–2	28.8	23.3	63.8	64.7	422	1,750	1,440	897	569	389	261	182	508
1902–3	147	277	319	409	766	786	740	533	336	208	111	48.8	390
1903–4	21.3	53.6	168	230	588	2,510	2,660	1,460	762	483	302	188	786
1904–5	166	143	162	486	913	955	1,000	721	501	323	195	102	472
1905–6	56.0	30.3	30.7	328	696	1,220	1,510	907	659	450	285	165	528
1906–7	107	80.2	146	404	850	1,790	2,450	1,360	766	466	290	174	740
1907–8	119	96.7	129	292	634	726	566	381	228	132	71.5	26.2	283
1908–9	9.7	8.0	14.0	1,120	3,940	3,010	1,860	949	598	395	235	133	1,020
1909–10	90.4	86.0	163	253	462	555	576	402	248	132	66.5	18.4	254
1910–11	7.4	4.5	5.3	42.9	392	1,160	918	639	438	268	146	71.2	341
1911–12	45.7	35.3	27.6	40.4	77.2	138	155	138	94.9	48.4	13.8	8.8	68.5
1912–13	4.91	9.10	19.8	147	272	248	252	202	133	71.5	29.3	1.1	115
1913–14	3.21	1.75	59.7	1,780	2,960	2,100	1,040	696	492	314	190	111	800
1914–15	77.3	64.4	83.7	202	2,670	1,280	1,480	818	628	410	245	150	746
1915–16	101	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Av.	65.6	65.2	99.4	417	1,090	1,340	1,150	704	452	287	171	95.7	504

Monthly discharge, in second-feet, at stations in the Sacramento River Basin, Calif.—Continued

Cache Creek at Yolo

[Drainage area, 1,230 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1902–3	------	------	------	1,070	1,730	1,530	1,240	670	351	83.2	1.0	0.0	------
1903–4	0.0	410	295	235	3,230	4,630	3,190	1,660	676	323	105	55.8	1,230
1904–5	253	108	474	2,080	2,130	1,970	1,580	1,060	542	214	85.8	6.9	875
1905–6	.32	0	0	2,250	1,700	3,270	2,440	1,300	784	333	166	69.4	1,030
1906–7	13.6	0	652	1,750	2,360	5,380	3,580	1,430	747	421	189	36	1,380
1907–8	40.1	67.5	188	792	1,950	1,270	662	310	66.6	4.48	.03	0	446
1908–9	0	0	0	5,390	8,450	4,040	2,070	908	496	240	86.3	7.17	1,810
1909–10	18.6	32.6	391	766	890	1,010	727	317	31.3	.58	0	0	349
1910–11	0	0	0	988	1,140	3,870	1,160	626	319	109	10.3	4.3	685
1911–12	.1	0	0	51.9	51.4	306	116	82.2	.5	0	0	0	50.9
1912–13	0	0	33.8	691	355	38.6	90.7	4.66	0	0	0	0	99.9
1913–14	0	31.4	1,340	7,450	5,330	2,850	1,460	746	305	116	16	6.7	1,620
1914–15	14	60.5	128	1,200	7,360	3,730	2,410	1,370	529	207	49.1	9.16	1,380
1915–16	3.03	26.9	690	4,400	2,930	2,080	994	200	22.5	6.55	3.52	2.91	943
1916–17	7.48	37.6	108	371	1,410	386	129	23.6	19.5	6.04	0	2.23	200
1917–18	15.5	19.6	20.4	18.2	185	210	32.2	1.09	0	0	0	12.6	42.1
1918–19	12.5	4.79	7.37	133	891	684	89.8	0	0	0	0	0	147
1919–20	0	0	0	0	0	0	48.1	0	0	0	0	0	3.94
1920–21	0	194	934	2,770	2,280	314	58.3	10.4	2.77	0	0	0	538
1921–22	2.15	0	147	70.5	1,030	351	144	4.84	0	0	0	0	140
1922–23	0	37.9	540	425	217	59.7	236	25.0	0	0	0	0	128
1923–24	.13	.21	.15	9.53	93	0	0	0	0	0	0	0	8.22
1924–25	0	0	107	62.9	1,960	186	644	1,000	127	11.6	0	12.5	331
1925–26	15.9	0	0	95.3	1,580	134	1,530	39.7	.20	0	0	0	272
1926–27	0	378	561	1,050	5,560	2,300	1,790	73.9	3.0	0	0	0	943
Av.	16.5	58.7	276	1,360	2,190	1,620	1,060	474	201	83.0	28.5	9.00	611

Putah Creek near Guenoc

[Drainage area, 91 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1903–4	------	------	------	------	------	2,000	284	89.2	31.1	16.3	10.6	13.0	------
1904–5	79.8	42.1	542	1,280	619	629	288	120	85.0	12.4	8.8	10.0	310
1905–6	15.2	10.0	21.9	1,930	727	916	302	215	165	26.8	------	------	------

Putah Creek at Winters

[Drainage area, 805 square miles]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1905–6	10	12.5	20.4	3,450	1,370	3,120	935	387	250	53.3	22.7	14.7	804
1906–7	13.7	30.6	738	2,320	1,860	5,150	919	230	110	39.9	16.3	15.1	954
1907–8	17.7	24.7	197	808	1,390	662	130	64.7	27.6	7.32	5.35	3.55	278
1908–9	3.61	6.73	138	7,370	5,500	1,180	437	137	72.6	23.5	11.1	10.6	1,240
1909–10	16.2	59.1	745	1,120	644	762	300	87.7	26.3	7.85	5.27	2.67	326
1910–11	3.24	7.98	34.7	2,390	1,520	3,470	535	------	------	------	------	------	------
1911–12	9.9	15.6	23.5	238	75.3	392	91.4	------	------	2.99	.47	------	------
1912–13	3.68	148	106	1,470	156	135	136	34.1	6.68	.13	0	0	184
1913–14	0	117	2,600	7,710	2,990	754	436	162	64.9	21	8.5	7.1	1,240
1914–15	8.9	9.1	157	1,870	6,770	1,770	705	679	155	53.1	29.5	13.9	980
1915–16	10.1	21.1	1,340	6,770	1,800	1,130	333	147	68.0	17.1	9.45	8.51	977
1916–17	12.6	15.5	468	411	3,040	565	283	96.9	25.3	5.47	2.93	2.08	393
1917–18	1.42	3.32	21.9	19.1	670	629	140	25.8	2.69	.11	0	0	123
1918–19	0	2.14	37.2	448	3,580	1,190	162	54.0	6.19	.27	0	0	436
1919–20	0	0	24.9	16.0	12.8	171	429	53.0	.36	0	0	0	58.7
1920–21	0	1,050	1,940	3,760	965	448	180	69.6	17.4	1.60	0	0	705
1921–22	0	0	562	139	2,370	578	247	64.9	14.5	.68	0	0	317
1922–23	0	221	2,290	885	416	151	528	73.3	19.2	2.45	0	0	384
1923–24	0	0	2.9	53.4	557	37.7	12.5	1.11	0	0	0	0	53.2
1924–25	0	135	421	168	3,880	458	531	367	104	10.0	.14	0	482
1925–26	0	.78	15.8	581	3,000	236	2,030	116	23.5	1.81	0	0	479
1926–27	0	1,060	614	938	4,250	636	1,650	141	48.1	10.5	1.83	.07	752
Av.	5.05	134	568	1,950	2,130	1,070	507	150	52.1	12.3	5.41	3.91	558

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