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CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

1930

NATHAN C. GROVER, Chief Hydraulic Engineer

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N. C. GROVER, Chief Hydraulic Engineer

SURFACE WATER SUPPLY OF MINOR SAN FRANCISCO BAY, NORTHERN PACIFIC, AND GREAT BASINS IN 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 the Truckee River at Tahoe, and since that time it has gradually extended the work, as funds were made available, until it now has records of flow at a large number of points on California streams.

The records to June 30, 1912, for the drainage basins included in this report were published in Water-Supply Paper 300. Subsequent records are contained in the annual series of water-supply papers as follows:

	Water-Supply Papers		Water-Supply Papers		Water-Supply Papers
1912	330, 331	1917	460, 461	1923	570, 571
1913	360, 361	1918	480, 481	1924	590, 591
1914	390, 391	1919–20	510, 511	1925	610, 611
1915	410, 411	1921	530, 531	1926	630, 631
1916	440, 441	1922	550, 551	1927	650, 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 stations 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 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, hydroeconomics, and the use and distribution of water for agricultural purposes, and to that end, where possible and to the best interest 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 investigations 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 in the State was done 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 William 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.

MINOR SAN FRANCISCO BAY BASINS

COYOTE RIVER BASIN

The Coyote River rises on the sparsely wooded slopes of Pine Ridge on the east side of Santa Clara Valley. The surface of the drainage basin above the mouth of the canyon, opposite Madrone, is rough, and a considerable part of it has an altitude of more than 2,000 feet. The course of the Coyote River is peculiar in that three times on its way out of the mountains it doubles on itself by sharp turns. After leaving the mountains it hugs the east side of Santa Clara Valley for 7 or 8 miles and then passes through what is known as the lower gorge, about a mile below the station at Coyote. Here the Santa Clara Valley narrows to only 1,200 feet. Between 4 and 5 miles farther downstream the river passes behind the point of a projecting hill through what is known as The Narrows. Below The Narrows the valley recedes eastward, leaving the Coyote River 3 or 4 miles from its side. The stream continues its course through the broad level floor of the valley for about 18 miles and then enters the south end of San Francisco Bay.

ALAMEDA CREEK BASIN

Alameda Creek rises on the northern slope of Packard Ridge in Santa Clara County, 4 miles north of Mount Hamilton, at an altitude of 3,000 feet. The stream flows northwestward through Alameda County to the lower end of Sunol Valley, where it turns westward, follows Alameda Canyon for 6 miles to Niles, and enters San Francisco Bay 4 miles west of Alvarado.

The principal tributaries are Calaveras Creek, now regulated by the Spring Valley Water Co.'s reservoir at the outlet of Calaveras

Valley; San Antonio Creek, which drains La Costa Valley on the east; and Arroyo de la Laguna, which with its tributaries—Alamo Creek, Tassajero Creek, Arroyo Mocho, Arroyo las Positas, and Arroyo del Valle—drains Livermore and Amador Valleys. At the head of Alameda Canyon is the infiltration gallery of the Spring Valley Water Co., which supplies the aqueduct that serves the city of San Francisco.

The drainage area of Alameda Creek above the head of the débris cone at the mouth of the canyon at Niles is 634 square miles. Along the débris cone are many wells that furnish water for the irrigation of truck gardens and orchards. These wells receive their main supply through percolation from Alameda Creek.

SAN PABLO CREEK BASIN

San Pablo Creek rises near the western boundary of Contra Costa County, east of the Berkeley Hills, flows northwestward east of and parallel to San Pablo Ridge, and enters San Pablo Bay about 2½ miles west of San Pablo. An earth dam across San Pablo Creek in the canyon above San Pablo provides nearly complete regulation of this stream. This reservoir forms a part of the water-supply system of the eastern Bay cities.

NORTHERN PACIFIC BASINS

The principal streams that enter the Pacific Ocean in California north of San Francisco Bay are the Russian, Eel, Mad, Klamath, and Smith Rivers.

RUSSIAN RIVER BASIN

The Russian River rises in the eastern part of Mendocino County, on the western slope of the Coast Range, and flows southeastward to its junction with Santa Rosa Creek in Sonoma County, where it turns westward and enters the canyon through which it flows to the Pacific Ocean. The total length of the main river is about 100 miles.

The principal tributaries of the Russian River are the East Fork, Big Sulphur Creek, Dry Creek, Santa Rosa Creek, and Austin Creek—all very small except during the rainy season.

The Russian River Valley, in Sonoma County, is fertile and well cultivated. The climate is very equable throughout the year, and fruit raising is the important industry.

EEL RIVER BASIN

The Eel River rises on the western slope of the Coast Range, in the California National Forest, and drains parts of Lake, Trinity, Mendocino, and Humboldt Counties. From its junction with the Middle Eel at Two Rivers it flows northwestward about 110 miles to the Pacific Ocean. The principal tributaries below Two Rivers are the North Fork, the South Fork, and the Van Duzen River.

The lower part of the drainage area, below the mouth of the South Fork, is in the redwood belt. The remainder of the area is semiopen and contains very little merchantable timber except on a small tract near Grizzly Mountain. The lowlands are very fertile and well cultivated. The rolling and hilly lands are covered with grass and are used only for grazing.

The precipitation throughout the drainage area is very heavy during the winter.

MAD RIVER BASIN

The Mad River rises in the southern part of Trinity County and flows northwestward across Humboldt County to the Pacific Ocean. Its total length is about 90 miles.

The basin is very narrow, and the tributaries are small. The upper and lower parts contain good agricultural land; the middle part is suitable only for grazing.

During the rainy season the river is turbulent. In the upper part of its course its channel is practically dry during the summer, the water standing in pools; farther down flow continues throughout the year but is insufficient to irrigate all the land that is improved.

The lower course of the river is through the famous redwood belt; the upper part of the basin has only a fair forest cover consisting of scrubby timber without much brush.

KLAMATH RIVER BASIN

The Klamath River drains a territory lying east of the Cascade Range in south-central Oregon and south of the Siskiyou Mountains in California. The river rises in Upper Klamath Lake, flows generally southwestward, and empties into the Pacific Ocean at Requa, on the coast of northern California. Only that part of the basin lying in Oregon has been studied in detail. The drainage from this part of the area is collected in large lakes whose margins are wide, shallow marsh lands covered with tules and aquatic plants. From Upper Klamath Lake, which lies 4,141 feet above sea level, flows the Link River, a stream 1¼ miles long, discharging into Lake Ewauna at an altitude of 4,080 feet. Klamath Falls, the principal city of this section, is situated on the Link River. From Lake Ewauna to the town of Keno, a distance of 20 miles, the Klamath River flows through a flat, marshy country. About 5 miles above Keno the river is connected with Lower Klamath Lake by a channel known as Klamath Straits. About half a mile below Keno the river breaks over a rocky ledge and here begins its precipitous fall of 100 to 200 feet a mile to its mouth. The drainage area above Keno, exclusive of Lower Klamath Lake, is 3,150 square miles. The streams draining into Upper Klamath Lake rise about 6,000 feet above sea level. The altitude of Klamath Falls is 4,100 feet.

The principal tributaries of the Klamath River are the Sprague River, which drains the southwestern edge of the Great Basin divide in Oregon, and the Anna River, which heads in a large spring supposed to be fed by the waters of Crater Lake. The Williamson River, which drains the northern part of the Klamath Indian Reservation, is tributary to the Sprague River. The Lost River, although not a tributary of the Klamath, is usually considered with it, as a slough connects the two. Water formerly flowed either way, the direction depending on the heights of the streams, but the flow is now stopped by an artificial dike.

The mean annual rainfall at Klamath Falls, about 12 inches, fairly represents this section of the drainage area. A large part of this precipitation occurs as snow. As nearly all the streams are spring-fed and therefore rarely freeze, records of stream flow are little affected by ice.

Irrigation is practiced extensively in the upper part of the area, although dry farming has been fairly successful. The agricultural products consist chiefly of forage crops for stock and cattle, the country being well adapted to stock raising. Grains, alfalfa, and the hardier vegetables and fruits are grown with some success, but the climate is too rigorous for the intensive agriculture that is possible at lower altitudes.

SMITH RIVER BASIN

The Smith River is formed in Del Norte County, Calif., in the western part of T. 17 N., R. 2 E., Humboldt base and meridian, by the junction of its Middle and North Forks. The Middle Fork, which drains the larger area and is therefore considered the continuation of the main stream, rises on the western slope of the Siskiyou Mountains in the central part of T. 17 N., R. 5 E., flows northwestward 5 miles, then southwestward to the point at which it receives the North Fork. Below these forks the main river continues southwestward to the north-central part of T. 16 N., R. 1 E., where it turns abruptly to the west, and thence flows westward and northwestward to the Pacific, in T. 18 N., R. 1 W. The length from the mouth to the head of the Middle Fork is about 45 miles; the principal tributaries of the Middle Fork are Preston and Patrick Creeks.

The North Fork of the Smith River rises in the extreme southwestern part of Josephine County, Oreg., and flows somewhat west of south into Del Norte County, Calif. Its length, including major windings, is about 20 miles; the principal tributary is Stony Creek.

The South Fork, the principal tributary below the junction of the North and Middle Forks, rises on the western slope of the Siskiyou Mountains, in the northern part of T. 16 N., R. 4 E., Humboldt base and meridian, flows southwestward about 12 miles, then northwestward to its junction with the Smith River in the northern part of

T. 16 N., R. 1 E. Including its major windings this fork is 32 miles long. Its principal tributaries are Quartz, Jones, Hurdy Gurdy, Gorton, and Coon Creeks from the north and Goose and Rock Creeks from the south.

GREAT BASIN

SALTON SINK BASIN

The Salton Sink originally formed a part of the Colorado Desert, which has an area of nearly 2,000 square miles and extends northwestward almost 100 miles from the California-Mexico boundary line. It comprises two fertile valleys, one northwest of the sink, in Riverside County, known as the Coachella Valley, and the other southeast of the sink, in Imperial County, called the Imperial Valley. The Salton Sea, which now partly fills the sink, lies between the two valleys and is partly in Riverside County and partly in Imperial County. The longest diameter of the sea has a northwest-southeast direction. On December 31, 1908, its surface was 206 feet below mean sea level, and it had a length of nearly 45 miles, a maximum width of about 15 miles, a minimum width of 9.5 miles, a maximum depth of 67.5 feet, and a superficial area of about 443 square miles. In February, 1925, the surface of the sea was 249.6 feet below sea level and the area was 265 square miles. It is about 160 miles southeast of Los Angeles, 90 miles northwest of Yuma, and 50 miles north of Calexico.

A few thousand years ago, according to geologic evidence, what is now the Salton Sea was a part of the Gulf of California, which then extended about 200 miles farther northwest than at present. It is probable that the gulf waters then swept inland to the base, or nearly to the base, of San Jacinto Peak, although all evidence that would enable their exact limits to be fixed has been obliterated by more recent geologic events. At that time the mouth of the Colorado River was in the vicinity of Yuma, 60 miles in an air line north of its present location. Presumably, then as now, it was discharging large quantities of silt each year, cut from the great canyons of the upper Colorado and the Gila Valley and carried to the Gulf. Running water will carry in suspension matter that quickly settles in still water, and here the settling process is aided by the clarifying effect of the salt water.

As a result of these processes the Colorado delta was gradually extended southwestward toward the Cocopa Mountains, and when it reached them it had separated the old gulf into the present gulf and an inland sea. Delta growth, however, did not cease with the separation of the water body into two parts. Silt continued to be brought down the stream and to be deposited in its bed, along its banks, and in the still waters at its mouth. A stream by this process of deposition eventually builds its channel up until it is higher than the lands adjacent on both sides. The stream is then in a condition of unstable equilibrium, and at some favorable time, as during an exceptional flood, it will break out of its immediate banks and flow in some less restricted course. By this process, often repeated, it comes eventually to flow over all parts of its delta, building up each part in succession. By such a process the Colorado must have discharged alternately into the Gulf and into the depression now known as the Salton Sink, meanwhile building up the delta dam that separates them until it reached a height of about 40 feet above sea level. It is highly probable that during this process water filled the Salton depression and evaporated from it many times, for it must have quickly disappeared whenever the erratic river changed its course to the Gulf, the run-off from the mountains that surround the sink being too slight to maintain a permanent body of water in this region of intense evaporation. Meanwhile the original body of salt water that occupied the sink had been displaced by the volumes of fresh water poured into it from the river, and in the intermediate stages of the lake's existence, at least, its water was fresh or nearly fresh. A clear and definite indication of the last occupancy of this depression by a lake, presumably just before the river had shifted to the course that it now follows to the Gulf, may be seen in the remarkably well preserved old water line that rims the desert from Indio to the Cerro Prieto at a height of 40 feet above sea level. On the rocky points that projected into the lake this water line is marked by a thick deposit of calcium carbonate, by slightly cut sea cliffs, and by a change in the profile of the rocky spurs. Where alluvial cones and the sandy floor of the desert formed the shore line, beaches have been developed, and although of soft sand and easily eroded, they are even now well preserved, thus testifying to the recency of the action that produced them. Over the floor of the desert and along the sandy beaches are myriads of shells of fresh or brackish water mollusks[1] that lived in the lake.

There are some reasons for thinking that the lake at this latest stage was not perfectly fresh—at least that its waters were distinctly "hard." Its area when it stood at 40 feet above sea level was somewhat in excess of 2,100 square miles. The average flow of the Colorado has been determined from records for 1903–1925 at Yuma as about 16,800,000 acre-feet a year. The evaporation from a surface of the area of the old lake, under the conditions that prevail here, has never been determined but is undoubtedly high. If it is as high as 8 feet a year, it would nearly equal the average annual inflow from the Colorado; if it is but 7 feet a year, the average inflow would exceed

[1] Stearns, R. E. C., Remarks on fossil shells from the Colorado Desert: Am. Naturalist, vol. 13, pp 141–154, 1879.

the evaporation by 2,000 second-feet, or somewhat less than 14 per cent of the inflow. In either event, the waters of the lake would be markedly more alkaline after a term of years than those of the Colorado. The calcium carbonate incrustations on the rocky points about the shores of the old lake are best explained by supposing that the lake waters contained large quantities of this salt, so that wherever they broke in spray and evaporated more rapidly than usual, the carbonate was deposited. This necessary excess of inflow over outflow at the period of maximum area of the lake, taken in connection with the thick calcium carbonate incrustations on the shores, indicates distinctly hard water. It may be assumed that other salts than calcium carbonate were also present in large amount, for the conditions that would lead to the abundance of one salt would also lead to an abundance of the others. The shells so thickly distributed over the desert floor, however, are not salt-water forms, but are identical with those of creatures now living in the springs and occasional permanent streams about the desert borders. Many of these springs and streams are somewhat brackish, and the creatures flourish in them. It seems probable, then, that the lake waters also were rather alkaline, perhaps even brackish, at the time the lake attained its maximum area.

The period at which this lake disappeared can not be precisely fixed. The time units of geology are too large and too indefinite to translate satisfactorily into years, so that when we say that the disappearance of the lake is the most recent of geologic events we still leave the mind groping for a definite human standard of time. The sandy beaches that mark the borders of the ancient lake are cut away where washes cross them from the mountains, but in sheltered places they are still perfect. Where they stretch across an embayment from one rocky point to another they are mere embankments of sand, old barrier beaches, with depressions behind them once occupied by shallow lagoons. In other areas, where they contour the alluvial cones, they are gullied and cut away where streams have flowed across them but in other places are preserved unscarred. At one locality a low sea cliff that had been cut in alluvial-fan material was still preserved, although the loose sand and boulders would slump in a few heavy storms.

In a region of abundant rainfall such ephemeral forms as these would be more nearly obliterated within 50 years after the lake had disappeared than they are now in the desert. In such a region the precipitation is twenty times that of the desert. It is the crudest of estimates—merely a guess, in fact—to state that, reasoning from geologic evidence alone, it may be a thousand years since the lake disappeared, yet it puts in concrete form such a guess as the geologist is able to make, and this guess may be correct within a margin of error of 50 per cent.

When human records are studied some evidence on this point is found, but it is almost as uncertain as to time as that furnished by the physical features. The Indians in the Coachella Valley have distinct legends to the effect that at some time in the past the valley was occupied by a large body of water. Professor Blake records that they told him of a time when a great body of water existed in which were many fish, and of the manner in which that water disappeared "poco á poco" (little by little) until the lake became dry.

The Indians now living in the desert put this event as far back as the lives of four or five very old men, say, four or five centuries ago at the most. There are, of course, no records, and there is no known check on this assertion. Statements by Indians as to time, beyond the limits spanned by their own memories, are notoriously inaccurate. Furthermore, we do not know the means used to procure this statement. The native races are usually very prone to follow the suggestions contained in leading questions and so to give the answer desired by the questioner. To obtain an entirely independent and unguided answer is one of the most delicate of tasks. Yet their statement has some value, and combining the evidence of the physical conditions and the Indian legends we may say that it is probable that the lake disappeared and left the desert, as we have known it in historical time, from five hundred to one thousand years ago.

During the summer of 1891 the high water in the Colorado overflowed into Salton Sink to such an extent as to endanger the Southern Pacific Railroad at its lowest point. In the summer of 1905, after a succession of winter and spring floods in the Gila River, followed by an exceptionally heavy summer flow in the Colorado, there was a repetition of flood conditions in the sink on a much larger scale.

The gravity of the situation at this later time, however, was greatly augmented by the interference of man. For several years preceding a small quantity of water had been diverted from the Colorado below Yuma, Ariz., to be used by the settlers of the Imperial Valley for irrigation and domestic supply. The first water was diverted in the United States and conveyed to the Imperial Valley, after passing through Mexican territory, by means of an old river channel which had been one of the Colorado's distributaries during the formation of its delta and is now known as the Alamo River. The increased demand for water and the silting up of the original canal heading above the boundary line necessitated the cutting of an additional channel from the river below the boundary to connect with the canal. It likewise silted up, and to supply the urgent need for water a canal was cut 4 miles below the original heading to connect the Colorado and Alamo Rivers. This canal was not provided with protective headworks and had a gradient much greater than that of the river, so that with the unusual and prolonged summer flood in 1905, it began cutting, until in July it was carrying 87 per cent of the total flow of the river. This large quantity of water flooded several hundred square miles about Calexico, in the southern part of the Imperial Valley, and caused serious loss both in the United States and in Mexico. These waters ultimately reached the Salton Sea, but in so doing they deepened and widened the Alamo River into a great gorge and developed another drainage channel to the west through Imperial Valley in a second gorge now called the New River. Notwithstanding all attempts to control it the Colorado continued to pour its waters through the Alamo and New Rivers into the Salton Sea until the early fall of 1906, when it was finally shut off by the Southern Pacific Co. It broke again, however, on December 7, but was closed about two months later. Accounts of these operations have been published in the Transactions of the American Society of Civil Engineers, the Engineering News, and other engineering publications. In addition to the damage done to the railroad the sea completely submerged the plant of the New Liverpool Salt Co. below Mecca and a few ranches in the vicinity of Mecca.

There is some uncertainty as to the altitude of the lowest point of Salton Sink, and it is now believed that the depth below sea level has been overestimated in the past. From the record of the depth of the water as it filled the lowest portion of the basin, as kept by the New Liverpool Salt Co., it appears that the maximum depth of water was 17 feet on October 4, 1905 (according to the gage and as checked by soundings later), when on the same date the water surface just covered the United States Geological Survey bench mark a few feet from the old Salton railway station. As this bench mark is 256.5 feet below mean sea level, it would appear that the lowest point of the sink is 273.5 feet below mean sea level instead of 287 feet, which has been accepted heretofore. In 1891 Southern Pacific engineers reported the lowest point in the sink as −280.2 feet, which corresponds to −273.4 feet, United States Geological Survey.

Practically all the water that enters the Salton Sea is received through the Alamo and New Rivers, chiefly through the Alamo. These rivers run through Imperial Valley and are the drainage channels for all the excess and waste water from the irrigation system.

OWENS LAKE BASIN

Owens Lake is a body of saline water, covering about 75 square miles, in the central part of Inyo County. Like Mono Lake, which lies 125 miles farther north and about 3,000 feet higher, it derives its water from the vicinity of Mount Lyell.

The lake is fed by the Owens River, which rises among the high peaks of the Sierra east of Mount Lyell and directly opposite the headwaters of the San Joaquin, at an altitude of nearly 12,000 feet. It flows eastward into Long Valley, thence southeastward through the Owens River Canyon into Owens Valley, thence eastward and southward through the trough of the valley to Owens Lake, about 20 miles southeast of Mount Whitney. The total length of the river is about 125 miles—45 miles above the lower end of the canyon and 80 miles in Owens Valley.

The basin is long and comparatively narrow, and its topography is varied. It comprises a rough mountain slope 5 or 6 miles wide on its east side, a valley floor about 6 miles wide, and a slope 6 to 10 miles or more wide on the west. The west-side area is made up of a very rugged and precipitous mountain slope 4 or 5 miles wide and an alluvial plain composed of delta-fan surfaces, ranging in width from 1 to 5 miles and sloping down to the valley floor. Owens Valley is smooth and ranges in altitude from 3,600 feet at the south end to about 4,100 feet at the north end. The crest of the range of mountains on the east averages about 6,000 feet higher than the valley floor. The west-side plain consists of a porous granitic alluvium of considerable depth and ranges in altitude from about 4,000 feet at the west edge of the valley to about 6,000 feet at the foot of the mountains. It has a fairly uniform slope of 400 to 600 feet to the mile. The eastern slope of the Sierra is very steep and rugged and ranges in altitude from about 6,000 feet at the foot to 13,000 or 14,000 feet at the crest. The geologic formation is granitic.

The basin is poorly forested. The eastern slope is practically barren of vegetation, except in places where there is a scanty desert growth. The western slope has a very slight soil covering and only a sparse timber growth, found chiefly along the watercourses. All the western slope, a large part of the eastern slope, and the central part of Owens Valley are included in national forests.

The only precipitation records available indicate that the mean annual precipitation in the valley is about 5 inches. On the Sierra slope precipitation probably increases northward and certainly increases with increase in altitude. On the higher slopes it may reach 40 inches or more and falls almost entirely as snow.

The Owens River has many tributaries. More than 40 lateral streams, many of them, however, comparatively small, drain a part of the eastern slope of the Sierra and enter the main stream from the west. The principal tributaries, in order from north to south, are Rock, Pine, Horton, McGee, Birch, and Bishop Creeks opposite the San Joaquin Basin; Coyote, Baker, Big Pine, Birch, Tinemaha, Taboose, Goodale, Division, Sawmill (Eightmile), Thibaut, Oak, Pine, and Symmes Creeks opposite the Kings River Basin; and

Shepard, Bairs (Moffett), George, Hogback, Lone Pine, Tuttle, Richter, Cottonwood, and Ash Creeks opposite the Kern River Basin. No water enters the Owens River from the east except during the rare exceptionally heavy rainstorms.

Nearly all the streams rise in glacial lakelets and marshes, which lie near the crest of the Sierra and serve to a certain extent as storage reservoirs in regulating the flow. The streams emerge from the mouths of their canyons upon the porous alluvial plain at the base of the Sierra, across which they flow to the river. The porous alluvial belt permits considerable loss, part of which feeds many springs throughout the valley. Perhaps stronger evidence of the great loss by seepage is afforded by the broad belt of somewhat boggy land that extends over a large part of the trough of the basin. Undoubtedly large quantities of water can be obtained by sinking wells within this area. Several artesian wells that have been sunk in the vicinity of Independence yield a strong flow and give convincing evidence of an artesian belt in the valley. With a view to the greatest ultimate utilization of the valley's water supply, the city of Los Angeles has conducted special investigations to determine the depth to and fluctuations in the ground-water plane and the rate of evaporation from free water surface and saturated gravel near Independence;[2] also to determine the amount of precipitation on the alluvial plain at the base of the Sierra between the 4,000 and 6,000 foot contours and the seepage losses of creeks crossing it.

Owens Valley is extensively cultivated and particularly adapted to stock raising. Numerous diversions are made for irrigation at different points on the Owens River and its tributaries, particularly in the upper part of the valley. Considerable water is also used for irrigating meadow lands in Long Valley north of the Owens River Canyon, but it is returned to the river above the head of Owens Valley.

ANTELOPE VALLEY BASIN[3]

Antelope Valley is in the southwestern part of the Mohave Desert, between the rugged mass of the San Gabriel Range and the northwest end of the San Bernardino Range on the south and the Tehachapi Range on the west.

The lowest part of this depression, lying at an altitude of about 2,300 feet, is occupied by Rosamond, Buckhorn, and Rogers Dry Lakes, and the surface of the valley slopes toward this area with a grade that decreases with distance from the mountains. The margin of the valley lands ranges in altitude from 2,600 feet along the south foot of the Rosamond Buttes to more than 4,000 feet on the Tehachapi flanks. The valley is an undulating brush-covered plain, except for

[2] See U. S. Geol. Survey Water-Supply Paper 294, 1912.

[3] From Johnson, H. R., Water resources of Antelope Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 278, 1911, to which the reader is referred for more detailed information.

barren steep-sided buttes and ridges, which rise island-like above the level land and which are typified by the Sand Hills, just southwest of Cottonwood Creek Wash; Antelope Buttes, near Fairmont; Little Buttes, about halfway across the valley between Del Sur and Willow Springs; Quartz Hill, about 5 miles southwest of Lancaster; a butte at the northwest end of Buckhorn Dry Lake; and, in the eastern part of the valley, many sand dunes.

Although in its general features Antelope Valley resembles the Mohave Desert, its position at the immediate base of the Tehachapi Range and Sierra Madre modifies favorably the amount and quality of the waters which reach the lowlands. Some of the streams flowing from these higher ranges are perennial, and all supply better water than the smaller streams that flow from the buttes of the desert proper. The two ranges are so high that their snow cover often remains until midsummer and maintains a continuous though gradually diminishing flow of water, but the region is prevented by its position on the landward side of the ranges from receiving the benefit of the heavy winter precipitation and consequent heavy run-off of the more favored southern and western slopes.

In general the streams of Antelope Valley flow at right angles to the trend of the mountains in which they originate; most of these streams converge toward Oban and thence, though their channels are less clearly defined, sweep northeastward and empty into Rosamond Dry Lake or its extensions, Buckhorn and Rogers Dry Lakes.

None of the streams in the valley are large. On the northern slope of the San Gabriel Range and the southeastern slope of the Tehachapi a few have worked their way back far enough into the ranges to become important as water carriers. Of these Rock, Little Rock, and Amargosa Creeks are the largest.

The main fork of Rock Creek rises in the rugged region north of North Baldy, at an altitude of 6,500 feet, and the uppermost tributaries of its south branch, which drains the region immediately north of Mount Islop, head at an altitude of fully 8,000 feet. The creek flows northwestward past the Shoemaker ranch to the northwest corner of T. 4 N., R. 9 W., where it turns northward to the gravelly margin of Antelope Valley. Here it breaks into several distributaries, which diverge from the apex of the alluvial fan built up by the stream itself. The more or less constant flow of Rock Creek is utilized by irrigation canals that extend for some distance east and west from the mouth of the canyon.

Little Rock Creek, which rises in the high granitic mountain country in T. 3 N., R. 10 W., flows northwestward and enters Antelope Valley near Little Rock, in the northeast quarter of T. 5 N., R. 11 W. The channel of this creek in Antelope Valley is better preserved than that of any of the other streams, and it is traceable almost to C. N.

Reid's ranch, nearly 7 miles east of Lancaster. Here, however, the channel begins to lose its character and is not easily followed farther toward Rosamond Dry Lake. The waters of this stream are used to irrigate lands adjacent to the settlement of Little Rock.

Amargosa Creek, which enters Antelope Valley about 3 miles west of Palmdale, is the only stream with even moderate flow between Little Rock Creek and the extreme west end of Antelope Valley.

A number of streams which, though draining rather small areas, carry considerable water, rise at the west end of Antelope Valley, between the junction of the Tehachapi and San Gabriel Ranges. They are fed by copious springs, which are particularly numerous at the southwest end of the Tehachapi Range, near the foot of the steep slopes. The largest of these creeks is called Little Cottonwood. No accurate measurements of any of these springs or creeks are available, but the large spring at the Liebre ranch is said to flow 1,500 gallons an hour.

Between Little Cottonwood and Cottonwood Creeks are Fish, Livsey, Tierra Seca, and Little Oak Creeks, each less than 5 miles long but a source of considerable water even in summer. It is stated that the drainage basins of these streams contain large springs which furnish much of the stream water that eventually finds its way into the gravel in this part of the Antelope Valley.

Cottonwood Creek, the largest stream flowing into Antelope Valley from the Tehachapi Range, rises at an altitude of more than 6,000 feet at a point some 8 miles west of the Knecht ranch, which is practically at the apex of the great alluvial fan built by this stream below the mouth of its canyon. Since this fan was deposited the erosional ability of the creek has been changed, either through uplift or climatic oscillations, so that it has carved a sharply defined gulch in its own fan.

Lakes and ponds, most of them intermittent, exist at a number of points in and near Antelope Valley. The most permanent—Hughes and Elizabeth Lakes—lie in depressions in an alluvial trough coinciding with the San Andreas fault zone. Elizabeth Lake receives the drainage of a small area in the surrounding hills and may be fed by springs. Its waters remain fairly fresh, however, for at the northwest end it overflows occasionally through a meandering channel into the smaller Hughes Lake, which in turn feeds the headwaters of a southward-flowing stream that is a part of the Santa Clara drainage system.

Intermittent lakes of another type are formed in the lowest portions of the broader alluvial basins by the addition of flood waters from the surrounding drainage area that have not been absorbed on the way by the gravel of the basin. In this arid region such waters, combined with those due to upward leakage, usually hold in solution considerable saline material and on their evaporation leave the salts as an incrustation within and about the margin of the dry lakes. These lake or "playa" deposits are nearly level and form a smooth, hard surface which, as in Rogers Dry Lake, extends for many miles. Except during the hardest storms the lakes rarely contain water, unless the ground-water plane approaches sufficiently near the surface to produce small scattered pools and damp spots of alkali-charged waters. Several such lakes of minor extent occur southeast of Antelope Valley.

MOHAVE RIVER BASIN

The Mohave River rises in San Bernardino County, Calif., on the northern slope of the Sierra Madre, its headwaters flowing from altitudes of 5,000 to 8,000 feet above sea level. It takes a circuitous course, winding successively to the west, north, and east, decreases in volume as it passes onto the plains, and finally disappears in the sandy bed a short distance below Barstow, at an altitude of 1,900 feet. As measured by planimeter on the San Bernardino County map, the basin comprises 1,470 square miles, of which 251 square miles may be classed as mountains, 219 square miles as foothills, and 1,000 square miles as plains and desert buttes.[4]

Many of the mountains on the west drain toward the Mohave Desert, but the streams are few and small and the water disappears as soon as it reaches the hot sands. The general slope of the valley from the west is toward the Mohave River at the rate of 2 feet to the mile, but the rainfall is so light—about 3 inches a year—and the summer heat is so great that the run-off is not visible on the surface. In the mountains of the basin heavy rains are frequent, and, falling on slopes that are both rugged and steep, they make floods that pour out of the hills far beyond the limit of the surface flow into the desert, fill the porous sand and gravel of the river beds, and then disappear as rapidly as they come.

South of Victorville, at a point known as The Narrows, the river has cut through a low range of hills. The gorge is narrow and its bounding walls are abrupt granite cliffs.

MONO LAKE BASIN

Mono Lake lies at the eastern base of the Sierra Nevada in east-central California, within a few miles of the California-Nevada boundary. The western rim of its drainage area, formed by the crest line of the Sierra, coincides for 36 miles with the western margin of the Great Basin.

The lake is 6,412 feet above the sea. The lowest pass in the serrate mountain crest along its western border is 3,000 feet above its surface. The highest peaks that overshadow it rise more than 6,000 feet above

[4] U. S. Geol. Survey Nineteenth Ann. Rept., pt. 4, pp. 14-16, 1898.

the level of the lake. The eastern portion of the basin partakes of the character of the arid interior region and includes valleys covered with sagebrush and rugged mountain slopes scantily clothed with cedar and piñon. Over this portion no running water can be found during the greater part of the year. That it is not really a desert is shown by the fact that among the clumps of sagebrush it produces nutritious bunch grass in sufficient abundance to afford pasturage for a few cattle and horses.

The southwestern border of the basin includes magnificent mountains that are clothed in favored places with forests of pine. The highest peaks reach far above the timber line and bear a varied and beautiful alpine flora.

The lake derives its principal water supply from the creeks that descend the eastern slope of the Sierra and empty into it from the south and west. The surface drainage is supplemented by a number of springs, some of which are of considerable size.

The creeks tributary to Lake Mono are clear and flow through channels excavated for the most part in granite and metamorphosed sediments, but near their mouths they have eroded small gorges through material deposited during previous high-water stages of the lake. No chemical analyses of these waters have been made, but they undoubtedly hold a small percentage of mineral matter in solution, which is left when evaporation takes place.

Most of the springs of the basin are either in the bottom of the lake or near its shores, and they are most numerous near the base of the mountains, which lie close to the western shore. Only three of those that rise on the land have a temperature noticeably above the normal. The character of most of those rising in the bottom of the lake is uncertain. Some of them reveal their presence in cold weather by vapor, seen on the lake surface above them, and are thus known to be thermal. None of the springs of the basin are highly charged with mineral matter; on the contrary, some of the more copious are remarkable for their purity.

WALKER LAKE BASIN

Walker Lake, which next to Pyramid Lake is the most picturesque and attractive of the desert lakes of Nevada, lies in the northern part of Esmeralda County. It is supplied entirely by the Walker River, which enters at its north end.

As one of the lakes of the region occupied by glacial Lake Lahontan, it was described by Russell [5] as follows:

> The lake is 25.6 miles in its longer, or north and south axis and has an average width of between 4.5 and 5 miles. Its area is 95 square miles. * * * Over a

[5] Russell, I. C., Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: U. S. Geol. Survey Mon. 11, pp. 69–70, 1885.

large area in the central and western portions it has a remarkably uniform depth of 224 feet; but as a rule the depth increases as one approaches the western shore, which is overshadowed by rugged mountains. The bottom throughout the central portions is composed of fine tenacious mud, which in many places is black in color and has the odor of hydrogen sulphide. Coarser deposits, consisting of sand and gravel, mingled with the empty shells of *Pyrgula* and *Pompholyx*, etc., were found only in the immediate neighborhood of the shore. * * *

As in the case of the other lakes in the Great Basin situated at an elevation of less than 5,000 feet, the shores of Walker Lake are totally lacking in arboreal vegetation except at the river mouth and are clothed only with desert shrubs. At the northern end and following the immediate shores of Walker River for many miles are luxuriant cottonwood groves, together with willow banks and meadow lands. * * *

The waters at a distance from the river mouth are of a clear deep blue, changing to a bright-green tint near the shore, as in Pyramid Lake. They are charged with saline matter to such an extent that carbonate of lime is now being deposited.

The Walker River, the inflowing stream, rises on the eastern slope of the Sierra Nevada in two main branches whose basins are separated by the Sweetwater Range. The East Fork of the Walker River receives the drainage from the eastern slope of the Sweetwater Range and the western slope of the Walker River Range; the West Fork flows at the base of the main range of the Sierra Nevada. From the union of the forks near Mason the river flows sluggishly northward, passing through the fertile Yerington Valley (Mason Valley) to a point east of Wabuska, where it turns east and then southeast, and 50 miles beyond the forks enters Walker Lake. The length of the river from Walker Lake to the junction of Virginia and Green Creeks, which form the East Fork, is about 120 miles, in which distance its fall is about 2,400 feet. In the 50 miles below the junction of the East and West Forks the fall is about 400 feet.

The basin contains but three large valleys—Antelope Valley on the West Fork; Smith Valley, a fertile table-land presenting ample opportunity for reclamation, also on the West Fork; and Mason Valley, which takes its water from the two forks. Only recently have the water rights in Mason Valley been adjusted. The minimum flow is not sufficient to supply the demand during the summer, although excellent reservoir sites near the headwaters of the forks are available for storing the flood waters for use during the dry season. The snowfall is very heavy, giving assurance of an ample water supply for reservoirs.

A line of levels run by the Bureau of Reclamation from a point above Yerington to the Carson River near the Towle ranch shows that water can be easily diverted by gravitation from the Walker River to the Carson River. The opportunities for the production of power afforded by both forks are as yet undeveloped because of the small demand for power near the rivers. Power development from the main stream is not feasible.

CARSON SINK BASIN

Carson Sink lies in Churchill County, Nev., in the northern part of the Carson Desert. During the winter and spring it receives a considerable supply of water from the Humboldt and Carson Rivers and becomes a shallow, playa lake from 20 to 25 miles long and 14 miles broad. In arid summers the water supply fails and the lake evaporates to dryness, and as desiccation becomes more intense the salts impregnating the lake beds are brought to the surface and form an efflorescence several inches thick. In October, 1881, the sink was a broad mud-colored plain, covered in places with a white alkaline crust that looked like patches of snow. In 1908 Carson Sink was mapped by the topographers of the United States Geological Survey as a permanent water body, 12 miles long by 12 miles broad, receiving the Carson River on the south. The drainage line from Humboldt Lake to the sink was marked as an intermittent river.

The Carson River is formed by its East[6] and West Forks, which rise in the extreme eastern part of California and flow northeastward to their union near the town of Gardnerville, Nev. From this point the river flows northward to Empire, Nev., where it turns to the east and finally disappears into Carson Sink. It is about 160 miles long to the head of the East Fork, and its total fall is about 6,400 feet. The fall of the East Fork above the junction is 5,500 feet, and the fall of the main stream in the 108 miles below the junction is about 900 feet. Between Empire and Dayton the river occupies a deep, rugged canyon.

The principal tributaries of the East Carson are Silver King, Wolf, Silver, Markleeville, and Leviathan Creeks. These streams drain a rough, mountainous country, ranging in altitude from 5,000 to 11,000 feet. Good storage sites exist on all the large tributaries. Part of the reservoir sites in Pleasant Valley and on Silver Creek have been developed.

The area drained by the West Carson is not so large as that of the East Carson and its altitudes are in general lower. By constructing a reservoir at Hope Valley a large amount of power may be developed in the West Carson Canyon.

The soil throughout the Carson and Dayton Valleys is very porous, and its irrigation requires a large amount of water. The low-water flow is sufficient to reclaim only a small part of the land. The irrigated acreage may, however, be greatly increased by constructing reservoirs on the headwaters to store the spring floods.

TRUCKEE RIVER BASIN

The Truckee River system comprises the main river and several minor tributaries, all having as their chief sources of supply small mountain lakes. The Truckee River itself is the natural outlet of

[6] Called East Carson River above mouth of Markleeville Creek.

Lake Tahoe, a beautiful mountain lake, 193 square miles in area, lying more than 6,000 feet above sea level, and noted as the largest body of fresh water in the United States at so high an altitude. Nearly three-fourths of the lake is in California, and the rest is in Nevada.

Issuing from the northwest side of Lake Tahoe the Truckee flows almost due north to the town of Truckee, Calif., where it turns east. At Wadsworth, Nev., the river again turns north and discharges into Pyramid and Winnemucca Lakes. From Lake Tahoe to Verdi, Nev., a distance of 35 miles, the country is heavily timbered with fir and pine; below Verdi barren wastes alternate with small and fertile valleys—the Verdi Valley, the Reno or Truckee Valley, and the Wadsworth Valley—all of which have a rich, productive soil. The total length of the Truckee is about 110 miles, and its total fall is about 2,350 feet.

Donner Creek, the natural outlet of Donner Lake, is the first large tributary of the Truckee, which it enters at the town of Truckee. Prosser Creek, the second tributary and the natural outlet of several small lakes, enters about 5 miles northeast of Truckee, and the Little Truckee River, the natural outlet of Webber and Independence Lakes, comes in at Boca, Calif., about 2 miles farther along. Each of these tributaries rises at an altitude of 6,000 feet, and each flows from a lake whose capacity can be enlarged by building a dam across its outlet. The region about the lakes is thickly forested and receives very heavy snowfall during the winter. During the season of thaw this snow affords an immense run-off, almost all of which could be stored by enlarging the natural lakes.

Three power plants have been installed on the Truckee—the Farad (Mystic), Fleish, and Washoe plants—with an emergency plant near Reno, Nev. The plants have an average capacity of about 2,500 horsepower each and they supply practically all the power used by the towns of Verdi, Reno, Carson City, Yerington, Gardnerville, Sparks, and Virginia City, Nev. There are many falls on the headwaters of the small tributaries.

Only data pertaining to that part of the stream which lies in California are published in this paper.

PYRAMID AND WINNEMUCCA LAKE BASINS [7]

Pyramid and Winnemucca Lakes occupy two long, narrow basins in Washoe and Humboldt Counties, Nev., and receive the waters of the Truckee River, which sends a stream to each lake. The first published account of the bifurcation of the Truckee River so as to supply two lakes is given by King,[8] who says:

> At the time of our first visit to this region, in 1867, the river bifurcated; one half flowed into Pyramid Lake, and the other through a river 4 or 5 miles long into

[7] Abstracted from Russell, I. C., Geological history of Lake Lahontan: U. S. Geol. Survey Mon. 11, pp. 56-66, 1885.

[8] U. S. Geol. Expl. 40th Par. Rept., vol. 1, pp. 505-506, 1878.

Winnemucca Lake. At that time the level of Pyramid Lake was 3,890 feet above the sea and of Winnemucca about 80 feet lower. Later, owing to the disturbance of the balance between influx and evaporation already alluded to as expressing itself in Utah by the rise and expansion of Great Salt Lake, the basin of Pyramid Lake was filled up and a backwater overflowed the former region of bifurcation, so that now the surplus waters go down the channel into Winnemucca Lake, and that basin is rapidly filling.

Between 1867, the time of my first visit, and 1871, the time of my last visit, the area of Winnemucca Lake had nearly doubled, and it has risen from its old altitude about 22 feet, Pyramid Lake in the same time having been raised about 9 feet. The outlines as given upon our topographical maps are according to the survey of 1867 and form interesting data for future comparison.

The differences in altitude between Pyramid and Winnemucca Lakes as reported by King and determined by Russell in 1882 are as follows: In 1867 Pyramid was 80 feet higher than Winnemucca; in 1872 Pyramid was 67 feet higher than Winnemucca; in 1882 Pyramid was 12 feet higher than Winnemucca, as determined by engineer's level. In 1890, when the region was surveyed by the topographers of the United States Geological Survey, Pyramid was but 5 feet higher than Winnemucca. The waters of both lakes are alkaline and brackish. Their shores, like those of all the lakes in the lower part of the Great Basin, are clothed only with scanty growths of desert vegetation.

In the southern part of Pyramid Lake the water is slightly discolored by multitudes of shining particles that are rendered visible when a ray of light is passed through it. The lack of transparency is apparently due to the suspended silt brought down by the Truckee River. In the northern part of the lake the water is wonderfully clear and at some distance from the land is deep blue.

The largest islands in Pyramid Lake are Pyramid and Anaho, which rise in its southern part near the eastern shore. Anaho Island rises 520 feet above the water level of 1890 and is surrounded by water 150 to 300 feet deep. Pyramid Island rises 320 feet above the water level of 1890, and the water near its base is 150 to 175 feet deep.

HONEY LAKE BASIN[9]

Honey Lake occupies a shallow depression in the eastern part of Lassen County, Calif. It is supplied principally from the Susan River, which enters it from the northwest, but during the rainy season it receives some water from Long Valley and from springs along its north side. The lake varies in area with the seasons, as well as from year to year, and in times of unusual aridity it becomes completely dry. Its shores are, as a rule, low and marshy and in places form broad tule swamps. Its water is strongly alkaline, unfit for human use, and always of a greenish-yellow color from the impalpable mud it holds in suspension.

[9] Abstracted from Russell, I. C., Geological history of Lake Lahontan: U. S. Geol. Survey Mon. 11, pp. 55–56, 1885.

A considerable area of land is irrigated by water from the Susan River, and several projects for irrigating other extensive areas by storage of its waters both above and below the town of Susanville have been under consideration.

The principal tributary of the Susan River, Willow Creek, flows from springs which are presumably fed by seepage from Eagle Lake, which has no surface outlet. It flows southward and joins the Susan River about 12 miles below Susanville. Its only large tributary is Petes Creek, which drains a considerable area in the eastern part of the basin. The drainage area of the main stream has a good timber covering, but that tributary to Petes Creek is barren of timber. The entire basin is composed of lava rock with a light covering of soil and contains large stretches of barren table-lands with scattered peaks of volcanic origin. There is a large area of cultivated land along Willow Creek above the gaging station at Standish, and considerable water is diverted for irrigating lands adjoining the stream.

STREAM FLOW

GAGING STATIONS

The following list comprises the gaging stations that have been maintained in California in the minor San Francisco Bay, northern Pacific, and Great Basins. The stations are arranged in downstream order, and tributaries are indicated by indention. A dash after the last date in a line indicates that the station was being maintained September 30, 1927.

MINOR SAN FRANCISCO BAY BASINS

COYOTE RIVER BASIN

Coyote River near Madrone, Calif., 1902–1912; 1917–
Coyote River at Coyote, Calif., 1916–1923.
Coyote River near Edenvale, Calif., 1916–
Coyote River at San Jose, Calif., 1917.
    Laguna Seca near Coyote, Calif., 1918.

ALAMEDA CREEK BASIN

Alameda Creek near Sunol, Calif., 1911–
Alameda Creek at Sunol, Calif., 1900–
Alameda Creek at Niles Dam, Calif., 1891–1900.
Alameda Creek near Niles, Calif., 1916–
Alameda Creek near Decoto, Calif., 1916–1919.
    Calaveras Creek near Sunol, Calif., 1910–
    San Antonio Creek near Sunol, Calif., 1912–
    Arroyo de la Laguna near Pleasanton, Calif., 1912–
        Alamo Creek at Dublin, Calif., 1914–1920.
        Tassajero Creek near Pleasanton, Calif., 1914–
        Arroyo Mocho near Livermore, Calif., 1912–
            Arroyo las Positas near Livermore, Calif., 1912–
        Arroyo del Valle near Livermore, Calif., 1912–

Alameda Creek—Continued.
  Spring Valley Water Co.'s aqueduct near Sunol, Calif., 1903–
  Laguna Creek at Irvington, Calif., 1916–1919.
  Dry Creek near Decoto, Calif., 1916–1919.

SAN PABLO CREEK BASIN

San Pablo Creek near San Pablo, Calif., 1917–1919.
San Pablo Creek at San Pablo, Calif., 1917–1919

NORTHERN PACIFIC BASINS

RUSSIAN RIVER BASIN

Russian River near Ukiah, Calif., 1911–1913.
Russian River at Geyserville, Calif., 1911–1913.
  East Fork of Russian River near Ukiah, Calif., 1911–1913.

MATTOLE RIVER BASIN

Mattole River near Petrolia, Calif., 1911–1913.

EEL RIVER BASIN

South Eel River at Hullville, Calif., 1922–
South Eel River and Snow Mountain Water & Power Co.'s tailrace near Potter Valley, Calif., 1909–
South Eel River at Hearst, Calif., 1911–1913.
Eel River at Two Rivers, Calif., 1911–1913.
Eel River at Scotia, Calif., 1911–
  Snow Mountain Water & Power Co.'s tailrace near Potter Valley, Calif., 1922–
  Middle Fork of Eel River near Covelo, Calif., 1911–1921.
  South Fork of Eel River at Garberville, Calif., 1911–1913.
  Van Duzen River at Bridgeville, Calif., 1911–1913.
    Yager Creek at Carlotta, Calif., 1911–1913.

MAD RIVER BASIN

Mad River near Arcata, Calif., 1911–1913.

REDWOOD CREEK BASIN

Redwood Creek near Korbel, Calif., 1911–1913.
Redwood Creek at Orick, Calif., 1911–1913.

KLAMATH RIVER BASIN

Klamath River near Copco, Calif., 1923–
Klamath River near Seiad Valley, Calif., 1912–1925.
Klamath River near Happy Camp, Calif., 1911–12.
Klamath River near Requa, Calif., 1911–1926.
  Antelope Creek near Macdoel, Calif., 1921–22.
  Butte Creek near Macdoel, Calif., 1921–22.
  Bear Creek near Macdoel, Calif., 1921–22.
  Shasta River near Montague, Calif., 1911–
  East Fork of Scott River near Callahan, Calif., 1910–11.
  Scott River near Scott Bar, Calif., 1911–1913.
  Indian Creek near Happy Camp, Calif., 1911–12.
    Reeve Davis flume near Happy Camp, Calif., 1911–12.
  Salmon River at Somesbar, Calif., 1911–1913.
  Trinity River near Trinity Center, Calif., 1911–12.

Klamath River—Continued.
- Trinity River at Lewiston, Calif., 1911–
- Trinity River near China Flat, Calif., 1911–1913.
- Trinity River at Hoopa, Calif., 1911–1914; 1916–1918.
  - Coffee Creek at Coffee, Calif., 1911–1914.
  - East Fork of Trinity River near Trinity Center, Calif., 1911.
  - Swift Creek near Trinity Center, Calif., 1911.
  - North Fork of Trinity River at Helena, Calif., 1911–1913.
  - South Fork of Trinity River near China Flat, Calif., 1911–1913.

SMITH RIVER BASIN

Middle Fork of Smith River near Crescent City, Calif., 1911–1913; 1915–16.
North Fork of Smith River near Crescent City, Calif., 1911–1913.
South Fork of Smith River near Crescent City, Calif., 1911–1913.

GREAT BASIN

SALTON SINK BASIN

Alamo River near Brawley, Calif., 1909–1911.

WHITEWATER RIVER BASIN

Snow Creek near Whitewater, Calif., 1921–
- Southern Pacific Co.'s ditch near Whitewater, Calif., 1921–
- Falls Creek near Whitewater, Calif., 1922–

OWENS LAKE BASIN

Owens River near Round Valley, Calif., 1903–1923.
Owens River at Pleasant Valley, near Bishop, Calif., 1925–
Owens River near Big Pine, Calif., 1906–
Owens River near Lone Pine, Calif., 1909–1918.
Owens River near Citrus, Calif., 1904–5.
- Rock Creek at Sherwin Hill, near Bishop, Calif., 1925–
- Rock Creek near Round Valley, Calif., 1903–1924.
  - Pine Creek at division box near Bishop, Calif., 1925–
  - Pine Creek near Round Valley, Calif., 1903–1924.
- Bishop Creek near Bishop, Calif., 1903–1911.
- Baker Creek near Big Pine, Calif., 1907.
- Big Pine Creek near Big Pine, Calif., 1904–1911.
- Tinemaha Creek near Big Pine, Calif., 1907–1911.
- Birch Creek near Big Pine, Calif., 1907–1911.
- Taboose Creek near Aberdeen, Calif., 1906–1911.
- Goodale Creek near Aberdeen, Calif., 1906–1911.
- Division Creek near Independence, Calif., 1906–1910.
- Sawmill Creek near Independence, Calif., 1906–1909.
- Oak Creek near Independence, Calif., 1906–1911.
- Little Pine Creek near Independence, Calif., 1905–1911.
- Shepard Creek near Thebe, Calif., 1906–1909.
- Bairs Creek near Thebe, Calif., 1906–1909.
- George Creek near Thebe, Calif., 1906–1909.
- Lone Pine Creek near Lone Pine, Calif., 1906–1911.
  - Tuttle Creek near Lone Pine, Calif., 1906–1911.
- Cottonwood Creek near Olancha, Calif., 1906–1911.
- Ash Creek near Olancha, Calif., 1906–1909.

ANTELOPE VALLEY BASIN

Little Rock Creek near Palmdale, Calif., 1896–1899.
Rock Creek near Valyermo, Calif., 1923–

MOHAVE RIVER BASIN

Mohave River at Victorville, Calif., 1899–1905.

MONO LAKE BASIN

Rush Creek near Mono Lake, Calif., 1910–1912.
Leevining Creek near Mono Lake, Calif., 1910–1913.

WALKER LAKE BASIN

East Walker River near Bridgeport, Calif., 1921–
Robinson Creek near Bridgeport, Calif., 1910–1912.
Buckeye Creek near Bridgeport, Calif., 1910–1912.
Swager Creek near Bridgeport, Calif., 1911–1912.
West Walker River near Coleville, Calif., 1902–1910; 1915–
East Fork of West Walker River near Bridgeport, Calif., 1910.

CARSON SINK

East Fork of Carson River near Markleeville, Calif., 1910–
East Fork of Carson River at California-Nevada State line, 1911–1914.
Silver Creek near Markleeville, Calif., 1910–1912.
Markleeville Creek near Markleeville, Calif., 1911–
Markleeville Creek at Markleeville, Calif., 1910–
Pleasant Valley Creek at Markleeville, Calif., 1910–11.
West Fork of Carson River at Woodfords, Calif., 1900–1920.

PYRAMID AND WINNEMUCCA LAKES BASINS

Truckee River at Tahoe, Calif., 1895–
Truckee River at Boca, Calif., 1890.
Truckee River at Iceland, Calif., 1912–
Truckee River at Nevada-California State line, 1899–1912.
Donner Creek at Donner Lake, near Truckee, Calif., 1909–10.
Donner Creek near Truckee, Calif., 1902–1915.
Prosser Creek near Truckee, Calif., 1903–1912.
Prosser Creek at Boca, Calif., 1889–90.
South Fork of Prosser Creek near Truckee, Calif., 1909–10.
Little Truckee River near Truckee, Calif., 1909–10.
Little Truckee River at Starr, Calif., 1903–1910.
Little Truckee River at Boca, Calif., 1890; 1911–1915.
Webber Creek near Truckee, Calif., 1909–10.
Independence Creek below Independence Lake, Calif., 1902–1910.

HONEY LAKE BASIN

Long Valley Creek near Scotts, Calif., 1917.
Baxter Creek near Lassen, Calif., 1913–1915; 1918–19.
Schloss Creek at Lassen, Calif., 1915; 1918–19.
Janesville Creek at Lassen, Calif., 1915; 1918–19.
Susan River near Susanville, Calif., 1900–1905; 1917–1921.
Gold Run Creek near Susanville, Calif., 1915–16.
Lassen Creek near Susanville, Calif., 1915.
Willow Creek at Merrillville, Calif., 1904–5.
Willow Creek near Standish, Calif., 1905.

SURPRISE VALLEY BASIN

Bidwell Creek near Fort Bidwell, Calif., 1911–12; 1918.
Bidwell Creek at Fort Bidwell, Calif., 1918–19.
Keeno Creek near Fort Bidwell, Calif., 1918–19.
Twelvemile Creek near Fort Bidwell, Calif., 1918–19; 1922.
East Fork of Horse Creek near Fort Bidwell, Calif., 1918–19.
West Fork of Horse Creek near Fort Bidwell, Calif., 1917–1919.
Rock Creek near Fort Bidwell, Calif., 1918–19.

MAXIMUM AND MINIMUM DISCHARGES

Maximum and minimum discharges recorded at stations in the minor San Francisco Bay, northern Pacific, and Great Basins, Calif.

Minor San Francisco Bay Basins

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.*
Alameda Creek near Niles	1916–1927	633	Feb. 10, 1922	12.44	13,900	22.0	0
Coyote River near Madrone	1902–1912 1917–1927	193	Mar. 11, 1911		25,000	130	0
Coyote River near Edenvale	1916–1927		Feb. 11, 1922	12.8	10,000		0

Northern Pacific Basins

Station	Period of record	Drainage area	Date	Gage height	Discharge	Discharge per square mile	Minimum discharge
Eel River at Scotia	1911–1927		Feb. 2, 1915	55.5	290,000		10
Klamath River near Requa	1911–1926		do	33.3	182,000		1,340
Shasta River near Montague	1911–1927		Feb. 11, 1925	14.9	5,700		1.0
Trinity River at Lewiston	1911–1927		Nov. 30, 1926	18.3	31,900		23

Great Basin

Station	Period of record	Drainage area	Date	Gage height	Discharge	Discharge per square mile	Minimum discharge
West Fork of Carson River at Woodfords.	1900–1920	70	May 9, 10, 1906.	6.8	1,570	22.4	0
Owens River near Big Pine	1906–1927		Jan. 26, 1914	11.2	3,220		36
Owens River near Lone Pine	1909–1918		July 7, 1909	10.6	2,050		4
Owens River near Round Valley	1903–1923	450	June 30, 1907	4.0	1,190	2.64	5.4
Pine Creek near Round Valley	1903–1923	32	June 22, 1911		370	11.6	.1
Rock Creek near Round Valley	1903–1923	46	Jan. 25, 1914	5.0	360	7.83	14
Susan River at Susanville	1900–1905, 1913, 1916–1921		Feb. 22, 1904	9.9	1,750		.8
Truckee River at Iceland	1907–1927	937	Mar. 18, 1907		[a] 15,300	16.3	[a] 40
Truckee River at Tahoe	1895–96 1900–1924	519	July 13–20, 1907.		[a] 1,340	2.58	0
West Walker River near Coleville	1915–1927	245	June 12, 1921	5.74	2,710	11.1	14

[a] Mean daily discharge.

MONTHLY-DISCHARGE RECORDS

Monthly discharge, in second-feet, at stations in minor San Francisco Bay basins, Calif.

Coyote River near Madrone

[Drainage area, 193 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1902–3	0.75	1.93	2.61	290	153	490	400	20.4	11.4	7.42	4.92	0.66	115
1903–4	.60	1.20	1.29	2.12	105	384	67.8	17.7	6.16	2.47	.81	2.78	49.3
1904–5	2.73	3.20	1.09	9.77	165	252	35.5	48.0	10.8	4.18	1.82	.61	44.6
1905–6	.43	.92	1.49	539	235	778	235	73.1	38.5	14.4	6.68	4.48	161
1906–7	3.18	6.92	372	932	326	1,380	217	61.9	29.5	13.2	8.32	4.97	280
1907–8	4.3	14.4	120	195	234	156	27.4	14.7	8.82	4.7	2.33	1.90	65.3
1908–9	1.82	2.19	3.07	1,100	1,260	346	173	48.9	28.6	15.6	11.2	9.9	250
1909–10	10.7	12.0	105	355	129	139	59.7	17.6	7.7	4.6	3.3	3.1	70.6
1910–11	3.4	3.6	4.6	524	292	1,190	45.1	7.0	3.9	2.5	1.8	1.5	173
1911–12	1.6	1.8	1.8	2.9	3.2	59.4	23.4	3.6	2.8	1.9	1.4	1.2	8.75
1916–17	--------	--------	--------	112	773	114	41.4	17.5	7.14	2.63	1.61	1.19	--------
1917–18	.39	.74	1.45	1.95	11.7	168	9.94	3.47	1.90	.38	.1	--------	--------
1918–19	--------	--------	--------	8.31	455	256	30.4	15	10	4.60	1.49	.51	--------
1919–20	.39	1.02	18.1	5.12	3.95	122	62.2	11.8	4.34	.83	.02	0	19.3
1920–21	0	.5	118	543	117	120	18.6	10.3	5.00	2.0	1.0	.5	78.4
1921–22	.50	.62	115	58.4	781	142	67.6	20.0	10.1	3.91	1.48	.86	95.5
1922–23	1.15	3.65	224	331	117	30.1	99.8	16.9	8.00	3.79	1.71	1.04	69.9
1923–24	.98	.94	1.23	1.83	1.50	1.72	3.31	1.75	.87	.18	0	.21	1.21
1924–25	.40	2.86	3.25	10.7	142	16.5	37.2	9.68	4.50	1.69	.44	.16	18.2
1925–26	.11	.30	.77	1.24	512	18.7	158	12.9	4.05	1.37	.63	.39	55.7
1926–27	.52	21.2	8.24	25.9	652	89.5	108	17.3	7.36	3.04	1.50	.61	73.7
Average	1.79	4.21	58.1	240	308	298	91.4	21.4	10.1	4.54	2.50	1.83	90.5

Coyote River at Coyote

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1916–17	0	0	56.6	73.4	716	82.4	5.87	0.048	0	0	0	0	73.5
1917–18	0	0	0	0	0	67.3	0	0	0	0	0	0	5.71
1918–19	0	0	0	0	329	149	.07	0	0	0	0	0	37.9
1919–20	0	0	.32	0	0	51.2	14	0	0	0	0	0	5.52
1920–21	0	0	61.4	318	77.0	30.4	1.27	0	0	0	0	0	40.8
1921–22	0	0	113	18.2	752	126	26.0	.67	0	0	0	0	81.7
1922–23	0	0	200	265	82.5	3.2	70.6	1.11	0	0	0	0	52.0

Monthly discharge, in second-feet, at stations in minor San Francisco Bay basins, Calif.—Continued

Coyote River near Edenvale

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1916–17	0	0	41.2	60.9	698	84.8	13.6	3.15	1.30	0	0	0	70.9
1917–18	0	0	0	0	0	42.6	0	0	0	0	0	0	3.62
1918–19	0	0	0	0	266	162	.06	0	0	0	0	0	34.2
1919–20	0	0	0	0	0	33.5	8.57	0	0	0	0	0	3.54
1920–21	0	0	23.2	325	51.1	8.80	0	0	0	0	0	0	34.2
1921–22	0	0	75.5	15.9	748	130	30.2	0	0	0	0	0	78.6
1922–23	0	0	156	284	85.9	3.3	58.5	0	0	0	0	0	49.1
1923–24	0	0	0	0	0	0	0	0	0	0	0	0	0
1924–25	0	0	0	0	79.6	0	0	0	0	0	0	0	6.10
1925–26	0	0	0	0	301	0	99.8	0	0	0	0	0	31.3
1926–27	0	1.57	0	0	471	46.5	64.3	0	0	0	0	0	45.5
Average	0	.14	26.9	62.3	246	46.5	25.0	.29	.12	0	0	0	32.5

Coyote River at San Jose

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1916–17	------	------	------	72.4	672	82.4	10.8	1.84	0.383	0	0	0	------

Laguna Seca near Coyote

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1917–18	------	------	------	------	0.075	0.326	1.23	1.06	0.376	0	0	0	------

Alameda Creek near Sunol

[Drainage area, 33.1 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1910–11	------	------	------	------	------	------	------	------	3.47	2.86	2.57	0.61	------
1911–12	0.29	0.42	0.70	17.3	4.17	37.5	7.90	4.24	2.94	2.10	1.27	.48	6.67
1912–13	.35	.36	.43	40.2	3.76	7.82	4.93	1.95	1.43	.37	.20	.12	5.21
1913–14	0	.13	56.0	204	108	11.3	4.42	2.50	1.55	0	0	0	32.1
1914–15	0	0	8.31	90.9	248	32.7	17.8	72.5	8.72	2.52	1.02	.93	39.0
1915–16	.77	.73	11.7	307	124	37.9	9.25	3.54	1.27	.96	.36	.20	41.4
1916–17	0	0	40.2	31.8	168	35.5	11.3	6.85	3.82	0	0	0	23.8

1917–18	0	0	0	0	11.4	42.3	4.97	1.41	.68	0	0	4.10	5.39
1918–19	.22	5.32	5.70	6.00	173	103	11.1	3.40	1.08	0	0	0	24.8
1919–20	0	0	4.14	.83	.80	47.6	34.8	1.97	.16	0	0	0	7.55
1920–21	0	3.79	62.7	88.7	52.3	13.0	5.76	3.59	1.10	0	0	0	19.2
1921–22	0	0	37.6	23.0	214	9.9	32.5	8.72	2.09	0	0	0	32.8
1922–23	0	4.06	93.4	49.4	46.3	8.73	28.2	3.87	0	0	0	0	19.4
1923–24	0	0	0	0	0	.04	.19	0	0	0	0	0	.02
1924–25	0	0	7.85	7.42	76.4	4.73	10.6	10.6	0	0	0	0	9.33
1925–26	0	0	0	7.68	151	10.3	39.6	2.68	.007	0	0	0	16.6
1926–27	0	31.7	10.2	26.6	140	34.5	44.9	5.24	.07				
Average	.10	2.91	21.2	56.3	95.1	32.3	16.8	8.32	1.67	.55	.34	.40	18.9

Alameda Creek at Sunol

[Drainage area, 620 square miles]

1900–1901	10.9	391	52.1	282	993	161	66.0	57.8	23.1	9.31	2.57	0	
1901–2	0	.52	17.4	7.11	521	685	127	39.3	14.7	5.03	2.29	0	116
1902–3	0	5.42	.730	267	329	677	519	38.9	3.36	.958	0	0	152
1903–4	0	23.8	.32	5.83	420	812	273	90.1	9.00	1.22	.229	.031	135
1904–5	.01	.02	.103	52.8	166	350	102	79.5	7.88	.106	.039	0	62.8
1905–6	.003	.016	.099	898	397	1,400	462	130	57.7	9.18	1.63	.87	281
1906–7	.03	.03	321	1,140	518	2,780	381	106	41.0	29.3	11.5	1.86	447
1907–8	2.07	7.46	74.2	229	241	175	27.2	12.9	.78	.65	.35	.75	63.9
1908–9	.20	.44	1.27	1,780	1,830	352	80.9	13.1	5.40	4.68	.020	.229	330
1909–10	1.61	1.44	155	552	259	276	112	29.4	5.78	3.67	1.32	.72	116
1910–11	.290	.29	1.09	1,540	756	2,050	103	29.8	5.65	4.40	3.73	2.26	375
1911–12	1.83	2.72	3.47	67.7	27.5	134	28.6	5.03	.239	.001	0	0	22.7
1912–13	0	0	0	89.6	2.15	14.6	.329	0	0	0	0	0	9.04
1913–14	0	0	175	1,720	926	131	38.5	2.98	1.08	.17	.003	0	247
1914–15	0	0	15.8	404	1,960	254	126	355	31.7	3.77	.11	0	251
1915–16	0	0	64.4	2,440	938	291	55.7	24.0	17.9	11.4	7.4	2.2	321
1916–17	5.34	.39	45.3	89.9	979	157	28.9	17.8	15.5	30.4	32.8	49.7	115
1917–18	68.1	5.41	.52	0	7.66	82.9	1.09	0	0	16.8	23.5	43.1	21.0
1918–19	37.9	3.51	29.6	13.6	795	660	40.1	11.6	14.2	27.8	22.0	28.9	136
1919–20	1.89	0	.18	0	0	58.6	29.7	14.4	20.5	5.42	0	0	10.9
1920–21	0	0	195	513	208	16.0	13.2	7.02	.70	0	0	.66	79.2
1921–22	.10	0	175	86.0	1,290	281	65.8	13.5	18.7	2.62	0	0	154
1922–23	.80	9.70	336	257	195	36.8	39.4	18.4	46.6	56.8	41.7	23.9	88.3
1923–24	14.2	9.88	5.27	.79	.32	0	0	0	0	0	0	0	2.55
1924–25	0	0	0	0	236	3.60	23.3	12.8	30.3	15.4	0	0	25.2
1925–26	0	0	0	2.84	370	.28	92.5	.46	.46	.46	.39	.20	36.4
1926–27	0	31.6	3.17	8.57	470	43.1	61.0	23.6	23.2				
Average	5.38	18.3	61.9	461	549	440	107	42.0	14.6	9.21	5.83	5.98	144

Monthly discharge, in second-feet, at stations in minor San Francisco Bay basins, Calif.—Continued

Alameda Creek at Niles Dam

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1890-91	----	----	----	57.0	705	717	147	57.5	34.4	14.3	1.40	0	----
1891-92	0	0	157	79.6	83.6	273	185	110	27.2	7.59	0	0	77.1
1892-93	0	741	1,980	675	1,220	916	281	121	31.1	20.2	13.6	11.1	497
1893-94	5.59	10.7	25.4	807	1,340	214	53.2	32.4	22.3	13.0	3.93	1.30	204
1894-95	9.37	7.90	874	2,330	703	174	113	89.5	32.8	15.5	4.19	4.69	364
1895-96	10.1	12.6	15.2	963	117	119	516	137	31.9	10.7	3.93	4.24	162
1896-97	5.11	76.3	122	132	1,410	1,360	243	67.6	29.1	15.9	6.46	3.61	282
1897-98	5.05	2.71	5.40	13.2	45.7	32.9	10.2	3.25	.45	0	.15	0	9.69
1898-99	1.04	.94	.28	24.0	3.79	939	55.3	13.7	5.27	1.63	.04	0	88.5
1899-1900	2.26	28.1	108	494	36.2	113	37.2	21.0	3.98	.93	.06	1.34	71.3
Average	4.28	97.8	365	557	566	486	164	65.3	21.8	10.0	3.38	2.63	195

Alameda Creek near Niles

[Drainage area, 633 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1916-17	6.05	3.13	48.9	92.8	1,050	150	23.6	12.1	11.9	34.4	28.5	42.5	119
1917-18	57	3.35	.50	.21	6.33	86.0	.43	.12	.04	6.31	18.8	27.6	17.4
1918-19	38.4	5.75	19.0	13.1	881	701	46.7	10.5	16.2	30.7	27.8	34.8	147
1919-20	2.50	.43	.93	.60	.50	54.1	29.0	11.5	25.5	----	----	----	----
1920-21	.5	.5	250	640	245	24.5	20.0	16.9	2.31	.44	.29	1.43	99.9
1921-22	1.87	1.84	247	95.4	1,500	305	80.1	22.6	24.7	4.21	1.00	1.06	181
1922-23	1.83	8.53	323	261	191	38.9	42.6	13.1	18.9	25.6	16.4	24.4	80.2
1923-24	21.6	5.22	1.82	2.41	1.54	.64	.42	.10	0	0	0	0	2.84
1924-25	0	.08	1.04	1.59	231	7.57	27.0	17.4	28.7	14.6	0	0	25.9
1925-26	0	0	.08	1.43	418	2.51	99.7	24.9	1.52	.14	0	0	42.8
1926-27	.23	36.8	4.98	17.0	545	56.2	79.7	38.0	39.4	26.0	.10	0	66.7
Average	11.8	5.97	81.6	102	461	130	40.8	15.2	15.4	14.2	9.29	13.2	78.3

Alameda Creek near Decoto

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1916-17	0	0	38.4	78.2	1,010	135	9.92	0	0	4.42	5.32	21.3	102
1917-18	40.5	1.42	0	0	0	68.4	0	0	0	0	0	6.96	9.94
1918-19	18.6	0	.60	2.32	811	690	33.4	0	0	3.23	5.61	1.82	126

Calaveras Creek near Sunol

[Drainage area, 100 square miles]

1909–10	-----	-----	-----	-----	-----	-----	-----	-----	-----	8.98	5.94	4.19	-----
1910–11	4.31	2.64	4.33	449	298	607	69.7	36.5	17.9	10.7	8.00	5.64	126
1911–12	5.06	6.58	8.08	37.7	14.0	121	36.7	12.8	4.60	2.76	1.36	1.00	21.1
1912–13	.84	1.09	2.45	108	8.42	14.7	8.83	4.18	2.91	1.92	1.19	.86	13.1
1913–14	.56	.57	153	744	347	26.6	15.5	9.97	5.00	0	0	0	108
1914–15	0	0	40.8	222	717	101	60.2	175	31.3	7.09	2.87	2.61	109
1915–16	2.17	2.06	28.4	778	239	21.4	4.75	11.3	11.7	16.0	20.0	17.9	96.1
1916–17	10.6	6.52	8.40	21.0	357	34.0	11.1	16.2	23.3	64.7	58.1	76.6	55.2
1917–18	86.7	5.87	2.47	1.36	2.49	3.94	15.7	1.46	0	37.0	40.5	38.2	19.8
1918–19	58.6	15.1	21.8	10.6	127	271	33.8	31.7	49.3	62.1	53.8	63.5	66.3
1919–20	11.4	1.05	17.3	4.23	6.86	7.71	10.0	38.1	53.4	26.7	12.0	12.6	16.8
1920–21	14.1	14.8	156	188	56.5	1.39	29.9	28.9	25.5	31.5	34.5	35.4	51.7
1921–22	30.7	18.5	167	52.6	373	80.4	23.3	20.7	47.0	24.8	29.7	32.9	73.1
1922–23	27.2	23.4	98.1	52.7	54.0	24.6	12.3	27.9	41.7	59.0	49.9	63.2	44.5
1923–24	45.5	32.4	19.6	18.6	17.9	14.3	15.2	18.3	17.7	15.3	14.3	7.12	19.7
1924–25	2.18	4.16	2.54	.23	.13	0	23.9	25.0	64.3	35.9	16.3	30.4	17.1
1925–26	36.4	31.0	32.6	23.5	1.74	20.3	9.40	58.9	59.7	65.9	65.2	64.1	39.3
1926–27	62.3	53.9	53.7	36.0	3.25	4.55	22.3	93.9	97.2	-----	-----	-----	-----
Average	23.4	12.9	48.0	162	154	79.6	23.7	35.9	32.5	27.7	24.3	26.8	54.8

NOTE.—Construction of Calaveras Reservoir was begun in July, 1915.

San Antonio Creek near Sunol

[Drainage area, 38.7 square miles]

1911–12	-----	-----	-----	5.54	2.24	9.19	2.82	1.60	0.47	0.13	0.006	0	-----
1912–13	0	0.16	0.80	15.6	2.25	3.85	4.08	2.17	.17	.15	0	0	2.45
1913–14	0	.11	27.0	151	70.3	21.2	11.3	5.91	2.53	0	0	0	24.0
1914–15	0	0	3.40	42.3	205	28.7	11.1	42.8	5.12	.92	.47	.40	27.2
1915–16	0.35	.34	13.9	258	98.3	46.0	8.17	3.89	2.01	.42	.18	.16	36.0
1916–17	.37	.37	12.0	12.0	60.9	22.9	5.43	2.48	.70	0	0	0	9.44
1917–18	0	.04	.19	.29	3.82	28.6	1.93	.61	0	0	0	2.84	3.21
1918–19	.15	3.71	1.47	4.34	106	74.4	9.36	4.63	.56	0	0	0	16.5
1919–20	0	0	.67	.95	2.89	29.7	13.5	1.46	0	0	0	0	4.11
1920–21	0	0	25.1	62.5	37.5	11.8	6.84	5.23	1.47	0	0	0	12.5
1921–22	0	0	19.6	16.2	128	46.2	14.9	3.00	.69	.03	0	0	18.3
1922–23	0	1.28	37.7	28.3	20.9	4.60	7.57	1.03	.05	0	0	0	8.42
1923–24	0	0	0	0	0	0	0	0	0	0	0	0	0
1924–25	0	0	2.32	1.99	42.3	5.11	7.92	2.17	.40	0	0	0	4.92
1925–26	0	0	0	.12	63.5	3.75	17.6	.43	0	0	0	0	6.69
1926–27	0	5.11	5.39	12.9	60.8	17.8	19.0	5.86	2.53	-----	-----	-----	-----
Average	.06	.74	9.97	38.3	56.5	22.1	8.84	5.20	1.05	.11	.04	.02	12.4

Monthly discharge, in second-feet, at stations in minor San Francisco Bay basins, Calif.—Continued

Arroyo de la Laguna near Pleasanton

[Drainage area, 401 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1911–12	------	------	------	11.5	6.47	7.72	6.48	5.25	3.39	1.33	0.56	0.61	------
1912–13	0.44	1.02	0.84	2.23	.95	.87	.83	.61	.38	0	0	0	0.68
1913–14	0	0	105	1,350	625	72.1	11.5	8.15	3.73	0	0	0	179
1914–15	0	0	1.41	76.3	728	93.3	38.7	74.0	11.5	7.42	4.52	2.98	82.1
1915–16	1.89	1.01	6.45	1,190	443	154	41.9	19.0	14.0	13.2	8.68	7.03	158
1916–17	9.75	5.74	21.1	35.0	385	64.3	22.0	15.8	10.0	6.70	5.35	5.38	46.5
1917–18	3.93	2.11	1.26	1.31	1.58	15.1	1.25	.42	0	0	0	0	2.27
1918–19	0	0	0	13.9	403	207	13.7	8.17	5.26	0	0	0	51.9
1919–20	0	0	.99	------	------	------	------	0	0	0	0	0	------
1920–21	0	0	7.63	162	54.0	8.35	4.95	3.02	1.58	1.03	.88	.42	20.3
1921–22	1.36	1.54	20.5	18.6	589	82.4	24.3	10.1	5.79	2.90	2.76	3.34	59.9
1922–23	4.35	3.74	99.7	107	59.8	11.6	16.6	8.31	6.59	3.91	1.48	1.75	27.0
1923–24	2.47	2.96	3.13	.98	.83	.52	.11	0	0	0	0	0	.92
1924–25	0	0	0	0	95.2	2.99	1.25	.21	0	0	0	0	7.68
1925–26	0	0	0	0	259	.67	59.8	.53	.16	0	0	0	24.9
1926–27	0	13.4	.72	.29	325	32.2	40.5	1.10	.70	------	------	------	------
Average	1.61	2.10	17.9	198	265	50.2	18.9	9.67	3.94	2.43	1.62	1.43	50.9

Alamo Creek at Dublin

[Drainage area, 40.4 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1914–15	0	0	0.93	17.8	86.7	15.0	11.8	14.2	0.31	0	0	0	11.7
1915–16	0	0	8.79	159	41.3	13.5	4.03	.91	.25	0	0	0	19.1
1916–17	0	0	1.30	6.57	51.2	9.72	3.14	.96	.08	0	0	0	5.77
1917–18	0	0	0	0	0	1.47	0	0	0	0	0	0	.12
1918–19	0	0	0	2.24	79.7	30.7	2.93	.10	0	0	0	0	9.16
1919–20	0	0	0	0	0	.19	.03	0	0	0	0	0	.02

Tassajero Creek near Pleasanton

[Drainage area, 27.9 square miles]

1914-15	-----	-----	0.61	4.07	40.5	7.09	4.57	7.46	1.03	0	0	0	5.20
1915-16	0	0	1.25	88.0	38.3	12.5	5.66	2.15	1.21	1.95	0	0	12.6
1916-17	0	1.02	1.96	1.36	7.99	3.23	1.46	.46	.31	0	0	0	1.44
1917-18	0	0	.39	.55	.74	1.12	.28	0	0	0	0	0	.25
1918-19	0	0	0	.61	25.8	7.72	1.54	.55	-----	-----	-----	-----	-----
1921-22	0	0	.35	.55	29.0	2.81	1.05	0	0	0	0	0	2.63
1922-23	0	.73	6.08	7.48	2.35	.93	1.76	.44	0	0	0	0	1.65
1923-24	0	0	0	0	0	0	0	0	0	0	0	0	0
1924-25	0	0	.38	.27	13.8	.92	.46	0	0	0	0	0	1.23
1925-26	0	0	0	.13	2.03	.30	.71	0	0	0	0	0	.25
1926-27	0	.14	.14	.38	19.7	5.72	5.91	.19	0	-----	-----	-----	-----
Average	0	.19	1.01	9.40	16.4	3.85	2.13	1.02	.26	.22	0	0	2.81

Arroyo Mocho near Livermore

[Drainage area, 38.3 square miles]

1911-12	-----	-----	-----	1.82	0.54	3.32	0.54	0.38	0.08	0.01	0	0	-----
1912-13	0	0.07	0.24	2.71	.32	.53	.30	.05	0	0	0	0	0.35
1913-14	0	.06	2.55	-----	64.9	3.46	.79	.53	.36	0	0	0	-----
1914-15	0	0	2.47	18.4	100	9.55	5.60	8.99	.52	.09	.07	.06	11.6
1915-16	0.06	.22	2.52	111	54.2	18.1	5.93	3.13	.70	.19	.06	.06	16.3
1916-17	.39	.39	3.09	3.80	39.3	3.69	.45	.15	.09	0	0	0	4.04
1917-18	0	0	.22	.24	1.41	5.99	.46	.19	0	0	0	0	.71
1918-19	0	0	0	.61	26.1	23.6	2.31	.46	.23	0	0	0	4.31
1919-20	0	0	.51	.77	.89	9.73	4.20	0	0	0	0	0	1.35
1920-21	0	0	2.32	16.3	6.28	2.00	.85	.08	0	0	0	0	2.30
1921-22	0	.09	5.80	4.95	61.1	8.80	2.53	.46	0	0	0	0	6.60
1922-23	0	.11	8.31	6.01	5.48	1.00	2.72	.12	0	0	0	0	1.96
1923-24	0	0	0	.09	.35	0	0	0	0	0	0	0	.04
1924-25	0	0	.28	1.00	4.72	.92	1.10	.50	0	0	0	0	.68
1925-26	0	0	0	.14	31.2	1.52	9.32	.73	.017	0	0	0	3.36
1926-27	0	4.45	1.57	2.19	27.2	7.84	7.67	2.47	1.29	-----	-----	-----	-----
Average	.03	.36	1.99	11.3	26.5	6.25	2.80	1.14	.21	.02	.01	.01	4.12

Monthly discharge, in second-feet, at stations in minor San Francisco Bay basins, Calif.—Continued

Arroyo las Positas near Livermore

[Drainage area, 69.5 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1911-12				2.33	1.32	1.65	0.76	0.35	0.18	0.13	0.09	0.10	
1912-13	0.08	0.11	0.15	.46	.39	.35	.19	.02	0	0	0	0	0.14
1913-14	0	0	.69	19.8	4.15	1.22	.76	.61	.45	0	0	0	2.31
1914-15	0	0	.40	5.89	35.5	8.13	4.33	7.87	.51	.38	.40	.39	5.11
1915-16	.37	.36	1.93	88.4	30.7	17.3	7.80	2.00	1.01	1.50	1.09	.94	12.8
1916-17	.94	.97	1.50	1.79	3.42	1.55	.77	.46	.15	0	0	0	.95
1917-18	0	0	.35	.40	.52	1.83	.31	.11	0	0	0	0	.29
1918-19	0	0	0	.60	10.3	9.74	.46	0	0	0	0	0	1.71
1919-20													
1920-21													
1921-22	0	0	.36	3.89	19.1	1.02	.29	0	0	0	0	0	1.94
1922-23													
1923-24	0	0	0	0	0	0	0	0	0	0	0	0	0
1924-25	0	0	.22	.47	5.95	.21	0	0	0	0	0	0	.53
1925-26	0	0	0	.09	3.13	.61	1.43	.27	.15	.035	0	0	.46
1926-27	0	.93	.84	.76	6.96	1.47	1.43	.23	0				
Average	.12	.20	.54	9.61	9.34	3.47	1.43	.92	.19	.17	.13	.12	2.39

Arroyo del Valle near Livermore

[Drainage area, 149 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1911-12				7.08	4.18	20.3	5.27	3.01	1.01	0.35	0.17	0.11	
1912-13	0.05	0.16	0.19	11.7	3.58	5.29	4.08	1.81	1.10	.26	0	0	2.35
1913-14	0	0	88.6	851	415	40.0	22.1	9.64	4.16	0	0	0	118
1914-15	0	0	8.90	109	522	71.5	37.2	57.9	8.55	1.45	.14	.06	64.9
1915-16	.03	.003	19.1	630	264	94.3	24.8	10.1	4.90	0	0	0	87.2
1916-17	0	0	21.7	36.9	293	41.6	10.4	4.34	1.44	0	0	0	32.3
1917-18	0	0	0	0	5.10	42.1	3.78	1.19	0	0	0	0	4.38
1918-19	0	0	4.19	7.30	239	120	18.1	9.33	.40	0	0	0	31.8
1919-20	0	0	0	0	0	40.1	21.0	2.57	0	0	0	0	5.34
1920-21	0	0	17.7	121	42.2	13.1	5.47	2.87	.93	0	0	0	16.9
1921-22	0	0	49.7	27.6	444	61.3	21.4	5.55	1.04	0	0	0	48.1
1922-23	0	0	89.3	65.4	58.6	9.29	25.2	3.11	.28	0	0	0	20.8
1923-24	0	0	0	0	0	0	0	.08	0	0	0	0	.007
1924-25	0	0	0	2.47	49.1	6.76	7.42	3.29	2.42	.23	0	0	5.66
1925-26	0	0	0	0	249	8.58	87.0	2.07	.52	.29	.074	0	27.2
1926-27	0	69.2	10.6	17.9	281	39.0	40.3	3.61	.84				
Average	.005	4.62	20.7	118	179	38.3	20.8	7.53	1.72	.17	.03	.01	33.2

Spring Valley Water Co.'s aqueduct near Sunol [a]

1902–3	----	----	----	----	----	----	----	24.7	26.0	26.7	22.2	18.4	----
1903–4	16.6	19.9	25.2	25.2	24.1	25.2	25.0	25.6	25.9	26.1	23.4	18.3	23.4
1904–5	18.2	19.4	20.3	24.1	24.0	24.4	25.1	25.5	26.2	25.6	22.6	16.5	22.7
1905–6	14.1	13.8	14.2	18.0	25.1	25.0	17.9	10.5	20.8	23.0	24.8	25.0	19.3
1906–7	23.1	22.1	21.8	23.4	25.7	18.8	26.3	27.1	27.0	26.7	27.2	26.5	24.6
1907–8	25.6	25.6	23.8	22.8	25.1	26.0	26.1	26.2	26.9	25.9	19.5	17.8	24.3
1908–9	15.2	15.2	15.7	16.6	7.99	19.8	24.6	26.6	25.5	24.3	25.3	24.8	20.2
1909–10	25.0	23.2	23.7	29.7	27.9	27.7	27.9	25.9	24.8	22.3	24.7	20.7	25.3
1910–11	11.1	16.0	21.3	24.3	19.4	21.6	25.0	27.0	26.7	24.8	26.4	23.6	22.3
1911–12	25.8	25.4	26.3	25.7	25.8	26.2	26.0	26.1	26.9	21.4	18.2	16.2	24.2
1912–13	15.4	13.0	16.1	21.1	26.1	27.0	32.8	27.6	22.6	18.2	13.2	16.8	20.8
1913–14	15.3	16.3	19.2	33.0	35.4	35.5	35.6	32.4	35.4	32.3	30.6	25.6	28.9
1914–15	24.3	20.1	30.4	34.8	35.3	35.4	36.1	36.8	37.3	34.8	32.0	32.1	32.4
1915–16	29.4	27.5	32.3	32.6	33.0	33.3	31.2	29.7	26.0	29.9	33.8	33.5	31.0
1916–17	24.7	33.8	32.0	32.9	32.7	33.2	34.1	33.7	31.6	27.9	33.1	31.9	31.8
1917–18	34.1	29.6	24.6	22.4	27.1	32.4	32.3	31.6	25.5	29.4	32.5	29.1	29.2
1918–19	31.2	24.0	31.3	31.5	31.8	33.0	33.0	32.7	32.6	33.0	33.1	32.9	31.7
1919–20	32.0	25.6	25.8	29.1	28.5	29.5	32.3	32.7	33.0	32.9	31.9	32.1	30.5
1920–21	30.2	31.7	30.7	30.4	32.3	32.8	33.0	33.3	33.2	33.3	33.3	33.3	32.3
1921–22	31.8	31.8	29.5	29.2	30.9	31.2	32.9	33.4	33.3	31.1	32.5	32.7	31.7
1922–23	32.0	30.9	31.6	32.2	32.6	33.3	33.2	33.5	31.2	32.6	34.9	33.3	32.6
1923–24	32.4	32.8	33.2	34.1	31.9	32.9	33.2	32.0	32.8	32.8	29.9	31.8	32.5
1924–25	32.5	29.2	30.8	32.4	33.0	32.2	33.2	34.3	30.6	31.2	31.3	39.1	32.5
1925–26	44.4	44.5	45.0	44.8	46.5	43.5	41.4	48.4	79.7	79.3	76.9	76.8	56.0.
1926–27	76.9	75.8	72.2	65.6	69.8	73.6	74.8	74.7	73.5	----	----	----	----
Average	27.6	27.0	28.2	29.8	30.5	31.4	32.2	31.7	32.6	30.2	29.7	28.7	28.7

Laguna Creek at Irvington

[Drainage area, 10.8 square miles]

1916–17	0	0.14	0.84	1.69	2.12	2.74	----	----	----	----	----	----	----
1917–18	0	0	0	0	.06	.52	0.40	0.02	0	0	0	0	0.08
1918–19	0	0	0	.27	3.02	5.39	2.70	.86	.03	0	0	0	1.01

Dry Creek near Decoto

1916–17	0	0	0.24	2.63	10.9	2.85	0	0	0	0	0	0	1.32
1917–18	0	0	0	0	0	1.0	0	0	0	0	0	0	.1
1918–19	0	0	0	0	18.2	5.10	.18	0	0	0	0	0	1.85

[a] Station moved to mouth of Alameda Canyon at Niles, Oct. 1, 1926.

Monthly discharge, in second-feet, at stations in minor San Francisco Bay basins, Calif.—Continued

San Pablo Creek near San Pablo

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1917-18	0	0	0	0	9.2	11.1	0.2	0.03	0	0	0	0	1.7
1918-19	0	0	0	0	80.7	25.8	.2	.2	.2				

San Pablo Creek at San Pablo

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1917-18	0	0	0	0	4.4	15.5	0.6	0	0	0	0	0	1.7
1918-19	0	0	0	0	105	32.2	2.27	1.29	.65				

Monthly discharge, in second-feet, at stations in northern Pacific basins in California

Russian River near Ukiah

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1910-11												0.08	
1911-12	0.04	0.30	5.25	214	108	368	81.3	135	12.1	4.84	1.01	2.78	78.1
1912-13	3.6	443	291	761	69.4	74.2	109	16.3	7.3	2.0			

Russian River at Geyserville

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1910-11					3,140	3,300	1,180	534	228	117	6.7	0	
1911-12	3.4	20.7	51.8	1,050	846	1,840	718	1,020	322	85.7	16.0	70.0	504
1912-13	16.9	1,120	1,140	4,010	588	597	740	356	164	40.4	15.8		

East Fork of Russian River near Ukiah

1910-11												10.8	
1911-12	13.4	14.4	32.0	258	279	521	326	367	197	82.2	35.5	107	186
1912-13	39.7	437	355	1,140	106	182	268	226	102	76.8	23.6	2.0	248

Mattole River near Petrolia

[Drainage area, 264 square miles]

1911-12			299	5,060	3,030	2,110	1,010	1,690	436	182	89.9	179	
1912-13	191	4,230	3,090	5,960	576	675	1,360	417	199	91.9	40.9	34.7	1,410
1913-14	39.2												

South Eel River at Hullville

1922-23			215	257	439	311	723	259	247	227	214	215	
1923-24	240	218	110	56.2	64.7	69.4	56.7	63.0	64.8	69.6	65.2	48.8	93.9
1924-25	57.6	212	149	188	2,650	554	1,100	764	296	295	277	274	552
1925-26	270	261	239	177	836	194	537	225	239	240	258	246	306
1926-27	249	181	552	1,270	3,810	1,120	1,400	395	287	289	308	306	825

NOTE.—Flow is regulated at Scott Dam.

South Eel River and Snow Mountain Water & Power Co.'s tailrace near Potter Valley

1909-10			883	1,350	1,380	1,390	663	250	69.7	23.1	5.5	10.8	
1910-11	17.1	74.6	200	1,540	1,390	2,150	1,410	578	309	55.8	19.5	18.9	644
1911-12	22.8	36.2	45.5	652	377	683	551	1,000	258	53.6	17.7	50.2	313
1912-13	30.8	603	634	2,090	879	587	969	416	160	53.3	20	8.4	536
1913-14	11.6	179	1,910	6,770	3,060	1,530	906	342	179	50.6	17.1	13.6	1,240
1914-15	37.6	36.5	231	1,780	4,930	1,780	1,370	1,420	512	98.2	37.2	14.0	993
1915-16	19.4	74.0	1,140	2,890	3,480	2,020	611	292	122	54.2	23.2	14.4	889
1916-17	18.3	62.0	378	521	2,740	1,100	1,400	573	187	37.2	22.2	13.1	572
1917-18	14.3	31.0	173	123	845	1,130	602	158	44.3	14.1	10.8	14.8	259
1918-19	18.7	97.4	132	1,230	2,750	1,690	813	322	76.5	23.8	13.5	10.9	585
1919-20	12.5	19.7	186	61.3	42.0	376	1,150	187	40.5	13.0	4.3	4.7	174
1920-21	24.2	1,760	2,330	2,710	2,370	1,280	575	291	154	34.6	12.9	12.1	955
1921-22	6.0	32.2	129	269	541	778	873	429	279	305	317	312	354
1922-23	321	253	468	492	695	332	750	268	277	243	222	224	376
1923-24	244	222	118	78.0	159	72.5	60.1	63.9	61.9	59.8	59.7	30.8	102
1924-25	77.3	274	347	297	3,030	638	1,410	556	296	298	268	274	629
1925-26	259	250	253	245	1,270	262	647	251	252	250	262	257	364
Average	70.9	250	562	1,360	1,760	1,050	868	435	193	98.1	78.4	75.5	562

Monthly discharge, in second-feet, at stations in northern Pacific basins in California—Continued

South Eel River at Hearst

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1910-11				1,560	1,430	2,000	1,240	457	135	17.9	6.9	4.3	
1911-12	5.6	10.6	18.5	732	407	870	506	1,010	120	20	10	25.6	312
1912-13	9.5	983	705	2,170	675	486	824	227	21.4	5.9			

Eel River at Two Rivers

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1911-12			125	4,540	2,750	3,700	2,660	4,820	847	115	30.0	173	
1912-13	101	4,870	4,060	9,890	2,950	2,370	4,260	2,040	599	107	41.6	19.0	2,610

Eel River at Scotia

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1910-11				21,000	15,500	12,500	9,480	4,670	2,010	336	150	112	
1911-12	75.0	294	581	15,400	8,730	11,900	5,890	11,600	2,180	538	224	692	4,840
1912-13	444	14,200	12,100	28,100	8,430	6,580	11,500	3,440	1,190	393	174	117	7,220
1913-14	110	1,850	18,100	67,500	22,600	9,890	13,100	7,130	1,330	362	208	210	11,900
1914-15	431	350	7,070	32,100									
1916-17	90.0	840	6,040	8,120	24,500	10,900	14,400	4,500	1,340	337	146	98.7	5,800
1917-18	84.0	429	2,870	2,280	12,500	11,100	6,140	1,170	367	103	59.0	81.0	3,040
1918-19	104	1,050	2,610	20,800	31,000	20,300	8,170	2,810	665	208	97.2	81.5	7,180
1919-20	99.0	134	3,300	766	388	5,530	10,000	1,490	427	202	59.4	53.7	1,870
1920-21	513	26,400	33,100	25,000	22,700	12,100	4,570	2,810	788	190	115	96.2	10,600
1921-22	108	728	6,000	3,720	20,400	12,300	10,500	4,640	1,210	210	114	91.7	4,890
1922-23	185	949	11,000	11,000	5,860	2,070	9,060	1,520	599	207	91.9	86.5	3,540
1923-24	206	157	1,350	2,580	7,380	946	703	278	75.7	25.1	22.1	19.4	1,120
1924-25	1,940	9,720	12,900	7,560	50,100	7,300	19,500	7,140	1,930	389	163	233	9,600
1925-26	188	855	3,910	5,570	32,600	4,310	4,340	1,590	342	108	51.1	40.1	4,300
1926-27	351	16,100	15,700	19,200	48,700	13,500	12,500	2,960	978	312	111	84.1	10,600
Average	329	4,940	9,110	16,900	20,800	9,420	9,320	3,850	1,030	261	119	140	6,180

Snow Mountain Water & Power Co.'s tailrace near Potter Valley

1922-23	294	228	239	265	264	265	264	265	275	241	220	222	254
1923-24	242	220	115	76.0	123	70.5	58.1	61.9	59.9	57.8	57.7	28.8	97.5
1924-25	75.3	272	305	295	276	292	278	284	294	296	266	272	267
1925-26	257	248	249	215	235	252	246	249	250	248	260	255	247
1926-27	249	250	249	234	245	241	249	249	262	263	274	276	253

Middle Fork of Eel River near Covelo

1910-11												11.9	
1911-12	14.4	43.6	36.4	1,420	1,480	947	1,180	2,470	549	81.7	23.0	132	696
1912-13	68.3	1,720	1,420	1,920	1,290	1,100	2,370	1,420	360	60.0	29.3	14.3	978
1913-14	12.7	193	1,970	6,360	2,940	3,010	4,150	1,290	492	106	20.9	15.1	1,710
1914-15	71.6	48.0	183	1,480	4,270	2,840	2,940	3,120	946	130	27.7	9.77	1,320
1915-16	12.9	129	2,520	2,020	4,200	2,790	1,530	798	325	99.7	18.1	9.42	1,200
1916-17	12.0	121	422	640	2,240	1,260	3,350	1,650	447	61.1	17.0	12.0	840
1917-18	9.50	55.1	296	424	924	1,840							
1920-21	74.8	3,280	3,520	2,760	2,480	1,990	1,330	1,310	399	74.7	20.2	9.90	1,430

South Fork of Eel River at Garberville

[Drainage area, 84 square miles]

1910-11												47.1	
1911-12	56.6	102	209	4,200	2,430	2,930	1,180	2,220	376	129	77.7	143	1,170
1912-13	134	4,110	3,220	7,100	856	1,060	1,820	510	233	110	54.5		

Van Duzen River at Bridgeville

[Drainage area, 194 square miles]

1911-12	12.6	57.2	82.1	2,440	1,390	1,120	1,010	1,410	237	53.9	16.3	66.8	657
1912-13	61.2	1,580	1,460	2,300	859	633	1,250	535	131	58.3			

Yager Creek at Carlotta

[Drainage area, 146 square miles]

1910-11												0.49	
1911-12	0.80	20.0	86.0	1,080	800	650	496	507	64.8	19.0	5.20	22.0	311
1912-13	16.3	628	931	1,180	205	270	418	136	31.9	21.2	7.06	1.25	322

Monthly discharge, in second-feet, at stations in northern Pacific basins in California—Continued

Mad River near Arcata

[Drainage area, 452 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1910–11				3,390	3,020	2,190	2,160	1,320	273	82.7	36.8	25.9	
1911–12	29.5	121	262	3,760	3,270	2,110	1,540	2,290	416	125	54.8	128	1,170
1912–13	78.3	2,680	3,290	4,310	1,780	1,670	2,390	872	238	120	49.6	34.0	1,460

Redwood Creek near Korbel

[Drainage area, 81 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1911–12	6.73	30.6	39.4	660	831	368	419	664	112	28.8	15.8	29.8	265
1912–13	26.6	538	753	900	291	258	408	203	66.9	38.5			

Redwood Creek at Orick

[Drainage area, 262 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1911–12	30.0	117	183	3,050	3,530	1,420	854	1,730	318	124	141	115	961
1912–13	181	3,420	3,650	3,690	773	716	1,730	574	166	101			

Klamath River near Copco

[Drainage area, 4,300 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1923–24	1,470	1,430	1,400	2,020	1,760	1,850	1,540	1,080	751	845	1,070	1,380	1,380
1924–25	1,660	1,760	1,650	1,460	1,640	1,910	1,470	1,920	1,990	1,520	1,520	1,630	1,680
1925–26	1,630	1,470	1,840	1,440	1,500	1,300	1,300	830	1,180	1,100	1,090	1,190	1,320

Klamath River near Seiad Valley

1912–13			3,050	3,750	4,400	5,230	7,780	7,780	5,800	3,910	2,780	2,210	
1913–14	2,180	2,720	3,220	9,760	7,340	9,810	9,510	8,590	5,720	3,280	1,990	1,800	5,480
1914–15	2,920	2,870	2,960	3,410	5,790	5,710	7,170	5,900	4,780	2,520	1,490	1,330	3,890
1915–16	1,590	2,370	3,630	3,690	8,520	7,970	7,170	5,740	4,880	3,120	1,960	1,690	4,340
1916–17	1,820	2,200	2,660	2,970	3,820	4,220	6,750	7,830	6,200	3,040	1,800	1,520	3,730
1917–18	1,780	1,630	4,330	4,140	4,300	4,390	4,640	3,150	1,640	1,010	830	1,240	2,750
1918–19	1,720	2,110	2,280	3,430	5,370	5,440	7,740	4,750	2,910	2,000	1,530	1,330	3,370
1919–20	1,620	1,930	2,560	2,480	2,480	2,310	2,360	2,490	1,800	1,530	1,320	1,290	2,010
1920–21	1,610	3,740	4,240	6,670	9,120	9,130	7,390	6,930	5,130	2,260	1,390	1,520	4,900
1921–22	1,850	2,420	3,720	3,320	3,610	4,380	6,040	7,990	4,200	1,960	1,730	1,610	3,570
1922–23	1,800	2,230	2,940	5,440	4,120	2,730	3,030	2,880	2,720	1,950	1,990	1,830	2,800
1923–24	2,270	2,320	2,470	3,310	3,680	2,880	2,610	1,970	1,330	1,370	1,730	2,210	2,340
1924–25	2,720	3,950	3,720	3,870	8,890	4,580	4,860	5,380	3,690				
Average	1,990	2,540	3,210	4,330	5,500	5,290	5,930	5,490	3,910	2,330	1,710	1,630	3,560

NOTE.—Record not very satisfactory after Copco power plant was placed in operation in January, 1918.

Klamath River near Happy Camp

1911–12	1,930	2,290	2,530	4,850	7,130	5,470	5,450	8,300	6,190	3,120	2,070	2,120	4,270

Klamath River near Requa

1910–11				18,300	23,200	26,900	30,300	25,100	18,300	6,440	2,930	2,520	
1911–12	2,760	4,190	4,450	28,200	37,800	21,000	19,100	36,200	20,000	7,950	4,310	5,110	15,800
1912–13	4,530	21,800	20,100	26,600	22,100	21,200	32,100	27,900	16,600	8,360	4,860	4,340	17,500
1913–14	3,570	9,260	13,400	68,100	37,600	39,800	39,600	27,800	17,200	7,810	3,620	3,940	22,600
1914–15	7,500	5,930	9,800	21,700	46,400	33,400	36,400	31,400	23,500	9,970	4,130	3,190	19,200
1915–16	3,310	8,240	20,800	24,200	55,400	45,600	28,800	21,700	16,700	9,220	4,330	3,390	20,000
1916–17	3,220	6,600	9,580	11,100	23,200	19,400	33,600	29,600	18,900	6,860	3,130	2,830	13,900
1917–18	2,820	4,500	13,100	13,600	19,500	22,600	20,000	10,600	5,030	2,280	1,670	2,060	9,760
1918–19	3,130	6,180	7,840	24,200	35,400	33,300	39,800	24,300	11,000	5,030	2,550	2,600	16,100
1919–20	2,930	3,970	11,300	7,490	6,260	11,300	17,500	12,600	6,300	3,600	2,020	2,460	7,320
1920–21	5,740	30,500	37,500	40,100	49,300	34,900	25,300	25,300	18,600	6,800	2,990	2,700	23,100
1921–22	3,040	10,000	13,400	10,500	18,000	20,900	27,400	28,500	14,600	4,270	2,860	2,470	12,900
1922–23	3,280	4,050	13,100	22,600	12,200	10,700	16,300	12,400	7,610	4,070	2,970	3,020	9,350
1923–24	3,850	3,820	7,520	7,450	14,200	6,920	6,270	3,970	2,110	1,730	1,890	2,500	5,160
1924–25	6,400	23,600	15,600	19,900	63,600	17,700	32,400	22,100	11,400	4,770	2,230	3,850	18,300
1925–26	4,020	8,600	9,170	8,730	39,300	14,200	13,200	7,610	3,860				
Average	4,010	10,100	13,800	22,000	31,500	23,700	26,100	21,700	13,200	5,940	3,100	3,130	15,100

Monthly discharge, in second-feet, at stations in northern Pacific basins in California—Continued

Antelope Creek near Macdoel

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1921–22	16.4	18.0					27.4	137					

Butte Creek near Macdoel

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1921–22	32.2	32.5	38.6					89.2					

Bear Creek near Macdoel

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1921–22	6.39						19.9	72.7					

Shasta River near Montague

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1911–12	142	206	224		203	158	99.5	277	216	89.1	66.9	147	
1912–13	121	260	246	295	287	266	313	308	218	148	135	114	226
1916–17	140	186	221				248	171	96.4	41.0	41.7	72.8	
1917–18	118	192	223	209	192	201	69.5	31.5	35.7	24.4	39.3	95.2	119
1918–19	149	200	213	278	398	320	261	141	52.5	25.4	32.0	53.9	176
1919–20	130	169	230	192	156	158	84.0	58.3	36.9	44.5	39.1	54.5	113
1920–21	144	412	335	562	863	595	202	267	128	17.2	25.4	73.2	298
1921–22				227	297	210	203	211	66.8				
1922–23										14.5	12.5	46.4	
1923–24	143	177	178	196	226	129	14.9	12.2	9.36	8.77	10.7	40.0	94.9
1924–25	130	164	142	173	498	226	252	151	88.8	15.9	14.5	86.2	159
1925–26	140	166	223	220	328	134	93.6	23.2	12.0	14.2	14.3	48.8	117
1926–27	115	380	536	301	490	378	348	235	151	27.0	23.3	79.4	253
Average	134	228	252	265	358	252	182	157	92.6	39.2	37.9	76.0	173

East Fork of Scott River near Callahan

1910–11		13.2	29.4	29.7	40.0	128	106	121	107	8.0	2.0	2.0	
1911–12	1.4	2.9	7.0										

Scott Creek near Scott Bar

1911–12	100	145	132	649	1,130	534	578	1,900	1,790	727	395	433	707
1912–13	400	639	541	627	691	912	1,360	1,960	1,510	454	201	109	783
1913–14	86.2	265											

Indian Creek near Happy Camp

1911–12	35.9	114	73.0	964	1,600	477	378	795	339	92.5	47.2	61.2	407

Reeve Davis flume near Happy Camp

1911–12	11.0								35.5	34.3	33.9		

Salmon River at Somesbar

1911–12	217	299	290	3,950	4,470	1,540	1,610	4,990	3,220	765	342	404	1,830
1912–13	298	2,200	1,580	1,980	2,000	1,740	3,210	4,350	2,400	843	351	277	1,760
1913–14	351	949	1,680										

Trinity River near Trinity Center

1910–11				445	595	1,390	1,480	1,560	1,510	431	145	110	
1911–12	121	124	142	665	729	640		2,850	1,790	496	155	251	

Monthly discharge, in second-feet, at stations in northern Pacific basins in California—Continued

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
Trinity River at Lewiston													
1910-11	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	168	-----
1911-12	206	222	226	1,330	1,550	1,470	1,950	5,330	3,290	784	242	423	1,420
1912-13	245	1,380	963	899	1,510	1,760	3,510	4,430	2,070	634	243	189	1,480
1913-14	168	532	1,080	5,020	3,910	5,360	6,280	6,410	3,420	1,060	254	206	2,800
1914-15	504	321	404	1,060	5,020	5,630	6,990	7,020	6,310	2,050	454	212	2,980
1915-16	189	315	1,260	939	4,550	5,380	4,320	3,740	2,790	1,100	271	176	2,070
1916-17	162	201	330	310	1,030	890	2,240	3,210	1,920	334	117	104	901
1917-18	92.3	362	689	585	1,100	1,850	2,910	1,580	500	129	76.8	161	832
1918-19	269	376	366	1,340	2,620	2,280	5,040	4,800	1,460	381	128	123	1,590
1919-20	157	165	523	428	370	686	1,540	1,820	719	196	65.6	75.4	562
1920-21	205	3,060	2,010	3,060	3,090	4,650	3,960	5,060	3,480	857	248	150	2,480
1921-22	178	352	580	494	815	1,230	2,600	4,340	1,870	329	119	73.4	1,080
1922-23	285	341	596	838	823	1,360	2,850	2,620	1,030	363	137	135	948
1923-24	269	230	300	333	1,400	519	725	442	115	42.7	41.0	41.1	367
1924-25	272	1,590	1,070	1,150	5,180	2,620	5,610	4,570	2,040	575	195	317	2,070
1925-26	235	317	697	430	3,010	2,200	4,390	1,560	474	147	76.2	80.5	1,120
1926-27	222	3,020	3,580	2,330	4,600	3,320	4,350	4,670	3,160	812	258	174	2,520
Average	229	799	917	1,280	2,540	2,580	3,700	3,850	2,170	612	183	165	1,580
Trinity River near China Flat													
1911-12	-----	676	682	4,870	6,490	4,250	4,550	10,800	6,320	1,760	637	918	-----
1912-13	529	3,540	2,860	3,200	4,810	4,090	7,340	7,770	3,800	1,500	-----	-----	-----
Trinity River at Hoopa													
1911-12	521	734	721	7,750	8,720	6,290	5,980	13,800	6,690	1,990	835	1,250	4,600
1912-13	931	5,630	5,540	7,560	8,380	6,800	10,600	9,210	4,630	1,860	823	543	5,180
1913-14	554	2,090	4,720	33,000	-----	-----	-----	-----	-----	-----	-----	-----	-----
1916-17	-----	1,110	1,860	1,660	8,600	8,590	-----	-----	-----	-----	535	418	-----
1917-18	559	1,290	3,030	3,000	5,690	7,930	7,140	3,380	1,520	466	305	-----	-----

Coffee Creek at Coffee

1910–11				99.9	138	326	705	828	844	242	58.9	43.0	
1911–12	47.3	53.0	48.9	172	211	162		1,140	945	183	61.5	79.0	
1912–13	48.3	176	80.2	69.2	137	185	466	1,140	612	175	89.2	56.7	270
1913–14										292	79.0	52.9	

East Fork of Trinity River near Trinity Center

1910–11				156	694	758	852	790	408	36.2	7.5	9.7	
1911–12	13.1	14.4	14.1										

Swift Creek near Trinity Center

1910–11				30	45	120	315	393	399	94.1			

North Fork of Trinity River at Helena

1910–11												28.5	
1911–12	34.4	41.6	42.5	700	862	497	504	1,070	614	197	67.7	103	393
1912–13	46.9	742	384	357	641	682	976	841	416	179	63.3	26.3	444

South Fork of Trinity River near China Flat

1911–12		132	150	1,710	2,120	2,260	1,590	2,730	1,170	387	171	280	
1912–13	168	1,990	2,250	3,230	3,170	2,380	3,130	1,690	740	292			

Middle Fork of Smith River near Crescent City

[Drainage area, 146 square miles]

1911–12	103			2,400	2,200	850	564	938	277	134	94.0	134	
1912–13	177					584	946	588	262	171	90.7	82.0	
1915–16		1,190	1,300	1,860	3,060								

Monthly discharge, in second-feet, at stations in northern Pacific basins in California—Continued

North Fork of Smith River near Crescent City

[Drainage area, 81 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1911–12	115			4,000	3,300	1,360	989	1,340	555	197	107	284	
1912–13	323					1,250	1,480	660	298	217	119	194	

South Fork of Smith River near Crescent City

[Drainage area, 290 square miles

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1911–12	247	718	1,010	8,400	6,950	2,250	1,720	2,750	1,050	452	250	343	2,170
1912–13	427	4,530	3,020	4,750	1,500	1,780	2,840	1,980	712	528	231	219	1,880

Monthly discharge, in second-feet, at stations in Great Basin in California

Alamo River near Brawley

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1908–9										339	856	580	
1909–10	344	377	404	376	61.8	47.6	77.2	104	94.2			248	
1910–11	405	534	259										

Snow Creek near Whitewater

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1920–21											0.68	0.66	
1921–22	0.48	0.34							13.3	6.67	3.06	1.98	
1922–23	1.60	1.50	6.56	1.51	2.04	1.77	5.80	5.04	2.05	1.43	.33	.30	2.50
1923–24	.34	.52	.72	.68	.71	.93	2.39	2.55	.84	.67	.25	.20	.90
1924–25	.25	.56	.56	.41	.70	.84	1.40	1.17	.80	.41	.54	.42	.67
1925–26	1.81	.54	.96	.44	1.37	.55	6.45	6.45	4.24	1.14	.54	.56	2.08
1926–27	.60	1.03	5.21	4.33									

Snow Creek and Southern Pacific Co.'s ditch near Whitewater

1920-21											5.55	5.17	
1921-22	6.11	4.68							26.6	17.2	11.2	8.21	
1922-23	6.91	8.18	16.4	9.08	10.4	9.32	15.5	14.0	8.47	6.30	5.30	5.26	9.58
1923-24	5.27	5.56	6.45	5.97	5.22	6.39	10.7	10.7	5.85	4.36	4.14	4.19	6.23
1924-25	4.45	4.99	6.30	5.32	5.42	6.03	10.1	9.08	6.25	4.63	4.68	4.12	5.95
1925-26	7.66	5.43	7.17	5.11	8.39	6.75	15.2	12.9	9.21	6.27	5.24	4.31	7.79
1926-27	3.98	5.14	10.5	8.28									

Southern Pacific Co.'s ditch near Whitewater

1920-21											4.86	4.51	
1921-22	5.64	4.34	10.9	8.49	14.0	10.7	11.1	14.5	13.4	10.5	8.16	6.23	9.81
1922-23	5.31	6.70	9.81	7.57	8.31	7.54	9.73	8.95	6.42	4.87	4.97	4.96	7.09
1923-24	4.93	5.04	5.73	5.29	4.51	5.46	8.33	8.11	5.01	3.69	3.89	3.99	5.33
1924-25	4.21	4.43	5.74	4.92	4.72	5.18	8.75	7.91	5.45	4.22	4.14	3.70	5.28
1925-26	5.84	4.89	6.22	4.67	7.01	6.21	8.73	6.45	4.97	5.13	4.69	3.75	5.70
1926-27	3.38	4.13	5.32	3.95	12.0	14.8	18.2	18.4	14.1	10.8	8.15	7.23	10.0

Falls Creek near Whitewater

1921-22												2.96	
1922-23	2.52	2.81	3.21	2.64	2.57	2.25	2.74	2.66	1.81	1.34	1.12	1.34	2.25
1923-24	1.47	1.81	2.32	2.26	1.81	1.96	2.49	2.13	1.15	.65	.52	.59	1.60
1924-25	.89	1.23	1.83	1.60	1.57	1.48	1.56	1.24	1.05	.76	.78	.87	1.24
1925-26	1.99	1.77	2.02	1.63	1.97	1.75	7.90	4.25	2.78	2.37	2.67	2.23	2.77
1926-27	2.33	2.63	5.67	4.22									

Owens River near Round Valley

[Drainage area, 450 square miles]

1902-3												167	
1903-4	172	163	161	157	221	260	202	300	532	428	336	281	268
1904-5	266	246	218	193	196	213	177	246	392	275	169	180	231
1905-6	180	197	179	199	205	270	345	328	624	696	535	330	341
1906-7	273	239	256	247	281	341	270	438	616	856	432	305	380
1907-8	285	252	245	227	223	279	242	274	313	289	264	222	260
1908-9	192	184	182	235	186	179	374	317	637	531	296	211	294
1909-10	188	217	249	222	201	227	237	374	519	314	216	184	262
1910-11	192	163	163	203	238	257	313	331	674	881	512	257	349
1911-12	247	229	205	172	187	215	205	218	327	206	188	175	214

Monthly discharge, in second-feet, at stations in Great Basin in California—Continued

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
Owens River near Round Valley—Continued													
1912–13	186	165	146	156	176	200	185	230	281	266	197	184	198
1913–14	161	157	147	258	196	197	589	523	650	476	428	300	340
1914–15	283	207	178	170	175	175	268	273	363	431	268	184	248
1915–16	184	165	160	177	235	223	362	308	502	376	204	208	258
1916–17	237	183	168	170	188	217	247	294	739	550	233	198	286
1917–18	200	220	185	176	174	171	225	202	466	245	166	190	218
1918–19	256	206	191	178	184	203	269	382	312	195	156	144	223
1919–20	157	152	146	152	175	205	149	202	313	184	171	162	181
1920–21	162	160	158	157	178	178	138	214	338	246	166	155	187
1921–22	140	141	140	168	197	195	329	257	572	435	220	177	247
1922–23	173	203	202	197	205	211	163	205	243	271	175	175	202
Average	207	192	184	191	201	221	264	296	471	408	267	209	259
Owens River at Pleasant Valley, near Bishop													
1925–26	188	188	181	166	186	239	217	321	324	169	158	144	207
1926–27	181	224	200	190	225	294	234	332	681	530	259	224	298
Owens River near Big Pine													
1905–6				436	358	438	388	200	729	2,230	1,210	448	
1906–7	339	423	510	500	493	646	315	264	660	1,280	698	310	536
1907–8	460	538	527	539	584	485	145	58.1	56.9	188	274	173	336
1908–9	298	397	409	608	541	396	311	144	910	968	286	214	457
1909–10	311	437	522	650	494	503	160	250	424	269	139	106	355
1910–11	286	415	464	498	661	636	509	194	920	1,630	544	253	584
1911–12	429	486	464	474	406	316	255	160	333	144	82.3	81.9	303
1912–13	273	380	381	401	440	421	158	62.9	112	93.7	90.8	132	244
1913–14	212	376	393	804	587	467	391	285	905	938	584	203	512
1914–15	421	451	477	520	558	449	241	273	448	590	134	138	391
1915–16	310	425	482	676	877	656	500	343	644	722	285	181	507
1916–17	530	559	527	522	698	549	353	138	498	595	241	107	442
1917–18	251	452	475	444	487	525	268	68.8	592	258	76.0	80.3	330
1918–19	466	446	444	451	462	405	253	258	315	85.1	68.6	62.9	309

1919-20	181	323	392	379	352	362	153	78.7	216	107	66.1	63.9	222
1920-21	187	358	380	400	389	240	67.3	60.9	286	151	63.5	57.0	219
1921-22	165	348	517	432	525	398	310	117	698	775	227	91.9	383
1922-23	295	429	511	481	457	312	95.9	67.7	94.6	123	71.5	87.7	251
1923-24	269	366	386	390	334	230	145	65.9	51.9	58.4	53.5	48.2	200
1924-25	99.1	255	245	268	199	133	123	91.4	198	286	130	67.0	175
1925-26	213	262	270	270	320	325	175	126	311	128	80.5	63.1	211
1926-27	210	392	356	369	437	422	227	153	470	490	179	161	321
Average	295	406	435	478	484	423	252	157	449	550	254	142	347

Owens River near Lone Pine

1908-9				625	653	437	323	123	948	1,220	288	216	
1909-10	329	482	313	800	522	514	186	199	373	221	110	94.2	345
1910-11	253	409	473	459	688	624	485	139	802	1,460	537	235	547
1911-12	426	525	514	509	411	345	283	143	291	128	59.1	63.9	308
1912-13	222	379	398	384	411	344	49.5	10.6	7.67	7.35	50.1	124	198
1913-14	152	161	365	713	693	465	334	203	837	937	543	120	459
1914-15	283	439	427	543	510	333	160	231	325	413	95.6	76.3	319
1915-16	228	412	405	648	880	687	366	263	572	514	168	26.1	429
1916-17	206	382	402	374	641	490	366	111	205	371	160	74.3	313
1917-18	11.9	74.1	99.2	68.4	82.8	260	140	12.8	248	95.5	6.37	5.67	91.9
1918-19	104												
Average	221	363	377	512	549	450	269	144	461	537	202	104	334

NOTE.—Los Angeles Aqueduct, which has its intake above this station, was formally opened Feb. 13, 1913.

Owens River near Citrus

1903-4				290	268	290	160	76.8	572	350	318	125	
1904-5	451	388	378	369	540					175			
1905-6	107	219	301										

Rock Creek at Sherwin Hill, near Bishop

1925-26	13.0	13.2	9.81	4.88	12.3	11.4	28.5	45.9	51.9	22.4	17.2	10.2	20.1
1926-27	10.1	12.8	13.1	14.5	17.4	15.2	22.2	53.8	106	95.5	36.1	17.6	34.6

Monthly discharge, in second-feet, at stations in Great Basin in California—Continued

Rock Creek near Round Valley

[Drainage area, 46 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1902-3												18	
1903-4	15	18	20	17.4	20.5	23.6	21	50	91.7	60.5	59	29	35.5
1904-5	47	36	27.7	24.8	24.9	21.5	18.7	28.8	51.1	38.5	20.1	19.0	29.8
1905-6	19.3	21.1	26.9	38.8	29.7	45.7	24.6	54.2	145	a 150	107	47.4	59.1
1906-7	35.9	42.6	43.5	41.1	36.0	40.7	33.5	72.6	101	157	77.6	40.9	60.2
1907-8	44.6	41.9	33.6	29	30	27	22	25	30	52	53	36	35.3
1908-9	25	22	26	41.8	38.3	24.4	22.0	41.0	110	97.2	37.5	36.3	43.5
1909-10	29.1	32.7	49.7	44.8	41.2	29.2	27.1	42.8	65.5	56.0	36.4	25.3	40.0
1910-11	31.6	28.8	31.1	44.7	39.6	40.4	37.7	47.5	144	159	86.8	38.7	60.8
1911-12	36.1	37.9	34.6	37.4	36.4	30.7	24.9	30.2	51.0	36.2	26.8	22.8	33.8
1912-13	27.5	27.6	19.4	23.9	32.9	25.3	19.1	29.9	45.4	49.0	40.0	37.1	31.4
1913-14	27.0	25.0	26.3	72.6	45.8	31.2	28.2	63.1	113	107	68.1	38.2	53.9
1914-15	46.3	31.5	28.0	30.7	37.1	29.5	23.2	29.9	87.1	63.6	28.8	29.5	38.7
1915-16	32.3	31.0	33.3	48.6	49.5	42.4	40.4	64.4	115	74.6	46.6	41.7	51.6
1916-17	52.4	42.8	39.3	40.8	48.7	52.3	43.1	51.5	110	119	46.0	27.6	56.2
1917-18	29.6	30.2	27.5	28.8	31.4	29.1	25.3	26.3	97.7	40.5	23.4	29.9	34.9
1918-19	47.9	30.7	30.6	28.8	30.4	29.7	25.6	72.3	61.8	35.2	29.2	26.7	37.5
1919-20	29.8	33.4	33.0	30.4	27.1	24.3	22.6	42.9	61.6	34.5	26.5	24.0	32.5
1920-21	24.7	30.0	30.7	27.8	27.0	26.0	23.8	35.5	89.8	66.2	27.7	22.3	36.0
1921-22	24.5	24.1	31.9	34.5	36.8	29.7	23.9	59.5	108	86.6	47.5	29.7	44.8
1922-23	25.8	31.6	36.7	33.7	32.0	26.6	23.1	44.2	39.0	59.2	34.6	29.1	34.7
1923-24	28.7												
Average	32.4	30.9	31.5	36.0	34.8	31.5	26.5	45.6	85.9	77.1	46.1	30.9	42.5

Pine Creek at division box near Bishop

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1925-26	18.5	16.1	15.4	14.3	14.6	15.3	40.7	90.8	92.7	39.3	26.1	18.8	33.6
1926-27	18.0	18.3	20.7	19.0	19.5	19.2	26.4	74.5	175	156	64.3	34.5	53.9

Pine Creek near Round Valley

[Drainage area, 32 square miles]

1902–3												4.7	
1903–4	10.8	11.8	12.6	13	12.4	12.9	9	21.7	142	70	44	12	31.0
1904–5	28	25	17.5	12.7	10.6	7.9	6.5	9.0	68.1	47.9	4.8	4.6	20.2
1905–6	8.7	8.5	9.5	13.7	8.6	14.5	8.7	16.0	130	160	105	46.2	44.1
1906–7	15.5	7.6	7.5	10.4	11.6	13.4	11.7	28.3	111	193	101	30.8	45.2
1907–8	19.3	15.3	14.4	10.1	8.2	6.2	3.6	2.8	17.5	62.0	42.0	7.5	17.4
1908–9	7.7	4.7	4.0	4.96	6.08	3.52	3.43	16.8	208	172	45.7	20.5	41.4
1909–10	10.2	5.13	8.77	8.38	6.17	3.78	7	65.1	192	36.2	8.22	3.65	29.6
1910–11	3.49	3.36	4.72	10.0	5.54	6.72	3.17	17.8	178	256	59.4	10.6	46.6
1911–12	12.2	8.69	6.73	4.81	3.14	2.23	1.43	19.2	68.2	20.5	2.63	1.45	12.6
1912–13	2.46	2.97	2.15	1.63	3.66	4.32	1.43	7.78	15.3	41.1	18.7	8.93	9.28
1913–14	4.40	4.71	3.82	20.1	5.48	3.94	3.54	35.0	138	145	65.4	4.69	36.4
1914–15	5.71	3.77	2.13	2.99	5.17	2.83	2.70	6.93	102	86.8	3.44	1.66	18.8
1915–16	4.03	2.19	3.98	5.98	12.1	5.94	8.31	18.5	100	87.9	6.43	6.09	21.8
1916–17	4.75	2.16	1.98	2.17	5.02	4.52	3.35	2.66	155	105	4.02	2.43	24.4
1917–18	1.05	1.47	4.00	4.87	5.38	4.74	1.82	1.58	118	26.1	2.31	2.09	14.3
1918–19	18.7	5.10	4.15	3.90	4.34	3.95	1.08	48.0	35.3	2.35	1.15	.31	10.8
1919–20	1.24	1.80	1.93	2.11	3.38	2.89	1.91	8.48	57.2	14.1	1.23	1.53	8.09
1920–21	2.52	3.63	2.76	2.65	2.48	1.65	1.02	1.55	85.0	33.5	2.39	1.47	11.7
1921–22	2.33	3.12	5.35	4.03	6.94	3.73	2.24	14.5	169	115	14.6	2.65	28.6
1922–23	1.77	3.16	3.90	3.78	3.56	1.70	1.34	4.74	28.6	34.3	6.39	.94	7.88
1923–24	2.36												
Average	7.96	6.21	6.09	7.11	6.49	5.57	4.16	17.3	106	85.4	26.9	8.32	24.0

Bishop Creek near Bishop

1902–3												50.5	
1903–4	38.6	28.6	27.3	27.0	31.8	42.0	56.6	149	373	233	212	64	107
1904–5	78	41	29	22.5	25.2	38.2	56.6	113	299	215	92.1	53.6	88.6
1905–6	36.1	25.6	24.3	33.4	16.4	42.0	52.8	172	382	[a] 706	350	124	164
1906–7	45.3	17.5	50.0	56.4	54.0	55.4	75.8	131	297	354	231	83.7	121
1907–8	66.0	49.4	52.5	58.8	58.6	64.3	59.7	76.6	94.5	150	143	73.7	78.9
1908–9	60.4	55.7	49.4	47.5	47.2	46.6	59.3	124	379	363	134	78.0	120
1909–10	61.4	69.2	85.5	83.9	77.5	124	85.7	186	125	134	97.6	46.9	98.1
1910–11	50.2	52.7	55.3	63.2	89.5								
Average	54.5	42.5	46.7	49.1	50.0	58.9	63.8	136	278	308	180	71.8	111

[a] Estimated.

Monthly discharge, in second-feet, at stations in Great Basin in California—Continued

Baker Creek near Big Pine

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1908–9				9.94	10	10.2	14.5	35.1	21.6	16.6	11.7	10.4	

Big Pine Creek near Big Pine

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1903–4				11	12	16.8	20.5	72.7	132	119	95.8	49	
1904–5	24	21	15	21.7	23.9	18.9	17.9	46.7	118	187	122	51.1	55.6
1905–6	13.7	9.6	12.5										
1906–7				18	20	20	38	56	110	202	118	46	
1907–8	30	24	20	a 20	a 20	a 23	a 25	28	39	131	100	50	42.5
1908–9	18.0	13.0	15.0	17.1	19.2	13.7	22.4	54.2	189	157	103	48.2	55.9
1909–10	31.9	18.3	17.0	26.0	18.1	19.5	29.7	74.0	92.6	116	82.1	37.3	46.9
1910–11	26.2	15.9	12.7	15.5	18.5								

Tinemaha Creek near Big Pine

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1906–7				4.9	4.4	4.0	5.3	11.0	18.0	39.0	20.0	6.1	
1907–8	5.4	5.5	5.7	6.0	5.8	4.4	4.3	4.4	8.5	32	21	9.8	9.40
1908–9	5.5	5.0	5.3	4.68	9.55	5.98	2.99	9.90	45.9	45.8	24.3	12.8	14.8
1909–10	8.49	6.87	10.2	10.7	9.14	7.53	6.74	15.6	27.4	25.9	16.2	9.04	12.8
1910–11	5.82	5.20	5.10	7.3	7.3								

Birch Creek near Big Pine

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1906–7				7.6	6.2	8.2	8.0	12.5	20.0	32.0	19.3	5.0	
1907–8	4.6	4.3	4.3	5.2	5.2	5.5	5.6	5.7	9.6	14.3	11.9	6.5	6.89
1908–9	4.1	3.0	3.0	4.68	6.35	4.42	7.67	12.1	37.0	41.5	13.0	6.81	12.0
1909–10	4.32	4.87	16.3	12.3	8.20	7.24	8.55	13.5	21.5	23.2	15.3	4.72	11.7
1910–11	3.81	3.62	4.06	7.26	5.71								

Taboose Creek near Aberdeen

[Drainage area, 13.9 square miles]

1905-6				3.7	2.9	3.3	5.8	10.4	21.8	46.3	25.7	15.0	
1906-7	3.7	3.6	3.5	2.3	2.3	7.3	12.0	23.0	21.0	18.0	12.0	5.0	9.48
1907-8	4.2	3.6	3.2	3.0	2.3	2.3	3.1	4.9	6.0	10.9	8.2	6.4	4.84
1908-9	4.5	4.0	5.5	4.33	4.05	2.73	4.92	8.65	25.7	22.6	9.87	5.64	8.54
1909-10	4.01	3.53	5.60	4.61	2.11	3.52	3.97	7.06	11.8	10.7	6.97	3.23	5.59
1910-11	3.35	3.0	3.0	3.5	3.4								

Goodale Creek near Aberdeen

1905-6				[a] 2.0	[a] 1.0	[a] 1.0	3.5	6.3	11.2	19.0	6.4	5.9	
1906-7	5.6	5.3	4.3	3.9	3.6	3.3	5.1	7.0	10.2	15.1	10.3	3.9	6.47
1907-8	2.8	2.8	2.8	3.0	2.6	2.6	2.7	4.4	5.8	7.3	5.0	4.1	3.82
1908-9	3.3	3.0	3.0	2.34	2.40	2.40	3.83	8.58	18.7	16.5	8.83	5.59	6.54
1909-10	4.06	4.02	4.95	3.80	3.10	3.78	4.54	8.02	10.9	7.87	4.49	3.63	5.26
1910-11	3.50	3.10	3.10	3.55	3.24								

Division Creek near Independence

1905-6				6.7	5.1	6.1	6.0	7.3	8.4	17.2	14.3	10.9	
1906-7	12.6	11.5	10.1	10.6	10.8	11.2	10.1	9.7	11.1	12.4	10.1	9.9	10.8
1907-8	10.0	9.0	7.7	7.0	6.7	5.9	5.8	7.0	7.2	7.2	7.7	7.7	7.41
1908-9	7.5	7.7	7.6	7.2	6.9	7.3	7.9	10.0	16.7	16.4	15.6	14.8	10.5
1909-10	13.4	11.9	11.2										

Sawmill Creek near Independence

1905-6				[a] 3.0	2.7	3.7	3.4	4.3	7.6	16.3	12.6	9.8	
1906-7	6.7	[a] 5.0	[a] 5.0										
1908-9				4.1	5.0	4.9	6.6	7.3	14.1	17.8	13.1	10.6	
1909-10	9.0	8.7	8.0										

[a] Estimated.

Monthly discharge, in second-feet, at stations in Great Basin in California—Continued

Oak Creek near Independence

[Drainage area, 26.9 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1905-6				[a] 6.0	7.3	7.8	11.9	28.0	69.9	140	73.5	32.2	
1906-7	20.5	11.8	11.3	10.8	10.4	12.2	18.8	26.9	42.2	57.0	32.8	20.4	22.9
1907-8	14.5	13.0	13.0	10.0	9.2	9.3	12.3	15.8	21.0	29.0	22.5	15.5	15.4
1908-9	13.0	11.6	10.5	11.4	10.6	10.8	15.1	36.8	102	131	38.9	18.9	34.2
1909-10	14.5	15.0	13.6	12.2	11.1	11.8	16.3	28.8	34.9	31.6	13.9	8.56	17.7
1910-11	8.03	8.17	7.37	8.40	8.76								

Little Pine Creek near Independence

[Drainage area, 21.4 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1904-5										23.5	10.9	4.6	
1905-6	3.2	3.6	3.6	4.0	2.8	4.8	8.0	29.6	96.4	127	54.4	22.9	30.0
1906-7	12.4	6.1	5.2	5.5	3.5	4.9	14.9	26.0	62.0	70.6	35.8	16.7	22.0
1907-8	6.6	7.6	6.9	4.3	2.4	3.4	7.4	15.7	21.5	29.0	19.9	8.3	11.1
1908-9	9.0	6.6	6.3	6.40	5.54	5.44	9.92	40.5	95.2	81.6	34.7	16.1	26.4
1909-10	7.88	9.82	10.8	8.60	7.22	6.57	13.6	32.8	46.4	35.5	14.1	6.88	16.7
1910-11	5.25	4.74	3.80	4.24	4.62								

Shepard Creek near Thebe

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1905-6				2.0	2.0	2.0	9.0	26.5	62.2	104	63.0	12.0	
1906-7	2.6	0.5	3.0	2.0	2.4	3.4	8.1	14.0	26.0	37.0	21.0	4.7	10.4
1907-8	5.1	4.7	2.9	1.3	1.3	1.3	2.6	6.2	13.4	22.0	21.0	9.6	7.62
1908-9	5.7	2.6	2.0	4.7	3.0	2.5	8.8	14.8	37.9	42.4	20.6	11.0	13.0
1909-10	4.7	3.0	3.0										

Bairs Creek near Thebe

1905–6				1.0	1.0	1.0	3.2	12.5	31.3	30.3	13.4	4.3	
1906–7	2.0	1.0	0.5	1.0	1.0	3.0	7.0	9.6	12.2	11.7	4.4	1.1	4.54
1907–8	1.7	2.1	1.5	1.0	0	0	1.2	3.0	4.0	4.5	4.0	1.6	2.05
1908–9	1.4	1.2	1.0	1.0	.5	1.5	7.7	13.0	24.0	15.2	5.0	3.9	6.28
1909–10	1.2	1.0	1.0										

George Creek near Thebe

1905–6				1.0	1.0	2.0	10.3	21.1	52.9	86.9	42.3	21.0	
1906–7	7.7	2.6	1.7	2.0	2.5	5.0	11.0	17.0	19.0	28.0	13.0	4.0	9.46
1907–8	5.2	3.8	2.3	2.7	1.9	2.2	5.3	8.0	11.0	18.0	14.0	8.1	6.88
1908–9	6.0	3.2	3.0	2.8	2.3	3.2	11.4	19.4	43.7	38.4	14.7	8.7	13.1
1909–10	3.5	2.0	1.9										

Lone Pine Creek near Lone Pine

1905–6				[a] 3.0	2.9	3.8	7.2	28.5	73.5	129	68.4	27.2	
1906–7	14	8	8	8.2	6.5	8.8	19.5	[a] 30.0	45.6	61.5	39.5	11.5	21.8
1907–8	19.6	16.2	8.5	8.0	7.7	8.2	11.3	17.4	32.0	44.0	58.0	24.0	21.2
1908–9	11.3	7.6	6.3	6.97	8.76	6.10	12.2	31.3	95.0	75.1	43.3	21.6	27.1
1909–10	9.05	7.81	8.01	6.39	8.04	6.29	10.4	24.5	32.2	31.3	21.2	14.0	14.9
1910–11	9.23	5.80	5.87	5.56	7.00								

Tuttle Creek near Lone Pine

1905–6				[a] 5.0	4.8	4.3	5.4	11.1	26.0	54.1	33.1	14.2	
1906–7	9.6	9.0	8.0	7.4	8.5	7.4	7.3	[a] 9.0	17.1	18.8	15.0	7.1	10.4
1907–8	7.8	7.6	5.9	5.0	4.5	5.0	5.5	6.0	10	14	15	12	8.20
1908–9	8	7	7	5.1	6.1	6.0	7.43	11.8	26.6	29.9	12.8	10.2	11.5
1909–10	7.36	7.3	14.9	10.7	12.7	6.13	8.97	7.94	11.9	11.9	9.39	8.9	9.84
1910–11	7.29	6.87	6.61	6.4	7.5								

[a] Estimated.

Monthly discharge, in second-feet, at stations in Great Basin in California—Continued

Cottonwood Creek near Olancha

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1905–6				6.2	8.2	10.9	24.2	114	333	225	104	42.4	
1906–7	15.9	13.3	12.8	10.0	10.5	12	56.3	[a] 115	[a] 110	67.1	28.8	12.5	38.7
1907–8	28.0	18.6	15.8	[a] 12.0	12.5	22.2	58.1	62.2	48.5	31.2	18.7	18.0	28.8
1908–9	[a] 19.0	16.3	14.4	14.6	15.0	15.4	41.2	158	221	99.2	34.5	19.9	55.7
1909–10	12.6	11.0	13.1	14.2	11.9	17.2	47.2	66.7	42.0	20.4	14.3	16.2	23.9
1910–11	12.8	10.6	11.3	12.8	14.4	14.5							

Ash Creek near Olancha

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1905–6				1.7	3.2	4.5	8.3	14.8	30.6	25.3	5.8	4.0	
1906–7	3.0	2.5	2.2	2.5	2.5	2.5	20	39.4	29.4	5.5	3.5	2.5	9.62
1907–8	4.0	4.5	4.0	4.0	3.7	6.6	10.9	11.5	7.3	3.2	2.2	3.0	5.41
1908–9	3.0	2.6	3.0	3.2	4.5	6.3	14.0	33.6	49.7	13.2	5.4	3.8	11.9
1909–10	3.6	3.5	3.5										

Little Rock Creek near Palmdale

[Drainage area, 78 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1895–96				18.6	18.6	54.2	7.9	1.8	0.5	0.2	0.2	0.5	
1896–97	1.0	1.5	3.8	14	52	68	106	36	6.7	.4	.2	.2	24.2
1897–98	5.5	6.9	5.7	6.06	7.00	6.04	6.10	5.20	0	0	.4	0	4.04
1898–99	0	0	0	4.90	4.41	7.66	4.50	1.50	2.00	.20	.20	.20	2.13
1899–1900	0	0	1.0										

Rock Creek near Valyermo

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1922–23					15.2	17.2	20.3	16.4	13.9	10.8	7.36	6.25	
1923–24	6.65	6.93	7.00	5.27	44.9	3.97	11.8	9.95	5.13	2.97	2.43	2.61	5.77
1924–25	2.76	2.43	3.35	3.53	3.14	3.89	8.54	7.90	4.94	2.40	2.18	2.39	3.95
1925–26	2.33	2.68	3.02	3.06	4.41	6.73	78.7	45.7	25.5	15.0	8.69	6.32	16.8
1926–27	5.89	8.18	12.3	12.2	62.1	35.8	34.9	35.4	23.4	16.5	11.9	9.57	22.0

Mohave River at Victorville

[Drainage area, 400 square miles]

1898–99						37	37	33	29	27	24	22	
1899–1900	23	27	32	44	49	57	35	33	30	26	29	29	34.5
1900–1901	32	139	33	183	925	178	44	49	42	40	50	55	148
1901–2	69	77	73	50	60	66	59	43	50	40	40	44	55.9
1902–3	47	46	64	57	63	503	765	47	39	37	39	41	148
1903–4	52	55	58	60	57	58	45	80	38	33	35	34	47.7
1904–5	48	50	59	60.1	309	[a]695	110	164	43.4	32.3	31.6	40.0	135
1905–6	46.5	64.0	67.0										

Rush Creek near Mono Lake

1910–11			46.7	50.4	82.1	78.6	422	730	968	554	146	47.6	
1911–12	34.1	29.7	21.5	20.0	16.0					93.5	40.9	17.7	
1912–13	14.3	13.9							191	144	81.8	52.0	

Leevining Creek near Mono Lake

1910–11			22.6	26.0	33.2	26.0	44.1	95.0	419	423	110	45.8	
1911–12	28.0	25.5	21.0	19.6	18.7					90.8	51.1	25.6	
1912–13	21.9	20.9	17.4					114	129	114	81.7	57.6	
1913–14	22.6	21.1	20.4						280	306	154	48.3	

East Walker River near Bridgeport

1921–22	61.5	62.7							823	519	189	70.4	
1922–23	72.8	104	121	90.2	116	171	98.4	244	294	307	138	128	157
1923–24	99.2	89.3	79.7	88.5	65.8	65.5	57.2	75.8	36.0	20.4	13.3	19.1	59.2
1924–25		([b])	([b])	([b])	([b])	65.1	136	166	199	160			
1925–26	30.4	24.1	19.2	4.9	5.0	21.2	121	227	285	255	130	82.0	101
1926–27	31.5	11.4	10.6	2.0	2.0	5.4	83.8	238	293	341	321	203	129

Robinson Creek near Bridgeport

1910–11			6.24				56	106	374	409	177	87.2	
1911–12	57.7	21.1	7.79	15.3	30.3	30.4	23.1	35.8	161	135	110	45	56.0

[a] Estimated.

[b] Reservoir gates closed, seepage about 2.0 second-feet.

Monthly discharge, in second-feet, at stations in Great Basin in California—Continued

Buckeye Creek near Bridgeport

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1910–11			30.0				49.5	95.9	432	399	115	65.6	
1911–12	40.2	35.9	31.8	25.5	27.0	24.7	22.8	50.1	163	90	44	29	48.7

Swager Creek near Bridgeport

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1910–11									117	44.7	19.2	14.3	
1911–12	12.3	11.5	11.2	6.23	12.7	15.3	9.28	19.1	10.8	11	5.5	3.5	10.7

West Walker River near Coleville

[Drainage area, 245 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1902–3		83	75	69	79	105	246	888	1,512	402	143	75	
1903–4	67	77	67	62.7	131	187	384	919	1,188	785	332	172	364
1904–5	299	125	85.7	75.3	86.1	133	266	558	791	334	107	64.1	244
1905–6	59.4	58.1	61.9	77.6	81.6	105	360	1,140	2,050	2,180	506	192	573
1906–7	98.5	95.6	94.5	95.7	132	380	523	1,150	1,960	2,480	685	269	664
1907–8	165	140	119	116	102	165	336	548	693	460			
1908–9						75.8	323	873	1,630	830	232	87.8	
1909–10	74.2	121	110	87.1	85.0	243	636	1,030	991	381	122		
1914–15										744	161	67.1	
1915–16	[a] 58.0	[a] 48.0	[a] 45.0	[a] 80.0	88.1	201	476	827	1,200	743	253	107	344
1916–17	159	103	69	35	74	93	342	667	1,520	850	220	98.1	353
1917–18	72.5	69.1	44.0	53.7	49.9	80.5	338	598	1,290	362	110	114	265
1918–19	182	113	105	89.4	94.0	108	357	1,040	609	189	77.2	58.0	253
1919–20	56.7	68.2	71.0	73.6	76.8	95.4	202	810	918	275	104	73.0	235
1920–21	85.6	88.3	66.9	63.3	102	179	296	747	1,340	533	155	80.3	311
1921–22	58.7	53.3	47.3	47.7	50.8	58.9	133	1,060	1,810	811	188	80.3	368
1922–23	68.9	67.4	72.6	62.9	61.3	119	285	965	914	758	175	98.1	305
1923–24	90.8	55.0	44.5	41.9	46.9	47.1	157	469	106	26.9	17.4	16.1	93.6
1924–25	25.5	36.8	31.5	38.1	58.1	111	309	951	978	549	145	60.7	275
1925–26	59.9	54.3	47.9	42.7	46.9	95.7	477	717	410	101	40.0	29.9	177
1926–27	28.2	45.3	64.0	60.3	82.5	131	318	918	1,370	661	167	57.7	326
Average	94.9	79.0	69.6	66.9	80.4	136	338	844	1,160	688	197	94.7	322

NOTE.—March, 1909, station was moved downstream about half a mile.

East Fork of West Walker River near Bridgeport

1909–10	----------	----------	----------	----------	----------	----------	----------	195	200	82.7	34.9	----------	----------

East Fork of Carson River near Markleeville

1910–11	----------	----------	61.1	128	144	211	618	1,010	1,700	1,080	248	133	----------
1911–12	116	79.5	50.0	63.6	84.6	84.9	----------	----------	----------	----------	----------	----------	----------

Note—Records fragmentary since 1912.

East Fork of Carson River at California-Nevada State line

1910–11	----------	----------	----------	224	271	376	832	1,390	2,450	1,260	370	151	----------
1911–12	141	[a] 118	[a] 73.2	103	95.6	98.5	165	683	808	208	75.0	59.5	220
1912–13	64.2	74.5	68.9	80.1	79.8	106	352	816	495	155	95.5	64.2	205
1913–14	51.3	61.3	87.4	325	215	555	957	2,020	1,800	744	211	108	596

Silver Creek near Markleeville

1910–11	----------	----------	11.7	62.7	78.8	43.2	101	166	343	104	43.1	11.3	----------
1911–12	11.4	[a] 10.0	[a] 8.0	13.6	14.0	13.5	21.1	123	157	----------	----------	----------	----------

Markleeville Creek near Markleeville

1911–12	----------	----------	----------	6.67	9.10	8.21	----------	----------	----------	5.12	[a] 1.5	----------	----------

NOTE.—Records fragmentary since 1912.

Markleeville Creek at Markleeville

1910–11	----------	----------	22.5	83.7	73.8	85.3	257	418	699	217	33.3	20.4	----------
1911–12	12.1	12.8	18.5	16.5	17.6	17.3	----------	----------	----------	20.7	----------	----------	----------

NOTE.—Records fragmentary since 1912.

[a] Estimated.

Monthly discharge, in second-feet, at stations in Great Basin in California—Continued

Pleasant Valley Creek at Markleeville

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1910–11			14.8	36.4	58.2	48.4	134	255	373	102	17.5	13.0	
1911–12	3.61												

West Fork of Carson River at Woodfords

[Drainage area, 70 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1900–1901		48	53	51	111	170	234	476	289	136	77	43	
1901–2	49	56	82	107	238	138	175	287	319	121	40	32	137
1902–3	34	46	58	49	63	64	174	389	353	106	42	30	117
1903–4	31	63	66			169	305	651	368	158	74.4	67.1	
1904–5	78.4	64.6	64.5		102	125	202	271	187	75.8	28.7	23.7	
1905–6	31.3	34.4	56.5	72.3	65.3	66.5	236	925	690	324	154	50.4	225
1906–7	52.8	76.9	58.4	78.8	139	211	502	841	664	525	223	107	290
1907–8	75.8	65.8	76.8	68.2	166.6	90.3	191	228	165	58.1	75.5	35.0	99.7
1908–9	46.4	35.3	37.7	169	02	92.8	343	628	632	164	68.4	25.5	195
1909–10	52.1	139	123	44.3	73.2	156	451	376	166	69.6	27.1	27.2	142
1910–11	24.5	28.5	43.5	31	54	57	217	590	934	362	89	46	206
1911–12	42	57	53	51.7	52.1	56.8	90.5	395	279	73.1	20.6	33.8	100
1912–13	32.9	31.8	35.6	53.3	33.8	46.3	259	341	228	84.5	48.0	36.0	103
1913–14	23.0	25.1	35.2	65.0	54.1	96.7	277	648	281	172	65.2	33.1	149
1914–15	27.1	35.9	29.9	33.8	32.6	49.5	221	473	424	89.4	14.0	13.1	120
1915–16								555	306	145	47.4	25.3	
1916–17	28.4	47.9	41.5	27.8	24.6	26.5	166	484	542	129	41.2	10.8	131
1917–18	9.06	20.1	20.4	21.7	23.7	27.2	274	307	175	28.7	6.03	17.8	77.5
1918–19	13.2	17.8	26.6	25.1	31.8	33.9	396	528	108	11.5	11.4	5.9	101
1919–20	14.6	30.9	23.1	22.2	23.2	28.3	71.3	367	238	46.5	5.0	5.0	73.0
Average	37.0	48.6	51.8	57.1	71.7	89.7	252	488	367	144	57.9	33.4	142

NOTE.—No correction made for possible ice effect.

Truckee River at Tahoe

[Drainage area, 519 square miles]

1894–95										914	425	374	
1895–96	415	437	250	262	290								
1899–1900						0	0	0	52	214	232	196	
1900–1901	159	135	81	102	81	30	9	0	30	225	419	326	133
1901–2	282	247	111	125	73	52	48	97	95	204	406	350	174
1902–3	324	346	326	266	103	190	13	13	38	205	344	398	214
1903–4	374	255	260	305	111	401	610	799	899	873	787	761	536
1904–5	672	711	614	410	433	321	20.9	173	212	303	391	385	387
1905–6	390	305	271	304	396	443	488	543	594	725	753	759	498
1906–7	726	695	647	697	732	765	806	919	1,130	1,300	1,250	1,210	906
1907–8	1,100	925	823	752	666	596	212	56.8	53.9	311	453	390	528
1908–9	354	300	278	220	630	660	584	321	569	555	525	452	454
1909–10	413	374	559	883	791	982	315	148	332	656	628	436	481
1910–11	339	281	262	307	590	671	592	153	4.7	771	409	377	433
1911–12	359	365	400	422	261	229	67.0	23.5	22.1	154	425	356	257
1912–13	335	273	295	368	272	196	8.3	6.3	16.1	236	375	418	234
1913–14	364	299	263	70.1	50.1	24.0	5.0	103	188	247	342	486	204
1914–15	392	497	512	346	200	202	7.5	5.2	9.0	186	438	363	264
1915–16	288	297	292	361	315	626	34.1	17.7	12.9	96.3	479	395	269
1916–17	406	388	319	481	324	251	30.8	23.0	817	602	560	430	386
1917–18	337	300	325	354	342	316	18.0	18.0	83.8	631	638	398	314
1918–19	236	270	284	285	217	227	0	0	194	482	538	434	265
1919–20	328	352	306	303	255	248	19.3	0	50.5	364	454	255	245
1920–21	142	113	156	134	68.2	1.3	0	0	0	214	447	451	145
1921–22	318	191	150	216	280	348	123	0	0	163	453	477	226
1922–23	377	341	330	285	272	151	0	0	0	179	479	468	240
1923–24	331	338	348	379	244	283	105	114	225	134	193	249	245
1924–25	98.5	24.4	0	0	0	0	0	0	0	321	361	159	81.3
1925–26	124	79.4	63.3	50.8	54.8	17.4	0	0	199	276	130	42.5	86.7
1926–27	3.71	0	21.6	27.2	36.1	0	0	0	5.3	119	387	413	84.6
Average	357	326	305	311	289	294	147	126	224	402	473	421	307

Truckee River at Boca

1889–90						637	2,751	5,275	4,291	1,870	736	513	
1890–91	555												

Monthly discharge, in second-feet, at stations in Great Basin in California—Continued

Truckee River at Iceland

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1911-12											539	459	
1912-13	405	438	403	464	403	467	1,010	1,340	685	494	513	484	593
1913-14	400	409	390	867	531	1,400	2,840	3,100	2,140	856	543	529	1,170
1914-15	503	570	581	490	416	600	1,620	1,910	1,460	614	574	490	820
1915-16	402	391	433	580	679	1,930	3,060	2,250	1,750	742	631	506	1,110
1916-17	491	524	516	574	486	533	1,670	2,030	2,560	1,120	697	530	979
1917-18	438	409	447	440	493	577	1,410	1,250	779	668	692	532	679
1918-19	473	428	446	442	453	567	2,140	2,300	691	600	600	512	806
1919-20	408	415	434	411	386	492	791	1,430	673	495	502	330	565
1920-21	222	340	350	453	427	1,000	1,170	1,520	1,280	540	514	509	695
1921-22	384	308	282	395	424	499	915	3,310	2,240	648	521	504	872
1922-23	419	417	456	426	456	631	1,300	1,900	979	586	530	517	720
1923-24	422	405	407	439	434	409	488	499	284	181	220	279	372
1924-25	171	144	88.7	96.1	604	567	1,120	1,330	632	471	419	258	490
1925-26	240	185	209	202	288	523	1,100	772	411	322	212	102	381
1926-27	69.8	221	260	320	681	962	1,720	2,310	2,020	635	510	491	849
Average	363	374	380	440	477	744	1,490	1,820	1,240	598	514	440	740

Truckee River at Nevada-California State line

[Drainage area, 955 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1899-1900	35.4	581	295	392	318	797	902	1,530	950	459	396	367	612
1900-1901	481	480	407	314	1,080	1,280	1,480	2,480	1,600	686	486	472	936
1901-2	470	469	445	322	506	402	1,660	1,930	1,360	501	506	482	754
1902-3	450	416	482	522	463	686	1,300	1,660	1,150	513	490	489	718
1903-4	507	855	403	419	1,350	2,470	2,900	3,710	2,750	1,500	1,020	903	1,560
1904-5	1,030	893	834	755	754	1,100	1,110	1,450	1,120	548	503	477	881
1905-6	487	405	366	592	746	1,130	2,850	3,650	2,830	1,800	763	675	1,360
1906-7	629	670	662	702	1,220	2,590	3,880	3,980	3,570	2,720	1,680	1,430	1,980
1907-8	1,200	1,080	1,040	1,020	938	1,140	1,360	1,040	893	550	544	448	938
1908-9	445	394	370	1,930	1,150	1,170	2,810	2,960	2,850	1,320	762	642	1,400
1909-10	610	1,010	1,110	1,250	1,180	1,680	1,980	1,430	943	755	668	498	1,090
1910-11	427	418	473	664	968	1,200	3,250	3,580	4,170	2,080	673	545	1,540
1911-12	486	521	541	609	381	404	474	1,310	1,120	391	535		
Average	583	630	571	730	850	1,230	2,000	2,360	1,950	1,060	694	619	1,150

Donner Creek at Donner Lake, near Truckee

[Drainage area, 13.6 square miles]

1909–10		30.3	57.4	10.6	11.1	55.8	93.6	88.7	21.0	4.0	1.0		

Donner Creek near Truckee

[Drainage area, 30 square miles]

1902–3		14	17	54	60	83	166	267	156	23	3	1	
1903–4	3	92	16	29.6	145	391	312	482	326	59.4	11.4	30.6	158
1904–5	50.6	12.0	9.2	17.8	53.1	130	163	218	114	8.6	.51	3.6	65.0
1905–6	4.4	.29	1.6	38.3	32	54.5	161	506	493	269	21.4	13.5	133
1906–7	11.1	16.3	20.0	29.9	92.5	239	296	392	349	158	40.1	29.9	139
1907–8	12.1	10.3	11.2	30.7	35.9	54.3	145	147	120	44.0	10.9	8.1	52.5
1908–9	3.2	6.4	15.4	214	38.2	51.0	150	264	176	69.2	11.8	4.9	83.7
1909–10	3.4	140	208	72.0	75.6	148	252	210	59.6	10.1	1.41	1.89	98.5
1910–11	2.50	7.47	20.5	59.4	110	50.7	210	354	526	136	14.4	6.88	
1911–12	5.92	10.4	10.8	24.1	12.4	8.82	31.0	173	148	44.8	3.60	1.36	39.6
1912–13	2.39	11.1	4.29	6.74	2.62	6.82	47.8	71.7	28.6	8.46	37.3	1.26	19.2
1913–14													
1914–15				23.5	47.4	34.3	203	313	199	40.7	10.2	9.17	
Average	9.86	29.1	30.4	50.0	58.7	104	178	283	225	72.6	13.8	9.35	87.6

Prosser Creek near Truckee

[Drainage area, 48 square miles]

1902–3										31.3	16.8	10.5	
1903–4			75.0	102	363	329	380	433	296	128	45.8	26.4	
1907–8	39.5	35.3	[c] 29.0	[c] 29.0	[c] 29.1	107	177	173	160	56.0	8.9	21.9	72.1
1908–9	34.3	30.0	41.6	277	92.0	110	375	460	374	142	23.4	16.1	165
1909–10	45.6	151	187	236	245	212	299	226	175	32.0	10.0	10.7	152
1910–11	11.2	19.5	27.7	118	105	91.1	290	486	513	179	45.9	19.4	159
1911–12	22.0	26.1	10.2	[c] 16.0	19.3	26.0	63.6	99.7					

Prosser Creek at Boca

1888–89							[a] 100	259	110	17	3	2	
1889–90							340	817	580	382	102	57	
1890–91	42	38											

[a] Estimated.

[c] Estimated on account of ice.

Monthly discharge, in second-feet, at stations in Great Basin in California—Continued

South Fork of Prosser Creek near Truckee

[Drainage area, 5.8 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1909-10		56.3	39.4	19.7	19.1	25.9	65.7	65.8	28.4	6.8	4.0		

Little Truckee River near Truckee

[Drainage area, 33.2 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1909-10		103	76.5	46.9	56.6	172	306	332	136	29.9	1.5		

Little Truckee River at Starr

[Drainage area, 166 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1902-3										89	22		
1903-4		117	63	140	467	742	981	1,010	688	209	49.3	37.8	
1904-5	115	55.6	64.6	101	89	188	334	477	337	86.3	42.1	37.4	161
1905-6	44.2	55.4	106	359	141	159	729	972	950	478	91.9	56.7	345
1906-7	60.9	79.7	103	204	229	417	974	908	761	461	149	95.4	370
1907-8	97.3	96.9	122	67.6	65.9	162	316	332	297	79.5	26.0	21.9	
1908-9	40.7	41.0	38.7	520	154	144	786	946	895	235	77.7	22.5	325
1909-10	34.5	200	189	366	526	484	782	552	189	33.5	12.9	17.0	282

NOTE.—Determinations during winter may be in error on account of ice. Discharge estimated Nov. 17-30, 1907.

Little Truckee River at Boca

[Drainage area, 186 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1889-90							958	1,998	1,491	749	200	97	
1890-91	86												
1910-11				61.4	108	194	1,120	1,260	1,210	435	66.3	28.7	
1911-12	22.3	32.3	23.2	29.4	28.4	56.3	106	379	353	50.7	20.7	35.7	94.7
1912-13	20.5	58.4	28.6	20.5	29.7	66.6	358	471	212	57.0	28.2	21.6	114
1913-14	14.1	33.2	39.3	283	173	558	1,370	1,210	684	199	47.5	30.9	387
1914-15	34.2	28.4	25.7	23.2	40.6	107	654	630	452	105	20.1	14.4	178

Webber Creek near Truckee

[Drainage area, 14 square miles]

1909–10		63.3	42.2	28.2	21.5	53.4	143	133	32.5	2.4	1.0		

Independence Creek below Independence Lake

[Drainage area, 8.5 square miles]

1902–3		9.50	8.01	17.9	37.2	19.7	26.1	92.6	73.2	19.3	3.56	0.73	
1903–4	3.22	28.0	6.88	6.24	39.7	56.5	41.4	128	114	43.7	5.97	2.41	39.8
1904–5	19.6	6.13	29.0	44.3	18.4	34.5	53.0	118	99.9	8.41	2.42	.22	36.2
1905–6	0	4.90	3.37	27.2	8.33	18.6	21.8	89.7	159	141	16.0	4.55	41.2
1906–7	15.0	11.5	27.8	37.9	32.9	64.9	65.1	124	158	[d] 64	[d] 21	[d] 13	52.9
1909–10		54.6	49.6	7.3	7.3	35.0	72.9	66.4	42.3				

Long Valley Creek near Scotts

1916–17							60.5	32.6	2.96	0	0	0.10	

Baxter Creek near Lassen [e]

1912–13						12.4	11.3	18.0	14.1	6.11	4.76	3.62	
1913–14	3.88	5.72	11.0	77.4	46.2	38.0	50.1	49.5	22.4	1.78	.42	.54	25.5
1914–15	2.62	3.38	3.48	4.45	14.8	9.09	9.63	26.7	3.98				
1917–18				.69	4.09	15.4	9.88	6.18	.34	(f)	(f)	(f)	
1918–19	.54	.41	.56	2.83	13.3	12.1	13.3	18.0	4.0	[f] .01	[f] .01	[f] .02	5.38

Schloss Creek at Lassen [e]

1914–15							1.04	2.14	0.49				
1917–18				0	0	0.28	.92	.40	.03	0	0	0	
1918–19	0	0	0	0	.06	.20	1.07	1.22	.008	0	0	0	0.214

[d] Estimated from record at Starr. [e] Formerly called Janesville. [f] Creek practically dry.

Monthly discharge, in second-feet, at stations in Great Basin in California—Continued

Janesville Creek at Lassen [e]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1914–15							1.97	2.53	0.94				
1917–18				0.25	0.43	1.13	2.47	1.98	.432	0.024	(f)	(f)	
1918–19	[a] 0.05	[a] 0.10	0.13	.05	1.73	1.60	3.60	3.59	.32	[a] .2	[a] 0.1	0	0.949

Susan River near Susanville

[Drainage area, 256 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1899–1900									31	13	11	11	
1900–1901	17	47	60	43	308	363	371	420	56	18	10	6	143
1901–2	10	19	61										
1902–3				90		205	372	266	63	11	7	11	
1903–4	17	137	42	27	349	629	695	600	160	51	31	16	230
1904–5	22	21	47	76.9	96.9	234	264	160	61.3	23.4	12.1	12.3	85.9
1905–6	15.7	19.0	18.0										
1916–17						76.4	280	246	130	109	77.3	7.37	
1917–18	9.11	13.8	13.8	12.1	24.0	89.2	132	63.1	59.9	2.11	2.66	7.71	35.7
1918–19	13.1	14.5	10.5	13.6	47.5	98.6	274	104	85.5	65.4	2.83	3.72	60.8
1919–20	7.77	8.28	5.82	7.8	12.0	38.0	106	74.5	52.1	3.93	1.41	3.65	26.7
1920–21	6.75	26.9	37.6	114	108	246	178	217	117				
Average	13.2	34.1	32.9	48.0	135	220	297	239	81.6	33.0	17.3	8.75	97.0

Gold Run Creek near Susanville

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1914–15							16.5	39.1	13.8	3.68			
1915–16				13.9	37.2	39.5	35.1	35.1					

Lassen Creek near Susanville

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1914–15							2.27	6.55	0.95	0.06			

Willow Creek at Merrillville

1903–4	--	--	--	--	--	--	--	--	--	19	18	19	--
1904–5	19	20	20	18.5	18.8	18.6	17.6	17.1	17.0	16.9	17.7	18.7	18.3
1905–6	21.9	22.2	24.0	--	--	--	--	--	--	--	--	--	--

Willow Creek near Standish

1904–5	--	--	--	80.4	89.4	33.5	22.9	17.0	21.1	46.2	19.6	41.0	--
1905–6	31.8	39.6	38.7	--	--	--	--	--	--	--	--	--	--

Bidwell Creek near Fort Bidwell

1911–12		4.0	4.0	4.8	7.5	6.2	47.1	111	108	--	--	--	--
1917–18	--	--	--	1.20	1.01	1.87	11.6	16.0	9.93	1.25	0.43	0.44	--

Bidwell Creek at Fort Bidwell

[Drainage area, 27 square miles]

1917–18	--	--	--	6.76	5.89	12.4	32.5	34.4	15.5	3.25	2.40	3.74	--
1918–19	4.25	5.50	3.5	3.0	3.0	9.76	51.7	82.0	21.0	4.94	1.57	.60	16.0

Keeno Creek near Fort Bidwell

1918–19	0	0	0	0	0	[a] 1.0	[a] 9.5	0	0	0	0	0	--

Twelvemile Creek near Fort Bidwell

1917–18	--	--	--	2.72	2.70	4.05	16.5	39.7	14.8	1.85	1.42	1.43	--
1918–19	1.81	2.59	2.02	1.2	1.2	2.86	15.8	68.6	18.3	3.25	1.28	1.27	10.1
1921–22	--	--	--	--	--	--	--	--	70.7	--	--	--	--

[a] Estimated.

[e] Formerly called Janesville.

[f] Creek practically dry.

Monthly discharge, in second-feet, at stations in Great Basin in California—Continued

East Fork of Horse Creek near Fort Bidwell

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1917-18				[a] 0.6	[a] 0.6	1.27	0.65	0.40	[a] 0.4	[a] 0.3	[a] 0.3	[a] 0.3	
1918-19	0.4	0.3	0.2	.2	.4	2.5	7.0	.5	.4	.3	.2	.2	

West Fork of Horse Creek near Fort Bidwell

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1917-18	0	0	0	0	0	2.80	0.04	0	0	0	0	0	
1918-19	0	0	0	0	0	0	9.8	0	0	0	0	0	

Rock Creek near Fort Bidwell

[Drainage area, 33 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Mean
1917-18				[a] 0.2	[a] 0.5	26.8	4.08	0.10	[a] 0.1	[a] 0.1	[a] 0.1	[a] 0.1	
1918-19	0.2	0.2	0.1	0	0	16.5	105	1.6	.04	0	0	0	

[a] Estimated.

PRELIMINARY REPORT ON THE GROUND-WATER SUPPLY OF MIMBRES VALLEY, NEW MEXICO

By Walter N. White

GENERAL FEATURES OF MIMBRES VALLEY

This report relates to the supply of water that occurs below the surface of the Mimbres Valley, an extensive plain in the southwestern part of New Mexico, which may be defined as the lowland part of the potential drainage basin of the Mimbres River. (See pl. 1.) Thus defined, the Mimbres Valley, north of the Mexican border, nearly coincides with Luna County and covers an area of about 2,500 square miles. North of this great plain is an extensive upland area which includes the Mimbres, Black, and Pinos Altos Mountains and the Cooks Range. The Mimbres River and its principal tributaries rise in these mountains and discharge southward upon the lowland plain. They are all ephemeral streams except for a few stretches in the mountains that are fed by springs.

The mountains consist of hard rocks of many kinds that have a wide range in age and a complex structure. The lowland plain is in most places underlain to considerable depths by clay, sand, and gravel that have been derived from the rock waste washed out from the mountains. The plain is diversified by numerous mountains and buttes, which are projecting parts of rock masses partly buried by the valley fill. The porous beds of the valley fill form a great underground reservoir, which contains a large supply of water that has been contributed during a long period by the Mimbres and other mountain streams. Over a large part of the Mimbres Valley the ground water stands within 100 feet of the surface, and in a few relatively small tracts the depth to the water table is less than 25 feet.

The city of Deming, which is estimated to have a population of about 3,500, is near the center of the Mimbres Valley. It is on the main line of the Southern Pacific Railroad and on the branch line of the Atchison, Topeka & Santa Fe Railway that leads to Silver City. It is also on a well-improved east-west highway, which is extensively used in transcontinental travel, especially in winter. The valley is utilized for cattle ranching and irrigation farming. The precipitation, which averages about 10 inches a year and occurs chiefly in rainstorms during the summer, is not sufficient to permit farming without irrigation, but in favorable years it produces a good growth of grass on the range. Irrigation is accomplished chiefly with water pumped from wells.

HISTORY OF IRRIGATION WITH GROUND WATER

Irrigation by pumping from wells began in the Mimbres Valley during the period 1908 to 1911. About 1912 there was a rapid expansion in pumping development, which at first had been more or less of an experiment, and, according to Darton,[1] by 1914 nearly 200 pumping plants were installed or under erection. These pumping plants were spaced over a large area, extending from Deming southward 33 miles to the Mexican border, eastward about 15 miles to Miesse, and westward about 7 miles to the locality of Red Mountain. (See pl. 1.)

A large part of the development was undertaken by men who had practically no experience in the operation of pumping plants, many knew little or nothing about irrigation of any kind, and some had never farmed before. Little attention was given by these inexperienced men to economy in pumping-plant installation and operation or to the question whether the soils of the lands placed under irrigation were adapted for producing the crops irrigated. As a result operating costs exceeded crop returns, and many of the pumping-plant owners became discouraged and abandoned their farms. The decline in pumping activity was almost as rapid as its rise, and, according to the best information available, by 1918 or 1919 only about 25 pumping plants were in operation. The slump continued for several years. About 1923 or 1924 a revival in development began, and there has been a gradual but steady increase ever since. There are now 116 pumping plants in operation. This number includes the railroad, smelter, sanitarium, county, and city plants, all located at or near Deming, but does not include small outfits used for stock or family supply. About 6,000 acres is under irrigation with pumped water. This year there has been a net gain of 9 in the number of plants operated and an increase of 500 acres in the irrigated area. The present pumping-plant owners with few exceptions are good farmers. The lands are well cultivated, and good judgment is shown in the choice of crops and in the methods used in irrigating them. The pumping plants are operated with fair efficiency, although in some the machinery is in poor condition. As a result most of the farmers are making money.

PURPOSE AND SCOPE OF PRESENT INVESTIGATION

The recent success of irrigation has led the landowners in the valley and the business men of Deming to believe that the ground-

[1] Darton, N. H., Geology and underground water of Luna County, N. Mex.: U. S. Geol. Survey Bull. 618, p. 122, 1916.

water resources of the valley should be developed to the safe limit of the available supply. It is recognized that overdevelopment would be fatal to the best interests of the community and that future expansion in pumping activities should be guided by as adequate information as it is possible to obtain concerning the extent of this resource.

About two years ago the Deming Chamber of Commerce, through the influence of several of its most public-spirited members, requested Herbert W. Yeo, State engineer of New Mexico, to make plans for a survey of the valley that would lead to a quantitative estimate of the water supply. At his request, Albert G. Fiedler, a hydraulic engineer in the United States Geological Survey, made a preliminary study of the problem in August, 1927. Shortly thereafter Mr. Fiedler incorporated his findings in a report,[2] copies of which were transmitted to the State engineer and to the Deming Chamber of Commerce. The report contained a summary of the information then available that had a bearing on the problem and concluded with the estimate that a proper investigation would require the services of a geologist and engineer equivalent to the time of one man for a period of about two years.

Late in September, 1927, Mr. Fiedler revisited the valley and selected 25 observation wells, on five of which automatic water-stage recorders were installed. Under the direction of the State engineer observations of water levels in these wells were made at frequent intervals during the fall, winter, and spring of 1927–28. In the meantime arrangements were made through the State engineer to have the desired investigation made by the United States Geological Survey, under the direction of Oscar E. Meinzer, geologist in charge of the division of ground water. The writer was assigned to the project and began field work in July, 1928. More than a year has since elapsed, and it is now deemed advisable to submit a preliminary report giving some of the results. The investigation is by no means completed, however, and therefore only tentative conclusions can be drawn.

The investigation is chiefly concerned with the quantity of ground water available, the practical problem being to determine how much water can be pumped without seriously depleting the underground reservoir and lowering the water table below the limits of the economic pumping lift.

An underground reservoir is not unlike a surface reservoir. If inflow exceeds withdrawal the water level in the reservoir rises, but if withdrawal is greater than inflow the level declines. In an underground reservoir, especially if it is of great size, the withdrawal may for a time exceed the average annual recharge without causing serious

[2] Fiedler, A. G., Report on a reconnaissance of the ground-water area of the Mimbres Valley, Luna County, N. Mex.: New Mexico State Engineer Eighth Bienn. Rept., pp. 159–171, 1928.

trouble, but eventually a considerable lowering of the water level may result and it may become necessary to restrict pumping to an amount no greater than the recharge.

Fluctuations in ground-water levels afford a valuable clue as to the amount of the annual recharge and as to whether discharge is less, equal to, or in excess of recharge. An important part of the investigation therefore is being devoted to studies of seasonal and yearly changes in ground-water levels. Regular observations of water-level fluctuations are being made on about 150 wells, including 23 of the wells selected by Mr. Fiedler (two wells selected by Mr. Fiedler have become dry). These wells are spaced to cover a wide area from Deming north to the mountains and south to the Mexican border. Six of the wells located at critical points are equipped with automatic water-stage recorders, which are constructed to give continuous graphic records of all changes in water level. The other observation wells are measured monthly with a steel tape.

It is important to know how and where the water reaches the underground reservoir. Studies have therefore been made of the facilities for the intake of ground water in different parts of the valley and surrounding areas. The Mimbres River is the largest contributor to the ground-water supply, and hence current-meter measurements have been made to determine the rate of seepage losses from different sections of this stream. One set of such measurements has also been made on Lampbright Draw. Elsewhere the areas of possible intake have been studied by observing the materials underlying the surface and making tests of these materials to determine their capacity for quick absorption of water during the comparatively brief periods that surface flows exist. Much depends upon the capacity of the water-bearing beds to conduct ground water from areas of intake to the pumped areas. Considerable time, therefore, has been devoted to studies of the permeability of the water-bearing formations, the gradient of the water table, and finally the rate of ground-water movement. Measurements of the underflow beneath the bed of the Mimbres River have been made at two points in the cross section at the dam site 30 miles north of Deming, and further work of this sort will be undertaken in the summer of 1930.

SOURCE OF THE GROUND WATER

The volume of water stored in the beds of sand and gravel that underlie the Mimbres Valley is very great—probably several times the volume annually discharged by the Rio Grande at the Elephant Butte Reservoir. Where does the water come from? This question can be definitely answered. A contour map of the water table has been prepared from data obtained by carrying lines of levels to about 200 wells in which the depth to the water level was measured. (This map will be submitted with the final report.) It shows that practically everywhere under the valley the water table slopes from northwest to southeast. As ground water, following the laws of hydraulics, moves in the direction of the hydraulic gradient or slope of the water table, the map shows that the ground water is coming chiefly from the upper end of the valley. The Mimbres River and its tributaries, the chief of which is San Vicente Arroyo, enter the valley there and contribute the greater part of the inflow of surface water into the valley. These streams shrink rapidly upon reaching the plain and in times of low flow disappear within a short distance after leaving the bedrock of their mountain courses. At the upper end of the valley the water table slopes away from the river as well as in the direction of the surface slope, and wells near the stream display a rapid and pronounced rise after a run of water of fair magnitude and length. From these facts and others discussed later in this report it is concluded that a very large part of the supply comes from the main Mimbres River. Lesser quantities are contributed by San Vicente Arroyo and its tributaries. Comparatively little water is contributed by run-off from the Florida Mountains or from the low mountains and hills on the west side of the valley. The run-off from the Cooks Range is a factor of some importance, because storm waters from the northwest slopes of the range discharge into the Mimbres River and later a part of this run-off reaches the ground water through the sand and gravel of the river bed. Run-off from the south and southeast slopes of the range also provides ground-water recharge, but the amount is believed to be small. Northward from Spalding the surface gradients are steep and there is considerable run-off from precipitation on the valley floor itself, which reaches the Mimbres River or its tributaries and later seeps underground through the river bed. Moreover, large areas in that part of the valley are underlain by coarse gravel through which some ground-water recharge may take place directly from rainfall, although the gravel is nearly everywhere cemented or partly cemented, and the amount of such recharge is probably small. It may safely be stated that southward from Spalding practically no recharge takes place from precipitation on the valley floor and the area of ground-water intake is largely limited to the bed of the Mimbres River.

The opinion has been expressed by several residents of Deming that the ground water of the Mimbres Valley comes from the headwaters of the Rio Grande in Colorado or from some other distant mountain area. This is believed to be impossible. Hundreds of miles of high plateau and mountainous country, underlain by dense rocks through which water moves very slowly if at all, lies between the Mimbres Valley and those distant regions. Even if it were possible for water to move great distances through rocks of this character the amount that could percolate would be exceedingly small.

STREAM DISCHARGE AND UNDERFLOW

The State engineer's office and the United States Geological Survey have together maintained gaging stations on the Mimbres River near Faywood and near Mimbres and on Lampbright Draw and Cameron Creek, two of the larger tributaries of San Vicente Arroyo, for periods of varying lengths during the last 20 years or so. The stations on Lampbright Draw and Cameron Creek have been discontinued, but those on the Mimbres River are still in operation.

Summary of records of discharge of Mimbres River, Lampbright Draw, and Cameron Creek

[Compiled from published records of the State engineer and United States Geological Survey]

Stream	Drainage area above station (square miles)	Period of record	Length of record (years)	Average annual discharge (acre-feet)		
				Full period	1914–16	Rest of period
Mimbres River [a]	450	1908–1910, 1912–1928	20	16,400	54,500	9,700
Lampbright Draw	30	1913–1922	10	1,300	3,000	400
Cameron Creek	20	1907–1910, 1914	5	[b] 1,600	6,000	500

[a] Faywood gaging station.
[b] Discharge in 1914.

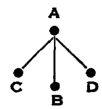
The writer has not examined the sites of the discontinued stations on Lampbright Draw and Cameron Creek. At Faywood station on the Mimbres, where the 20-year record was obtained, the river bed is sandy and shifts considerably with every large flood. Under such conditions the computation of stream discharge from records of gage height is subject to some inaccuracy, particularly during periods of very large or very small discharge. However, the figures for average discharge given in the table were prepared by engineers of experience in the interpretation of stream flow in shifting channels and are assumed to be accurate within reasonable limits.

The outstanding feature of the performance of these streams is the proportionately great discharge that occurred during the wet years 1914 to 1916. The total discharge of the Mimbres River during these three years amounted to about 164,000 acre-feet, whereas the total during the remaining 17 years of record amounted to only about 165,000 acre-feet.

The figures in the table give the surface discharge but do not include the underflow, the amount of which, for the Mimbres River, is popularly believed to be large. Considerable attention was given to this question in the investigation.

About 1,000 feet above the Faywood gaging station the river cuts across a ridge of highly resistant and relatively impermeable igneous rock. At this point the width of the channel between opposite rock walls is only 750 feet, and depths to the bedrock beneath the channel as disclosed by exploratory drilling are comparatively small. This is the site on which it has been proposed to construct a dam to conserve the flood and waste waters of the Mimbres.

As a result of the constriction of the valley at this point, both in width and in depth, much of the underflow is brought to the surface as springs, the discharge from which flows down past the gaging station and is taken into account in the gaging records. Some of the underflow continues underground through the gravel overlying the crest of the rock barrier. Measurements of this underflow were undertaken according to Slichter's methods with some variations. Four well points were driven into the gravel in ground plan about as follows:



In this arrangement A is the upstream well; B, C, and D were driven 4 feet from A in a downstream direction, B directly downstream and C and D respectively 2 feet to the right and 2 feet to the left. The rate of underflow was determined by introducing salt water into well A and then recording the time interval required for the salt to reach one of the downstream wells, a silver nitrate solution being used to detect the arrival of the salt in the lower well. The work was attended by considerable difficulty. The river sand and gravel at the dam site were interspersed with boulders, and the points could be driven only 2 or 3 feet below the water table. The first wells were put down early in August and before the experiment could be completed were caught by a flood on August 9 and filled with mud and silt. The experimental work was renewed early in September, and eventually determinations were made showing velocities of 26 and 29 feet a day, respectively, at two points in the cross section, one about 200 feet from the east bank and the other about 250 feet from the west bank.

The exploratory drilling at the dam site was done many years ago, and no accurate figures as to the depths to bedrock have yet been found by the writer. According to report the average depth was found to be about 20 feet. On this basis the gravel along the line between rock outcrops would have a cross-section area of 15,000 square feet. Practically everywhere that underflow measurements have been made it has been found that the velocity of the underflow decreased with the depth below the bed of the stream.

If it is to be assumed that the underflow at the Mimbres dam site does not decrease with the depth of the gravel, that the average of the two observed rates of underflow (27.5 feet a day) represents the average velocity in the entire cross section, and that the effective porosity of the gravels is 25 per cent, this total underflow amounts to 1.17 second-feet, or 850 acre-feet a year. In the table below these figures are compared with the results of several well-known underflow measurements and estimates made by Slichter on other streams.

Comparison of tentative estimate of underflow of Mimbres River with underflow measurements on other streams made by Slichter

Stream	Locality	Area of cross section (square feet)	Velocity (feet per day)	Total underflow (second-feet)
Mimbres River	Near Faywood gaging station	15,000	27.5	1.17
Rio Grande	Near El Paso, Tex	11,200	3	.13
Mohave River	Near Victorville, Calif	4,160	50	1—
Arkansas River	Near Garden City, Kans	75,000	10	2.9

It is estimated that the run-off from about 400 square miles in addition to the 500 square miles drained by the Mimbres River, Lampbright Draw, and Cameron Creek contributes to the ground-water supply of the Mimbres Valley. This additional area comprises the mountains back of Silver City and Santa Rita, the northwest and south slopes of the Cooks Range, and the foothills and steeper parts of the valley floor at the upper end of the valley. According to the records the rate of run-off from a square mile of the drainage basins of Lampbright Draw and Cameron Creek does not differ greatly from that from a square mile of the main Mimbres drainage basin in corresponding years.

For purposes of computation it is assumed that the average rates of run-off from these three drainage areas are equal and that the average rate of run-off from the additional 400 square miles referred to is half as great. On this basis the observed 20-year discharge of the Mimbres River plus the estimated underflow is made applicable to the entire 900 square miles, and the total stream discharge from which the ground water of the valley is chiefly derived is computed as follows:

Estimated stream discharge into Mimbres Valley from which the ground water is chiefly supplied

Period	Number of years	Average annual discharge (acre-feet)
1908–1928	20	26,700
1914–1916	3	85,700
1908–1910, 1912–13, 1917–1928	17	16,300

FACILITIES FOR GROUND-WATER INTAKE

Considerable attention has been given during the investigation to studies of the permeability of the soils of the valley and of the stream-bed gravel, sand, and clay, with the object of obtaining information as to the facility of these materials for taking in water. Penetration by rainfall has been studied, and observations have been made of the rate at which storm waters sink in borrow pits and in trenches along the roadside. Cylinders were driven into the normal bed of the Mimbres River and into the soils of adjacent areas over which the river spreads during periods of high discharge, and later tests were made of the rate at which the water would penetrate into the inclosed soil columns.

It was found that water under a small head percolated downward very rapidly in river-bed gravel and sand—so rapidly, in fact, that attempts to compute the rate of movement were unsuccessful. Percolation was also rapid in the sandy soils, a depth of a foot or more of water disappearing in such soils in a day. The rate of downward movement in the cemented gravel underlying the bench at the north end of the valley is slow, observed rates of subsidence of storm waters in gravel pits in these materials ranging from 2 to 5 inches a day. Observed depths of water penetrating clay or clay loam in natural depressions and in borrow pits under a head of 6 inches to a foot ranged from half an inch to 4 inches a day. In silty soils the movement was found to be much slower, observed rates of penetration under a head of 1 foot ranging from a small fraction of an inch to an inch daily.

At the upper end of the valley the normal and flood channels of the Mimbres River and other large streamways consist in great part of gravel and boulder beds which are highly permeable and take in water with great rapidity. The bed of the Mimbres River below Spalding consists of gravel and sand, much finer than the gravel and boulders of the upper river and not nearly so permeable, although they take in water with considerable readiness. The high boulder-strewn alluvial slopes adjacent to the Cooks Range and the Florida Mountains are well adapted for ground-water intake, but the portion of these slopes underlain by coarse materials is not over a mile or two in width. Once the streams are across this narrow belt the opportunities for the water to penetrate to any considerable depth are not good, the middle and lower portions of the alluvial slopes as well as the lowlands at the foot of these slopes being underlain in most places by comparatively impervious clay loam and silt. The surface gravel of the plain at the upper end of the valley, as has been stated, is more or less cemented and takes in water slowly. In wet years, however, local precipitation and run-off may penetrate in moderate quantities to the water table through this gravel. San Vicente Arroyo delivers the run-off from about 200 square miles to the Mimbres. In its upper reaches the beds of this arroyo and its tributaries consist of boulders, gravel, and sand, which are favorable for ground-water intake. From a point near Whitewater (see pl. 1) downstream to its junction with the Mimbres the arroyo is largely in clay loam and silt that are only slightly permeable. Moreover, the water that reaches the lowermost few miles of the arroyo is diverted and spread over pasture lands, where it is largely dissipated by transpiration of the grasses and by evaporation. The water that reaches the lower part of the Mimbres River below the bridge 6 miles east of Deming is largely spread over a rather wide expanse of valley land. During the growing season ordinary runs of water, up to about 75 second-feet are diverted through the Wamel Canal at a point about 2 miles southwest of Black Mountain (see pl. 1) and used for the irrigation of pasture land and a small area of cultivated land northwest and west of Deming. Downstream from a point about 8 miles east of Deming the channel of the river becomes small, and still farther on, near the north point of the Florida Mountains, it disappears entirely. As there is nothing to restrain the water in these localities the floods spread out over the valley in shallow sheets, the area covered depending upon the amount of water brought down by the floods. In general neither the areas served by the Wamel Canal nor the lands subject to inundation on the lower reaches of the stream north and east of the Florida Mountains offer very favorable facilities for ground-water intake, especially if the periods of flooding are brief. Small portions of the flood lands are underlain by surface gravel and sand that offer an opportunity for the ingress of water, but most of the surface of these areas is underlain by clay loam and silt of considerable depth. If the floods persist for a long time considerable ground-water recharge may occur in these areas. If the floods are short the recharge is likely to be small or none.

QUANTITY OF INTAKE

The studies of the intake of ground water have been devoted chiefly to a consideration of seepage losses from the Mimbres River. Several runs of water were followed from the mountains down to the locality of Deming, and current-meter measurements were made every few miles to determine the rate of loss by seepage in different stretches of the stream. The floods generally rise with great rapidity, nearly always during the night. The crest is usually reached within an hour, as shown by the automatic water-stage recorder at the Faywood gaging station, and almost immediately thereafter the stage begins to decline. Under such conditions any data which it is possible to obtain concerning loss of flow in a particular stretch of the streams are subject to considerable error. If the stream gager moves downstream at a more rapid rate than the average rate of stream flow his estimate of seepage losses is likely to be too small; if he moves at a slower rate his estimate is likely to be too large.

Results based on six sets of measurements in 1928 and 1929 indicate that for moderate runs (75 to 125 second-feet at Faywood gaging station) the losses by seepage run from 4½ per cent to the mile downward. The results differ considerably for different sets of observations, the percentage of loss usually but not always varying inversely with the amount of discharge. Average figures computed from the measurements are approximately as follows: Foothills to mouth of San Vicente Arroyo, 35 per cent; mouth of San Vicente Arroyo to intake of Wamel Canal, 25 per cent; intake of Wamel Canal to bridge 6 miles due east of Deming, 25 per cent. The indicated percentage of loss is that of the flow entering each stretch—that is, a discharge of 100 second-feet at the Faywood gaging station declines to about 65 second-feet at the mouth of San Vicente Arroyo, to about 49 second-feet at the intake of the Wamel Canal, and to about 36 second-feet at the bridge 6 miles east of Deming. Practically all the measurements were taken during floods, when the water was heavily laden with sand and silt. This is the normal condition of the water, at least during the summer. Only one set of measurements of fairly clear water was made. This was on August 29, 1929, following about three weeks of continuous runs during which the water had cleared up considerably. On that date a discharge of 40 second-feet disappeared entirely in the section between the gaging station and a point about 3 miles south of the mouth of San Vicente Arroyo. This rate of loss was materially higher than occurred at other times when the water was muddy. As previously stated, the stream discharge during moderate floods is usually diverted into the Wamel Canal, and only occasionally is the water allowed to flow downstream to the locality of Deming. However, when the discharge of the river at the canal intake becomes much greater than 75 second-feet, a part of it is allowed to pass the head gate of the canal and to continue on downstream.

The amount of seepage loss is proportional to the area wetted by the stream, the length of time the wetted area is submerged, and the depth of water in the stream. The velocity of the stream is proportional to its discharge. At the Deming bridge small runs of water have velocities ranging from 2 to 3 feet a second, whereas large floods have velocities that are much greater. For example, the flood of August 10, 1929, at its highest stage (approximately 2,000 cubic feet a second), had a velocity of about 8 feet a second. No attempts have been made to estimate seepage losses below the bridge 6 miles east of Deming. Some water from moderate runs and even from small runs flows as far downstream as the El Paso road in the Miesse district, but the water seldom crosses the road in any considerable quantity. Early in September, 1925, a flood submerged the road and continued down the valley for many miles. This did not occur again until August 10, 1929. Therefore, proportionately much less water sinks into the sand and gravel of the river bed during periods of high flood than during small or moderate runs. During large floods there is so much sand and silt in suspension and the channel is so constantly changing that it is impossible to obtain accurate determinations of the discharge of water or of the seepage losses.

A part of the water lost in the bed of the stream goes to fill the pores in the sand and gravel. These materials are depleted of moisture during the long dry seasons and to some extent also between successive floods in the rainy season. The amount of depletion, however, as estimated from moisture determinations by the writer, is not great.

In winter the water tends to be clearer than in summer, less water is diverted, and evaporation losses are small. Moderate continuous runs of water during the winter and spring, therefore, contribute proportionally most heavily to ground-water intake. Most of the large floods occur in summer, and much of the water of these floods is dissipated by evaporation and transpiration from submerged areas and irrigated lands.

Although the data manifestly are fragmentary and incomplete, it is believed that some tentative estimate of the intake of ground water to the Mimbres Valley should be made at this time. On page 76 the stream discharge, which is believed to be the source of practically all the ground-water recharge, is computed as averaging 26,700 acre-feet a year during 20 years. After careful consideration of the daily records at the Faywood gaging station for 20 years and of the data obtained in 1928 and 1929 on the facilities for ground-water intake the annual recharge is estimated in terms of a percentage of the stream discharge as follows: Wet years 1914–1916, 30 per cent; remainder of period of record, 50 per cent; mean average for 20 years, approximately 40 per cent. On this basis the average annual increment to the ground-water supply of the Mimbres Valley during 20 years was between 10,000 and 11,000 acre-feet a year.

SHAPE OF WATER TABLE AND MOVEMENT OF GROUND WATER

Lines of levels aggregating about 250 miles in length have been run to determine the altitude of the water level in about 200 wells, and from these figures a contour map of the water table has been compiled covering the ground-water areas with which this report is chiefly concerned. Some additional leveling in localities 15 to 20 miles south of

Deming still remains to be done. This map, which will be submitted in completed form in the final report, gives information as to the direction of the slope of the water table and therefore as to the direction in which the ground water is moving. It also shows the hydraulic gradient, or rate of slope of the water table in each locality. This is important, because the rate of flow of the ground water depends on the hydraulic gradient as well as on the permeability and thickness of the water-bearing bed. It is found that nearly everywhere in the valley the ground water is moving northwest to southeast. From Black Mountain down to the east and south limits of the pumping area the slope of the water table ranges from 10 to 15 feet to the mile and averages about 13 feet. Above Black Mountain the slope is steeper; in the locality of Spalding it ranges from 25 to 35 feet to the mile.

If in a locality in which considerable pumping is done the pumping produces a depression or even a flattening of the water table that persists throughout the year, it may be inferred that little or no water is moving down the valley past the pumps in that particular locality. If no permanent depression or flattening occurs, it must be inferred that some of the ground water percolates through the locality and escapes in the direction of the slope of the water table. The leveling has disclosed that a depression of the water table has been developed in a part of the Miesse district but not in other parts of the pumping area. It is believed, therefore, that except perhaps in a part of the Miesse district, the pumps are not recovering all the underflow but that some ground water is escaping toward the south each year.

A study is being made of the natural rate of the flow of the ground water. For this purpose a method is being used which was developed by Dr. Thiem, of Germany, and which may be called the pumping method of determining permeability. Three wells are required to make a test by this method. One of the wells is pumped at a measured rate for several hours, and observations are made as to the resulting drawdown in the other two wells. The natural rate of flow can then be computed by means of a mathematical formula. Tests of this kind have been made at the Gaskell, Cleary, Rutland, and Ernst farms and at the Chinese Gardens, and additional tests are to be made next summer. Observation wells have recently been put down on the Williams and Russell farms, and additional wells will be put down if necessary. Computations based on observations made thus far show a rate of natural ground-water movement averaging between 2 and 3 feet a day.

FLUCTUATIONS IN GROUND-WATER LEVEL

All available sources of information have been consulted in the effort to obtain accurate figures on the amount of water-table fluctuation which has occurred since pumping began on a large scale. The few pumping-plant owners whose activities began in the early days of pumping have been interviewed. The large volumes of data concerning water-table altitudes in 1914 given by N. H. Darton in United States Geological Survey Bulletin 618 and in the records of pumping tests made by the State engineer's office have been consulted. These records show the water levels in 1914 in many wells that are still in existence.

It is found that practically everywhere in the valley the water level has declined. Since 1914 the decline under an area of about 100,000 acres west, south, and east of Deming has ranged from about 4 to 8 feet and has averaged about 6 feet. Within the city of Deming the decline in the same period has amounted to about 10 feet, and in the heavily pumped portion of the Miesse district it has averaged not less than 15 feet. Wells that are close to the Mimbres River east of Deming show the smallest decline. These wells, according to their owners, are subject to a pronounced rise following long-continued runs of water in the lower Mimbres.

In general wells at a considerable distance from the river have failed to develop much of a rise in recent years, but after the wet years 1914 to 1916 the water levels rose materially in a number of such wells. Two instances are reported of a rise in wells at some distance from the river after the flood of late August and early September, 1925. Mr. Wasdin reported that in his well west of Deming (No. 90a, pl. 1) the water level rose about 3 feet after this flood. Mr. J. E. Hestand reported that in his well (160b), in the southeast corner of the Miesse district, the water level rose an appreciable amount after the flood. Mr. J. N. Cobb reported that in his well (44a) about three-quarters of a mile east of the courthouse at Deming, the water level has gone down about 7 feet since the well was sunk in 1912, as disclosed by a long series of careful observations. He states that the decline has been gradual but persistent. After the wet years 1914 and 1915 the water level rose somewhat and for two years was higher each spring than it had been the spring preceding. Throughout the rest of the period, however, there has been a gradual decline from year to year. The water rises each winter but invariably fails to come back to the level of the preceding spring. A similar gradual but persistent decline has been noted in the Bowman (104), Holiday (137), J. B. Anderson (169a), Smyer (147), Hatfield (144), and other wells.

Records of water levels obtained during the last two years show that the decline is still in progress. A large number of measurements have been made, but it is not within the scope of this preliminary report to analyze all these data, and, indeed, a longer record should be obtained before a detailed analysis of water-level fluctuations is attempted. The most accurate information as to the net rise or decline of the water table can be obtained by comparing the water levels of late winter or early spring in successive years. Such data are thus far available only for the original group of observation wells selected by Mr. Fiedler in the fall of 1927, of which 11 are pumped for irrigation in summer and 13 are unused. Records of water level in these wells on January 30–31, 1928, and February 3–4, 1929, are given in the following table. The location of the wells is shown on the map.

Midwinter depths to water in a part of Mimbres Valley observation wells, 1928 and 1929

No.	Name	Jan. 30–31, 1928	Feb. 3–4, 1929	Decline or rise in water level (feet)
29	Unoccupied ranch	77.35	79.99	−2.64
[a] 70	Mr. Wells	62.65	64.59	−1.94
[a] 93	Mr. Trubee	60.83	61.83	−1.00
[a] 111	Mr. Gaskell	60.44	61.27	−.83
123	Mr. Humphries	56.73	57.90	−1.17
166	Long S ranch	48.61	48.49	+.12
180	Unoccupied	55.92	56.08	−.16
190	Miss Birchfield	23.16	23.20	−.04
[a] 174	Mr. Watkins	42.26	42.57	−.31
179	Mr. Gaines	44.42	44.77	−.35
108	Unoccupied	46.16	46.34	−.18
107	do	16.58	17.82	−1.24
[a] 104	Mr. Bowman	[b] 47.63	47.80	−.17
88	Unoccupied	53.34	53.59	−.25
[a] 40	Mr. Ernst	50.45	51.21	−.76
[a] 50	Miss Browning	31.14	31.42	−.28
[a] 52	Mr. Thompson	29.47	29.74	−.27
[a] 58	Mr. Remondini	25.11	25.05	+.06
[a] 59	do	24.80	24.76	+.04
134	Mr. Kretek	12.36	12.57	−.21
[a] 149	Mr. Harris	67.45	69.62	−2.17
154	Unoccupied	57.87	58.29	−.42
155	do	57.92	58.26	−.34
156	do	65.40	66.57	−1.17

[a] Pumped for irrigation during summer. [b] Feb. 21, 1928.

In three of the wells the water level was slightly higher in 1929 than in 1928. In the remaining wells, however, the water level was lower in 1929, the average net decline for the year being 0.75 foot, or 9 inches. The greatest decline took place in the areas of heaviest pumping or on the borders of these areas. In all these wells, except Nos. 29 and 166, the water level rose somewhat during the winter, the average rise being 7.8 inches during the winter of 1927–28 and 8.8 inches during the winter of 1928–29. The average rise in the pumped wells during the winter of 1928–29 was 13.08 inches; that in the unused wells was 4.68 inches. Well 29 showed a decline of 12 inches during the winter of 1927–28 and a decline of 13 inches during the winter of 1928–29. Well 166 dropped about 1 inch both winters.

About 150 wells are now under observation. These wells are widely spaced over the valley with a view to obtaining representative figures on fluctuation of the water table, both in areas that are probably affected by ground-water intake and in areas that are known to be affected by ground-water discharge. The period of record of all the wells except those listed in the table on page 83 is only a little more than a year and is therefore still too short to serve as a basis for any very definite conclusions. Briefly, the figures obtained show that practically everywhere in the valley the water level was lower August 1, 1929, than it was August 1, 1928. This condition prevailed alike in pumped areas, in areas of ground-water intake, and in the intermediate or conduit areas. The cause of the decline was everywhere the same: The outflow or discharge of ground water was greater than the inflow or recharge. In the pumping districts the discharge is effected partly by pumping and partly by natural outflow. Elsewhere both recharge and discharge occur chiefly by natural underflow, the rate of which is determined by the hydraulic gradient, or slope of the water table, and the thickness and permeability of the water-bearing beds.

The amount of drawdown in pumped wells varies to a certain degree with the length of time the well is pumped and with the amount of pumping activity in the immediate vicinity. If pumping is temporarily discontinued the water rises rapidly for a few hours and very slowly thereafter, the amount and rate of rise being more or less affected by pumping in near-by wells. Under such circumstances records of water levels obtained from the pumping-plant wells during the irrigation season have little value as a basis for estimating annual fluctuations, and no particular effort has been made to obtain such records. Records of summer fluctuations of water level in unused wells in the pumping districts, however, have value, particularly if the wells are as much as half a mile from any pumped well. Records obtained from a few wells of this kind indicate that between August 1, 1928, and August 1, 1929, the water level declined on the average about 9 inches in the heavily pumped localities and only about 2 inches in the lightly pumped localities.

A pronounced decline of the water table also took place in the areas of intake, far from the pumping districts. For example, from August 1, 1928, to August 1, 1929, the water level declined 4 to 6 inches in areas near San Vicente Arroyo or Silver City Draw, 2 miles west of Spalding (wells 5 and 6). Well 4, a quarter of a mile from the Mimbres River, on the old Jacobson ranch, about 3 miles northeast of Spalding, showed a decline of about 7 feet for the year. Wells 11 to 15 on the Spalding tract, comprising 6,000 acres near Spalding camp, showed declines of 1.9 to 3.5 feet during the year, the wells nearest to the river showing the greatest decline. Well 2 (unused) of the Peru Smelting Co. (map No. 21), about 350 feet from the Mimbres River, 3½ miles northwest of Deming, showed a decline of 6 inches during the year. The ground waters in the locality of this unused well may be somewhat affected by pumping. Elsewhere in the areas of intake above referred to the decline in water level was the result of natural conditions, the rate of down-valley movement or outflow being greater than the rate of inflow or recharge. The decline, in fact, was a manifestation of intermittent recharge. During the winter of 1926–27 the river flowed to the locality of Black Mountain and farther almost continuously for several months, and seepage losses therefrom raised the water table to comparatively high levels in areas closely adjacent to the stream. From the spring of 1927 to the later part of July, 1929, the surface discharge was small, there was no great amount of ground-water recharge, and the ground-water level showed a continuous decline in stage. A few short runs in the river during the summer of 1928 provided only enough ground-water recharge to raise the water table temporarily in localities close to the river and slightly retard the rate of water-table decline in areas farther away. Floods during late July and August, 1929, the largest in several years, caused a general rise of the water table in areas of intake at the upper end of the valley. Early in October, 1929, the water level in wells close to San Vicente Arroyo had risen a few inches, wells close to the Mimbres River on the Jacobson ranch and Spalding tract had risen several feet, and wells on the Spalding tract as far as 3 miles from the river had risen at a rate which seemed to promise a return to the levels of August 1, 1928, if not to higher levels. In the valley near Deming the floods of late July and August, 1929, were followed by a considerable rise in water level in several wells that are within 2,000 feet or so from the river, but wells at greater distances showed no evidence of rise at the end of the field season, early in October.

In most of the wells in the intermediate or conduit belt the water level declined only a few inches between August 1, 1928, and August 1, 1929. In well 29 (see table), however, the water level declined 2.57 feet from August 1, 1928, to June 9, 1929, and a few days later the water level had declined so low that the recorder float would no longer operate. This well is about 2 miles northwest of the north boundary of the heavily pumped district west of Deming. It was measured by Mr. Fiedler in 1927 and was continuously equipped with an automatic water-stage recorder from September 27, 1927, until June 15, 1929. This record shows a slight rise from October 29 to November 15, 1927. During the remainder of the period the water level declined persistently, the net decline in about 20½ months amounting to 4.96 feet. It may be that the decline in this well is due in part to the same reason that caused the wells in the Spalding tract to show a decline—that is, intermittent recharge. If so, it was to be expected that a marked rise would occur in the well during the winter of 1929–30, as a result of the floods of July and August, 1929.

PUMPAGE AND NATURAL DISCHARGE OF GROUND WATER

So far as has been learned none of the irrigators in the Mimbres Valley have kept accurate long-time records of the amount of water they have pumped. Partial records have been obtained from some of the farmers, and a considerable volume of data in the files of the Deming Ice & Electric Co. has been consulted. On the basis of this information it is estimated that the average depth of water used in irrigation is about 20 inches a year and that the present annual consumption of water, including supplies used for domestic and industrial purposes, amounts to about 10,500 acre-feet. No one knows how much water was used in former years. During the boom years 1914 to 1917 the annual pumpage may have been more than twice as great as at present, but during the slump years 1918 to 1923 the annual average was probably less than half as great as at present. The mean annual pumpage since 1914 has almost certainly not exceeded 10,000 acre-feet.

Before pumping was begun a state of equilibrium existed in the ground-water conditions, the average annual inflow being balanced by an equivalent average outflow or discharge. The inflow then as now was contributed chiefly by seepage from the Mimbres River and its tributaries. Discharge took place by percolation southward and eastward out of the valley and by evaporation from the soil and transpiration from plants. This balance was a delicate one and was easily subject to disturbance.

The chief effect of pumping has been to cause additional discharge without substantially reducing the natural discharge or increasing the recharge. Losses by evaporation have been eliminated since the decline of the water table, but the area formerly subject to loss by evaporation was small, and the saving thus effected has been meager. Losses continue by transpiration in the areas of shallow ground water. The mesquite in the Mohave Desert in California is known to send its roots to a depth of 40 feet to obtain ground water, and the mesquite in the Mimbres Valley may possibly be absorbing some ground water where the depth is even greater. Mesquite roots were traced to a depth of 41 feet in a test well put down by the writer on a tract of land about 1½ miles southeast of Deming belonging to the city. Water was encountered in this well at 48.5 feet.

The lowering of the water table resulting from pumping has slightly increased the hydraulic gradient toward the pumping areas, but in general terms the increase is so slight that the rate of inflow into these areas is probably only a little more rapid than it was before pumping began. A part of the underflow is diverted toward the pumps during the irrigation season, and some is diverted during the winter to fill up the depressions caused by pumping. In most of the pumping areas only a slight depression is formed in the water table during the pumping season, and this depression is almost completely smoothed out during the winter. In parts of the Miesse district the depression produced by pumping is somewhat deeper and is only partly filled during the winter. From this it is concluded that natural outflow continues to a degree, except perhaps in parts of the Miesse district, and that the existing pumps are not intercepting all the underflow. To accomplish this fully, however, would require a lowering of the water table below the limits of the economic pumping lift.

FLUCTUATIONS IN STORAGE OF GROUND WATER

Changes of considerable magnitude in ground-water storage have taken place since pumping was begun on a large scale. It is estimated that fully 500,000 acre-feet of valley fill, consisting of gravel, sand, silt, loam, and clay loam in varying proportions, was unwatered as a result of the decline of the water table in the 15-year period ending in 1929. It is further estimated that about 25,000 acre-feet of valley fill became saturated in each of the winters of 1927 and 1928, as a result of the rise of the water table, but that the net unwatering from August 1, 1928, to August 1, 1929, amounted to about 30,000 acre-feet of valley fill.

In order to compute the amount of water drained from the zone or belt of water-table decline it is necessary to assume some figure for the specific yield of the materials in which the decline took place. The specific yield may be defined as the ratio of the volume of water that will drain by gravity from a given water-bearing material to the volume of the material drained.

The interstices in sand and gravel are comparatively large, and consequently the effect of molecular attraction in them tending to resist the pull of gravity is comparatively slight. Therefore a large part of the water which they contain in a saturated condition drains out as the water table declines. In other words, their specific yield is high. The pore spaces in silt and clay loams are very small, and therefore the effect of molecular attraction in them is correspondingly great. These materials therefore retain a much higher proportion of water as the water table declines than is retained by sand and gravel. Moreover, the process of drainage in fine materials continues for a long time, although at a greatly reduced rate. Experiments by the writer in Escalante Valley, Utah, showed that during periods ranging from 12 hours to several days fine-textured soils such as silt and clay loams yield a volume of water ranging from less than 0.5 per cent to 8 per cent and averaging about 3 per cent of the volume of material drained. With the passing of many months or years the clay and silt probably continue to lose water, but not much is known on this subject.

Studies were made of the specific yield of materials of this character in the unwatered zone in a well recently put down at the Chinese Gardens, 1 mile east of Deming; in test holes put down by the writer in a tract 1½ miles southeast of Deming belonging to the city; and at the Williams farm, 9 miles southeast of Deming. It is estimated from these studies that at different depths in the unwatered zone the volume of water that drained out ranged from 8 to 14 per cent of the volume of material drained. In order to have a basis for computation it will be assumed that the unwatered silt and clay loams in the pumping districts of the Mimbres Valley have parted with a volume of water representing 10 per cent of the volume unwatered and that the unwatered sand and gravel have yielded 20 per cent of their volume. From studies of the logs of 100 or more widely spaced wells in the pumping districts it is computed that 75 per cent of the drained materials consist of silt and clay loams and 25 per cent of sand and gravel. This computation leads to the conclusion that the volume of water drained from the unwatered zone amounted to 12½ per cent of the volume of material drained. The ratio of the volume of water required to refill the partly emptied pore spaces to the volume of material resaturated with the rise of the water table each winter is a somewhat smaller figure, because the pores have had only a few months to drain as compared with several years of continuous drainage from materials that were unwatered early in the pumping development. This ratio is assumed to be 10 per cent.

If the ground-water storage in the pumping districts was reduced during the 15-year period ending in 1929 by 12 per cent of 500,000 acre-feet, or 60,000 acre-feet, it follows that 40 per cent of the water pumped from the Mimbres Valley during this period was taken from storage. If the increase in storage in the pumping districts during each of the two winters covered by the investigation (1927–28 and 1928–29) amounted to 10 per cent of 25,000 acre-feet, and the pumpage during each winter is assumed to be 500 acre-feet, the average winter recharge of these districts amounted to about 3,000 acre-feet. If there was an equal amount of recharge during the summers, the average annual recharge of the pumping districts in the last two years has amounted to about 6,000 acre-feet. This is somewhat less than the estimated long-term average annual intake into the entire underground reservoir of the Mimbres Valley. Although the yearly intake of ground water varies within wide limits, the rate of movement through the water-bearing materials between the intake and pumping areas and therefore the yearly delivery of water through this underground conduit is more nearly constant.

CONCLUSIONS AND RECOMMENDATIONS

Practically all the fundamental facts disclosed by the present investigation have been considered in the preparation of this preliminary report, but the detailed observations have covered only a little more than a year, and it is therefore too early to arrive at final conclusions. The investigation, however, indicates that the present irrigators in the Mimbres Valley are reasonably secure in their water supply provided no large additional pumping developments are made. The quantity of water stored in the underground reservoir is very large, but the annual recharge of this reservoir is relatively small. In the 15 years since pumping began the water table has declined 2 to 15 feet in different parts of the pumping districts, the average decline being about 6 feet. This decline represents no particularly unfavorable condition, for a certain amount of decline in water levels is an inherent and unavoidable consequence of any ground-water development. The present rate of pumping will entail further decline, but it should occur at a decreasing rate and may to a large extent be offset by rise in years of heavy rainfall.

In view of the indications of the data now available, it would be unwise to formulate plans at this time for any large additional pumping development. Detailed observations are to be continued for at least two years, and arrangements should be made to have measurements of water levels in some of the observation wells made at regular intervals by State or local agencies for several years thereafter. If these observations should show unexpectedly large recharge it will then be time for contemplating additional development of magnitude.

A small amount of additional development in areas now lightly pumped could be attempted with reasonable safety, and thereby some of the water that would otherwise escape from the valley by underflow would be salvaged. No additional developments should be permitted at this time in the most heavily pumped localities.

Only a few deep wells have been drilled in the valley. These wells have a relatively high head and seem to show that another water-bearing bed lies below those from which the present irrigation supply is obtained and is separated from them by a more or less effective confining bed. This deeper bed may contain a moderate reserve supply that could be developed in the event that the water in some of the existing pumped wells should fall below the economic pumping lift. No information is available as to whether this deeper bed would yield freely enough to be of practical value for irrigation, but it may be a significant fact that all these deeper wells have been abandoned. Moreover, it can not be safely assumed that the water in the deeper bed is completely isolated from that in the shallow beds.

The intake from the Mimbres River could be artificially increased by temporary storage of the flood water in a surface reservoir and gradual release of this water, but this plan would require the construction of an expensive dam. This phase of the subject will be further considered in the final report.

In 1927 the State legislature of New Mexico enacted a law [3] which declared that waters in underground streams, channels, artesian basins, reservoirs, and lakes belong to the public and are subject to appropriation for beneficial use. The State supreme court, in a decision [4] rendered in April, 1929, upheld the principle of this law but declared the law itself unconstitutional on account of certain technicalities. If this law is reenacted by the next legislature, with the unconstitutional features removed, the irrigators in the Mimbres Valley should, under its provisions, form a ground-water district and file applications for the appropriation of ground water. The granting of such requests will give them definite water rights and will protect them in the use of such waters.

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[3] New Mexico State Legislature, 8th sess., ch. 182, H. B. 314, approved March 16, 1927.

[4] Yeo *v.* Tweedy and Yeo *v.* Pearson; Supreme court of New Mexico, January term, 1929.

WATER-POWER RESOURCES OF THE McKENZIE RIVER AND ITS TRIBUTARIES, OREGON

By BENJAMIN E. JONES and HAROLD T. STEARNS

SUMMARY

The McKenzie River is a valuable power stream from Clear Lake to Coburg Bridge, which is only 3 miles above its mouth. It has a large fall and well-sustained flow, but storage on the main stream would be expensive. On Olallie Creek, Lost Creek, Horse Creek to the mouth of Separation Creek, Separation Creek from its mouth to Mesa Creek, and the Roaring River, tributary to the South Fork of the McKenzie River, there are a number of power sites that can be economically developed when a market is available. The South Fork of the McKenzie River has some potential power, but it would be more expensive to develop than that on the other streams. The Blue River possesses no advantageous power sites, but a reservoir might be built on it to store water for use at sites on the McKenzie River. The Mohawk River has no power value.

Clear Lake is of little value as a reservoir because of leakage. Two proposed reservoir sites on the McKenzie River, the Paradise site and the Eugene municipal site No. 3, would have a total capacity of 197,000 acre-feet, of which 47,000 acre-feet would be required in the bottom of the reservoirs to create head, leaving a net capacity of 150,000 acre-feet. A proposed reservoir on the Blue River would have a total capacity of 59,000 acre-feet, and the Mesa site, at the head of Separation Creek, would have a capacity of 5,000 acre-feet.

Only one power site was being utilized at the time of the field examination in 1926. It is a plant with a net head of 45 feet and a capacity of 4,300 horsepower owned by the city of Eugene. A second plant for the city of Eugene is under construction near Leaburg. It will have an initial capacity of 10,000 horsepower and an ultimate capacity of 20,000 horsepower.

The water power of the McKenzie River is assumed to be capable of development at 16 sites, including the two being utilized by the city of Eugene. The potential power at these sites without storage is 207,000 horsepower for 90 per cent of the time and 327,000 horsepower for 50 per cent of the time. With storage at the four proposed reservoir sites the potential power is increased to 243,000 horsepower for 90 per cent of the time, with no change in the power available 50 per cent of the time.

The water power on tributaries of McKenzie River is assumed to be capable of development at 18 sites. The potential power at these sites without storage is 82,600 horsepower for 90 per cent of the time and 117,000 horsepower for 50 per cent of the time. As only 5,000 acre-feet of storage would be available on the tributaries, this would not appreciably affect the flow available 90 per cent of the time, although it would increase the power available 100 per cent of the time.

The total potential power of the McKenzie River Basin without storage is 290,000 horsepower for 90 per cent of the time and 444,000 horsepower for 50 per cent of the time. With storage at the four proposed reservoir sites the potential power for 90 per cent of the time would be increased to 325,000 horsepower, but the potential power for 50 per cent of the time would remain unchanged.

The following table summarizes the data regarding the two power sites developed by the city of Eugene and the proposed power sites in the McKenzie River Basin:

Water-power resources of the McKenzie River Basin

[Estimates of power based on static head and over-all plant efficiency of 70 per cent]

Index No.	Name of site	Stream	With existing flow					With regulated flow				
			Gross head (H) (feet)	Flow (second-feet)		Horsepower		Gross head (H) (feet)	Flow (second-feet)		Horsepower	
				90 per cent of time (Q90)	50 per cent of time (Q50)	0.08HQ90	0.08HQ50		90 per cent of time	50 per cent of time	0.08HQ90	0.08HQ50
12ND 1	Upper Falls	McKenzie River	250	242	340	4, 840	6, 800				4, 840	6, 800
12ND 2	Middle Falls	do	150	322	440	3, 860	5, 280				3, 860	5, 280
12ND 3	Lower Falls	do	270	480	660	10, 400	14, 200				10, 400	14, 200
12ND 4	Smith River	do	310	530	730	13, 100	18, 100				13, 100	18, 100
12ND 5	Deer Creek	do	170	820	1, 120	11, 100	15, 200				11, 100	15. 200
12ND 6	Belknap	do	300	870	1, 190	20, 900	28, 600				20, 900	28, 600
12ND 7	Paradise	do	145	1, 160	1, 590	13, 400	18, 400	111	1, 300	1, 590	11, 500	18. 400
12ND 8	McKenzie Bridge	do	225	1, 410	1, 940	25, 400	34, 900	225	1, 550	1, 940	27, 900	34, 900
12ND 9	Combination	do	140	1, 680	2, 290	18, 800	25, 600	140	1, 820	2, 290	20, 400	25, 600
12ND 10	Eugene municipal No. 3	do	170	1, 750	3, 150	23, 800	42, 800	138	2, 600	3, 150	28, 700	42, 800
12ND 11	Vida	do	100	1, 750	3, 150	14, 000	25, 200	100	2, 600	3, 150	20, 800	25, 200
12ND 12	Eugene municipal No. 2 [a]	do	90	1, 780	3, 350	12, 800	24, 100	90	2, 640	3, 350	19, 000	24, 100
12ND 13	Deerhorn	do	45	1, 790	3, 550	6, 440	12, 800	45	2, 650	3, 550	9, 540	12, 800
12ND 14	Eugene municipal No. 1 [b]	do	55	1, 790	3, 550	7, 880	15, 600	55	2, 650	3, 550	11, 600	15, 600
12ND 15	Hayden Bridge	do	90	1, 790	3, 500	12, 900	25, 200	90	2, 650	3, 500	19, 000	25, 200
12ND 16	Coburg	do	50	1, 810	3, 590	7, 440	14, 400	50	2, 670	3, 590	10, 700	14, 400
	Total McKenzie River					207, 060	327, 180				243, 340	327, 180
12ND 17	Olallie Creek	Olallie Creek	140	165	200	1, 850	2, 240				1, 850	2, 240
12ND 18	Lost Creek	Lost Creek	250	225	300	4, 500	6, 000				4, 500	6, 000
12ND 19–21	Horse Creek above Separation Creek.	Horse Creek				4, 000	8, 000				4, 000	8, 000
12ND 22	Foley Springs	do	280	275	400	6, 160	8, 960				6, 160	8, 960
12ND 23	Mouth of Horse Creek	do	300	280	410	6, 720	9, 840				6, 720	9, 840
12ND 24	Mesa Creek	Mesa Creek	1, 450	100	125	11, 600	14, 500	(c)	100	125	10, 400	13, 500
12ND 25	Harvey Creek	Harvey Creek	850	125	160	8, 500	10, 900				8, 500	10, 900
12ND 26	Rainbow Creek	Separation Creek	720	186	235	10, 700	13, 500				10, 700	13, 500
12ND 27	Elk Creek	South Fork McKenzie River	250	70	105	1, 400	2, 100				1, 400	2, 100
12ND 28	Augusta Creek	do	430	180	270	6, 200	9, 300				6, 200	9, 300
12ND 29	Hardy Creek	do	290	185	280	4, 300	6, 500				4, 300	6, 500
12ND 30	Slide Creek	do	220	185	285	3, 250	5, 000				3, 250	5, 000

12ND 31	East Fork	do	265	200	300	4,240	6,360	---	---	---	4,240	6,360
12ND 32	Cougar Creek	do	120	208	315	2,000	3,050	---	---	---	2,000	3,050
12ND 33	Roaring River	Roaring River	850	100	150	6,800	10,200	---	---	---	6,800	10,200
12ND 34	Blue River	Blue River	200	25	50	400	800	---	---	---	400	800
	Total tributaries	---	---	---	---	82,620	117,250	---	---	---	81,420	116,250

[a] Under construction. [b] Constructed. [c] Variable.

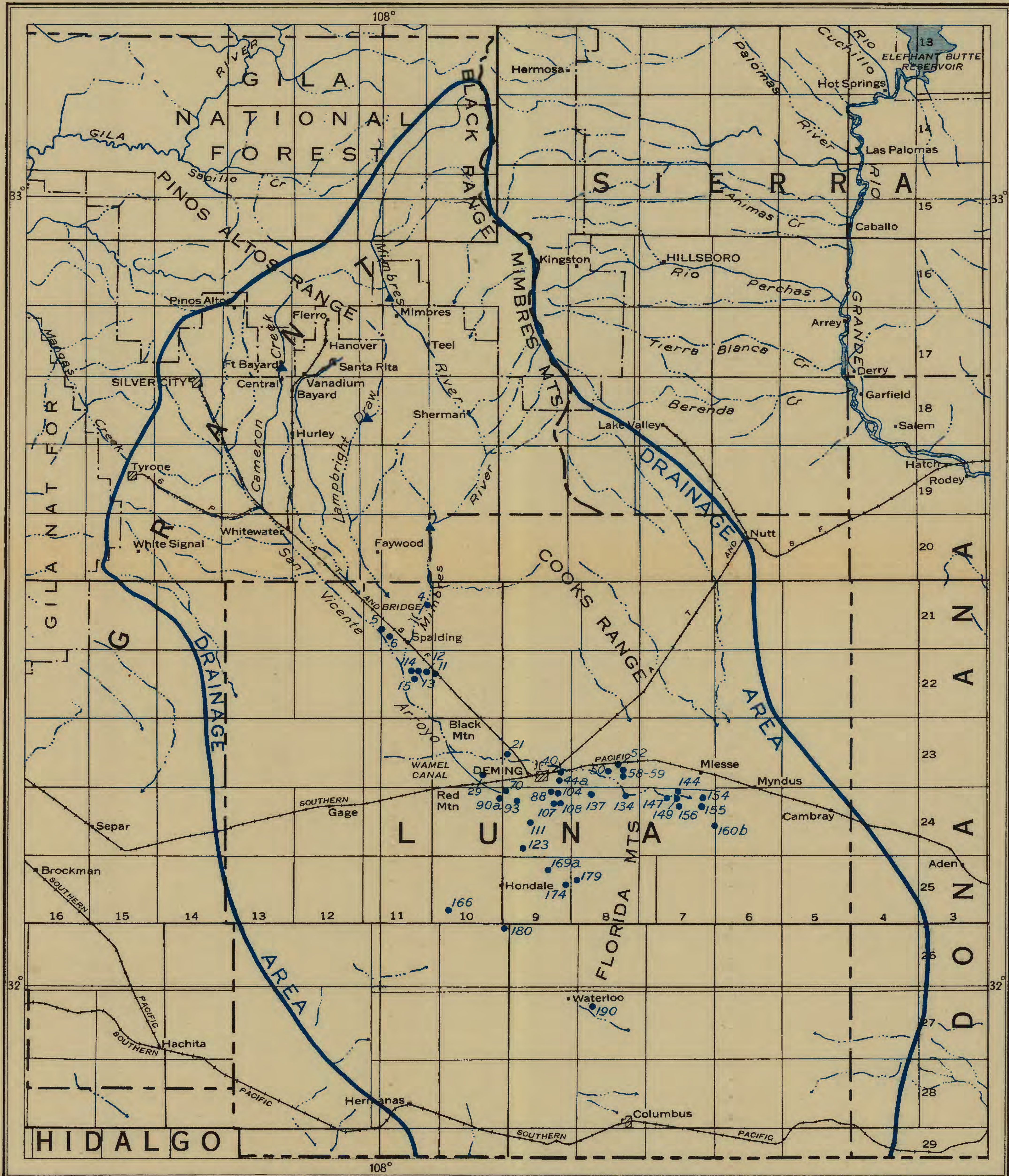
INTRODUCTION

This report is a study of the power resources of the McKenzie River and its tributaries, prepared primarily to determine the probable use of the public lands in the basin in connection with the utilization of the power resources. For this purpose it is not necessary to make detailed studies of individual sites or estimates of costs, but it is essential to formulate a general plan of development in order to determine the power available; and if the water supply, stream slope, and topography are such that the probable scheme of development can be determined with fair accuracy, a definite determination can be made as to the power value of individual tracts of public land. For that reason topographic maps of the main river were prepared and geologic examinations were made at three proposed dam sites. Gaging stations to determine the discharge of the rivers have been maintained at several points, which are listed elsewhere in this report. Many miscellaneous measurements of stream flow have been obtained, and three temporary gaging stations were maintained to determine the low-water flow on tributaries. A topographic survey of the McKenzie River, the South Fork of the McKenzie River to mile 18, the Blue River to mile 9, Horse Creek to mile 10, and Lost Creek to mile 4 was made in 1925 by C. W. H. Nessler, topographic engineer of the United States Geological Survey. Separation Creek, tributary to Horse Creek, from the mouth to a point 2 miles above Mesa Creek, and Mesa Creek from the mouth to a point 2 miles upstream, were surveyed in 1927 by R. O. Helland, land classifier. The geology of the Martins Rapids dam site, the Eugene municipal site No. 3, and the outlet of Clear Lake was examined by H. T. Stearns in 1926. A field examination of the river basin was made during the summer of 1926 by B. E. Jones. Previous reports on the water power of the McKenzie River by E. C. LaRue, hydraulic engineer, and the recommendations of F. F. Henshaw, district engineer, have been drawn upon in the preparation of this report.

All the data gathered in various ways by members of the Geological Survey have been combined and studied to determine a feasible method of developing the power resources of the basin.

GEOGRAPHY

The McKenzie River, tributary to the Willamette River at Eugene, Oreg., has a length of 86 miles from its mouth to the outlet of Clear Lake, its source, and the total drainage area above the gaging station at Hendricks Bridge is 1,100 square miles. The basin is narrow, and the upper section, above the Blue River (see pl. 2) is mountainous and heavily timbered, with little chance for future agricultural development. Even down as far as Leaburg there is little agriculture, and practically no water is diverted for irrigation. The river is largely



MAP OF MIMBRES VALLEY, NEW MEXICO, AND TRIBUTARY DRAINAGE AREA

Scale $\frac{1}{500,000}$

10 0 10 20 Miles

1930

▲ Gaging station

107 ● Observation well. Number referred to in text

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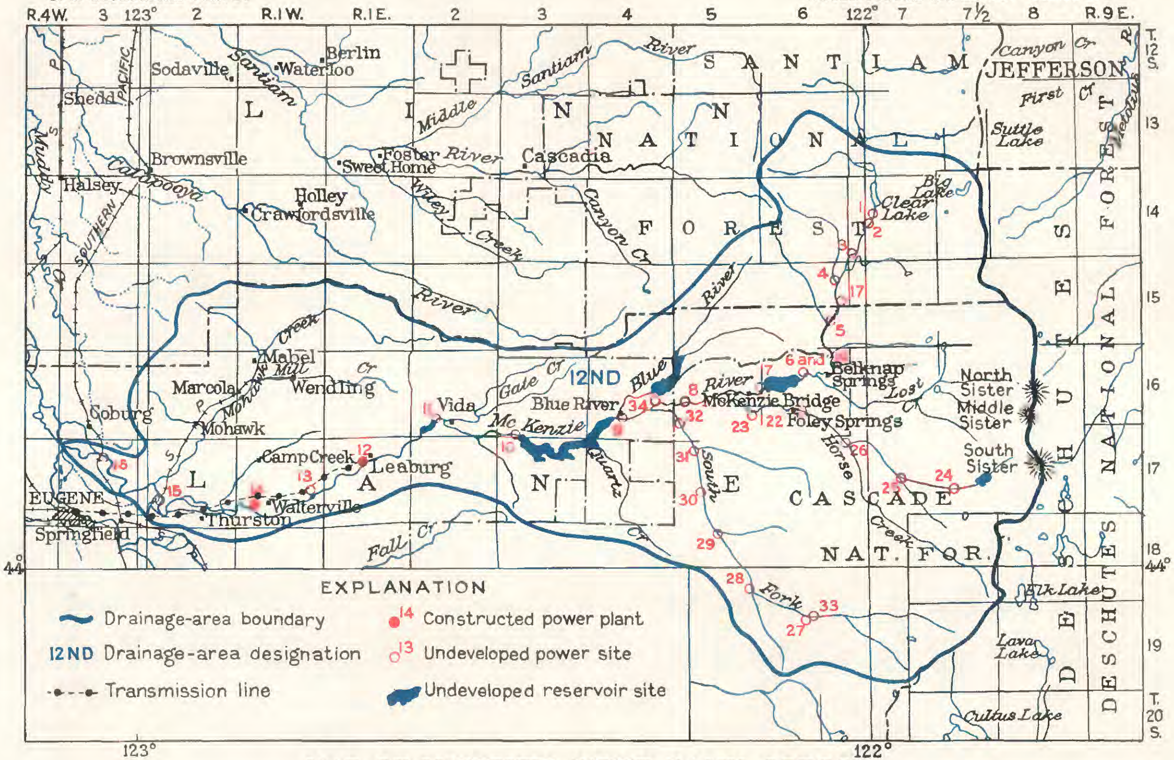


MAP OF McKENZIE RIVER BASIN, OREGON

5 0 10 20 Miles

1930

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

spring-fed near its source; it has a large flow during the low-water season and considerable power possibilities. Power from this stream now supplies the city of Eugene and could be transmitted to Portland, which is 124 miles north by State highway. The Middle Fork of the Willamette River flows to the south of the McKenzie, and the Santiam River to the north. Plate 2 shows the relative location of the basin and is an index to the location of the power sites, which are numbered 1, 2, etc. The drainage-area designation is 12ND, the number 12 designating the North Pacific slope drainage area, 12N the Willamette River Basin, and 12ND the McKenzie River Basin.

Clear Lake is fed by a large spring near its head and other springs in its bottom. Above Clear Lake there is, during the rainy season, a shallow lake called Fish Lake, into which some small creeks flow and which in turn drains into Clear Lake. A mile below the outlet of Clear Lake are the Upper Falls, with a drop of 120 feet, and a quarter of a mile farther down are the Middle Falls, with a drop of 70 feet. In the 3-mile stretch between the Middle Falls and the Lower Falls the flow of the river is largely subterranean; during the summer the bed is dry for a long distance above the Lower Falls, but the stream reappears, apparently in full volume, in a pool below the falls. About 9 miles below Clear Lake Olallie Creek, a short spring-fed stream, discharges more than 100 second-feet at low stages into the McKenzie River. Other spring-fed tributaries are Horse Creek and the South Fork of the McKenzie. The Blue River is not spring-fed and has a low flow during the summer. The low-water flow of Horse Creek comes mostly from Separation Creek, which rises on the edge of the Three Sisters and has a fall of 3,360 feet in a little over 12 miles. The South Fork of the McKenzie River has a well-sustained flow and sufficient fall to make it a valuable power stream. Plate 3 shows a profile of the McKenzie River and its principal tributaries.

GEOLOGY

A brief summary of the principal events in the geologic history of western Oregon and of the areal distribution of the chief formations is desirable as a setting for a description of the geology of the reservoirs and dam sites.

Little is known of the geologic history of this region before Cretaceous time, for the earlier sediments have been completely metamorphosed to schist, slate, and serpentine. These rocks are exposed along the lower part of the Rogue River in Jackson, Josephine, and Curry Counties.

The Cretaceous period was ushered in with great intrusions of granodiorite and other igneous rocks and with extensive movements of the crust. During this period the northern and central parts of western Oregon lay below sea level and received sedimentary deposits, which were later consolidated to conglomerate, shale, and sandstone. These beds were subjected to considerable folding, which has altered their original character and tilted them at steep angles. Many of the rugged canyons and consequently the sites of dams and reservoirs are in the intrusive rocks of this period. In general these intrusive rocks form excellent sites, from the point of view of both the geologist and the engineer, and they are as a whole better than the sites in any of the later formations. The granodiorite, diabase, and other intrusive rocks of this period cooled under the weight of overlying sedimentary deposits and consequently do not have the porous structure and leaky contacts and joints that characterize so many of the later, extrusive rocks. Moreover, in crushing strength most of the intrusive rocks are equal to granite, and all are sufficiently strong to support large structures.

The chief event during the Tertiary period was the building of the Cascade Range by uplift and volcanic action. In the early part of the period extensive beds of sandstone and conglomerate were deposited in marine waters, and thick dikes and sills of basaltic lava were intruded into the sediments. The sites located in the sedimentary rocks of this period are generally good, although there may be a slight leakage along bedding planes. During the later half of Tertiary time marine deposition continued over northwestern Oregon, interrupted by occasional epochs of uplift. The late Tertiary and the succeeding Pleistocene witnessed great volcanic activity. Enormous volcanoes along the Cascade Range poured forth thick lava flows and emitted showers of pumice. Many of the lava flows coursed down river valleys and partly filled them. Since that time the rivers have excavated portions of these lava fills and formed narrow canyons with vertical walls of lava. Most of this rock is fractured and fissured, and much of it covers ancient gravel beds, through which impounded water might escape rapidly. Although some of these canyons in lava offer excellent dam sites so far as purely physical form is concerned, such places are treacherous for storing water, because of probable leakage. Late Tertiary pumice deposits cover wide areas, especially in the vicinity of Crater Lake, and form a thick flow in the Rogue River Valley. The misplaced drainage and concealed channels caused by this volcanism make reservoir sites in these deposits hazardous.

During Pleistocene time the high peaks of the Cascade Range were covered with glaciers, which moved down the valleys of most of the larger streams. While these glaciers existed the master streams were heavily loaded with débris and aggraded their valleys. Later erosion excavated valleys in the glacial gravel, leaving the remnants of the fill as terraces. Dam sites located in this material are poor because of the amount of excavation necessary to reach bedrock.

CLIMATE

The climate of the McKenzie River Basin is mild, the temperature seldom dropping below the freezing point for any long period. Even in the upper part of the basin the winters are not severe, though there is considerable snow.

Above Vida the mean annual rainfall ranges between 70 and 100 inches; below Vida it decreases rapidly to 38.5 inches at Eugene. In all of western Oregon there is heavy precipitation during the winter and spring but very little in the summer and early fall. The flow of the McKenzie River is sustained during this period of low precipitation by the discharge of large springs, as well as by some water coming from the melting glaciers on the Three Sisters.

Mean temperature (°F.) in the McKenzie River Basin

Month	Eugene	McKenzie Bridge		Month	Eugene	McKenzie Bridge	
		Mean	Mean minimum, 1902–1908			Mean	Mean minimum, 1902–1908
January	40.3	35.4	0	September	60.3	57.0	22
February	42.8	39.0	8	October	53.2	51.6	24
March	45.8	43.2	10	November	46.3	42.5	19
April	50.5	49.0	22	December	40.9	36.3	12
May	55.2	54.0	25				
June	60.2	58.7	33	Yearly mean	52.2	49.5	
July	65.8	64.8	29	Altitude (feet)	450	1,375	1,375
August	65.6	63.0	32				

Mean monthly and yearly precipitation, in inches, in the McKenzie River Basin

Month	Eugene, 1908–1923	Vida, 1913–1916	McKenzie Bridge, 1902–1913	Month	Eugene, 1908–1923	Vida, 1913–1916	McKenzie Bridge, 1902–1913
January	5.65	10.16	10.30	September	2.08	3.36	2.81
February	4.25	7.19	8.65	October	2.68	4.54	5.66
March	3.59	8.85	6.82	November	6.31	11.34	12.25
April	2.45	4.84	4.05	December	5.19	7.00	10.13
May	2.38	5.09	4.49				
June	1.65	4.23	2.76	Yearly mean	37.15	68.86	70.08
July	.53	1.80	1.13	Altitude (feet)	450	780	1,375
August	.39	.46	1.03				

FACTORS AFFECTING HYDRAULIC STRUCTURES

The little ice that forms on the streams in the McKenzie River Basin would not cause much trouble in the operation of power plants. The rivers carry practically no silt except during floods, and floating débris could be removed at the dams.

Irrigation does not appreciably affect the flow of the McKenzie River. In the upper section there is little cultivable land, and even in the lower stretches, where the valley is wider, little effort is made to divert water for irrigation. Water is diverted for municipal purposes by the city of Eugene, but this is well down toward the mouth of the river. There is no navigation on the McKenzie River, and the Willamette River, to which it is tributary, is navigable only as far up as Oregon City.

ANNUAL YIELD AND MINIMUM FLOW

The estimates of power available at different sites are based on the normal flow of the stream for 50 per cent and 90 per cent of the time (expressed as Q50 and Q90). The principal gaging stations on whose records the estimates are based are at the outlet of Clear Lake, at McKenzie Bridge, at Vida, and at Hendricks Bridge, above Springfield. (See fig. 1.) Miscellaneous discharge records on

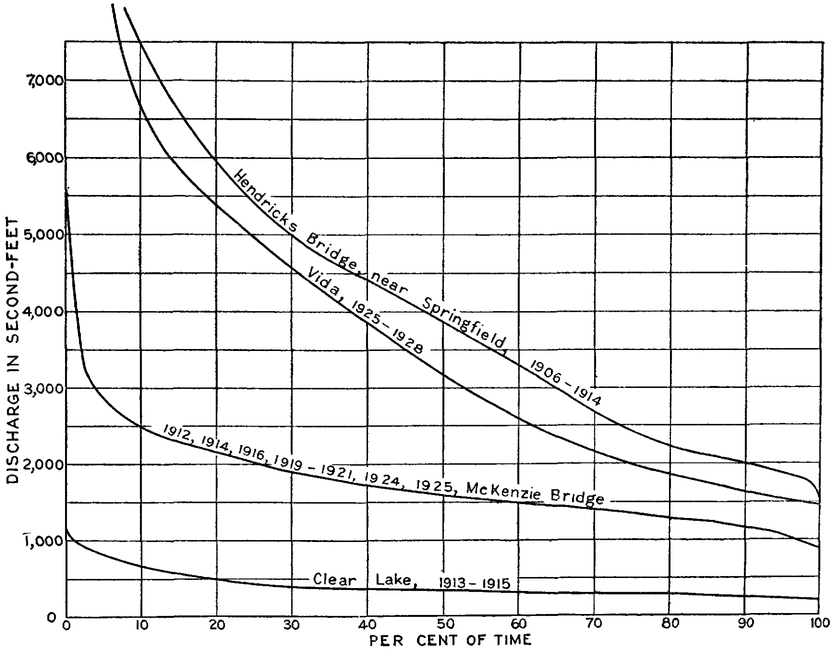


FIGURE 1.—Curves showing relation of discharge in McKenzie River Basin, Oreg., to per cent of time

Olallie Creek are available, and some short summer records were collected in 1926 on Horse Creek and Lost Creek, and in 1927 on the South Fork of the McKenzie River.

The minimum recorded discharge at McKenzie Bridge was 890 second-feet in October, 1924. The minimum daily discharge for the year ending September 30, 1926, was 934 second-feet in September. In the years of record prior to 1924 the minimum discharge was 924 second-feet in October and November, 1915. The minimum discharge in August and September, 1926, at Vida was 1,430 second-feet, as compared with a minimum of 1,420 second-feet in September, 1914, at Hendricks Bridge. The flow in 1926 was in general the lowest of record in western Oregon, and yet the minimum flow of the McKenzie River was not as low as would be expected by comparison with other streams. The minimum flow of the Umpqua River at Elkton was 1,040 second-feet in September, 1914, and 670 second-feet in September, 1926. The McKenzie River, therefore, ranks close to the Deschutes and Klamath Rivers in having a well-sustained low-water flow—a valuable asset in the utilization of water power. The mean annual discharge at McKenzie Bridge for the year ending September 30, 1924, was 1,540 second-feet, as compared with 1,570 second-feet for the year ending September 30, 1920. It seems probable that the glaciers on the Three Sisters supplied enough additional water during the hot, dry seasons of 1924 and 1926 to offset the deficiency in stream flow caused by low precipitation.

In spite of the well-sustained low-water flow the discharge of the lower McKenzie varies considerably from year to year, depending on the rainfall. For this reason it is necessary to make some allowance in the Q50 and Q90 discharge for the period covered by the record. Thus the Q90 discharge at Hendricks Bridge for the years 1906 to 1914 was 2,010 second-feet, while the Q90 flow at Vida, a short distance upstream, with no large tributaries entering between, for the years 1925 to 1928 was 1,650 second-feet. In 1906 to 1914 the annual precipitation was above the average, whereas in 1926 the precipitation was the lowest of record. The Q90 discharge for 1925, 1927, and 1928 at Vida was 1,800 second-feet. This is probably a fair estimate of the Q90 flow for a long period, but it has been reduced to 1,750 second-feet in estimating potential power at sites in the vicinity of Vida. The Q50 discharge for 1925, 1927, and 1928 at Vida was 3,400 second-feet as compared with 3,150 second-feet for the four years 1925 to 1928.

The Q90 discharge at Hendricks Bridge has been arbitrarily reduced from 2,010 second-feet for the period of record to 1,800 second-feet, which seems the more probable average for a long period and agrees with the estimate of the flow at Vida. The Q50 discharges at Vida and Hendricks Bridge agree fairly well, and the figures obtained from the records available have been retained.

Records on Horse Creek at the bridge 3 miles above the mouth for July, August, and September, 1926, indicate a Q90 discharge of 250 second-feet during that year of low flow. The flow of Separation Creek, tributary to Horse Creek, was 100 second-feet greater on July 25, 1927, in a wet year, than on September 9, 1926. On the basis of these short records, the Q90 flow of Horse Creek at the bridge has been estimated at 280 second-feet.

Records are available on Lost Creek near the mouth for the months of July to November, 1926. These records indicate a Q90 discharge for that very dry season of 173 second-feet, but on the basis of the records at McKenzie Bridge the Q90 flow of Lost Creek has been estimated at 225 second-feet and the Q50 flow at 300 second-feet.

A number of discharge measurements were obtained on the South Fork of the McKenzie River during 1926 and 1927 which indicate a Q90 flow below the East Fork of 195 second-feet in 1926 and 245 second-feet in 1927, or, roughly, a mean of 220 second-feet.

Gaging stations maintained on McKenzie River

Outlet of Clear Lake	June, 1912, to July, 1915.
Hendricks Bridge, in sec. 32, T. 17 S., R. 1 W.	September, 1905, to March, 1915.
Near Springfield	August and September, 1926.
McKenzie Bridge	October, 1910, to September, 1914; April, 1915, to September, 1916; April to December, 1917; March, 1918, to October, 1921; May to December, 1922; April, 1923, to December, 1925; May, 1926, to date.
Above Vida, in NE. ¼ sec. 5, T. 17 S., R. 3 E.	October, 1924, to date.

The records of daily discharge obtained at these stations up to 1923 are published in United States Geological Survey Water-Supply Papers 178, 214, 252, 272, 292, 312, 332, 362, 394, 414, 444, 464, 484, 514, 534, 554, 574, and 594. Water-Supply Paper 370 contains all records to and including 1910. Bulletins 4 and 7 of the State engineer of Oregon, compiled in cooperation with the United States Geological Survey and entitled "Water resources of the State of Oregon," contain monthly summaries of discharge data through 1924.

Monthly discharge of Horse Creek at bridge 3 miles above the mouth in 1926

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
June 25–30	304	300	302	3,600
July	288	256	273	16,800
August	253	240	250	15,400
September	383	235	281	16,700

Monthly discharge of Lost Creek at bridge near the mouth in 1926

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
June 26–30	235	227	231	2,290
July	238	204	226	13,900
August	214	186	200	12,300
September	199	163	180	10,700
October	193	163	171	10,500
November 1–27	257	170	200	10,700

Miscellaneous discharge measurements in the McKenzie River Basin

Date	Stream	Tributary to—	Locality	Discharge
				Sec.-ft.
Aug. 8, 1924	McKenzie River	Willamette River	Trail Bridge, ½ mile below outlet of Clear Lake, in NE. ¼ sec. 17, T. 14 S., R. 7 E.	172
Sept. 12, 1913	do	do	1½ miles below Clear Lake, below Middle Falls, in sec. 20, T. 14 S., R. 7 E.	642
Oct. 20, 1913	do	do	do	686
Aug. 30, 1926	do	do	Hendricks Bridge [a]	711
Sept. 23, 1926	do	do	do	1,040
Aug. 26, 1912	Smith River	McKenzie River	At mouth, in sec. 11, T. 15 S., R. 6 E.	21
June 26, 1913	do	do	do	154
July 21, 1926	Anderson Creek	do	1 mile above trail crossing	22
Do	do	do	At trail crossing	15
Apr. 30, 1924	Olallie Creek	do	600 feet above mouth, in SW. ¼ sec. 12, T. 15 S., R. 6 E.	200
May 13, 1924	do	do	do	165
Aug. 12, 1924	do	do	do	197
July 20, 1926	do	do	do	135
Sept. 6, 1926	do	do	do	140
Aug. 30, 1912	Deer Creek	do	At mouth, in sec. 26, T. 15 S., R. 6 E.	20
Sept. 11, 1912	Lost Creek	do	Just above lake	57
Sept. 12, 1912	do	do	Sec. 13, T. 16 S., R. 6 E.	243
Oct. 10, 1910	do	do	Bridge in NE. ¼ sec. 15, T. 16 S., R. 6 E., near McKenzie Bridge.	206
Mar. 11, 1911	do	do	do	191
July 20, 1911	do	do	do	339
Nov. 18, 1911	do	do	do	259
Sept. 26, 1915	do	do	do	184
June 30, 1926	do	do	do	220
Aug. 9, 1926	do	do	do	175
Sept. 6, 1926	do	do	do	172
Sept. 22, 1926	do	do	do	166
Sept. 10, 1912	White Branch	Lost Creek	Foot of glacier	2
Aug. 28, 1926	Horse Creek	McKenzie River	Above Separation Creek	25
Aug. 8, 1910	do	do	1 mile south of McKenzie Bridge, in sec. 24, T. 16 S., R. 5 E.	285
Oct. 11, 1910	do	do	do	319
Dec. 18, 1910	do	do	do	526
Mar. 9, 1911	do	do	do	425
May 5, 1911	do	do	do	686
July 19, 1911	do	do	do	354
Aug. 1, 1911	do	do	do	[b] 306
Aug. 3, 1911	do	do	do	302
Aug. 18, 1911	do	do	do	294
Aug. 23, 1911	do	do	do	270
Aug. 31, 1911	do	do	do	270
Sept. 9, 1911	do	do	do	306
Sept 23, 1911	do	do	do	274
Nov. 20, 1911	do	do	do	642
Sept. 25, 1915	do	do	do	245
May 24, 1921	do	do	do	974
Sept. 16, 1921	do	do	do	327
Aug. 13, 1923	do	do	do	642
Aug. 13, 1924	do	do	do	265
June 30, 1926	do	do	do	302
Aug. 9, 1926	do	do	do	247
Sept. 22, 1926	do	do	do	300
July 20, 1927	Separation Creek	Horse Creek	12¼ miles above mouth, at altitude of 5,300 feet.	66
July 12, 1927	do	do	Above mouth of Mesa Creek	76
July 20, 1927	do	do	do	79
Sept. 9, 1926	do	do	At mouth of Separation Creek	206
July 25, 1927	do	do	do	308
July 12, 1927	Mesa Creek	Separation Creek	1 mile above mouth of Separation Creek.	51
Do	Tributary of Mesa Creek.	Mesa Creek	At mouth of Mesa Creek	19
Sept. 15, 1926	Louisa Creek	Separation Creek	One-half mile above mouth of Separation Creek.	26
July 26, 1927	do	do	Altitude, 3,100 feet	23
Do	do	do	At mouth of Separation Creek	35
Do	Rainbow Creek	do	Above falls	25
Sept. 15, 1926	do	do	At mouth	13
July 26, 1927	do	do	do	25
July 28, 1927	South Fork of McKenzie River.	McKenzie River	Below Elk Creek	76
July 23, 1926	do	do	One-quarter mile below Augusta Creek.	168

[a] Does not include diversion to Eugene power plant.
[b] Discharge estimated from gage reading.

Miscellaneous discharge measurements in the McKenzie River Basin—Continued

Date	Stream	Tributary to—	Locality	Discharge
				Sec.-ft.
June 16, 1926	South Fork of McKenzie River.	McKenzie River	Above East Fork	228
Aug. 8, 1926	do	do	do	185
Sept. 22, 1926	do	do	do	225
July 27, 1927	do	do	do	253
Aug. 20, 1927	do	do	do	246
Sept. 15, 1927	do	do	do	298
Sept. 3, 1912	do	do	Sec. 5, T. 17 S. R., 5 E	114
July 29, 1927	Roaring River	do	At mouth	126
June 29, 1926	South Fork of McKenzie River.	do	Near mouth	219
June 16, 1926	East Fork of South Fork.	do	At mouth	10.6
Aug. 8, 1926	do	do	do	1.7
Sept. 22, 1926	do	do	do	11.5
June 17, 1926	Blue River	do	do	50
Aug. 8, 1926	do	do	do	16

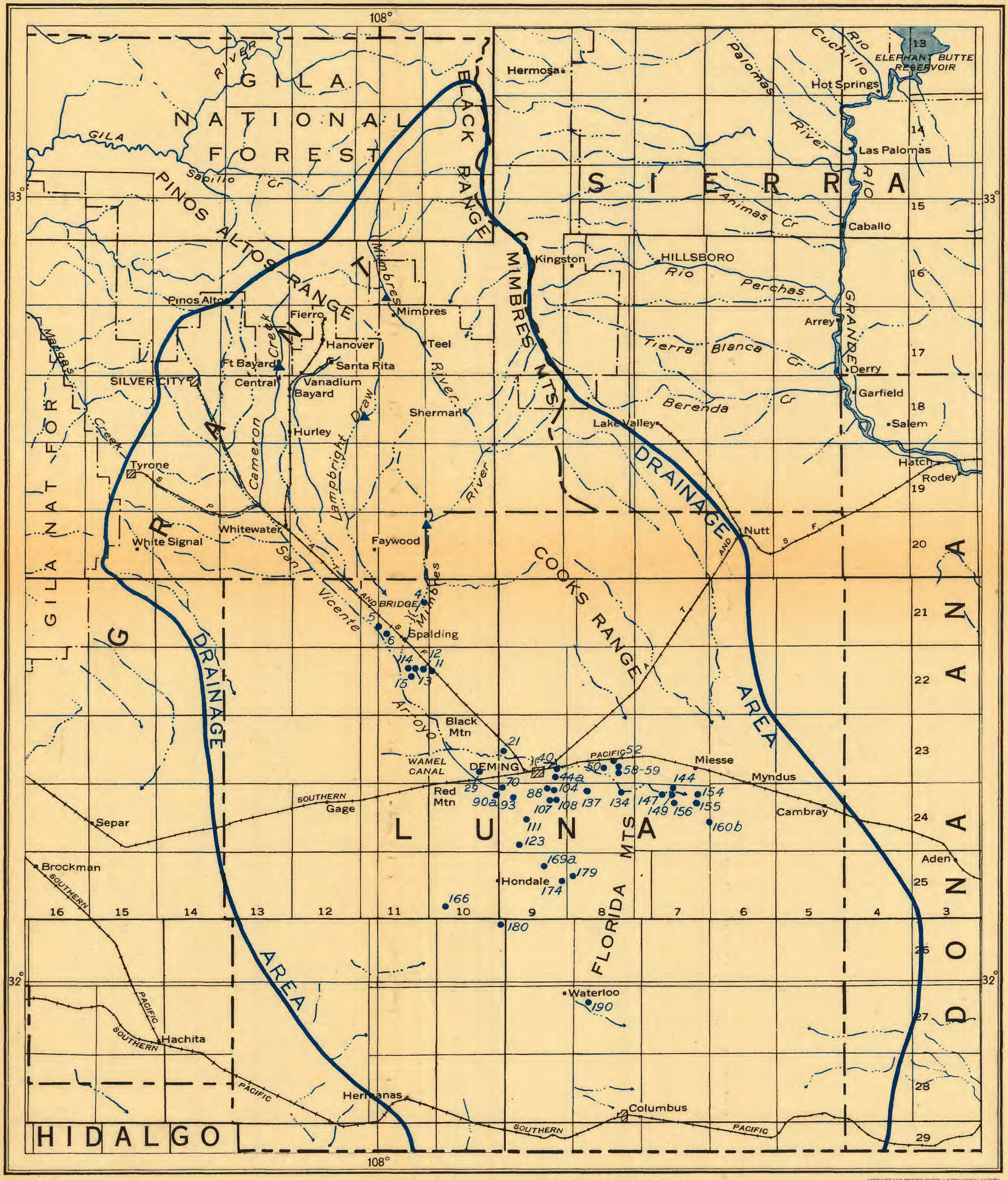
MAGNITUDE, DURATION, AND FREQUENCY OF FLOODS

The McKenzie River Valley is narrow and wooded, and both the tributaries and the main stream have a considerable fall. The soil of the basin is very porous, and a large part of the precipitation sinks into the ground. All these factors tend to reduce the flood flow, and at points above McKenzie Bridge the flood flows are small. The maximum recorded daily discharge at McKenzie Bridge was 8,600 second-feet in December, 1920. Probably the peak flow was 10,000 second-feet. At the gaging station at Hendricks Bridge, near Springfield, the maximum recorded discharge was 37,900 second-feet in February, 1907. At the time of the floods in the Umpqua River Basin, in November, 1909, the discharge at Hendricks Bridge reached a maximum of 35,400 second-feet.

On the headwaters of the McKenzie the ground is pervious and would absorb a large amount of precipitation, and in the glacial area of the Three Sisters freezing temperatures occur at night during the months when flood discharges can be expected. The maximum recorded flow for 24 hours at Hendricks Bridge was 37,900 second-feet and at McKenzie Bridge 8,600 second-feet. Probably at Hendricks Bridge the peak flow was several thousand second-feet higher than the 24-hour flow, but at McKenzie Bridge the peak was probably not much greater than the 24-hour flow.

PRIOR WATER RIGHTS

Diversions for irrigation are not sufficient to have an appreciable effect on the flow of the McKenzie River. The city of Eugene diverts about 1,000 second-feet in the SE. ¼ sec. 23, T. 17 S., R. 1 W., for its municipal power plant No. 1 (12ND 14) and this water is returned to the river in sec. 25, T. 17 S., R. 2 W. The city probably has a right to the entire flow of the river through this section. The Eugene municipal power plant No. 2 (12ND 12), which is being constructed farther upstream, near Leaburg, will divert water in sec. 31, T. 16 S., R. 2 E., and return it to the river in sec. 9, T. 17 S., R. 1 E.



MAP OF MIMBRES VALLEY, NEW MEXICO, AND TRIBUTARY DRAINAGE AREA

▲ Gaging station

107 ● Observation well. Number referred to in text

Scale $\frac{1}{500,000}$

10 0 10 20 Miles

1930

A. CLEAR LAKE, McKENZIE RIVER BASIN, FROM OUTLET

B. POOL BELOW LOWER FALLS OF THE McKENZIE RIVER
Dry falls in background, with springs issuing from their base.

C. DRY BED OF THE McKENZIE RIVER A QUARTER OF A MILE ABOVE LOWER FALLS

PROFILE OF THE McKENZIE RIVER, OREG., AND ITS TRIBUTARIES, FROM CLEAR LAKE TO WILLAMETTE RIVER

Shows the South Fork of the McKenzie River to mile 18, the Blue River to mile 9, Horse Creek to mile 10, Lost Creek to mile 4, Separation Creek to mile 12, and Mesa Creek to mile 1. The numbers indicate the location of proposed and constructed power projects. No. 14 is the Eugene municipal power plant No. 1.

A. MIDDLE FALLS, McKENZIE RIVER

All this water sinks into the ground a short distance downstream and rises in a pool below Lower Falls.

B. ANCIENT TREE TRUNK PRESERVED IN THE WATER OF CLEAR LAKE

The tree grew before the lava flow dammed the valley and formed Clear Lake.

A. UPPER FALLS, McKENZIE RIVER

B. CASCADES BELOW UPPER FALLS

Falls in background.

These plants are not provided with storage. The 20-foot diversion dam at the upper site will provide some pondage, and at the lower plant some extra water can be obtained for a short period by drawing down the canal. It is possible that the total pondage would amount to half of the daily discharge during the low-water months, permitting the plants to use all the water when operating on a 50 per cent load factor. The city of Eugene also diverts water from the McKenzie River for municipal purposes, but this diversion is so near the mouth that it will not interfere with water-power development.

RECREATIONAL USE

The McKenzie River is paralleled by a highway from its mouth to Lost Creek and has been extensively advertised by the city of Eugene as a recreational area. Hotels are located at natural hot springs and at other points in the valley, and there are a number of summer homes along the river. The city plans to allow 300 second-feet to flow continuously in the river channel to preserve the natural charm and for fishing. Clear Lake also provides good fishing and boating, and there are ideal camping sites along its shores. (See pl. 4, *A*.)

Development of the power resources of the river under proper safeguards need not interfere with a large recreational use of the river as well as the lake. The Upper Falls, below Clear Lake, present a beautiful scenic effect (see pl. 5), and it seems fitting that they should not be marred by the development of power but be preserved in their natural state. However, in the opinion of the writers the Middle and Lower Falls are less beautiful—in fact, the Lower Falls are dry for a large part of the year, because the water flows beneath the surface. (See pls. 4, *B*, *C*, and 6, *A*.) By diversion farther upstream the head at the Lower Falls could be used for power, or the drop at both the Middle and Lower Falls might well be so used.

RIVER CONTROL

The flow of the McKenzie River is very effectively controlled by ground storage in the area above McKenzie Bridge and by the snow and glaciers on the Three Sisters. The effect of this storage is evident in the well-sustained flow during the summer at McKenzie Bridge and Vida.

There are no large reservoir sites in the basin. The lakes are of little value for storage. Clear Lake is caused by a lava flow which dammed the old river valley, and at all stages there is a considerable leakage from the lake through or around this lava dam. Horse Lake, at the head of Horse Creek, is small and has only a few square miles of drainage area. Considerable storage could be developed by constructing dams on the main stream, the principal obstacle being the cost of the land and improvements that would be flooded. A small amount of storage could be obtained on the South Fork of the McKenzie River, but it would be expensive because of the steep slope of the valley. A reservoir could be constructed on the Blue River, but it would require two dams of considerable length, and the capacity would not be great; with a very large demand for power storage at this site might prove feasible. On account of the well-sustained flow due to ground storage, however, reservoirs are not so necessary as on some other rivers, and, because of this fact and the large uniform fall, power will be developed mostly by low dams and conduits. Some storage can be obtained on the main stream by drawing down the head above proposed dams, but the net gain in power will not be very great.

In the main, power developed on the McKenzie River will be dependent on the natural flow and will require interconnection with other water-power systems or steam stations to obtain the most effective and most economical results.

STORAGE SITES

There are no developed storage sites in the McKenzie River Basin. No reservoir sites capable of development for storage only were found on the McKenzie River itself. Some storage can be developed by drawing down the head at the Paradise site (12ND 7) and the Eugene municipal site No. 3 (12ND 10), on the McKenzie River, and at the Mesa Creek site (12ND 24), on Separation Creek, but as it is assumed that these sites are of value primarily for power, the storage is discussed in connection with the power. (See pp. 111, 113, 119.) The only site proposed to be developed primarily for storage is on the Blue River (12ND 34). In estimating the potential power with storage it was assumed that regulation will be provided to give a uniform flow. This plan would give the best results for the river as a whole, but if a single plant were concerned the storage would probably be used to give a uniform power output. The capacity of the proposed storage sites is given in the table below. Further description is given under the individual sites.

Capacity of reservoir sites in the McKenzie River Basin

Name	Stream	Location of dam	Net capacity		
			Acre-feet	Millions of kilowatt-hours	
				At site	At all sites
Paradise	McKenzie River	Sec. 18, T. 16 S., R. 6 E.	60,000	−3½	+36
Eugene municipal No. 3	do	Sec. 32, T. 16 S., R. 3 E.	90,000	−1	+27
Blue River	Blue River	Sec. 14, T. 16 S., R. 4 E.	59,000	+5½	+35
Mesa	Separation Creek	Above Mesa Creek	5,350	+4	+16
			214,350		+114

CLEAR LAKE RESERVOIR SITE

The location of Clear Lake at the head of the McKenzie suggests that it might be a reservoir site, but owing to the nature of the rock formations at the outlet it is extremely doubtful if the lake could be made to hold any large amount of water, and therefore it has not been considered in this report a potential reservoir.

Clear Lake (see pl. 4, *A*) lies in secs. 5 and 8, T. 14 S., R. 7 E. It is about one-third of a mile wide and 1¼ miles long and occupies a narrow valley. The west shore is a relatively steep soil-covered slope supporting a growth of large firs and pines. The east shore rises gently, and much of it consists of rough, clinkery aa lava, in places nearly barren of vegetation. About 200 feet from the northeast shore of the lake, Great Spring issues quietly in a pool of green water with a temperature of 39°. It discharges about 20 second-feet of water, which flows westward into the lake.

In September, 1926, Ikinick Creek was discharging less than 1 second-foot of water into the northwest corner of the lake. During wet weather Fish Lake becomes the head of the McKenzie River and overflows into Clear Lake, but in September, 1926, it was practically dry and no water was flowing in its outlet channel. A measurement at the outlet of Clear Lake on August 8, 1924, showed a discharge of 172 second-feet, and doubtless the inflow at that time did not exceed 25 second-feet, so that 147 second-feet is left to be accounted for. This water rises in the bottom of the lake.

The dam site at Clear Lake is in the NE. ¼ NE. ¼ sec. 17, near the outlet, and its west abutment is composed of loose blocks of basalt of an aa lava flow. Pine trees 3 feet in diameter grow on the surface of the lava flow, indicating that it is fairly ancient. This lava flow dammed the McKenzie River, producing the lake. A submerged upright forest is visible in the shallow northern part of the lake. This forest was growing on the river bank at the time the lava dammed the valley, and the trees, being submerged, have been preserved. (See pl. 6, *B*.)

An investigation of the southeast shore of the lake revealed a curious condition. Attention was attracted to this part of the shore by great quantities of driftwood. Because the wind does not usually blow from the northwest at this place, it was concluded that the driftwood was carried there by a current. A muddy channel 30 feet wide filled with driftwood was found leading away from the lake shore at this place. It is evident that during wet weather this entire channel is submerged. In the first 200 feet the channel is filled with numerous small springs, which had a temperature of 40° F. and a combined discharge of about 8 second-feet. About 300 feet from the shore the channel ends abruptly against the end of the aa lava that formed the dam to the lake. At this place the entire flow of the springs cascades into a sinkhole 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 occur near by. These holes apparently receive water during high stages of the lake.

On September 12, 1913, according to the daily discharge records,[1] the flow at the outlet of Clear Lake was 319 second-feet. On the same day a measurement of the McKenzie River 1½ miles below Clear Lake and below the 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 day 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 from the river bed. Most of this inflow is believed to be leakage from Clear Lake that finds its way underground through the natural lava dam at its outlet.

[1] U. S. Geol. Survey Water-Supply Paper 362, p. 659, 1915.

It is evident that a dam at the proposed site would fail to impound the water, because of leakage through the lava flows at the south end of the lake. The history of many other lakes in Oregon formed by lava flows shows that it is impossible to store water in them.

FOLEY RIDGE RESERVOIR SITE

A dam 150 feet high at mile 69.3, at the point where the Foley Ridge Trail intercepts the McKenzie Highway, would create a reservoir with a capacity of 35,000 acre-feet, of which 27,000 acre-feet would be in the upper 60 feet. An earth dam at this site 150 feet high would contain about 3,000,000 cubic yards of material. The water from the reservoir could be dropped through penstocks to a power house on the north side of the McKenzie River and be discharged into a canal leading to a power house at the mouth of the Blue River. If the upper 60 feet were used for storage, the stored water would generate 24,000,000 kilowatt-hours at all proposed sites on the McKenzie River, but if the period of drawdown were to cover four months the loss of power due to loss of head would

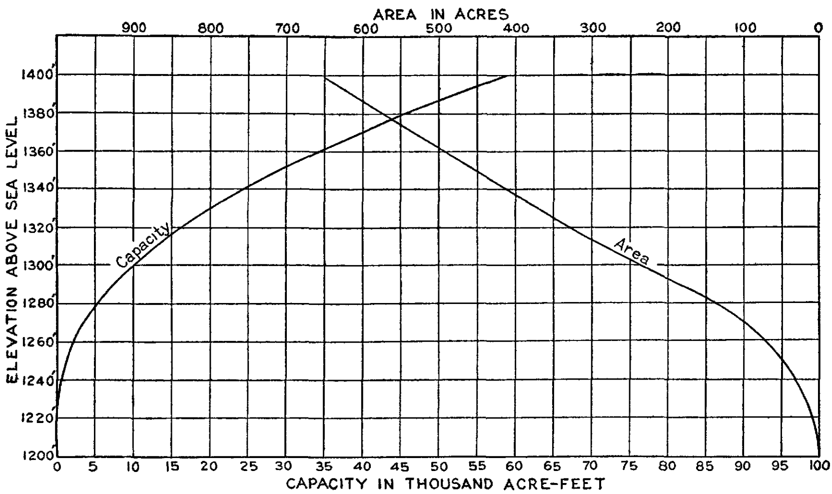


FIGURE 2.—Area and capacity curves, Blue River reservoir site, McKenzie River Basin

amount to 5,000,000 kilowatt-hours, leaving a net development of 19,000,000 kilowatt-hours. The cost of developing the head by a dam would be much greater than by a tunnel, such as that proposed for the Belknap project (12ND 6). In addition to the greater cost of a dam, which might be justified, there is serious question as to whether the geologic conditions are such that the reservoir would hold water. There would also be much opposition to the flooding of Belknap Hot Springs. In view of all these adverse conditions, this site is considered impracticable.

BLUE RIVER RESERVOIR SITE (12ND 34)

A dam 200 feet high on the Blue River in the NW. ¼ sec. 14, T. 16 S., R. 4 E., would create a reservoir with a capacity of 59,000 acre-feet (see fig. 2) of which 49,000 acre-feet would be in the upper 100 feet. Bedrock, apparently andesite, is exposed in the bed of the river. About 15 feet of gravel would have to be cleaned off the right bank for a distance of 400 feet, and also from the right abutment. The left abutment is a rock ledge and would require little excavation.

There are two possible sites very much alike, about a quarter of a mile apart. A dam at the upper site would be 100 feet longer but 10 feet lower. A dam at either site would be expensive. An auxiliary dam 100 feet high and 2,000 feet long would be required to close the gap between the Blue River and the McKenzie River. Water from this site would be carried through the gap to the McKenzie River at mile 57, where it could be used at the Blue River power site. (See p. 123.)

The reservoir would have an area of 700 acres, but as all the land is of very poor character, the principal cost would be for the dams. The water stored above the 1,300-foot level could be used through a total head of 925 feet on the McKenzie River, and at an efficiency of 70 per cent it would generate 33,000,000 kilowatt-hours of energy. The water stored below the 1,300-foot level could be used through a total head of 600 feet and would generate 4,000,000 kilowatt-hours. The loss of power due to loss of head at this site would be negligible, as the Blue River has a very low flow in summer.

The drainage area of the Blue River above the dam site amounts to 40 square miles, and as the mean annual run-off is estimated at 106,000 acre-feet, there would be no trouble in filling the reservoir even in a dry year. During the summer the run-off drops to about 20 second-feet, so that the reservoir could be completely emptied, thus destroying the head, and yet there would be little loss of power at the dam site due to not using this small natural flow.

WATER POWER

The annual precipitation on the headwaters of the McKenzie River averages about 100 inches. Most of this occurs during nine months of the year, but the porous volcanic soil provides a large underground regulating reservoir, so that the river has a well-sustained flow throughout the summer. Even in such years as 1924 and 1926, which were the driest of record in western Oregon, the flow of the McKenzie River was not affected to nearly so great a degree as that of other streams in the same general locality. The river has a fall of 2,630 feet in 86 miles—1,650 feet in the 21 miles from Clear Lake to McKenzie Bridge and 980 feet in the 65 miles from McKenzie Bridge to the mouth.

From the mouth of Clear Lake to Belknap Springs the river flows in a canyon; in this section power will be developed by means of low dams and conduits, partly because of the steep slope and partly because of probable leakage if high dams were built. From Belknap Springs to Martin Rapids the river valley is rather narrow but still so wide that high dams would be long and expensive except possibly at two sites, which are discussed elsewhere. Below Martin Rapids development will be effected by low dams and open-cut canals, as in the developed project of the city of Eugene.

Separation Creek, tributary to Horse Creek, has a well-sustained flow even at 5,000 feet above sea level, and because of its rapid fall the cost of developing the power should not be great. At present the creek, especially the headwater portion, is very inaccessible, but roads to reach it will probably be built in the course of a few years.

Horse Creek has a good flow of water below the mouth of Separation Creek, but above that point the discharge drops as low as 25 second-feet in a dry summer.

The flow of the South Fork of the McKenzie River amounts to at least 150 second-feet at the mouth of the Roaring River, even in a dry year, and power development on this stream should be financially feasible, as the fall is between 50 and 100 feet to the mile.

DEVELOPED POWER

EUGENE MUNICIPAL POWER PLANT No. 1 (12ND 14)

Water for Eugene municipal power plant No. 1 (see pls. 8, *A*, and 9, *B*) is diverted from the river into a large open canal in the SE. ¼ sec. 23, T. 17 S., R. 1 W., and carried about 4 miles to a plant in the NW. ¼ sec. 29, T. 17 S., R. 1 W. The net head is about 45 feet. The hydraulic machinery has a capacity of 4,300 horsepower, consisting of two turbines rated at 1,200 horsepower each and one rated at 1,900 horsepower. The three generators have a rated capacity of 3,285 kilovolt-amperes. There is no auxiliary power, but the city purchases power from the Mountain States Power Co. Water from the plant is discharged into a short canal, from which it flows down an old channel, reaching the river again at the mouth of Camp Creek, in sec. 25, T. 17 S., R. 2 W. A second plant (12ND 12) is under construction near Leaburg.

Potential power at site 12ND 14

[Gross head, 55 feet]

	Flow in second-feet		Horsepower	
	90 per cent of time	50 per cent of time	90 per cent of time	50 per cent of time
Natural flow	1,790	3,550	7,880	15,600
With storage at Eugene municipal site No. 3	2,220	3,550	9,770	15,600
With storage at all proposed sites	2,650	3,550	11,600	15,600

UNDEVELOPED POWER

In outlining power schemes and in estimating the potential power of the sites described below all the fall and stream flow has been included. Because of the recreational use of the area, however, it will probably be necessary to allow some water to flow continuously in the channel of the river, and possibly some stretches will never be developed because of their scenic value. Owing to the steep slope of the stream bed in the upper section and the wide valley in the lower section, most of the development will be effected by means of low dams and conduits.

UPPER FALLS POWER SITE (12ND 1)

The Upper Falls site is considered as a single unit because it may be desirable to preserve these falls (see pl. 5) for their scenic value rather than to use them for the development of power. Water would be diverted at the outlet of Clear Lake and carried along the left bank of the McKenzie River in a lined conduit or pipe for about a mile, to a point between the Upper and Middle Falls, where a head of 250 feet would be obtained. Clear Lake would furnish storage to take care of any daily fluctuations in load, and plants at this site and those immediately below it might become valuable peak-load plants if the power were used for city lighting. As the country is rough and construction of open conduits would be expensive, it is probable that a pipe line would be used. The natural Q90 flow at this site is 242 second-feet, and the Q50 flow is 340 second-feet. With a gross head of 250 feet 4,840 horsepower could be developed for 90 per cent of the time and 6,800 horsepower for 50 per cent of the time.

MIDDLE FALLS POWER SITE (12ND 2)

The Middle Falls project was selected in order to allow the Upper Falls to be preserved for their scenic value, if desired, and at the same time to develop the power of the remainder of the river. The intake would be a short distance below the Upper Falls, at the point considered for the power house of that site (12ND 1). Water would be diverted by a low dam and carried in a lined or closed conduit for less than half a mile to a power house below the Middle Falls, at the 2,600-foot contour crossing, where a head of 150 feet would be obtained. This location of the power house would take advantage of the inflow of underground water, so that the maximum flow in the river would be obtained for diversion for the next project below. The flow below the Middle Falls is considerably greater than at the outlet of Clear Lake, whereas at the Lower Falls the stream is dry in the summer. A view of the Middle Falls is given in Plate 6, *A*.

The Q90 flow for this project is assumed to be 80 second-feet greater and the Q50 flow 100 second-feet greater than at the outlet of Clear Lake. This assumption is based on two measurements made below the Middle Falls in 1913. The first measurement, on September 12, gave 642 second-feet below the Middle Falls, compared with 319 second-feet at the outlet of Clear Lake, showing an inflow of 323 second-feet. A second measurement on October 20 gave 686 second-feet below the Middle Falls and 364 second-feet at the outlet of Clear Lake, showing an inflow of 322 second-feet. The increase of 45 second-feet in discharge at the outlet of Clear Lake seemed to cause no increase in the flow from the springs that supplied the inflow between Clear Lake and the Middle Falls. It is felt that at least part of this increase would enter the river below the Upper Falls and so be available for this project.

The natural Q90 flow at this site is estimated at 322 second-feet, and the Q50 flow at 440 second-feet. With a head of 150 feet, 3,860 horsepower could be developed for 90 per cent of the time and 5,280 horsepower for 50 per cent of the time.

LOWER FALLS POWER SITE (12ND 3)

Water for the Lower Falls project would be diverted just below the proposed power house of the Middle Falls project (12ND 2), at the point of maximum low-water flow in the river. This point has been tentatively set at the 2,600-foot contour crossing.

The discharge at this site on September 12 and October 20, 1913, was 322 second-feet greater than at the outlet of Clear Lake. (See also discussion of site 12ND 2). The flow at the outlet of Clear Lake was 319 second-feet on September 12 and 364 second-feet on October 20, 1913, or nearly the same as the Q50 discharge, which was 340 second-feet for the 3-year period 1913–1915. From these data the Q50 discharge at the Lower Falls site is estimated at 660 second-feet. The Q90 discharge at the outlet of Clear Lake was 242 second-feet for 1913–1915, or about 100 second-feet less than the Q50 discharge. If it is assumed that the inflow between the outlet of the lake and this site would be somewhat more constant, as it comes from springs, and that the inflow for 90 per cent of the time was only 82 second-feet less than the inflow for 50 per cent of the time the Q90 flow at this site would be 480 second-feet.

The conduit would be a pipe line about 3½ miles long, with perhaps some stretches of lined canals. The right bank is an older and more weathered formation than the left bank, which is a recent lava flow, and the conduit would probably follow the right bank. The water from the power house would discharge into the pool just below the Lower Falls. (See pl. 4, *B*.) With a gross head of 270 feet and a natural Q90 flow of 480 second-feet and a Q50 flow of 660 second-feet, 10,400 horsepower could be developed for 90 per cent of the time and 14,200 horsepower for 50 per cent of the time.

For the construction of the projects here proposed, it would be necessary to extend a road up the McKenzie River from Belknap Springs to Clear Lake, to transport material, but such a road is a natural development and probably will be built by the United States Forest Service before the water power is developed.

SMITH RIVER POWER SITE (12ND 4)

Water for the Smith River project would be diverted from the McKenzie River just below the power house of the Lower Falls site (12ND 3) and carried by a conduit for 3 miles along the right bank of the river to a power house at the mouth of the Smith River, where a head of 310 feet would be obtained.

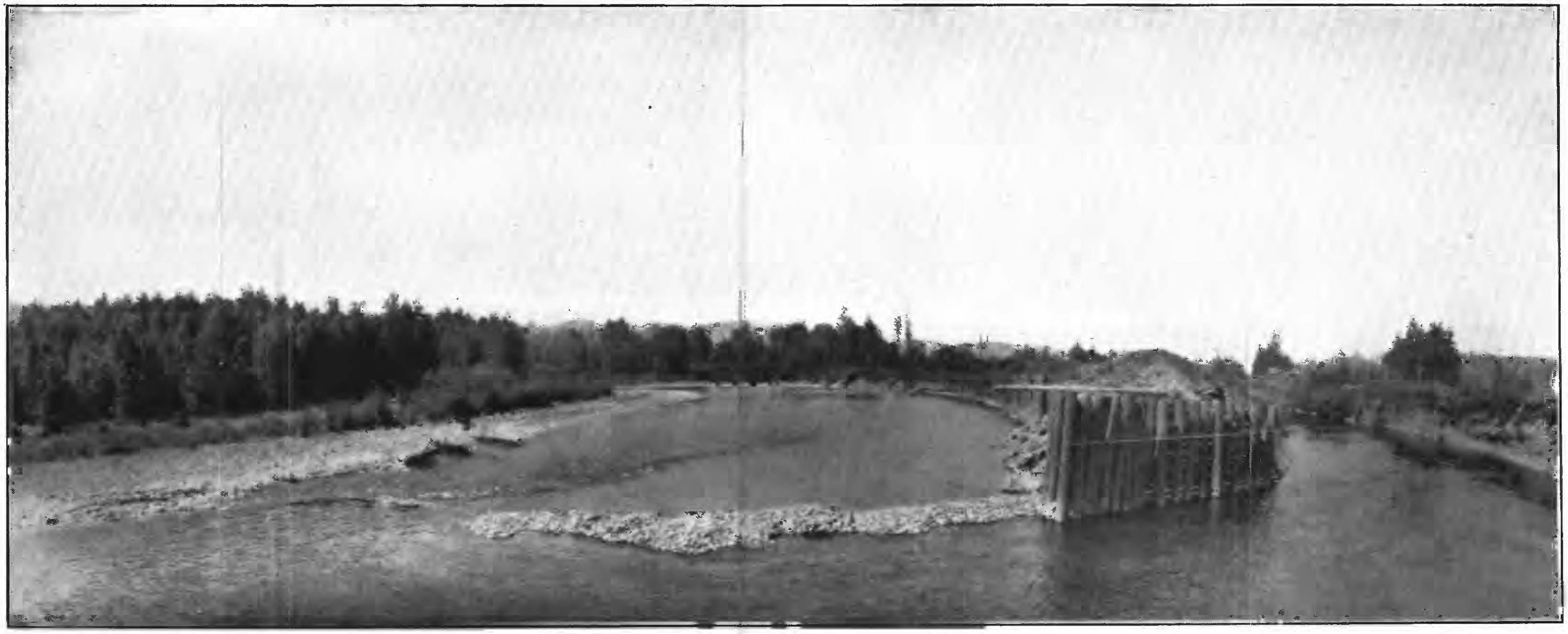
Between the Middle Falls and McKenzie Bridge there is an increase of 680 second-feet in the Q90 flow and of 930 second-feet in the Q50 flow. Some of this increase is accounted for by the flow of Horse and Olallie Creeks, but there is still a considerable surplus, which must come largely from springs. It is assumed that the Q90 flow at this site is 50 second-feet greater and the Q50 flow 70 second-feet greater than the flow available for use at site 12ND 3. The natural Q90 flow at this site is 530 second-feet, and the Q50 flow 730 second-feet. With a gross head of 310 feet 13,100 horsepower could be developed for 90 per cent of the time and 18,100 horsepower for 50 per cent of the time.

DEER CREEK POWER SITE (12ND 5)

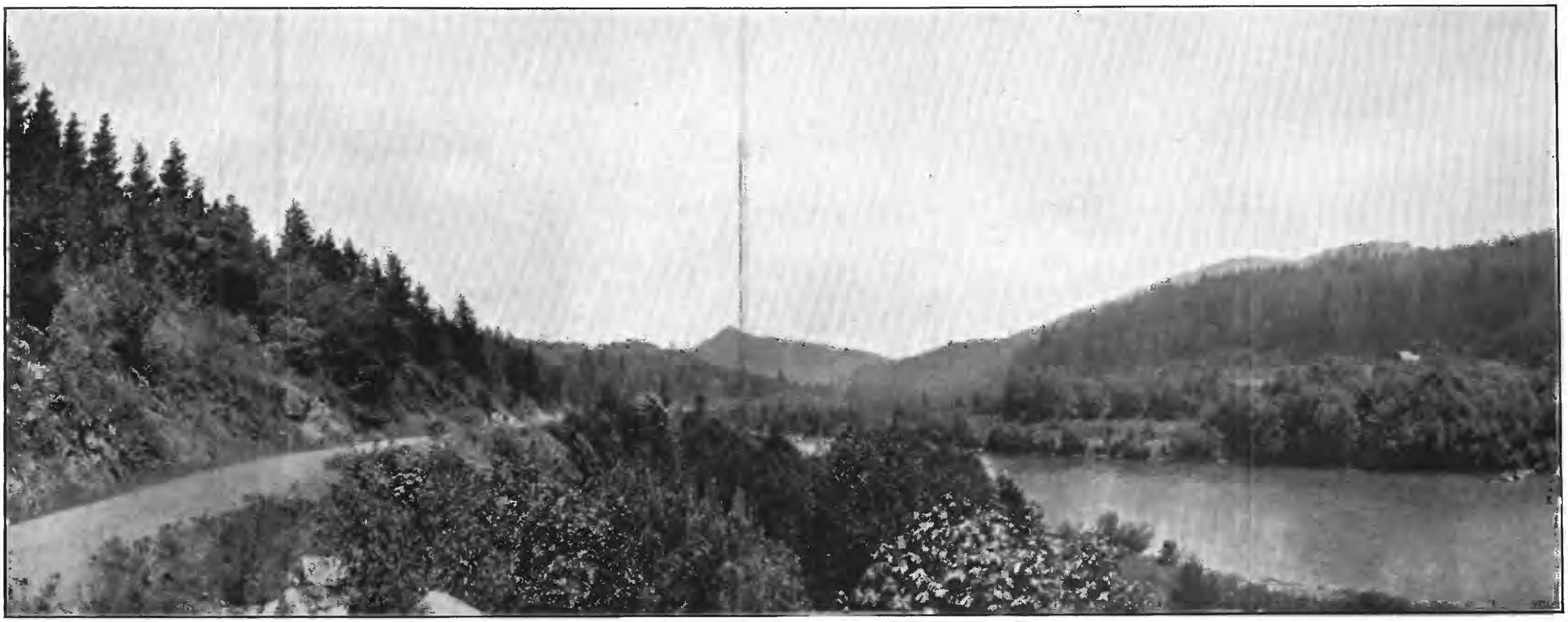
Water for the Deer Creek project would be diverted below the power house of site 12ND 4, at the mouth of the Smith River. By carrying the conduit along the left bank of the river both Anderson Creek and Olallie Creek could be diverted and used. The proposed power-house site is just above Deer Creek, at mile 75.6, where a head of 170 feet would be obtained. The discharge for this site would be considerably greater than that for the Smith River site, because numerous spring-fed creeks enter the river just above the proposed intake. Anderson Creek is a surface stream with a low-water flow of 16 to 20 second-feet. Olallie Creek is fed by two springs at about the 2,180-foot contour. Measurements in 1926 showed 135 second-feet on July 20 and 140 second-feet on September 6; this was an extremely dry period. Measurements in 1924, which was also a dry year, showed 200 second-feet on April 30, 165 second-feet on May 13, and 197 second-feet on August 12. It would seem safe to assume a Q90 discharge of 165 second-feet for Olallie Creek. Adding 15 second-feet for Anderson Creek and 110 second-feet for the springs and creeks between the Lower Falls and Smith River sites gives a total Q90 discharge for this site of 820 second-feet.

There would be no unusual features in the development of this site. The conduit would be about 3 miles long, and for a large part of the way an open lined canal could be used.

The natural Q90 flow at this site is 820 second-feet, and the Q50 flow, estimated from this Q90 discharge and the ratio of Q50 to Q90 at McKenzie Bridge, is 1,120 second-feet. With a gross head of 170 feet 11,100 horsepower could be developed for 90 per cent of the time and 15,200 horsepower for 50 per cent of the time.



A. EUGENE MUNICIPAL POWER PLANT No. 1, McKENZIE RIVER
Shows diversion dam and head gates.



B. MARTIN RAPIDS DAM SITE, LOOKING UPSTREAM

A

B

EUGENE MUNICIPAL POWER SITE No. 3, McKENZIE RIVER

A, View showing rocks in river channel; *B*, view down the valley, the river to the left.

A. EUGENE MUNICIPAL POWER SITE No. 2, McKENZIE RIVER, DURING CONSTRUCTION OF DIVERSION DAM

B. EUGENE MUNICIPAL POWER SITE No. 1
General view, showing headrace to left, tailrace to right.

BELKNAP POWER SITE (12ND 6)

The diversion site for the Belknap project is at the mouth of Deer Creek. Water would be carried by a conduit, probably a pipe line, for about 2 miles along the right bank of the river, and then by 2 miles of tunnel to a point in the NE. ¼ sec. 9, T. 16 S., R. 6 E., where a head of 300 feet would be obtained. About 200 feet of this head would be obtained by the tunnel, which could be made a separate unit if desired.

Any statement of the increase in discharge available for this project over that at the Deer Creek site is little more than a guess, owing to the scantiness of the information available. The Q90 flow at McKenzie Bridge is 340 second-feet greater than the estimated flow available for site 12ND 5. Lost Creek would supply about 225 second-feet, leaving 115 second-feet inflow to be accounted for. It has been assumed that 50 second-feet of this amount would come from Deer Creek and springs between the Smith River and Deer Creek. This would give

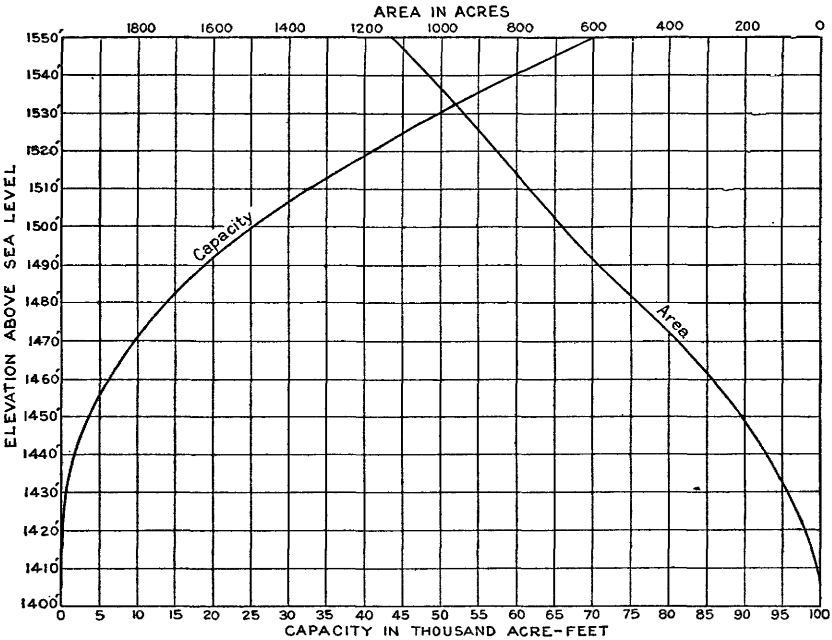


FIGURE 3.—Area and capacity curves, Paradise reservoir site, McKenzie River Basin

a Q90 flow of 870 second-feet for this project. The Q50 flow is estimated from the Q90 flow by using the ratio of Q50 to Q90 at McKenzie Bridge. It is proposed to divert the flow of Lost Creek (see 12ND 18) at the 1,800-foot contour and carry it to a power house on the left bank of the river opposite the power house of the Belknap site. If desired, the water could be brought across the river so that one power house would serve for both units.

The natural Q90 flow at this site is 870 second-feet and the Q50 flow 1,190 second-feet. With a head of 300 feet 20,900 horsepower could be developed for 90 per cent of the time and 28,600 horsepower for 50 per cent of the time.

PARADISE POWER SITE (12ND 7)

The Paradise site could be developed at the least cost by a conduit, but a dam 145 feet high at mile 66, in the NW. ¼ sec. 18, T. 16 S., R. 6 E., would raise the water level to 1,550 feet and create a reservoir with a capacity of 70,000 acre-feet (see fig. 3), of which 60,000 acre-feet would be in the upper 80 feet. Such a dam would be 3,000 feet long, and an earth-fill structure would require over 4,000,000 cubic yards of material.

No bedrock is exposed in the river channel, which probably consists of glacial material. Both banks rise steeply at the dam site, and probably rock is not more than 10 or 15 feet below the surface. The depth of the gravel deposit in the river channel and on the bottom land on the right bank would determine the feasibility of the project, but at best it would be a very expensive development.

The stored water would generate 44,000,000 kilowatt-hours at this and other proposed sites lower down on the McKenzie River. If the period of drawdown is assumed to be four months the loss of power due to loss of head would amount to about 8,000,000 kilowatt-hours, leaving a net development of 36,000,000 kilowatt-hours. As the stored water would generate 4,500,000 kilowatt-hours at this site, the net loss at the site due to drawing down the head for storage would be 3,500,000 kilowatt-hours.

Under present conditions in Oregon it is not financially feasible to utilize this storage, but there is a possibility that conditions 25 years or more from now may justify its cost. If the power is not developed by means of a dam it can de developed by a conduit, which would provide potential power with natural flow nearly as great as if it were developed by a dam. The natural flow at the dam site is practically the same as at the gaging station at McKenzie Bridge.

Potential power at site 12ND 7

[Gross head, 145 feet; mean head with 80 feet drawdown, 111 feet; regulation for unifoım flow]

	Flow in second-feet		Horsepower	
	90 per cent of time	50 per cent of time	90 per cent of time	50 per cent of time
Natural flow	1,160	1,590	13,400	18,400
Regulated flow	1,300	1,590	11,500	18,400

The greatest recorded flow at this site was 8,600 second-feet. Very little valuable land would be overflowed by this proposed reservoir, and there would be little damage to the scenic beauty of the site.

McKENZIE BRIDGE POWER SITE (12ND 8)

A diversion dam about 10 feet high at mile 65.5, in the NE. ¼ sec. 13, T. 16 S., R. 5 E., would back water within 5 feet of the power house of the Paradise site (12ND 7). It is proposed to divert Horse Creek into the McKenzie River above this dam, so that the Q90 flow would be at least 250 second-feet greater than the natural flow at McKenzie Bridge. The water would be carried by a conduit down the right bank of the river for 6 miles, to the mouth of Mill Creek, where a head of 225 feet would be obtained. Most of the conduit would probably be an open canal excavated by steam shovel, but the last mile would be on a steep hillside, and a pipe line would probably be necessary.

Potential power at site 12ND 8

[Gross head, 225 feet]

	Flow in second-feet		Horsepower	
	90 per cent of time	50 per cent of time	90 per cent of time	50 per cent of time
Natural flow	[a] 1,410	[b] 1,940	25,400	34,900
Regulated flow	[a] 1,550	[b] 1,940	27,900	34,900

[a] Includes 250 second-feet from Horse Creek. [b] Includes 350 second-feet from Horse Creek.

COMBINATION POWER SITE (12ND 9)

A diversion dam about 5 feet high below the mouth of Mill Creek is proposed for a combination project to divert water into a canal on the right bank. A conduit about 5½ miles long would lead to a power house just above the mouth of the Blue River, where a head of 140 feet would be obtained. The flow of the South Fork of the McKenzie River could be diverted to the McKenzie River above this site by building a canal a little over a mile in length. If the Blue River Reservoir (12ND 34) is constructed, 48,000 acre-feet of water stored on the Blue River would be available for use in this project.

Such measurements of the South Fork of the McKenzie River as are available indicate that the Q90 discharge was about 195 second-feet in 1926, a very dry year, and 245 second-feet in 1927, a wet year, giving a mean of 220 second-feet. The Q50 discharge is estimated at 350 second-feet.

The water from the Blue River Reservoir would pass through a power house just above the conduit of this project and be discharged into the conduit. The reservoir would probably be completely emptied during the driest period of the year, and the water below an altitude of 1,300 feet would be discharged into the Blue River and used in the plants below. Only the water above an altitude of 1,300 feet could be diverted across the ridge to this power site.

Potential power at site 12ND 9

[Head, 140 feet]

	Flow in second-feet		Horsepower	
	90 per cent of time	50 per cent of time	90 per cent of time	50 per cent of time
Natural flow	[a] 1,680	[b] 2,290	18,800	25,600
Regulated flow	[a] 1,820	[b] 2,290	20,400	25,600

[a] Includes 250 second-feet from Horse Creek and 220 second-feet from the South Fork of the McKenzie River.
[b] Includes 350 second-feet each from Horse Creek and the South Fork of the McKenzie River.

EUGENE MUNICIPAL POWER SITE No. 3 (12ND 10)

The Eugene municipal power site No. 3 is in the SW. ¼ sec. 32, T. 16 S., R. 3 E., just above Bear Creek. (See pl. 7.) A masonry dam is proposed to raise the water 170 feet. The south bank at the site is a brush-covered rock wall of the preglacial McKenzie River Valley and will form a good abutment for the proposed dam. A reef of rock crosses the river in this vicinity, and a specimen from an outcrop in the river was determined under the microscope by C. S. Ross, of the United States Geological Survey, to be andesite. The rock is fresh and dense wherever exposed, and although somewhat jointed it will form an excellent foundation for the proposed dam. The right abutment is a broad bench about 300 feet wide of Pleistocene alluvium, which, wherever it is exposed, consists almost entirely of large cobbles. North of the gravel bench there is a rocky cliff with a short talus at its base. A specimen from the cliff was determined by Mr. Ross to be a diorite. It is apparently intruded into diabase. The contacts are all tight, and so far as the rock is concerned this site is an excellent location. The problem is entirely one of the cost of excavating the gravel bench. Test pits have been put down to bedrock in this bench by the city of Eugene, and it is reported by local people that the altitude of the bedrock under the bench is lower than that of the rock in the river. Such a condition is not surprising, for the ancient channel before it was filled with glacial outwash may well have been cut deeper in bedrock than the present one. Geologically the site is perfectly feasible.

An alternative site for the dam is at Martin Rapids (see pl. 8, *B*), in the SW. ¼ sec. 36, T. 16 S., R. 2 E. At this site a series of conformable lava beds dipping upstream are exposed. The uppermost bed is a feldspar porphyry, determined by C. S. Ross to be a coarse andesite. Below this is a bed of green felsite also determined by Mr. Ross to be an andesite. Under this andesite is a dark igneous rock which is probably a diabase. A narrow gravel bench borders the river on the south abutment, and beyond this are outcrops of sound rock. The north abutment is a rocky cliff composed of the igneous rocks described above. The rock is jointed, but seepage under and around the dam can easily be prevented by cement grouting. The river at the site flows quietly, suggesting a deep channel. The Oregon Power Co., which drilled this site, is reported to have found bedrock between 30 and 40 feet below the surface of the river. Except for the possibly great depth to bedrock this dam site is an excellent one, and it should be carefully investigated before abandonment. If the dam is built at the Eugene municipal site No. 3, then the power between the two sites could be developed by a canal.

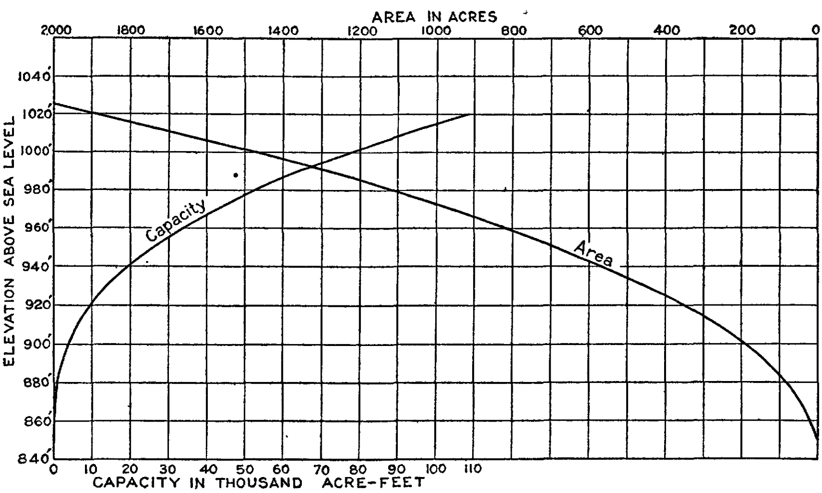


FIGURE 4.—Area and capacity curves, Eugene municipal site No. 3, McKenzie River Basin

The indications are that the municipal site is the better of the two. The dam proposed at that site would raise the water to an altitude of 1,020 feet. This would create a reservoir with a capacity of 109,000 acre-feet (see fig. 4), of which 90,000 acre-feet would be in the upper 80 feet. This water could be used through a mean head of 138 feet and would generate at 70 per cent efficiency 9,000,000 kilowatt-hours. The stored water could also be used through 430 feet of head at sites lower down the river and would generate 28,000,000 kilowatt-hours, or a total at all sites of 37,000,000 kilowatt-hours. If it is assumed that the period of drawdown would last four months and that the flow during this period would average 1,800 second-feet, the loss of power due to loss of head would amount to 10,000,000 kilowatt-hours. Thus there would be an actual loss of 1,000,000 kilowatt-hours at the site itself due to drawing down the head, but the stored water would permit the adjustment of the power supply to the load during the period of low flow, and if the sites below were developed there would be the further advantage of a net gain of 27,000,000 kilowatt-hours. The gaging station near Vida shows the flow at this site.

Potential power at site 12ND 10

[Head without drawdown, 170 feet; mean head with 80 feet drawdown, 138 feet; regulation for uniform flow]

	Flow in second-feet		Horsepower	
	90 per cent of time	50 per cent of time	90 per cent of time	50 per cent of time
Natural flow	1,750	3,150	23,800	42,800
With storage at this site	2,180	3,150	24,100	42,800
With storage at all proposed sites	2,600	3,150	28,700	42,800

VIDA POWER SITE (12ND 11)

Water for the Vida project would be diverted just below the power house of the Eugene municipal site No. 3 (12ND 10) and carried along the left bank of the river to a power house at mile 37, in the NE. ¼ SE. ¼ sec. 29, T. 16 S., R. 2 E., giving a gross head of 100 feet. The flow would be the same as for the municipal power site No. 3. The conduit would be difficult to construct in places, but this project will probably be financially feasible as soon as there is a market for the power. The conduit would be about 6½ miles in length.

Potential power at site 12ND 11

	Flow in second-feet		Horsepower	
	90 per cent of time	50 per cent of time	90 per cent of time	50 per cent of time
Natural flow	1,750	3,150	14,000	25,200
With storage at Eugene municipal site No. 3	2,180	3,150	17,400	25,200
With storage at all proposed sites	2,600	3,150	20,800	25,200

EUGENE MUNICIPAL POWER SITE No. 2 (12ND 12)

The project at Eugene municipal power site No. 2 is under construction by the city. (See pl. 9, *A*.) Water will be diverted by a 20-foot concrete dam in the NE. ¼ sec. 31, T. 16 S., R. 2 E., at mile 35.5 and carried in a conduit along the right bank to a power house in the SE. ¼ sec. 9, T. 17 S., R. 1 E., at mile 30, which will give a gross head of 90 feet. The conduit will be an unlined canal for most of the distance, but probably the over-all efficiency will be at least 70 per cent, which is the efficiency assumed in computing the potential power. The flow would be somewhat greater than at the gaging station at Vida.

Two units are planned, of which only one will be installed at first. Each unit will consist of a 10,000-horsepower turbine with a 7,500-kilovolt-ampere generator. The canal will have a capacity of 2,200 second-feet. Two penstocks 12 feet in diameter will extend 275 feet from the forebay to the power house.

The city of Eugene plans to allow at least 300 second-feet to flow past the dam unused at all seasons of the year, it being the intention to avoid thereby any injury to the scenic and recreational features of the river channel between the points of diversion and return of the water utilized for power development. This reserve will not affect the potential power of the site, however, but only the operation of the power plant. In case of an emergency or for any other good reason the water could all be diverted and used.

Potential power at site 12ND 12

[Head, 90 feet]

	Flow in second-feet		Horsepower	
	90 per cent of time	50 per cent of time	90 per cent of time	50 per cent of time
Natural flow	1,780	3,350	12,800	24,100
With storage at Eugene municipal site No. 3	2,210	3,350	15,900	24,100
With storage at all proposed sites	2,640	3,350	19,000	24,100

DEERHORN POWER SITE (12ND 13)

The Deerhorn site includes the stretch of river between the power house of the Eugene municipal plant No. 2 (12ND 12), below Leaburg, now being built, and the point of diversion of the Eugene plant No. 1 (12ND 14), already constructed. Water would be diverted just below the Leaburg site and carried along the right bank of the river to a power house in the NW. ¼ sec. 24, T. 17 S., R. 1 W., giving a gross head of 45 feet. Tail water from this plant would be discharged directly into a canal leading to Eugene power plant No. 1. The water available at this site is assumed to be 10 second-feet less than the flow at Hendricks Bridge for 90 per cent of the time and 20 second-feet less for 50 per cent of the time.

Potential power at site 12ND 13

[Gross head, 45 feet]

	Flow in second-feet		Horsepower	
	90 per cent of time	50 per cent of time	90 per cent of time	50 per cent of time
Natural flow	1,790	3,550	6,440	12,800
With storage at Eugene municipal site No. 3	2,220	3,550	8,000	12,800
With storage at all proposed sites	2,650	3,550	9,540	12,800

HAYDEN BRIDGE POWER SITE (12ND 15)

Water for the Hayden Bridge site would be diverted just below the Eugene municipal power plant No. 1 and carried by a conduit to a point near Hayden Bridge, in the SW. ¼ sec. 20, T. 17 S., R. 2 W., giving a gross head of 90 feet. This project would involve 6½ miles of conduit, compared with 5½ miles for Eugene municipal site No. 2 (12ND 12). There would be no dam to construct, as the conduit could be made a continuation of the tailrace of Eugene plant No. 1. A siphon about a quarter of a mile long would be necessary at Camp Creek, but the head on the siphon would amount to only about 30 feet. The power plant would be only 11 miles from the mouth of the McKenzie River, on the Southern Pacific Railroad. Altogether this seems to be an inexpensive development and financially feasible whenever a market is ready for the power. The water available would be the same as for the Eugene municipal plant No. 1 (12ND 14).

Potential power at site 12ND 15

[Gross head, 90 feet]

	Flow in second-feet		Horsepower	
	90 per cent of time	50 per cent of time	90 per cent of time	50 per cent of time
Natural flow	1,790	3,500	12,900	25,200
With storage at Eugene municipal site No. 3	2,220	3,500	16,000	25,200
With storage at all proposed sites	2,650	3,500	19,000	25,200

COBURG POWER SITE (12ND 16)

Water for the Coburg site would be diverted by a dam 10 feet high just below the mouth of the Mohawk River and carried along the right bank of the McKenzie River for 5 miles to the Coburg Bridge, giving a gross head of 50 feet. A long dam on a gravel foundation would be required. The water available is assumed to be 10 second-feet more than at Hendricks Bridge for 90 per cent of the time and 20 second-feet more for 50 per cent of the time. The canal could be dug with a steam shovel but would probably require lining at the lower end. The power house would be close to Springfield and Eugene, and only a short transmission line would be required. This appears to be a feasible development as soon as a market for the power is available.

Potential power at site 12ND 16

[Gross head, 50 feet]

	Flow in second-feet		Horsepower	
	90 per cent of time	50 per cent of time	90 per cent of time	50 per cent of time
Natural flow	1,810	3,590	7,440	14,400
With storage at Eugene municipal site No. 3	2,240	3,590	8,840	14,400
With storage at all proposed sites	2,670	3,590	10,700	14,400

OLALLIE CREEK POWER SITE (12ND 17)

Water can be diverted from the springs that contribute the entire low-water flow of Olallie Creek at an altitude of 2,160 feet and carried in a conduit along the left bank of the creek for about a mile to a power house where a head of 140 feet can be obtained. Water from the power house will be discharged into the conduit of the Deer Creek power site (12ND 5). The following miscellaneous discharge measurements have been made near the mouth of the creek:

Date	Second-feet
Apr. 30, 1924	200
May 13, 1924	165
Aug. 12, 1924	197
July 20, 1926	135
Sept. 6, 1926	139

As both 1924 and 1926 were years of very low run-off it is assumed that the Q90 flow amounts to 165 second-feet and that the Q50 flow amounts to 200 second-feet. With a gross head of 140 feet 1,850 horsepower could be developed for 90 per cent of the time and 2,240 horsepower for 50 per cent of the time.

LOST CREEK POWER SITE (12ND 18)

Lost Creek receives most of its low-water flow from springs near the mouth of White Branch. By diverting it at the 1,800-foot contour crossing, practically the whole flow of Lost Creek would be obtained. The water would be carried by a conduit along the left bank of Lost Creek and then through a long penstock to a power house in the NE. ¼ SE. ¼ sec. 9, T. 16 S., R. 6 E., where a head of 250 feet would be obtained. If desired it could be carried across the river to the Belknap power house (12ND 6).

A temporary gaging station was maintained on Lost Creek near the mouth in 1926, a very dry year. The records at this station show a Q90 discharge of 173 second-feet, but the Q90 flow in 1926 at McKenzie Bridge was only 67 per cent of the normal flow, and if this was true of Lost Creek then the normal Q90 flow would amount to about 250 second-feet. It has been assumed that the Q90 flow is 225 second-feet and the Q50 flow 300 second-feet.

This project would require about 3 miles of canal and 0.6 mile of penstock. It is close to good roads, the right of way is across lands of little value, and outside of the transmission lines the cost should not be very high. If desired the water could be carried across the McKenzie River to the power house at the Belknap site (12ND 6).

With a head of 250 feet 4,500 horsepower could be developed for 90 per cent of the time and 6,000 horsepower for 50 per cent of the time.

POWER SITES ON HORSE CREEK ABOVE SEPARATION CREEK (12ND 19, 20, AND 21)

During periods of low flow most of the water in Horse Creek comes from Separation Creek. For example, on September 9, 1926, the flow of Separation Creek at its mouth was 206 second-feet, and on August 28 Horse Creek above the mouth of Separation Creek was flowing 25 second-feet. Probably in a wet year the flow of Horse Creek would be considerably higher, but it is doubtful if the Q90 flow above the mouth of Separation Creek would exceed 50 second-feet. Upstream the flow gradually diminishes until at Horse Lake it amounts to only about 5 second-feet. The area of Horse Lake is roughly 100 acres, and it is estimated that a dam 50 feet high and 500 feet long would store not to exceed 8,000 acre-feet of water.

The fall below Horse Lake amounts to several hundred feet to the mile, but with a low-water flow of not more than 10 second-feet the development of this site will not be economically feasible for many years. No survey of Horse Creek above Separation Creek has been made, and therefore detailed power estimates can not be given, but three sites are proposed, as follows: 12ND 19, at Horse Lake; 12ND 20, from a point about a mile below Horse Lake to the mouth of Eugene Creek; 12ND 21, from the mouth of Eugene Creek to the mouth of Separation Creek. These three sites would have a total potential capacity, without storage, estimated roughly at 4,000 horsepower for 90 per cent of the time and 8,000 horsepower for 50 per cent of the time.

FOLEY SPRINGS POWER SITE (12ND 22)

Water for the Foley Springs project would be diverted from Horse Creek just below the mouth of Separation Creek and carried along the left bank of the creek to a power house at the 1,700-foot contour crossing, about 1 mile above Foley Springs, where a head of 280 feet would be obtained.

In 1926 the Q90 flow of Horse Creek at the bridge at mile 3 amounted to 250 second-feet. As 1926 was the year of lowest flow recorded in western Oregon, it seems probable that in an ordinary year there would be a Q90 flow of at least 280 second-feet at the bridge and 275 second-feet at this site. No records are available to show the Q50 flow, but it is estimated roughly at 400 second-feet. It is possible that 5,000 acre-feet of storage would be developed on Mesa Creek, a tributary of Separation Creek, but this would not greatly affect the Q90 flow at the Foley Springs site, and it has been disregarded. With a head of 280 feet 6,160 horsepower could be developed for 90 per cent of the time and 8,960 horsepower for 50 per cent of the time.

POWER SITE AT THE MOUTH OF HORSE CREEK (12ND 23)

Water for the project at the mouth of Horse Creek would be diverted at the 1,700-foot contour crossing on Horse Creek and carried along the right bank of the creek and through a tunnel to a power house in the NW. ¼ NE. ¼ sec. 24, T. 16 S., R. 5 E., where a head of 300 feet would be obtained. Water after passing through the power house would be carried in an open canal to the McKenzie River at the diversion site for project 12ND 8. The Q90 flow available for this project would not be over 5 second-feet greater than the flow just below

Separation Creek and the Q50 flow 10 second-feet greater. The basis for the estimate of the water available at this site is discussed under site 12ND 22.

The natural Q90 flow at this site is 280 second-feet and the Q50 flow 410 second-feet. With a head of 300 feet 6,720 horsepower could be developed for 90 per cent of the time and 9,840 horsepower for 50 per cent of the time.

MESA CREEK POWER SITE (12ND 24)

The Mesa Creek site is near the Three Sisters, at the head of Separation Creek, a tributary of Horse Creek. It is proposed to construct a dam 100 feet high on Separation Creek at the 4,800-foot contour. Water would be diverted into the reservoir thus formed from Mesa Creek and Honey Creek, tributaries of Separation Creek. A penstock about 1½ miles long would lead to a power house at an altitude of 3,550 feet, giving an average head of 1,300 feet. The capacity of the reservoir would be 5,350 acre-feet, which could be used through a head of 2,870 feet on Separation Creek and a total head of 4,415 feet on the McKenzie River, Horse Creek, and Separation Creek. This amount of stored water would generate 5,000,000 kilowatt-hours of energy if used through a head of 1,300 feet at 70 per cent efficiency and 17,000,000 kilowatt-hours if used through a head of 4,415 feet. The loss of power due to drawing down the head would amount to 1,000,000 kilowatt-hours. If it is considered better to develop this site without storage the water could be diverted at an altitude of 5,000 feet, giving a total head of 1,450 feet.

Very little information is available on the flow of Separation Creek and its tributaries, Mesa, Honey, Rainbow, and Louisa Creeks. On July 12, 1927, Mesa Creek 1 mile above its mouth was flowing 51 second-feet, and a tributary entering Mesa Creek at an altitude of 4,250 feet was flowing 19 second-feet. Probably most of the flow of this tributary could be diverted and used, as it lies between Mesa Creek and Separation Creek. Separation Creek at the mouth of Mesa Creek was flowing 76 second-feet on July 12 and 76 second-feet on July 20. At an altitude of 5,400 feet it was flowing 50 second-feet on July 20. Probably at the 4,800-foot contour the flow was about 60 second-feet. Honey Creek has very little water, but it could be easily diverted into Separation Creek. The flow in July, 1927, available for this project is estimated at 50 second-feet from Mesa Creek, 15 second-feet from a tributary of Mesa Creek, 60 second-feet from Separation Creek, and 7 second-feet from Honey Creek, a total of 132 second-feet. As 1927 was a wet year the flow ordinarily would amount to perhaps three-fourths of this, or 100 second-feet, and this is taken as the Q90 flow ordinarily available. No records are available for the winter, but even if the winter flow is low on Separation Creek it is high on most streams in western Oregon, and any load could be carried by other stations.

The flow at the mouth of Separation Creek on July 25, 1927, was 308 second-feet, and on September 9, 1926, at the end of a very dry season, it was 206 second-feet. Horse Creek at the highway bridge was flowing 264 second-feet on July 25, 1926, and 235 second-feet on September 9, 1926. It seems safe to assume that the Q90 flow of Separation Creek would be at least three-fourths of the flow measured in July, 1927. There are no records on which to base an estimate of the Q50 flow, but it has been assumed as at least 25 per cent greater than the Q90 flow.

The records of stream flow available are not sufficient to permit an estimate of the potential power for 90 per cent of the time with storage, but the amount of storage available would not afford much increase in the power. Part of this stored water would be required to bring the minimum flow up to the Q90 flow. A plant of this kind with some storage and high head should be valuable in any system to carry the peak load.

Potential power at site 12ND 24

[Gross head without storage, 1,450 feet; gross head with storage, 1,300 feet]

	Flow in second-feet		Horsepower	
	90 per cent of time	50 per cent of time	90 per cent of time	50 per cent of time
Natural flow	100	125	[a] 11,600 [b] 10,400	[a] 14,500 [b] 13,000

[a] Without storage; water diverted at higher altitude than proposed reservoir.
[b] With storage.

HARVEY CREEK POWER SITE (12ND 25)

Water for the Harvey project would be diverted from Separation Creek at an altitude of 3,550 feet, just below the power house of the Mesa site (12ND 24). A conduit about 5 miles long down the right bank of Separation Creek would lead to a power house a third of a mile above Harvey Creek, where a head of 850 feet would be obtained. If an open canal is used for the conduit for this project it probably will have to be lined for most of its length. The flow for this site would be slightly greater than that for the Mesa site.

On July 12, 1927, Separation Creek at the mouth of Mesa Creek was flowing 76 second-feet, and Mesa Creek at the mouth was flowing 80 second-feet. The flow of Honey Creek at the mouth is estimated at 10 second-feet. This gives a total of 166 second-feet available for diversion in July, 1927. The Q90 flow is assumed to amount to three-fourths of this quantity, or 125 second-feet. The Q50 discharge is roughly estimated at 160 second-feet. With a gross head of 850 feet 8,500 horsepower could be developed for 90 per cent of the time and 10,900 horsepower for 50 per cent of the time.

RAINBOW CREEK POWER SITE (12ND 26)

Detailed studies are necessary to determine the most economical method of developing the Rainbow Creek site. The method proposed would not obtain all the power available, but by combining all the power in one site it would provide economical operation. Harvey Creek can easily be diverted into Separation Creek above the 2,700-foot contour, the point of diversion for this project. A conduit would be carried along the right bank of Separation Creek, and Rainbow Creek and Louisa Creek would be diverted into it, the combined flow being used at a power house at the mouth of Separation Creek, where a head of 720 feet would be obtained. It may be found more economical to split this site into two projects, with one power house between Rainbow and Louisa Creeks and one at the mouth of Separation Creek. This method would allow about 50 second-feet more water to be used in the lower project, which would add about 900 horsepower to the capacity for 90 per cent of the time, but it would require an extra penstock, power house, and power-house machinery, so unless the construction of the conduit on the higher ground would prove too difficult, a single plant will probably be preferred.

In July, 1927, the measured flow of Separation Creek below the mouth of Mesa Creek amounted to 166 second-feet, Louisa Creek at the 3,100-foot contour was flowing 23 second-feet, and Rainbow Creek above the falls 25 second-feet; if the flow of Harvey Creek is estimated at 14 second-feet it gives a total discharge of 228 second-feet. The flow at the mouth of Separation Creek was 308 second-feet, and probably 20 second-feet of this difference enters Separation Creek above Harvey Creek and below Mesa Creek. This gives a total discharge in July, 1927, of 248 second-feet. On the assumption, as for the other sites, that the Q90 flow equals three-fourths of the flow in July, 1927, it is 186 second-feet. The Q50 flow is estimated at roughly 25 per cent more than the Q90 flow, or 235 second-feet. This estimate of the Q50 flow is probably low, but it is conservative. With a gross head of 720 feet, 10,700 horsepower could be developed for 90 per cent of the time and 13,500 horsepower for 50 per cent of the time.

The power that could be obtained from water stored above Mesa Creek is discussed under site 12ND 24. These data are not sufficient to justify an estimate of the power for 90 per cent of the time with storage.

ELK CREEK POWER SITE (12ND 27)

The Elk Creek project involves a diversion dam on the South Fork of the McKenzie River just below the mouth of Elk Creek. A conduit about 2½ miles long would lead to the power house at the mouth of the Roaring River, where, according to the topographic map of the Waldo Lake quadrangle, a head of 250 feet would be obtained. On July 28, 1927, the flow at the mouth of Elk Creek was 76 second-feet, and the Q90 discharge is estimated at 70 second-feet from this measurement and fragmentary records of the flow above the East Fork in 1926 and 1927. The Q50 discharge is estimated roughly at 105 second-feet. These estimates may be considerably in error, but they afford some idea of the power value of this site. With a gross head of 250 feet 1,400 horsepower could be developed for 90 per cent of the time and 2,100 horsepower for 50 per cent of the time.

AUGUSTA CREEK POWER SITE (12ND 28)

Water for the Augusta Creek project would be diverted from the South Fork of the McKenzie River at the mouth of the Roaring River, at an altitude of about 2,550 feet. (See map of the Waldo Lake quadrangle.) A conduit about 6 miles long would lead to the mouth of Augusta Creek, where a head of 430 feet would be obtained.

On July 23, 1926, the flow of the South Fork below Augusta Creek amounted to 168 second-feet, of which perhaps 5 second-feet came from Augusta Creek. On July 28, 1927, the South Fork below Elk Creek was flowing 76 second-feet, and on July 29 the Roaring River was flowing 126 second-feet, a total of 202 second-feet. The Q90 flow at this site is estimated at 180 second-feet from these measurements and fragmentary records on the South Fork of the McKenzie River above the East Fork in 1926 and 1927. The Q50 flow is estimated roughly at 50 per cent more than the Q90 flow, or 270 second-feet. With a gross head of 430 feet 6,200 horsepower could be developed for 90 per cent of the time and 9,300 horsepower for 50 per cent of the time.

HARDY CREEK POWER SITE (12ND 29)

Water for the Hardy Creek project would be diverted from the South Fork of the McKenzie River at about mile 17, just below Augusta Creek, and carried by a conduit to a point above the mouth of Hardy Creek, where a head of 290 feet would be obtained. The water available at this site would be the same as for the Augusta site (12ND 28), with the addition of that from Augusta Creek, which is estimated roughly to have a Q90 flow of 5 second-feet and a Q50 flow of 10 second-feet. The natural Q90 flow of the South Fork at the Hardy Creek site is thus 185 second-feet, and the Q50 flow 280 second-feet. With a gross head of 290 feet 4,300 horsepower could be developed for 90 per cent of the time and 6,500 horsepower for 50 per cent of the time.

SLIDE CREEK POWER SITE (12ND 30)

Water for the Slide Creek project would be diverted from the South Fork of the McKenzie River just above the mouth of Hardy Creek, at mile 12½, and carried by a conduit for 3½ miles to a point near the mouth of Slide Creek, where a head of 220 feet would be obtained. The Q90 flow at this site would be practically the same as for the Hardy Creek site, or 185 second-feet. The Q50 flow is estimated at 5 second-feet greater than that for the Hardy Creek site, or 285 second-feet. With a gross head of 220 feet 3,250 horsepower could be developed for 90 per cent of the time and 5,000 horsepower for 50 per cent of the time. Perhaps a pressure pipe line near the river would be less expensive than a conduit along the 1,820-foot contour as proposed.

EAST FORK POWER SITE (12ND 31)

Water for the East Fork site would be diverted from the South Fork of the McKenzie River just above the mouth of Slide Creek, at mile 9.1, and carried by a conduit for nearly 4 miles to a point above the East Fork of the South Fork, where a head of 265 feet would be obtained. A number of creeks enter between the point of diversion for this site and the Slide Creek power site (12ND 30), but their flow is not great. The Q90 flow below the mouth of the East Fork is estimated from fragmentary records at 195 second-feet in 1926 and 245 second-feet in 1927, or a mean of 220 second-feet. The Q90 flow at this site is estimated at 200 second-feet and the Q50 flow at 300 second-feet. With a head of 265 feet 4,240 horsepower could be developed for 90 per cent of the time and 6,360 horsepower for 50 per cent of the time.

COUGAR CREEK POWER SITE (12ND 32)

Water for the Cougar Creek site would be diverted from the South Fork of the McKenzie River just below the mouth of the East Fork and carried by a conduit to a point opposite the 1,200-foot contour crossing at mile 3, where a head of 120 feet would be obtained. The flow at this site would be increased by the flow of the East Fork. In 1926 this amounted to 11 second-feet on June 16, 1.7 second-feet on August 8, and 11 second-feet on September 22. In an average year the Q90 flow of the East Fork would probably amount to 8 second-feet and the Q50 flow to 15 second-feet. The natural Q90 flow at this site is 208 second-feet and the Q50 flow 315 second-feet. With a head of 120 feet 2,000 horsepower could be developed for 90 per cent of the time and 3,050 horsepower for 50 per cent of the time.

ROARING RIVER POWER SITE (12ND 33)

The Roaring River supplies nearly 60 per cent of the low-water flow of the South Fork of the McKenzie River. This stream is shown on the topographic map of the Waldo Lake quadrangle. On July 29, 1927, a current-meter measurement showed a discharge of 126 second-feet. By diverting the two forks of the Roaring River at the 3,400-foot contour crossing with about 4 miles of conduit a head of 850 feet could be obtained. Probably the low-water flow at the proposed point of diversion would be almost as great as that at the mouth. The Q90 flow at the mouth is estimated at 115 second-feet, and that at the point of diversion at 100 second-feet. A road is being built up the South Fork of the McKenzie River, and this project appears to be feasible for the not distant future. The natural Q90 flow at this site is estimated at 100 second-feet and the Q50 flow at 150 second-feet. With a head of 850 feet 6,800 horsepower could be developed for 90 per cent of the time and 10,200 horsepower for 50 per cent of the time.

BLUE RIVER POWER SITE (12ND 34)

The plant at the Blue River site would be built primarily to use the water stored in the Blue River reservoir. (See p. 106.) The water would be carried in a penstock about half a mile long to a power house on the McKenzie River, in the NE. ¼ NE. ¼ sec. 23, T. 16 S., R. 4 E., where a head of 125 to 225 feet would be obtained. Only the water stored at an altitude of more than 1,300 feet, amounting to 49,000 acre-feet, could be used at this site, and with an average head of 185 feet it would generate 6,500,000 kilowatt-hours of power. Water from the plant would be discharged into the conduit of the combination project 12ND 9 at an altitude of 1,175 feet.

It would be possible to use this site to develop power from the natural flow of the Blue River, but it would not be feasible to build so expensive a project for the amount of water available. There are very few data on which to base an estimate of the Q90 or Q50 flow of the Blue River. On August 14, 1924, the discharge 1 mile above the mouth was 18 second-feet. On August 8, 1926, the discharge at a point near the mouth was 16 second-feet, and on June 17, 1926, it was 50 second-feet. Both 1924 and 1926 were very dry years, and it is assumed that the Q90 flow is 25 second-feet and the Q50 flow 50 second-feet. With a head of 200 feet 400 horsepower could be developed for 90 per cent of the time and 800 horsepower for 50 per cent of the time.

The stored water would be used not to equalize the flow of the Blue River but in connection with the sites on the McKenzie River. The total amount of power that could be obtained from the stored water is given in connection with the Blue River reservoir site. (See p. 106.)

MARKET

The power developed at present on the McKenzie River is all used in the city of Eugene. The total resources of the basin without storage, however, amount to 290,000 horsepower for 90 per cent of the time and 444,000 horsepower for 50 per cent of the time. This amount of potential power in a modern interconnected power system, with steam stand-by plants to carry the load in dry seasons, would produce nearly 2,000,000,000 kilowatt-hours of usable power. This is more than twice the total amount of power produced by public-utility and municipal plants in the State of Oregon in 1927. The complete development of the resources of the McKenzie River Basin is a long way in the future if the power is used only to supply the ordinary lighting and manufacturing load in the vicinity. At present there seems no inclination on the part of privately owned companies to start development on the McKenzie River, and unless this is done the only market for power is Eugene.

The ordinary growth of the lighting and power load in Eugene without the introduction of extraordinary development of market for power may require new plants on the McKenzie River, such as those considered herein, at intervals of approximately 10 or 15 years. The introduction of new industries, such as the electrochemical and electrometallurgical industries, which are large consumers of power, may bring more rapid development of these power resources.

Power from this river could be economically developed and transmitted to Portland, but that market is already well supplied, and many other supplementary sites are available. The probabilities are therefore that only a part of the potential power resources of the McKenzie River will be developed in the near future.

GEOLOGY AND WATER RESOURCES OF THE MIDDLE DESCHUTES RIVER BASIN, OREGON

By Harold T. Stearns

ABSTRACT

The middle Deschutes River Basin lies in Deschutes and Jefferson Counties, in central Oregon. The principal town in the area is Madras, and the principal streams are the Deschutes, Crooked, and Metolius Rivers. These rivers occupy deep canyons in a northward-sloping, elevated lava plain which is bounded on the west by the Cascade Range and on the east by a low mountain range that has no general name.

The Trail Crossing basalt, not less than 200 feet thick, is the oldest rock exposed. Above it lies the Clarno (?) formation, of Eocene (?) age, consisting essentially of fine-grained consolidated yellow, cream-colored, gray, green, and red tuffs. Some beds are soft; others are massive and resistant. The Clarno (?) formation has a probable thickness of over 1,000 feet. Dark-colored massive andesite, usually containing glassy feldspar phenocrysts 2 to 4 millimeters in diameter, crops out in the southern part of the area. The age of this andesite is unknown, but it is tentatively correlated with the andesite flows of the Cascade Range, which are in general Pliocene.

Separated from the andesite and the Clarno (?) by a marked unconformity is the Deschutes formation, consisting of sand, silt, gravel, and stratified fluviatile deposits of volcanic detritus, mostly basic, intercalated with and in most places capped by basalt flows. Several of the cinder cones that were the sources of this basalt are still preserved. This formation, which is about 1,000 feet thick, contains commercial deposits of diatomite.

Partly filling the Deschutes and Crooked River Canyons cut in the Deschutes formation is an intracanyon basalt flow which originated south of the area and which has in places filled these canyons to a depth of 900 feet. A considerable part of this lava has been removed by erosion, but the remnants form conspicuous benches along these rivers.

The geology of the upper and lower box canyon dam sites on the Crooked River is described in detail. The upper site is considered not feasible for a dam, because of the presence of a cave in one abutment. The Metolius dam site, on the Deschutes River, is described and also the hydrologic conditions which affect its success.

The monthly maximum, minimum, and mean discharges of the Deschutes, Crooked, and Metolius Rivers are given for all gaging stations in the area. The quality of the surface and ground water of the area is excellent. The rivers are mostly fed by large springs, many of which lie within the area described. Records of all the wells and a map showing the contours of the water table are given. All the rocks older than the Deschutes formation yield water sparingly or not at all, but wells obtain large yields in the Deschutes formation, especially in the intercalated basalt flows below the water table. The intracanyon basalt also is very permeable but usually yields water only near the base.

The springs in the area are too numerous to describe in detail. There are dozens of them that discharge over 1 cubic foot a second. Opal Springs, the

largest of all, discharge about 300 cubic feet a second. The spring inflow into the Crooked River in a stretch of about 19 miles amounts to about 950 cubic feet a second, or 620 million gallons a day. Likewise, the Deschutes River in traversing the area gains about 400 cubic feet a second of spring water. The total annual ground-water discharge of this area amounts to about 1,000,000 acre-feet.

The power possibilities and the existing plants on the Deschutes and Crooked Rivers are described.

INTRODUCTION

Location and extent of area investigated.—The area covered by this report lies in central Oregon, 96 miles south of The Dalles and 28 miles north of Bend as measured along The Dalles-California Highway, which crosses the area from north to south. The distances are only 66 and 18 miles, respectively, by air line. (See fig. 5.) The area has no natural boundaries but occupies the middle portion of the drainage basin of the Deschutes River. It is 24 miles long north and south and 12 miles wide east and west, and thus covers about 288 square miles. It lies midway between the forty-fourth and forty-fifth parallels and the one hundred and twenty-first and one hundred and twenty-second meridians, in Deschutes and Jefferson Counties. The northwest corner is in the Warm Springs Indian Reservation. It includes Tps. 11 to 14 S., Rs. 12 and 13 E. Willamette meridian. (See pl. 10.) Its altitude ranges from 4,006 feet at Haystack Butte, on the eastern edge of the area, to 1,470 feet in the bottom of the Deschutes River Canyon, on the northern edge. The principal towns in the area from north to south are Madras, Metolius, Culver, Opal City, and Terrebonne. The Oregon Trunk Railway, running from Wishram to Bend, crosses the area from north to south.

Purpose of the investigation.—The purpose of the investigation was to make a geologic examination of dam sites on the Crooked River from its mouth to Trail Crossing. It was made at the request of O. C. Merrill, executive secretary of the Federal Power Commission, and was in part paid for by that commission. A report entitled "Geologic examination of dam sites on Crooked River" was submitted in October, 1925, and the present report is a by-product of that work. The writer spent from August 8 to September 5, 1925, in the field, and of this time about one week was devoted to a reconnaissance of the headwaters of the Deschutes River.

The topography shown on Plate 10 was taken from the Bend and Madras topographic maps of the United States Geological Survey, which were made after the writer did the geologic mapping. In transferring the geologic boundaries to the new base a certain amount of unavoidable error is involved, especially in the altitude of the formations in the canyons.

Acknowledgments.—The writer is greatly indebted to Mr. F. F. Henshaw, then district engineer, United States Geological Survey,

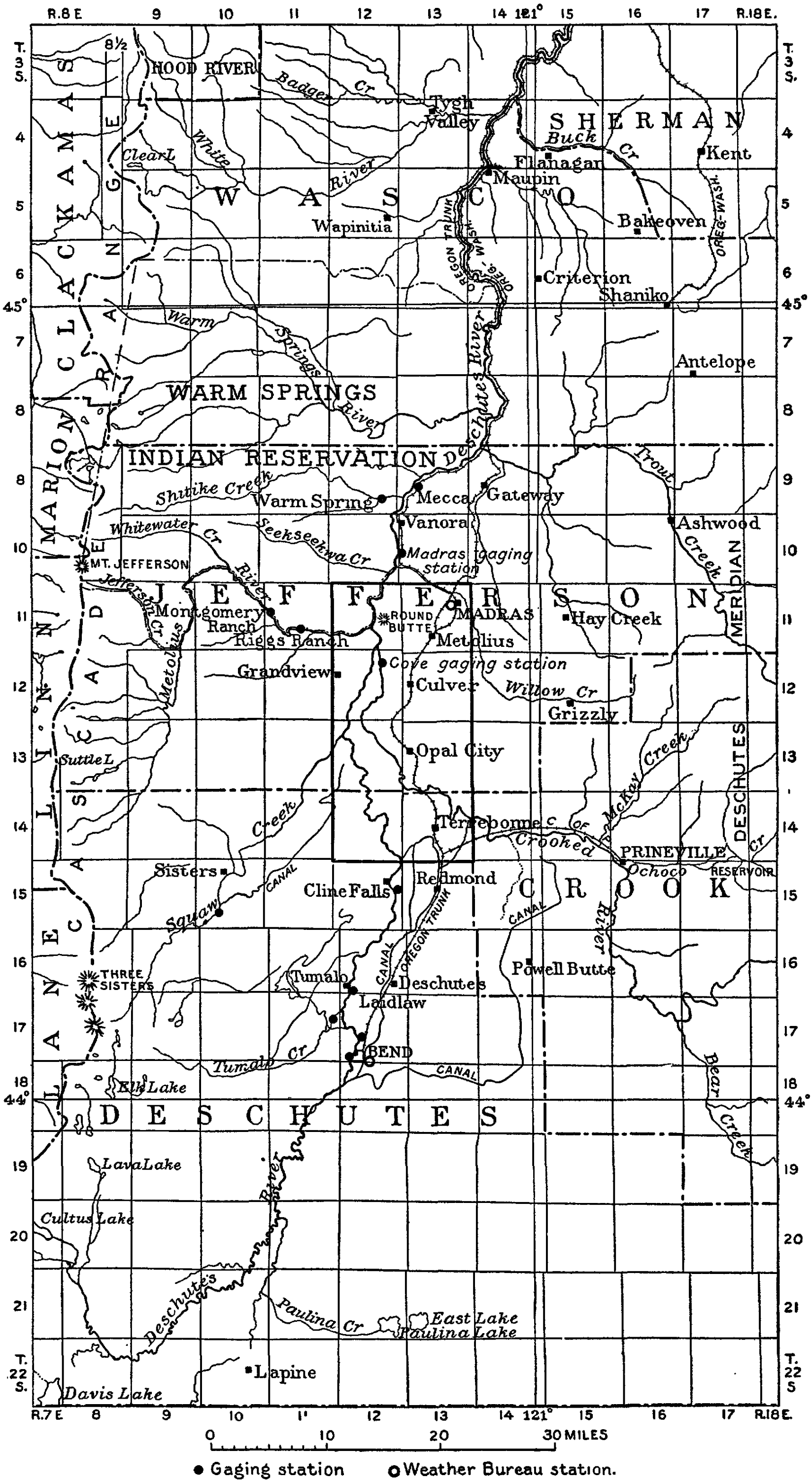


FIGURE 5.—Index map showing location of middle Deschutes River Basin, Oreg gaging stations, and Weather Bureau stations

and Mr. Ira A. Williams, consulting geologist, Portland, Oreg., for spending time in the field, imparting freely information they had gained by years of work in Oregon, and criticizing the report. He is particularly grateful to Mr. S. Murray, assistant chief engineer of the Union Pacific System, for permission to publish an abstract of Dr. A. C. Boyle's report on the diatomite deposit near Terrebonne. Acknowledgments are due also to the Columbia Valley Power Co., for maps and data on the area; to the Oregon Trunk Railway, for logs of the railroad wells in the area; to many drillers and residents, who gave valuable information regarding the underground water; and to Mr. H. V. Gates, for his cordial hospitality.

PHYSIOGRAPHY

The area is crossed from south to north by the Deschutes River. The Crooked River enters from the southeast and in the northern part of the area joins the Deschutes River. Two miles north of the mouth of the Crooked River, the Metolius River enters the Deschutes from the west. These rivers occupy canyons in a northward-sloping elevated lava plain, which is bounded on the west by the foothills of the Cascade Range and on the east by a low mountain range that has no general name. Haystack and Juniper Buttes belong to this low range.

The Deschutes River enters the area at an altitude of 2,720 feet above sea level, in a canyon about 100 feet deep and one-eighth mile wide. The canyon increases in depth toward the north. The river leaves the area at an altitude of 1,470 feet, where it flows in a canyon nearly a mile wide and about 850 feet deep. Between these two points the canyon is usually less than half a mile wide, and at the mouth of the Metolius it is 1,000 feet deep. The river has an average fall within the area of 35.2 feet to the mile.

The three waterfalls on the Deschutes River in this area, named in order downstream, are Odin Falls, Big Falls, and Steelhead Falls. At Odin Falls, in the SE. ¼ sec. 26, T. 14 S., R. 12 E., at an altitude of 2,675 feet, the water drops from one bed of basalt to another one, 10 feet below. About 8 miles downstream from Odin Falls, in the SE. ¼ NE. ¼ sec. 9, T. 14 S., R. 12 E., is the graceful Big Falls. (See pl. 11, *A*.) It is 30 feet high and is produced by a layer of hard basalt between softer sedimentary beds. In the SW. ¼ NW. ¼ sec. 27, T. 13 S., R. 12 E., 4½ miles downstream from Big Falls, is Steelhead Falls. The Deschutes at this place makes a vertical leap of 15 feet over a bed of basalt interstratified with soft strata of sedimentary origin.

Numerous narrow valleys separated by flat-topped ridges break the west rim of the Deschutes Canyon. Most of these valleys, except the Metolius and Squaw Creek Canyons, are occupied by ephemeral streams. The Metolius River is fed by numerous large springs and flows throughout the year. The only tributary on the east side of the Deschutes is Crooked River, which above its junction flows nearly parallel to the Deschutes for about 10 miles. The greater part of the strip of land between the canyons of these two rivers is known as the Peninsula. It is a northward-sloping, flat-topped, soil-covered lava bench bounded by the nearly vertical cliffs of the Deschutes and Crooked River Canyons. The top of the Peninsula near the north end lies nearly 1,000 feet above the two rivers. North of the Peninsula and at a slightly lower altitude, in the angle between the Deschutes and Crooked Rivers, is the Island, a mass of solid basalt 2 miles long, three-fourths of a mile widc, and about 900 feet thick, separated from the Peninsula by a low V-shaped pass through which a road crosses. (See pl. 11, *B*.)

The physiographic development of the Deschutes Valley has a long and complicated history, which is described at length on pages 150 to 152. It will suffice to note at this place that there is a northward-sloping lava bench on the east side of the Deschutes Canyon extending for a distance of about 10 miles north of the point where the river enters the area, and that remnants of this bench are found to a point within 4½ miles of the mouth of the Crooked River. In the remaining 4½ miles there are remnants of a southward-sloping bench that is much higher above the river.

The altitude of the Crooked River where it enters the area is about 2,750 feet; at Trail Crossing, in the NE. ¼ sec. 33, T. 13 S., R. 13 E., it is 2,550 feet above sea level. Upstream from Trail Crossing there is a fairly wide canyon with a narrow flood plain. The south wall is steep and consists of soft tuff beds surmounted by a rim of basalt about 40 feet thick. The opposite canyon wall extends to the crest of a ridge which is about 500 feet above the river. This wall is composed of tilted light-colored tuffs of unequal hardness. Weathering has caused some of these beds to stand out as spiny, serrated ridges and pinnacles. Russell[1] named this part of the canyon "Monument Canyon," but his name has not come into common use. The prominent spur in this area around which the river bends is known as Smith Rock. One mile upstream from Trail Crossing the north side of the canyon changes from light-colored tuffs and picturesque erosion forms to a ruddy brown slope covered with rounded knobs. This abrupt change is due to the cropping out of dense but minutely fractured ancient weathered basalt.

At Trail Crossing the Crooked River plunges into a narrow lava canyon. The following quotation from Russell[2] admirably describes this interesting crossing:

[1] Russell, I. C., Preliminary report on the geology and water resources of central Oregon: U. S. Geol. Survey Bull. 252, p. 87, 1905.
[2] Idem, p. 86.

Below Forest [now O'Neil] all the way to the Deschutes, a distance of over 30 miles, Crooked River flows in a narrow canyon with essentially, and often actually, vertical walls, and there is no alluvial land in its bottom. Throughout this portion of the river there is but one place where a team and wagon or even a pack train can be taken across it, namely, at Trail Crossing, about 18 miles below Prineville and 7 miles below Forest. Toward this locality Indian trails formerly converged on each side of the river; later frontiersmen, with their saddle ponies and pack horses, sought the same breaks in the canyon walls; and within the past few years a road has been graded on the declivities of the opposite facing precipices and a good bridge thrown across the river. Trail Crossing is thus an instructive locality in reference to the control exerted by geographic conditions on the affairs of men. The canyon, too, is of great geologic interest and on account of its wildness and picturesqueness will no doubt, in the future, attract to its secluded depths many curious travelers.

Trail Crossing was abandoned in 1926 because of its dangerous grades, and now the highest single-arch highway bridge in the United States, 350 feet above the stream and 330 feet long, spans the canyon, half a mile downstream from Trail Crossing. The canyon at this place is shown in Plate 12, *A*.

Below Trail Crossing the Crooked River Canyon increases in depth until at the mouth of the river it is more than 1,000 feet deep. The canyon is more remarkable, however, for the presence in places of an inner gorge. At the confluence of the Crooked and Deschutes Rivers the altitude is 1,614 feet above sea level. Thus the Crooked River falls 837 feet between Trail Crossing and its mouth, having an average gradient of nearly 40 feet to the mile. No falls occur in this stretch, although there are many rapids. The outer canyon ranges in width from half a mile to a little over a mile. The inner canyon is not present everywhere, but in long stretches of the river there is a northward-sloping lava bench, first on one side of the stream and then on the other, which has the same altitude as the rim of the inner canyon. In places this bench is over half a mile wide and carries sufficient soil to be farmed. It is 250 feet above the river at Trail Crossing, where it first appears, and its height increases downstream to 800 feet at the mouth of the river.

A remnant of the same bench forms the Island, and many portions of it are still preserved in the Deschutes Valley, the northernmost one occurring half a mile north of the area here mapped. Small remnants of this same bench are found also in the Deschutes Canyon for a distance of 4½ miles upstream from the mouth of the Crooked River (pl. 11, *B*), and two small remnants occur in Metolius Canyon. It is significant that the remnants of the bench along the Deschutes upstream from the mouth of the Crooked River slope southward, whereas those along the Crooked River slope northward. Likewise, those in the Metolius Canyon slope westward, whereas the remnants in the Deschutes Canyon downstream from the Crooked River slope northward. The significance of these differences is discussed on pages 145–148.

Squaw Creek and the Metolius River are the two remaining perennial tributaries of the Deschutes River in this area. Squaw Creek enters the area in sec. 18, T. 13 S., R. 12 E., and after flowing 2 miles northeastward joins the Deschutes in sec. 7. It rises at the foot of the glaciers on the east slope of the Cascade Range and, where it enters the area, occupies a canyon about 500 feet deep and a mile wide.

The Metolius River enters the area at an altitude of 1,625 feet and after flowing nearly 3½ miles joins the Deschutes at 1,555 feet. It occupies a canyon 1 to 1½ miles wide and about 1,000 feet deep. Like many parts of the Deschutes Canyon, the walls show a "grained" effect as a result of the erosion of hard and soft horizontal sedimentary beds. This canyon, like the others already described, is not visible from a point 1 mile from the rim.

Two miles northeast of the confluence of the Metolius and Deschutes Rivers, Round Butte rises from the canyon rim. Viewed from the south it is seen to be a dome 4 miles wide rising from the plain with slopes of about 5° and surmounted by a conical hill 350 feet high. (See pl. 13, *B*.) The top of the butte is about 700 feet above the adjacent plain. Viewed from either the east or west, however, it is found to be crowned by two conical hills, the northern hill being less conspicuous than the southern hill. On the north and east sides of Round Butte are Willow and Dry Creek Canyons, both 200 feet deep and occupied by ephemeral streams.

Another conspicuous feature on the Deschutes plain in this area consists of the Tetherow Buttes, in T. 14 S., R. 13 E. These buttes have a northwest trend and rise about 300 feet above the adjacent plain. Half a mile east of them, in secs. 21 and 28, is an abandoned canyon 2 miles long and in one place 200 feet deep, which is now farmed. About 2 miles northwest of Terrebonne rim rock outlines another abandoned canyon tributary to the Crooked River, but this is much less distinct than the one east of the Tetherow Buttes. Smaller abandoned canyons southwest of the Tetherow Buttes are also indicative of a disturbed drainage.

The dry canyon half a mile east of Tetherow Buttes is an abandoned spring alcove similar to those along the Snake River in Idaho described by Russell.[3] Some of the canyons near by also appear to be spring alcoves modified by later lava flows. These abandoned alcoves suggest that the springs now entering Deschutes and Crooked Rivers once may have discharged farther upstream. The writer has found evidence in the study of the spring alcoves along the Snake River to indicate that the size of the alcove reflects the volume of the water and the geologic age of the spring. As the large springs along the Deschutes and Crooked Rivers discharge from basalt

[3] Russell, I. C., Geology and water resources of the Snake River plains of Idaho: U. S. Geol. Survey Bull. 199, pp. 127-129, 1902.

similar to that along the Snake River, and as they do not have alcoves, it follows that the positions of their vents are geologically recent. This deduction is further borne out by the place in geologic history of the rocks from which most of them issue.

GEOLOGY

PREVIOUS GEOLOGIC WORK

Very little geologic work had been done in this area prior to the present investigation. In 1903 I. C. Russell made a hurried reconnaissance through central Oregon. On this trip he traveled down the Crooked River as far as Opal Springs and visited the Deschutes Canyon south of Squaw Creek. His admirable description of this part of the area appears in Bulletin 252 of the United States Geological Survey.

In 1921 A. C. Boyle, jr., made a geologic report to the Union Pacific Railroad Co. on the diatomite deposit near Terrebonne. An abstract of this report is given on pages 152–155.

In 1924 Ira A. Williams examined several dam sites below the confluence of the Metolius and Deschutes Rivers for the Columbia Valley Power Co., and he has imparted freely to the writer geologic information regarding the area.

STRATIGRAPHY

GENERAL CHARACTER AND AGE OF THE ROCKS

The middle Deschutes River Basin contains both sedimentary and igneous rocks. The sedimentary rocks are composed chiefly of volcanic materials, and no sediments older than Eocene are known in the area. The igneous rocks comprise lava flows, cinder cones, and fragmental volcanic deposits. Because the chief problems of underground water and possible leakage through and around proposed dams rest with the igneous rocks attention was centered on their structure and character.

A tabular summary of the general stratigraphy of the basin is given below and is followed by a detailed description of the rock units and a further discussion of their age. The general absence of fossils in the area makes the lithologic descriptions essential for the recognition of the formations in the field, and it is upon the lithologic characteristics that the interpretations regarding stratigraphy and structure here given depend.

Stratigraphic section of the middle Deschutes River Basin

Geologic age	Formation	Thickness	General character	Water-bearing characteristics
Recent.		Not measured.	Alluvium about 20 feet; pockets of fluviatile pumice; and 1 inch to 3 feet of loess.	Permeable, but occurs in too small an area to be an important source of water.
Late Pleistocene or Recent.		100–800 feet.	Fresh blue-black columnar-jointed basalt flows occupying and partly filling the Deschutes and Crooked River canyons and other tributary valleys; for convenience called intracanyon basalt.	Permeable, but contains no water, except in the vicinity of Trail Crossing, where springs issue from it. Elsewhere it lies above the water table.
Unconformity				
Early Pleistocene or late Pliocene.	Deschutes formation.	1,000± feet.	Horizontal beds of yellow, brown, and black partly consolidated sand, silt, gravel, and stratified fluviatile deposits of volcanic detritus, mostly basic, intercalated with and in most places capped by basalt flows. The lower basalt flow, more than 150 feet thick, is named the Pelton basalt member, and the upper flow, 25 to 150 feet thick, is for convenience referred to as the rim-rock basalt. Includes in a few places beds of white diatomite, which have a maximum thickness of 40 feet.	A little water found in the fluviatile portions, especially the black sand. The intercalated basalt flows are extremely permeable, and the lower ones are full of water. A great number of springs issue from them. The Pelton basalt is the chief water bearer of this formation. The rim-rock basalt is permeable but contains no water because it lies above the water table.
Unconformity				
Pliocene (?) or Miocene (?).		Not measured.	Dark-colored andesite, usually containing glassy feldspar phenocrysts 2 to 4 millimeters in diameter; believed to be flows from sources in the Cascade Range to the west.	Poor water bearer and in most places impermeable.
Unconformity				
Eocene (?).	Clarno (?) formation.	Not measured. Probable thickness over 1,000 feet.	Fine-grained consolidated yellow, cream-colored, gray, green, and red tuff, some beds soft and others massive and resistant.	Poor water bearer. A few seeps occur from these beds, and wells in them have small yields.
	Unconformity (?)			
	Trail Crossing basalt.	Estimated at not less than 200 feet.	Dipping massive brown columnar-jointed basalt, in most places minutely fractured. Outcrop usually characterized by reddish-brown soil containing small chips of weathered basalt.	A poor water bearer, and yields from wells in it are small.

TRAIL CROSSING BASALT (EOCENE ?)

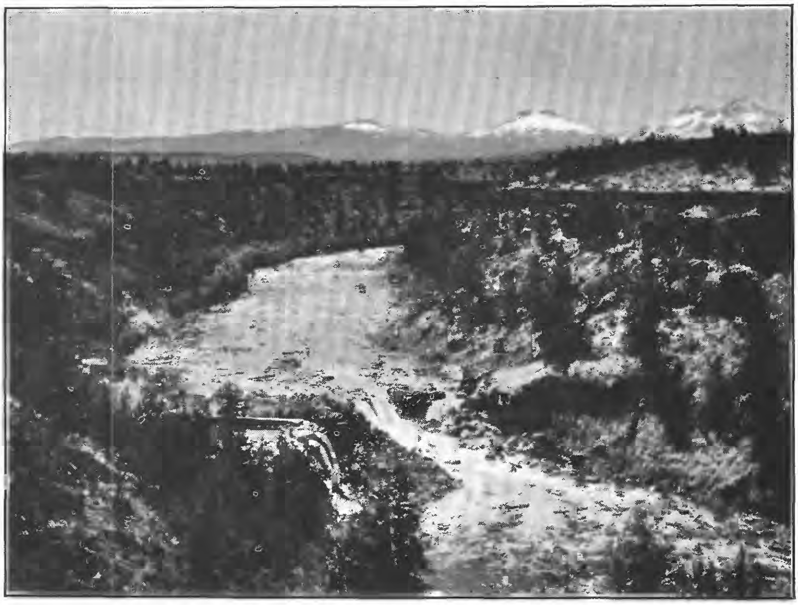
The oldest rocks that crop out in the area are weathered, minutely fractured basalt. They are exposed on both banks of the Crooked River at Trail Crossing and extend northeastward across the Haystack Butte country in a belt about 1 mile wide. Rocky ledges are absent, except in the river canyon. Elsewhere the basalt is traced by a dark-brown residual soil containing chips of weathered basalt. The boundary of this basalt is shown in most places on Plate 10 by a broken line, because time was not available to trace out carefully its contacts. Russell,[4] in his reconnaissance report on this area, refers to an outcrop of a great basic dike 1,000 feet wide at this place. A careful search was made for this dike, but it was not found. Instead, tilted basalt exhibiting typical columnar structure such as characterizes extrusive and not intrusive basalt was found exposed for a mile upstream. Some of the columns on the south side of the Crooked River in the Trail Crossing dugway are 2 feet in diameter. The basalt lacks the tight and regular jointing so characteristic of intrusive basalt. The tuff resting on it shows no sign of metamorphism at the few contacts observed, such as would be expected from a body of lava of this size, but time was not available to study the contacts in the hills north of Smith Rock. Consequently, the question whether the basalt is a sill or an extrusive mass will be left to the future investigator.

The tilted basalt in this canyon is exposed for more than 5,000 feet along the Crooked River. At Trail Crossing it is separated by an angular unconformity from overlying fresh black basalt flows.

Except near Trail Crossing it was difficult to determine strikes and dips with certainty because of poor exposures. At this place the basalt strikes N. 43° W. and dips 22° SW. and has an exposed thickness of over 200 feet. Between this basalt and the fresh black basalt in the canyon rim in the NW. ¼ sec. 3, T. 14 S., R. 13 E., several feet of thin-bedded greenish-yellow tuff is exposed, which strikes N. 68° W. and dips 20° SW. There is a marked angular unconformity between the tuff and the overlying black basalt, but the tuff appears to be nearly conformable with the underlying weathered basalt.

The tuff beds resting on the Trail Crossing basalt lithologically resemble the Clarno formation. Because the main purpose of the field work did not involve the basalt nor the overlying tuffs the stratigraphic details of these formations were not worked out. A reconnaissance of the area north and east of Trail Crossing suggests that this basalt may be intercalated with the Clarno and that some of the tuff near Haystack Butte is stratigraphically below the basalt. In any event this basalt is below the great mass of tuffs described in the following

[4] Russell, I. C., op. cit. (Bull. 252), p. 88.



A. BIG FALLS OF THE DESCHUTES RIVER

View looking southwest, showing the Three Sisters in the background. August 24, 1925.

B. VIEW LOOKING SOUTHWEST FROM THE EAST RIM OF CROOKED RIVER CANYON

Shows the pass between the Peninsula and the Island. The Island is a solid mass of intracanyon basalt. In the right background is a remnant of the same basalt in Deschutes Canyon.

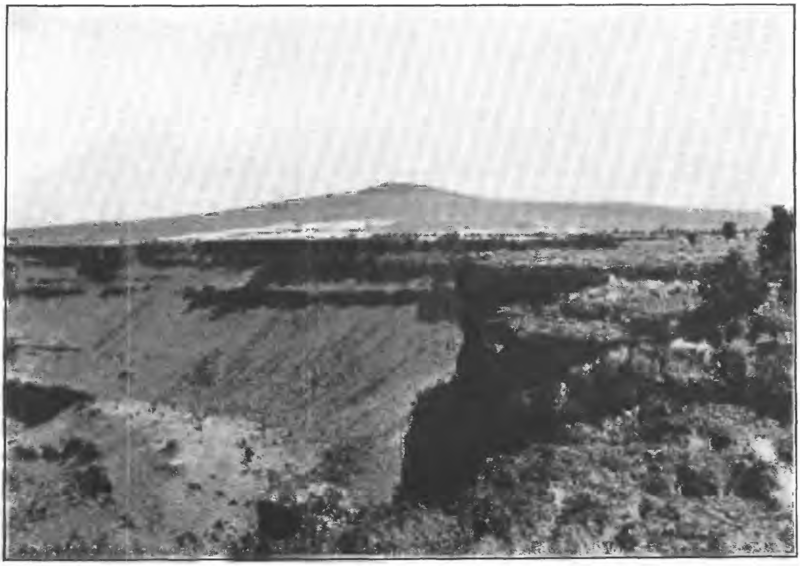
A. CROOKED RIVER CANYON

View looking up the canyon, showing railroad bridge and location of new highway bridge. The walls are intracanyon basalt.

B. EROSIONAL UNCONFORMITY OF THE INTRACANYON BASALT WITH THE DESCHUTES FORMATION IN NE. ¼ SW. ¼ SEC. 11, T. 12 S., R. 12 E.

A. DESCHUTES CANYON

View looking up the canyon from the NE. ¼ sec. 6, T. 13 S., R. 12 E. Shows the horizontal beds of the Deschutes formation. The cedars in the lower right corner grow on a remnant of the intracanyon basalt.



B. ROUND BUTTE

A cinder cone surmounting a low lava dome and the source of the rim-rock basalt which forms the rim. Looking northeast from east rim of Crooked River Canyon in the SE. ¼ sec. 35, T. 11 S., R. 12 E.

A. COLUMNAR JOINTING IN THE INTRACANYON BASALT

View on west abutment of the upper box canyon dam site on Crooked River.

B. UPPER BOX CANYON DAM SITE ON CROOKED RIVER

View taken from the SE. ¼ SE. ¼ sec. 28, T. 12 S., R. 12 E., showing narrow box canyon cut in the intracanyon basalt.

pages as Clarno (?) formation; hence the basalt is believed to be as old as Eocene.

CLARNO (?) FORMATION (EOCENE ?)

Resting upon the Trail Crossing basalt and so far as observed nearly conformable with it is a great series of soft but consolidated light-colored tuff beds. Although no fossils were found in these beds, a visit to the type localities of several Tertiary formations in the John Day Basin convinced the writer that these beds are lithologically similar to the Clarno. As a whole these beds contain less coarse pyroclastic material than at the type locality. Calkins[5] describes the Clarno formation in the John Day region as follows:

> Lithologically, the Clarno is a volcanic formation, in which truly detrital matter plays an unimportant part. The lower portion of the Clarno is composed in greater part of pyroclastic material, while in the upper half lavas including several different varieties are abundant.

Among these lavas Calkins describes a quartz basalt and Collier[6] shows a basalt sill in the Clarno.

The tuffs mapped as Clarno (?) formation in this report are estimated to be at least 1,000 feet thick. They are well exposed in both thin and thick beds in the region of Smith Rock, in the Crooked River Canyon above Trail Crossing. They also form Haystack and Juniper Buttes and occupy most of the adjacent country. The area covered by them is shown on Plate 10. This area, wherever traversed, was searched for fossils, but none were found. However, the mountainous area north of Smith Rock, where the beds are well exposed, is worthy of a careful examination. Two outliers of the beds were found in sec. 11, T. 12 S., R. 13 E.

Two specimens from this formation were examined under the microscope by C. S. Ross, of the United States Geological Survey, who describes them both as volcanic tuffs. Specimen B–10 is composed chiefly of pumice fragments. The pumice is partly silicified, and small veinlets of quartz cut the feldspar phenocrysts.

On the east side of Lone Pine Valley, 12 miles due east of Trail Crossing, there are exposed some white tuff beds overlain by basalt.[7] Although no fossils were found here, it appears very likely that these white tuffs belong to the John Day formation and that the overlying basalt is of Miocene age, as determined by Merriam.[8] Again, half a mile north of the area mapped basalt lithologically similar to that

[5] Calkins, F. C., A contribution to the petrography of the John Day Basin: California Univ. Dept. Geology Bull., vol. 3, p. 113, 1902.

[6] Collier, A. J., The geology and mineral resources of the John Day region: Mineral resources of Oregon, vol. 1, No. 3, fig. 1, Oregon Bur. Mines and Geology, 1914.

[7] The writer is indebted to F. F. Henshaw for showing him this locality.

[8] Merriam, J. C., and Sinclair, William, Tertiary faunas of the John Day region: California Univ. Dept. Geology Bull., vol. 5, pp. 303–305, 1907.

at Pine Valley crops out in the Deschutes Canyon. These basalts are traceable into known Columbia River basalt in the lower part of the Deschutes Valley. Through the personal guidance of Mr. Williams the writer saw the contact of this basalt with underlying white tuffs of the John Day formation at Mecca, about 10 miles north of the area shown on Plate 10. From the hurried visit to these two localities it seems that the John Day formation and the basalt at Mecca were once connected with outcrops on the east side of Lone Pine Valley and have since been removed by erosion from the top of the great anticlinal fold, with the subsequent exposure of the Clarno (?) tuffs in the Smith Rock and Haystack Butte region.

ANDESITE (MIOCENE? OR PLIOCENE?)

In the southern part of the area occur masses of andesite which have been uncovered by erosion. The age of the andesite is unknown, but it is separated from the overlying horizontal sedimentary beds by a steep erosional unconformity. The proximity of these andesite masses to the great andesitic volcanoes of the Cascade Range suggests that they originated in that range. They are correlated tentatively with the older andesitic lava flows of the Cascades, which are usually assigned to the Pliocene. One large mass of andesite covering about 3 square miles occurs along the line between Tps. 13 and 14 S., R. 12 E. Three other areas of it were mapped in the southwestern part of T. 14 S., R. 13 E. One small outlier in sec. 15, T. 13 S., R. 12 E., on the Peninsula, consists of only a few large weathered blocks, which appear to be in place. An excellent contact of the andesite with the overlying sediments is found along the Deschutes River in sec. 4, T. 14 S., R. 12 E. At this place blocks of andesite are distributed through the overlying beds of tuff and pumice close to the contact in such a way as to show that they accumulated as successive talus heaps during intermittent ash showers. At other places the contact is not conspicuous. The andesite is black in fresh specimens, but in the field it forms weathered brown knobs a few feet high. All the andesite examined in hand specimens is porphyritic, containing phenocrysts of glassy yellow feldspar 2 to 4 millimeters in diameter embedded in a black matrix. Specimen B–7, collected in the N. ½ sec. 7, T. 15 S., R. 13 E., was examined under the microscope by C. S. Ross, who describes it as follows: Porphyritic andesite with phenocrysts of plagioclase and augite. The groundmass consists of very fine-grained feldspar laths in a glassy matrix.

DESCHUTES FORMATION (LATE TERTIARY OR EARLY PLEISTOCENE)

Character and occurrence.—Resting unconformably upon all the rocks previously described is a remarkable series of horizontally bedded, partly consolidated sand, silt, gravel, and stratified fluviatile deposits of volcanic materials, with volcanic débris, mostly basic, resulting from ash showers of volcanoes. These beds make up the Deschutes formation. (See pl. 13, A.) Intercalated with them and in most places capping them are basalt flows and in a few places diatomite deposits.

At the contact of the Deschutes beds with the andesite in the Deschutes River Canyon in sec. 4, T. 14 S., R. 12 E., is field evidence that some of the horizontal and evenly bedded ash and pumice members of this formation were deposited subaerially. Within a few feet of the andesite the lamination and bedding loses its distinctness, and the beds end abruptly in wedge-shaped masses filled with andesite talus. (See fig. 6.) Without this striking contact it would be natural to think that all the evenly laminated volcanic beds of the Deschutes formation were subaqueous.

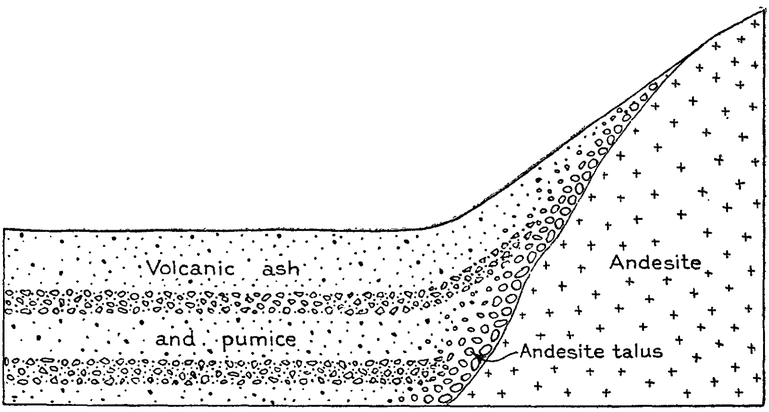


FIGURE 6.—Subaerial depositional contact of ash and pumice of the Deschutes formation with andesite in sec. 4, T. 14 S., R. 12 E., Oregon

The Deschutes formation, as these interbedded sediments and basalt flows are here designated, is known to be present over nearly 250 square miles of the area mapped, and it has been traced many miles in all directions from this area. (See pl. 10.) It is estimated that when fully mapped it will cover at least 1,000 square miles. It has an exposed thickness of more than 1,000 feet in the Deschutes Canyon. The uppermost basalt flows of the formation are for convenience designated rim-rock basalt, because they form the rim of the Deschutes and other canyons, and for the lowest intercalated basalt member Ira A. Williams has suggested the name Pelton basalt.

The Deschutes formation was first described by Russell,[9] who suggested the name Deschutes sand for it. Because it contains lava

[9] Russell, I. C., op. cit., p. 90.

beds, diatomite, and many other deposits, the name Deschutes formation was given to it by Williams [10] in 1924.

An aneroid measurement of the Deschutes formation was made along the foot trail descending to the Metolius dam site on the east side of the Deschutes Canyon. The section at this place is as follows:

Section of east wall of Deschutes Canyon in sec. 22, T. 11 S., R. 12 E.

	Feet
Yellow loess soil	0.5
Deschutes formation:	
Basalt flow (rim-rock basalt)	10
Two basalt flows (rim-rock basalt), total thickness	15
Volcanic agglomerate, containing mostly basic ejectamenta with some lenses of gravel	55
Bed of columnar-jointed basalt	40
Two basalt flows, total thickness	55
Volcanic agglomerate, containing mostly basic ejectamenta in form of dense explosion blocks	55
Basalt flow	10
Volcanic agglomerate, containing basic ejectamenta cemented in ash	15
Basalt flow	15
Basic volcanic agglomerate of explosive volcanic débris, containing an intercalated bed of basalt a short distance north of this section	290
Basalt flow	20
Basic, massive volcanic agglomerate	215
Basalt flows, number indeterminable (Pelton basalt member)	150+
	945+

The following section measured by aneroid on the east wall of the Crooked River Canyon, 3½ miles south of the section given above, shows how variable the beds are in the Deschutes formation:

Section of Deschutes formation in east wall of Crooked River Canyon in sec. 11, T. 12 S., R. 12 E.

	Feet
Massive columnar-jointed basalt flow (rim-rock basalt)	30
Basalt flow (rim-rock basalt)	15
Thick and thin beds of water-laid black and yellow sand, pumice, tuff, and coarse gravel	700
Bedded basalt flows, number undetermined (Pelton basalt member)	130
	875

The following section is incomplete for the exposed part of the Deschutes formation on the east wall of the Crooked River Canyon but is complete from the top of the bench near Opal Springs to the river. Above this section 325 feet of the Deschutes formation crops out.

[10] Williams, I. A., Geology of the Pelton dam site, Oregon, unpublished report in the files of the Federal Power Commission.

Section of Deschutes formation from altitude of 2,375 feet to Crooked River in sec. 33, T. 12 S., R. 12 E.

	Feet
Stratified sand and tuff	30
Aa basalt, porous and brecciated	50
Red tuff, fine grained	20
Fine-grained tuff and agglomerate	115
Coarse conglomerate	20
Pahoehoe basalt flow	25
Soil, probably loess	4
Basalt flow	36
Stratified sand and tuff, with thick bed of coarse conglomerate at base	125
	425

In the Deschutes Canyon the beds are even more complex in places. (See pl. 13, *A*.) It is known that some of the interstratified basalt flows were erupted in the basin, because buried cinder cones have been penetrated by the drill. In well 5 (pl. 10), in the NE. ¼ sec. 2, T. 12 S., R. 13 E., 84 feet of red basaltic cinders was struck below 221 feet of conglomerate. Deposits of cinders such as were struck in this well are indicative of a cinder cone near by. Some of the other wells in the basin also encountered cinders.

Pelton basalt member.—The lowest interstratified basalt in the Deschutes formation is exposed in the Deschutes Canyon from the line between Tps. 12 and 13 S., R. 12 E., all the way to the north boundary of the area. It was not traced beyond this point but is known to continue for several miles downstream. In the northern part of T. 11 S., R. 12 E., this basalt forms a bench nearly a quarter of a mile wide on both sides of the Deschutes River. It also extends northward and underlies the former railroad station of Pelton. Because of the importance of this bed as a water bearer and its critical relation to the dam sites in the region, it has been named, for convenience, the Pelton [11] basalt member, after the old railroad station. It has a known thickness of over 150 feet and is traceable up the Crooked River nearly 4 miles from its mouth. It also extends up the Metolius River for at least 2 miles and then passes under the sedimentary beds of the Deschutes formation. Undoubtedly it is the most extensive and the thickest of all the interstratified basalt members of the Deschutes formation. The Pelton basalt usually consists of several beds that were laid down in rapid succession, and it is not unlikely that they were all poured out during a single eruption. Mr. Williams has kindly furnished the following microscopic description and analysis of a sample of the Pelton basalt taken from a hill on the west side of the Deschutes Canyon at the Pelton dam site, 3 miles north of the area mapped.

[11] This name has been hitherto used in private reports by Ira A. Williams.

Microscopic description: Diabasic, micropoikilitic, and vesicular in texture. Pore space amounts to about 10 to 15 per cent. Feldspar laths 2 millimeters in length, and some olivine the same size. The amount of glass is small and filled with magnetite.

Percentage composition: Labradorite, 65; augite, 15; olivine, 15; magnetite, 3; glass, 2.

Rim-rock basalt.—The Deschutes sedimentary beds are capped in about one-half of the middle Deschutes River Basin by beds of basalt. In the rest of the area this basalt cover has been removed by erosion. It is very prominent because it forms the rim rock to the canyons and underlies at shallow depths much of the agricultural area. Its thickness varies according to the distance from its source, and most, if not all, of its sources are still visible as cones on the plain. This upper member of the Deschutes formation also forms a wide plateau, known as Agency Plains, extending northward from the area mapped and from the Metolius River. Because this basalt is conspicuous as the protective, resistant rock of the region it is here referred to as the rim-rock basalt, a term in common use among the local people. The distribution of this basalt and the cones from which most of it issued is shown on Plate 10. Fourteen well-preserved cones were found in the area, but they were not the source of all of this upper member of the Deschutes formation, for basalt flows entered the area from the west, overlapping and interfingering with the flows from these cones. The largest vent in the area is Round Butte, which is a double cinder cone surmounting a low lava dome. (See pl. 13, *B*.) Considerable lava issued from this vent before activity ceased, but most of it has since been removed by erosion. The effect of a semiarid climate on erosion is clearly exemplified by this butte. Its form is perfectly preserved, and its surface has been scarcely rilled by water. The cinders of which it is composed are weathered at the surface but are fresh at shallow depths. Sufficient wind-blown dust has been deposited on its lower slopes to make agriculture feasible, but otherwise its form is the same as it was eons ago. This is due largely to its extreme permeability. Its lava flows were spread out evenly upon the plain, and if it were not for the great canyon carved through them no one would suspect that the cone had long been silent. However, not only has a 1,000-foot canyon been carved since it was in eruption but also a second canyon nearly as deep in the intracanyon basalt.

From points on the rim of the Deschutes Canyon is seen a striking contrast between the canyon, representing immense lapses of time, and the perfect cone with the seemingly short interval of time since its last eruption—a view which gives a geologist a deep impression of the work of a swift river in a desert land. (See pl. 13, *B*.)

An inconspicuous symmetrical round cinder cone about 40 feet high occurs in sec. 3, T. 13 S., R. 12 E. Its weathered cinder surface is covered entirely by grain fields. In the heaps of stone cleared from this land are numerous large cindery masses and a great number of round breadcrust bombs. Dozens of spiral or twisted bombs also lie on the surface of the cone. The flows from this cone spread out in all directions. In the NE. ¼ sec. 11 of the same township there is a lava knoll about 40 feet high that may be another vent. It has a cone shape, but no cinders were found on it. It was not mapped as a cone because of insufficient evidence.

Two other low cinder cones are present in secs. 18 and 20, T. 13 S., R. 13 E. They are very inconspicuous, but numerous cinders are scattered on their surface in the loess cover. One of these cones gave vent to an aa flow which is seen in a railroad cut in sec. 13, T. 13 S., R. 12 E., where it is overlain by 3 to 5 feet of soil and caliche. The vesicles of the lava are filled with a transparent white mineral that was not determined.

In the northeast corner of sec. 31, T. 13 S., R. 13 E., there is a cinder cone whose structure is excellently exposed in the adjacent railroad cut. In this excavation there are beds of black and red cinders as fresh as those formed on Kilauea Volcano, Hawaii, in historic time. They are overlain by a little wind-blown sand and caliche.

The Tetherow Buttes, in T. 14 S., R. 13 E., are three cinder cones in a line running northwest and southeast. They rise nearly 200 feet above the plain, and their slopes are cut in places by erosion. A fine exposure of cinders occurs in a pit on the slope of the southern one from which road material is being removed. The three cones are connected by a deposit of cinders, and it is believed that they were all in eruption at the same time. Doubtless a considerable portion of the rim-rock basalt flowed from these vents.

In a line with the Tetherow Buttes and about 5 miles northwest of them on the Peninsula is a group of cones. The northern one is about 75 feet high; the others are not over 25 feet high. The lava from these vents flowed northwestward down a gentle slope, indicating that the Deschutes had begun its work of erosion. The rim rock basalt on the opposite canyon rim did not come from these vents but from others southwest of the area mapped.

An inspection of Plate 10 shows a northwest-southeast alignment of the cones. They were certainly formed by eruptions along a fissure, and their direction may indicate buried fault lines in the Deschutes Valley. The fact that the alignment is almost parallel with the axis of the valley suggests that northwest-southeast faults may have played an important part in the formation of this valley.

Age and correlation.—The Deschutes formation was carefully searched for fossils, but none were found, except the minute one-celled siliceous algae skeletons that make up the diatomite deposits. Mr. Charles Heim, of Terrebonne, informed the writer that an Indian who worked for him but who was away at the time had found fossil shells in the vicinity of Steelhead Falls. He kindly sent one of his other men with the writer to search for the fossil bed, but it was not found. The age of the beds therefore remains unknown. In the John Day region, where the stratigraphy has been carefully worked out, there exists a formation, very similar in structure and lithology to the Deschutes formation, known as the Rattlesnake formation. The following short description of the Rattlesnake formation, by Calkins,[12] shows this similarity:

> This lies in almost horizontal attitude upon the tilted and truncated Mascall beds in the elongated area mentioned above. Doctor Merriam named this formation and considered it of Pliocene age. It appears to be of fluviatile origin in large part and comprises a large amount of coarse gravel and sandstone, together with fine material that may be tuffaceous. Somewhere in the middle of the section there occurs a widely spread sheet of light-colored pumiceous tuff, overlain by a glassy gray rhyolite.

If the Deschutes formation is the correlative of the Rattlesnake it is Pliocene. However, Williams[13] found unconformably above the Columbia River basalt in the Columbia River gorge a similar series of sedimentary beds which have been correlated with the Satsop formation of the Pacific coast of Washington. Dr. R. W. Chaney identified from these beds numerous fossil plants tentatively referred to the Pleistocene, and the Satsop formation as recognized in the Cascade Range has been assigned to that epoch. Mr. Williams, who is very familiar with the middle Deschutes Basin, believes that the Deschutes formation may possibly be a correlative of the Satsop because of its lithologic resemblance to the Satsop and because it rests unconformably on the Columbia River basalt. However, in the Columbia River gorge the beds called Satsop are overlain in places by andesite flows, whereas in the middle Deschutes River Basin the Deschutes formation everywhere rests upon andesite; hence the Deschutes formation may be younger than the Satsop. Andesite flows were erupted in the Cascade Range over a long interval of time; hence the andesite that overlies the beds identified as Satsop in the Columbia River gorge may be much younger than the andesite in the middle Deschutes Basin. In the northern part of the Deschutes Valley, near Maupin, the Deschutes formation certainly occupies the same position in relation to the Columbia River basalt as the beds identified as Satsop formation[14] occupy in

[12] Calkins, F. C., op. cit., p. 114.

[13] Williams, I. A., The Columbia River gorge: Oregon Bur. Mines and Geology Bull., vol. 2, No. 3 (revised reprint), p. 128, May, 1923.

[14] A recent article by J. P. Buwalda and B. N. Moore (Science, new ser., vol. 66, p. 236, Sept. 9, 1927) states that they have obtained from the Dalles formation of the Columbia River gorge fragmentary mammalian fossil remains of upper Miocene or lower Pliocene age, and that inasmuch as they have found that the so-called Satsop formation in the eastern part of this gorge underlies the Dalles formation it can not be correlated with the typical fossiliferous marine Pleistocene Satsop formation of the Washington coast. They have therefore renamed the gorge deposit Hood River formation and assigned it to the upper Miocene or lower Pliocene.

the Columbia River gorge. It would be unwarranted to assign the age of the Deschutes formation by means of such long-range correlation; hence it is tentatively classified as late Tertiary or early Pleistocene. It is possible that fluviatile deposition continued from Tertiary into Pleistocene time in the Deschutes Basin without cessation and that the Deschutes formation represents deposits during both Rattlesnake and Satsop epochs.

LATE PLEISTOCENE OR RECENT BASALT (INTRACANYON BASALT)

After the excavation of canyons 200 to 1,000 feet deep in the Deschutes formation many basaltic lava flows were poured out in the vicinity of Bend, some of which spread northward and entered the canyons of the middle Deschutes Basin. Because all of this basic lava occupies ancient or existing canyons in the middle Deschutes Basin it is for convenience here referred to as the intracanyon basalt. South of this area it will probably be found on the surface and be conformable in places with the rim-rock basalt. This intracanyon lava ranges from 100 to about 800 feet in total thickness, in places consisting of only one thick bed and in others of a number of beds. Nearly all of it came from the same source at the same general time. It is separated from the underlying formations everywhere in the middle Deschutes Basin by a sharp, steep erosional unconformity. (See pl. 12, *B*.) A specimen of the intracanyon basalt, collected by Ira A. Williams on the east side of the Deschutes Canyon 1 mile upstream from the Metolius dam site, was examined by the writer. It has a blue-gray color and resembles a diabase in appearance. Small pale-yellow crystals of olivine and minute crystals of feldspar are determinable under the hand lens. The specimen abounds in tiny irregular-shaped cavities as well as spherical vesicles 1 millimeter or more in diameter. Under the microscope labradorite, olivine, augite, and magnetite are readily distinguished. The augite and olivine appear in about the same amounts, and numerous well-formed magnetite crystals are present as inclusions. The augite and olivine in the specimen examined do not exceed 0.2 millimeter in diameter, and the feldspar rarely exceeds 0.5 millimeter in length. Transparent glass may be present in exceedingly small amounts.

The intracanyon basalt along the Crooked River is a remarkable flow. It was not traced to its source, hence its total length is unknown. However, the numerous exposures of this lava in the Crooked River Canyon throw considerable light on its history. Above Trail Crossing it has a thickness of 10 to 50 feet wherever exposed. It is believed to be considerably thicker than this, for the Crooked River was pushed northward by the lava flow, and its ancient buried channel lies about half a mile south of the present river. A mile downstream from Trail Crossing, near the railroad bridge, the river has not yet exposed the underlying Deschutes formation—a fact indicating that the lava exceeds 350 feet in thickness. (See pl. 12, *A*.) The present river at this place lies above its buried channel. In the south wall of the canyon near the bridge some remarkable fan jointing similar to that described by Judd[15] is exposed. The upper 25 feet consists of imperfect columnar-jointed basalt crossed by parallel horizontal joints that make blocks about 1 cubic foot in volume. This material changes downward abruptly into about 100 feet of finely jointed basalt. The joints in this mass are tight and divide the lava into long, slender blocks a few inches in diameter. In several places these slender blocks are arranged like the ribs of a fan 30 feet long radiating downward from points 25 feet below the surface of the flow. There are several such fans side by side which spread out in arcs of about 45°. The upper joint structure indicates that the top 25 feet cooled by fairly rapid radiation through vertical shrinkage cracks. The fan jointing seems to indicate that below this upper 25 feet cooling progressed downward in all directions from certain definite points. These points were probably determined by large deep cracks in the surface of the flow. Below the massive bed, with slender jointing, where no definite pattern exists, except for the few fans near its top, there are three beds with regular columnar jointing. All these patterns are apparently developed in one thick flow.

From the south boundary of the area mapped to the railroad bridge the intracanyon basalt has a width of a mile or more, apparently obliterating an open canyon. Below the bridge the flow narrows to a width generally not exceeding half a mile, as a result of being confined in a narrow, deep canyon. About 1½ miles downstream from the bridge, in sec. 31, T. 13 S., R. 13 E., the entire south wall of the canyon is made up of the Deschutes formation, except for a narrow tongue of basalt that occupies what appears to have been an ancient gulch tributary to the Crooked River. Along the south line of this section the intracanyon flow of the Crooked River merges without a perceptible break into the intracanyon lava in the Deschutes Valley to the south. It appears that at this place the Deschutes flow was concurrent with the Crooked River flow and that it spilled over the rim of the Crooked River Canyon and united with the intracanyon basalt of the Crooked River. The relative age of the two great flows can not be determined definitely until they have been traced southward to their sources.

Because lava is considerably more viscous than water, the surface of the flow does not retain the gradient of the prelava valley bottom, but the flow thickens downstream. Thus at the Cove power plant the top of the flow is 2,380 feet above sea level, and it is 580 feet thick.

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[15] Judd, J. W., Volcanoes, p. 106, New York, D. Appleton & Co., 1881.

At the railroad bridge 16 miles upstream it has an altitude of 2,800 feet and is about 400 feet thick. For the intervening distance of 16 miles it has a gradient of 26 feet to the mile, whereas the gradient of the valley bottom is about 38 feet to the mile. All long lava flows are thicker toward their terminations, because lava becomes cooler and hence more sluggish as it flows.

The general character of the Crooked River flow changes considerably from place to place. Near Opal Springs four distant layers of jointed basalt occur, some vertically and others irregularly jointed. (See pl. 14, *A*.)

Where it entered the Deschutes Canyon the Crooked River flow made an immense triangular fill occupying the combined width of Deschutes and Crooked Canyons. The flow did not stop here, however, but continued on down the Deschutes for many miles. The farthest known remnant of this flow downstream is 125 feet thick and lies in Deschutes Canyon, 8 miles below the mouth of the Crooked River. However, this remnant is only a small piece of the flow and does not represent the total thickness, hence it is not unlikely that the flow continued at least another 10 miles down the canyon. A small remnant of the flow was found over 2 miles up the Metolius Canyon, showing that the Crooked River intracanyon lava not only flowed many miles down the Deschutes Canyon but also flowed up the Metolius Canyon. Thick remnants of intracanyon basalt that slope southward, or upstream, occur in the Deschutes Canyon for a distance of 4½ miles above the mouth of the Crooked River. These remnants are parts of the Crooked River flow that flowed up the Deschutes Canyon. Such a statement sounds paradoxical, for it has just been said that lava is less fluid than water. The feat was accomplished, nevertheless, by an accumulation of lava sufficiently thick at the confluence of the two rivers to cause a down grade for the lava in the direction from which the Deschutes River had previously been flowing. These lava masses at the confluence of the Deschutes and Crooked Rivers and of the Metolius and Deschutes Rivers acted as immense dams that temporarily ponded these rivers. Evidence of this ponding is shown by the alluvial deposits 20 feet thick on top of the intracanyon remnants in the Deschutes Canyon east of Grandview. One of these lava remnants is shown in Plate 11, *B*.

The question immediately arises how such a flow with a known length of 36 miles and a probable length of 50 miles could keep hot enough to flow such a distance. This question would be difficult to answer from observations in the Crooked River Canyon, for the structure of the flow throws little light on the subject. However, as pointed out above, the jointing and bedding vary from outcrop to outcrop. On the west wall of the Deschutes Canyon in sec. 15,

T. 11 S., R. 12 E., the intracanyon basalt consists of 23 distinct layers. Such variations in structure indicate that the flow at no time or place was a great moving river of lava several hundred feet thick. The distribution of lava to such distances as are indicated by the length of this flow is accomplished by means of a great subway system of tubes connecting the source with the end of the flow. The tubes or tunnels through which the lava moves are formed within the flow itself by the crusting over of a lava river. Once they are formed the lava is able to travel long distances underground without any great loss of heat, for radiation through the crust of a lava flow is very slow. This method of distribution has been frequently witnessed. Thus during the great eruption of Mauna Loa, Hawaii, that lasted for nine months in 1880–81 lava flowed about 30 miles underground and at the margin of the advancing flow was still very fluid. Furthermore, people walked on the crust of the flow near the vent and saw through cracks the molten lava flowing in great subterranean channels. The occurrence of numerous caverns in every great basaltic lava field is proof that this is the usual method of flow of lava of such types.

A great intracanyon fill similar in most respects to the Crooked River intracanyon basalt was formed in historic time in Iceland. In June, 1783, Skaptâr Jökull poured out immense volumes of lava that exceeded in volume any other eruption of historic time. According to Henderson,[16] the lava descended Skaptâ Valley for a distance of 50 miles, making a lava fill in places 600 feet deep. It also sent a tongue down the valley of the Hverfisfliot for 40 miles, and yet after the eruption ceased the river again returned to its valley. The Skaptâ Valley was filled in about a month, although the vent was in eruption for several months before it ceased flooding the surrounding country with lava. It must have been a similar eruption that sent the immense flow down the Crooked River Canyon.

A prehistoric intracanyon flow of andesite over 15 miles long in the Tieton and Naches Valleys, Wash., has been described by Smith.[17] Intracanyon lava flows are not uncommon in the western part of the United States, but few of them were formed during a single great eruption such as the one in the Crooked River Canyon.

In several places in the Deschutes and Crooked River Canyons, especially near Cove Crossing, erosion has left the intracanyon basalt as wedge-shaped segments high on the canyon walls. The open and slaggy contacts of the basalt with the Deschutes sediments serve as drains for ground water seeping out of the sediments at the contact and for surface water running off the canyon wall. In places where conditions have been favorable these wedge-shaped masses of

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[16] Henderson, E., Iceland, p. 229, Edinburgh, 1819.

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

the basalt have been detached along the contact by this process and have slid into the bottom of the canyon.

The intracanyon basalt flow in the Deschutes Canyon is not as well exposed as the Crooked River flow, but it plays an important part in the routes of underground water and in the displacement of streams. It enters the area in three distinct divisions occupying the same number of ancient valleys, indicating that the whole region not far upstream was deluged with a great flood of lava that drained northward through these three valleys. In sec. 31, T. 14 S., R. 13 E., the lava flowed south up a valley and not north down the valley, as one would naturally suppose. Plate 10 does not clearly show this condition. One mile north of the point where they enter the area the three intracanyon flows unite as two flows, each over a mile wide. Separating the two flows at this place is a narrow outlier of rim-rock basalt 2 miles long that formed a flat-topped ridge between two ancient valleys. Farther north the two flows unite into one flow 2 miles wide. Still farther north, in sec. 12, T. 14 S., R. 12 E., the flow again separates into three streams. One small stream flowed north to the Crooked River; another stream terminated 3½ miles to the north against the rim-rock basalt of the Peninsula, and a third stream flowed down the valley of the Deschutes. Near Lower Bridge this third stream of lava flowed 2 miles up an unnamed canyon. In secs. 29 and 30, T. 14 S., R. 12 E., there is a short intracanyon flow that came from two small vents in the same sections. This flow has no connection with any of the other intracanyon lava. One of the vents is a driblet cone in the NW. ¼ sec. 29, the other a lava cone in the SW. ¼ sec. 30.

The Deschutes intracanyon lava obliterates an intricate drainage pattern. As the field work was largely centered on the Crooked River the details of the drainage disturbances on the Deschutes were not worked out. It appears, however, that the Deschutes River is entirely displaced from its former channel from the point where it enters the area to the line between Tps. 13 and 14 S., R. 12 E., where it again enters its prelava channel. The position of the buried portion of the old channel is not definitely known. The erosion remnants of rim-rock basalt with their cliff walls and the great stretch of intracanyon basalt suggest that the Deschutes formerly flowed due north for 7½ miles after it entered this area and then flowed northwest. If the Deschutes did not follow such a course it is certain that some tributary did. This buried channel has an important bearing on ground water and is believed to cause the numerous springs that enter the west side of the Crooked River in sec. 14, T. 13 S., R. 12 E. The presence of two other partly filled valleys west of Tetherow Bridge points to the former existence of two other streams. Whether these valleys were occupied by tributaries to the Deschutes is not known. In order to determine this question the geologic mapping will have to be carried a considerable distance south of T. 14 S. It is possible that the valleys were both formed by the Deschutes River and that flows of basalt have occurred at this place on different occasions separated by long intervals of time during which the Deschutes excavated new canyons.

The remnants of basalt in the Deschutes Canyon indicate that the last flow went within 4½ miles of the mouth of the Crooked River. These remnants do not exceed 100 feet in thickness and lie low on the canyon wall. If this flow occurred simultaneously with the one in the Crooked River Canyon, the two flows must have met in the vicinity of the confluence of the two rivers. It is believed that this occurred, but that the lava flowing down the Deschutes was much less in volume and probably reached the confluence in the later phases of the eruption, owing to its pooling in the area north of Tetherow Bridge. In any event, it was so overwhelmed by the great Crooked River lava flood that all traces of it below sec. 29, T. 12 S., R. 12 E., are gone.

The age of the intracanyon basalt is unknown, but from its stratigraphic position it is thought to be late Pleistocene or Recent. It is little weathered, and all the original surface features of the flows are preserved, except the thin glassy crust a fraction of an inch thick, which has flaked off and lies in the depressions on the surface. The immense canyons cut into it give an impression of great antiquity, yet the jointed and fractured lava yields readily to the swift rivers of the region. The great postglacial canyon of the Niagara River is mute evidence of the gigantic erosive power of a river during the time that has elapsed since the end of the Pleistocene epoch. Dry River,[18] a wide, dry canyon, dozens of miles long, that enters the Crooked Canyon a few miles upstream from this area, may have contributed immense volumes of water to the Crooked River during the final stages of glacial time and aided considerably in the task of excavating a canyon in the intracanyon basalt.

RECENT ALLUVIUM

Recent alluvium occupies too small an area to be shown on Plate 10. The largest deposit found covers only a few square yards at the top of the highway grade, 1½ miles east of Grandview post office. At this place there is a bed of coarse gravel 20 feet thick on the intracanyon basalt. The gravel has been exposed by an artificial cut made to obtain material for road building. A similar bed also appears to cap the remnant of intracanyon basalt on the east wall of the Deschutes Canyon. It was deposited at this level by the Deschutes River soon after the canyon was filled with the intracanyon basalt. Another deposit of fine débris is associated with the intracanyon basalt

[18] Russell, I. C., op. cit., p. 76.

at Trail Crossing. A few alluvial deposits occur elsewhere in the area, as, for instance, thin gravel layers covering a few square feet or pockets of fluviatile white pumice on the surface of the benches formed of intracanyon basalt.

LOESS

Fine yellow loess covers most of the rim-rock basalt and in places is 3 feet thick. It is composed chiefly of fine volcanic ash that has drifted eastward during volcanic eruptions in the Cascade Range.

STRUCTURE

The structure of the area is relatively simple. The Trail Crossing basalt and the Clarno (?) formation have been folded into a broad anticline. The axis trends northeast and the beds dip away from it at angles of 5° to 30°. Near Trail Crossing the anticline plunges southwest and passes under later rocks.

The relation of the andesite to the Clarno (?) beds is unknown, but it is believed to be separated from them by an erosional as well as a deformational unconformity.

The Deschutes formation in contact with the andesite is well exposed in sec. 4, T. 14 S., R. 12 E. At this contact the sedimentary beds of the Deschutes rest unconformably on the andesite. Elsewhere the contact is not exposed, but it is believed that the Deschutes formation is later than the andesite and everywhere rests unconformably upon it. A few miles upstream from the area mapped the Deschutes formation rests unconformably upon the Trail Crossing basalt and Clarno (?) beds, indicating that the andesite does not completely underlie the middle Deschutes Basin. The andesite appears to have flowed into the basin along ancient valleys and is in the form of long tongues. The volcanic origin of much of the Deschutes formation suggests that the andesite may not have been long separated in time from it. The thick Pelton basalt member at the base of the Deschutes formation, though very different physically from the andesite, is chemically very much like it, and hence there may not have been a long interval between the two kinds of lavas. The volcanoes of the Cascade Range may have poured out andesite about the same time basalt was issuing from vents in the Deschutes plain.

Considerable time intervened between the deposition of the Deschutes formation and the intracanyon basalt flows, for they are everywhere separated by a steep erosional unconformity. The Deschutes formation is horizontal or inclined at angles of less than 5° wherever exposed. There are no signs of folding or faulting, but the whole formation was probably uplifted, because the long cycle of deposition gave way to one of rapid erosion.

GEOLOGIC HISTORY

The geologic history of the area began with the downwarping of the Trail Crossing basalt and the Clarno (?) tuffs, accompanied perhaps by faulting. This movement aided by erosion formed a broad basin more than 1,000 feet deep, bordered on the east by the upturned beds of the Clarno (?) formation and on the west by the volcanoes of the Cascade Range. These volcanoes must have been active soon after the basin was formed, for they poured andesitic lava into it.

The next event chronicled by the rocks of the area is the flooding of the basin by basalt flows, which accumulated to a thickness of at least 150 feet. Where this lava came from is unknown, but it probably issued from cones along some buried fissure in the Deschutes Valley. Soon after or perhaps during this period of volcanism the ancestral Deschutes and Crooked Rivers, together with lesser streams, began depositing silt, sand, and gravel in the depression. The occurrence of cross-bedding indicates that the streams were wide and braided, like the Platte River of to-day. Frequently the ash or pumice from adjacent volcanoes fell in the basin. These ash deposits also blanketed the surrounding hills, with the result that erosion was increased and streams tributary to the basin brought in large amounts of volcanic detritus. The horizontal beds of pumice, 10 to 15 feet thick, exposed continuously for several miles in the canyon walls of the Crooked and Deschutes Rivers, testify to the violence of some of the explosions.

During the accumulation of this débris basaltic lava was occasionally extruded from cones and fissures and spread out on the floor of the basin in thin sheets covering many square miles. Often several volcanic outbreaks occurred in rapid succession, so that the lava accumulated to a thickness of 75 to 150 feet before fluviatile materials were deposited on it. The fact that these flows are basic and that practically all the pumice is more acidic in composition signifies that there were concurrent eruptions of basic lava in the valley and of andesitic pumice somewhere in the adjacent area. It is safe to assume that the pumice corresponds to the explosive decadence of the Cascade volcanoes in Pleistocene time.

The stratigraphic record also shows that occasionally sufficient time elapsed between eruptions for several hundred feet of sediments to be deposited. Beds of diatomaceous earth seen here and there in the Deschutes formation and particularly prominent at Lower Bridge (across the Deschutes) indicate that shallow spring-fed lakes were at times formed by damming of the drainage by lava. Diatoms will form pure deposits only in clear water where the tributaries do not bring in sand, silt, and other foreign substances. Such conditions exist only where the lake is supplied by springs on the bottom or along the shores. Spring-fed lakes are not uncommon in the lava fields of Oregon, and the permeable basalt flows in the Deschutes formation may have formed many such lakes. Diatomite deposits of good commercial quality are known only in the upper part of the Deschutes formation, suggesting that in the earlier stages of Deschutes deposition local spring-fed ponds were not able to exist for any considerable period of time but were either filled with volcanic sediment or drained by erosion.

The closing phase of the Deschutes formation was another period of volcanic activity during which numerous basic flows of the rim-rock basalt welled out from cones and fissures in the basin, spreading out in thin sheets of great extent that completely covered the Deschutes sedimentary beds. The cones and chains of cones marking the site of the fissures from which the rim-rock basalt issued are shown on Plate 10.

After the rim-rock flows were extruded, deposition ceased in the basin and a new cycle of erosion began. As the beds of the Deschutes formation are everywhere horizontal, the new cycle of erosion must have been initiated without local disturbance. The field work did not extend over a large enough area to determine whether this cycle was due to regional uplift or to the filling of the basin so that the rivers found an outlet. As soon as the rivers had sawed through the rim-rock basalt the rate of erosion was doubtless accelerated because of the softness of the sedimentary beds in the Deschutes formation. However, temporary checks in the rate of erosion occurred wherever the rivers reached interstratified beds of basalt. Falls often resulted, and the arrested streams slowly cut these falls back and then renewed their work in the soft sediments. Big Falls and Steelhead Falls on the Deschutes River and many rapids on the Crooked River are caused by the water tumbling from hard beds of lava to underlying soft sediments.

At the junction of the Deschutes and Crooked Rivers a canyon 1,000 feet deep had been excavated before this erosion cycle was interrupted by volcanic eruptions that occurred several miles south of this region. A flow of lava spilled into the canyon of the Deschutes River near Tetherow Bridge and partly filled the canyon for many miles downstream. The river was forced to change its course in many places. The several abandoned channels near Tetherow Bridge may mean that this order of events was repeated at intervals or else that there were several tributary canyons at this place which were all filled at the same time. The details of these accidents to the Deschutes can be worked out only by investigating the area south of the middle Deschutes Basin. However, these interruptions were small and insignificant compared with the great change wrought by a flood of lava spilling into the canyon of the Crooked River near

Smith Rock. This lava flowed downstream, filling every nook in the canyon and in a few places flowing up tributary valleys. The lava continued to pour into the canyon until near Smith Rock it obliterated all signs of the former canyon and spread out in the form of a plain. At the junction of the Deschutes and Crooked Rivers it made an immense fill and flowed up the Deschutes Canyon for several miles. The lava also flowed downstream from this point for more than 8 miles before it stopped. This intracanyon lava fill initiated another cycle of erosion, and the rivers began to excavate new canyons. The Deschutes and Metolius Rivers were temporarily dammed by the Crooked River intracanyon basalt, but doubtless it was not long before they overflowed their dams and began the long task of sawing through 700 feet of lava. The rivers have now practically completed this task and in most places are again cutting into the underlying members of the Deschutes formation.

DIATOMITE DEPOSITS

Sufficient time was not available to investigate the diatomite deposits of the region. A deposit of apparently commercial quality occurs in the Deschutes formation in the east wall of the Crooked River Canyon in sec. 27, T. 12 S., R. 12 E., above the intracanyon basalt. It has a heavy overburden, including the rim-rock basalt, hence it will be necessary to work it by tunneling. Other diatomite deposits are reported to exist in the area, but they were not visited. The only diatomite deposit that is being quarried is in sec. 16, T. 14 S., R. 12 E., about 6 miles by road west of Terrebonne. (See pl. 10.) The following description of this deposit is abstracted from a report to the chief engineer of the Union Pacific system by Dr. A. C. Boyle, jr., dated December 30, 1921. It is published here for the first time by permission of the author and Mr. S. Murray, assistant chief engineer of the Union Pacific system.

The diatomite deposit near Terrebonne is owned by the Western Diatomite Co. The area underlain by the deposit is shown in Figure 7. It has a maximum thickness of about 40 feet and is covered in nearly all places by tuff and sand of the Deschutes formation. It thins out slightly, however, toward the southwest corner of sec. 16. In some places the overburden reaches a maximum thickness of 12 feet, but in others it is thin, and burrowing animals have brought the diatomite to the surface from their shallow holes. An examination of the overburden shows that it averages somewhat less than 11 feet in thickness. In one area the diatomite is overlain by basalt. In order to explore the deposit the Western Diatomite Co. has sunk numerous test pits, the location of which is shown in Figure 7 and their logs in Plate 15.

The deposit of diatomite is tabular in form, and its nearly uniform thickness shows that it was probably laid down in a broad lake of unknown dimensions. The bed has been cut through by the Deschutes River, for it crops out on both canyon walls. In a few places small channels in the deposit indicate that the bed was also eroded before its burial by later sediments. One of these channels is about 10 feet wide and 3 feet deep. The slope of the cross-bedded débris in

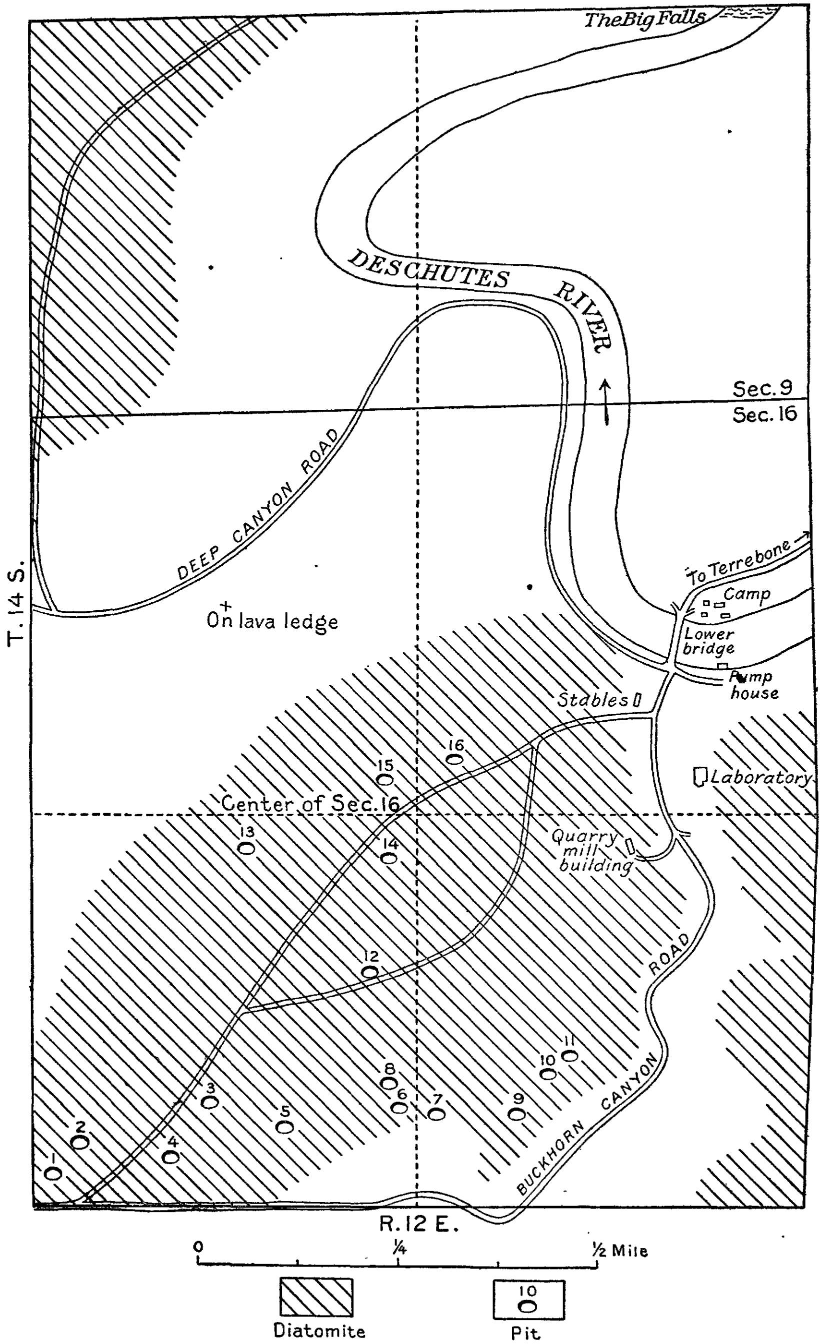


FIGURE 7.—Map of diatomite deposits of Western Diatomite Co., near Terrebonne, Oreg., showing location of test pits. Numbers of pits are the same as those used in Plate 15

this channel suggests that the stream flowed from the southwest. The number of these channels is unknown, but they are believed to be few. Wherever they occur they represent, bulk for bulk, the amount of fossil earth which can not be counted upon in the final computations of quantity.

The deposit is characterized by bands from a few inches to several feet in width. The banding is due to slight variations in the composition of the fossil earth, principally in the content of iron oxide. Although the diatomite has a low specific gravity it is fairly compact and easily supports the weight of a steam shovel.

The stratum of highest grade, known at the quarry as No. 6, is characterized by the absence of bedding planes and by good conchoidal fracture. It is extremely soft, very white, and massive and is easily distinguished from every other member of the deposit by the peculiar pitch of sound produced when a sharp-pointed stick is thrust into it. This stratum is found in most of the pits and varies only slightly from 6 feet in thickness. It is made up of practically one species of diatoms and is almost free from injurious impurities.

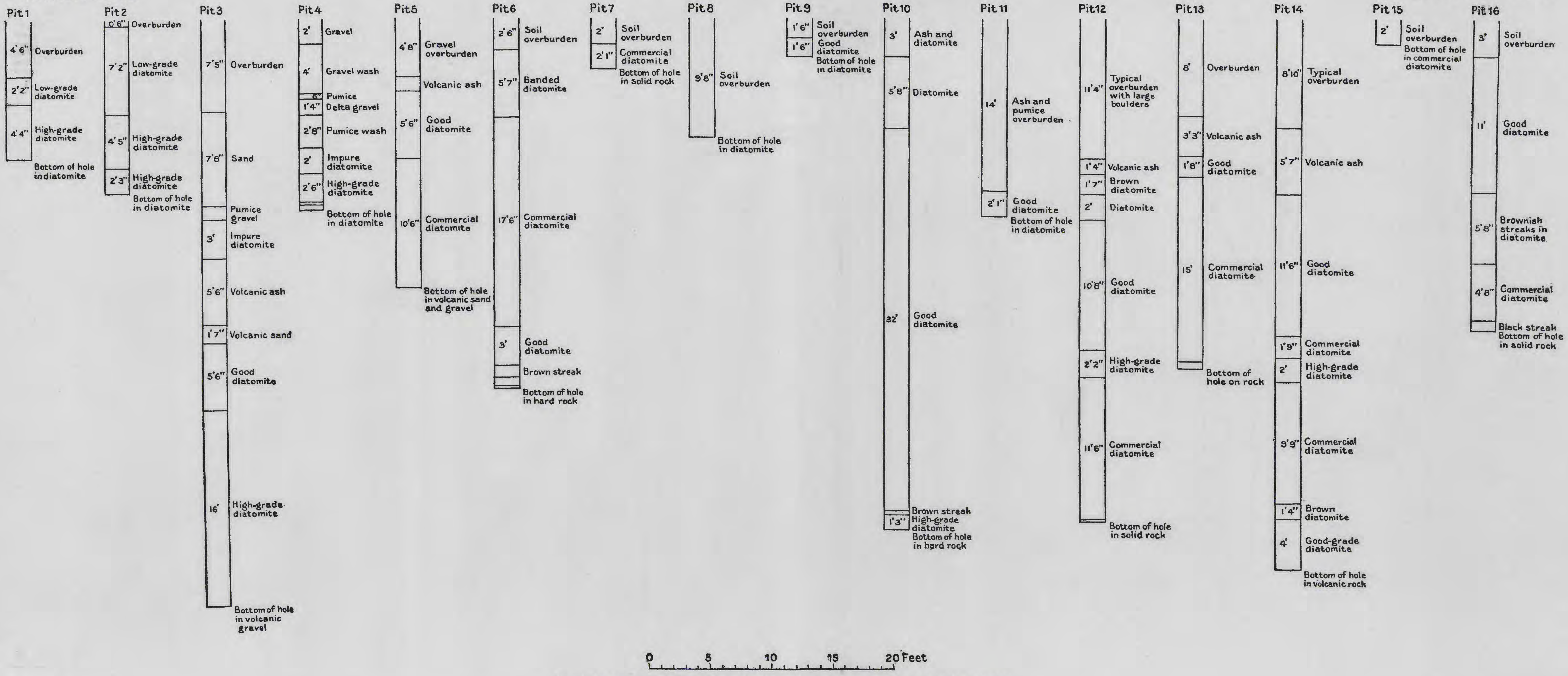
Vertical fissures, in places curved, break up the mass and are probably due to shrinkage. Water percolating through these fissures has deposited foreign substances, chiefly iron oxide, along their faces. The fissures aid considerably in the mining operations.

The overburden is stripped with a steam shovel, and the diatomaceous earth is then quarried and placed in racks or on a platform for air drying. It is then transported to the mill on the property, where it receives a preliminary crushing. The finished product is loaded in 60-pound sacks to trucks that deliver it to the warehouse at Terrebonne, the nearest rail point.

No accurate survey of the area underlain by diatomaceous earth has been made, but by pacing about 265 acres in this unit of the area filed upon by the Western Diatomite Co. was found to be underlain with the fossil earth. The area east of Buckhorn Canyon probably includes 40 acres. This land is underlain by the same bed as that on the west bank of the canyon, but it is not included in the 265 acres of the main deposit. The company reports also about 40 acres of marketable product in the W. ½ SW. ¼ sec. 9. This area also was omitted from the computation. If these areas are ever mined, they will greatly augment the supply.

For convenience of computation the area of 265 acres is taken as the basis and is believed to be everywhere underlain by 36 feet of fossil earth, so that the deposit contains 415,562,400 cubic feet, or 15,391,200 cubic yards, of diatomite. Of this amount it is conservative to estimate that about 9,000,000 cubic yards, or 60 per cent of the deposit, will be ultimately shipped. The other 40 per cent covers the loss by water, thinning of the deposit, and other causes. On the assumption that an average railroad car will carry 153 cubic yards, it would require 60,000 cars to transport the amount of diatomite available in this one unit.

Diatomaceous earth is composed of the residuary remains or hard parts of diatoms, one of the group of aquatic plants called algae, which occur almost universally in all waters from the Arctic to the Torrid Zone, fresh or salt, still or running, hot or cold, and shallow or deep. "The diatom ornaments its shell with fine lines, somewhat over 125,000 to the inch. The fineness in texture of the diatomaceous earth can be appreciated when it is stated that in 1 cubic inch of a Bohemian sample 40,000,000,000 individuals (*Gallionella distans*) find an abundance of room. Diatoms multiply with amazing rapidity, a single individual producing 9,000,000 descendants in a period of four weeks." The diatoms of this deposit appear to have lived in a spring-fed fresh-water lake, probably caused by lava damming a watercourse during the deposition of the Deschutes formation.



LOGS OF TEST PITS OF WESTERN DIATOMITE CO., NEAR TERREBONNE, OREG.

By A. C. Boyle, Jr.

The siliceous shells of these plants accumulated in the bottom of the lake. The chemical purity of the fossil earth varies according to the amount of silt, clay, ash, and other foreign substances deposited simultaneously with the siliceous casings.

The following table of analyses is given in the hope that it may be useful for comparisons. Analyses 11 to 13 represent diatomite from this deposit.

Analyses of diatomaceous earth

	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	65.62	86.92	72.50	86.89	86.90	80.53	80.66	81.53	84.15	75.68	86.00	86.26	88.51
Al_2O_3	-------	4.27	11.71	2.32	4.09	5.89	3.84	3.43	1.40	9.88	1.06	3.22	1.28
Fe_2O_3	-------	-------	2.35	1.28	1.26	1.03	-------	3.34	.70	2.92	.92	1.54	1.28
CaO	-------	1.60	.32	.43	.14	.35	.58	2.61	1.75	.29	.27	.05	1.06
MgO	-------	Trace.	.83	Trace.	.51	-------	-------	-------	1.10	.69	.09	Trace.	.91
K_2O	-------	} 2.48	}	1.26	-------	-------	-------	1.43	-------	.02	-------	-------	-------
Na_2O	-------	}	} 1.88	2.32	1.18	-------	-------	1.16	-------	.08	-------	-------	-------
H_2O	11.00	5.13	9.54	4.89	5.99	12.03	14.01	6.04	10.40	8.37	7.60	4.94	5.15
	-------	100.40	99.13	99.39	100.07	99.83	99.09	99.54	99.50	-------	99.96	100.00	-------

1. Soft shale, Harris, Santa Barbara County, Calif. W. T. Schaller, analyst, 1907.
2. Porcelain diatomaceous shale, Point Sal, Santa Barbara County, Calif. Fairbanks, H. W., California Univ. Dept. Geology Bull., vol. 2, p. 12, 1896.
3. Soft shale, Orcutt, Santa Barbara County, Calif. W. T. Schaller, analyst, 1907.
4. Monterey, Monterey County, Calif. Lawson, A. C., and Posada, J. C., California Univ. Dept. Geology Bull., vol. 1, p. 25, 1893.
5. Fossil Hill, Nev. California State Min. Bur. Bull. 38, p. 289, 1906.
6. Lake Umbagog, N. H. Merrill, G. P., U. S. Nat. Mus. Rept. for 1899, p. 220, 1901.
7. Norris County, N. J. Idem.
8. Popes Creek, Md. Idem.
9. Hanover, Germany. California State Min. Bur. Bull. 38, p. 289, 1906.
10. Diatomite, Richmond, Va. U. S. Geol. Survey Bull. 483, p. 27, 1911. J. M. Cabel, analyst.
11. Standard filtration diatomite, Terrebonne, Oreg. Unpublished analysis by Dr. L. V. Hampton, Portland, Oreg., Feb. 4, 1920.
12. Diatomite No. 10, Terrebonne, Oreg. Gascoyne & Co., analysts, Dec. 14, 1920, for Pomery & Fischer, New York City.
13. Diatomite No. 6, Terrebonne, Oreg. American Sugar Refining Co., analyst, 117 Wall Street, New York City.

It is evident from these analyses that Nos. 2, 4, 5, 11, 12, and 13 are products which are in commercial demand.

Diatomaceous earth has a great many uses. In general its uses are closely associated with its physical, chemical, and mineralogical properties, all of which combine to influence the market for the product. It is used as a cleanser and polisher, as a nonconductor of heat, as a pipe covering for heating apparatus, in filtration, and in a multitude of other ways. The two largest uses at the present time are heat insulation and filtration, both of which depend more upon the physical than the chemical composition of the material.

GEOLOGY OF DAM SITES

UPPER BOX CANYON DAM SITE

The upper box canyon dam site is near the south line of sec. 28, T. 12 S., R. 12 E. A rock-fill dam, 100 feet high, has been proposed for this site. The topography of the dam site is shown on Plate 16, and the location is shown on Plate 10. Both the intracanyon basalt and sedimentary beds of the Deschutes formation are exposed at the dam site, and the areal distribution of these rocks is shown on Plate 16. The proposed dam would tie into only the intracanyon basalt cliffs that form the walls of the canyon. Plate 14, *B*, is a view of the canyon at the dam site. The intracanyon basalt is about 450 feet thick here and comprises several beds, which were probably all derived from the same source and laid down in rapid succession, for sufficient time did not elapse to allow any accumulation of soil on one bed before the next was poured out. The basalt is massive and fairly dense, and in cooling it contracted into columnar blocks, some of which now form the talus slopes in the canyon near the dam site. Plate 14, *A*, illustrates the jointed basalt flows that form the west wall of the canyon at the site. The joints are open in the canyon walls but are probably considerably tighter a few feet back.

The geologic cross section of the Crooked River Canyon at the dam site given on Plate 16 shows the relation of the intracanyon basalt to the Deschutes formation in the prelava canyon of the Crooked River. Because of the sluggishness of the lava near the edge of the flow during the period of accumulation it sometimes failed to freeze tightly against the wall of the canyon. As a result cavernous openings exist at the contact of the intracanyon basalt with the buried canyon wall. Plate 17, *A*, is a view of a bat cave about 105 feet above the river at the dam site, where the intracanyon basalt fails to fit closely to the ancient canyon wall. The cave is partly filled with bat guano, and in places the roof is 12 feet above the guano. The cave follows the contact downward toward the river, but because of the steepness of the contact slope it was not explored to the bottom. At a contact between two beds of lava 35 feet above the river there are holes 1 foot in diameter which appear to open into the cave. The original contact of the basalt with the Deschutes formation was probably fairly tight but was later enlarged by percolation from the river during the early stages of cutting, when the river was flowing near the top of the intracanyon basalt.

A dam tied only to the basalt cliffs would fail to impound water, because of leakage through this cave around the east abutment. In order to make a dam hold water at this site it would be necessary either to fill the cave with concrete or to lay a concrete cut-off wall from the dam to the Deschutes formation at the contact. The cost of such a wall would probably make the proposed dam at this site impracticable.

LOWER BOX CANYON DAM SITE

The lower box canyon dam site is three-quarters of a mile north (downstream) from the upper site. It is shown only approximately on Plate 10, because the height and type of the dam at this site will determine its exact location. The water surface at the site is 1,920 feet above sea level and 49 feet below Opal Springs. The geology of this dam site is practically the same as that of the upper site, for intracanyon basalt occurs on both abutments and back of it lies the Deschutes formation. The geologic section is so nearly like that of the upper site that Plate 16 suffices to illustrate both of them.

The success of a dam at this place will depend chiefly upon three factors—a satisfactory foundation must be found for the dam; a reasonably tight contact must be found between the intracanyon basalt and the Deschutes formation; and the height of the dam must not greatly exceed 155 feet above the river, or 2,075 feet above sea level. Test holes should be drilled at the site to determine how far below the river bed the Pelton basalt lies. If a reasonable thickness of Deschutes sediments is found above the Pelton basalt under the river, then it will be safe to assume that the Pelton lavas will not cause appreciable seepage under the dam. The tightness of the contact of the Deschutes formation with the intracanyon basalt in the abutments can be determined by drilling holes through the basalt to the contact. If after testing the holes under pressure the leakage is found not to be great the contact can doubtless be grouted successfully. Water impounded by a dam at this site would flood the bat cave at the upper site, but the water entering the cave would be returned to the river above the dam because a gap exists between the intracanyon basalt of the east abutment of the upper site and the intracanyon basalt of the east abutment of the lower site. If a dam at the lower site were constructed much more than 155 feet above the river the water impounded by it would flood the bed of interstratified basalt in the east wall of the canyon, 105 feet above the river at Opal Springs.

The contact of this bed of lava with the underlying sediments is slaggy and cavernous. The fact that water can find its way along the contact with ease is demonstrated by a group of springs that discharge from it. (See fig. 8.) A slight head of water on this bed of lava would cause leakage around the dam, for the same bed crops out below the lower dam site.

The success of a dam at the lower site depends also upon the origin of Opal Springs. A test hole should be drilled close to the springs to determine whether they rise from the Pelton basalt or some other interstratified lava bed in the Deschutes formation below the river. Further information regarding these springs and their relation to the proposed reservoir created by a dam at this site is given on pages 202–203. If Opal Springs have their source in the interstratified bed of basalt, 105 feet above them, then the construction of a 155-foot dam at the lower site would not cause a reversal of the hydraulic gradient of the springs, and hence the reservoir would not be endangered by leakage.

METOLIUS DAM SITE

The proposed Metolius dam site is near the line between secs. 15 and 22, T. 11 S., R. 12 E., on the Deschutes River. (See pl. 10.) The water surface at this site is 1,527 feet above sea level. A 300-foot dam would back water up the Metolius, Deschutes, and Crooked Rivers for several miles. The river at the site is flowing in a narrow V-shaped gorge nearly 1,000 feet deep, cut in the Deschutes formation. The geologic section of the east wall of the site is given on page 138. The west wall is very similar except for a thin wedgelike remnant of intracanyon basalt that consists of 23 fissured flows apparently laid down in rapid succession.

The river at the dam site is flowing on the Pelton basalt, which is the lowest interstratified basalt member exposed in the Deschutes formation. The Pelton basalt on the east abutment is exposed

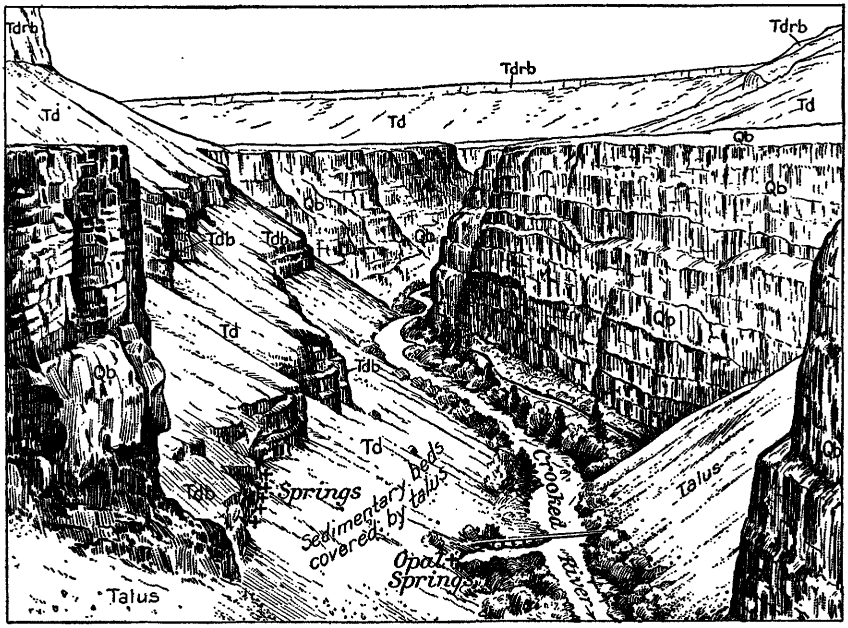
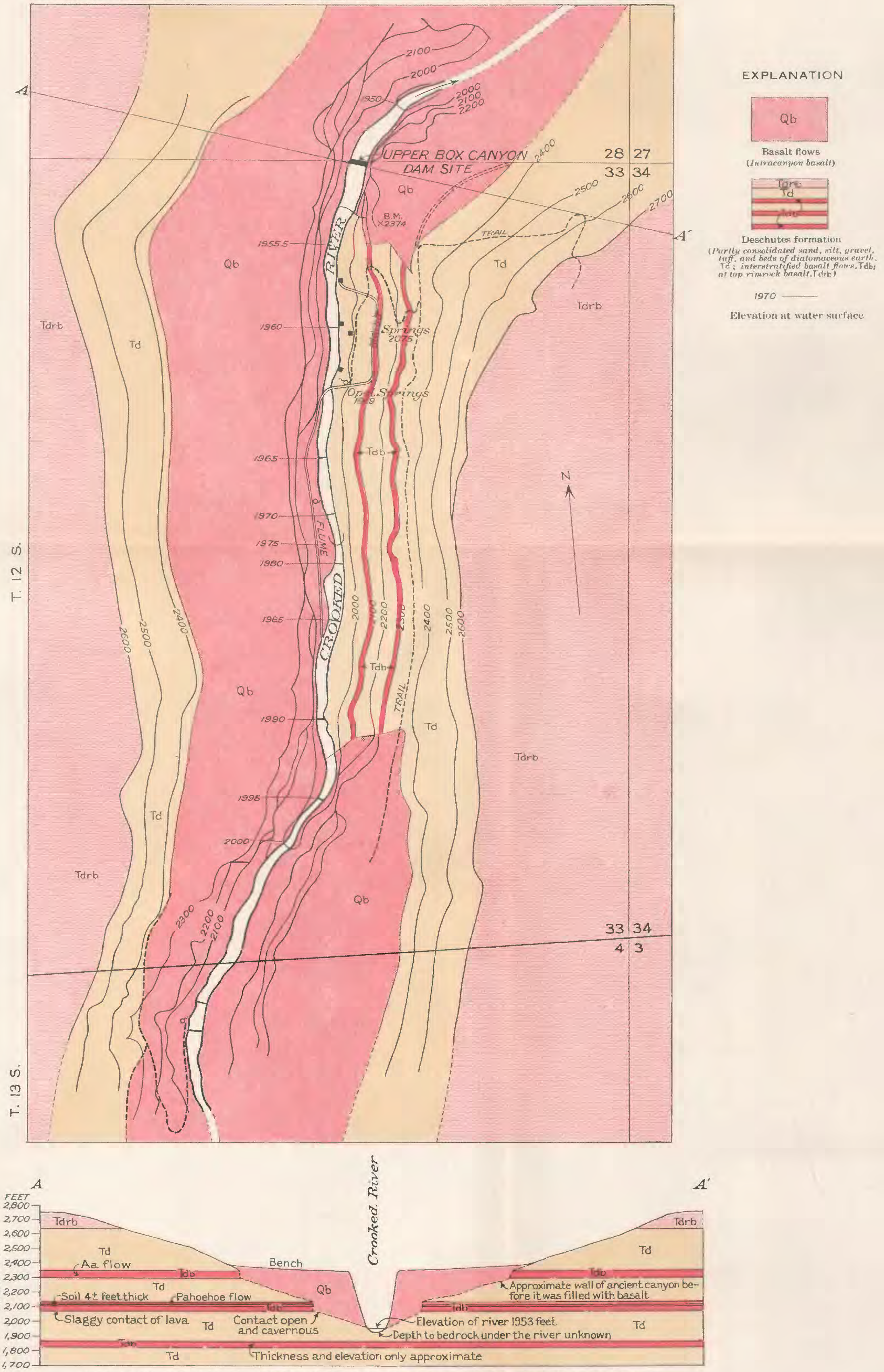


FIGURE 8.—Geologic sketch of Crooked River Canyon near Opal Springs. Qb, Basalt flows (intracanyon basalt); Tdrb, basalt flows (rim-rock basalt) overlying fluviatile deposits; Tdb, basalt flows interstratified with fluviatile deposits; Td, partly consolidated sand, silt, gravel, tuff, and beds of diatomaceous earth constituting fluviatile deposits

above the river for 150 feet and comprises several fissured and jointed flows. Resting on it is a bed of volcanic agglomerate 215 feet thick, which because of its impermeability and its height above the river is not involved in the problem of leakage of the proposed reservoir. The Pelton basalt, which would form the lower 150 feet of the abutments of a dam at this site, crops out continuously up the Metolius River for nearly 4 miles above its mouth, also for about 9 miles up the Deschutes and about 4 miles up the Crooked River. The areal distribution of this lava bed is shown on Plate 10. The extensive exposures of the Pelton basalt indicate that it was spread in successive



GEOLOGIC MAP AND SECTION OF UPPER BOX CANYON DAM SITE ON CROOKED RIVER, JEFFERSON COUNTY, OREGON

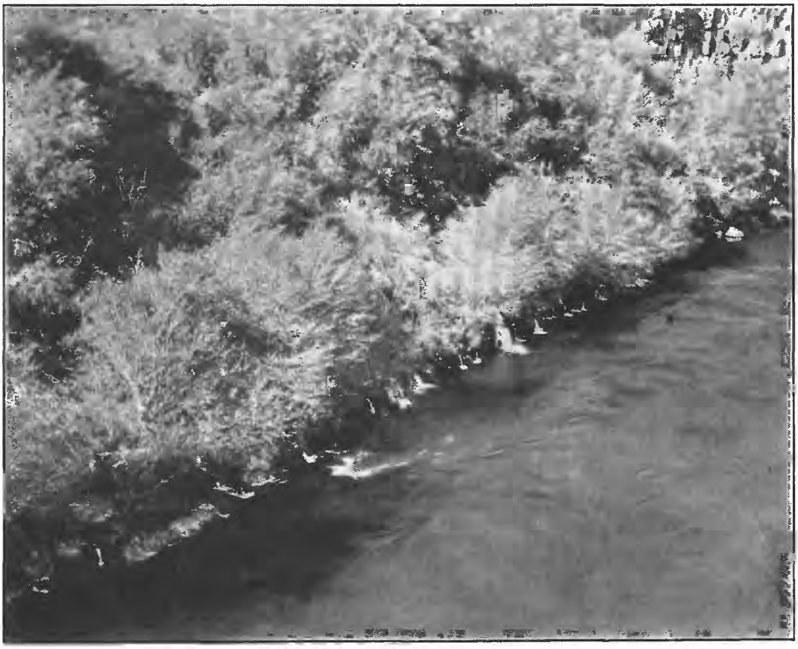
500 0 500 1,000 1,500 2,000 FEET

Contour interval 100 feet

Datum is mean sea level

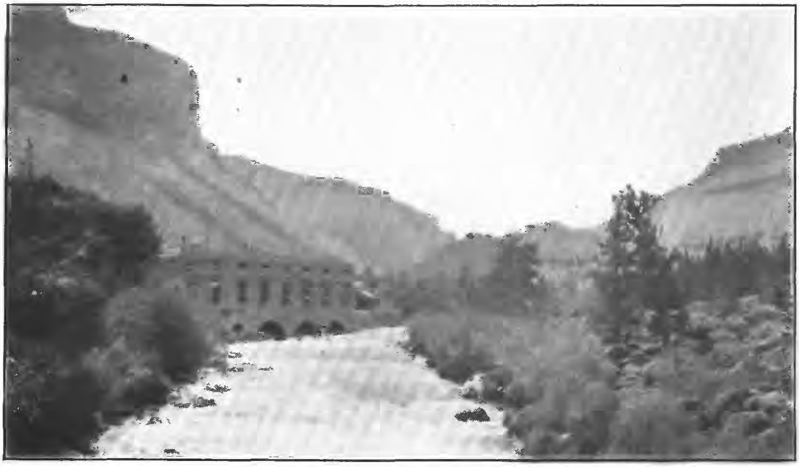
A. BAT CAVE IN THE EAST ABUTMENT OF THE UPPER BOX CANYON DAM SITE

The cave is at the contact of the intracanyon basalt with the Deschutes formation.



B. SPRINGS ISSUING FROM THE PELTON BASALT IN THE WEST WALL OF DESCHUTES CANYON IN SEC. 27, T. 11 S., R. 12 E.

A. OPAL SPRINGS, CROOKED RIVER CANYON
August 26, 1925.



B. COVE POWER PLANT FROM BRIDGE ACROSS CROOKED RIVER
August 12, 1925.

sheets of wide extent in the broad flat valley of the ancestral Deschutes River.

From the Pelton basalt emerge practically all the springs in both the Deschutes and Crooked River Canyons in the middle Deschutes Basin. The total discharge of the springs that issue from it is several hundred second-feet. About half a mile above the mouth of the Metolius River, on the west bank of the Deschutes, there is a line of springs extending nearly three-quarters of a mile. The total discharge is hard to estimate but is probably 80 to 100 second-feet. The view of these springs shown in Plate 17, *B*, gives a conception of their number.

The reservoir created by a dam at the Metolius site would inundate the Pelton basalt for many miles, and the impounding of the water would doubtless cause leakage in some amount around a dam at this site. The exact amount of the leakage, which will increase with the height of the dam, can not be forecast without further drilling or other underground exploration. A thorough drilling program should be carried out to determine the extent of the Pelton basalt at the dam site, and tunnels into the basalt would give additional information regarding its structure. It is understood that all of this investigatory work is included in the proposed program of the company holding the license for the site. This work should be carried on, as it has been in the past, under the supervision of a geologist, and further detailed geologic work should be done at the reservoir site. A power dam at this site has the advantage that it will not have to hold over storage, and any additional underground storage may to some extent offset leakage. A reservoir at this site can stand considerable leakage provided it is made a part of a hydroelectric system with other dams downstream, for the seepage will be returned to the river below the dam and will benefit lower power plants during low-water periods.

CLIMATE

Precipitation.—Only one precipitation station is maintained within the area. It is at an altitude of about 2,300 feet at Madras, in the northeastern part of the plain. Most of the precipitation falls during the winter in the form of snow. In the following table, which has been compiled from United States Weather Bureau reports, the snowfall has been converted to the equivalent in inches of rain:

Monthly, annual, and mean precipitation in inches, at Madras, Oreg., 1909–1926 [a]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1909	------	1.29	0.32	Tr.	0.47	0.46	0.30	Tr.	2.03	0.55	2.17	2.40	------
1910	------	------	------	------	------	------	.05	Tr.	.62	.85	3.10	.73	------
1911	1.25	.09	------	0.02	.90	.63	.00	0.17	2.02	------	.73	.61	------
1912	2.45	.88	.76	.80	1.74	.78	.75	.64	.34	.20	.62	1.30	11.26
1913	.79	.38	.25	.71	1.35	1.27	.15	.00	------	.21	.69	1.24	------
1914	1.91	.75	------	------	------	------	------	------	------	------	------	------	------
1916	------	------	.10	.11	.70	------	------	------	------	------	------	------	------
1920	.32	.04	.58	.63	.03	.74	------	------	------	1.15	1.41	1.29	------
1921	1.25	1.25	.40	.54	1.74	.92	.00	.15	.00	.36	2.74	.71	10.06
1922	.22	.68	1.00	.18	.42	1.69	.00	.63	.08	.98	1.43	1.64	8.95
1923	1.50	.38	.12	1.01	1.06	.58	1.44	.04	.75	1.51	.21	.88	9.48
1924	.24	.42	.56	.02	.03	.15	.01	.19	.21	1.19	1.12	1.29	5.43
1925	.66	.65	.77	1.07	2.89	.15	.02	.27	.99	.08	1.08	.30	8.93
1926	.77	1.30	.11	.70	.56	.13	Tr.	1.32	.02	.37	3.08	.77	9.13
Mean	1.03	.68	.45	.48	1.00	.66	.25	.31	.70	.68	1.53	1.10	8.87

[a] Record from April, 1911, to May, 1916, inclusive, for Metolius, about 3 miles sonthwest from Madras.

The precipitation over the rest of the plain is about the same as at Madras, although it increases slightly toward the south. The annual precipitation at Bend, which lies 12 miles due south of this area, at an altitude of 3,629 feet, is given in the following table for comparison:

Annual precipitation in inches, at Bend, Oreg., 1902–1926

[From United States Weather Bureau reports]

1902	10.90	1914	8.12	1922	16.41
1903	13.37	1915	11.75	1923	15.66
1904	17.10	1917	8.80	1924	9.39
1906	10.42	1918	10.27	1925	12.78
1907	25.75	1919	11.07	1926	13.27
1912	16.62	1920	11.27		
1913	12.39	1921	12.99	Mean	13.80

An appreciable increase in precipitation occurs in the vicinity of Haystack and Juniper Buttes, where the altitude is more than 1,200 feet higher than Madras.

The snowfall varies considerably from year to year at Madras. Thus, during 1925, when the annual precipitation was 8.93 inches, only 4.5 inches of snow fell, whereas in 1924, when there was only 5.43 inches of precipitation, 24.7 inches of snow fell. In the sheltered canyons the snowfall is usually less than on the plain.

Temperature.—The monthly and annual mean temperature at Madras is given in the following table, and the mean temperature at Bend is given for comparison. Only five years' records are available, and the average annual temperature for the period is 47.8° F.

Monthly and annual mean temperature in degrees Fahrenheit, at Madras and annual mean at Bend, Oreg., 1922–1926

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	
													Madras	Bend
1922	25.0	31.2	[a]37.1	40.7	[a]51.0	[b]61.4	66.8	65.8	59.4	49.2	33.6	28.2	45.8	46.8
1923	35.6	27.6	40.2	46.0	52.0	57.6	67.2	66.2	59.0	45.9	41.2	33.2	47.6	47.5
1924	28.6	40.6	37.6	45.8	56.7	60.5	65.4	63.2	58.2	47.4	37.2	22.2	47.0	47.5
1925	38.2	38.7	39.4	48.6	55.0	60.2	68.2	64.0	58.5	45.4	39.0	35.2	49.2	48.8
1926	32.8	41.6	43.2	52.3	54.0	63.0	67.5	64.2	51.5	48.6	40.8	31.8	49.3	49.9

[a] 1 day missing from record. [b] 5 days missing from record.

There is a wide diurnal range, and extremes of heat and cold are not uncommon in the basin. Frosts occur in all months of the year, except July and August. On June 30, 1924, a maximum temperature of 105° F. was reached, and on December 24 of the same year a temperature of −40° F. was recorded. The lowest temperature on record by the Weather Bureau for the east slope of the Cascade Range occurred at Madras on December 12, 1919, when the thermometer registered −45° F. The climate of the region is similar to that of many other semiarid high plateaus in the Northwest. The air is dry, and the extreme temperatures are not as disagreeable as the records might suggest. Over 200 sunny days usually occur during the year. Even in the middle of the summer the nights are cool, and it is necessary to sleep under blankets.

CROPS, VEGETATION, AND FAUNA

The semiarid character of the climate and the frosty nights preclude any great diversity of agriculture. About 1900 it was discovered that wheat and other cereals could be grown here, and since that time the area has been given over to dry farming. The soil is excellent, and during wet years or years of heavy snowfall good crops are grown. The long periods of dry years or poor markets have driven out a number of farmers during the last decade, so that many of the farms are abandoned and the towns are on the decline. However, in 1925 a bumper crop combined with a good market enabled many of the farmers to pay off their mortgages and left some of them prosperous. The Haystack country, which has a deeper soil and one better adapted for retaining the moisture, yields the best crops.

In the irrigated areas near Terrebonne alfalfa is the principal crop and dairying is on the increase. The cream is shipped by railroad to the nearest creameries through cooperative or private organizations.

Truck gardening is successfully practiced on the Gates ranch, in the Crooked River Canyon, though during some years early frosts prevent the vegetables from maturing. In the sheltered canyon of the Crooked River at Cove Crossing fruit and vegetables are easily grown. Clay loam and sandy loam predominate in the area, but in a few places gravelly loam has resulted from the weathering of a bed of conglomerate in the Deschutes formation.

The natural vegetation of the area is sagebrush, but this has been largely removed except on the stony land. Junipers grow on the hills in the Haystack country and in the vicinity of Round Butte. Sufficient bunch grass grows in uncultivated areas to warrant grazing. On the inaccessible ledges in the Deschutes and Crooked River Canyons bunch grass grows knee high. Russian thistle, as in most other parts of the Northwest, covers most of the abandoned farm land.

Coyotes, jackrabbits, badgers, and gophers inhabit the area. Rattlesnakes are seldom met except in rocky talus slopes along the rivers. Sagehens and a few varieties of ducks are the principal game birds. The trout of the Crooked River are famous for their size and abundance.

WATER RESOURCES

SURFACE WATER

DESCHUTES RIVER

The Deschutes River is described [19] as

> a swift-flowing stream of conspicuously clear greenish-blue water broken by many rapids and cascades and is a delight to the beholder on account of its beautiful colors, refreshing coolness, and the picturesque and impressive scenery of its canyon walls. The flow of the river is more remarkably uniform than that of any other river in the United States comparable with it in size, and its economic value is almost incalculable. At the mouth of the stream the maximum discharge is only six times the minimum. Ocular evidence of this uniformity of flow is presented by the low grass-grown banks between which the river flows for much of its course. From the mouth of Crooked River upstream to Benham Falls, near Lava Butte, a distance of about 50 miles, the variation in the height of the river throughout the year is not more than 8 or perhaps 10 inches where the width is not abnormally restricted.

This remarkably uniform flow of the Deschutes, above the Crooked River is due to its being fed by immense springs near Benham Falls. The springs themselves do not vary much, because their drainage areas are covered with thick pumice deposits into which all water sinks. The water drains underground into numerous buried channels or permeable lava beds through which it travels for miles and finally makes its appearance in springs.[20]

Numerous gaging stations have been maintained by the United States Geological Survey on the Deschutes River and its tributaries. Only records for those stations which lie in and adjacent to the

[19] Henshaw, F. F., Lewis, J. H., and McCaustland, E. J., Deschutes River, Oreg., and its utilization: U. S. Geol. Survey Water-Supply Paper 344, p. 12, 1914.

[20] Meinzer, O. E., Large springs in the United States: U. S. Geol. Survey Water-Supply Paper 557, pp. 64–68, 1927.

middle Deschutes Basin are included in this report. Some of the stations whose records are given do not lie in the area mapped, but the records are included because they are the only data available to indicate the flow of the streams within the area. The location of the stations is shown in Figure 5.

DESCHUTES RIVER AT BEND

Discharge records are available for the Deschutes River at Bend from January 1, 1905, to June 30, 1906, and from January 1, 1909, to November 21, 1914, when the station was discontinued. These records can be found in other water-supply papers.[21]

DESCHUTES RIVER BELOW BEND

A station has been maintained since November 27, 1914, on the Deschutes River 2 miles north of Bend, in the SE. ¼ sec. 20, T. 17 S., R. 12 E., 22 miles south of the area mapped. The gage now in use is a Stevens water-stage recorder on the right bank. The channel consists of coarse gravel and boulders. This gaging station is below the intakes of five large canals (Arnold, Central Oregon, Pilot Butte, North, and Swalley Canals) which divert water from the Deschutes River near Bend. Only small ditches divert water below the station. The flow is regulated by two hydroelectric plants, one at North Canal Dam and one at Bend. The accuracy of the records is good. The maximum discharge for the period 1905 to 1926 was 4,820 second-feet at 7.45 a. m. November 27, 1909, when there were no diversions. The minimum discharge at this station has at times fallen to a few second-feet owing to the large diversions above the gage.

The records given below have been collected by the United States Geological Survey, except those from 1924 to 1926, which were obtained by the office of the State engineer of Oregon.

Monthly discharge, in second-feet, of Deschutes River below Bend, Oreg., for 1914–1926

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1914–15				
October	1,320	940	1,140	70,100
November	1,290	930	1,160	69,000
December	1,450	860	1,210	74,400
January	1,500	1,180	1,380	84,800
February	1,240	860	1,130	62,800
March	1,360	1,060	1,220	75,000
April	1,500	750	1,060	63,100
May	850	580	683	42,000
June	540	260	378	22,500
July	398	175	238	14,600
August	270	170	207	12,700
September	338	190	277	16,500
The year	1,500	170	839	608,000

[21] U. S. Geol. Survey Water-Supply Paper 344, pp. 27–28, 1914; Water-Supply Paper 362, pp. 554–556, 1915; Water-Supply Paper 394, pp. 40–41, 1917; Water-Supply Paper 414, p. 41, 1918.

Monthly discharge, in second-feet, of Deschutes River below Bend, Oreg., for 1914–1926—Continued

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1915-16				
October	760	316	544	33,400
November	1,180	696	967	57,500
December	1,260	1,000	1,120	68,900
January	1,280	1,000	1,130	69,500
February	1,300	950	1,170	67,300
March	1,500	850	1,220	75,000
April	1,570	994	1,350	80,300
May	1,300	961	1,110	68,200
June	1,160	750	879	52,300
July	1,360	732	1,020	62,700
August	741	588	637	39,200
September	830	628	782	46,500
The year	1,570	316	992	721,000
1916-17				
October	1,090	780	937	57,600
November	1,470	960	1,220	72,600
December	1,400	1,040	1,350	83,000
January	1,320	828	1,170	71,900
February	1,090	780	963	53,500
March	1,150	828	1,020	62,700
April	1,680	1,040	1,340	79,700
May	1,900	1,150	1,470	90,400
June	1,650	1,150	1,280	76,200
July	1,210	670	940	57,800
August	758	592	669	41,100
September	910	670	809	48,100
The year	1,900	592	1,100	795,000
1917-18				
October	1,080	763	940	57,800
November	1,340		1,170	69,600
December	1,780		1,370	84,200
January	1,850	1,280	1,640	101,000
February	1,850	1,230	1,540	85,500
March	1,640	1,210	1,410	86,700
April	1,650	890	1,140	67,800
May	1,080	720	902	55,500
June	825	500	627	37,300
July	521	340	435	26,700
August	520	370	430	26,400
September	710	385	583	34,700
The year	1,850	340	1,010	733,000
1918-19				
October	1,140	637	927	57,000
November	1,300	970	1,190	70,800
December	1,240	850	1,150	70,700
January	1,360	900	1,120	68,900
February	1,240	870	1,130	62,800
March	1,360	770	1,100	67,600
April	1,450	1,020	1,250	74,400
May	1,240	680	852	52,400
June	850	464	645	38,400
July	450	265	336	20,700
August	352	238	264	16,200
September	698	228	516	30,700
The year	1,450	228	871	631,000
1919-20				
October	1,300	485	802	49,300
November	1,680	920	1,280	76,200
December	1,730	1,000	1,310	80,600
January	1,540	970	1,190	73,200
February	1,610	1,020	1,160	66,700
March	1,300	970	1,160	71,300
April	1,420	920	1,210	72,000
May	970	418	603	37,100
June	450	285	364	21,700
July	300	125	214	13,200
August	215	70	120	7,380
September	568	212	372	22,100
The year	1,730	70	814	591,000

Monthly discharge, in second-feet, of Deschutes River below Bend, Oreg., for 1914–1926—Continued

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1920–21				
October	808	560	656	40, 300
November	1, 390	756	1, 110	66, 000
December	1, 390	1, 030	1, 220	75, 000
January	1, 590	1, 210	1, 360	83, 600
February	1, 440	1, 160	1, 320	73, 300
March	1, 590	1, 300	1, 430	87, 900
April	1, 590	1, 120	1, 330	79, 100
May	1, 340	1, 030	1, 140	70, 100
June	1, 490	850	1, 210	72, 000
July	895	640	745	45, 800
August	760	640	686	42, 200
September	1, 100	688	859	51, 100
The year	1, 590	560	1, 090	786, 000
1921–22				
October	1, 110	930	1, 000	61, 500
November	1, 910	1, 060	1, 330	79, 100
December	2, 280	1, 560	1, 900	117, 000
January	1, 700	1, 250	1, 480	91, 000
February	1, 430	1, 270	1, 340	74, 400
March	1, 430	1, 220	1, 300	79, 900
April	1, 560	1, 240	1, 410	83, 900
May	1, 490	------------	1, 340	82, 400
June	1, 700	758	1, 120	66, 600
July	722	406	540	33, 200
August	785	370	453	27, 900
September	821	382	512	30, 500
The year	2, 280	370	1, 140	827, 000
1922–23				
October	1, 170	508	881	54, 200
November	1, 270	800	1, 140	67, 800
December	1, 380	755	1, 100	67, 600
January	1, 490	1, 170	1, 280	78, 700
February	1, 220	935	1, 120	62, 200
March	1, 220	1, 070	1, 160	71, 300
April	1, 380	800	1, 130	67, 200
May	845	228	476	29, 300
June	630	205	364	21, 700
July	408	79	265	16, 300
August	295	65	218	13, 400
September	403	26	216	12, 900
The year	1, 490	26	777	563, 000
1923–24				
October	678	285	515	31, 700
November	845	------------	715	42, 500
December	1, 120	672	983	60, 400
January	1, 220	755	995	61, 200
February	1, 650	755	1, 310	75, 400
March	1, 580	888	1, 260	77, 500
April	1, 080	185	759	45, 200
May	470	40	208	12, 800
June	423	14	116	6, 900
July	285	24	93. 7	5, 760
August	176	15	101	6, 210
September	168	18	120	7, 140
The year	1, 650	14	596	433, 000
1924–25				
October	449	140	256	15, 700
November	1, 120	764	999	59, 400
December	1, 120	------------	1, 000	61, 500
January	1, 190	888	1, 010	62, 100
February	1, 510	972	1, 300	72, 200
March	1, 200	825	1, 080	66, 400
April	1, 200	------------	1, 050	62, 500
May	991	443	674	41, 400
June	730	198	422	25, 100
July	270	98	163	10, 000
August	640	154	262	16, 100
September	664	189	484	28, 800
The year	1, 510	98	721	522, 000

Monthly discharge, in second-feet, of Deschutes River below Bend, Oreg., for 1914–1926—Continued

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1925–26				
October	705	537	605	37,200
November	1,200	764	1,050	62,500
December	1,250	782	1,160	71,300
January	1,250	518	1,030	63,300
February	1,300	714	1,130	62,800
March	1,250	722	1,090	67,000
April	756	103	406	24,200
May	391	7	104	6,400
June	154		55.8	3,320
July	111		67.9	4,180
August	124		49	3,010
September	229	5	126	7,500
The year	1,300	5	570	413,000

DESCHUTES RIVER AT LAIDLAW

A gaging station was maintained on the Deschutes River at Laidlaw (now Tumalo) from 1909 to 1912, and records were also obtained for short periods in 1914 and 1915. The accuracy of the records at this station is not very good, because the measuring section was unsatisfactory. The records indicate that there is only a slight increase in flow between this station and the one at Bend; hence they are not included in this report. They can be found in Water-Supply Paper 344, pages 28–29.

DESCHUTES RIVER NEAR CLINE FALLS

The Cline Falls gaging station is in sec. 13, T. 15 S., R. 12 E. (see fig. 5), about 4 miles south of the point where the Deschutes River enters this area. A staff gage was maintained on the right bank from 1910 to 1913. The channel consists of sand, gravel, and boulders and is practically permanent. The records for this station are good.

Monthly discharge, in second-feet, of Deschutes River near Cline Falls, Oreg., for 1910–1913

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1910				
February 15–28	1,600	1,460	1,580	43,900
March	2,480	1,820	2,100	129,000
April	1,820	1,670	1,740	104,000
May	1,900	1,390	1,710	105,000
June	1,820	1,160	1,310	78,000
July	1,160	1,020	1,090	67,000
August	1,270	974	1,110	68,200
September	1,160	974	1,050	62,500
The period				658,000
1910–11				
October	1,110	1,020	1,070	65,800
November	1,530	1,060	1,350	80,300
December	1,600	1,270	1,380	84,800
January	1,330	1,160	1,250	76,900
February	1,270	1,110	1,220	67,800
March 1–4			1,190	9,440
The period				385,000

Monthly discharge, in second-feet, of Deschutes River near Cline Falls, Oreg., for 1910–1913—Continued

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1912				
February 19–29	1,670	1,270	1,440	31,300
March	1,330	1,060	1,200	73,800
April	1,460	1,060	1,270	75,600
May	1,740	1,270	1,430	87,900
June	1,820	1,530	1,670	99,400
July	1,530	1,060	1,220	75,000
August	1,160	1,040	1,090	67,000
September	1,250	1,140	1,200	71,400
The period				581,000
1912–13				
October	1,250	1,110	1,190	73,200
November	1,500	1,220	1,330	79,100
December	1,530	1,270	1,430	87,900
January	1,560	1,160	1,390	85,500
February	1,370	1,180	1,300	72,200
March	1,390	1,110	1,280	78,700
April	1,670	1,290	1,490	88,700
May	1,850	1,330	1,510	92,800
The period				658,000

DESCHUTES RIVER NEAR MADRAS

A station has been maintained in the NW. ¼ sec. 19, T. 10 S., R. 13 E., at the proposed Pelton Dam site, 5 miles above the mouth of Shitike Creek, and 9 miles northwest of Madras. (See fig. 5.) A staff gage on the right bank was used up to May 5, 1924, but since then a Stevens 8-day water-stage recorder has been in operation. The channel and control are composed of boulders and heavy gravel and are apparently permanent. The maximum stage for 1924 to 1926, as shown by the water-stage recorder, was 6.54 feet on February 6, 1925, when a discharge of 10,700 second-feet occurred. The minimum stage as shown by the recorder occurred on August 21, 22, and August 30 to September 2, 1926, when the discharge was 3,220 second-feet. The flow is affected by diversions from the upper Deschutes River, the Crooked River, and Tumalo and Squaw Creeks. Most of the low-water flow comes from springs entering the river below irrigation diversions. Some fluctuation occurs, due to power plants and canal intakes near Bend.

Monthly discharge, in second-feet, of Deschutes River near Madras, Oreg., for the years ending September 30, 1924–1926

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1924				
January	6,060	4,160	4,550	280,000
February	7,320	5,060	5,840	324,000
May	3,860	3,360	3,620	223,000
June	3,710	3,320	3,440	205,000
August	3,420	3,240	3,340	205,000
September	3,400	3,240	3,340	199,000

Monthly discharge, in second-feet, of Deschutes River near Madras, Oreg., for the years ending September 30, 1924–1926—Continued

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1924–25				
October	3,710	3,400	3,460	213,000
November	5,940	3,910	4,460	265,000
December	5,440	3,860	4,370	269,000
January	9,230	4,470	5,120	315,000
February	10,200	5,190	6,560	364,000
March	6,320	4,940	5,540	341,000
April	6,940	5,190	6,030	359,000
May	6,820	4,360	4,980	306,000
June	4,580	3,860	4,130	246,000
July	3,960	3,660	3,750	231,000
August	4,010	3,560	3,680	226,000
September	4,110	3,610	3,900	232,000
The year	10,200	3,400	4,650	3,370,000
1925–26				
October	4,010	3,810	3,930	242,000
November	4,580	3,810	4,350	259,000
December	4,700	4,260	4,510	277,000
January	4,580	4,060	4,390	270,000
February	6,820	4,260	5,160	287,000
March	5,820	4,470	5,060	311,000
April	5,060	3,660	4,250	253,000
May	3,710	3,440	3,530	217,000
June	3,510	3,270	3,360	200,000
July	3,330	3,270	3,310	204,000
August	3,340	3,230	3,290	202,000
September	3,410	3,240	3,320	198,000
The year	6,820	3,230	4,030	2,920,000

DESCHUTES RIVER AT MECCA

A station was maintained from June 7, 1911, to January 14, 1927, at Mecca, in the SW. ¼ sec. 20, T. 9 S., R. 13 E., 1½ miles below the mouth of Shitike Creek and about 10 miles north of this area. (See fig. 5.) There was a staff gage at this station until August, 1924, when a Gurley 8-day recorder was installed. The bed of the river is composed of rock and gravel and is subject to seasonal shifts. The maximum stage occurred on the night of January 6, 1923, at gage height 6.90 feet, with a discharge of 15,200 second-feet. The minimum stage was on August 27 to 30, 1920, at gage height 1.95 feet, with a discharge of 3.170 second-feet. The flow at this station is affected by diversions from the upper Deschutes River near Bend, Tumalo, and Cline Falls. The summer flow of the Crooked River above Trail Crossing and of Tumalo and Squaw Creeks is practically all diverted. The records are good.

Monthly discharge, in second-feet, of Deschutes River at Mecca, Oreg., from June 7, 1911, to September 30, 1926

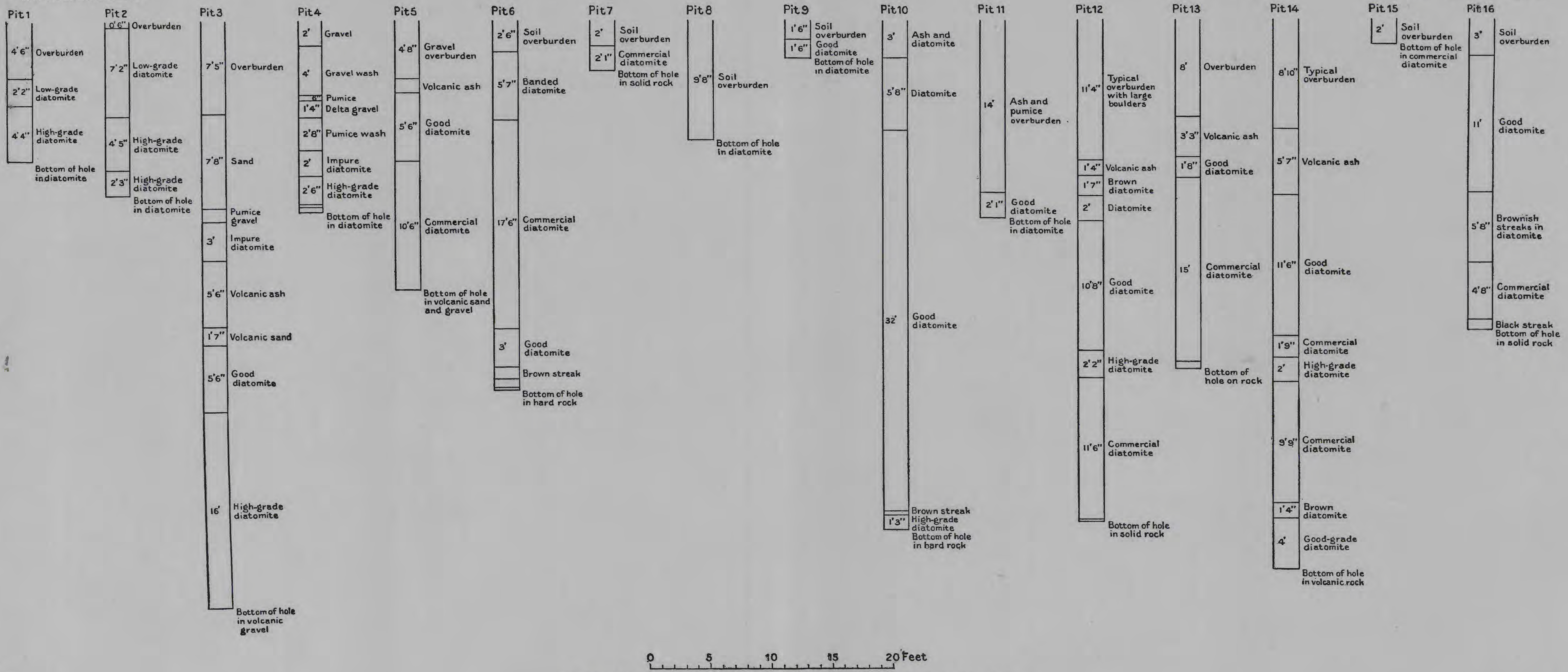
Month	Maximum	Minimum	Mean	Run-off in acre-feet
1911				
June 7–30	5,260	4,540	4,880	232,000
July	4,720	4,040	4,360	268,000
August	4,200	3,880	4,050	249,000
September	4,200	4,040	4,150	247,000
The period				1,096,000

Monthly discharge, in second-feet, of Deschutes River at Mecca, Oreg., from June 7, 1911, to September 30, 1926—Continued

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1911-12				
October	4,200	3,880	4,090	251,000
November	4,540	3,880	4,210	251,000
December	4,370	4,200	4,300	264,000
January	6,800	3,300	5,050	311,000
February	8,490	4,900	5,940	342,000
March	5,830	4,900	5,200	320,000
April	7,410	5,830	6,460	384,000
May	8,270	6,400	7,100	437,000
June	6,800	5,450	6,020	358,000
July	6,210	4,370	4,850	298,000
August	5,080	4,370	4,550	280,000
September	4,720	4,370	4,520	269,000
The year	8,490	3,300	5,190	3,760,000
1912-13				
October	4,900	4,200	4,390	270,000
November	5,260	4,307	4,770	284,000
December	5,080	4,540	4,670	287,000
January	5,080	4,540	4,880	300,000
February	6,020	4,540	4,810	267,000
March	6,400	4,540	5,350	329,000
April	9,410	6,210	7,450	443,000
May	6,210	4,900	5,710	351,000
June	6,020	5,080	5,490	327,000
July	5,640	4,720	5,060	311,000
August	4,720	4,200	4,400	271,000
September	4,540	4,200	4,250	253,000
The year	9,410	4,200	5,100	3,690,000
1913-14				
October	5,080	4,200	4,520	278,000
November	5,080	4,540	4,820	287,000
December	5,080	4,540	4,800	295,000
January	6,020	4,900	5,270	324,000
February	6,400	4,540	5,080	282,000
March	8,320	6,050	7,250	446,000
April	7,890	5,480	6,610	393,000
May	5,480	4,740	5,080	312,000
June	5,100	4,380	4,630	276,000
July	4,740	4,050	4,230	260,000
August	4,050	3,900	4,020	247,000
September	4,740	3,900	4,200	250,000
The year	8,320	3,900	5,040	3,650,000
1914-15				
October	4,740	4,380	4,590	282,000
November	4,740	4,380	4,700	280,000
December	5,100	4,210	4,580	282,000
January	4,920	4,380	4,640	285,000
February	4,740	4,380	4,540	252,000
March	7,260	4,740	5,310	326,000
April	7,470	4,380	5,480	326,000
May	4,740	4,210	4,380	269,000
June	4,050	3,470	3,810	227,000
July	3,750	3,470	3,580	220,000
August	3,750	3,470	3,500	215,000
September	3,750	3,470	3,580	213,000
The year	7,470	3,470	4,390	3,180,000
1915-16				
October	4,050	3,680	3,860	237,000
November	5,860	4,050	4,500	268,000
December	5,480	4,740	4,820	296,000
January	4,740	4,380	4,580	282,000
February	10,400	4,560	7,240	416,000
March	11,700	5,370	7,710	474,000
April	9,350	6,350	7,460	444,000
May	6,850	4,900	5,730	352,000
June	5,850	4,670	5,220	311,000
July	6,600	4,450	5,610	345,000
August	4,670	4,250	4,410	271,000
September	4,450	4,250	4,410	262,000
The year	11,700	3,680	5,450	3,960,000

Monthly discharge, in second-feet, of Deschutes River at Mecca, Oreg., from June 7, 1911, to September 30, 1926—Continued

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1916–17				
October	4,450	4,070	4,370	269,000
November	4,900	4,450	4,740	282,000
December	4,900	4,450	4,750	292,000
January	4,900	4,070	4,550	280,000
February	4,900	4,070	4,470	248,000
March	7,100	4,070	4,730	291,000
April	11,600	4,900	7,580	451,000
May	9,560	6,360	7,720	475,000
June	6,840	5,100	5,850	348,000
July	5,500	4,400	5,110	314,000
August	4,400	4,100	4,250	261,000
September	4,400	4,100	4,300	256,000
The year	11,600	4,070	5,200	3,770,000
1917–18				
October	4,580	4,140	4,310	265,000
November	6,360	4,400	4,670	278,000
December	9,300	4,760	6,010	370,000
January	6,840	5,920	6,480	398,000
February	7,320	5,330	6,040	335,000
March	7,800	5,140	6,020	370,000
April	7,080	4,760	5,390	321,000
May	4,760	4,400	4,560	280,000
June	4,760	3,970	4,420	263,000
July	4,050	3,820	3,950	243,000
August	4,050	3,740	3,860	237,000
September	4,580	3,890	4,040	240,000
The year	9,300	3,740	4,970	3,600,000
1918–19	4,580	3,970	4,290	264,000
November	4,760	4,400	4,560	271,000
December	4,580	4,050	4,480	275,000
January	5,920	4,220	4,820	296,000
February	4,760	4,580	4,750	264,000
March	7,320	4,580	5,050	311,000
April	10,300	6,470	7,550	449,000
May	6,470	4,900	5,310	326,000
June	4,900	4,220	4,600	274,000
July	4,550	4,060	4,180	257,000
August	4,060	3,840	3,920	241,000
September	4,220	3,840	4,120	245,000
The year	10,300	3,840	4,800	3,470,000
1919–20				
October	4,550	3,980	4,260	262,000
November	7,120	4,550	4,940	294,000
December	6,050	4,550	5,000	307,000
January	10,100	4,550	5,380	331,000
February	6,430	4,330	5,060	291,000
March	5,150	4,330	4,720	290,000
April	5,990	4,730	5,350	318,000
May	5,360	3,760	4,520	278,000
June	4,330	3,580	3,870	230,000
July	3,580	3,380	3,500	215,000
August	3,410	3,170	3,320	204,000
September	3,850	3,250	3,590	214,000
The year	10,100	3,170	4,460	3,230,000
1920–21				
October	4,330	3,850	3,960	243,000
November	5,990	4,040	4,780	284,000
December	6,880	4,730	4,930	303,000
January	7,340	5,260	6,030	371,000
February	9,820	5,080	6,420	357,000
March	9,560	6,680	7,440	457,000
April	7,800	6,470	7,040	419,000
May	7,340	5,650	6,410	394,000
June	6,900	5,080	5,860	349,000
July	5,450	4,380	4,720	290,000
August	4,550	4,060	4,240	261,000
September	4,900	4,060	4,320	257,000
The year	9,820	3,850	5,510	3,980,000



LOGS OF TEST PITS OF WESTERN DIATOMITE CO., NEAR TERREBONNE, OREG.

By A. C. Boyle, Jr.

Monthly discharge, in second-feet, of Deschutes River at Mecca, Oreg., from June 7, 1911, to September 30, 1926—Continued

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1921–22				
October	4,730	4,330	4,480	275,000
November	9,820	4,730	5,700	339,000
December	10,600	5,360	6,450	397,000
January	5,570	4,330	5,160	317,000
February	5,150	4,730	5,070	282,000
March	6,650	4,730	5,480	337,000
April	9,300	5,780	7,240	431,000
May	7,570	5,570	6,610	406,000
June	6,430	4,330	5,440	324,000
July	4,330	3,850	4,150	255,000
August	4,330	3,760	3,860	237,000
September	4,330	3,760	3,860	230,000
The year	10,600	3,760	5,290	3,830,000
1922–23				
October	4,730	3,760	4,200	258,000
November	4,730	4,330	4,640	276,000
December	5,570	4,330	4,700	289,000
January	12,100	4,940	6,450	397,000
February	5,360	4,730	4,910	273,000
March	7,340	5,150	5,590	344,000
April	7,800	5,360	6,670	397,000
May	5,570	4,110	4,840	298,000
June	5,150	4,140	4,350	259,000
July	4,940	3,670	4,230	260,000
August	3,760	3,580	3,670	226,000
September	3,950	3,410	3,600	214,000
The year	13,100	3,410	4,829	3,490,000
1923–24				
October	4,330	3,760	3,990	245,000
November	4,730	4,040	4,230	252,000
December	5,360	4,330	4,590	282,000
January	6,430	4,330	4,570	281,000
February	7,570	5,150	5,900	339,000
March	5,570	4,330	5,030	309,000
April	5,150	3,720	4,540	270,000
May	4,170	3,400	3,730	229,000
June	3,990	3,400	3,520	209,000
July	3,640	3,320	3,420	210,000
August	3,480	3,310	3,380	208,000
September	3,480	3,310	3,400	202,000
The year	7,570	3,310	4,190	3,040,000
1924–25				
October	----------	3,400	3,490	215,000
November	6,880	----------	4,770	284,000
December	4,900	----------	4,590	282,000
January	10,100	4,710	5,350	329,000
February	11,700	5,400	7,060	392,000
March	6,430	5,200	5,790	356,000
April	7,570	5,400	6,390	380,000
May	7,340	4,620	5,300	326,000
June	5,000	4,080	4,400	262,000
July	4,170	3,720	3,830	236,000
August	4,170	3,560	3,750	231,000
September	4,170	3,640	3,980	237,000
The year	11,700	3,400	4,870	3,530,000
1925–26				
October	4,170	3,900	4,010	247,000
November	4,800	3,900	4,520	269,000
December	5,100	4,440	4,780	294,000
January	4,800	4,350	4,620	284,000
February	7,340	----------	5,370	298,000
March	5,600	----------	5,200	320,000
April	5,200	3,810	4,480	267,000
May	3,810	3,480	3,620	223,000
June	3,640	3,310	3,440	205,000
July	3,340	3,240	3,300	203,000
August	3,380	3,200	3,310	204,000
September	3,320	3,240	3,280	195,000
The year	7,340	3,200	4,150	3,010,000

TUMALO CREEK

Tumalo Creek rises on the east slope of the Cascade Range at the foot of Broken Top Mountain. It flows east and then a little north and joins the Deschutes about 4 miles below the Deschutes gaging station near Bend. The station on Tumalo Creek is in sec. 23, T. 17 S., R. 11 E., 4 miles above the mouth of the creek and a quarter of a mile above the intake of the Tumalo Feed Canal, the principal diversion. (See fig. 5.) The monthly discharge, including diversions, from 1913 to 1926 is given below. Although the creek lies outside of the middle Deschutes Basin (see pl. 10), the records are included here because it is the only perennial stream that enters the Deschutes River above Squaw Creek and below the Bend gaging station. From 1914 to 1926, for which records at Cline Falls are not available, the flow of this creek, except during the irrigation season, should be added to the flow of the Deschutes at Bend to obtain the flow of the Deschutes at Cline Falls or any place above the mouth of Squaw Creek in the middle Deschutes Basin.

Monthly discharge, in second-feet, of Tumalo Creek near Bend, Oreg., for the years ending September 30, 1914–1926

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1913–14				
October			86.5	5,320
November	127		95.9	5,710
December			83.5	5,130
January	86	67	76.7	4,720
February	92	80	85.1	4,730
March	120	82	100	6,150
April	461	90	145	8,630
May	336	140	215	13,200
June	361	122	183	10,900
July	231	82	118	7,260
August	88	63	71.3	4,380
September	97	60	72.7	4,330
The year	461		111	80,500
1914–15				
October	94	74	78.4	4,820
November	130	73	83.5	4,960
December	80	62	71.5	4,400
January	72	62	64.7	3,980
February	76	67	69.9	3,880
March	91	56	68.2	4,190
April	152	88	118	7,020
May	165	107	129	7,930
June	199	101	135	8,030
July	113	67	80.5	4,950
August	67	53	58.2	3,580
September	53	46	49	2,920
The year	199	46	83.3	60,600
1915–16				
October	58	44	48.4	2,980
November	91	52	62.5	3,720
December	66	58	62.5	3,840
January			[a] 50	3,070
February	110	44	62.3	3,580
March	90	50	64.6	3,970
April	155	70	102	6,070
May		144	180	11,100
June	525	126	316	18,800

[a] Estimated.

Monthly discharge, in second-feet, of Tumalo Creek near Bend, Oreg., for the years ending September 30, 1914–1926—Continued

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1915–16				
July	572	172	323	19,900
August	197	97	135	8,300
September	123	73	81.9	4,870
The year	572	44	124	90,200
1916–17				
October	75	61	67.9	4,180
November	92	60	71.7	4,270
December	63	54	60.4	3,710
January	62	60	60.1	3,700
February	71	49	62	3,440
March	75	46	58.9	3,620
April	96	52	67	3,990
May	201	80	133	8,180
June	382	198	293	17,400
July	340	115	266	16,400
August	113	78	94.1	5,790
September	92	65	77.7	4,620
The year	382	46	109	79,300
1917–18 [b]				
October	73	65	68.4	4,210
November	99	62	66.8	3,970
December	455	65	130	7,990
January	225	93	140	8,610
February	122	72	84.4	4,690
March	85	69	73.9	4,540
April	142	76	100	5,950
May	191	117	149	9,160
June	498	149	300	17,900
July	165	89	109	6,700
August	103	70	79.8	4,910
September	77	67	71.4	4,250
The year	498	62	114	82,800
1918–19				
October	104		74.1	4,560
November	90	70	78.2	4,650
December	71		55.9	3,440
January			47.9	2,950
February	60	46	51.8	2,880
March	60	45	51.8	3,190
April	164	65	96.1	5,720
May	482	133	228	14,000
June	302	139	222	13,200
July	318	96	157	9,650
August	95	54	80.9	4,970
September			72.2	4,300
The year	482	45	101	73,500
1919–20				
October			59.7	3,670
November	149		72.1	4,290
December			62.3	3,830
January	248		89.1	5,480
February	114	54	82.2	4,730
March	78	53	69.8	4,290
April	78	57	68.4	4,070
May	194	63	127	7,810
June	283	117	204	12,100
July	219	90	131	8,060
August	109	67	83	5,100
September	111		74	4,400
The year	283		93.8	67,800
1920–21				
October	115	76	93.6	5,760
November	243	88	122	7,260
December	193	69	87.6	5,390
January	160		101	6,210
February	160	85	113	6,280
March	114	77	92.8	5,710
April			112	6,660
May	316		203	12,500

[b] These discharges include diversion above station, mostly in Columbia Southern Canal. Beginning with 1917 discharge includes that of Crater Creek Canal in addition to natural flow of Tumalo Creek.

Monthly discharge, in second-feet, of Tumalo Creek near Bend, Oreg., for the years ending September 30, 1914–1926—Continued

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1920–21				
June	463	189	339	20,200
July	360	119	205	12,600
August	162	102	124	7,600
September	198	83	108	6,430
The year	463	69	144	103,000
1921				
October	100	62	79.9	4,910
November	450	57	104	6,190
1922 [c]				
May	270	114	173	10,600
June	450	252	329	19,600
July	282		191	11,700
August			97.3	5,980
September			94	55,90
The period				53,500
1923				
April			[d] 97.3	5,790
May	291	91	206	12,700
June	366	150	212	12,600
July	266	93	182	11,200
August	95		85.1	5,230
September			[d] 71.3	4,240
The period				51,800
1923–24				
October			[d] 69.0	4,240
November			[d] 72	4,280
December	103		[d] 74.3	4,570
January			67.8	4,170
February	92	66	74.0	4,260
March	73		64.4	3,960
April	119	58	81.1	4,830
May	298	105	190	11,700
June	200	85	109	6,490
July	114	60	71.2	4,380
August	67	56	63.9	3,930
September	61	49	55.9	3,330
The year	298	49	82.9	60,100
1924–25				
October	57	45	[d] 49.5	3,040
November	161	55	[d] 87.3	5,190
December	76		[d] 59.1	3,630
January		58	[d] 66.9	4,110
February	125	60	79.4	4,410
March	80	57	62.0	3,810
April	206	65	116	6,900
May	533	131	280	17,200
June	392	169	258	15,400
July	272	104	172	10,600
August	125		[d] 85.5	5,260
September		66	[d] 73.9	4,400
The year	533	45	116	84,000
1925–26				
October	74	64	68.3	4,200
November	75		66.6	3,960
December	114	62	70.7	4,350
January	70	62	65.2	4,010
February	112	62	74.9	4,160
March	89	64	70.7	4,350
April	225	77	134	7,970
May	272	105	164	10,100
June	199	75	118	7,020
July	96	57	72.3	4,450
August	78	58	63.8	3,920
September		54	59.4	3,530
The year	272	54	85.6	62,000

[c] Diversion in Columbia Southern Canal estimated the same as in 1921.
[d] Partly estimated.

SQUAW CREEK [22]

Squaw Creek rises at the foot of the glaciers of the Three Sisters and flows northeastward into the Deschutes River. Its drainage basin embraces six glaciers. The largest, Bend Glacier, lies on the north slope of Broken Top; the others rest on the east slope of the Three Sisters. Their areas are as follows:

	Acres
On Broken Top:	
Bend Glacier	250
On South Sister:	
Prouty Glacier	170
Carver Glacier	150
On Middle Sister:	
Diller Glacier	190
Between Middle and North Sisters:	
Hayden Glacier	220
On North Sister:	
Thayer Glacier	60
	1,040

A gaging station was maintained from July, 1906, to May, 1913, in sec. 29, T. 15 S., R. 10 E., about 4 miles above Sisters and above all diversions except McCallister ditch. (See fig. 5.) The flow of McCallister ditch is included in the published records of discharge. Since May, 1913, the station has been just above the intake of McCallister ditch, the highest diversion on the creek. The drainage area above this station is 45 square miles. This drainage area includes the area tributary to Snow Creek, part of the waters of which are diverted into Three Creek, but excludes Pole Creek, practically all of which is diverted. Of this area 23 square miles, or practically one-half, lies at an altitude of 6,000 feet or more. Three extensive mountain masses rise above 8,000 feet in this basin. The one north of Broken Top comprises about 300 acres; another of 210 acres, mostly covered by Prouty Glacier, is on South Sister; and a third of 1,050 acres is on Middle and North Sisters. The area lying above an altitude of 8,000 feet amounts to practically 2½ square miles. Only a narrow strip of the lower portion of the drainage area above the gaging station lies below 4,500 feet.

The records from 1906 to 1909 published on pages 399 to 405 of Water-Supply Paper 370 and on pages 41 and 42 of Water-Supply Paper 344 may be subject to considerable error. The records from 1909 to 1926, given below, are good. The entire flow of the creek is diverted below this station during the summer. Miscellaneous measurements and estimates show that the flow at the mouth during the irrigation season does not exceed 10 second-feet.

[22] Data furnished by F. F. Henshaw.

Monthly discharge, in second-feet, of Squaw Creek near Sisters, Oreg., for the years ending September 30, 1910–1926

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1909–10				
October	82	58	68.4	4,210
November	1,960	69	255	15,200
December	253	84	133	8,180
January	155	68	86.3	5,310
February	112	54	73.0	4,050
March	253	84	118	7,260
April	172	80	116	6,900
May	310	112	183	11,300
June	317	139	201	12,000
July	226	146	178	10,900
August	144	84	112	6,890
September	188	66	95.0	5,650
The year	1,960	54	135	97,800
1910–11				
October	250	57	81.2	4,990
November	307	41	102	6,070
December	115	62	81.6	5,020
January	76	50	61.7	3,790
February	76	47	52.5	2,920
March	62	42	50.4	3,100
April	97	49	68.5	4,080
May	128	80	93.8	5,770
June	313	144	237	14,100
July	344	163	223	13,700
August	194	97	124	7,620
September	117	65	80.4	4,780
The year	344	41	105	75,900
1911–12				
October	65	45	56.8	3,490
November	65	46	58.3	3,470
December	60	41	47.2	2,900
January	186	49	68.8	4,230
February	130	43	64.5	3,710
March	56	32	45.7	2,810
April	84	46	59.5	3,540
May	261	60	131	8,060
June	395	191	249	14,800
July	261	158	202	12,400
August	336	102	168	10,300
September	152	72	90.2	5,370
The year	395	32	104	75,100
1912–13				
October	102	44	64.7	3,980
November	104	54	70.6	4,200
December	66	50	55.1	3,390
January	------	------	[a] 51.0	3,140
February	43	37	37.4	2,080
March	72	37	40.4	2,480
April	133	56	80.5	4,790
May	------	68	[a] 143	8,790
June	420	195	278	16,500
July	375	210	280	17,200
August	255	135	199	12,200
September	405	80	136	8,090
The year	420	------	120	86,800
1913–14				
October	270	62	81.7	5,020
November	100	62	70.1	4,170
December 1–5	59	50	51.5	1,530
April 7–30	150	75	98.0	4,670
May	270	90	166	10,200
June	288	112	190	11,300
July	288	150	215	13,200
August 1–17	205	125	165	5,560

[a] Estimated.

Monthly discharge, in second-feet, of Squaw Creek near Sisters, Oreg., for the years ending September 30, 1910–1926—Continued

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1915				
May 9–11	150	54	90.4	4,120
June	175	100	133	7,910
July	205	100	149	9,160
August	205	100	126	7,750
The period				28,900
1916				
March 24–31	82	76	77.8	1,230
April	112	76	89.9	5,350
May	197	90	116	7,130
June	404	110	239	14,200
July	514	228	309	19,000
August	268	147	209	12,900
September	206	78	125	7,440
The period				67,200
1917				
April 5–30	90	39	54.3	2,800
May	158	68	108	6,640
June	302	133	233	13,900
July	472	225	347	21,300
August	240	142	184	11,300
September	183	77	118	7,020
October	100	56	76.8	4,720
November	168	51	62.7	3,730
December 1–5	84	63	69.4	688
The period				72,100
1918				
March	67		[b] 60.2	3,700
April	89	62	72.8	4,330
May	139	76	99.8	6,140
June	440	115	267	15,900
July		130	[b] 202	12,400
August			[b] 151	9,280
September	193	93	135	8,039
The period				59,800
1919				
June 25–30	340	255	300	3,570
July	415	187	258	15,900
August 1–23	205	157	176	8,030
The period				27,500
1920				
March 17–31	68	58	62.6	1,860
April	80	60	67.7	4,030
May	179	69	111	6,820
June	248	106	174	10,400
July	248	158	190	11,700
August	176	106	144	8,850
September	170	85	107	6,430
The period	248	60	127	50,100
1921				
May 6–31	233	88	151	7,790
June	433	190	304	18,100
July	388	184	255	15,700
August		111	[b] 156	9,600
September	164		103	6,130
The period	433		195	57,300
1922				
April 23–30	60	52	57.5	912
May	177	64	119	7,320
June	360	197	275	16,400
July	340	161	226	13,900
August	193	98	149	9,160
September	134	67	102	6,070
October	72	42	56.5	3,470
November	114	35	45	2,680
December 1–15	58	22	35.8	1,060
The period				61,000

[b] Partly estimated.

Monthly discharge, in second-feet, of Squaw Creek near Sisters, Oreg., for the years ending September 30, 1910–1926 —Continued

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1923				
April 13–30	92	67	76.6	2,740
May	210	69	144	8,850
June	300	117	178	10,600
July	320	172	224	13,800
August	159	119	138	8,490
September	132	55	93.2	5,550
The period				50,000
1924				
April (8 days)	84	55	65.6	1,040
May	204	76	138	8,450
June	175	94	124	7,380
July	170	98	125	7,690
August	123	78	103	6,330
September	111	43	70.4	4,190
The period	204	43		
1925				
April 23–30	114	92	100	1,590
May	341	116	205	12,600
June	375	144	227	13,500
July	257	163	212	13,000
August	202	92	134	8,240
September	106	58	87.9	5,230
The period (161 days)				54,200
1925–26				
October			[b]55.6	3,420
November	53	44	47.8	2,340
December	110	43	56.7	3,490
January	78	32	47.4	2,910
February	128	36	65.2	3,620
March	53	41	[b]46.1	2,830
April	166	49	89.2	5,310
May	238	80	[b]134	8,240
June	199	102	143	8,510
July	173	96	132	8,120
August	204	75	110	6,760
September	78	39	58.1	3,460
The year	238	32	82.2	59,500

[b] Partly estimated.

CROOKED RIVER

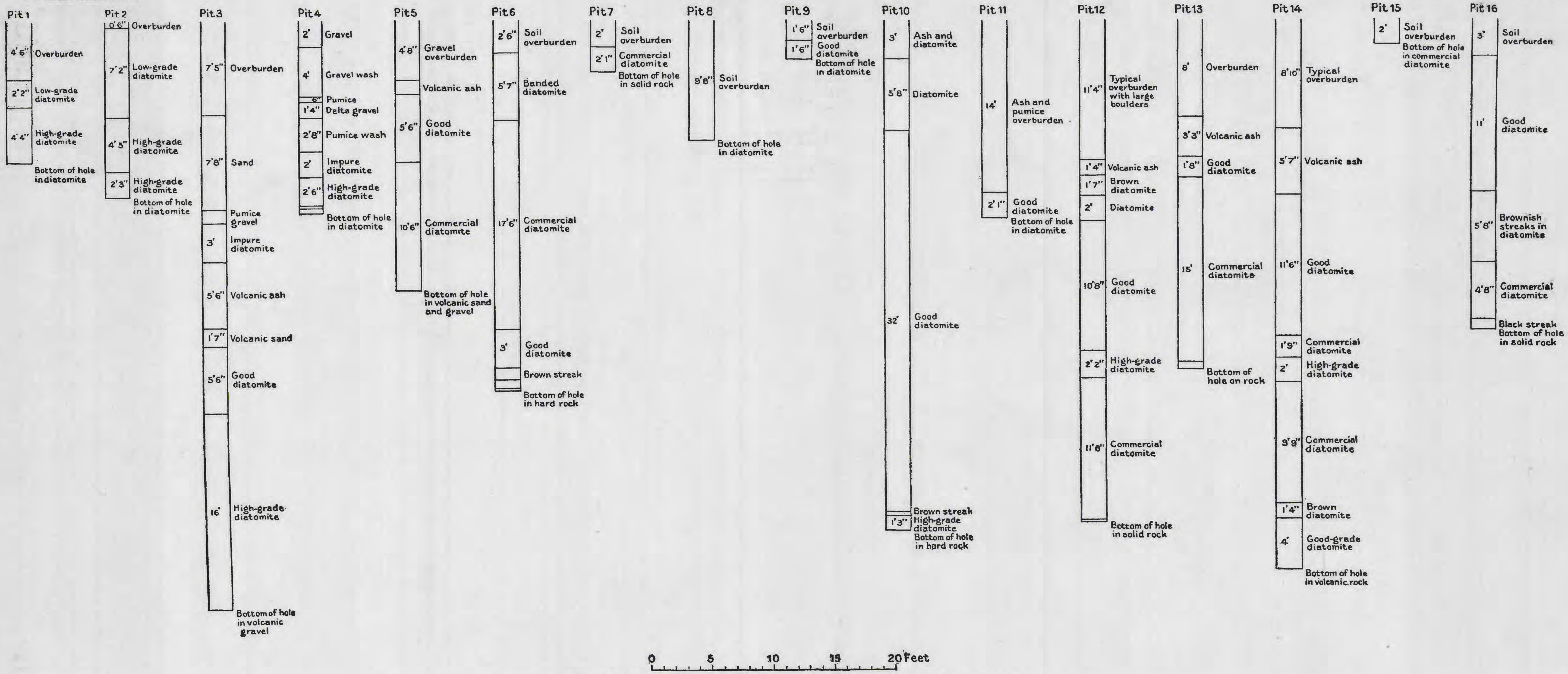
The Crooked River, the next perennial stream north of Squaw Creek to enter the Deschutes, rises in a group of mountains in central Oregon and flows west. At Trail Crossing it enters a deep canyon, and a few miles farther west it turns and flows northward to the Deschutes. Since October 1, 1917, a gaging station has been maintained in the NW. ¼ sec. 11, T. 12 S., R. 12 E., at the Cove power plant, about 6 miles west of Culver. (See fig. 5.) Until February 15, 1922, an inclined staff gage was installed on the left bank one-eighth mile below the power house; after that date a vertical gage was installed on the right bank 100 feet below the power house. The maximum stage was recorded on February 6, 1925, at gage height 5.60 feet, with a discharge of 7,320 second-feet. The minimum discharge was 970 second-feet at gage height 1.70 feet from July 12 to September 5, 1921. Practically all the flow of Crooked River above Prineville is diverted during the irrigation season. Miscellaneous measurements and reliable observations indicate that the summer flow at Trail Crossing was generally less than 10 second-feet from 1900 to 1910. Since then a summer flow of about 50 second-feet has passed Trail Crossing as a result of storage in Ochoco Reservoir and return flow from irrigation. Consequently, nearly all the low-water flow at this station comes from springs between Trail Crossing and the gaging station. The records obtained at this station are good.

Monthly discharge, in second-feet, of Crooked River near Culver, Oreg., for the years ending September 30, 1918–1926

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1917–18				
October	1,120	1,120	1,120	68,900
November	1,210	1,120	1,130	67,200
December	1,460	1,210	1,250	76,900
January	1,530	1,330	1,440	88,500
February	2,010	1,330	1,530	85,000
March	3,300	1,390	2,020	124,000
April	2,900	1,270	1,760	105,000
May	1,270	1,210	1,210	74,400
June	1,210	1,100	1,130	67,200
July	1,100	1,100	1,100	67,600
August	1,150	1,100	1,110	68,200
September	1,100	1,100	1,100	65,500
The year	3,300	1,100	1,320	958,000
1918–19				
October	1,150	1,100	1,110	68,200
November	1,150	1,150	1,150	68,400
December	1,150	1,150	1,150	70,700
January	1,390	1,150	1,210	74,400
February	1,390	1,210	1,260	70,000
March	3,200	1,210	1,490	91,600
April	5,200	2,540	3,430	204,000
May	2,360	1,150	1,420	87,300
June	1,150	1,100	1,110	66,000
July	1,100	1,050	1,080	66,400
August	1,100	1,100	1,100	67,600
September	1,150	1,100	1,110	66,000
The year	5,200	1,050	1,380	1,000,000
1919–20				
October	1,060	1,060	1,060	65,200
November	1,120	1,060	1,120	66,600
December	2,010	1,060	1,260	77,500
January	4,100	1,120	1,460	89,800
February	1,770	1,250	1,400	80,500
March	1,690	1,250	1,380	84,800
April	2,270	1,390	1,790	107,000
May	2,180	1,120	1,460	89,800
June	1,060	1,060	1,060	63,100
July	1,120	1,060	1,060	65,200
August	1,060	1,060	1,060	65,200
September	1,180	1,060	1,090	64,900
The year	4,100	1,060	1,270	920,000
1920–21				
October	1,120	1,120	1,120	68,900
November	1,530	1,120	1,190	70,800
December	1,250	1,120	1,160	71,300
January	2,720	1,180	1,560	95,900
February	4,900	1,250	2,160	120,000
March	4,400	2,360	2,900	178,000
April	3,700	2,270	2,760	164,000
May	3,400	1,490	2,360	145,000
June	2,180	1,020	1,300	77,400
July	1,040	970	995	61,200
August	970	970	970	59,600
September	1,040	970	1,030	61,300
The year	4,900	970	1,620	1,170,000

Monthly discharge, in second-feet, of Crooked River near Culver, Oreg., for the years ending September 30, 1918–1926—Continued

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1921–22				
October	1,120	1,090	1,100	67,600
November	1,250	1,120	1,180	70,200
December	2,340	1,140	1,280	78,700
January	1,190	1,090	1,150	70,700
February	1,310	1,180	1,210	67,200
March	2,630	1,180	1,480	91,000
April	6,240	1,570	3,090	184,000
May	3,420	1,300	2,240	138,000
June	1,400	1,120	1,210	72,000
July	1,120	1,110	1,110	68,200
August	1,120	1,110	1,110	68,200
September	1,140	1,120	1,120	66,600
The year	6,240	1,090	1,440	1,040,000
1922–23				
October	1,180	1,120	1,150	70,700
November	1,200	1,150	1,170	69,600
December	1,280	1,180	1,190	73,200
January	2,450	1,220	1,370	84,200
February	1,510	1,180	1,260	70,000
March	3,280	1,300	1,670	103,000
April	3,720	1,630	2,620	156,000
May	1,760	1,220	1,410	86,700
June	1,260	1,180	1,200	71,400
July	1,450	1,140	1,240	76,200
August	1,140	1,120	1,130	69,500
September	1,180	1,140	1,150	68,400
The year	3,720	1,120	1,380	999,000
1923–24				
October	1,200	1,180	1,180	72,600
November	1,200	1,180	1,190	70,800
December	1,200	1,160	1,180	72,600
January	3,280	1,160	1,240	76,200
February	3,880	1,400	1,900	109,000
March	1,570	1,220	1,340	82,400
April	1,630	1,220	1,360	80,900
May	1,200	1,110	1,140	69,500
June	1,110	1,110	1,110	66,000
July	1,110	1,110	1,110	68,200
August	1,110	1,110	1,110	68,200
September	1,110	1,110	1,110	66,000
The year	3,880	1,110	1,240	902,000
1924–25				
October	1,150	1,110	1,120	68,900
November	1,510	1,150	1,210	72,000
December	1,180	1,160	1,170	71,900
January	5,640	1,160	1,600	98,400
February	6,660	1,510	2,330	129,000
March	3,020	1,400	1,910	117,000
April	2,900	1,690	2,320	138,000
May	2,050	1,300	1,490	91,600
June	1,300	1,180	1,230	73,200
July	1,180	1,180	1,180	72,600
August	1,180	1,180	1,180	72,600
September	1,220	1,180	1,200	71,400
The year	6,660	1,110	1,490	1,080,000
1925–26				
October	1,220	1,220	1,220	75,000
November	1,220	1,220	1,220	72,600
December	1,220	1,220	1,220	75,000
January	1,240	1,220	1,220	75,000
February	2,720	1,260	1,540	85,500
March	2,290	1,400	1,670	103,000
April	2,290	1,220	1,540	91,600
May	1,220	1,160	1,180	72,600
June	1,160	1,160	1,160	69,000
July	1,160	1,140	1,150	70,700
August	1,140	1,140	1,140	70,100
September	1,150	1,120	1,140	67,800
The year	2,720	1,120	1,280	928,000



LOGS OF TEST PITS OF WESTERN DIATOMITE CO., NEAR TERREBONNE, OREG.

By A. C. Boyle, Jr.

METOLIUS RIVER

The Metolius River rises at the foot of the snow fields of three great peaks in the Cascade Range—Mount Washington, Three Finger Jack, and Mount Jefferson. Practically all of its normal flow comes from huge springs. Several gaging stations have been maintained by the United States Geological Survey on the river, but none of them are in the part of the basin covered by this report.

METOLIUS RIVER AT RIGGS RANCH

The gaging station at the Riggs ranch is only about 4 miles west of the area mapped. (See fig. 5.) It is 7 miles above the mouth of the river, in the NE. ¼ sec. 28, T. 11 S., R. 11 E. The drainage area above the station is 347 square miles. Only a few small private irrigation ditches divert water above the gaging station. There are no diversions between the station and the mouth of the river, and miscellaneous measurements indicate that the flow at the mouth is the same as at the station. Records of monthly discharge for this station are good.

Monthly discharge, in second-feet, of Metolius River at Riggs ranch, near Sisters, Oreg., for the years ending September 30, 1908–1912

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1908–9				
October 22–31	1,740	1,490	1,550	30,700
November	1,650	1,490	1,510	89,800
December	1,570	1,410	1,470	90,400
January	2,320	1,410	1,650	101,000
February	1,830	1,570	1,640	91,100
March	1,650	1,570	1,620	99,600
April	1,650	1,570	1,610	95,800
May	1,740	1,570	1,640	101,000
June	1,830	1,650	1,710	102,000
July	1,650	1,570	1,610	99,000
August	1,650	1,490	1,530	94,100
September	1,530	1,410	1,470	87,500
The period				1,080,000
1909–10				
October	1,490	1,410	1,450	89,200
November	3,890	1,410	1,870	111,000
December	2,020	1,570	1,730	106,000
January	1,880	1,530	1,610	99,000
February	1,920	1,570	1,610	89,400
March	2,770	1,780	2,090	129,000
April	1,830	1,700	1,750	104,000
May	1,920	1,700	1,740	107,000
June	1,740	1,610	1,650	98,200
July	1,610	1,570	1,600	98,400
August	1,570	1,490	1,540	94,700
September	1,530	1,450	1,490	88,700
The year	3,890	1,410	1,680	1,210,000
1910–11				
October	1,830	1,450	1,490	91,600
November	1,920	1,450	1,580	94,000
December	1,830	1,530	1,610	99,000
January	1,650	1,490	1,520	93,500
February	1,490	1,410	1,490	82,800
March	1,650	1,410	1,490	91,600
April	1,570	1,490	1,550	92,200
May	1,650	1,570	1,610	99,000
June	1,830	1,650	1,670	99,400
July	1,650	1,570	1,620	99,600
August	1,570	1,490	1,500	92,200
September	1,570	1,490	1,490	88,700
The year	1,920	1,410	1,550	1,120,000

Monthly discharge, in second-feet, of Metolius River at Riggs ranch, near Sisters, Oreg., for the years ending September 30, 1908–1912—Continued

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1911–12				
October	1,490	1,410	1,440	88,500
November	1,570	1,410	1,470	87,500
December	1,490	1,410	1,420	87,300
January	2,020	1,330	1,590	97,800
February	2,430	1,650	1,860	107,000
March	1,830	1,650	1,680	103,000
April	1,740	1,650	1,660	98,800
May	2,020	1,650	1,760	108,000
June	2,120	1,740	1,890	112,000
July	1,740	1,650	1,660	102,000
August	1,830	1,650	1,660	102,000
September	1,650	1,490	1,580	94,000
The year	2,430	1,330	1,640	1,190,000

METOLIUS RIVER NEAR GRANDVIEW

A station has been maintained since October 1, 1921, on the Metolius River in the NE. ¼ sec. 19, T. 11 S., R. 11 E., at the Montgomery ranch, 11 miles above the mouth of the river and 10 miles northwest of Grandview post office. A vertical staff is placed on the right bank of the river. The maximum stage recorded was 3.32 feet on January 7, 1923, when the discharge, from approximate extension of the rating curve, was 5,780 second-feet. The minimum discharge was 1,300 second-feet, October 1–30 and December 18–25, 1924. There are no diversions and no regulation above the station.

Monthly discharge, in second-feet, of Metolius River near Grandview, Oreg., for the years ending September 30, 1922–1926

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1921–22				
October	1,610	1,450	1,490	91,600
November	3,870	1,450	1,820	108,000
December	3,710	1,610	2,010	124,000
January	1,610	1,500	1,530	94,100
February	1,500	1,450	1,480	82,200
March	1,500	1,450	1,470	90,400
April	1,660	1,660	1,610	95,800
May	1,830	1,610	1,720	106,000
June	1,950	1,720	1,870	111,000
July	1,720	1,500	1,610	99,000
August	1,500	1,500	1,500	92,200
September	1,500	1,400	1,450	86,300
The year	3,870	1,400	1,630	1,180,000
1922–23				
October	1,400	1,400	1,400	86,100
November	1,610	1,400	1,410	83,900
December	1,830	1,400	1,500	92,200
January	4,370	1,610	2,250	138,000
February	1,610	1,500	1,550	86,100
March	1,610	1,500	1,550	95,300
April	1,720	1,660	1,680	100,000
May	1,830	1,610	1,770	109,000
June	1,950	1,660	1,730	103,000
July	1,830	1,660	1,720	106,000
August	1,610	1,500	1,560	95,900
September	1,500	1,450	1,480	88,100
The year	4,370	1,400	1,640	1,180,000

Monthly discharge, in second-feet, of Metolius River near Grandview, Oreg., for the years ending September 30, 1922–1926—Continued

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1923-24				
October	1,450	1,450	1,450	89,200
November	1,950	1,400	1,470	87,500
December	1,660	1,400	1,460	89,800
January	1,660	1,450	1,490	91,600
February	1,610	1,500	1,580	90,900
March	1,500	1,400	1,450	89,200
April	1,400	1,400	1,400	83,300
May	1,610	1,400	1,480	91,000
June	1,500	1,400	1,430	85,100
July	1,450	1,400	1,410	86,700
August	1,400	1,350	1,370	84,200
September	1,400	1,300	1,340	79,700
The year	1,950	1,300	1,440	1,050,000
1924-25				
October	1,400	1,300	1,300	79,900
November	2,480	1,350	1,510	89,800
December	1,720	1,300	1,400	86,100
January	2,200	1,450	1,590	97,800
February	2,930	1,720	2,060	114,000
March	1,720	1,560	1,620	99,600
April	1,950	1,560	1,650	98,200
May	2,340	1,610	1,770	109,000
June	1,720	1,660	1,700	101,000
July	1,660	1,560	1,600	98,400
August	1,560	1,450	1,500	92,200
September	1,450	1,400	1,440	85,700
The year	2,930	1,300	1,590	1,150,000
1925-26				
October	1,400	1,400	1,400	86,100
November	1,450	1,400	1,400	83,300
December	1,720	1,400	1,420	87,300
January	1,400	1,350	1,370	84,200
February	2,070	1,350	1,570	87,200
March	1,500	1,400	1,450	89,200
April	1,500	1,450	1,460	86,900
May	1,500	1,400	1,460	89,800
June	1,450	1,400	1,410	83,900
July	1,400	1,350	1,370	84,200
August	1,400	1,300	1,320	81,200
September	1,300	1,300	1,300	77,400
The year	2,070	1,300	1,410	1,020,000

SHITIKE CREEK

Shitike Creek, the only perennial stream that enters the Deschutes River between the Metolius River and Mecca, rises on the east slope of the Cascade Range and flows eastward to the Deschutes, which enters 1½ miles above the Mecca gaging station. (See fig. 5.) A gaging station on Shitike Creek was located in the NE. ¼ sec. 26, T. 9 S., R. 12 E., at Warm Spring, about 2 miles above the mouth of the creek and below all tributaries. The records are good, except for high water and for certain periods not covered by measurements.

Monthly discharge, in second-feet, of Shitike Creek at Warm Spring, Oreg., from June 11, 1911, to October 31, 1916, and from April 1, 1923, to September 30, 1925

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1911				
June 11–30	248	120	151	5,970
July	134	66	93.2	5,730
August	75	50	59.8	3,680
September	86	50	61.9	3,680
The period				19,060
1911–12				
October	66	57	57.3	3,520
November	147	57	72.9	4,340
December	75	57	63.6	3,910
January	593	57	172	10,600
February	383	112	195	11,200
March	265	190	212	13,000
April	190	102	135	8,030
May	296	112	188	11,600
June	338	148	200	11,900
July	161	102	125	7,690
August	102	66	80.2	4,930
September	112	58	67.2	4,000
The year	593	57	131	94,700
1912–13				
October	73	58	62.5	3,840
November	112	66	83.9	4,990
December	149	73	83.5	5,130
January	156	76	104	6,400
February	130	76	92.1	5,120
March	405	96	122	7,500
April	365	140	191	11,400
May	295	128	178	10,900
June	260	176	195	11,600
July	295	151	161	9,900
August	151	77	95.4	5,870
September	84	72	77.8	4,630
The year	405	58	121	87,200
1913–14				
October	295	77	106	6,520
November	128	70	86.5	5,150
December	91	77	85.9	5,280
January	245	84	105	6,460
February	128	70	79.6	4,420
March	176	91	131	8,060
April	216	91	118	7,020
May	151	100	122	7,500
June	128	91	108	6,430
July	151	70	90.4	5,566
August	70	63	63.9	3,930
September	100	63	80.8	4,810
The year	295	63	98.2	71,100
1914–15				
October	122	62	78.9	4,850
November	147	62	93.2	5,550
December	111		87.4	5,370
January	100	47	63.8	3,920
February	90	54	60.4	3,350
March	122	59	90.6	5,570
April	134	100	116	6,900
May	175	100	118	7,260
June	134	62	82.5	4,910
July	90	47	67.7	4,160
August	47	41	41.8	2,570
September	47	36	41.2	2,450
The year	175	36	78.5	56,900

Monthly discharge, in second-feet, of Shitike Creek at Warm Spring, Oreg., from June 11, 1911, to October 31, 1916, and from April 1, 1923, to September 30, 1925—Continued

Month	Maximum	Minimum	Mean	Run-off in acre-feet
1915–16				
October	62	37	41.5	2,550
November	342	62	145	8,630
December	161	100	126	7,750
January	134	90	109	6,700
February	720	111	274	15,800
March	450	147	209	12,900
April	220	171	200	11,900
May	330	140	184	11,300
June	370	155	223	13,300
July	292	155	213	13,100
August	155	77	106	6,520
September	120	57	83.9	4,990
The year	720	37	159	115,000
1916				
October	77	60	64.5	3,970
1923				
April	206	145	176	10,500
May	305	137	202	12,400
June	245	141	172	10,200
July	206	102	154	9,470
August	98	69	81.7	5,020
September	69	61	64.1	3,810
The period				51,400
1923–24				
October	95	58	70.0	4,300
November	370	55	77.7	4,620
December	245	72	110	6,760
January	218	66	92.3	5,680
February	232	88	132	7,590
March	88	66	73.5	4,520
April	95	69	79.4	4,720
May	145	88	111	6,820
June	85	58	68.9	4,100
July	58	39	46.7	2,870
August	39	32	36.2	2,230
September	47	32	36.1	2,150
The year	370	32	77.9	56,400
1924–25				
October	72	37	45.5	2,800
November	440	52	105	6,250
December	520		87.7	5,390
January	392	77	136	8,360
February	445	123	219	12,200
March	123	99	116	7,130
April	310	115	163	9,700
May	410	131	189	11,600
June	172	108	131	7,800
July	128	76	105	6,460
August	87	56	68.3	4,200
September	67	46	53.5	3,180
The year	530	37	118	85,100

MISCELLANEOUS MEASUREMENTS

All the miscellaneous measurements that have been made in the middle Deschutes Basin from 1897 to 1927 are given below. These records are invaluable for the determination of the quantity of ground water in the basin, and they are discussed further on page 204.

Miscellaneous discharge measurements in the middle Deschutes Basin, Oreg., 1897–1927

Date	Stream	Tributary to—	Locality	Discharge
				Sec.-ft.
July 16, 1914	Deschutes River	Columbia River	Former Cline Falls gaging station	604
July 31, 1915	do	do	do	317
Oct. 10, 1897	do	do	Tetherow Bridge	1,720
July 16, 1914	do	do	do	606
Jan. 10, 1906	do	do	Sec. 36, T. 14 S., R. 12 E	1,350
Oct. 13, 1906	do	do	do	1,230
Aug. 23, 1908	do	do	4 miles below Tetherow Bridge	1,400
Aug. 26, 1908	do	do	Above mouth of Metolius River	[a]1,600
Dec. 4, 1905	Squaw Creek	Deschutes River	Sisters, above diversions	49
Dec. 5, 1905	do	do	do	50
Apr. 12, 1907	do	do	Sisters	46
Aug. 23, 1908	do	do	Sisters road crossing	10
Aug. 4, 1913	Crooked River	do	In T. 14 S., R. 14 E., near Terrebonne	41.8
Aug. 23, 1908	do	do	Trail Crossing, NE. ¼ sec. 33, T. 13 S., R. 13 E.	7
Oct. 29, 1919	do	do	do	61
Nov. 28, 1925	do	do	do	110
Aug. 13, 1927	do	do	do	25.6
Aug. 14, 1927	do	do	NE. ¼ sec. 24, T. 13 S., R. 12 E	67
Oct. 29, 1919	do	do	Gates ranch, sec. 14, T. 13 S., R. 12 E	301
Nov. 29, 1925	do	do	Above Opal Springs, NE. ¼ sec. 33, T. 12 S., R. 12 E.	841
Mar. 26, 1912	Metolius River	do	Allen ranch, sec. 14, T. 12 S., R. 9 E	1,040
June 22, 1915	do	do	do	1,100
Oct. 17, 1906	do	do	Mouth	[a]2,800
Aug. 26, 1908	do	do	do	[a]1,800

[a] Estimated.

QUALITY OF SURFACE WATER

The quality of the surface waters in the basin has been well described by Van Winkle.[23] He says:

Deschutes River proper drains a region in which the exposed rocks are Tertiary lavas, tuffs, and basalts, and the mineral matter carried in solution is made up largely of salts of sodium, chiefly bicarbonate, leached directly from the disintegrating rock material. The total amount of dissolved matter carried is small, averaging at Bend between 65 and 75 parts per million and at the mouth about 25 parts per million more. Seasonal variations in mineral content, at least above the confluence of Crooked River, are very small, owing to the remarkable constancy of volume of the run-off. The water of the upper Deschutes is excellent for irrigation, industrial, or domestic use. The amount of soap consumed by the hardening constituents in it is trifling, no treatment is in general required to prevent formation of scale in boilers, a quarter of a pound of lime to a thousand gallons of water at most being an ample corrective, and the water will not foam or cause corrosion in boilers. Though the water is soft it contains sufficient gas and disolved mineral matter to render it palatable and wholesome. With proper precautions against contamination by human agencies the water is almost ideal for domestic use. As almost no suspended matter is carried by it, no trouble from silting up of reservoirs or sedimentation basins need be feared. In short, the water compares favorably with the better waters used for municipal supply in this country or in Europe. Though not so low in mineral content as Portland's supply from Bull Run, it is superior in this respect to the new supply of Los Angeles from Owens River, to the present supply of San Francisco, to supplies of any of the middle western cities, and to many of those on the Atlantic seaboard.

[23] Van Winkle, Walton, in Henshaw, F. F., and others, in Deschutes River, Oreg., and its utilization: U. S. Geol. Survey Water-Supply Paper 344, pp. 85–86, 1914.

Crooked River furnishes only a small quantity of water to the Deschutes but is its chief tributary in point of size of drainage area. It flows from the highlands in the southeastern corner of Crook County westward to the Deschutes, which it enters below the mouth of Opal Canyon. The drainage basin is almost completely covered with tuffs and lavas and contains only a few exposures of Tertiary lake sediments. Though the water is of the same general type as that of Deschutes River it is less uniform in quality, much harder, and less free from suspended matter, owing to the much greater fluctuations in discharge to which it is subject. The marked seasonal variations in quality influence the water of the Deschutes very little because of the relatively small run-off of Crooked River, and the water below the confluence of the two streams is still of good quality and only slightly harder than the water at Bend. During high water the mineral content of Crooked River water is nearly the same as that of Deschutes River, and it is only at low water that high mineralization and consequent poorer quality are apparent. The chief effect of Crooked River on Deschutes River is the increased charge of suspended matter imported by it, but even this is not enough to increase the turbidity of Deschutes River to a very great amount.

In speaking of the Crooked River, Van Winkle evidently refers to the portion of the basin above the sampling station near Prineville. The large inflow to the river from springs below Trail Crossing tends to render the character of the water at the mouth less dissimilar to the upper Deschutes than it is at the Prineville station.

The good quality of the water for domestic supplies in the Deschutes Basin is likely to continue because of the foresight of the Oregon Legislature. In 1911 a law was enacted making it unlawful for any person, company, corporation, or city to contaminate the waters of the Deschutes River or its tributaries. This law required the towns in the basin to provide for the disposal of sewage other than by discharging it into surface streams.

GROUND WATER

WELL RECORDS

Records were obtained of all the wells in the middle Deschutes Basin. Practically all the wells that were drilled to the water table are successful, except those close to Round Butte. The location of the wells and the altitude of the water surface in them are shown on Plate 10. The records of the wells are tabulated below. The 200-foot contours of the water table shown on Plate 10 were drawn from these data. Many of the dug wells are developed hillside seeps and go dry in the summer. They were not used in plotting the water table. The quality of the well water is excellent.

Record of wells in the middle Deschutes Basin, Jefferson County, Oreg.

No.	Date (1925)	Location: Quarter	Location: Sec.	Location: T.S.	Location: R.E.	Owner	Altitude above sea level (feet)	Type	Depth reported (feet)	Depth to water reported (feet)	Log	Remarks
1	Aug. 22	SW.	5	11	13	Jerry Southman	[a] 2,450	Drilled	800	750	Alternating beds of lava, tuff, gravel, sand, etc., of Deschutes formation.	Well was finished in fine ash. Owner reports a small seep between 450 and 500 feet. Yield about 1,400 gallons a day.
2	Aug. 20	SW.	36	10	13	Oregon Trunk Ry	[a] 2,375	do	415	355	Alternating beds of ash, silt, sand, gravel, pumice, and lava. Well ends in gravel.	Railroad company states that it is either 315 or 355 feet to water. Yield over 60,000 gallons a day.
3	Aug. 22	NW.	28	11	13	do	[a] 2,500	do	878	645	Alternating beds of ash, silt, sand, gravel, pumice, and lava.	
4	do	SW.	30	11	13	Fred Hensky	[a] 2,575	do	1,300	750	Alternating beds of sand, clay, gravel, and tuff with one bed of basalt 100 feet thick.	Yield only 1½ barrels a day. Owner states that at 1,295 feet a black shale was struck. Tools kept sticking in claylike beds.
5	Aug. 11	NE.	2	12	13	H. I. Alexander	[a] 2,725	do	441	420	Conglomerate 0–221 feet; cinders 221–305 feet; blue lava 305–434 feet; red lava 434–441 feet.	Driller reports that water disappeared rapidly in the cinders. Strong flow at 434 feet.
6	Aug. 22	NW.	6	12	13	Theo. Hartnagel	[a] 2,575	do	695	690	Basalt 0–100 feet; cinders 100–104 feet; sandrock; lava.	Dug 228 feet. Plenty of water from the lava in the bottom of the well.
7	Aug. 11	NW.	12	12	13	W. F. Thomas	[a] 2,750	do	378	340	Conglomerate or sandrock 0–125 feet; lava 125–275 feet; various soft formations.	Owner states that water is in lava sand.
8	do	SE.	13	12	13	A. W. Boyce	[a] 2,830	Dug	30	23	Tuffs, mostly basic	
9	Aug. 12	SE.	15	12	13	Jess Eads	[a] 2,700	Drilled	342	302	Acidic tuffs	Helper to driller reports that water is found in loose white pumice.
10	Aug. 21	NE.	16	12	13	Orla C. Hale	[a] 2,760	do	630	540	Sandstone 0–210 feet; lava 210–520 feet; soft red rock, probably tuff, 520–620 feet.	Struck water at 560 feet, which rose 20 feet. Owner states that when, wind blows from west, southwest, or northwest, air blows out; when the wind blows from northeast, east, or south, air is sucked in.
11	Aug. 20	SE.	18	12	13	William Barber (Culver townsite well)	[a] 2,640	do	774	700	Alternating beds of sand, gravel, tuff, and basalt.	
12	Aug. 11	NE.	24	12	13	Kate Burson	[b] 2,830	Dug		[c] 18		
13	Aug. 12	SE.	27	12	13	R. L. Tate	[a] 2,800	do		[c] 14.4		
14	Aug. 13	SW.	28	12	13	George Rodman	[a] 2,875	do	18	Dry.	Tuff	Goes dry in July and then used for cistern. Hillside seep developed.

15	do	NE.	29	12	13	do	a 2,800	Drilled	760	692	Hardpan 0-18 feet; sandstone and pumice 18-200 feet; red rock 200-600 feet; soft green and red rock 600-690 feet; gravel 690-692 feet; green rock 692-760 feet.	Water obtained in 2 feet of gravel. 692 feet below surface.
16	Aug. 19	NW.	9	13	13	Verne Merchant		do	150	Dry.	Gravel and sand in bottom	Never completed.
17	Aug. 21	NE.	34	12	13	Perry Reed	b 2,880	do	148	28	Tuff	
18	Aug. 11	SE.	5	13	13	Jacob Harrington	b 2,940	do	852	400	Broken rock 0-30 feet; pumice 30-38 feet; broken rock 38-68 feet; diatomite 68-113 feet; hard and soft lava to bottom.	At 630 feet a small seep of 6 gallons in 24 hours. At 775 feet there was a flow of about 100 gallons in 24 hours.
19	Aug. 19	SW.	10	13	13	L. L. Hobbs	b 2,980	do	222	150	Tuff	Struck water at 215 feet, in soft blue tuff.
20	do	SW.	10	13	13	O. H. Wilson	b 2,980	do		150		According to Mr. Hobbs, this well is similar to No. 19.
21	Aug. 29	SW.	12	13	13	J. M. King	b 3,020	do	82	30	Green acidic tuff	Plenty of water.
22	Aug. 20	NE.	18	13	13	Oregon Trunk Ry	a 2,859	do	1,690	657	Alternating sand, cinders, gravel, lava, and stratified tuff. The last 800 feet is probably in the Mascall (?) formation.	The first water was struck at 715 feet. Water was obtained at six horizons.
23	Aug. 15	SW.	27	13	13	J. M. Healy	b 2,925	do		210		Renter states water tastes of sulphur. Depth to water estimated from the fact that there is 240 feet of pump rods in it. It can be pumped dry.
24	do	NW.	16	14	13	Town of Terrebonne	a 2,860	do	392	302		
25	Aug. 19	SW.	31	12	12		a 2,600	Dug		c 14.5		In bed of a dry creek.
26	do	SE.	6	13	12	Robert E. Jordan	a 2,800	do	210	dry.	Basalt 0-6 feet; gravel, sand, silt, and tuff to bottom.	
27	Aug. 12	SE.	1	12	11	L. Z. Nance	a 2,750	do	22	dry.	Basalt underlain by sandstone	Dry except during November to July. In a dry creek bed.
28	Aug. 22	NE.	34	10	13	Madras State Bank		Drilled	120			Can be pumped dry. A small seep of water at 60 feet.
29	Aug. 11	SE. (?)	19	12	14	Dayton Grant	b 2,920	do	190	75	Blue clay (like putty) 0-185 feet; red rock 185-188 feet; pumice 188-190 feet.	Driller states that he struck a large flow at 188 feet; there was a small seep at 130 feet.
30	do	NE.	30	12	14	Mason Grant	b 3,000	do	298	208	Tuff	Owner states that a small seep was struck at 130 feet (1 quart an hour). Hit main flow at 290 feet, in a crevice.
31	do	NE.	30	12	14	Jim Brown	b 2,950	do	154	142	do	

a Determined from Bureau of Reclamation map.
b Determined by barometer.
c Measured.

The logs of certain wells and numerous reliable data on the water-bearing formations in them were furnished by Mr. W. H. Marsh, assistant chief engineer of the Oregon Trunk Railway, and Mr. H. C. O'Neel, assistant engineer of the Oregon-Washington Railroad & Navigation Co. They throw considerable light on the stratigraphy and the occurrence of ground water. These logs are given in the following tables:

Record of Oregon-Washington Railroad & Navigation Co.'s well at Madras, Oreg.

[No. 2, pl. 10. Altitude, 2,375 feet]

	Thickness	Depth		Thickness	Depth
	Feet	*Feet*		*Feet*	*Feet*
Sand and silt	112	112	Volcanic ash	8	228
Fine gravel	9	121	Kaolin [a] and lava	27	265
Lava (basalt)	16	137	Kaolin [a] and volcanic ash	28	293
Volcanic ash	11	148	Volcanic ash	7	300
Lava (basalt)	39	187	Lava and volcanic ash	30	330
Pumice	11	198	Volcanic ash	25	355
Red basalt	8	206	Mixed rock and gravel	35	390
Trap rock (dense basalt)	14	220	Gravel filled with water	25	415

[a] Probably fine white ash or diatomite.

Record of Oregon Trunk Railway well No. 1 at Metolius, Oreg.

[No. 3, pl. 10. Altitude 2,500 feet]

	Thickness	Depth		Thickness	Depth
	Feet	*Feet*		*Feet*	*Feet*
Dark soil	3	3	Brown sand	10	400
Light-gray, fairly hard cemented gravel	18	21	Cemented gravel	34	434
Black and dark-gray loose rock	22	43	Soft red sandstone	6	440
Black basalt	14	57	Sandy brown clay	95	535
Red basalt	10	67	Sharp black gravel	15	550
Blue basalt	15	82	Coarse black gravel	10	560
Porous blue basalt	2	84	Brown gravel	10	570
Fairly hard gray cemented gravel	15	99	Soft brown shale	35	605
Soft blue sandstone	30	129	Black sandstone	18	623
Fairly hard volcanic conglomerate	50	179	Soft red sandstone; first water	42	665
Soft red volcanic ash and partly cemented gravel	34	213	Hard brown sandstone	30	695
Fairly soft volcanic conglomerate	77	290	Soft red sandstone	30	725
Coarse gravel	3	293	Hard black rock	120	845
Partly cemented gravel (easy drilling	97	390	Soft black rock	33	878

Record of Oregon Trunk Railway well at Opal City, Oreg.

[No. 22, pl. 10. Altitude, 2,859 feet]

	Thickness	Depth
	Feet	*Feet*
Soil and cemented gravel	12	12
Hard black rock and boulders	16	28
Loose brown cinders	19	47
Hard black rock and boulders	92	139
Loose cinders	75	214
Medium hard cemented gravel	24	238
Hard black basalt	157	395
Soft volcanic conglomerate	184	579
Soft yellow shale	51	630
Medium hard cemented gravel	65	695
Soapstone (?), caving; first water; water rose 20 feet to 695 feet	20	715
Soft brown shale	45	760
Soft yellow shale	89	849
Soft conglomerate	41	890
Soft blue shale	30	920
Soft red shale	48	968
Gray rock; second water; water rose 354 feet to 630 feet	16	984
Green rock and shale, medium hard	6	990
Hard gray rock	10	1,000
Green shale	2	1,002
Brown shale	54	1,056
Solid brown shale	45	1,101
Hard gray rock	18	1,119
Soft red shale	2	1,121
Hard gray rock	16	1,137
Hard brown rock	20	1,157
Hard gray rock	8	1,165
Hard brown rock	63	1,228
Hard black rock	100	1,328
Green rock or shale; third water; water rose 740 feet to 605 feet	17	1,345
Hard black rock	61	1,406
Hard brown rock	8	1,414
Red rock; fourth water; water rose 890 feet to 580 feet	56	1,470
Dark-brown rock	10	1,480
Black rock; fifth water; water dropped in well to 657 feet below surface	150	1,630
Green and white shale	15	1,645
Black rock	30	1,675
Green shale; sixth water; water remained at 657 feet below surface	15	1,690

WATER TABLE

The water table for the area north of the line between Tps. 12 and 13 S. is shown on Plate 10 by 200-foot contours. The contours are not shown south of this line because there are too few wells in that area to give the necessary data. In a general way the water table slopes gently northward for about 6 miles from the southern boundary of the area. From the north side of T. 14 S. the gradient increases, owing to the deepening of the Deschutes and Crooked Canyons, until in T. 11 S. the water table has a gradient of about a hundred feet to the mile. The general northward slope of the water table in the basin is disturbed by the ground water discharged into the basin from the mountains on the east side, which produces a steep northwestward gradient. This steep gradient is doubtless due in part to the fact that the formations in this area are less permeable than in the middle of the basin, and in part to the cascade of the ground water into extremely permeable lava beds that are drained northwestward by the Deschutes Canyon. Thus in the region between Haystack Butte and Round Butte the water table slopes steeply to the northwest, with a gradient of more than 200 feet to the mile.

Ground-water investigations were not carried far enough west of the basin to determine the shape of the water table in that area, but a hurried reconnaissance indicated that the ground water flows northeastward in that area and ultimately discharges into the Deschutes Canyon as springs.

The numerous springs in the Deschutes and Crooked Canyons doubtless derive their main supply of water from the vast area of subdrained, permeable, fissured lava beds in the upper Deschutes Basin. The geologic structure indicates that the springs from interstratified beds of basalt on the west wall of the Crooked River Canyon in secs. 10 and 14, T. 13 S., R. 12 E., near the Gates ranch, are due to leakage from the Deschutes River. Their origin is discussed in detail on page 199. A large part of the ground water comes also from leaking canals and return irrigation water near and south of Terrebonne. It is reported by water masters in that vicinity that less than one-half of the immense amount of water diverted from the Deschutes River near Bend ever reaches the irrigated area because of the great leakage into the basalt through which the canals are constructed. Furthermore, the amount of water used on the land irrigated is large because of the seepage through the shallow soil into the permeable basalt beneath the surface. All the water lost in this way ultimately reaches the Deschutes or the Crooked River and issues in the form of springs. The numerous buried channels near Terrebonne, together with their buried tributaries, also collect great quantities of ground water from an extensive area to the south and east.

WATER IN SEDIMENTARY ROCKS

WATER IN THE CLARNO (?) FORMATION

Wells 16, 17, 19, 20, and 21 are in the area of the Clarno (?) formation and are shown on Plate 10. Wells 15, 18, and 22 may derive their supply of water from these same beds. A few other wells in T. 13 S., R. 14 E., outside the area mapped, were visited in order to obtain additional data on the water-bearing characteristics of this formation. These beds wherever exposed have the appearance of being poor water bearers. Many of the beds consist of fine-grained tuff resembling shale, and others are massive and only sparingly jointed.

Well 29, belonging to Dayton Grant, in sec. 19, T. 12 S., R. 14 E., obtained a good supply of water from this formation. It is on a hill and is reported to be 190 feet deep. The depth to water is about 75 feet, and the water stands about 2,845 feet above sea level. Mason Grant, the driller, states that in this well he struck 185 feet of blue puttylike clay from which there was a small seep of water at 130 feet. Below the clay there is 3 feet of red rock and 2 feet of pumice, the pumice full of water.

Well 30, owned by Mason Grant, in the SE. ¼ NE. ¼ sec. 30, T. 12 S., R. 14 E., lies at an altitude of about 3,000 feet. This well is 298 feet deep, and the water stands 208 feet below the surface. A small seep was encountered at 130 feet, but at 290 feet a crevice was struck that yields a large amount of water. A small pump with a capacity of 400 gallons an hour can not pump it dry.

Well 10 derives its supply at 560 feet from a soft red rock, possibly a sandstone member of the Deschutes formation but more probably a red tuff of the Clarno (?) formation. This conclusion is based on the fact that more of the Clarno (?) beds are red than those of the Deschutes formation.

Well 15 is supplied from a gravel bed, 2 feet thick, 690 feet below the surface. This gravel bed appears from the log to be a member of the Clarno (?) formation. The owner has developed a hillside seep by a dug well (No. 14) which saves considerable pumping during the spring. After this dug well goes dry it is utilized as a reservoir, and water from the drilled well (No. 15) is lifted into it. Such a system is economical and enables the owner to have gravity water in his house.

In general it may be said that drilled wells in this formation are successful and yield ample water for domestic purposes. There seems to be no clearly defined water table, and wells are brought in at various depths according to the depth of a permeable bed or crevice. The pervious beds of the formation seem to be filled with water even at shallow depths. Well 21 obtained a good supply of water at 82 feet.

Shallow dug wells are in general unsuccessful in this formation, although a few have been developed from hillside seeps with success. Such wells are mainly catchment basins for the spring run-off from banks of snow and the locally saturated adjacent ground. Although these dug wells all go dry during the summer, yet they save the farmer hauling water for several months each year.

WATER IN THE DESCHUTES SEDIMENTS

The sedimentary deposits in the Deschutes formation consist of silt, sand, gravel, diatomite, tuff, pumice, and volcanic agglomerate. (See pl. 13, *A*.) The beds of sand and gravel in this formation that lie in the zone of saturation and are not consolidated yield supplies of water sufficient for domestic use. However, very few of the great number of springs issue from the sedimentary beds of the Deschutes formation in either the Deschutes or the Crooked Canyon; hence they must be as a whole less permeable than the basalt members of this formation. Because of the fluviatile origin of most of the beds they are in many places cross-bedded and lens-shaped, and permeable beds are not continuous over a very large area.

Fourteen wells have been drilled into the Deschutes formation in the area shown in Plate 10. Eight of them obtained water in sedimentary beds. Well 22, which has been included in the group, obtains some water also from igneous rocks, but it is highly probable that the last water struck in this well comes from the Clarno (?) tuffs rather than from the Deschutes sediments. The logs of two of the wells are unknown. Four of the wells are supplied from igneous rocks in the Deschutes formation if well 18 is included, and five if well 22 is included. The yields from the wells vary according to their depth or location, and it has been found that the deepest wells do not necessarily yield the most water.

Well 1 is reported to be 800 feet deep. It was finished in ash at a cost of $4,500. According to the owner's statement, he can pump only 400 gallons a day from this well. At about 475 feet water was struck in lava rock but was insufficient for domestic purposes. This well was almost a failure, but at greater depths sufficient water for domestic and stock use was obtained. The cause of the low yield was not the lack of permeable beds but the draining of the aquifers by Deschutes River, which lies only 3 miles west and 170 feet lower than the bottom of the well. Deeper drilling at this place would probably not develop much additional water.

Well 2 obtains its water from a bed of gravel in the Deschutes formation at the bottom of the well. In 1924 60 gallons a minute was pumped from this well during a 72-hour pumping test, without any appreciable lowering of the water level in the well. This test shows that some of the Deschutes sedimentary beds are good aquifers.

Well 3 obtains its water at 665 feet in pink sandstone of the Deschutes formation. Its yield is sufficient to supply the town of Metolius with water and also some of the adjacent ranches.

Well 4 is 1,300 feet deep and is cased for 1,077 feet. A little water was struck at 750 feet but not enough for domestic and stock use. At 1,295 feet black clay was encountered which caused the tools to stick. The yield from this well was only 1½ barrels a day, so it was capped. This hole extends 305 feet lower than the surface of the Deschutes River, which flows 2½ miles west of the well. The owner knows very little about the material in the hole; hence it is difficult to explain why the well was a failure. He states that only 100 feet of lava was encountered. This lava may have been the Pelton basalt. It is interesting to note that in the canyon wall of the Crooked River nearest to the well there are no intercalated beds of lava in the Deschutes formation above the Pelton basalt member. The fact that there existed around this well an area which, during the eruption of the several intrasedimentary basalts, was not flooded with lava until the rim-rock basalt issued suggests that the well may have penetrated some peculiarity of structure or buried outlier of impermeable shale belonging to an older formation.

Well 6, only 1 mile southwest of well 4, obtained plenty of water in the Pelton basalt 695 feet below the surface, a result which gives further support to the suggestion above made regarding well 4.

Well 7 obtains a good yield from a bed of black lava sand that is presumably in the Deschutes formation, although it is very close to some outliers of the Clarno (?) formation. (See pl. 10.)

Well 8 is 30 feet deep and is dug into basic tuff in a dry gulch. Near by, within 1 acre, are nine other wells belonging to farmers in the vicinity. For years this was the only locality in this area where water was known, hence each farmer dug a well in this little gulch and hauled his water from it. In the last few years most of these wells have been abandoned because wells have been drilled on the owners' property. The water in these dug wells is derived from the underflow of an ephemeral stream that flows northward from the Haystack country.

Dry dug well 26 represents an earnest but unwise effort to obtain water by digging in the Deschutes formation in this locality. It lies less than half a mile from the Deschutes Canyon where the canyon is 750 feet deep. The well is 210 feet deep, and much labor could have been saved if the owner had realized that owing to the absence of perched springs in the canyon a well at least 700 feet deep would have been necessary at this place to obtain water.

It is concluded from the data above set forth that the yield of wells in the sedimentary beds of the Deschutes formation is extremely variable and may, in places, be insufficient for even domestic use.

WATER IN ALLUVIUM

According to the statement of J. Southman, of Madras, dug wells in the alluvium of Willow Creek formerly contained water throughout the year. Water was obtained for three or four years in these wells, after which they dried up each summer. At that time Willow Creek flowed until May each year, which it now rarely does. In digging through this alluvial fill in the valley dry lava is struck. The change in the dug wells in Willow Creek near Madras may be due to the extensive dry farming that is now being carried on in its drainage basin. However, water occurs in the Willow Creek Valley about 2½ miles upstream from Madras and 3 miles east of Metolius, in a well about 10 feet above the creek bed. On August 12, 1925, when the creek was dry, the depth to water in this well was 25.8 feet. This well, however, derives its water from the Deschutes sedimentary beds rather than from the alluvium. These beds probably have a lower percolation factor than the alluvium at Madras, and hence water seeps into the well throughout the year. Moreover, this well is seldom used, and the water in it may be only stagnant water that seeped in from the creek during the spring.

Wells 13 and 25 are both shallow wells in ephemeral creek beds and apparently yield a little water throughout the year.

WATER IN IGNEOUS ROCKS

WATER IN THE TRAIL CROSSING BASALT

The Trail Crossing basalt wherever exposed in this basin is minutely fractured but tightly jointed and gives the appearance of being a poor aquifer. No clinkery or aa beds are exposed. If beds of aa basalt occur in the basin there is a possibility of obtaining large yields of water, provided these beds lie in the zone of saturation. Only one well in the basin, well 23, is known to obtain its water from this basalt. It is near the southeast corner of the SW. ¼ sec. 27, T. 13 S., R. 13 E., and is known to be more than 240 feet deep, for there is 240 feet of pump pipe in the well. The renter reports that the water from this well tastes of sulphur and that the well is easily pumped dry with a small lift pump. A small spring discharges about 1 quart a minute from the basalt in sec. 1, T. 13 S., R. 13 E.

Well 18, in sec. 5, T. 13 S., R. 13 E., is 852 feet deep and is unsuccessful. This well has an unusual history, and the log could not be ascertained accurately enough to interpret the exact stratigraphy. The driller and owner, who are both familiar with the diatomite deposit near Terrebonne, state that 45 feet of diatomite was drilled through in this well between 70 and 115 feet below the surface. This indicates that the well penetrates the Deschutes formation, which is at least 100 feet thick at this well, although the nearest outcrops are members of the Clarno (?) formation. At 630 feet a small seep yielded 6 gallons in 24 hours from a medium-hard light-gray rock. At 775 feet a small trickle was encountered that furnished 100 gallons in 24 hours. The water comes from a tough, hard rock, probably diabase. Mason Grant, the driller, states that the first 404 feet was drilled in 13 days and that the last 200 feet of the well took three or four months. The owner believed that the yield of the well could be increased by "shooting it," so they lowered several hundred pounds of dynamite on the end of ordinary barbed wire into the hole and discharged it. The explosion at that depth caused only a sharp thud in the immediate vicinity of the hole and nothing blew out of it. The barbed wire was unrolled from a spool and evidently coiled up in the hole as the dynamite went off. At any rate, the hole was very effectively plugged by balls of wire. The driller spent several months fishing out the wads of wire, and the hole had not been entirely cleaned out when the writer saw it. The last 200 feet or so is probably in the Trail Crossing basalt, although there is a slight possibility that the hole was drilled into a basaltic neck or plug.

On the basis of observations and the record of the wells, it is believed that the Trail Crossing basalt is a poor water bearer and scarcely worth exploring for water in this basin.

WATER IN ANDESITE

Insufficient field work was done on the andesite in the area to decide regarding its capacity as a water bearer. In the outcrops observed it is dense, massive, and tightly jointed, giving the appearance of relative impermeability. No wells or springs occur in it, and without further proof of its water-bearing capacity, it is classed as a poor aquifer. Wells in it will probably have small yields or will be failures.

WATER IN THE BASALT MEMBERS OF THE DESCHUTES FORMATION

All the basalt members of the Deschutes formation are pervious, as is testified by the immense number of springs that issue from them. They are all flows, and because of their similarity of structure and water-bearing characteristics they are discussed together to avoid repetition. Whether water occurs in them in this basin depends entirely upon whether they lie in the zone of saturation or have not been completely drained by the surface streams that expose them.

The open spaces in this basalt through which water can circulate are enumerated in order of their volume as follows: (1) Large open spaces at the contact of one lava flow with another, or of a lava flow with the underlying formation; (2) interstitial spaces in cinders and aa lava formed during deposition; (3) open spaces in joints due to shrinkage of the basalt at the time of cooling; (4) tunnels or caverns formed by the draining away of subterranean rivers of lava during the final phases of eruptions; (5) vesicles and cavities due to the expansion of gases during the cooling of the lava; (6) tree molds resulting from lava surrounding trees and solidifying before the wood has burned away.

The slaggy contact of one flow with another is the principal passageway for ground water in the basin. These contacts are usually recognized in drilling by a thin layer of easily drilled lava rock, commonly red and lying between two layers of hard blue or black lava. Many of these contacts are visible in the walls of Crooked and Deschutes Canyons, and from some of them issue innumerable springs. (See pl. 17, *B*.) The crust of these basalt flows is generally rough and broken, because of the sudden chilling of the lava and subsequent movement of the flow. Inundation by another lava flow never completely fills these irregularities, and the bottom of the overlying flow is usually slaggy for several feet above the contact, owing to the accumulation of doughy masses of lava that cooled from beneath while the flow was in motion. A fine example of such a contact may be seen 105 feet above the river at Opal Springs, on the east wall of the canyon.

Open slaggy contacts result also at the base of a lava flow where it rests upon sedimentary rocks. The permeability of such contacts is variable, for in some places the lava fits tightly to the underlying bed, as shown in Plate 12, *B*, while in other places the two may be separated by a cavern large enough to walk through, as shown in Plate 17, *A*.

Immense volumes of water can flow through the interstitial spaces in cinders and aa lava. In this basin, however, cinders and aa lava are much less common than the regularly jointed basalt known as pahoehoe and hence they play a much less effective part than in many other lava regions. Furthermore, the cinders and aa basalt that are known in the basin lie above the zone of saturation. Cinders are present in several of the wells, notably in 22 and 5. In well 5 there is 84 feet of cinders below 221 feet of conglomerate. Although not prominent in the zone of saturation, good-sized deposits of both cinders and aa basalt occur in the zone of aeration, where they doubtless serve as efficient intake beds. The area of the cinders on the surface of the basin is shown on Plate 10.

Open spaces in the joints due to shrinkage of lava at the time of cooling are so well known that they need no further description. They can be seen in any of the basalt beds and in most of the photographs shown in this report. The distance of gaping of the joints depends chiefly upon the thickness of the flow and the slowness of cooling. Many of the thicker flows are jointed, but the joints are tight and the basalt is not very permeable, whereas the thin flows have more irregular jointing and are much more permeable.

Tunnels and caverns are formed in basalt by the draining away of subterranean rivers of lava during the final phase of eruptions. They are essential to the spreading out of such extensive sheets of basalt as occur in the Deschutes formation. Their presence is indicated in wells by the dropping of the drill when penetrating lava rock. No lava tunnels were discovered during the investigation in this portion of the Deschutes Basin, but many of them are known in the Bend region. The immense volume of Opal Springs suggests that the water is concentrated in a lava tube before it reaches the surface.

Vesicles and cavities due to gas expansion in the lava at the time of cooling are very common, especially near the tops of the flows. They are not everywhere connected, and unless the lava is extremely cellular they probably do not allow any great amount of water to circulate. However, the fact that the vesicles in most of the ancient basalts are filled with minerals deposited from percolating waters indicates that some circulation of water takes place even through these small and apparently disconnected cavities.

Tree molds formed by lava surrounding a tree and solidifying before the wood has completely burned away are roughly circular holes 1 to 3 feet in diameter and as much as 40 feet deep. None were seen in the basin, but this is not surprising because most of the flows are covered with soil. Tree molds were found by the writer in lava flows near Bend. It is an established fact based on observations in the Hawaiian Islands that many tree molds act as conduits for streams of underground water. They occur only locally, hence they are probably the least important water-bearing features in the lava.

Dikes or feeders to volcanic vents are not exposed in this basin. They must exist, however, for fissure eruptions occurred during the extravasation of the rim-rock basalt. They are impermeable and in places act as barriers to the circulation of ground water. The effect of dikes in the basin could not be ascertained.

Wells that penetrate the basalt members of the Deschutes formation that lie in the zone of saturation yield ample supplies of water, and for large supplies these beds should certainly be explored.

WATER IN THE INTRACANYON BASALT

The main mass of the intracanyon basalt in the basin lies above the water table and hence does not contain water. The fact that it contains practically all the features described above indicates that in itself it is permeable. Moreover, near Trail Crossing several springs issue from it. South of this area it is thinner and will doubtless yield water when tapped by drilled wells. The water will occur near the base of the formation, and hence holes several hundred feet deep may be necessary. It is believed that wells will be successful when drilled into it along the axis of the buried valleys north of Tetherow Bridge, but wells on either side of the buried valleys may fail to yield sufficient water.

SPRINGS

SPRINGS IN CROOKED RIVER CANYON

Hundreds of springs occur in the Crooked River Canyon, and many of them are so close together that they issue as sheets of water. The largest are Opal Springs. (See pp. 200–203.) A great number of springs issue in the bed of the Crooked River where they can not be definitely counted, and others issue in the talus slopes and flow into the river unseen.

The first large group of springs downstream from Trail Crossing is near the Gates ranch, in sec. 14, T. 13 S., R. 12 E. The water of these springs has been collected in a flume for the development of power, and because they are typical of the other springs in the canyon they warrant further description. These springs discharge about 20 second-feet of clear, sparkling water which had a temperature of 56° F. on August 20, 1925. About 25 feet above the river, which flows on Deschutes sandstone, there is a bed of basalt 80 feet thick. This bed is made up of three and in places four distinct flows. They were not all laid down during the same eruption, for a short distance upstream there is a wedge of sandstone intercalated with them. Most of the springs issue from the slaggy, open contact between the lowest bed and the one above it, but a few issue from the contact of the second and third flows. The highest spring is 92 feet above the river. Tunnels have been driven into the lava where many of the springs issue. The longest of these tunnels is 185 feet long; most of them are 25 feet or less. They follow the water southwestward and usually rise along joints to the contact above, indicating that much of the water issuing from the contact of the first and second flows has dropped a short distance back of the canyon wall from the contact between the second and third flows. A few small springs issue from this same 80-foot bed of basalt on the east canyon wall, and a large spring bubbles up in the river at this place.

The source of the water that issues from the lava on the west wall is difficult to determine. It can not be many feet west of these springs that the lava bed is again cut in two by the ancient channel of the Crooked River of preintracanyon basalt time. The explanation must be that the water has been concentrated into this ancient channel from the region to the south and not unlikely by means of the buried Deschutes Canyon, which has a ground-water connection through interstratified basalt. It is forced to escape into the present Crooked River Canyon either because of the extreme permeability of the 80-foot interstratified bed of basalt at this place or because of a change from a permeable to a relatively impermeable condition of the intracanyon basalt occupying the buried valley. The latter explanation seems more plausible, for the interstratified basalt seems to be everywhere permeable, whereas the structure of the intracanyon basalt changes considerably from place to place; hence it might easily form a ground-water dam at this locality.

Another interesting group of springs that represent a perched water table issue near Opal Springs. At this place half a dozen springs pour out from the contact of an interstratified bed of basalt with the underlying Deschutes sediments 105 feet above the river. (See fig. 8.) They are collected into a flume and utilized for developing power.

A large spring issues from the Pelton basalt in the fore bay of the Cove power plant at Cove Crossing, on the Crooked River. It is impossible to estimate the discharge of this spring, because it is submerged. Other springs issue on the bank of the river in this vicinity. A profile of the Crooked River between mile 9 and mile 13 above its mouth is shown in Figure 9 to illustrate the large number of springs that issue along the river between these two points.

Opal Springs are in the NE. ¼ sec. 33, T. 12 S., R. 12 E., on the east bank of the Crooked River. They receive their name from the polished siliceous pebbles that occur in the springs. Many of the pebbles are translucent or transparent chalcedony that have a polish which could not be improved by a lapidary. A few of the tiny pebbles are shaped like cabochon opals ready for setting. People come from long distances to gather these natural polished gems, and a few have been mounted in jewelry. The pebbles have been derived from siliceous veins in the Clarno (?) formation and appear to have been polished by rubbing against one another in the spring water.

Opal Springs have a mean annual discharge of about 300 second-feet, and on August 25, 1925, the water had a temperature of 54° F. The water discharges in a small pool at the level of the river, but a considerable amount breaks out of the coarse talus about 4 feet above the river and tumbles into the pool. (See pl. 18, *A*.) As the formation that yields the water is buried, its character can not be stated.

The Crooked River at Opal Springs is flowing near the contact of the sedimentary beds of the Deschutes formation with the intracanyon basalt. (See fig. 8.) The basalt forms a vertical cliff about 350 feet high at the west edge of the river. The east bank consists of a steep talus slope rising to a vertical cliff of interstratified basalt 105 feet above the river. A steep slope broken by another vertical cliff formed by interstratified basalt at an altitude of 2,345 feet rises above this lower cliff of basalt to the rim-rock basalt. (See fig. 8.) Numerous springs issue from the basal contact of the bed of basalt 105 feet above the river. The talus slope extending from this bed to the river is covered with water-loving vegetation, indicating that the talus is saturated with water, although most of the water from the visible springs is collected in a flume and used for the development of power. The numerous springs

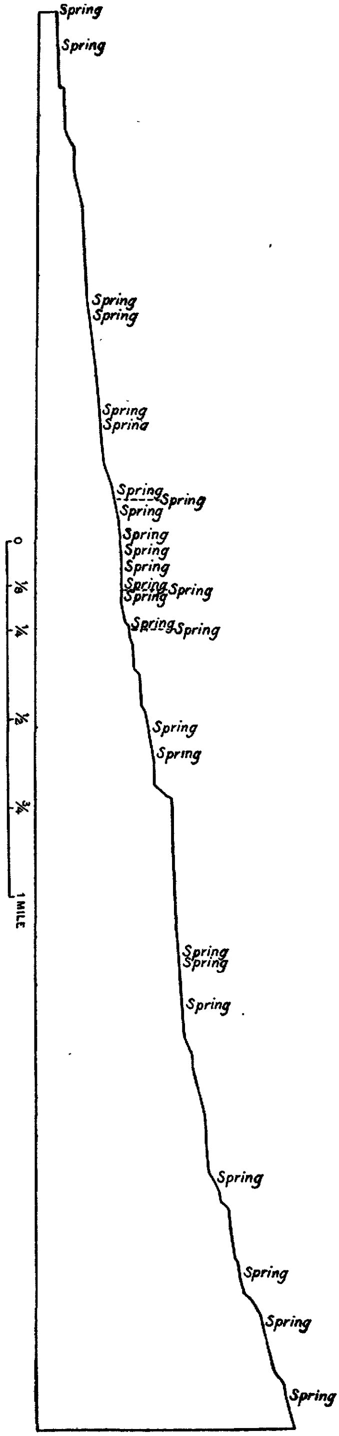


FIGURE 9.—Profile of Crooked River, Oreg., from mile 9 to mile 13 above its mouth, showing location of springs. By W. B. Upton, Jr., U. S. Geological Survey

flowing into the river from the talus at the river's edge afford additional proof that considerable water is finding its way into the talus, probably a short distance back from the outcrop of the interstratified basalt. Moreover, a shallow cut made in the talus slope from the river near Opal Springs to the interstratified basalt contains numerous seeps and small springs that come from the base of the basalt cliff 105 feet above the river. The water is ground water that has been perched in the basalt because of the impermeable sediments underneath it.

A study of the minor springs associated with Opal Springs but 105 feet higher suggests that the water in Opal Springs comes from the same bed of basalt. If it does, then the water is leaking down to the river a short distance back from the canyon wall through an enlarged fissure. The water of Opal Springs would then have its source in the large area to the east and south, where there is no surface run-off and where the intake area of the stratified basalt probably meets the edge of the structural basin. The location of the springs at this point in the canyon is doubtless determined by a projecting buried spur of relatively impermeable beds of the Clarno (?) formation extending toward the canyon from Juniper Butte. (See pl. 10.) An examination of the sedimentary beds of the Deschutes formation exposed near Opal Springs shows no bed sufficiently permeable to yield the quantity of water discharged by these springs. It is probable from analogy with other large springs that the accumulation at this place of 300 second-feet of water is due to an elaborate system of drainage buried by a lava flow. However, it is impossible to state with certainty whether Opal Springs are supplied by water that has found its way to its present outlet from the water-bearing bed of basalt 105 feet above it or from another similar bed of basalt below the river.

About 2 miles downstream from Opal Springs the Pelton basalt appears under the intracanyon basalt. This Pelton bed, if continued horizontally, would be about 100 feet below the Crooked River at Opal Springs. As it has a gentle slope to the north, however, it may be considerably nearer the surface than 100 feet. It is not at all unlikely that the Crooked River has at some time eroded its channel in this vicinity to a depth sufficient to tap the water moving through this underlying bed of Pelton basalt and allowed its escape to form Opal Springs.

The source of Opal Springs bears a significant relation to the success of a dam built at either the lower or upper box canyon dam site, for the spring is an important source of supply of the Crooked River during low stages. Moreover, it issues at an altitude of 1,969 feet above sea level, or only 19 feet above the water surface of the Crooked River at the upper dam site and 49 feet above the water surface at the lower site. Consequently, the proposed dam at either site will impose a considerable head of water on Opal Springs. Until the exact origin of these springs is determined it is impossible to state whether a reservoir flooding the springs would hold water. If the springs are supplied by water from the underlying Pelton basalt, then any considerable head on it would cause the water to escape from the outcrops of the basalt downstream from the dam. If the springs are due to water leaking from the interstratified basalt 105 feet above the river, then a head of 105 feet could be safely placed on Opal Springs before the springs would cease to flow and emerge elsewhere.

The fact that all the springs downstream to the Metolius River along the Crooked and Deschutes Rivers issue from the Pelton basalt proves beyond question that it is a great aquifer. The only way to determine whether this bed supplies the water in Opal Springs is to drill near the spring and determine the depth to the underlying lava. The hole should be located 50 to 100 feet upstream from Opal Springs, and fluorescein dye should be pumped into the hole. If the hole is properly cased, the fluorescein should not appear in Opal Springs unless the springs have their source in the Pelton basalt. Such a test should establish the source of the springs.

SPRINGS IN DESCHUTES RIVER CANYON

About 100 feet up the Deschutes River from the mouth of the Crooked River there is a long line of springs which issue from the Pelton basalt and together discharge about 30 second-feet. Upstream from this place the canyon was not explored for springs but probably contains no large groups of springs, for none have been reported by local fishermen.

Downstream from the Crooked River many springs occur. A notable line of springs extends for three-quarters of a mile on the west bank of the Deschutes River half a mile above the mouth of the Metolius River. These springs issue from the Pelton basalt and range from river level to a height of 25 feet above it. (See pl. 17, *B*.) The discharge of this group of springs is between 80 and 100 second-feet. Below the mouth of the Metolius River many small springs enter the Deschutes River, but they are too small and too numerous to warrant description.

QUANTITY OF GROUND WATER

A good idea of the amount of ground water discharged into the basin is obtained from a study of the stream-flow records. Unfortunately, though many records exist, it is difficult to compare them for the different stations because the stations were not all maintained at the same time. More data are available for determining the amount of ground water discharged directly into the Crooked River than into the other streams in the basin.

QUANTITY OF GROUND WATER DISCHARGED INTO CROOKED RIVER

Before 1910 the Crooked River went practically dry at Trail Crossing during the summer. Since then, however, Ochoco Reservoir and one power reservoir have been created in the headwaters of the Crooked River, and these with the increased irrigation in the vicinity of Prineville have caused the summer flow at Trail Crossing to increase from waste water and return flow. Thus, on August 23, 1908, a measurement at Trail Crossing showed 7 second-feet; one on August 4, 1913, 41.8 second-feet; and one on October 29, 1919, 61 second-feet. On this last date a measurement was also made at the Gates ranch, about 9 miles by river downstream from Trail Crossing, and showed a flow of 301 second-feet. A measurement at the Cove gaging station on the same day showed 1,020 second-feet, or a net gain below Trail Crossing of 959 second-feet, or 620,000,000 gallons a day, due to ground-water inflow. No surface stream enters the Crooked River between Trail Crossing and its mouth during the summer and fall.

At the Cove gaging station the mean monthly flow during the period June 1 to November 1, 1919, was 1,092 second-feet, the maximum 1,150 second-feet, and the minimum 1,050 second-feet. The fact that the difference between the maximum and minimum monthly discharge during this entire period was only 100 second-feet is proof of the constancy of the flow of the springs in Crooked River. This remarkably uniform flow is better illustrated by the following table showing the mean discharge of the Crooked River at the Cove gaging station for July, August, and September, 1918 to 1926, during which there was no surface inflow to the Crooked River below Trail Crossing.

On November 28 and 29, 1925, a similar series of measurements was made on the Crooked River to show the distribution of inflow from springs in the stretch of channel below Trail Crossing. They show a net gain in the river between Trail Crossing and a point 14 miles below it of 731 second-feet, and between this point and the Cove gaging station of 349 second-feet.

Measurements of lower Crooked River in 1925

	Second-feet
Trail Crossing	110
Below Opal Springs, NE. ¼ sec. 33, T. 12 S., R. 12 E., 14 miles by river below Trail Crossing	841
Cove gaging station	1,190

Mean discharge, in second-feet, of Crooked River at Cove gaging station, near Culver, Oreg., for July, August, and September, 1918–1926

Year	July	August	September	Average	Year	July	August	September	Average
1918	1,100	1,110	1,100	1,103	1923	1,240	1,130	1,150	1,173
1919	1,080	1,100	1,110	1,097	1924	1,110	1,110	1,110	1,110
1920	1,060	1,060	1,090	1,090	1925	1,180	1,180	1,200	1,187
1921	995	970	1,030	998	1926	1,150	1,140	1,140	1,143
1922	1,110	1,110	1,120	1,113					

It is conservative to estimate the flow of springs into the Crooked River as 950 second-feet throughout the year, which is equivalent to 56,529 acre-feet a month of 30 days or 687,770 acre-feet a year. This is an immense quantity of ground water to be discharged in a distance of about 20 miles into a single river in a semiarid land where the rainfall is about 12 inches a year. On the assumption that 5 inches of the total annual precipitation sinks into the ground each year it would require an intake area of about 2,570 square miles to supply the ground water discharged into the Crooked River.

QUANTITY OF GROUND WATER DISCHARGED INTO DESCHUTES RIVER

The amount of water discharged directly into the Deschutes River is much more difficult to calculate than the amount discharged directly into the Crooked River, because the gaging stations have not been located so advantageously for a study of this sort.

The following table was prepared to show the gains and losses in the Deschutes from Bend to Cline Falls, Bend to Mecca, and Cline Falls to Mecca in 1910 to 1912, for which comparisons could be made. The stretch of channel between Bend and Cline Falls is not within the middle Deschutes Basin, but the losses in this stretch are believed to contribute water to the springs in the Crooked River Canyon. The stretch of channel between Cline Falls and Mecca practically all lies in the basin, and the gain between these stations represents an inflow of ground water. The records at Cline Falls are incomplete, hence it was necessary to compute the gains between Bend and Mecca for certain months.

Comparison of discharge, in second-feet, of Deschutes River at Bend, Cline Falls, and Mecca, Oreg., 1910–1912

Month	Discharge								Increase or decrease		
	Discharge at Bend plus Tumalo Creek at mouth	Cline Falls	Squaw Creek above diversions	Crooked River at mouth[a]	Metolius River at Riggs	Shitike Creek at mouth	Mecca	Column 7 minus columns 3, 4, 5, and 6	Bend to Cline Falls (1 minus 2)	Bend to Mecca (8 minus 1)	Cline Falls to Mecca (8 minus 2)
	1	2	3	4	5	6	7	8	9	10	11
1910											
March	2,440	2,100	--------	--------	--------	--------	--------	--------	−340	--------	--------
April	2,050	1,740	--------	--------	--------	--------	--------	--------	−310	--------	--------
May	1,810	1,710	--------	--------	--------	--------	--------	--------	−100	--------	--------
June	1,390	1,310	--------	--------	--------	--------	--------	--------	−80	--------	--------
July	1,130	1,090	--------	--------	--------	--------	--------	--------	−40	--------	--------
August	1,210	1,110	--------	--------	--------	--------	--------	--------	−100	--------	--------
September	1,170	1,050	--------	--------	--------	--------	--------	--------	−120	--------	--------
October	1,280	1,070	--------	--------	--------	--------	--------	--------	−210	--------	--------
November	1,510	1,350	--------	--------	--------	--------	--------	--------	−160	--------	--------
December	1,580	1,380	--------	--------	--------	--------	--------	--------	−200	--------	--------
1911											
January	1,410	1,250	--------	--------	--------	--------	--------	--------	−160	--------	--------
February	1,420	1,220	--------	--------	--------	--------	--------	--------	−200	--------	--------
July	1,070	--------	[b] 10	1,070	1,620	93	4,360	1,570	--------	+500	--------
August	924	--------	[b] 10	1,070	1,500	60	4,050	1,410	--------	+490	--------
September	1,050	--------	[b] 10	1,070	1,490	62	4,150	1,520	--------	+470	--------
October	1,140	--------	45	1,100	1,440	54	4,090	1,450	--------	+310	--------
November	1,370	--------	46	1,150	1,470	73	4,210	1,470	--------	+100	--------
December	1,330	--------	41	1,200	1,420	64	4,300	1,570	--------	+240	--------
1912											
January	1,450	--------	69	1,420	1,590	172	5,050	1,800	--------	+350	--------
February	1,600	--------	65	--------	1,860	195	5,940	--------	--------	--------	--------
March	1,430	1,200	46	--------	1,680	212	5,200	--------	−230	--------	--------
April	1,450	1,270	60	--------	1,660	135	6,460	--------	−180	--------	--------
May	1,660	1,430	131	--------	1,760	188	7,100	--------	−230	--------	--------
June	1,860	1,670	[b] 200	1,150	1,890	200	6,020	2,580	−190	+720	+910
July	1,350	1,220	[b] 10	1,070	1,660	125	4,850	1,980	−130	+630	+760
August	1,230	1,090	[b] 10	1,070	1,660	80	4,550	1,730	−140	+500	+640
September	1,430	1,200	[b] 10	1,070	1,580	67	4,520	1,790	−230	+360	+590
October	1,430	1,190	63	1,100	[c] 1,490	63	4,390	1,670	−240	+240	+480
November	1,560	1,330	68	1,150	[c] 1,590	84	4,770	1,880	−230	+320	+550
December	1,660	1,430	54	1,200	[c] 1,500	84	4,670	1,830	−230	+170	+400

[a] Estimated on bases of later measurements.
[b] Estimated flow at mouth. Squaw Creek entirely diverted near Sisters during irrigation season.
[c] Estimate based on flow at Hubbard ranch, 9 miles upstream.

The tabulation shows a consistent loss in every month on record in the channel of the Deschutes River between Bend and Cline Falls (column 9). According to Henshaw[24] this loss probably occurs between Laidlaw (near Tumalo) and Cline Falls. It is probably due to leakage into the fissured basalt over which the river flows where the water table lies far below the river bed. Furthermore, the river is swift and, being spring-fed, carries little silt, hence there is little chance for the crevices to silt up even during long periods. It is believed that in this section of the river considerable water is contributed to the zone of saturation.

[24] Henshaw, F. F., and others, Deschutes River, Oreg., and its utilization: U. S. Geol. Survey Water-Supply Paper 344, p. 70, 1914.

The decided gain in the river due to flow from springs between Bend and Mecca, as shown in column 10, is too large to be anything but real, for the records at both stations are good. The great variation in the amount of inflow is due not so much to the fluctuation in the flow of the springs as to surface inflow during the spring season from ephemeral streams not included in the table and to small diversions for irrigation below the Bend gaging station. The gain between Cline Falls and Mecca is considerably larger, and it is believed that the inflow from springs between Cline Falls and Mecca averages 400 second-feet throughout the year. Furthermore, practically all of this inflow occurs along the stretch of the river within the area shown on Plate 10, for miscellaneous measurements (see p. 186) indicate that there is not much loss or gain between Cline Falls and Tetherow Bridge.

The following table shows the mean monthly discharge for the stretch of the Deschutes River between the station below Bend and the station near Madras during the hydrographic years 1925 and 1926, for which there are comparable records. The flow of Squaw Creek is largely estimated because of the lack of records. However, the summer flow of this creek is all diverted, and during the irrigation season the flow at the mouth is only about 10 second-feet. The increase in discharge of the Deschutes River during the spring at Madras is considerably larger than the increase during the summer, due to the flow of ephemeral streams which have not been included in the calculations because of lack of data. In the table on page 206 it is shown that there is probably a loss of more than 100 second-feet between Tumalo and Cline Falls,[25] which would add considerably to the gain at Madras during these years. With this exception for this stretch of channel during the summer the net gains are due to inflow from springs within the basin.

[25] In a letter dated Nov. 14, 1927, Mr. F. F. Henshaw states: "The record back in 1912 showed this. I was never able to account for it satisfactorily, although it may have occurred. However, the round of meter measurements which I made in 1915, at a much lower stage than had previously occurred, indicated no loss to speak of, and during the summer, at least during the later years of low run-off and large diversion, there isn't anywhere near 100 second-feet to lose and no evidence of any considerable loss."

Comparison of discharge, in second-feet, of Deschutes River below Bend and near Madras, Oreg., October 1, 1924, to September 30, 1930.

Month	Discharge								Increase Bend to Madras (8 minus 4)
	Deschutes River below Bend	Tumalo Creek at mouth	Squaw Creek at mouth [a]	Bend plus Tumalo and Squaw Creeks	Crooked River at mouth	Metolius River near Grandview	Deschutes River near Madras	Column 7 minus 5 and 6	
	1	2	3	4	5	6	7	8	
1924-25									
October	256	5	40	301	1,120	1,100	3,460	1,040	739
November	999	38	60	1,097	1,210	1,510	4,460	1,740	643
December	1,000	38	40	1,078	1,170	1,400	4,370	1,800	722
January	1,010	57	50	1,117	1,600	1,590	5,120	1,930	813
February	1,300	64	60	1,424	2,330	2,060	6,560	2,170	746
March	1,080	40	50	1,170	1,910	1,620	5,540	2,010	840
April	1,050	43	80	1,173	2,320	1,650	6,030	2,060	887
May	674	126	100	900	1,490	1,770	4,980	1,720	820
June	422	65	50	537	1,230	1,700	4,130	1,200	663
July	163	49	30	242	1,180	1,600	3,750	970	728
August	262	2	10	274	1,180	1,500	3,680	1,000	726
September	484	8	50	542	1,200	1,440	3,900	1,260	718
1925-26									
October	605	0	60	665	1,220	1,400	3,930	1,310	645
November	1,050	0	52	1,102	1,220	1,400	4,350	1,730	628
December	1,160	13	60	1,233	1,220	1,420	4,510	1,870	637
January	1,040	48	52	1,140	1,220	1,370	4,390	1,800	660
February	1,130	56	72	1,258	1,540	1,570	5,160	2,050	792
March	1,090	42	50	1,182	1,670	1,450	5,060	1,940	758
April	407	66	75	548	1,540	1,460	4,250	1,250	702
May	104	14	10	128	1,180	1,460	3,530	890	762
June	56	9	10	75	1,160	1,410	3,360	790	715
July	68	0	10	78	1,150	1,370	3,310	790	712
August	49	3	10	62	1,140	1,320	3,290	830	768
September	126	0	30	156	1,140	1,300	3,320	880	724

[a] Estimate based on flow at Squaw Creek gaging station near Sisters and miscellaneous measurements and estimates of flow during irrigation season at mouth.

From observations during the investigation it was estimated that at least 350 second-feet of ground water was discharged into the Deschutes River in this basin, for no notable springs enter in the stretch of channel between the north boundary of the basin and Mecca. The net gain in the Deschutes River between Bend and Madras for 1925 to 1926, according to data presented in the above table, was more than 600 second-feet, even during the months of low-water flow. Accordingly it appears that there is considerably more water finding its way into the Deschutes River in the basin than was observed during the investigation.

The annual inflow from springs to the Deschutes River, amounting to 600 second-feet, or 434,380 acre-feet, when added to the inflow to the Crooked River, gives a total annual ground-water discharge into the middle Deschutes Basin of 1,550 second-feet, or 1,122,150 acre-feet. There is no appreciable spring inflow to the Metolius River within the basin. The total annual ground-water discharge in this area therefore exceeds 1,000,000 acre-feet.

UTILIZATION OF WATER

DOMESTIC USE

For many years obtaining water for domestic use has been a problem in this basin, and it has not yet been entirely solved. The pioneers in the region hauled their water many miles in water wagons. As soon as the deep railroad wells were drilled, towns became possible, and the farmers found it no longer necessary to haul water such long distances. The town of Culver drilled a well to supply its inhabitants with water, but this well was abandoned, and the town now uses water pumped from a spring in the Crooked River Canyon, a short distance upstream from Opal Springs. This water is lifted more than 800 feet. Gradually, as the farmers became more prosperous, they drilled wells on their own land or installed rams on the river. The inhabitants of the Peninsula and in the vicinity of Grandview post office still haul their water from the Deschutes or Crooked River or from wells in the foothills of the Cascade Range. Domestic water is still scarce in places, but the scarcity is not due to the lack of underground water but to the great cost of drilling a well, buying equipment, and lifting the water to the surface. Many people in the vicinity of Terrebonne drink ditch water rather than haul it or bear the expense of a well.

IRRIGATION

The amount of land under irrigation at present in the basin is small. Water diverted from the Crooked River near Prineville irrigates a part of the land east of Terrebonne. The irrigable land south and west of Terrebonne is irrigated by water diverted from the Deschutes River near Bend. About 100 acres is irrigated by diversions from the Deschutes near Lower Bridge and Odin Falls. A few acres is irrigated by water pumped from the Crooked River at the Gates ranch and by diversion from the Crooked River at Cove Crossing.

Practically all the land in the basin, except the Haystack country, could be irrigated from the proposed storage reservoir at Benham Falls, on the Deschutes River above Bend. There is about 6,000 acres on the Peninsula alone that could be irrigated. It is only a question of time before this project will become a reality, for the constant increase in population and added demand for agricultural products will ultimately require the complete utilization of the Deschutes River.

WATER POWER

By F. F. Henshaw

The possible water power of the middle Deschutes Basin is only partly utilized. Maximum development will doubtless be made only when there is an adjacent market for the power, and this market will come into existence only when the land is irrigated and will support a larger population.

CROOKED RIVER

Small power projects are feasible in several places along the Crooked River above Opal Springs and below sec. 26, T. 13 S., R. 12 E. Small rock-fill diversion dams placed across the river and canals contouring the canyon walls would develop considerable head, owing to the rapid fall of the river. The amount of power developed in this manner would be determined by the length of the canal and the flow of the river. One such dam could be built at a low cost by blasting loose from the east canyon wall a small remnant of intracanyon basalt about 1 mile upstream from the Gates ranch. The minimum flow at this place is about 250 second-feet.

Power plant of H. V. Gates.—The Gates power plant is in the NE. ¼ NW. ¼ sec. 14, T. 13 S., R. 12 E. It was constructed by Mr. Gates to furnish electric energy for lighting, heating, and small power for farm use in connection with his house, barn, and farm buildings close to the plant. The conditions surrounding the development are unique. The Crooked River receives about 1,000 second-feet of water from springs within about 10 miles of the mouth. Some of these are large, Opal Springs discharging about 300 second-feet. Much of the water reaches the river in innumerable small streams; in the vicinity of the power house the water issues from the side of an almost vertical canyon wall at points between 50 and 100 feet above river level. Several hundred feet of flume and pipe have been built to collect the water into a single forebay. Several tunnels extend into the rock for distances up to 185 feet, intercepting and conducting into the flume water that formerly found its way to the surface at a lower level.

From a concrete fore bay a 24-inch wood pipe extends to a power house of frame construction, on the bank of the Crooked River. The 11½-inch twin Leffel turbine is belt-connected to a 50-kilowatt generator with governor, switchboard, etc. Arrangements are also made for connecting the turbine to a 6-inch centrifugal pump to furnish water for domestic and stock use and for irrigating land in and near sec. 14, at an altitude of about 350 feet above the river. This land is now irrigated by means of hydraulic rams driven by water piped from springs discharging into the canyon a few hundred yards above the upper end of the conduit leading to the power house. Practically no water has yet been pumped by this plant. The pipe line reaching from the head of the supply flume up the canyon is not yet complete, and the water supply now available serves only to run the generator.

The construction of this plant has presented unusual difficulties. Almost everything entering into its construction has been lowered into a box canyon about 350 feet in depth. Now there is a tramway, but when work was started only a steep winding trail was available. The original flume bents were poles from trees cut from the sides of the canyon, but most of these have now been replaced with sawed lumber. The flume has been gradually extended, and the flow of water from the rock gradually developed.

The power-house floor is fairly close to the river, and the generator foundation may be submerged in time of extreme flood. Provision has been made for raising the generator up the canyon slope on skids with block and tackle in case of emergency. The plant has been installed in a thoroughly workmanlike manner, and it runs with attention only twice a day.

Power plant of E. A. Thompson.—The Thompson power plant is used in pumping water for domestic use to settlements and ranches on bench lands lying west of the Crooked River in and near the towns of Opal City, Culver, and Metolius. A loose-rock wing dam in the NW. ¼ SE. ¼ sec. 33, T. 12 S., R. 12 E., diverts water on the left bank into a conduit, mostly in open canal, 1,400 feet long to the power house in the SW. ¼ NE. ¼ of the same section, where a net head of about 20 feet is developed. A 26-inch vertical Leffel turbine is direct-connected to a duplex pump of special design, 3½ by 10 inches, with a capacity of 4,000,000 gallons a month. There is also installed a hydraulic engine, with a capacity of 2,000,000 gallons a month. The pumps take water from a spring discharging into the river close to the power house. The water is carried through a 4-inch pipe down the river for about a quarter of a mile, across a bridge, and thence up the steep slope of the canyon to the Deschutes Valley water district's reservoir in the NW. ¼ sec. 34. The pumping plant and pipe, up to the reservoir, belong to Mr. Thompson; the reservoir and distribution system belong to the district.

Box canyon sites.—A power dam 100 feet high was proposed for the upper box canyon dam site, but for geologic reasons, described on page 155, it is not considered feasible.

At the lower box canyon dam site, about half a mile downstream, a dam at least 155 feet high is feasible providing that drilling shows the geology to be satisfactory. Even if a high dam is not feasible at this site, a diversion dam with a flume contouring the canyon wall could be constructed. The minimum flow at this site is probably over 900 second-feet, so that considerable power could be developed.

Cove hydroelectric power plant.—A hydroelectric plant has been constructed to utilize the flow of the lower stretch of the Crooked River, below Opal Springs. The diversion canal takes water directly out of the river in the SE. ¼ SW. ¼ sec. 11, T. 12 S., R. 12 E., and conducts it to the power house, in the NE. ¼ SW. ¼ of the same section. The canal is about 1,700 feet long, and the head obtained is about 33 feet. One unit was installed in 1912 and 1913, consisting of a 750-horsepower generator, 400 kilowatts, 2,300 volts, 100 amperes. The power house was enlarged and rebuilt in 1923 and a second unit installed, consisting of a 1,225-horsepower S. Morgan Smith 33-inch double-runner turbine and one General Electric alternating-current generator, 700 kilowatts (875 kilovolt-amperes), 2,200 volts. (See pl. 18, *B*.)

The distribution system supplies Prineville, Redmond, Madras, Metolius, and Culver and is also tied in with Bend by a line from Redmond to Bend. The plant is capable of being enlarged to a capacity of about 2,500 kilowatts, and by means of a rock-crib diversion dam the head can be increased to 34 or 35 feet. A flow of 1,100 second-feet of water has been appropriated. This flow has been available about 92 per cent of the time during the last nine years, and this figure is used by the company in the plans for future enlargement.

The plant now belongs to the Deschutes Power & Light Co., with main offices at Portland, which is controlled by interests associated with the Pacific Power & Light Co. of Portland.

DESCHUTES RIVER

The portion of the Deschutes River in this area is not capable of any great power development, except for local ranches above the mouth of the Metolius River, because it has so small a low-water flow, owing to irrigation diversions near Bend. At the Metolius dam site, on the Deschutes River about on the line between secs. 15 and 22, T. 11 S., R. 12 E., there is large low-water flow from the Crooked River, the Metolius River, and springs discharging directly into the Deschutes. This dam site is described on pages 157–159.

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