DEPARTMENT OF THE INTERIOR
Hubert Work, Secretary

U. S. GEOLOGICAL SURVEY
George Otis Smith, Director

WATER-SUPPLY PAPER 557

LARGE SPRINGS IN THE UNITED STATES

BY

OSCAR EDWARD MEINZER

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LARGE SPRINGS IN THE UNITED STATES

By Oscar Edward Meinzer

INTRODUCTION

What are the largest springs in the United States, how much water do they discharge, and what geologic conditions produce them are questions of much popular interest and considerable scientific and economic importance. Yet the information in regard to large springs has been so widely scattered and so difficult to interpret that most people have only very vague notions on the subject. The present paper is in a sense a by-product of a more comprehensive investigation of the origin, discharge, and quantity of ground water in the United States. It has, however, required extensive search for data and critical analysis of the data that were obtained. The task would have been virtually impossible except for the hearty cooperation of the district engineers and other members of the water-resources branch of the Geological Survey, who are really coauthors of this paper. I wish to acknowledge especially the help of Kirk Bryan, G. C. Stevens, W. E. Hall, W. R. King, E. L. Williams, H. C. Beckman, C. E. Ellsworth, C. E. McCashin, C. G. Paulsen, W. G. Hoyt, H. T. Stearns, H. D. McGlashan, R. C. Briggs, F. F. Henshaw, W. A. Lamb, G. M. Hall, E. C. LaRue, and A. B. Purton.

DISTRIBUTION AND CHARACTER OF LARGE SPRINGS

Difficulties in determining relative size of springs.—When an attempt is made to compare the large springs in the United States with respect to their size, or the quantity of water that they discharge, serious difficulties are at once encountered. First of all, it is very difficult to determine what constitutes a unit for comparison. The water seldom issues from a single opening and may issue from a great many openings, which may be close together or scattered over a considerable area. What is called a single spring in one locality may be equivalent to what in another locality is regarded as a group of springs, each of which has an individual name. This difficulty is made especially perplexing by the present lack of detailed maps or other data regarding most of the large springs. Some units are designated in the singular and some in the plural—for example, "Silver Spring" and "Thousand Springs." The idea that underlies this usage is that if the water issues from a single opening or from several openings that are close together it forms a "spring," whereas if it issues from a number of openings that are farther apart it forms "springs." In fact, however, local usage is so variable in this respect that there is no consistent distinction between "a spring" and "springs," and often there is no uniformity in usage even for the same group of openings.

Another serious difficulty in comparing springs results from the fact that some springs fluctuate greatly, whereas others are nearly constant. Moreover, one spring may be at a high stage when another is at a lower stage. Thus the discharge of a spring can be determined with fair accuracy only by establishing a gaging station and obtaining a continuous record over a period of years. To compare a single measurement of one spring with a single measurement of another spring made at an entirely different time may give a result that is almost as incorrect as would be obtained by a similar comparison of surface streams. Unfortunately only a few of the large springs in the United States have been accurately gaged during a period of several years. For some of them not even a single reliable measurement is available. Moreover, not all the available records specify whether the water that was measured was exclusively spring water or included other run-off.

The question also arises as to whether a comparison is made according to the minimum, maximum, or average discharge. Thus, if the average discharge of a nearly constant spring is about the same as that of a spring which fluctuates greatly, the constant spring will rank higher with respect to minimum discharge and the fluctuating spring higher with respect to maximum discharge. There is some popular interest in the maximum discharge, but the value of a spring, whether it is used for a public supply, irrigation, power, or other purpose, generally depends more nearly on its minimum discharge, or on its discharge at the time when the most water is needed. In so far as comparisons are attempted in the following discussion, they are based on the average discharge.

Classification of springs with respect to size.—What is a large spring? This question will be answered very differently in different localities. In localities of small springs the designation "Big Spring" is doubtless borne by springs that yield no more than 10 gallons a minute, and in many parts of the United States a spring that discharges 1 second-foot—that is, 1 cubic foot a second, or 448 gallons a minute, would be regarded as a remarkable spring. Such a spring would fill about a dozen barrels in a minute. In the entire country, however, there are doubtless thousands of springs that yield 1 second-foot or more, and hundreds that yield 10 second-feet or more. Moreover, according to the incomplete data summarized in the following pages, there are 65 springs in the United States that have an average yield of 100 second-feet or more, and several springs or groups of springs that have an average yield of 500 second-feet or more.

A second-foot of water is equal to about 646,000 gallons a day. With a daily consumption of 100 gallons for each inhabitant, a spring yielding 1 second-foot could supply a city of about 6,500 inhabitants, and a spring yielding 500 second-feet could supply a city of about 3,250,000 inhabitants. In 1922 the average daily consumption of water from the city waterworks in Washington, D. C., was about 63,000,000 gallons, or about 98 second-feet. About 65 different springs in the United States supply this amount of water. In 1916 the average daily consumption of New York City, with more than 5,500,000 inhabitants, averaged 566,000,000 gallons, or about 810 second-feet. There are springs or groups of springs in the country, each of which supplies this amount.

The following classification of springs according to their yield or discharge is suggested as convenient for use in the United States, although it is recognized that this classification may be inappropriate for countries that have other units of discharge.[1]

Proposed classification of springs according to discharge

Magnitude	Average discharge
First	100 second-feet or more.
Second	10 to 100 second-feet.
Third	1 to 10 second-feet.
Fourth	100 gallons a minute to 1 second-foot (448 gallons a minute).
Fifth	10 to 100 gallons a minute.
Sixth	1 to 10 gallons a minute.
Seventh	1 pint to 1 gallon a minute. About 200 to 1,500 gallons, or 5 to 40 barrels, a day.
Eighth	Less than 1 pint a minute. Less than about 200 gallons, or 5 barrels, a day.

The descriptions in this paper relate chiefly to springs of the first magnitude according to this classification.

Distribution of large springs.—The springs of first magnitude—those having an average discharge of 100 second-feet or more—occur in several regions in the United States, as shown in the following table and in Figure 1.

[1] Meinzer, O. E., Outline of ground-water hydrology, with definitions: U. S. Geol. Survey Water-Supply Paper 494, pp. 52–53, 1923.

Regions of springs of the first magnitude in the United States

Region	Ground-water provinces [a]	Number of first magnitude springs (having probable average discharge of 100 second-feet or more)	Number of springs having measured or estimated maximum discharge of 100 second-feet or more	Number of springs having measured or estimated minimum discharge of 100 second-feet or more	Kind of rocks	Age of rocks	Largest springs in region
Florida and adjacent parts of Georgia and Alabama.	Atlantic Coastal Plain	11	16	10	Limestone	Tertiary	Silver.
Northern Alabama and adjacent areas.	South-central Paleozoic and Blue Ridge-Appalachian Valley.	1	1	1	do	Paleozoic	Big.
Ozark region of Missouri and Arkansas.	South-central Paleozoic	8	10	5	do	Early Paleozoic	Big or Greer.
Balcones fault belt in Texas	Atlantic Coastal Plain	4	6	2	do	Cretaceous	Comal.
Snake River Basin in Idaho	Columbia Lava Plateau	[b] 15	15	15	Volcanic rock (also gravel).	Tertiary and Quaternary.	Portneuf, Malade, or Thousand.[b]
Sacramento River Basin, Calif.	Lava-covered areas chiefly in the Southwestern Bolson province.	[c] 7	8	7	do	do	Fall River.[d]
Deschutes River Basin, Oreg.	Columbia Lava Plateau	8	8	6	do	do	Sheep Bridge or Opal.[e]
Klamath River Basin, Oreg.	Lava-covered areas chiefly in the Southwestern Bolson province.	2	3	2	do	do	Spring Creek.
Willamette and Umpqua River Basins, Oreg.	Lava-covered areas in or adjacent to Columbia Lava Plateau.	5	5	5	do	do	Spring River.
Interior basins of Oregon	do	1	1	1	Lake beds overlying volcanic rock.	Tertiary	Ana River.
Montana	Montana-Arizona Plateau	3	3	3	Sandstone	Cretaceous and Jurassic.	Giant.
Northeastern Utah	Northern Rocky Mountain	0	1	0	Limestone	Cambrian(?)	Swan Creek.
		65	77	57			

[a] U. S. Geol. Survey Water-Supply Paper 489, pl. 31.

[b] The Portneuf and Malade are each counted as one unit, but they are groups rather than single units. Thousand Springs, which rank next, are more nearly a unit and may therefore properly be regarded as the largest spring in this region.

[c] Counting three springs of first magnitude on Fall River.

[d] If the several groups of springs that feed Fall River are regarded as separate units, the springs at the head of Fall River, yielding about 392 second-feet, are the largest springs in this region.

[e] The entire group of springs on Crooked River in the vicinity of Opal Spring discharge more than 1,000 second-feet and may properly be regarded as the largest springs in this basin. They are. however, rivaled as a group by the springs in the upper 10 miles of Metolius River, which also discharge more than 1,000 second-feet.

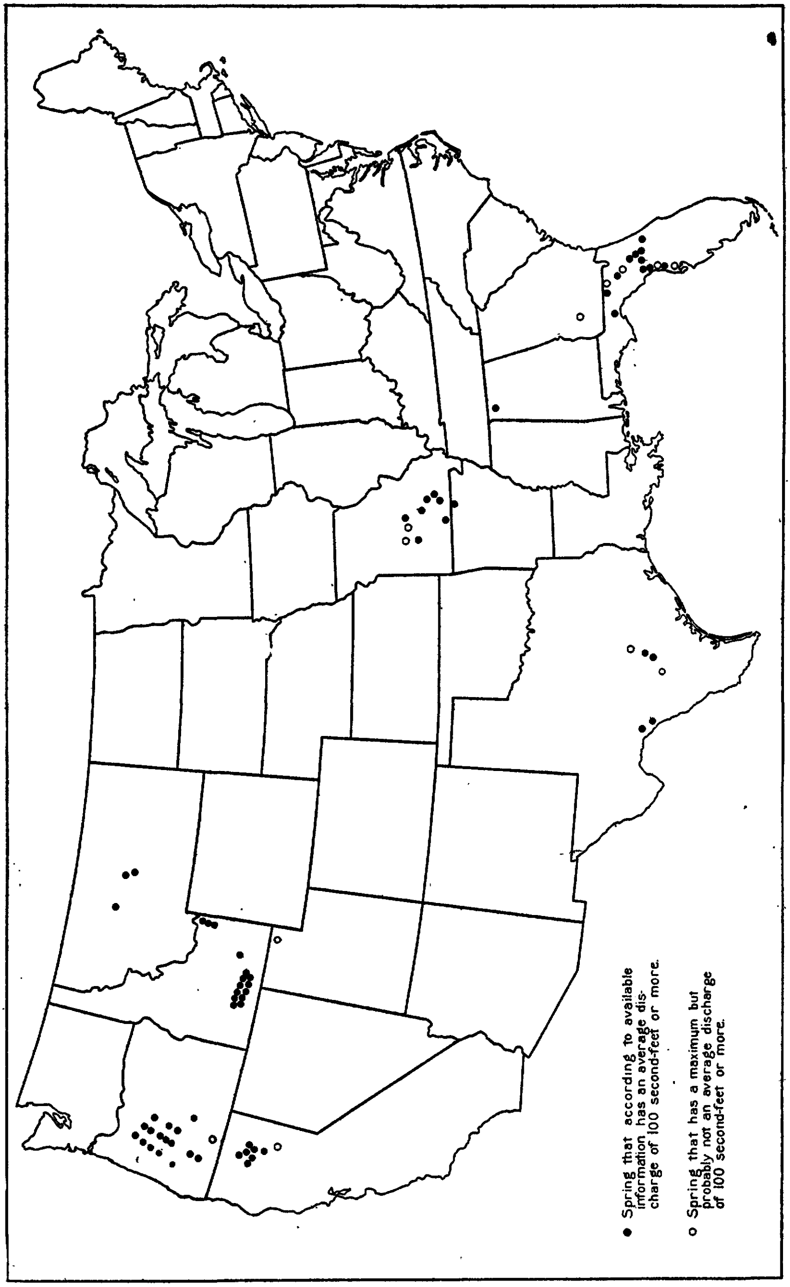

FIGURE 1.—Map of the United States showing springs that have a discharge of 100 second-feet or more

Relation of large springs to topography, kind of rock, and rock structure.—The occurrence of large springs depends chiefly on the kind of rock that yields the water. Limestone and extrusive volcanic rock are the main sources of the very large springs. The limestone must, of course, contain large solution channels produced by active and long-continued circulation of ground water. The volcanic rock is chiefly basalt that was greatly jointed and broken at the time it solidified, but large springs also issue from obsidian and rhyolite and from fragmental volcanic material. The only springs included in the foregoing table that issue from gravel are the Portneuf Springs, in Idaho, and these form a group of springs rather than a single unit. Their water probably has its source in basalt that lies not far below the surface. If full information were at hand other gravel springs of the first magnitude might be found, but although gravel yields water in large quantities its discharge is generally not sufficiently localized to be regarded as constituting very

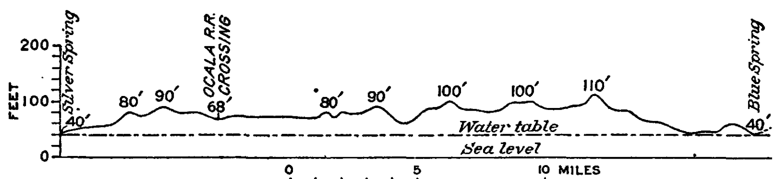

FIGURE 2.—Profiles of the land surface and of the water table in the vicinity of Silver and Blue Springs, Fla. (After E. H. Sellards, Florida Geol. Survey Bull. 1, p. 32. Also U. S. Geol. Survey Water-Supply Paper 319, fig. 2.)

large unit springs. Two of the first-magnitude springs issue from sandstone, doubtless from large fissures produced by faulting or other agency.

Most of the large springs issue in canyons or valleys that extend down into the water-bearing rocks or on lowlands at the base of escarpments formed in part by the water-bearing rocks (see pls. 3, *B*; 4, *A*; 6, *A*), but the large springs of Florida issue on plains that do not have much relief (see fig. 2 and pls. 1 and 2). The cavernous passages that conduct the water through the limestone in Florida were probably formed at a time when the land stood higher than at present. In Texas and in Montana faults provide large openings for the water to escape. In Idaho dense materials underlying very permeable rocks bring out the water on the side of the Snake River canyon, thus forming spectacular cataracts and providing much power. Some of the basalt springs issue from ancient valleys that have been inundated by lava flows. The alluvial gravel in an ancient channel of Missouri River apparently has an important part in producing the Giant Springs in Montana.

Fluctuation of large springs.—Fluctuation in discharge is due almost entirely to variability in precipitation, atmospheric temperature, and other weather conditions. The amount of fluctuation is however, affected by the topography, the rock structure, and especially the kind of rock, which determines chiefly the size and character of the openings through which the ground water passes. Springs in limestone are notably variable in their discharge. The present study has shown that the fluctuations of the large limestone springs, whether in Florida, Missouri, or Texas, are as a rule much greater and more sudden than those of the springs in volcanic rock, whether in Idaho, California, or Oregon.

There are, however, considerable differences in the behavior of limestone springs of different regions, which can be attributed to several causes. Probably the chief cause of differences in fluctuation is the position of the water table or of the underground and surface drainage with respect to the water levels of the past. Where the land has not subsided and nothing has occurred to raise the level of the streams and the water table, a nearly complete and perfect underground drainage system may be developed, with very cavernous rock above the level of the underground drainage and very tight rock below this level. Such an underground drainage system resembles a surface drainage system that is well developed on impervious rock without lakes or swamps. It lacks storage capacity and discharges its water swiftly after a rain. Its outlets form springs that fluctuate violently, in extreme cases discharging torrents of muddy water in wet periods and becoming entirely dry in periods of drought.

Where a limestone country has subsided with reference to sea level, great systems of caverns may be submerged beneath the water table and may function as huge subterranean reservoirs that equalize the spring discharge somewhat as a lake equalizes the discharge of a stream that flows through it. Limestone springs of this type are perennial and relatively constant, and they discharge clear water even at times of heaviest rainfall.

Of the large limestone springs described in this paper, those in the Ozark region have somewhat the character of the fluctuating type, and those in Florida belong rather to the relatively constant type. Extreme examples of the fluctuating type, such as have been observed by the writer in Cuba, are, however, very different from any springs described in this paper.

Quality, temperature, and origin of the water of large springs.—As a rule the water of very large springs is not highly mineralized. Salt Spring, in Florida, apparently forms an exception. The water of most large springs in volcanic rocks is remarkably low in dissolved mineral matter, and even that of the large limestone springs is only moderately hard. To produce such large springs the water must flow rapidly through large openings and hence is not brought into very intimate contact with the rock. The mineral matter that is dissolved becomes diluted by the great volume of water.

The very large springs, with few exceptions, have temperatures that are not much above the mean air temperatures of the regions in which they occur. Obviously where such large quantities of water are delivered, free and direct communication must exist between the points of intake and the points of discharge, and the water does not generally go to great depths. Moreover, the large amount of heat required to raise greatly the temperature of so much water is not generally available in the rocks of any locality. Doubtless the virtual absence of thermal springs in the lavas of the Snake River Plains of Idaho is due to the vast quantity of water that has percolated through these rocks and has long since cooled them to about the normal temperature of the region. In general the water discharged by the very large springs is meteoric water that has not reached depths of more than a few hundred feet below the surface. Probably Warm Spring, in Montana, and Ana River Spring, in Oregon, both of which have temperatures about 20° F. above the normal, have the deepest sources among the springs of first magnitude. Some of the springs of second magnitude, such as the large thermal springs in Nevada and Utah, must have a deep-seated origin and may deliver some juvenile water. Some large springs that are fed by streams or lakes probably have seasonal fluctuations in temperature corresponding to those of the surface water.

SPRINGS IN TERTIARY LIMESTONE IN FLORIDA, GEORGIA, AND ALABAMA

GENERAL FEATURES

A notable group of very large springs, including several springs of the first magnitude, is found in the northern and central parts of Florida and adjacent parts of Georgia and Alabama. These springs discharge great quantities of water from solution openings in soft cavernous limestone of Tertiary age, chiefly in the Vicksburg group (Oligocene) and the overlying Chattahoochee and Alum Bluff formations (Miocene). (See fig. 3.)

It has been generally believed that this region contains the largest limestone springs in the United States, but additional measurements will be required to determine the accuracy of this belief. A single spring, issuing chiefly from one large opening, may give rise to a river that is navigable by good-sized passenger and freight boats. The water before reaching the springs passes mainly through large channels in the limestone, and at least some of the springs fluctuate

A. BLUE SPRING, FLA.

Photograph by Florida Geological Survey

B. WAKULLA SPRING, FLA.

Photograph by Florida Geological Survey

A. GENERAL VIEW

Photograph by Roswell Allen Studios, Ocala, Fla.

B. NEAR VIEW

Photograph furnished by Marion County Chamber of Commerce

SILVER SPRING, THE LARGEST SPRING IN FLORIDA

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greatly with the rainfall. Owing, however, to the low relief of the land, the dense vegetation, and the mantle of sandy soil through which the water largely enters the limestone, the spring water is very clear and does not generally become muddy even at times of greatest discharge. The water of many of the springs, although

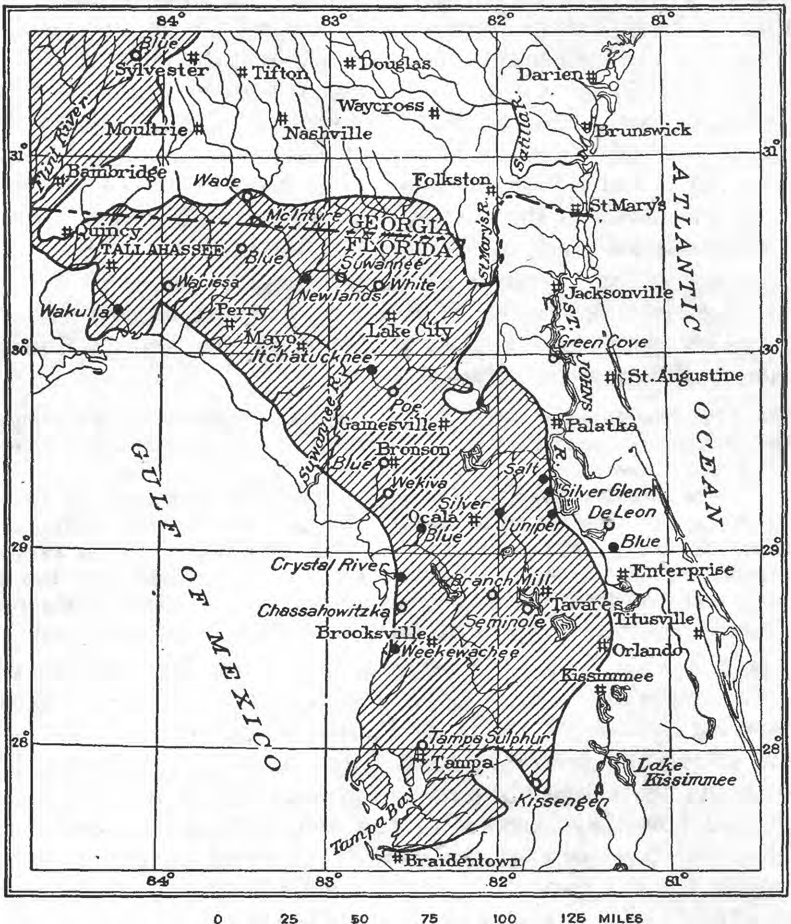

FIGURE 3.—Map showing large springs in Florida and Georgia. The shading shows approximately the area in which the Vicksburg group or a Miocene formation is at the surface. These formations include limestones that give rise to the large springs

very clear, has a beautiful delicate blue hue, and hence the name "Blue Spring" is applied to several of the springs in this region. Many of the springs issue from large, deep pools, in which the clearness and blue hue of the water are especially impressive. The water in some of these pools is so transparent that objects at the bottom are distinctly visible, and fish can be seen swimming about in the water. Although the water comes from limestone it is generally only moderately hard, because it passes rather rapidly through large openings and hence does not come into very intimate or long-continued contact with the rock. According to an analysis given by Sellards,[2] the total dissolved solids in eight of the large springs of Florida range from only 112 to 333 parts per million and average 232 parts per million, the total solids in the water of Silver Spring being 274 parts and in the water of Blue Spring, in Marion County, 112 parts. Salt Springs, however, were found to have 5,377 parts of total solids and 2,662 parts of chloride.[3] The temperature of the spring water is approximately the mean air temperature of the region. Some of the springs have become well-known resorts, but otherwise not much use is made of their water.

The fascinating character of these springs is indicated by the following vivid description of Silver Spring, abbreviated from a description given in a booklet published by the Marion County Chamber of Commerce. (See pl. 1.)

> The deep, cool water of Silver Spring, clear as air, flows in great volume out of immense basins and caverns in the midst of a subtropical forest. Seen through the glass-bottom boats, with the rocks, under-water vegetation, and fish of many varieties swimming below as if suspended in mid-air, the basins and caverns are unsurpassed in beauty. Bright objects in the water catch the sunlight, and the effects are truly magical. The springs form a natural aquarium, with 32 species of fish. The fish are protected and have become so tame that they feed from one's hand. At the call of the guides, hundreds of them, of various glistening colors, gather beneath the glass-bottom boats.

The following table gives information in regard to some of the largest springs in Florida. Because of the small number of measurements that have been made on the Florida springs, there is obviously much uncertainty as to their maximum, minimum, and average discharge and hence as to which ones rank as springs of the first magnitude and how they compare in size among themselves and with springs in other parts of the country. A brief discussion of the large springs in adjacent parts of Georgia and Alabama is given on pages 13–14. The locations of these springs are shown in Figure 3. Most of the discharge measurements were made by B. M. Hall or Warren E. Hall. Much assistance was generously given in the preparation of this part of the report by Warren E. Hall, who, in his long service as district engineer in the Geological Survey, has visited nearly all these springs. The assistance of Herman Gunter, State geologist of Florida, and of H. L. Smith, secretary of the

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[2] Sellards, E. H., A preliminary report on the underground water supply of central Florida: Florida Geol. Survey Bull. 1, p. 47, 1908.

[3] Sample collected by C. A. Hollaway, Apr. 24, 1924, and analyzed by C. S. Howard in the water-resources laboratory of the U. S. Geological Survey.

Marion County Chamber of Commerce, is also gratefully acknowledged. Much of the work by the United States Geological Survey has been done in cooperation with the Florida State Geological Survey.

Discharge of large springs in Florida

Name of spring	County	Temperature (°F.)	Discharge (second-feet)	Date of measurement	Authorities [a]
Silver	Marion	70	822	Dec. 20, 1898	W. 27, p. 45; W. 102, pp. 274-275; W. 319, pp. 367-369.
			545	May 26, 1906	W. 204, p. 50.
			608	Feb. 11, 1907	W. 242, p. 132.
			342	Feb. 27, 1917	W. 452, p. 61.
Blue	do	74	778	Dec. 22, 1898	W. 27, p. 45; W. 102, p. 275; W. 319, pp. 367-369.
			[b] 716	Dec. 24, 1904	W. 127, p. 182.
			[b] 847	Feb. 8, 1907	W. 242, p. 133.
			[b] 738	Feb. 21, 1917	W. 452, p. 61.
Wakulla	Wakulla	70	[c] 326	Feb. 13, 1917	W. 452, p. 61. See also W. 102, pp. 268, 269, 273; W. 319, p. 422; B. 32, p. 86.
Itchatucknee	Columbia	74	403	Dec. 23, 1898	W. 27, p. 45; W. 102, p. 275; W. 319, p. 287.
			44	Feb. 18, 1917	W. 452, p. 61.
			[d] 342	Feb. 19, 1917	W. 452, p. 61.
Blue	Volusia		300	([e])	Herman Gunter, State geologist.
Weekewachee	Hernando	78	[f] 220	([e])	W. 319, pp. 317, 319.
			[g] 145	Feb. 23, 1917	W. 452, p. 61.
Poe	Alachua	72	[f] 100	([e])	W. 319, p. 267.
			86	Feb. 19, 1917	W. 452, p. 61.
White	Hamilton	72	72	Feb. 13, 1907	W. 242, p. 136; W. 319, p. 314; unpublished data.
Wekiva	Levy		[f] 80	([e])	W. 319, p. 256.
			[h] 65	Feb. 21, 1917	W. 452, p. 61.
Suwannee	Suwannee	76	[f] 115	([e])	W. 319, pp. 409, 412.
			44	May 17, 1906	W. 204, p. 52.
Tampa Sulphur	Hillsboro	72	[f] 145	([e])	W. 319, pp. 323-325.
			[i] 35	Feb. 24, 1917	W. 452, p. 61.
Crystal River	Citrus		[f] 445	([e])	W. 319, pp. 281, 282.
Juniper, or Sweetwater.	Marion		445	([e])	W. 102, p. 267.
Silver Glen	do				Estimated by the secretary, Marion County Chamber of Commerce, to be larger than Juniper Spring.
Newland	Suwannee		167	([e])	Florida Geol. Survey Bull. 1, p. 86, 1908.
			[f] 220	([e])	W. 319, pp. 409, 412.
Salt	Marion	70	[f] 187	([e])	W. 319, pp. 367, 369; unpublished data.
Chassahowitzka	Citrus				W. 319, pp. 281, 282.
Seminole	Lake		[f] 56	([e])	W. 319, pp. 342, 343.
Blue	Levy		[f] 55	([e])	W. 319, pp. 355, 356.
Do	Jackson		[f] 55	([e])	Herman Gunter, State geologist.
Branch Mill	Sumter		[f] 48	([e])	W. 319, p. 406.
Kissengen	Polk		21	Feb. 25, 1917	W. 452, p. 61.

[a] W., Water-Supply Paper; B., Bulletin of the U. S. Geological Survey.
[b] Measured about 4 miles downstream from the spring. The flow consists of spring water.
[c] Measured 3 miles downstream from the spring. Nearly all the flow is spring water.
[d] Measured about 3 miles below head of Ichatucknee River, all the flow of which is derived from springs. Above the point of measurement there are about six large springs, one of which is Ichatucknee Spring.
[e] Estimated.
[f] Estimated discharge given in Water-Supply Paper 319. The estimates for Weekewachee, Poe, Wekiva, Crystal River, Salt, Seminole, Blue (in Levy County near Bronson; see fig. 3), and Branch Mill Springs were obtained from Sellards, E. H., Florida Geol. Survey Bull. 1, p. 86, 1908.
[g] Measured about 900 feet downstream from spring.
[h] Measured about one-fourth mile downstream from spring.
[i] Outlet of spring has been artificially raised 6 feet, which doubtless has reduced the discharge.

Other large springs which have been reported by Herman Gunter, State geologist of Florida, but of which no discharge measurements or estimates have been made are the Blue Springs, in Madison

County; Green Cove Springs, in Clay County; Deleon Springs, in Volusia County; Wacissa Springs, in Jefferson County; and Ponce de Leon Springs and Morrison Springs, in Holmes County.

DETAILED DESCRIPTIONS

Silver Spring.—Silver Spring is generally regarded as the largest spring in Florida and it is probably the largest limestone spring in the United States (pl. 1). The water emerges through several openings into a basin an acre or more in extent and fully 35 feet deep and gives rise to a navigable stream. The discharge of the basin as measured five times by the United States Geological Survey ranges from 342 to 822 second-feet. Daily readings on a gage maintained in the basin during a period of about 19 months, from May 25, 1906, to December 31, 1907, showed a total fluctuation in the water level amounting to 2.50 feet. When the gage read 1.12 feet above the lowest observed stage (or 1.38 below the highest) the discharge of the basin as measured with a current meter was 545 second-feet, and the stream at the point where the measurements was made had a width of 110 feet, a maximum depth of 11 feet, and an average velocity of about 0.6 foot a second. When the gage read 1.15 feet above the lowest stage the discharge was 608 second-feet. Silver Spring Run, which heads in the spring and discharges into Ocklawaha River, is about 9 miles long and increases greatly in volume downstream by percolation at many points. Thus on February 27, 1917, when Silver Spring had a discharge of only about 342 second-feet, Silver Spring Run at a point 2½ miles below the spring had a discharge of 674 second-feet, almost all of which was derived from springs. Comparison of the daily gage height from May 25, 1906, to December 31, 1907, with the daily precipitation at Ocala, 6 miles from Silver Spring, during the same period shows some unexplained anomalies but otherwise seems to indicate that the discharge is not greatly affected by single rain storms, even though the precipitation is heavy, but increases gradually in rainy seasons and decreases even more gradually in dry seasons. The very heavy rains in May, June, and July, 1906, persistently raised the gage height. On the other hand, the long period of slight rainfall in the autumn of 1906 and the following winter produced a slow but very persistent decline.

Blue Spring, Marion County, Fla.—Blue Spring, in the same county as Silver Spring (figs. 2 and 3), ranks next to it in maximum measured discharge (pl. 2, *A*). On December 22, 1898, its discharge was found to be 778 second-feet. This was only two days after the measurement of Silver Spring that gave a discharge of 822 second-feet. The water of this spring has a blue hue, in contrast to that of Silver Spring, which is said to be virtually colorless.

Wakulla Spring.—Wakulla Spring, several miles south of Tallahassee, issues from a pool in the limestone reported to be about 4 acres in area and about 80 feet deep (pl. 2, *B*). It gives rise to Wakulla River, which is large enough to carry good-sized boats, and is probably the third largest spring in Florida. On February 13, 1917, the discharge of the river 3 miles downstream from the spring, as measured by the Geological Survey, was 326 second-feet. The spring has been described as follows by W. A. McRae,[4] State commissioner of agriculture:

Wakulla Spring is of punch-bowl shape. with limestone sides covered with beautiful water mosses kept in constant motion due to the swift flow of the water from its mysterious subterranean source. The water is transparent, and one can see small objects on the bottom of the spring. * * * Seen from the shore, the central portion of the surface is of an intense blue, and the manifold reflections of overhanging trees, clouds, and sky produce a weird and exquisite picture that is impressed upon the memory.

The following description of the Wakulla River system by Sellards[5] throws much light on the origin and character of this spring. (See fig. 4.)

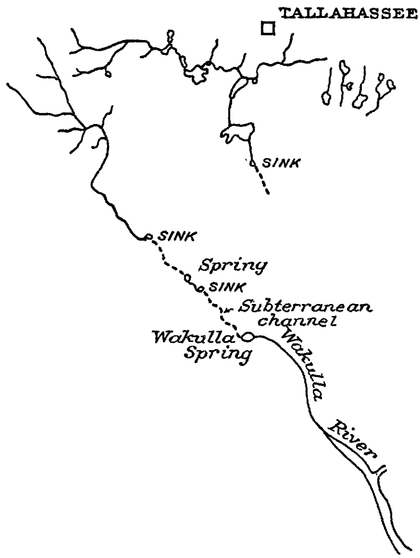

FIGURE 4.—Map of the Wakulla drainage system, showing its relation to Waknlla Spring, Fla. (After Sellards)

The Wakulla River system originates in small surface streams which reach northwest to within 1 or 2 miles of the Ocklocknee River in Leon County. These tributaries flow as surface streams in a general southeast direction until they reach the limestone area, when they become subterranean streams entering the limestone through sinks. After entering the limestone they may occasionally be seen owing to the caving of the roof above them. One such view of the stream making its way underground is to be had at what is known as the River Sinks in Wakulla County. These underground streams make their way, as we may believe, in a general southeast direction and reemerge, in part at least, to form the great Wakulla Spring, and from that place continue as an open surface stream to the Gulf.

Springs in Georgia and Alabama.—Many large springs also issue in southwestern Georgia and southeastern Alabama from cavernous limestones, chiefly of the Vicksburg group and the overlying Miocene

[4] McRae, W. A., North Florida: Florida Dept. Agr. Quart. Bull. Suppl., vol. 33, No. 4, p. 26, October, 1923.
[5] Sellards, E. H., Geology between the Ocklocknee and Aucilla Rivers in Florida: Florida Geol. Survey Nineteenth Ann. Rept., pp. 136, 137, 1917.

deposits (Chattahoochee and Alum Bluff formations). (See figs. 1 and 3.) Several of these are called "Blue Spring." The Blue Spring 4 miles south of Albany, Ga., on the east side of Flint River, is believed to be the largest spring in Georgia. Measurements of this spring, made by the United States Geological Survey,[6] show a discharge of 135 second-feet on April 19, 1904; 44 second-feet on September 23, 1904; 26 second-feet on November 16, 1904; and 69 second-feet on April 26, 1905. The water rises under considerable pressure from several openings in limestone of the Vicksburg group and has a faint bluish hue but is very clear and is said to remain clear even when the discharge is increased by rains. The main spring opening is 20 to 30 feet deep, and the temperature of the water is 69° F.[7]

Wade Spring, near Withlacoochee River, 7 miles east of Quitman, Ga., was roughly estimated by McCallie[8] in November, 1903, to yield 15 million gallons a day (about 23 second-feet). In an extremely dry season, however, this spring is reported to have gone dry. It is often called Blue Spring and is a typical "blue spring" of this limestone region. It seems to be the outlet of a subterranean stream that ascends with considerable force through a large opening. McIntyre Spring, on the same river near the Georgia-Florida line, was estimated by McCallie to discharge about twice as much water as Wade Spring.

SPRINGS IN PALEOZOIC LIMESTONE IN STATES EAST OF MISSISSIPPI RIVER

Numerous large springs issue from the Paleozic limestones in several States east of the Mississippi, but so far as known not any of these are springs of the first class except perhaps the Big Spring at Tuscumbia, Ala.

In northern Alabama and adjacent areas hundreds of large springs issue from solution passages in Paleozoic limestones and dolomites, chiefly from the Knox dolomite and limestones of Mississippian age.[9] In regard to most of these "big springs" no definite information is available. The Big Spring at Tuscumbia (fig. 1) discharged 177 second-feet on July 20, 1903, according to a measurement made by the United States Geological Survey.[10] On October 25, 1917, a measurement at a point about three-quarters of a mile

[6] U. S. Geol. Survey Water-Supply Papers 127, p. 120, 1905; 168, p. 98, 1906.

[7] Stephenson, L. W., Veatch, J. O., and Dole, R. B., Underground waters of the Coastal Plain of Georgia: U. S. Geol. Survey Water-Supply Paper 341, p. 240, 1915.

[8] McCallie, S. W., A preliminary report on the underground waters of Georgia: Georgia Geol. Survey Bull. 15, p. 58, 1908.

[9] Smith, E. A., The underground water resources of Alabama, pp. 49, 73, 79, 100, Alabama Geol. Survey, 1907.

[10] U. S. Geol. Survey Water-Supply Paper 98, p. 293, 1904.

below the spring, by L. J. Hall, of the Geological Survey, showed a flow of 55.9 second-feet, and on October 26, 1917, a measurement by Mr. Hall only 800 feet below the spring showed a flow of 55.4 second-feet. Coldwater Spring, about 7 miles southwest of Anniston, is estimated to yield from 23 to 28 million gallons a day (about 35 to 44 second-feet).[11] A large spring near Munfordville, Ky., on the south bank of Green River, is used to operate a hydroelectric power plant. An exceptionally large spring, known as Big Cave Spring, is also reported in Jackson County, Ala.[12]

The largest spring in Indiana is probably Wilson Spring, in the NE. ¼ sec. 19, T. 3 S., R. 3 E., near White Cloud, in the southern part of the State. It issues from the cavernous Mitchell limestone (Mississippian) and discharges through a stream about a mile long into Blue River, a tributary of the Ohio. According to estimates made by Tucker in 1910, the discharge of this spring is about 40 second-feet.[13]

In the great limestone valley that extends from Virginia to Pennsylvania, including the Shenandoah Valley of Virginia, many large springs issue from the Paleozoic limestones, but apparently none of these are springs of the first magnitude. C. E. Ryder, chief engineer of the water resources service of Pennsylvania, states that of 300 springs in that State of which records of flow have been obtained, there are two that discharge more than 25 second-feet. These are Boiling Spring, in Cumberland County, with a flow of 30 to 45 second-feet, and Bellefonte Spring, in Center County, with a flow reported at about 31 second-feet. Both of these springs issue from limestone of Ordovician or Cambrian age.

The following list of large springs in Pennsylvania was furnished by Mr. Ryder. He states that it is not definitely known whether the discharge data, as given, are based on actual measurements, except those of Boiling, Bellefonte, and Roaring Springs. Ingham Spring, 2 miles west of New Hope, is also mentioned as one of the large springs of the State, but it is not believed to be as large as Boiling Spring, which is considered the largest spring in Pennsylvania. According to G. M. Hall, all the springs listed in the following table issue from Ordovician or Cambrian limestone except Rock Spring, which probably issues from Pottsville sandstone, and the Big Spring in Blair County, which issues from sandstone or limestone of Oriskany or Helderberg age.

[11] Unpublished report by A. J. Ellis.

[12] Personal communication from Warren R. King, district engineer, U. S. Geol. Survey.

[13] Tucker, W. M., Water power of Indiana: Indiana Dept. Geology and Nat. Resources, Thirty-fifth Ann. Rept., pp. 30–38, 1911. Cummings, E. R., The geological conditions of municipal water supply in the driftless area of southern Indiana: Indiana Acad. Sci. Proc. for 1915, p. 137, 1912.

Discharge, in second-feet, of certain large springs in Pennsylvania

Name	Location	Reported discharge
Boiling Spring	Near Carlisle, Cumberland County	30-45
Bellefonte Spring	Bellefonte, Center County	31
Rock Spring	½ mile from Tomhicken Village, Luzerne County	15
Spring	2 miles southeast of Bellefonte, Center County	12
Roaring Springs	Roaring Springs Borough, Blair County	12
Big Spring	Tyrone Borough, Blair County	10
Crystal Spring	City of Allentown, Lehigh County	8.5
Falling Spring	3 miles east of Chambersburg, Franklin County	3.0

The following descriptions of springs in Alabama, by McCalley,[14] give a good idea of the character of the openings from which many of these springs issue. The two springs described are more or less typical of many others:

Through the hard, capping rocks forming the table-lands down into the underlying softer strata there are some immense sinks or basins of several miles in circumference. These basins sometimes have a running stream in them and are then long and narrow. The water that falls and rises in them disappears in smaller sinks, to reappear in big springs along the foot of the mountains at the head of coves, etc. In the softer strata of the steep mountain sides there are also numerous caves. Some of these caves are of immense size and have beautiful stalactites and stalagmites. They nearly all have running streams of water, and many of them afford vents for big springs. Some of them lead back to subterranean lakes.

* * * * * * *

Madison County is noted for its many big springs of lime water. These springs flow from beneath hills and bluffs and boil up from deep well-like holes or as numerous small springs over basin-shaped areas covered by their waters (pond springs). In whatever way they occur, they run off as large creeks. The Huntsville Spring * * * is a fair sample of these big springs, though it does not furnish as much water as some others. It flows from under the bluff, some 50 feet high, on which stands the Northern Bank of Alabama and other buildings on the west side of the public square. It supplies the city with water and formerly furnished its own power for pumping the water up into the reservoir. * * * This spring furnished enough water to float cotton boats, by means of a canal, to the Tennessee River in anterailroad times. The temperature of its water in the month of June, according to Prof. Tuomey, was 60.8° F.

* * * * * * *

Cave Spring, in Morgan County, is the coming to light, in large rock houses or caves, of a good-sized subterranean creek. The cave from which this creek flows has two large mouths. The creek runs from the larger or more western of these mouths under the partition between the mouths into the smaller or more eastern mouth and thence by a race for some 60 to 70 feet to the site of an old mill. The mill dam is a pile of rocks across the creek in the larger or more western mouth. The mill pond is therefore all subterranean.

[14] McCalley, Henry, Report on the valley regions of Alabama, pt. 1, The Tennessee Valley region, pp. 16, 139, 256, 257, Alabama Geol. Survey, 1896.

SPRINGS IN EARLY PALEOZOIC LIMESTONE IN THE OZARK REGION OF MISSOURI AND ARKANSAS

GENERAL FEATURES

The Ozark region of Missouri and Arkansas is essentially a structural dome with a northeast-southwest elongation. The underlying formations are mainly of Cambrian and Ordovician age and consist chiefly of cherty dolomitic rocks. The region reaches a maximum

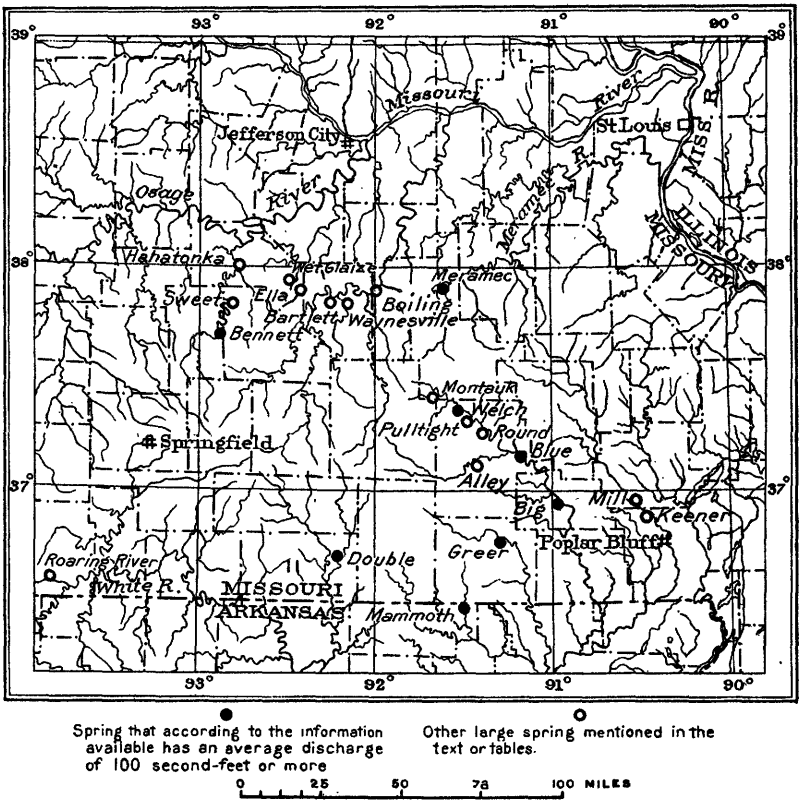

FIGURE 5.—Map showing large springs in the Ozark region of Missouri and Arkansas

altitude of about 1,800 feet above sea level and has a rugged topography, with deep canyon-like valleys. According to available information it contains seven springs which have discharges ranging from 100 to several hundred second-feet (fig. 5) and which therefore rank with the very large springs of the country, although not quite equaling the largest springs in Florida or the largest springs in the areas of volcanic rock in the Northwest. In addition to these springs of first magnitude there are many other large springs in the region. Thus the Geological Survey has measured 30 springs in Missouri which have discharges ranging from 20 to 100 second-feet. These great springs issue from large crevices or caverns in the limestone and are situated, for the most part, in deep valleys near the borders of the uplift. It is a region of sink holes, with many deep valleys that contain no streams except in very wet weather, all the water going underground. All the springs have marked fluctuations in discharge and often rise promptly after heavy rains or melting snows. This region has much greater relief than the big-spring region of Florida and Georgia, and consequently the subterranean circulation is, it seems, more vigorous, resulting in somewhat greater and prompter effects of rainfall on the discharge of the springs. On account of the greater relief and the smaller amount of sand mantling the surface, the water is more likely to become turbid or muddy in the springs of this region than in those of Florida and Georgia. In the latter region the volume of water stored in the crevices of the limestone at any given time is doubtless much greater.

The information in regard to the large springs of this region was obtained chiefly from brief descriptions and miscellaneous discharge measurements in water-supply papers of the United States Geological Survey, a report by T. J. Rodhouse,[15] of the Missouri Engineering Experiment Station, and unpublished records of the Geological Survey and the Missouri State Bureau of Geology and Mines, furnished by E. L. Williams and H. C. Beckman, district engineers. Good records of several of the springs were obtained in recent years through cooperation between the United States Geological Survey and the State Bureau of Geology and Mines.

The range in discharge and the average discharge of some of the largest springs in the region are given in the following table. The discharge data for different springs are, however, not entirely comparable, because for some springs they include estimates that were probably too large, and because the measurements were made at different times and, therefore, represent different stages of the springs. Until continuous records of discharge of all the springs have been obtained for a period of several years it will be impossible to determine which of them actually have an average discharge of as much as 100 second-feet or how they rank in maximum, minimum, and average discharge.

[15] Rodhouse, T. J., Study relating to the water resources of Missouri: Missouri Eng. Exper. Sta. ser. 22 (Missouri Univ. Bull., vol. 21, No. 35), 1920.

Discharge, in second-feet, of large springs in the Ozark region of Missouri and Arkansas

Spring	Length of record	Discharge		
		Lowest	Highest	Approximate average
Big	12 months	344	589	428
Greer	22.6 months	204	835	392
Mammoth	Various estimates and measurements	150	[a] 335	250+
Meramec	37 months	76	600	182
Double	One measurement	136	136	
Welch	do	115	115	
Bennett	43 months	69	168	110
Blue	Two measurements	84	133	
Alley	Three measurements	75	85	
Boiling	One measurement	65	[a] 150	
Hahatonka	do	54	[a] 250	
Montauk	do	63	63	

[a] Estimated.

DETAILED DESCRIPTIONS

Big Spring.[16]—Big Spring, which has also been called Van Buren Spring, is about 4 miles south of Van Buren, in Carter County, Mo., in sec. 6, T. 26 N., R. 1 E. The water issues with considerable velocity from cavernous holes in the rock at the base of the high cliff on the west side of the Current River valley and flows swiftly eastward about 1,000 feet into the river (pl. 3, *A*). The spring is only 6 feet above the mean stage of the river and is flooded by the river in high stages.

On August 27, 1912, the discharge was 345 second-feet, according to measurements by T. J. Rodhouse. A gaging station with a staff gage was established at the spring by the United States Geological Survey in cooperation with the Bureau of Geology and Mines on January 8, 1922, and semidaily records were obtained for parts of 1922 and 1923. On account of the effects of back water of Current River the results obtained during high stages of the river are somewhat uncertain. As shown in the following table, the discharge during nearly 11 months of record ranged from 344 to 840 second-feet and averaged 428 second-feet. The maximum discharge measured with current meter was 589 second-feet, and only on three days, in May, 1923, was the discharge as determined from the gage height greater than this. The maximum is therefore given as 589 second-feet in the table above. Apparently this spring does not fluctuate as greatly as many of the large limestone springs. If the irregularities shown by the record are not due to inaccuracies they seem to occur without close relation to the precipitation or with a lag of a number of days.

[16] U. S. Geol. Survey Water-Supply Papers 547, pp. 41–43, 1925; 567, pp. 41–43, 1925. Rodhouse, T. J., op. cit., pp. 21, 22.

Monthly discharge, in second-feet, of Big Spring, Mo.[a]

	Lowest	Highest	Average		Lowest	Highest	Average
1922				1923			
January 8-31	344	372	358	April	424	534	493
February	358	500	414	May	424	840	499
March	424	578	469	June	388	472	413
April	404	534	460	July	384	472	416
May	446	578	490	August	344	380	364
June	404	446	413	September	344	358	347

[a] The complete record is given in U. S. Geol. Survey Water-Supply Papers 547, pp. 41–43, 1925; 567, pp. 41–43, 1925.

Greer Spring.[17]—Greer Spring is in Oregon County, Mo., about 1½ miles northeast of Greer post office and about the same distance south of Eleven Point River, in the SW. ¼ sec. 36, T. 25 N., R. 4 W. About one-fourth of its water issues from a cave lined with stalactites and stalagmites, at the head of a deep ravine cut in Ordovician rocks, mainly cherty dolomite, with a few irregular beds of sandstone. The remaining three-fourths comes from a so-called "boil" 100 feet distant and 7 feet lower, the source of which is invisible.

The stream heading in the spring flows through a beautiful gorge cut in limestone, a distance of about 1¾ miles, to Eleven Point River, and has a total fall in this distance of 72 feet. The water is colorless except where contaminated by sediment washed in below its source in time of storm. It has no odor or taste and has a temperature of 54° F. In 1904 the spring furnished power for a large gristmill, but no other use was made of the water. Considerable additional water power could be developed.

At a gaging station maintained at Greer Spring by the United States Geological Survey from August 9 to December 31, 1904, a record of daily gage heights was obtained, with some interruptions, and two current-meter measurements were made. During this period there was not much rainfall, although there were a few moderate rains. The gage height declined very gradually and regularly from an arbitrary reading of 1.00 foot at the beginning of the period to 0.60 foot at the end. The discharge was 362 second-feet on August 9, when the gage height was 1.00, and 265 second-feet on October 1, when the gage height was 0.72. On July 30, 1919, the discharge as measured by T. J. Rodhouse was 338 second-feet.

A new gaging station, with staff gage read daily, was established by the United States Geological Survey November 18, 1921, and was maintained continuously to September 30, 1923. During this period of nearly two years the discharge ranged from 204 to 835 second-feet

[17] Shepard, E. M., U. S. Geol. Survey Water-Supply Paper 102, pp. 416, 422, 423, 435, 1904. U. S. Geol. Survey Water-Supply Paper 131, pp. 178–179, 1905. Fuller, M. L., Notes on certain large springs of the Ozark region, Mo. and Ark.: U. S. Geol. Survey Water-Supply Paper 145, p. 208, 1905. Rodhouse, T. J., op. cit., p. 25. U. S. Geol. Survey Water-Supply Papers 547, pp. 44–46, 1925; 567, pp. 44, 45, 1925.

and averaged 392 second-feet. The fluctuations are closely related to the precipitation at Birchtree, 18 miles distant, as recorded by the United States Weather Bureau. (See pl. 7.) A heavy rain is usually followed within a day by a conspicuous rise in the spring, and even a rainstorm of moderate intensity produces a noticeable increase in discharge. The large persistent rise in March and April, 1922, was due to the accumulative effect of a rainy season.

Mammoth Spring.[18]—Mammoth Spring is one-eighth of a mile north of Mammoth Spring post office, in Fulton County, Ark., near the line between secs. 5 and 8, T. 21 N., R. 5 W. It issues as a subterranean stream near the base of a high bluff of cherty limestone. The course of the subterranean river that feeds the spring is thought to be marked, 8 miles northwest, by a sink hole three-fourths of a mile long known as the "Grand Gulf." The spring pool is 64 feet deep at its mouth, and the water apparently issues from a large cavern and from other large crevices in the limestone. The water is described as having a bluish tinge but as being odorless and tasteless and having a temperature of 58° or 59° F. in summer. The water is hard, having about 158 parts per million of lime and 139 parts of magnesia.

The discharge was estimated by Purdue at about 150,000 gallons a minute, or about 335 second-feet, but in 1904 it was, according to Fuller, as low as 150 second-feet. On December 13, 1922, the discharge was 258 second-feet, according to a measurement by F. H. Davis, of the United States engineer office at Memphis, Tenn. The Morgan Engineering Co., made a number of approximate measurements of this spring and concluded that the discharge at low stages is about 250 second-feet. The water from the spring is now used to operate a modern hydroelectric plant, which, according to the owners, develops 1,100 horsepower and supplies electric energy for the town of Mammoth Springs and for several towns in Missouri. (See pl. 6, *B*.)

Meramec Spring.[19]—Meramec Spring, also called Messamer Spring, is about 6 miles southeast of St. James, in Phelps County, Mo., in the SE. ¼ sec. 1, T. 37 N., R. 6 W. The water issues from a circular pool about 100 feet in diameter, at the base of a precipitous cliff, and flows northward into Meramec River (pl. 4). Its temperature is reported to be 58° F.

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[18] Purdue, A. H., U. S. Geol. Survey Water-Supply Paper 102, pp. 385–387, 1904. Adams, G. I., Summary of the water supply of the Ozark region in northern Arkansas: U. S. Geol. Survey Water-Supply Paper 110, p. 182, 1904. Fuller, M. L., op. cit., p. 210. Unpublished information of the U. S. Army Engineers and the Morgan Engineering Co., Memphis Tenn.

[19] U. S. Geol. Survey Water-Supply Paper 99, pp. 235–237, 1904. Shepard, E. M., op. cit., p. 416. U. S. Geol. Survey Water-Supply Papers 131, pp. 123–125, 1905; 173, p. 17, 1906; 209, pp. 21–22, 1907; 547, pp. 14, 15, 1925; 567, pp. 12, 13, 1925. Rodhouse, T. J., op. cit., pp. 25–29. Unpublished records of the U. S. Geol. Survey and the Missouri Bur. Geology and Mines.

A gaging station was maintained at the spring by the United States Geological Survey from February 28, 1903, to July 21, 1906, and since November 21, 1921. Up to September 30, 1923, a total of 42 current-meter measurements had been made, and nearly complete daily records of gage heights were obtained for a total of 37 months. There is some uncertainty as to the interpretation of gage heights at high stages, owing to the backwater effects on Meramec River. The records, however, indicate that during these 37 months the discharge ranged from 76 to about 600 second-feet and averaged about 182 second-feet. The largest measured discharge was 467 second-feet. The relation of the spring discharge to the precipitation is shown in Plate 5. The record indicates that here, as in the Greer Spring, the discharge increases greatly and quickly after rainstorms in winter and spring but that in summer and autumn there is less response to rains and the flow of the spring is much more regular. In this as in other Missouri springs there was a pronounced increase in discharge during the cool rainy season of early spring. At high stages following heavy rains the water may become turbid and carry some débris, showing that it has rather direct connection with sink holes that receive surface water.

Monthly discharge, in second-feet, of Meramec Spring, Mo.[a]

Month	Lowest	Highest	Average	Month	Lowest	Highest	Average
1903				1922			
March	237	494(?)	405	January	100	152	119
May	180	570(?)	245	February	98	197	127
June	180	494	271	March	118	352	225
August	112	418	181	April	200	406	309
				May	127	266	164
1904				June	104	124	116
January	76	456(?)	204	July	104	152	115
March	136	185	160	August	95	120	103
April	212	570	367	September	85	120	98
June	160	646(?)	271	October	81	140	93
				November	79	87	83
1905				December	79	203	100
March	114	560(?)	235				
May	154	360(?)	210	1923			
July	96	595(?)	201	January	95	162	112
September	105	525(?)	235	February	95	299	138
October	114	525(?)	190	March	100	420	205
				April	100	316	145
1906				May	100	282	148
January	114	525(?)	258	June	114	334	168
March	177	560(?)	274	July	97	137	112
				August	85	147	98
1921				September	83	114	89
December	120	283	167		76	420+	182

[a] Discharges in 1903-1906 are based on records in Water-Supply Papers 99, 131, 173, and 209, recomputed by H. C. Beckman with allowances for backwater at high stages of Meramec River. Discharges in 1921-1923 are derived from daily and monthly records published in Water-Supply Papers 547 and 567.

Double Spring.[20]—Double Spring is about 20 miles west of West Plains, in Ozark County, Mo., in sec. 18, T. 23 N., R. 11 W., on the west side of the narrow valley of North Fork River. The water issues with a great rush from holes in the rock at the base of the cliff

[20] Rodhouse, T. J., op. cit., p. 29.

along the west side of the river and flows away in two brooks, one toward the south and the other toward the north. The name of the spring is due to this division of the water after it has come to the surface. The spring is about 8 feet above the river level. The temperature of the water was reported to be 60° F. The discharge on August 8, 1919, as measured by T. J. Rodhouse, was 136 second-feet.

Welch Spring.—Welch Spring, in sec. 14, T. 31 N., R. 6 W., near Cedar Grove, Shannon County, Mo., is tributary to Current River (pl. 6, *A*). On October 2, 1923, it was measured by the United States Geological Survey and found to have a discharge of 115 second-feet.

Bennett Spring.[21]—Bennett Spring, which has also been called Brice or Bryce Spring, is near the east boundary of Dallas County, Mo., in sec. 1, T. 34 N., R. 18 W. It issues from a circular basin in gravel about 30 feet in diameter and gives rise to a stream that is about 1½ miles long and that empties into Niangua River at a level about 22 feet below the spring. The spring furnishes power for a mill in the village of Brice. The temperature of the water is about 58° F. The spring was visited in 1903 by Shepard,[22] who states that at that time it boiled up with great force from a vertical cavelike opening through the limestone into a large oval basin (fig. 6).

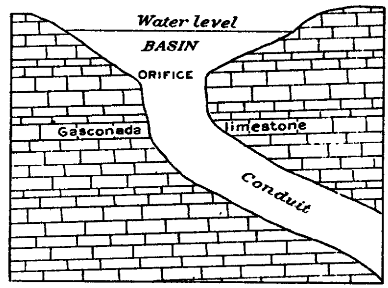

FIGURE 6.—Diagrammatic section showing the outlet of Bennett Spring, Dallas County, Mo., according to Shepard

A gaging station was maintained at this spring by the State Engineering Experiment Station from September 3, 1916, to the end of March, 1920. During this period of nearly four years the discharge ranged from 69 to 168 second-feet and averaged 110 second-feet (fig. 7). A measurement made by the Geological Survey September 18, 1923, showed a discharge of 80 second-feet. The discharge is increased promptly and greatly by rainfall and melting snow, and the water sometimes becomes muddy at high stages.

Blue Spring.[23]—Blue Spring is southwest of Deslet, in the SE. ¼ sec. 21, T. 29 N., R. 2 W., in Shannon County, Mo., about a quarter of a mile from Current River, into which it discharges.

[21] Rodhouse, T. J., op. cit., pp. 14–19. Shepard, E. M., op. cit., pp. 416, 418, 419; Spring system of the Decaturville dome, Camden County, Mo.: U. S. Geol. Survey Water-Supply Paper 110, pp. 117–119, 1904. Unpublished records of the U. S. Geol. Survey and the Missouri Bur. Geology and Mines.

[22] Shepard, E. M., Spring system of the Decaturville dome, Camden County, Mo.: U. S. Geol. Survey Water-Supply Paper 110, pp. 117–119, 1905.

[23] Unpublished notes by Josiah Bridge, geologist, Missouri Bur. Geology and Mines, and unpublished records furnished by H. C. Beckman, district engineer, U. S. Geol. Survey.

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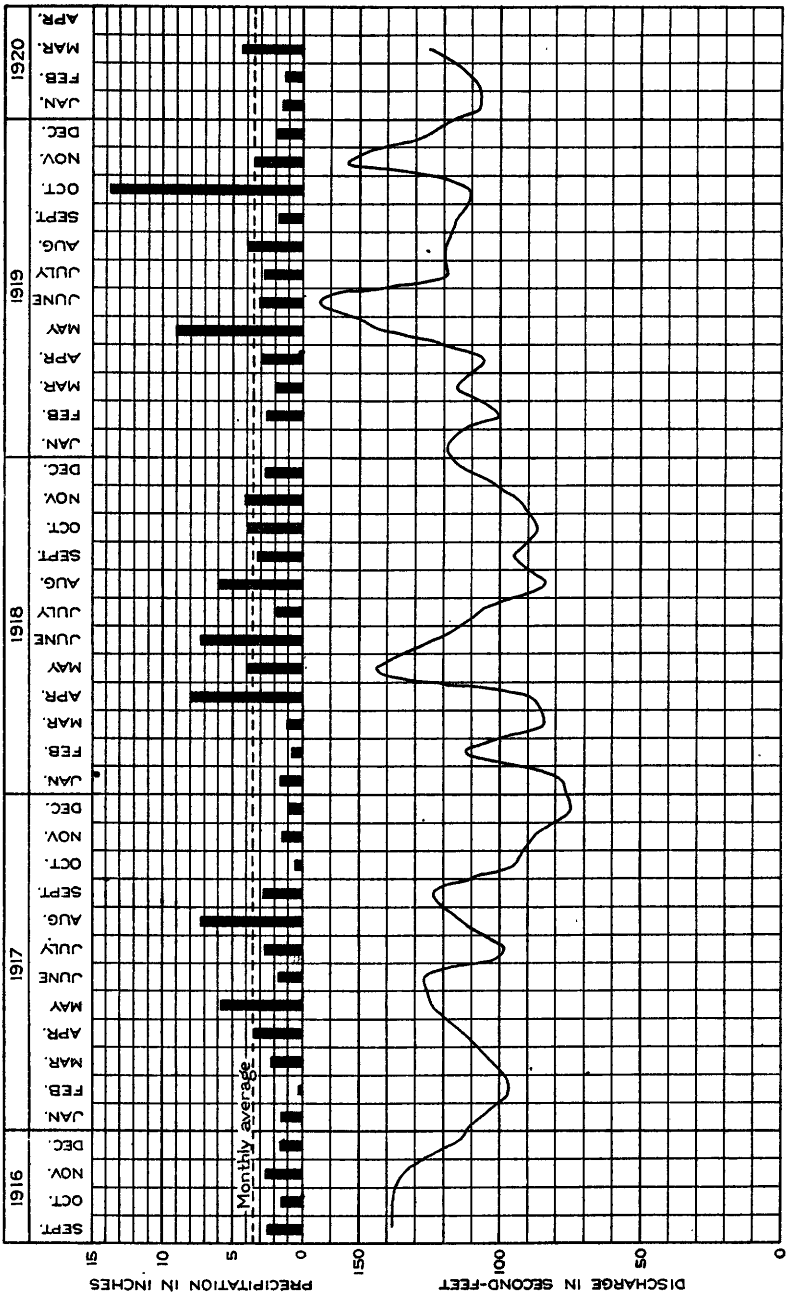
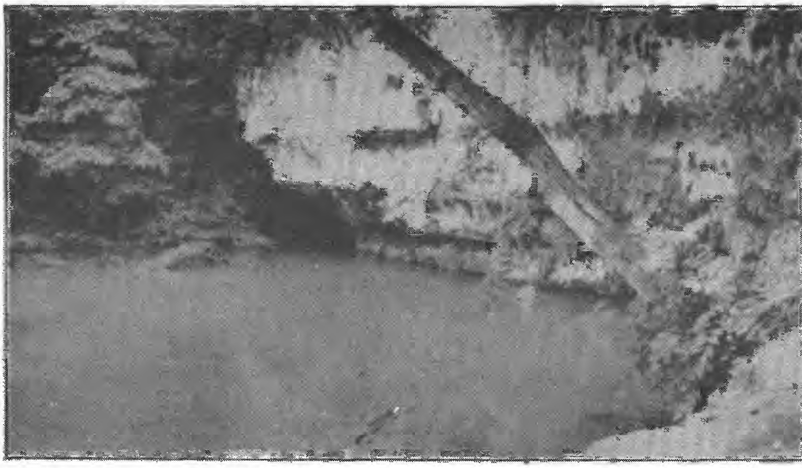


FIGURE 7.—Discharge of Bennett Spring and monthly precipitation at Lebanon, Mo., 12 miles from the spring, September, 1916, to March, 1920. (After T. J. Rodhouse)

A. WATER FLOWING FROM BIG SPRING, MO.

Photograph by H. C. Beckman



B. HAHATONKA SPRING, MO.

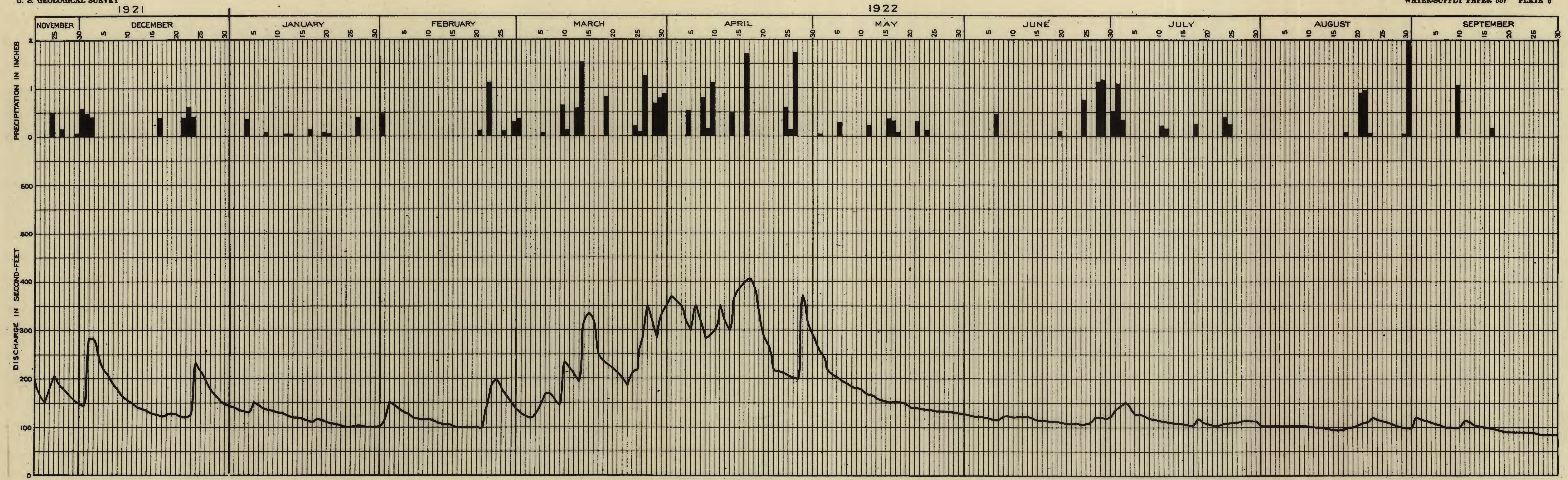
Photograph by E. L. Williams

A. GENERAL VIEW

B. WATER FROM SPRING FLOWING OVER DAM

MERAMEC SPRING, MO.

Photographs by E. L. Williams



DAILY DISCHARGE OF MERAMEC SPRING AND DAILY PRECIPITATION AT GANO, MISSOURI

A. WELCH SPRING, MO.

Photograph by H. C. Beckman

B. WATER FROM MAMMOTH SPRING, ARK., FLOWING OVER DAM

Photograph by E. L. Williams

The water issues from a basin at the foot of a bluff of dolomite 25 to 40 feet high. The basin is approximately circular and about 75 feet in diameter, and, according to soundings made by Bridge, it has a maximum depth of 45 feet. The water is very clear and has a temperature of 54° F. The discharge was 133 second-feet when measured August 1, 1923, and 84 second-feet when measured October 11, 1923.

Alley Spring.[24]—Alley Spring is at Alley, in sec. 25, T. 29 N., R. 5 W., in Shannon County, Mo. The water emerges from a deep pool, about 1 acre in extent, at the base of a dolomitic limestone cliff 150 feet high on the side of the broad valley of Jacks Fork, a tributary of Current River. The spring branch is about half a mile long and empties into Jacks Fork at a level about 17 feet below that of the spring. It furnishes power for running a grist and saw mill. The water is reported to be very clear and to be odorless, tasteless, and somewhat hard. Its temperature was observed to be 53° F. The discharge was 85 second-feet when measured by the Geological Survey October 2, 1904, 75 second-feet when measured by T. J. Rodhouse August 23, 1912, and 82 second-feet when measured by the Geological Survey September 25, 1922. All these measurements were made at times when the spring was probably at a low stage.

Boiling Spring.[25]—Boiling Spring is on Gasconade River 6 miles upstream from Arlington, Mo., in T. 36 N., R. 10 W., Pulaski County. The water issues largely from the bed of the river but partly near the base of a high limestone bluff that borders the river. It has a bluish color and a reported temperature of 60° F. Its discharge was roughly estimated in 1904 at 150 second-feet. A measurement on September 21, 1923, showed a discharge of 65 second-feet.

Hahatonka Spring.[26]—Hahatonka Spring, which was formerly known as Gunter Spring, is in Camden County, Mo., in sec. 2, T. 37 N., R. 17 W. The water issues from the Gasconade limestone at the base of a cliff 250 feet high (pl. 3, *B*), flows nearly 1,000 feet through a narrow canyon 300 feet in maximum depth, and then forms a lake of about 40 acres in the Niangua River valley. The lake discharges into the river, the length of the entire course of the spring branch from the spring to the point of discharge into the river is about three-fourths of a mile. The fall from the spring

[24] Fuller, M. L., op. cit., p. 209. Rodhouse, T. J., op. cit., p. 21. Unpublished records of the U. S. Geol. Survey and Missouri Bur. Geology and Mines.

[25] Fuller, M. L., Notes on certain large springs of the Ozark region, Mo. and Ark.: U. S. Geol. Survey Water-Supply Paper 145, p. 210, 1905. Unpublished records of the U. S. Geol. Survey and the Missouri Bur. Geology and Mines.

[26] Shepard, E. M., U. S. Geol. Survey Water-Supply Paper 102, pp. 416, 418, 426, 1904; Spring system of the Decaturville dome, Camden County, Mo.: U. S. Geol. Survey Water-Supply Paper 110, p. 120, 1905. Rodhouse, T. J., op. cit., p. 21. Unpublished records of the U. S. Geol. Survey and Missouri Bur. Geology and Mines.

DAILY DISCHARGE OF GREER SPRING AND DAILY PRECIPITATION AT BIRCHTREE, MISSOURI to the river is about 18 feet. The scenery is very beautiful. The temperature of the water was reported by Shepard to be 57° F. The spring opening has been sounded to a depth of 40 feet, where it bends to the south. The erosive work of the spring is described by Shepard as follows:

The district in the vicinity of this spring possesses great interest both from a scenic and a geological standpoint. Evidence of great erosion from underground waters, showing former outlets of this great spring, are everywhere seen. At one time it doubtless had its outlet at the Big Red Sink, one-half mile to the southwest. A few hundred feet on the other side of the bluff from which the spring now issues is a sink, 150 feet deep and 600 feet long, which is open at one end and spanned by a great natural bridge. This undoubtedly marks an old cavernous channel of the great spring. In fact, most of these sinks and canyons mark the site of ancient cavernous outlets.

According to Shepard, independent estimates of the discharge by several engineers at different times ranged between 230 and 250 second-feet, but a measurement made by Rodhouse July 4, 1913, gave only 54 second-feet.

Montauk Spring.—Montauk Spring is in sec. 22, T. 32 N., R. 7 W., at Montauk, Dent County, Mo., and is tributary to Current River. On October 2, 1923, when it was measured by the United States Geological Survey, it had a discharge of 63 second-feet.

Bartlett Springs.[27]—The Bartlett Springs issue along Gasconade River, 7 miles northwest of Waynesville, in Pulaski County, Mo. They constitute a group of five springs within a distance of three-fourths mile of one another. They were measured by Rodhouse in August, 1914, when the discharge of Bartlett Spring proper was 12 second-feet, that of Creasy Spring was 21 second-feet, and the total discharge of the other three was about 25 second-feet.

Roaring River Spring.—Roaring River Spring, the data for which are given in the table on page 27, is described as follows by Beckman:[28]

Roaring River Spring emerges from beneath a limestone cliff and is the source of Roaring River. The surrounding scenery is very pretty and forms the setting of an attractive summer resort. A dam has been built on the spring branch to form an artificial lake, which is used as a hatchery for rainbow trout. The water is colorless and odorless and is used for drinking at the resort.

Other large springs.—The measured or estimated discharges of some of the many second-magnitude springs in the Ozark region are given in the following table. Sweet or Big Blue Spring, in Laclede County, Mo., issues from a pool that is said to have been

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[27] Rodhouse, T. J., op. cit., p. 22.
[28] Beckman, H. C., district engineer, U. S. Geol. Survey, unpublished notes.

sounded to a depth of 150 feet.[29] The temperature of the water is reported to be 58° F. in Sweet Spring, 56° F. in Ella Spring, and 54° F. in Round Spring.[30]

Discharge of certain springs of second magnitude in Missouri

Name	County	Location	Discharge (second-feet)	Date of measurement	Authority [a]
Wet Glaize	Camden	NE. ¼ sec. 24, T. 37 N., R. 15 W.	60	([b])	W. 110, p. 121.
Pulltight	Shannon	Sec. 4, T. 30 N., R. 5 W.	31	Oct. 3, 1923	U. S. Geol. Survey.
Ella (West)	Camden	NE. ¼ sec. 6, T. 36 N., R. 14 W.	30	([b])	W. 110, p. 121.
Round	Shannon	Sec. 20, T. 30 N., R. 4 W.	23	Oct. 3, 1904	W. 145, p. 209
			31	July 28, 1923	U. S. Geol. Survey.
Roaring River	Barry	Sec. 27, T. 22 N., R. 27 W.	22	July 15, 1923	Do.
			23	do	Do.
			28	July 16, 1923	Do.
Sweet (Big Blue)	Laclede	NE. ¼ sec. 30, T. 36 N., R. 17 W.	23	July 1, 1913	Rodhouse, T. J., op. cit., p. 21.
			21	([c])	W. 110, p. 119.
Creasy	Pulaski	7 miles northwest of Waynesville.	21	Aug. 4, 1914	Rodhouse, T. J., op. cit., p. 22.
Keener	Butler	West bank of Black River, near Keener.	14	Aug. 18, 1913	Rodhouse, T. J., op. cit., p. 25.
Waynesville	Pulaski	East bank of Roubidoux River, near Waynesville.	12	Aug. 11, 1914	Rodhouse, T. J., op. cit., p. 22.
Bartlett	do	7 miles northwest of Waynesville.	12	Aug. 4, 1914	Do.
Mill	Wayne	Sec. 36, T. 28 N., R. 3 E.	10	([b])	Rodhouse, T. J., op. cit., p. 25.
			10	Oct. 4, 1922	U. S. Geol. Survey.

[a] W stands for U. S. Geol. Survey Water-Supply Paper.
[b] General estimate.
[c] Earlier measurement or estimate.

SPRINGS IN CRETACEOUS LIMESTONE IN TEXAS

OCCURRENCE

The traveler going from Austin through San Antonio to Del Rio, Tex., sees two very different physiographic provinces. On the right is a succession of low, flat-topped hills, which form the Balcones escarpment, or southeast front of the Edwards Plateau (fig. 8); on the left is the gently undulating Coastal Plain. The Edwards Plateau is underlain for the most part by Lower Cretaceous (Comanche) limestones, which dip toward the southeast and in that direction pass beneath the younger formations of the low-lying Coastal Plain. The Coastal Plain is underlain near the Edwards Plateau by Cretaceous formations (chiefly Upper Cretaceous) and farther seaward by Tertiary and Quaternary deposits. Along the general course of the Balcones escarpment the rocks are broken by a complicated system of faults.

Two kinds of large springs are found in this region—those at the edge of the Coastal Plain, in the fault zone, near the base of

[29] Shepard, E. M., Spring system of the Decaturville dome, Camden County, Mo.: U. S. Geol. Survey Water-Supply Paper 110, p. 119, 1904.

[30] Idem, pp. 119, 121. Fuller, M. L., Notes on certain large springs of the Ozark region, Mo. and Ark.: U. S. Geol. Survey Water-Supply Paper 145, p. 209, 1905.

the escarpment, and those at the heads of streams in the Edwards Plateau or wherever the stream valleys cut the water-bearing limestones. The springs in the fault zone issue, at least in part, from

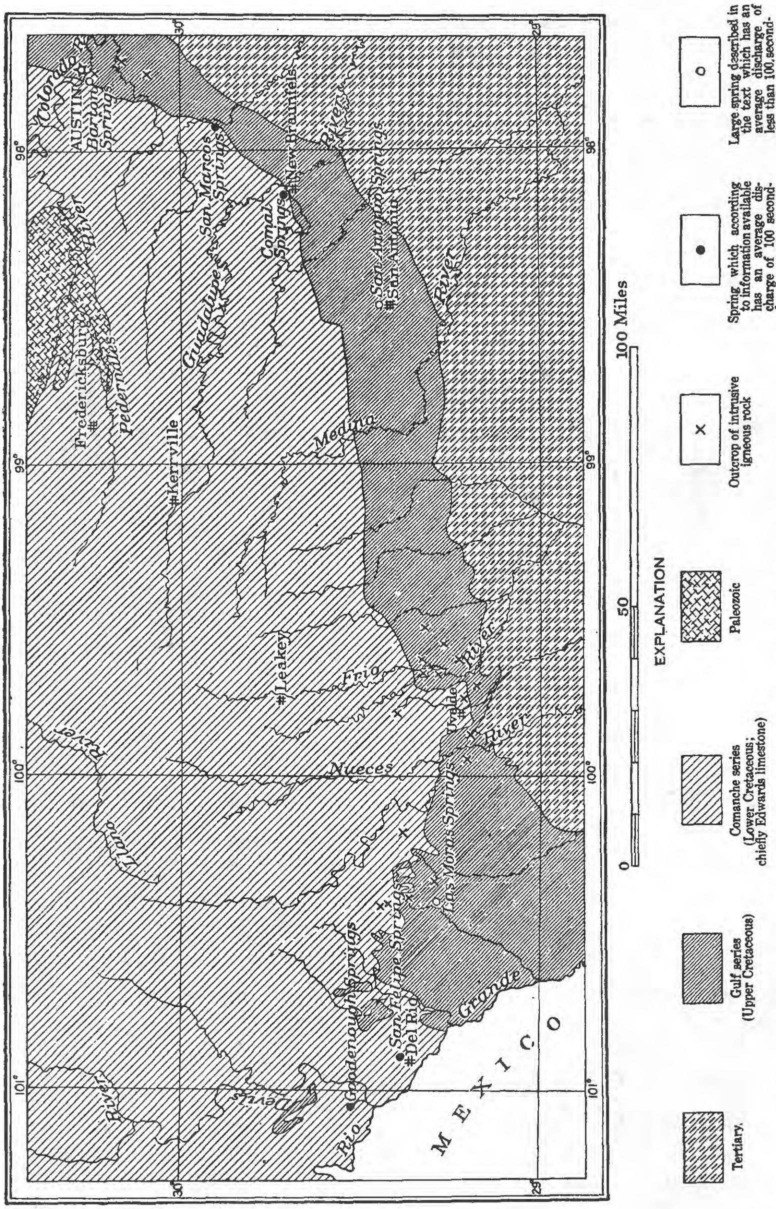

FIGURE 8.—Map showing large springs in the Balcones fault belt of Texas. The Balcones fault zone nearly coincides with the belt of Gulf series as shown in the map. Geology after Geologic map of Texas, Univ. Texas, 1916

fault fissures and are regarded as largely artesian springs; those in the Edwards Plateau are essentially gravity springs, the water generally appearing where the valleys reach down to the water table.

Both the artesian springs of the Balcones fault zone and the gravity springs of the Edwards Plateau appear to be less flashy than at least some of the large springs of the Ozark region. Their fluctuations occur more gradually and with greater lag and have a somewhat more moderate range. So far as information is available, their water is always clear, whereas that of some of the springs of the Ozark region becomes turbid or even muddy after freshets. On the whole, the Texas springs seem to resemble the Florida springs more nearly than those of the Ozark region, although the controlling structure and topography in the two regions are dissimilar.

In compiling the data for the large springs in Texas much valuable assistance was given by C. E. Ellsworth, district engineer of the Geological Survey, and C. E. McCashin, also of the Geological Survey. The work of measuring the springs and streams in Texas in recent years has been carried on in cooperation with the State through the Board of Water Engineers.

SPRINGS IN THE BALCONES FAULT BELT

GENERAL FEATURES

Character of springs.—The largest and most definite springs in the Texas region are those which occur along the fault belt on the Coastal Plain near the Balcones escarpment, chiefly between Austin and Del Rio. They do not break out from bluffs or fall in cascades but appear as extensive pools, some of them in the level prairie. The water is very clear but has a slight bluish or greenish color. The pools contain fish and abound in aquatic plants. Some of the springs are at the very foot of the Balcones escarpment; others are out on the plain, many miles from the edge of the plateau. A few of the largest and best known springs are described on pages 31–39, in the order in which they occur southwestward from Austin.

Origin of springs.—The large springs in the Balcones fault belt are believed to be artesian springs whose water rises through fissures produced by faulting. This origin is indicated by the general relation of the springs to the fault belt, by the fact that in some springs the water can be seen emerging from the fault fissures, and by the fact that at San Antonio the flow of the springs is affected by the discharge of the artesian wells. However, the wide fluctuations in the flow of these springs produced by wet and dry years and to some extent by heavy and prolonged rainstorms indicate that the water does not come from any very deep or distant source. Moreover, according to the meager data at hand, the temperature of the water is not appreciably higher than the normal temperature for shallow ground water in the region and is less than that of the deep wells.

Thus, the mean annual air temperature at Austin, New Braunfels, and San Antonio is about 68° F., the temperature of the Comal Springs, at New Braunfels, has been variously reported at 68° and 75°; and the temperature of the water in a 600-foot well at Austin is reported to be about 70°; whereas the temperature of water from a 1,420-foot well 20 miles east of Austin is reported to be 93°, and that of a 1,900-foot well at San Antonio 106°.[31] The origin of the spring water is discussed as follows by Hill and Vaughan:[32]

From the similarity of color, taste, temperature, etc., of this chain of springs extending in a continuous line 250 miles between Austin and Del Rio, and from their association with the line of Balcones scarp and faults, there can be no doubt that they are all of similar nature and origin. The temperature of the water brought by the springs from their subterranean source, about 75°, does not differ greatly from the mean annual temperature of the air in this part of Texas—68° to 69°; and as the normal downward temperature change requires only 50 or 60 feet of depth for 1° of temperature, the formation from which the water comes can not be many hundred feet below the surface. The great volume of the springs shows their chief source to be a formation transmitting water freely. Their freedom from sulphureted hydrogen and other ingredients that would be detected by taste or smell excludes from consideration the higher water horizons of the Edwards limestone as sampled by artesian wells. These various facts leave no reasonable doubt that their water is derived from either the "sweet water" horizon of the Edwards formation or the Travis Peak sands—that is, they have the same source as the purer waters of the artesian wells.

The fact that the flow from the springs is slow in showing sympathetic variation with drought or rainfall is evidence that the reservoir supplying them is of vast extent. * * *

When the wells of the city waterworks are allowed to flow the springs diminish in volume and the river is greatly lowered, being at times almost completely emptied. On the other hand, when the wells are stopped by valves the springs furnish their usual flow.

It is also an interesting fact that although the waters of the fissure springs of the Rio Grande Plain and the gravity springs of the Edwards Plateau, respectively, differ in mode of outflow, they are both derived from the same geologic horizons—the rock sheets of the Edwards beds and Trinity division. The difference in mode of outburst is due to the difference in structural arrangement which these horizons present in the regions of their occurrence.

Size of springs.—The following table gives the best available data as to the lowest, highest, and average discharge of the largest springs in the Balcones fault belt. For the springs on which only a few measurements have been made the figures given may, however, be far from the actual minimum, maximum, and average.

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[31] Hill, R. T., and Vaughan, T. W., Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Tex., with special reference to the occurrence of underground waters: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, pp. 279–312, 1898.

[32] Idem, pp. 312–313.

Discharge, in second-feet, of large springs in the Balcones fault belt of Texas

Springs	Locality	Length of record	Discharge		
			Lowest	Highest	Approximate average
Comal	New Braunfels	15 measurements	267	400+	350
Goodenough	12 miles southeast of Comstock.	5 measurements	181	256	222
San Marcos	San Marcos	6 years and 3 months; also miscellaneous measurements.	75	300+	135
San Felipe	Del Rio	8 measurements	85	150	115
San Antonio	San Antonio	6 years and 8 months; also miscellaneous measurements.	0	200+	90
Las Moras	Brackett	5 measurements	11	60	34
Barton [a]	Austin	17 months, plus 95 measurements	12	139	40

[a] The total discharge of all springs in the vicinity of Austin is much greater.

DETAILED DESCRIPTIONS

Barton Springs and other large springs at Austin, Tex.[33]—There are several groups of large springs in the vicinity of Austin Tex., at the edge of the Edwards Plateau. None of these have as great a discharge as most of the large springs described on subsequent pages, but their aggregate discharge is very large. They are believed to issue from fissures in the fault belt that passes through that locality.

The Barton Springs, which are among the best known and largest of these groups of springs, were measured 20 times by the United States Geological Survey in the period from 1894 to 1917. From April 25, 1917, to September 30, 1918, a gaging station was maintained just below the springs, and a daily record of the flow of the springs during this period was obtained. From October 1, 1918, to September 30, 1922, a total of 75 measurements were made of the stream just below the springs, and whenever these measurements were made the stream above the springs was also measured if it was not dry. Figure 9 shows the flow of the springs and of the stream into which they discharge for the period from April 25, 1917, to September 30, 1921. It is assumed that there was no water in the creek above the springs during the dry period, April 25, 1917, to September 30, 1918, in which the gage was operated. For the period beginning October 1, 1918, the discharge of the springs was obtained by subtracting the flow, if any, above the springs from the flow below the springs. For this later period the diagram was constructed by connecting the points representing measurements, and this part of the diagram is therefore only approximately correct.

[33] Hill, R. T., and Vaughan, T. W., op. cit., pp. 307–308. U. S. Geol. Survey Water-Supply Papers 132, pp. 43–45, 1905; 210, pp. 41–42, 1907; 438, p. 104, 1917; 458, pp. 55–56, 1919; 478, pp. 57–58, 1922; 508, pp. 63–64, 1922; 528, pp. 50–51, 1923; 548, pp. 60–61, 1925.

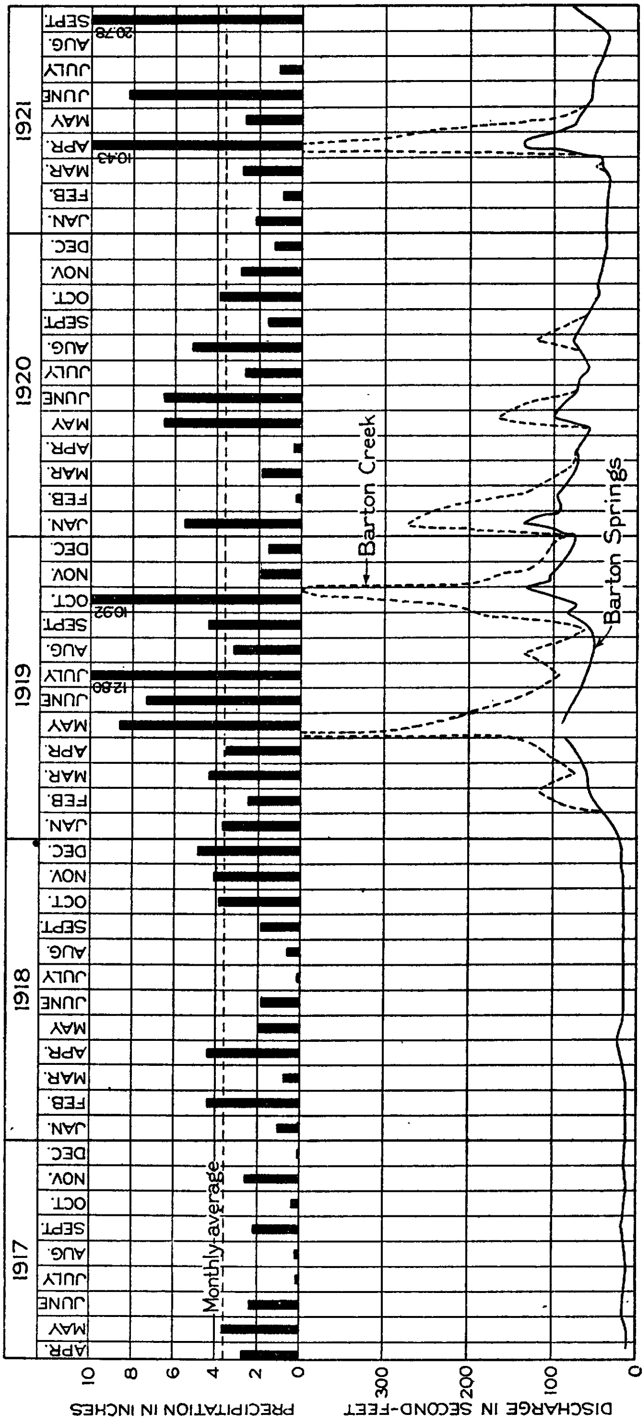

FIGURE 9.—Discharge of Barton Springs, near Austin, Tex., and of Barton Creek below the springs, and monthly precipitation at Austin, April 25, 1917, to September 30, 1921

In the following table are given the measurements made prior to April 25, 1917. In so far as the records show, the discharge from 1894 to 1922, inclusive, has ranged from 12 to 139 second-feet and has averaged about 40 second-feet.

Measured discharge, in second-feet, of Barton Springs, Austin, Tex., 1894–1917

1894	17	December, 1900	33	August, 1910	19
1895	25	June, 1902	19	August 29, 1916	33
March 26, 1898	20	August, 1902	19	August 31, 1916	30
May 3, 1898	30	June, 1903	69	September 2, 1916	30
December 23, 1898	19	June, 1904	43	September 6, 1916	28
December 24, 1898	19	July, 1905	65	February 23, 1917	17
August, 1900	69	June, 1906	24		

The relations shown in Figure 9 are very instructive. In April, 1917, after a very dry year, the springs were discharging only about 15 second-feet. Their flow continued very low during the dry years of 1917 and 1918, being increased only slightly in such relatively rainy months as May, 1917, and April, 1918. The abundant precipitation in the fall of 1918 and in the following winter, however, gradually took effect and increased the discharge notably in the early part of 1919. In the year 1919 the precipitation at Austin was about 32 inches above the normal, and as a result the discharge of the springs averaged close to 80 second-feet and reached a maximum of more than 100 second-feet. In 1920 and 1921 the precipitation was also above the normal and the spring discharge was above the average, although not as high as in 1919. The heavy precipitation in May and October, 1919, January and May, 1920, and April, 1921, produced great and prompt increases in the discharge of the springs. As the discharge measurements at the high stages were generally made several days after the heavy rains, it is impossible to say whether the measurements represent the peak discharge and whether a rise in the springs lagged several days behind the rains that caused it or occurred more promptly. Evidently the summer rains affect the springs less than the rains in late fall, winter, and spring. Thus the rainy months of June and July, 1919, June, 1920, and June, 1921, had no effects comparable with those produced in the similarly wet months of October, January, April and May already cited.

San Marcos Springs.[34]—The San Marcos Springs issue at San Marcos, Tex., from many openings at the foot of a line of bluffs that form the Balcones escarpment in this locality. The water forms a lake nearly half a mile long which gives rise to San Marcos River. According to measurements made by the United States Geological

[34] Hill, R. T., and Vaughan, T. W., op. cit., p. 308, 1898. U. S. Geol. Survey Bull. 140, p. 83, 1896. U. S. Geol. Survey Water-Supply Papers 210, p 44, 1907; 438, pp. 54–56, 1917; 458, pp. 61–64, 1919; 478, pp. 67–68, 1922; 508, pp. 76–79, 1922; 528, pp. 58–60, 1923.

Survey, the discharge of these springs was approximately 150 second-feet on November 14, 1894, and 89 second-feet on December 19, 1895. It was reported when these measurements were made that the discharge fluctuates from year to year and also from season to season, generally increasing from March to about the middle of May, remaining nearly constant from May to September, and then gradually declining. Both of these measurements were made during low stages. It was also reported that the springs did not rise during 1892, 1893, and 1894 but did rise during the spring of 1895. Measurements made by T. U. Taylor gave 150 second-feet in 1900, 153 second-feet in 1903, and 145 second-feet in 1906.

Only miscellaneous measurements were made until about July 1, 1915, when the Geological Survey established a gaging station on San Marcos River at San Marcos. From that time till September, 1921, a continuous record of the discharge was obtained except for a few interruptions.[35] As the river is supplied entirely by these springs during ordinary stages, the measured discharge is believed to represent the flow of the springs except in the brief periods of unusually large discharge, when storm water was probably added to the flow of the springs. During 1915 and January, 1916, a staff gage was used, but in March, 1916, an automatic gage was installed, and this was used during the rest of the period of observation. The many minor fluctuations shown by the record are believed to be due to regulation of the stream from day to day at a dam between the springs and the gage.

During the period of more than six years covered by this record the discharge of the springs fluctuated from 75 to probably 300 second-feet or possibly more, the average being considerably over 100 second-feet. The record shows that the discharge is usually largest in the spring and as a rule remains fairly constant during the rest of the year, with a slight tendency to decline in the fall. During this period the discharge varied greatly from one year to another, as is indicated by figure 10, which by showing only monthly minima eliminates storm waters. In July, 1915, the discharge was great, apparently averaging about 300 second-feet, but it declined rapidly. In 1916 the precipitation was below the normal, and during February and March no rain or snow fell at San Marcos. The discharge of the springs accordingly declined to about 125 second-feet by March, 1916, and remained between 100 and 150 second-feet during the rest of the year. In 1917, which was a very dry year, the discharge declined gradually from about 125 second-feet to about 90 second-feet. During 1918, in which the precipitation was also below the normal, the discharge was generally less than 100 second-

[35] See water-supply papers cited for daily records to Sept. 30, 1921.

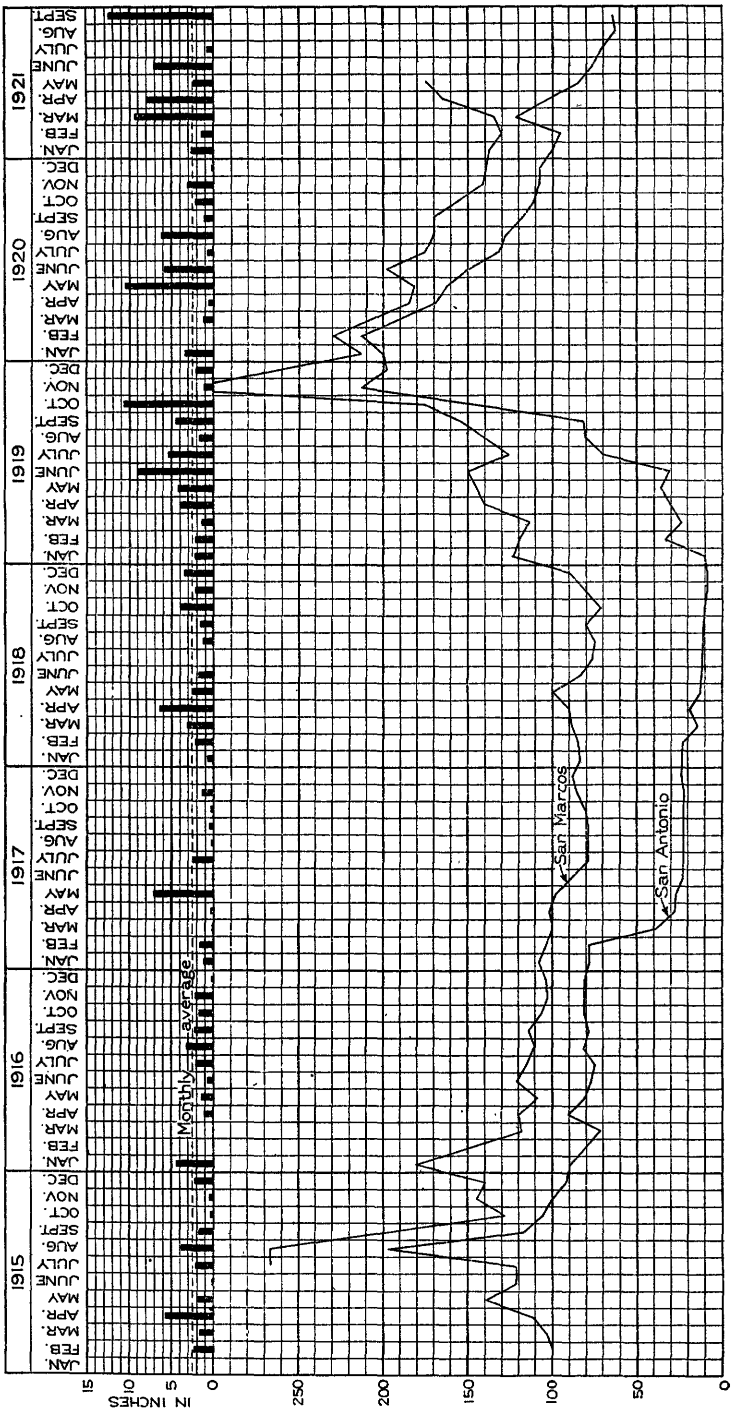

FIGURE 10.—Minimum monthly discharge of San Marcos and San Antonio Springs and monthly precipitation at San Marcos, Tex., February, 1915, to September, 1921. For the months of March and December, 1919, and January, 1920, the precipitation shown is that at San Antonio; no record was obtained for San Marcos in these months

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feet and in the summer went down to about 75 second-feet—the lowest stage reached by the springs during the period. In the winter of 1918–19, however, the springs rose notably. The year 1919 was one of the wettest on record, and the discharge of the springs was maintained at about 125 to 150 second-feet until September, when it increased. In the two months of September and October, 1919, about 15 inches of rain fell at San Marcos, which was about 10 inches more than the normal for these two months. It is not certain just how much of the discharge shown by the record in October and November, 1919, is spring water. As there was no precipitation at San Marcos in February, 1920, it is probable that the discharge of about 250 second-feet in the later part of the month all came from the springs. During the later part of 1919 and the early part of 1920 the springs were at their highest stage since 1915, the discharge being approximately 200 second-feet during much of 1920. In the fall of 1920 the discharge declined to about 150 second-feet. The heavy precipitation in March, April, and June, 1921, increased the discharge notably, but during the summer there was a gradual decline to about 125 second-feet in September, when the record ends.

Comal Springs.[36]—The Comal Springs, which are regarded as the largest springs in Texas, are near New Braunfels, Comal County. The Edwards Plateau ends in an escarpment about 1 mile northwest of New Braunfels, and many large springs issue from fissures in the Cretaceous limestone at the foot of the escarpment. The principal group is about a mile northwest of the town and includes one magnificent spring that was estimated to yield fully 100 second-feet. The water from all the springs in the vicinity flows together to form Comal Lake and Comal River, which empties into Guadalupe River just below the town. The water is very clear and supports much aquatic vegetation. Its temperature has been reported at 75° F.

A measurement of Comal River was made December 20, 1895, by C. C. Babb, of the United States Geological Survey, at a bridge a quarter of a mile from New Braunfels, about 1½ miles below the largest spring at the head of the river, and about 1 mile above the point where Comal River empties into the Guadalupe. The current at this point was very swift. The discharge was found to be 328 second-feet, and this was considered the normal flow of the springs. A number of miscellaneous measurements have been made by the Geological Survey since 1895, with the results shown in the following table. Apparently these springs do not fluctuate as much as some other Texas springs.

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[36] Hill, R. T., and Vaughan, T. W., op. cit., pp. 308–309. U. S. Geol. Survey Bull. 140. p. 84, 1896. Taylor, T. U., The water powers of Texas: U. S. Geol. Survey Water-Supply Paper 105, pp. 32–35. 1904. U. S. Geol. Water-Supply Papers 132, pp. 49–50, 1905; 210, p. 44, 1907; 308, p. 106, 1913; 408, p. 108, 1917.

Discharge, in second-feet, of Comal Springs, New Braunfels, Tex.

December 20, 1895	328	August, 1902	333	1910	299
1898	320	1903 [37]	412	1911	267
1899	310	1904	375	March 26, 1915	407
December 25, 1900	374	1905	390	February 7, 1921	329
March, 1902	343	1906	386	September 7, 1921	316

San Antonio Springs.[38]—The San Antonio Springs, in the vicinity of San Antonio, Tex., rank among the largest and most interesting springs in the State. Like the other springs that have been described, they issue from openings in the Cretaceous limestone. The principal springs of the group are 3 miles north of the city and form San Antonio River, which flows through the heart of the city. At this group of springs was situated one of the most ancient Indian settlements or pueblos in Texas. Between 1718 and 1731 the Spaniards established a military post and five missions in this vicinity. The natives were employed in the cultivation of farms and gardens irrigated by the spring water. The streets of the old town followed the ancient irrigation ditches, or acequias, and some of these streets are still in existence. The San Pedro Springs are about 2 miles southwest of the San Antonio Springs. They give rise to San Pedro Creek, which naturally discharges into San Antonio River below the city.

The San Antonio Springs fluctuate greatly from year to year or through a cycle of years in response to series of dry and wet years (fig. 10, p. 35). It appears that the springs were at a high stage about 1885, but declined from that time until about 1899. In December, 1895, when the first measurement of these springs was made by the Geological Survey, they discharged 49 second-feet, but in parts of 1897, 1898, and 1899 they ceased flowing entirely. This decline was attributed to the flowing artesian wells with large discharge that had been drilled in the vicinity, for it was demonstrated that these wells affected the spring discharge notably. By September, 1900, however, the discharge had increased to 103 second-feet, and since that time it has gone both up and down. The San Pedro Springs fluctuate less than the San Antonio Springs. They are reported to have had a discharge of about 9 second-feet at the times when the San Antonio Springs ceased to flow, though later measurements showed minimum discharges of only 2 or 3 second-feet. The discharge of San Antonio River below the mouth of San Pedro Creek

[37] Measurement made soon after rains. The record does not state whether the discharge is all from the springs or includes storm water.

[38] Hill, R. T., and Vaughan, T. W., op. cit., pp. 309–310. U. S. Geol. Survey Bull. 140, p. 84, 1896. Taylor, T. U., op. cit., pp. 23–25. U. S. Geol. Survey Water-Supply Papers 132, p. 50, 1905; 210, p. 45, 1907; 288, p. 135, 1911; 308, p. 106, 1913; 408, pp. 25–26, 1917; 438, pp. 58–61, 1917; 458, pp. 66–70, 1919; 478, pp. 71–76, 1922; 508, pp. 82–84, 1922; 528, pp. 63–65, 1923; 548, pp. 73–75, 1925.

was 41 second-feet in October, 1901; 65 second-feet in March, 1904; 61 second-feet in June, 1904; 117 second-feet in September, 1905; 54 second-feet in June, 1906; 18 second-feet in September, 1910; and 16 second-feet in November, 1911.

On January 26, 1915, a gaging station was established by the Geological Survey on San Antonio River at the Commerce Street Bridge, in the city, 3 miles below the San Antonio Springs but above the mouth of San Pedro Creek. At this station daily records of discharge were obtained. The station was still in operation at the end of September, 1921. An automatic gage was installed April 18, 1920. The normal flow covered by the record came from the San Antonio Springs, but two tributaries furnished considerable run-off at times of heavy precipiation. Variations in discharge during low stages are believed to be due in part to pumping from deep wells for the city water supply and using flowing wells for irrigation.

In Figure 10 the lowest discharge in each month from February, 1915, to September, 1921, is indicated.[39] Thus the curve eliminates all storm waters and represents somewhat less than the true spring discharge. The figure shows that in this period the springs have undergone very great fluctuations, comparable to those reported in earlier years. It also shows that the fluctuations were closely correlated with those of the San Marcos Spring, though they were more extreme. The fluctuations of both groups of springs were determined by the weather, the high stages coming as a result of wet years and the low stages as a result of dry years. During the period from February, 1915, to September, 1921, the spring discharge ranged from 10 to more than 200 second-feet and averaged approximately 90 second-feet.

Las Moras Springs.[40]—The Las Moras Springs are near Brackett, Tex., about 125 miles west of San Antonio. They break out through the Eagle Ford shale (Upper Cretaceous) in large pools and give rise to Las Moras Creek, which flows into the Rio Grande. Their discharge fluctuates in a manner similar to that of the other large springs. Five measurements made by the Geological Survey are shown below. They averaged 34 second-feet.

Discharge, in second-feet, of Las Moras Springs, near Brackett, Tex.

December 24, 1895	21
June 30, 1899	60
September, 1900	51
September, 1902	11
March 14, 1904	28

[39] For the daily records see the water-supply papers already cited.

[40] Hill, R. T., and Vaughan, T. W., op. cit., pp. 310–311. U. S. Geol. Survey Bull. 140, p. 85, 1896. Taylor, T. U., op. cit., p. 21. U. S. Geol. Survey Water-Supply Paper 132, p. 126, 1905.

San Felipe Springs.[41]—The San Felipe Springs are 2 miles northeast of Del Rio, Tex., and about 5 miles from the Rio Grande. They break out at the edge of the Edwards Plateau in a large pool. The following is a description, by Hill and Vaughan, of the springs about 1898:

From the deep-seated rock at the bottom of the pool the water can be seen welling up in a great column and has the same peculiar greenish-blue color as that of the other streams of this class. No trees surround it; it is alone—a fountain in the desert. The rocks from which it bursts—Fort Worth limestone (Cretaceous)—have the same kind of joints and faults as are found at San Antonio and Austin. The outflow of the pool forms a bold, rushing stream that runs off to the Rio Grande, some 5 miles distant.

The discharge of the San Felipe Springs has been measured several times by the Geological Survey, with the results shown below. These measurements averaged 115 second-feet.

Discharge, in second-feet, of San Felipe Springs, near Del Rio, Tex.

December 24, 1895	99	1902	115
June 29, 1899	113	March, 1904	118
1900	149	October 5, 1921	85
1901	150	October 25, 1922	92

Goodenough Springs.[42]—The Goodenough Springs are in Val Verde County, about 12 miles southeast of Comstock, Tex. They should perhaps be classed with the gravity springs of the Edwards Plateau rather than with the artesian springs of the Balcones fault zone. As described by McCashin, the water issues at the bottom of a canyon about 50 feet deep, from the base of one of the canyon walls, into a lake about half a mile long and 200 feet wide, which discharges into the Rio Grande, about 1 mile away. (Pl. 8.) The water in the lake has a deep-blue appearance. The results of five measurements made by the Geological Survey are given below. These measurements averaged 222 second-feet, apparently making these springs rank next in size to the Comal Springs among the large springs of Texas.

Discharge, in second-feet, of Goodenough Springs, about 12 miles southeast of Comstock, Tex.

October 9, 1921	197	February 18, 1923	240
November 18, 1921	181	July 1, 1923	238
October 27, 1922	256		

[41] Hill, R. T., and Vaughan, T. W., op. cit., p. 311. U. S. Geol. Survey Bull. 140, p. 85, 1896. Taylor, T. U., op. cit., pp. 20–21. U. S. Geol. Survey Water-Supply Paper 548, p. 121, 1925. Unpublished data.

[42] Unpublished data furnished by C. E. Ellsworth and C. E. McCashin. U. S. Geol. Survey Water-Supply Paper 548, p. 121, 1925.

SPRINGS IN THE EDWARDS PLATEAU AND ADJACENT COUNTRY

The following extract is taken from a description of the gravity springs in the canyons of the Edwards Plateau by Hill and Vaughan:[43]

Such springs usually occur in all the streams of the plateau from the Llano to the Pecos. Wherever the stream, in descending the summit of the plateau through the canyons to the Coastal Plain, cuts into a water-bearing bed the water drains out into the stream way. In many cases this forms large, deep pools of clear running water. Of this character are the so-called headwater holes of the various forks of the Llano, Pedernales, Guadalupe, Comal, Medina, Frio, Nueces, and Devils Rivers. The constant waters of all these streams are derived from springs of this character.

* * * * * * *

About 17 miles north of Leakey is the great headwater hole of the Frio, which occurs at the very head of the flat-bottomed canyon, just below where the steep ascent to the summit region begins. These springs break out from cavernous, slightly arenaceous layers in the Edwards limestone, about 300 feet below its summit. Between this point and Leakey there are many large, deep, and long pools of water in the stream way.

From Leakey the east prong of the Frio was ascended in a northeast direction. Fine springs burst out from the Glen Rose and Edwards beds and supply the river with much water. About 12 miles northeast of Leakey there are some springs the tufaceous deposits of which make a number of hemispherical concentric pools, arranged in descending series, resembling very much the illustrations of Gardner's Springs, in the Yellowstone Park. Below Leakey and thence to the mouth of the canyon the Glen Rose beds afford a large number of gravity springs. There are four large ones at Van Pelt's ranch, and at Rio Frio, about 5 miles south of Leakey, many acres of land are irrigated with spring water.

The Guadalupe and its several tributaries derive the abundant water which they contain above Kerrville from various strata in the Glen Rose and Edwards beds. At Kerrville the springs can be seen draining out of the Glen Rose beds. At Spencers Hole the water breaks out of a horizon high up in the Edwards limestone.

The various forks of the Llano, the East Fork of the Nueces, and its principal tributary, Hackberry Creek, reveal the same wealth of gravity-spring water in the upper portion of their flat-bottomed canyons, the water breaking out from various horizons of the Edwards and Glen Rose beds.

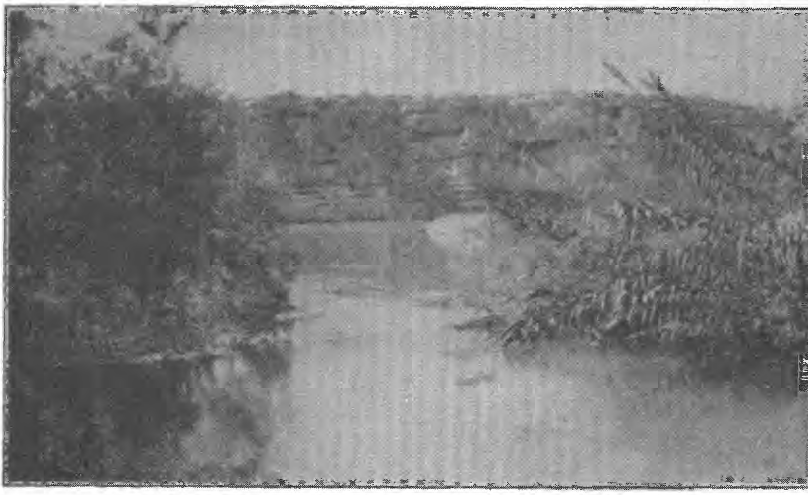
The waters of the Pedernales are largely derived from the basement beds of the Cretaceous. Many fine springs break out in the course of the stream and its tributaries, as seen around and below Fredericksburg.

Devils River as described by Taylor[44] is instructive as an example of the spring-fed streams that flow out of the Edwards Plateau:

Devils River is an illustration of the effect of the large springs of the Edwards Plateau. The river rises in Pecan Spring, about 45 miles north of the mouth and about 60 miles from Del Rio. This spring is on the old mail route from San Antonio to El Paso, which followed the course of the springs on the southern edge of the plateau. The river is only about 50 miles long,

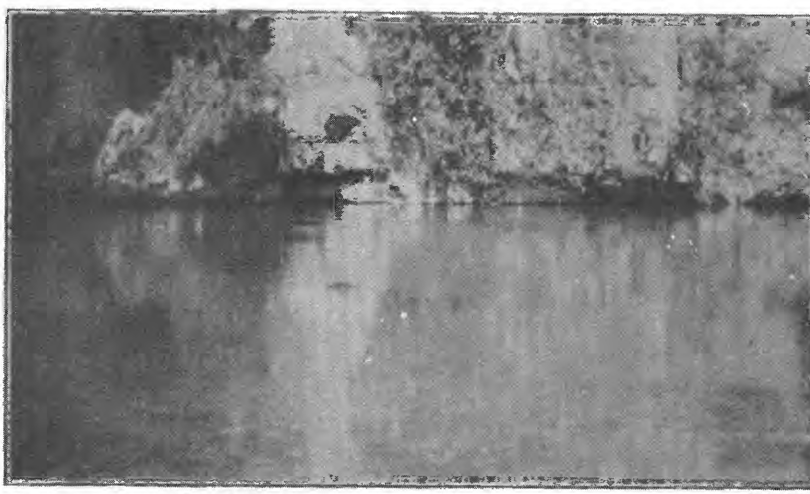
[43] Hill, R. T., and Vaughan, T. W., op. cit., pp. 267–270, 1898.

[44] Taylor, T. U., The water powers of Texas: U. S. Geol. Survey Water-Supply Paper 105, p. 19, 1904.



A. STREAM FROM SPRINGS DISCHARGING INTO RIO GRANDE

Rio Grande in background



B. NEAR VIEW

GOODENOUGH SPRINGS, TEX.

Photographs by C. E. Ellsworth

and yet, of all the rivers of Texas, it has the largest minimum flow. This, as determined by semiweekly measurements, 1900 to 1903, is slightly over 380 second-feet.

Daily records obtained by the Geological Survey of the discharge of Devils River from 1900 to 1913 support in general the description given by Taylor. They show that except for occassional floods the discharge is very uniform but changes gradually from year to year in response to differences in annual precipitation. During this period the minimum discharge was 245 second-feet. In nine different months the minimum discharge was between 245 and 300 second-feet, in 99 months it was between 300 and 500 second-feet, and in 53 months it was more than 500 second-feet.[45]

West of Pecos River, in Pecos and Reeves Counties, there are several large springs, none of which, however, are of the first magnitude. The largest of these springs for which records are available are the Comanche Springs,[46] at Fort Stockton. The water of the Comanche Springs is reported to rise through fissures, presumably in limestone of the Comanche series, and to flow into a pool about 100 feet wide and half a mile long. At these springs was established one of the first Government forts in the region and the oldest irrigation system in trans-Pecos Texas away from the Rio Grande. The following measurements of discharge have been made by the Geological Survey:

Discharge, in second-feet, of Comanche Springs, at Fort Stockton, Tex.

Summer, 1899	66
July 26, 1904	64
August 21, 1919	44
April 8, 1922	46
October 22, 1922	42

Other large springs in Pecos County are the Santa Rosa, Monument, Leon, Escondido, Agua Bonita, and Sulphur Springs.

Toyah Creek[47] rises in large springs in the vicinity of Toyahvale, Reeves County, Tex., about 55 miles west of Fort Stockton. No adequate data are at hand as to the geologic source of the springs. Phantom Lake, in the same vicinity, is described by Beede as due to the collapse of a solution channel in Lower Cretaceous (Comanche) limestone. According to measurements made by Taylor, the discharge of the principal spring was 46 second-feet both on September 5, 1900, and on July 21, 1904. A measurement of San Solomon Springs, in this vicinity, made by the Geological Survey indicated a discharge of 37 second-feet.

[45] U. S. Geol. Survey Water-Supply Paper 358, pp. 616–617, 1915.

[46] Taylor, T. U., op. cit., pp. 13–15. U. S. Geol. Survey Water-Supply Papers 132, pp. 121–122, 1905; 508, p. 134, 1922; 548, p. 121, 1925. Unpublished data.

[47] U. S. Geol. Survey Water-Supply Paper 105, pp. 13, 14. Unpublished data. Beede, J. W., The cycle of subterranean drainage as illustrated in the Bloomington (Ind.) quadrangle: Indiana Acad. Sci. Proc. for 1910, p. 106, 1911.

SPRINGS IN TERTIARY AND QUATERNARY VOLCANIC ROCKS AND ASSOCIATED DEPOSITS IN IDAHO, CALIFORNIA, OREGON, AND WASHINGTON

SPRINGS IN THE SNAKE RIVER BASIN, IDAHO

GENERAL FEATURES

The drainage basin of Snake River is notable for the numerous very large and spectacular springs which it contains (fig. 11). These springs issue chiefly from volcanic rocks or closely related deposits.

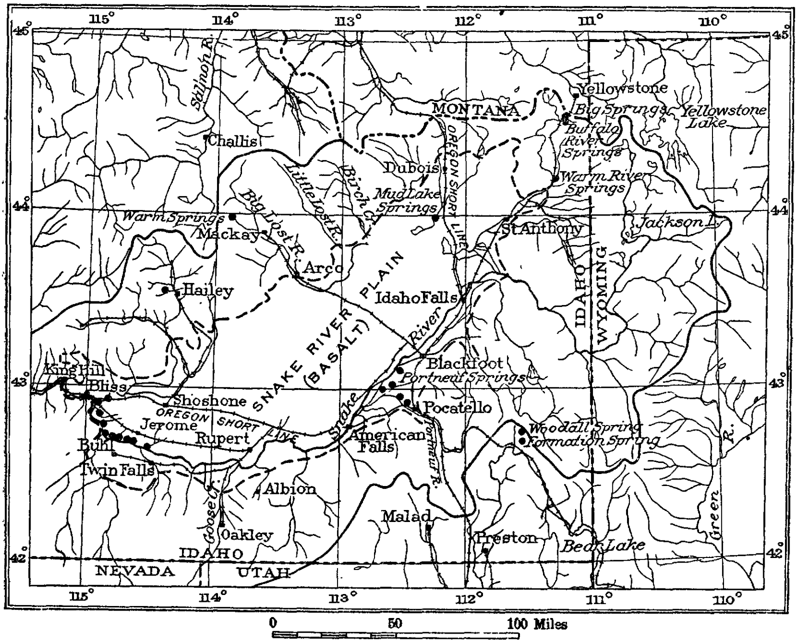


FIGURE 11.—Map of the drainage basin of Snake River above King Hill, Idaho, and adjacent closed basins that contribute ground water to Snake River, showing the general location of the largest springs in the basin. Dashed line shows border of Snake River Plain

The water-bearing volcanic rocks are largely basalt, but they also include jointed obsidian and rhyolite. A large part of the basin of Snake River above King Hill, Idaho, was inundated with basaltic lava during the Tertiary and Quaternary periods, and the lava rock is in many parts so broken or vesicular that it absorbs and transmits water very freely. Hence, much of the water that falls as rain or snow on the extensive lava plain or that flows upon this plain from the numerous streams that rise in the bordering mountains finds its way into the lava rock and percolates to localities at lower levels, where it reappears in large springs. In a stretch of about 40 miles along the canyon of Snake River below Shoshone Falls, where the river has cut through the water-bearing lava beds, an aggregate of more than 5,000 second-feet of ground water is discharged. In this stretch occur eleven springs of the first magnitude and four that yield more than 500 second-feet each. Farther up the river are the Portneuf Springs, which altogether discharge about 1,400 second-feet. There are also many other large springs in other parts of the drainage basin of Snake River or in adjacent country, the largest of which are the Big Springs, at Big Springs, Idaho, the only springs of first magnitude that are known to issue from rhyolite and obsidian.

In the preparation of the section relating to springs in Idaho much help was received from C. G. Paulsen, district engineer, United States Geological Survey, under whose supervision many of the measurements were made; also, from H. T. Stearns and W. G. Hoyt, of the Geological Survey. Thanks are especially due to the officers of the Twin Falls North Side Land & Water Co. for their generosity in making available the large amount of information in their possession.

DETAILED DESCRIPTIONS

SPRINGS ALONG SNAKE RIVER BETWEEN MILNER AND KING HILL [48]

Size of the springs.—Many large springs issue on the north side of Snake River between Milner and King Hill, Idaho, nearly all of them in the canyon below Shoshone Falls or in short tributary canyons (fig. 12). According to the measurements that have been made the total discharge of these springs was 3,885 second-feet in 1902, before any irrigation developments had been made on the north side, and averaged 5,085 second-feet in 1918, after the north-side irrigation project had been developed.

The great volume of water discharged by these springs can perhaps be better appreciated by recalling that in 1916 the aggregate consumption of New York, Chicago, Philadelphia, Cleveland, Boston, and St. Louis, with more than 12 million inhabitants, averaged only 1,769 million gallons a day (2,737 second-feet), or only slightly more than one-half of the yield of these Snake River springs in 1918.[49] In fact, these springs yield enough water to supply all

[48] Information in regard to the yield of these springs was obtained chiefly from the Twin Falls North Side Land & Water Co., which has very generously made all its valuable data available for publication. The information regarding the geology was obtained chiefly from U. S. Geol. Survey Bull. 199, by I. C. Russell, but in part from observations by the writer and by H. T. Stearns. Use was also made of a paper by Lynn Crandall, entitled "The springs of Snake River canyon" (Idaho Irr., Eng., and Agr. Societies Joint Conf. Proc., 1918 and 1919, pp. 146–150); an unpublished paper on the water-power resources of Idaho, prepared by W. G. Hoyt for the U. S. Geol. Survey; the maps of the profile survey of Snake River (U. S. Geol. Survey Water-Supply Paper 347); unpublished maps and diagrams of the Twin Falls North Side Land & Water Co.; and unpublished records of measurements of spring discharge by the U. S. Geol. Survey and the Idaho Power & Light Co. The discharge records for 1902 were obtained by the Twin Falls North Side Land & Water Co. from A. J. Wiley, Boise, Idaho.

[49] The municipal water supply system of the city of New York, Table 7, New York Dept. Water Supply, Gas, and Electricity, 1917.

the cities in the United States of more than 100,000 inhabitants with 120 gallons a day for each inhabitant.

As shown in Figure 12 and in the following table, there are 11 springs or groups of springs that yield more than 100 second-feet,

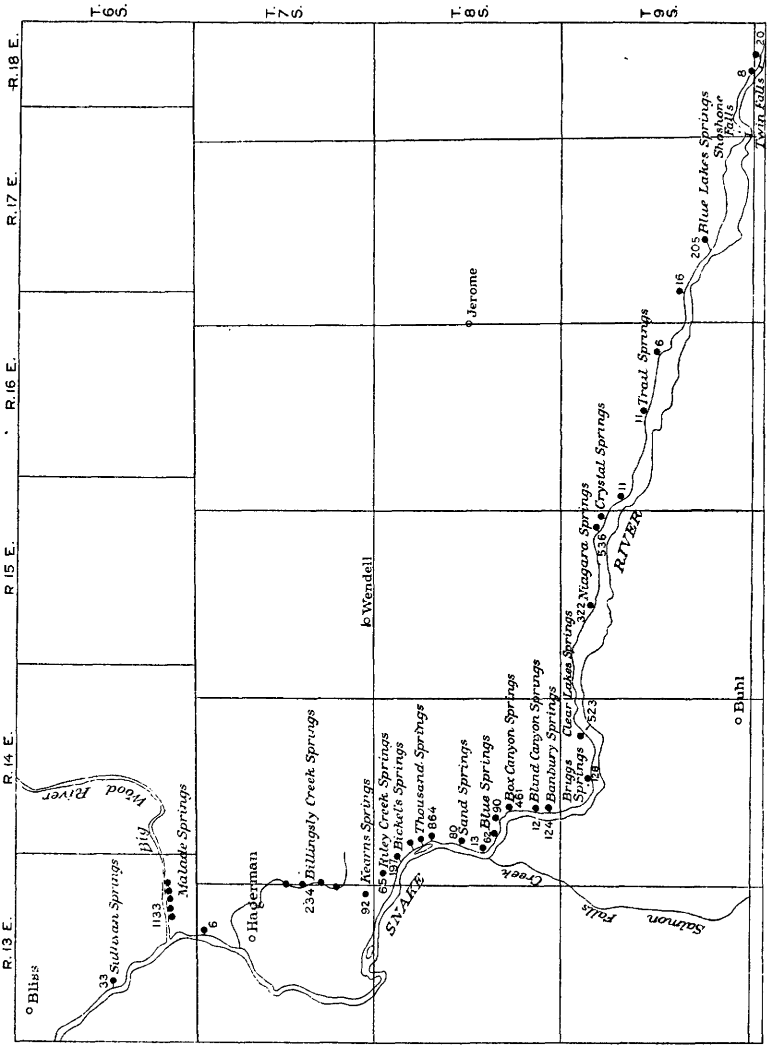


FIGURE 12.—Map showing location and yield of the large springs on Snake River between Milner and King Hill, Idaho. Numbers show yield of spring in second-feet. Most of the yields were measured in September or October, 1917, by Lynn Crandall, L. T. Burdick, and other engineers of the Twin Falls North Side Land & Water Co. Yield of Niagara and Sand Springs is that for September, 1918; of Thousand Springs, for August, 1920

of which 1 yields more than 1,000 second-feet, 3 yield between 500 and 1,000 second-feet, and 7 yield between 100 and 500 second-feet. Moreover here are 5 springs that yield between 50 and 100 second-feet and numerous so-called "small" springs which would be considered huge in most localities.

Discharge, in second-feet, of the large springs along Snake River between Milner and King Hill, Idaho

Spring	Location	Date of measurement	Measured discharge	Remarks
Devils Washbowl	Above Twin Falls	Aug. 20, 1923	19.7	
Devils Corral	½ mile below Twin Falls.	Aug. 6, 1923	8.4	
Blue Lakes	Sec. 28, T. 9 S., R. 17 E.	Sept. 7, 1913	191	Includes diversions.
Do	do	Aug. 6, 1914	199	
Do	do	Sept. 7, 1917		Estimated total 205 second-feet.
Do	do	Oct. 26, 1917	143	Estimated total 220 second-feet.
Do	do	——, 1917	192	Average daily, May to September, 1917.
Do	do	Apr. 26, 1918	136	Estimated total 200 second-feet.
Do	do	Oct. 7, 1918	140	Estimated total 218 second-feet.
Do	do	——, 1918	209	Average daily for 1918.
Do	do	Apr. 19, 1919	124	Estimated total 196 second-feet.
Do	do	July 2, 1919		Estimated total 209 second-feet.
Do	do	July 12, 1919	192	Does not include diverted water.
Do	do	July 27, 1919	202	
Do	do	Sept. 18, 1919		Estimated total, 204 second-feet.
Do	do	Nov. 5, 1919		Estimated total, 185 second-feet.
Do	do	——, 1919	202	Average daily for 1919.
Do	do	Feb. 4, 1920	196	Includes diversions.
Do	do	Apr. 26, 1920	192	Does not include diversions.
Do	do	June 10, 1920	187	Do.
Do	do	July 20, 1920	187	Do.
Do	do	Aug. 8, 1920	194	Do.
Do	do	Sept. 8, 1920	213	Do.
Do	do	——, 1920	197	Average daily for 1920.
Do	do	Mar. 30, 1921	192	Does not include diversions.
Do	do	July 25, 1921	193	Do.
Do	do	Aug. 12, 1921	190	Do.
Do	do	Sept. 19, 1921	200	Do.
Do	do	Apr. 30, 1922	198	
Do	do	Aug. 12, 1922	185	
Do	do	Apr. 14, 1923	209	
Do	do	May 5, 1923	192	
Do	do	July 23, 1923	210	
Spring 2 miles below Blue Lakes.		Oct. 9, 1917	16.5	
Spring 4 miles below Blue Lakes.		do	5.5	
8 springs above Crystal Springs.		do	10.9	
Crystal Springs (6 springs at fish hatchery).	Sec. 12, T. 9 S., R. 15 E.	Oct. 11–12, 1917.	536	
Do	do	Sept. 22, 1919	475	
Niagara	Sec. 10, T. 9 S., R. 15 E.	Sept. 8, 1917	242	Measurement at mouth of spring branch. Includes 14 second-feet of diverted water.
Do	do	Sept. 1, 1918	322	Includes 125 second-feet of diverted water.
Do	do	Sept. 23, 1919	250	Measurement at mouth of spring branch. Includes 10 second-feet diverted.
Do	do	Sept. 16, 1920	252	Measurement at mouth of spring branch. Does not include diversions.
Clear Lakes	Sec. 2, T. 9 S., R. 14 E.	Sept. 13, 1917	523	Includes diversions.
Do	do	——, 1917	504	Average daily for 1917.
Do	do	Apr. 28, 1918	457	
Do	do	Oct. 8, 1918	510	
Do	do	——, 1919	497	Average daily for 1918.
Do	do	Sept. 12, 1919	542	Measurement not considered reliable.
Do	do	Sept. 19, 1919	480	Includes diversions.
Do	do	——, 1919	484	Average daily for 1919.
Do	do	Aug. 5, 1920	479	Does not include diversions.
Briggs	Sec. 3, T. 9 S., R. 14 E.	Sept. 13, 1917	128	Measurement at ford above ranch house.
Do	do	Sept. 30, 1918	130	Do.
Do	do	Sept. 12, 1919	128	Do.
Do	do	Sept. 17, 1920	122	Do.

Discharge, in second-feet, of the large springs along Snake River between Milner and King Hill, Idaho—Continued

Spring	Location	Date of measurement	Measured discharge	Remarks
Banbury	Sec. 33, T. 8 S., R. 14 E.	Sept. 14, 1917	124	Measured at mouth of spring branch. Includes 4 second-feet diverted.
Do	do	Sept. 13, 1919	108	Measured at mouth of spring branch. Includes 3 second-feet diverted.
Do	do	Sept. 17, 1920	117	Measured at mouth of spring branch.
Blind Canyon	Sec. 28, T. 8 S., R. 14 E.	Oct. 13, 1917	11.8	Measurement at mouth of spring branch.
Do	do	Sept. 19, 1919	8.5	Do.
Box Canyon	Secs. 27, 28, T. 8 S., R. 14 E.	Sept. 14, 1917	341	Measured below falls, ¾ mile from Snake River. Flow into canyon between point of measurement and mouth estimated 120 second-feet.
Do	do	Sept. 30, 1918	338	Measured below falls, ¾ mile from Snake River.
Do	do	Sept. 13, 1919	302	Do.
Do	do	Sept. 15, 1920	308	Do.
Do	do	July 13, 1921	356	Do.
Springs at river level, ½ mile below Box Canyon.		Oct. 13, 1917		Estimated 90 second-fe t.
Blue (at outlet)		Oct. 13, 1917	61.5	
Do		Sept. 19, 1919	61.0	
Spring ½ mile below Riverside Ferry.		Oct. 13, 1917	13.2	
Sand	Sec. 17, T. 8 S., R. 14 E.	Sept. 15, 1917	80.4	Includes 14.2 second-feet of diverted water.
Do	do	Apr. 8, 1918	81.9	Includes 3 second-feet of diverted water.
Do	do	Sept. 30, 1918	94.5	Includes 11.2 second-feet of diverted water.
Do	do	Sept. 6, 1919	75.9	Includes 12.2 second-feet of diverted water.
Do	do	Oct. 21, 1919	71.9	Does not include diversions.
Do	do	Oct. 19, 1919	66.6	Measured at head.
Do	do	Sept. 21, 1920	80.7	Includes 8 second-feet of diverted water.
Do	do	July 13, 1921	66.5	Does not include diversions.
Springs below Sand Springs.		Oct. 13, 1917		Estimated 4.2 second-feet.
Thousand	Sec. 8, T. 8 S., R. 14 E.	Sept. 15, 1917	629	Water available for water power, including Snowbank Spring.
Do	do	Sept. 19, 1918	656	Do.
Do	do	Sept. 6, 1919	515	Do.
Do	do	Aug. 9, 1920	864	Includes springs below power plant shown in Figure 14.
Springs ½ mile above Bickel's house.		Sept. 17, 1917	112	Main channel.
Do		July 13, 1921	114	Do.
Springs on Bickel's ranch.		Sept. 17, 1917	69.0	Estimated total, 84.5 second-feet.
Do		July 13, 1921	71.4	Estimated total, 87.6 second-feet.
Riley Creek	Sec. 6, T. 8 S., R. 14 E.	Sept. 17, 1917	62.4	Estimated total, 65.4 second-feet.
Do	do	July 13, 1921	45.9	Not including diversions.
Kearns	Sec. 36, T. 7 S., R. 13 E.	Sept. 17, 1917	91.8	
Billingsley Creek (at State highway bridge)		Sept. 17, 1917	159	Including diversions, 234 second-feet.
Do		Sept. 24, 1919	128	Not including diversions.
Springs between Billingsley Creek and Malade River.		Sept. 17, 1917	6.5	
Malade	Secs. 34-36, T. 6 S., R. 13 E.	Aug. 28, 1913	1,060	
Do	do	Sept. 18, 1917	600	Above upper dam.
Do	do	do	1,133	Including inflow between upper dam and mouth.
Springs between Hagerman and Malade River.		Sept. 24, 1919		Estimated 20.5 second-feet.
Springs between Malade River and Bliss.		Sept. 18, 1917		Estimated 33 second-feet.
Do		Sept. 24, 1919		Estimated 14.8 second-feet.
Woodworth		July 11, 1921	7.7	6½ miles below Hagerman.
Bliss		July 11, 1921	2.0	7 miles below Hagerman.

Fluctuations in discharge.—The flow of these springs is relatively constant, and in this respect they differ notably from most of the large limestone springs. Thus the combined discharge of Blue and Clear Lakes during a period of more than 3½ years, from June 1, 1917, to December 30, 1920, ranged only between about 660 and 760 second-feet (fig. 13), and the combined flow of all the large springs on Snake River between Milner and King Hill from May 1, 1917, to December 30, 1918, ranged only between 4,827 and 5,377 second-feet.[50] Moreover, it is evident from Figure 13 that even these moderate fluctuations are due largely to irrigation, and that prior to irrigation the flow must have been even more nearly constant.

Relation of the springs to the canyon walls.—At most of the springs the water issues at considerable heights above river level. Thus the Blue Lakes lie about 160 feet above river level, Niagara Springs and the springs that feed the Clear Lakes issue at points about 125 feet above river level, most of the water in the Box Canyon issues at the head of the canyon about 200 feet above river level, the Sand Springs issue near the top of the canyon nearly 200 feet above river level, Thousand Springs issue about 30 feet below the rim rock and 195 feet above river level, most of the Bickel Springs issue 140 to 150 feet above river level, and much of the water of the Malade Springs also issues far above the level of Snake River.

[50] Crandall, Lynn, op. cit.

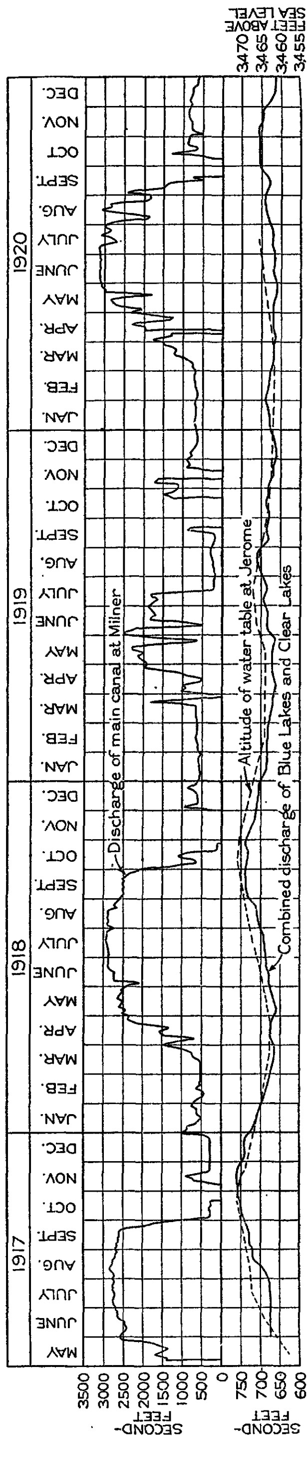


FIGURE 13.—Fluctuations in the discharge of two large springs on Snake River, Idaho (Blue and Clear Lakes), in relation to the quantity of irrigation water placed upon the upland back of these springs and to the fluctuations of the water table at Jerome, Idaho, on the upland. Diagram prepared by the engineering department of the Twin Falls North Side Land & Water Co.

On account of the notable height above the river at which most of these springs issue, together with the great volume of water which they discharge, they are capable of developing a great amount of water power. Large power plants have already been installed at Malade Springs and at Thousand and Sand Springs, and other large

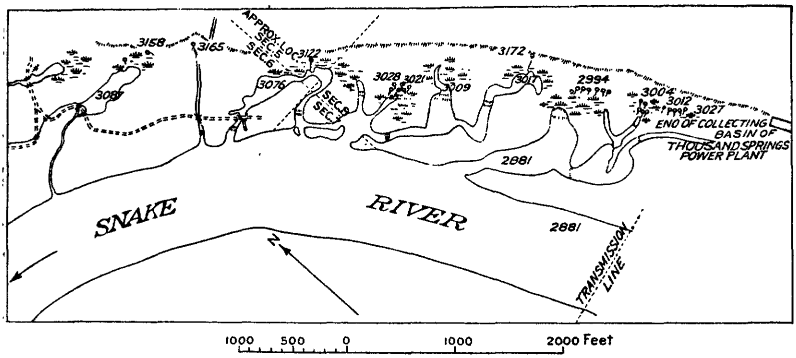


FIGURE 14.—Map of the Bickel Springs, along Snake River, Idaho, including springs that were regarded as belonging to Thousand Springs when the latter were measured August 9, 1920. The numbers show altitudes of springs, spring outlets, and the river, in feet above sea level. Numerous springs occur between the escarpment and the river throughout the area, but only those for which altitudes are given are shown on the map. Surveyed by Warren Oakey, U. S. Geol. Survey, in 1921

plants could be installed at other springs, especially at Clear Lakes, Box Canyon, and Bickel Springs.[51]

The most spectacular feature of these springs is the cataracts which they form, or which they formed before they were harnessed to develop electric energy (pls. 9 and 10). Thousand Springs formerly

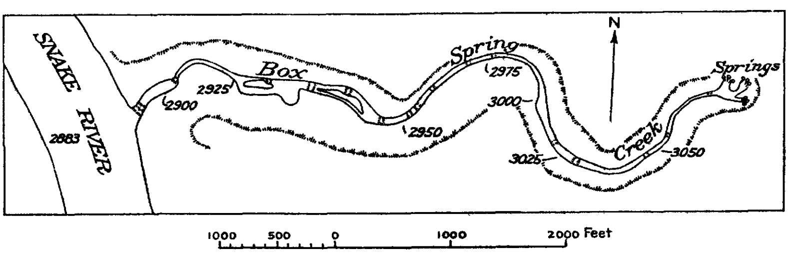
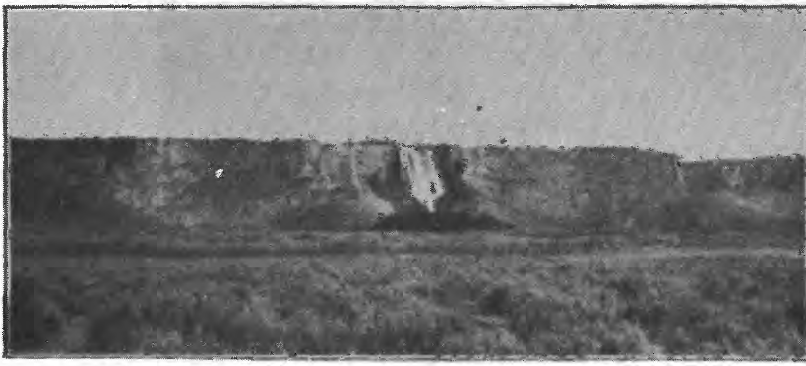


FIGURE 15.—Map of the Box Canyon Springs, along Snake River, Idaho. The numbers show altitudes of the water surface of the creek and river, in feet above sea level. Surveyed by Warren Oakey, U. S. Geol. Survey, in 1921

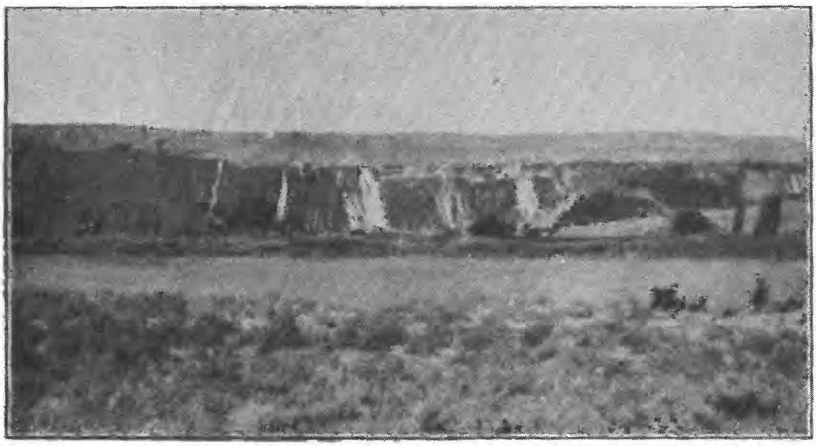
gave rise to a strikingly beautiful waterfall 2,000 feet long and 195 feet high. Snowbank Spring, which discharges 150 to 160 second-feet, is at the east end of the Thousand Springs and is included with them in Figure 12. Formerly its water dashed over the rough talus slope, forming a cataract of great beauty that suggested a snow-

[51] Unpublished manuscript by W. G. Hoyt.



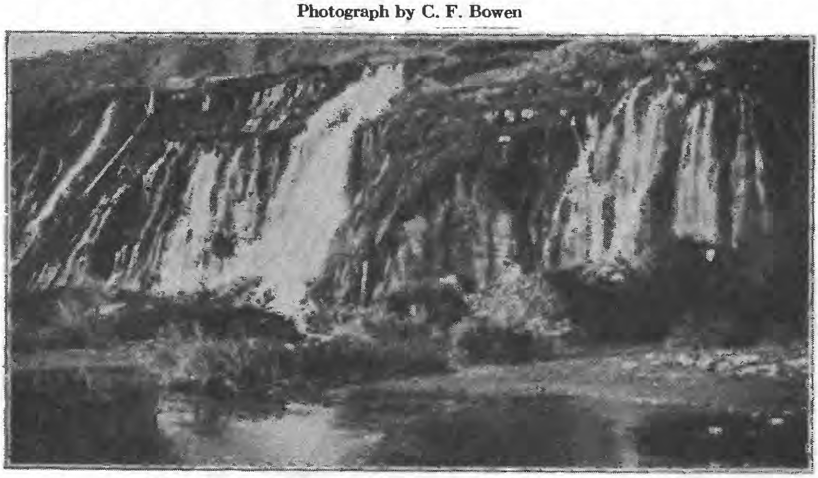
A. SAND SPRING, IDAHO

Photograph by C. F. Bowen



B. THOUSAND SPRINGS, IDAHO, AS SEEN FROM SOUTH SIDE OF SNAKE RIVER

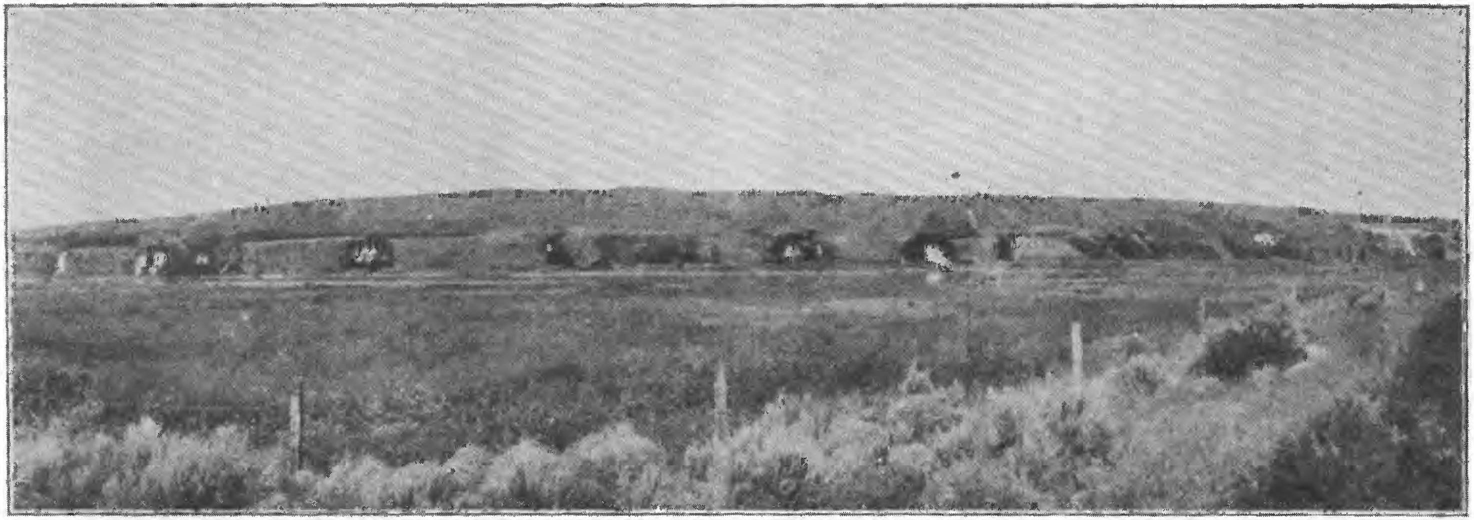
Photograph by C. F. Bowen



C. NEAR VIEW OF A PART OF THOUSAND SPRINGS, IDAHO

Photograph by C. F. Bowen

949296 O—51——5



DISTANT VIEW OF BICKEL SPRINGS AND A PART OF THOUSAND SPRINGS, IDAHO

Photograph by W. G. Hoyt. Compare map of Bickel Springs (fig. 14) bank. The Niagara Springs, which issue from the canyon wall 125 feet above the river level, also form a spectacular cataract. At some of the springs, however, the water emerges from the bedrock behind great talus slopes and can be heard descending through the talus.

Some of the springs, such as Thousand, Bickel, Crystal, and Niagara Springs, issue sheer from the canyon wall or occupy only slight alcoves; others, such as Blue Lakes, the Box Canyon Springs, and Malade Springs, occupy deep, narrow branch canyons, of considerable length, with precipitous walls at their sides and head. These branch canyons were apparently formed by the action of the springs themselves, though the precise process of excavation is difficult to explain.[52]

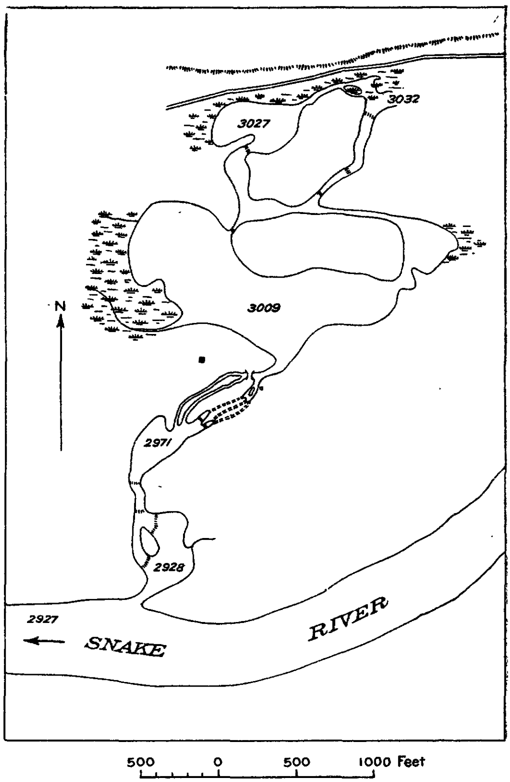


FIGURE 16.—Map of the vicinity of Clear Lakes, along Snake River, Idaho, which are fed by large springs. Numbers show altitude of water surfaces, in feet above sea level. Surveyed by Warren Oakey, U. S. Geol. Survey, in 1921

Some of the relations of the springs to the river and to the canyon wall are illustrated by the sketch maps in Figures 14, 15, and 16, which were furnished by W. G. Hoyt. The Bickel Springs (fig. 14), which are a downstream extension of the Thousand Springs, issue at many points along the side of the canyon. The main group of springs begins about 800 feet downstream from the north end of the collecting basin for the Thousand Springs power plant and extends for nearly a mile. Most of the springs apparently issue at 140 to 150 feet above the river.

The Box Canyon Springs (fig. 15), like the better-known Blue Lake Springs, issue in a precipitous blind canyon that opens into the canyon of Snake River. The uppermost springs issue at the head of the branch canyon, nearly 3,000 feet long, and give rise to a

[52] See explanation by I. C. Russell, op. cit., pp. 127–130.

stream that descends through the canyon to the river. Springs contribute to the flow of the stream throughout its length, but most of the water comes from the upper part of the canyon.

The Clear Lakes (fig. 16) are fed by numerous springs that issue from the lava rock about 125 feet above river level. They cover an area 2,500 feet long and 1,600 feet wide and lie 80 to 100 feet above the river. They discharge into the river through a stream about 2,000 feet long, but some of the water is used for irrigation. Considerable money has been expended in developing a summer resort at this point, and the lakes are well stocked with trout.

Relation of the springs to rock structure.—At the Thousand Springs the water can be seen gushing from innumerable openings in the exposed edge of a scoriaceous zone below a more compact sheet of lava rock. At Sand, Box Canyon, and Blind Canyon Springs the water, according to Russell,[53] comes from a stratum consisting largely of white sand which is overlain by a thick sheet of lava. At most of the springs there is so much talus that the true source of the water can not be observed, but it probably issues chiefly from the large openings in scoriaceous or shattered basalt where the basalt overlies more dense rocks. The fact that most of the springs are confined to rather definite localities and issue at points far above the river indicates that the flow of the ground water to the springs is governed by definite rock structure. The great body of ground water is obviously held up in the very permeable water-bearing rocks by underlying impermeable formations. It may be that the underlying surface which holds up the water is a former land surface and that the principal subterranean streams which supply the springs follow down the valleys of this ancient surface.

Character of the spring water.—The water of these springs does not contain much mineral matter. It is generally very clear, although the water of some of the springs, such as the Blue Lakes, has a beautiful blue color and a slight opalescence due to minute particles in suspension. So far as is known, all the springs have about normal temperatures. The following temperatures were observed[54] in June, 1921: Blue Lakes, at main road crossing, 61.5° F.; Crystal Springs, 58.5° and 59°; Niagara Springs, 56.5° and 57.5°; Sand Springs, 57.5°; Thousand Springs, 58° and 58.5°. The Banbury Springs mentioned in this report should not be confused with the Banbury Hot Springs, which are small springs on the opposite side of the river. At the Crystal Springs the clear, cold water is utilized in a fish hatchery, where great quantities of trout are raised.

Source of the spring water.—The lava plain lying north and northeast of these large springs extends over a few thousands of

[53] Russell, I. C.; op. cit., p. 165.
[54] Unpublished notes by O. E. Meinzer.

square miles and receives the drainage of a few thousand square miles of bordering mountainous country. (See fig. 11.) The great capacity of the broken lava rock to take in surface water is well established and is, moreover, shown by the fact that in the entire stretch of more than 250 miles from the head of Henrys Fork of Snake River to the mouth of Malade River no surface stream of any consequence enters Henrys Fork or the main river from the north. The greater part of this vast lava plain discharges no surface water into the Snake, and a number of rather large streams that drain the mountain area to the north lose themselves on this lava plain. A part of the water that falls on the plain and adjoining mountains is lost by evaporation and transpiration, but a large part percolates into the lava rock and thence to the large springs. Contour maps of the water table in parts of this region show to some extent the course of the ground water, but when the entire region has been studied the limits of the area contributing water to these springs will be better known. It was computed by Crandall [55] that the normal discharge of these springs, exclusive of the part supplied by the irrigation water on the North Side project, amounts to 42 per cent of the discharge of Snake River at American Falls and is equal to the run-off from nearly 7,000 square miles of drainage area as productive as the drainage area of the Snake above that point (fig. 11). These facts are very impressive and show that even with so large an area contributing ground water to these springs the percentage of precipitation that is absorbed and eventually discharged through the springs must be large. It is not improbable that the Snake, in parts of its upper course, itself contributes water to the lava beds, and that in this way water from the east side of the river gets into the rocks on the west side and eventually reaches these springs.

PORTNEUF SPRINGS [56]

About a hundred miles upstream from Shoshone Falls there is a large group of springs which together furnish nearly all the water of Portneuf River, a tributary of the Snake. These springs issue at many points, from gravel or from underlying lava rock, in a belt of bottom lands fully 10 miles long. Their flow is reported to be relatively constant, and together they contribute about 1,400 second-feet to Portneuf River. According to four current-meter measurements and daily gage heights from July 30 to September 17, 1910, the discharge of Portneuf River during this period ranged between 1,440 and 1,700 second-feet.

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[55] Crandall, Lynn, op. cit.

[56] Based on an account by W. B. Heroy in U. S. Geol. Survey Bull. 713 (Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho, by G. R. Mansfield), pp. 127–140, 1920, and on data furnished by H. T. Stearns; also maps by the U. S. Bureau of Reclamation.

The topographic and geologic conditions are evidently such that ground water is contributed in large quantities to this spring area from an extensive region on the southeast, east, and northeast. This catchment area probably includes not only the large undrained area of permeable lava rock in the region about Bancroft, but also Soda Springs Valley and the valley of Bear River above the bend. Apparently Bear River once flowed into the Portneuf and was diverted toward the south by a lava flow that dammed its valley in the vicinity of Alexander. Ground water probably follows the ancient lava-filled valley westward to the large springs along the Portneuf. Large quantities of ground water are doubtless also contributed by Blackfoot River and its tributaries. Moreover, the contour map of the water table along the Snake River, prepared by the United States Bureau of Reclamation, indicates that the Snake may itself make large contributions of ground water to the spring area.

The following notes were furnished by H. T. Stearns on the basis of a few days of field work in this region in September, 1925:

Batise Springs are on the west bank of Portneuf River, near Batise siding of the Oregon Short Line Railroad, about 4 miles northwest of Pocatello. The largest of these springs is pumped to supply the railroad shops in Pocatello. The water issues from basalt at the base of a stream-laid terrace. On September 14, 1925, the springs had a temperature of 57° F. and Portneuf River a temperature of 56° F. The total discharge of the springs on this date, according to a rough measurement, was 42 second-feet. There is one other spring below the section that was measured which would probably bring the total flow of this group to 50 second-feet.

About 1½ miles downstream from Batise Springs there are large springs owned by C. B. Ross and utilized by W. S. Meeder for a fish hatchery. The water issues from basalt at the base of the same gravel terrace as is found at Batise Springs and comes out of two well-defined vents about 10 feet above the river. The water flows northward a quarter of a mile before it enters the river. On September 14, 1925, these springs had a temperature of 54° F. and a discharge of about 75 second-feet.

Between the Fish Hatchery Spring and the mouth of Portneuf River the river receives two large spring-fed tributaries from the north. The upper of these is Ross Fork, which receives most of its water from Clear Creek, and the lower one is Spring Creek. Clear Creek rises in a number of springs on the bottom lands close to the base of the Gibson terrace, which is underlain by volcanic sand and alluvium. No measurements of its flow are recorded, but W. B. Heroy has estimated the flow at 100 to several hundred second-feet.

Large springs occur near the south base of Big Butte, in or near the NW. ¼ sec. 5, T. 4 S., R. 34 E. A large volume of beautifully clear water wells up in a pool about 50 feet in diameter and flows southward through a marsh. The stream from these springs was measured on March 17, 1916, at a point about one-eighth mile below the springs and on that date had a flow of 195 second-feet.[57] The available maps are conflicting as to the outlet of this stream, some indicating that it discharges directly into Snake River and others that it discharges into Clear Creek. According to Heroy, however, this stream is the head of Spring Creek, which discharges into the Portneuf a few miles below the mouth of Ross Fork. Heroy states further that at the bridge on the road from Fort Hall to Tilden Bridge Spring Creek is a deep, swift stream with a flow of perhaps 500 second-feet.

OTHER LARGE SPRINGS

Big Springs.—The Big Springs, at Big Springs post office (fig. 11), issue at the foot of a high cliff which consists of rhyolite and spherulitic obsidian. This cliff marks the edge of an extensive timber-covered plateau with little run-off. Most of the water of these springs issues from several large vents within a distance of less than a quarter of a mile, between the pool shown in Plate 12, *A*, and the cliff immediately to the right of the pool. Water can be seen flowing in large volume from both obsidian and rhyolite. The temperature of the water on July 22, 1921, was 53° F. The combined flow of the springs was 190 second-feet when measured on June 25, 1922, about 1 mile downstream from the springs, and 184 second-feet when measured on August 29, 1922, about 400 feet below the highway bridge shown in the view.[58]

Buffalo River Springs.—Buffalo River heads about 4 miles south of Big Springs, in sec. 21, T. 13 N., R. 44 E., in a group of springs that issue from alluvium at the foot of the rhyolite plateau of the Yellowstone. (Fig. 11.) The stream of remarkably clear water from these springs flows westward about 8 miles and discharges into Henrys Fork of Snake River. In a measurement made September 9, 1903, the flow of Buffalo River near its mouth was 183 second-feet, all of which was doubtless spring water.[59]

Warm River Springs.—Warm River, in northeastern Idaho, is a large constant stream of clear water which is fed by perennial springs that issue chiefly from lava rocks—balsalt, rhyolite, and obsidian. Owing to the permeable character of the rocks, it receives very little direct run-off even at times of heavy rains or melting snow. No perennial stream enters Warm River in its course of about 20 miles, yet where it discharges into Henrys Fork it has a large and remarkably constant flow, most of which is received in a

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[57] U. S. Geol. Survey Water-Supply Paper 443, p. 181, 1919.

[58] The first measurement was made by L. L. Bryan and the second by Berkley Johnson, both of the U. S. Geological Survey.

[59] U. S. Geol. Survey Water-Supply Paper 100, p. 461, 1904.

stretch of about 6 miles in the lower part of its course, in T. 10 N., R. 44 E. (fig. 11).

In the 35 months from 1912 to 1918 for which complete records have been obtained,[60] the flow of Warm River has ranged from 192 to 900 second-feet; in 25 of these months the flow has been between 200 and 400 second-feet, and in 18 months between 200 and 300 second-feet. From August 10, 1913, to April 9, 1914, the discharge ranged between 201 and 309 second-feet; from April 9 to May 4 it increased from 309 to 725 second-feet; from May 4 to June 23 it declined to 291 second-feet; and from June 23, 1914, to March 22, 1915 (when the record was interrupted), it ranged between 297 and 215 second-feet.

Mud Lake Springs.[61]—Mud Lake, which lies in a closed basin in northeastern Idaho, between Snake River and the sink of Big Lost River (fig. 11), is largely fed by a group of springs in a marshy area of several square miles near Hamer, Idaho, in T. 7 N., Rs. 35 and 36 E. The water issues from basalt and from overlying gravel and sand. These springs came into existence about 35 years ago as a result of irrigation on the so-called Egin Bench, about 20 miles to the east. The flow has increased from year to year but has a seasonal variation determined by the height of the water level in Mud Lake. In 1923 the aggregate flow of this entire group of springs averaged about 67 second-feet and probably reached a maximum of about 100 second-feet.

Birch Creek Springs.—Birch Creek, which terminates in the same sink as Big Lost River (fig. 11), also obtains most of its water from a group of springs and consequently has a remarkably constant flow. During the entire year from April 1, 1921, to March 31, 1922, its discharge a few miles below the springs ranged only between 68 and 95 second-feet, virtually all of which was doubtless derived from the springs.[62]

Warm Springs in Big Lost River valley.—One of the tributaries of Big Lost River is Warm Creek, which is formed by the Upper and Lower Warm Springs, in T. 8 N., R. 22 E. These springs issue from crevices in limestone that crops out below a rhyolite formation at the edge of the valley and from gravel that is doubtless fed by water from the limestone. The water of these springs, like that of Warm River, is not warm, as the name would imply, but has a temperature that is normal for the region or only slightly above normal.

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[60] U. S. Geol. Survey Water-Supply Papers 332, p. 316, 1916; 362, p. 51, 1917; 413, p. 49, 1918; 483, p. 71, 1922.

[61] Stearns, H. T., and Bryan, L. L., Preliminary report on the geology and water resources of the Mud Lake basin, Idaho: U. S. Geol. Survey Water-Supply Paper 560, pp. 118, 119, pl. 2, 1925; also unpublished records of the U. S. Geol. Survey.

[62] Daily records are published in U. S. Geol. Survey Water-Supply Papers 533, pp. 96–98, 1925; 553, pp. 102–103, 1926. Earlier records are published in Water-Supply Papers 312, pp. 307, 308, 1915, and 332, pp. 338, 339, 1916.

According to measurements made by Lynn Crandall[63] in 1920, the combined flow of these two springs was 55 second-feet on June 3, 65 second-feet on July 30, 65 second-feet on August 26, 58 second-feet on October 15, and 54 second-feet on December 1.

SPRINGS IN THE SACRAMENTO RIVER BASIN, CALIFORNIA

GENERAL FEATURES

The great region of Tertiary basalt and related volcanic rocks in which are found the large springs of Idaho extends into northern Nevada and northeastern California and includes most of Oregon and fully half of Washington. Large springs similar to those in Idaho occur in other parts of this region, especially in California and Oregon (fig. 17), and some of these rival the large springs on Snake River. In the following table are given summary data on the discharge of the largest springs in the Sacramento River basin, California:

Discharge, in second-feet, of large springs in Sacramento River basin, Calif.

Spring	Length of record	Discharge		
		Lowest	Highest	Approximate average
Fall River (entire group)	19 months in 1912 and 1913	1,240	1,590	1,400
Springs at head of Fall River	2 measurements	385	399	392
Springs at head of West Fork of Tule River (including Bear Lake).	1 measurement			376
Spring Creek	do			161
Rising River	44 months, corrected for estimated overflow of Hat Creek.	275	300—	300—
Great (on Hat Creek)	2 years	[a] 111	[a] 257	[a] 170
Burney Creek	20 months			150
Crystal Lake	1 or more measurements	114	[b] 160	
Dotta (in Big Meadows)	9 measurements	50	122	90
Salmon Creek	1 measurement and estimate.			50
Sisson (head of Sacramento River)	1 measurement			27
Springs northeast of Dotta	Estimated			20

[a] Complete information is lacking as to possible diversions or contributions between the springs and the gaging station.
[b] Identity not certain.

As a rule the large springs in this region fluctuate much less than the large limestone springs of Florida, Georgia, Alabama, Missouri, Arkansas, and Texas. In this respect they have a distinct family resemblance to the large springs in the volcanic rocks of Idaho. Thus the Fall River Springs have an average discharge of about 1,400 second-feet and in a period of more than two years their discharge did not depart from this average more than 10 or 15 per cent.

[63] Crandall, Lynn, Report on water distribution and ground-water investigations in Lost River valley, Idaho, during the season of 1920 (unpublished manuscript).

In compiling the data on these springs much valuable help was given by H. D. McGlashan, district engineer in the United States

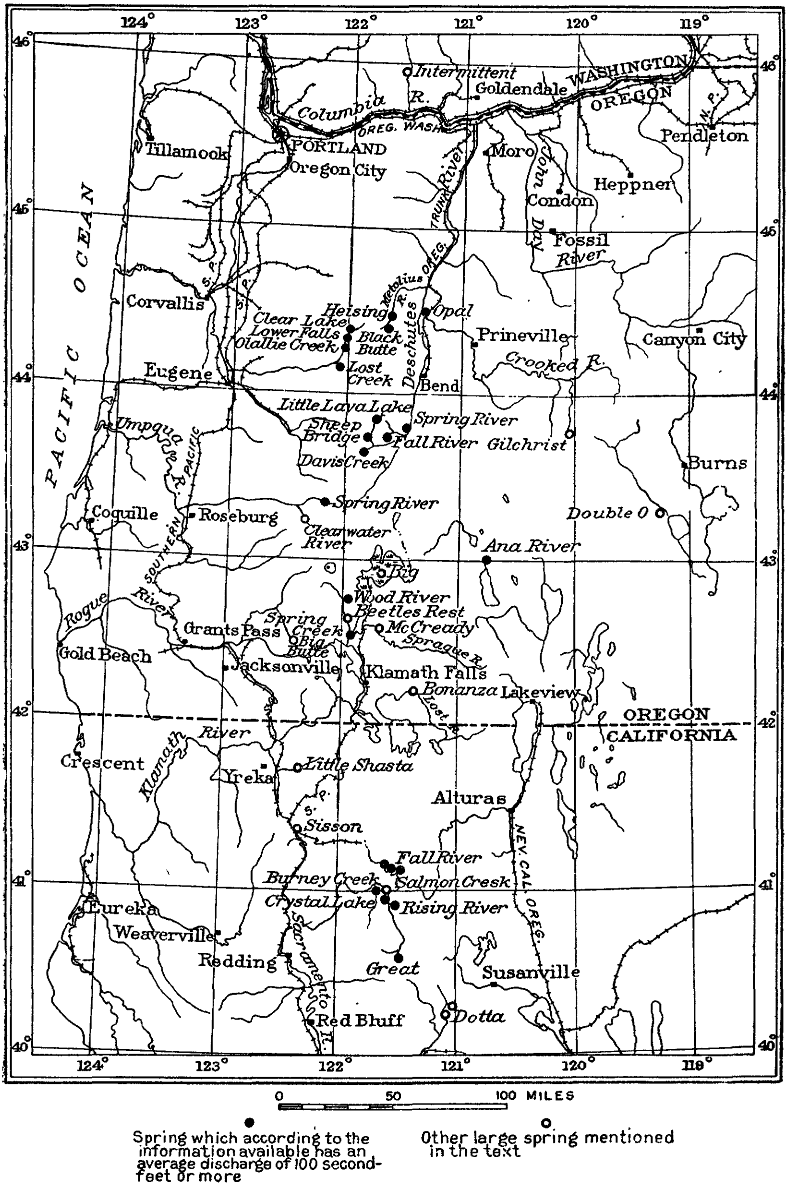
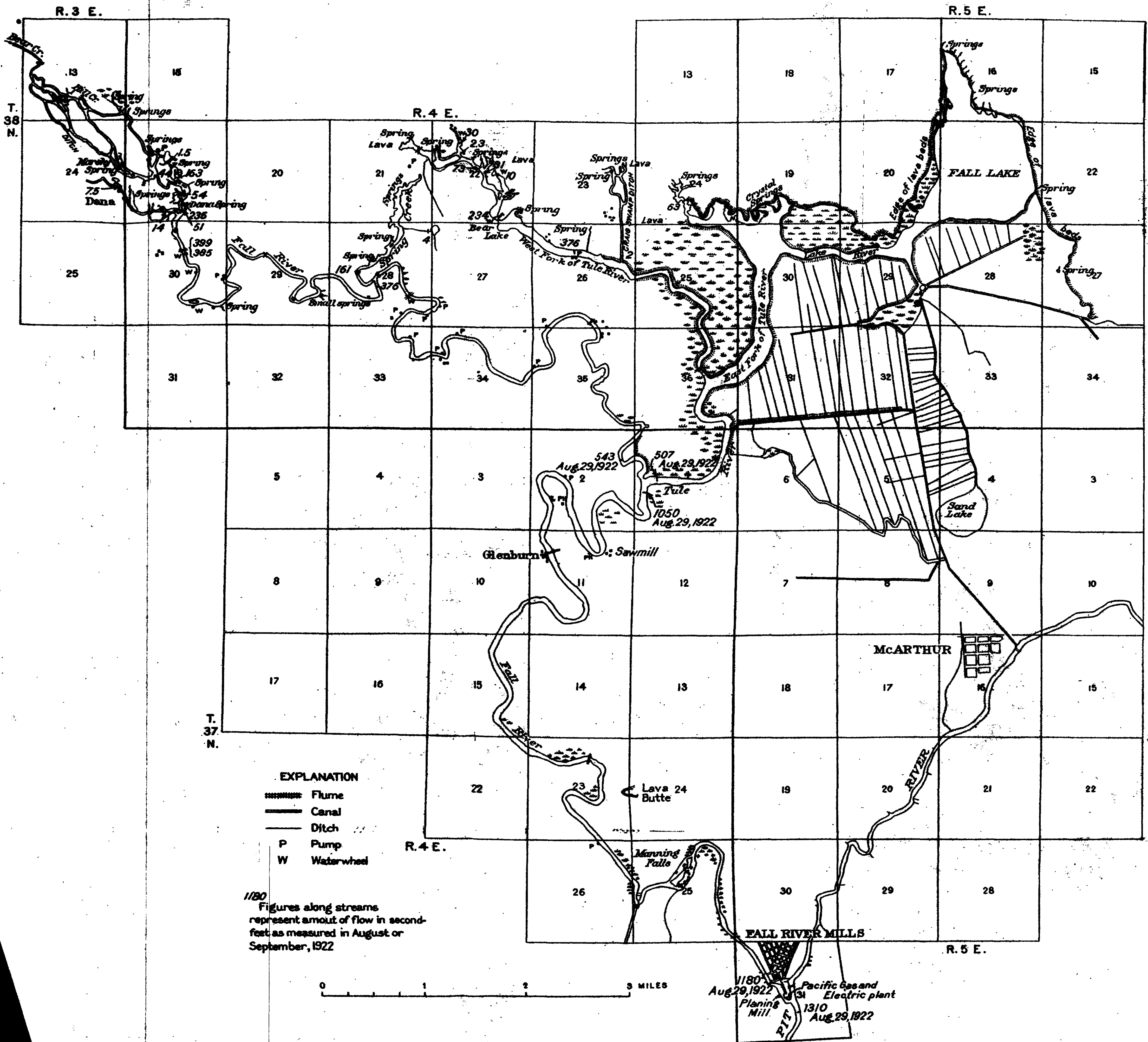


Figure 17.—Map showing large springs in the region of volcanic rocks in California, Oregon, and Washington

Geological Survey, and by R. C. Briggs, also of the Geological Survey. Especial thanks are due to E. A. Garland, of the Pacific



MAP OF A PART OF THE DRAINAGE BASIN OF FALL RIVER, CALIF., SHOWING LARGE SPRINGS THAT FORM THE RIVER

Compiled from map furnished by E. A. Garland, of Pacific Gas & Electric Co.

Gas & Electric Co., for his interest and hearty cooperation and for the large amount of specific information which he furnished in regard to the Fall River and other springs.

DETAILED DESCRIPTIONS

Fall River Springs.—Nearly all the water of Fall River comes from numerous large springs that occur in a belt about 10 miles long at the south margin of an extensive lava field, as is shown in Plate 11. Only a small amount of direct run-off is supplied by Bear River, which flows into Fall River from the northwest.

Early measurements made near the mouth of Fall River, at Fall River Mills, represent substantially the discharge of the springs,[64] but the measurements in the last few years doubtless represent less than the total spring flow because of the many small diversions that were made for irrigation, chiefly by pumping from the river or its tributaries.

The following measurements were made by the Geological Survey [65] near the mouth of the river prior to 1912: September 9, 1901, 1,447 second-feet; September 16, 1902, 1,543 second-feet; September 11, 1903, 1,510 second-feet; September 23, 1910, 1,470 second-feet. A gaging station was established on this river near its mouth on January 19, 1912, and daily records of discharge were obtained until August 10, 1913, when the station was discontinued.[66] During this period of nearly 19 months the discharge ranged between 1,240 and 1,590 second-feet and averaged about 1,400 second-feet, indicating that the springs do not fluctuate greatly. Owing to the deficient precipitation in 1912 and 1913 there was a general decline in discharge during the period, but with some fluctuations.

In addition to the record for 1912–13, daily gage-height records are now available for Fall River near Glenburn, just below the junction of Fall River and Tule River, from January 4 to September 30, 1922, and daily-discharge records for Fall River at Fall River Mills from May 14, 1921, to September 30, 1922. These later records show considerably less water than the earlier ones, owing partly to general conditions of low run-off and partly to diversions for irrigation. The gravity diversions from Tule River have a capacity of about 500 second-feet, and there are numerous small pumping plants along the banks of Fall River. Beginning October 23, 1922, the Pacific Gas & Electric Co. has diverted practically the entire flow of Fall River at a point about 1½ miles northwest of Fall River Mills as shown on Plate 11.

[64] U. S. Geol. Survey Water-Supply Papers 177, p. 133, 1906; 298, p. 16, 1912.
[65] U. S. Geol. Survey Water-Supply Paper 298, p. 387, 1912.
[66] U. S. Geol. Survey Water-Supply Paper 361, pp. 274–276, 1916.

On Plate 11 is given the flow of the principal springs and spring branches as measured by E. A. Garland, of the Pacific Gas & Electric Co., in August and September, 1922.

The springs at the head of Fall River, chiefly in sec. 19, T. 38 N., R. 4 E., had a combined flow of 385 second-feet, according to one measurement, and 399 second-feet, according to another. This flow was contributed chiefly by five groups of springs, which yielded 163, 44, 54, 51, and 14 second-feet. The springs that yielded 163 second-feet are regarded as forming the head of Fall River. The flow of 44 second-feet was measured on Mallard Creek and included the discharge of Beaver Creek.

Spring Creek, which is a spring-fed body of water a little over a mile long, in secs. 21 and 28, T. 38 N., R. 4 E., had a discharge of 161 second-feet. The springs at the head of Fall River and those on Spring Creek together produced a flow, as measured in sec. 2, T. 37 N., R. 4 E., of 543 second-feet, or approximately half of the total discharge of Fall River.

The springs at the head of the East Fork of Tule River, chiefly in sec. 22, T. 38 N., R. 4 E., had a total flow of 234 second-feet, as measured just above Bear Lake. All this flow except 81 second-feet came from springs in the SE. ¼ sec. 22. One of the most remarkable features is Bear Lake, or the "Big Hole," into which the springs at the head of East Fork discharge. Here the stream widens to about a quarter of a mile and, according to soundings that have been made, reaches a depth of about 100 feet. There is no visible inflow, but at the time of measurement the quantity of water increased by 142 second-feet, as shown by the flow of 234 second-feet just above the hole and a flow of 376 second-feet less than a mile below it.

On August 29, 1922, the discharge of Fall River was 1,180 second-feet near its mouth, 1,050 second-feet at a point just below the mouth of Tule River, and 543 second-feet just above the mouth of the Tule. Hence the discharge of Tule River at its mouth was computed to be 507 second-feet. As the flow a short distance below Bear Lake about this time was 376 second-feet, it follows that about 131 second-feet entered Tule River from other sources, chiefly on the East Fork. The largest of these East Fork sources is a group of six springs that form Squaw Creek. Fall Lake, which discharges into the East Fork through Lake River, lies at the edge of the lava and has an area of more than 1 square mile. It has no large visible inflow, but apparently it furnishes a considerable part of the flow of the East Fork.

Any decision as to the number of springs that supply Fall River is obviously an arbitrary matter. The entire group are comparable to the Portneuf Springs, in Idaho, in regard to size and dispersion.

They are somewhat larger and scattered over a much larger area than the Malade Springs. In comparison to the springs on Snake River it would be logical to consider that there are on Fall River three springs of first magnitude and many smaller ones. The three springs of first magnitude are those at the head of Fall River, which discharge about 385 to 399 second-feet; those at the head of the West Fork of Tule River, including Bear Lake, which discharge about 376 second-feet; and Spring Creek, which discharges about 161 second-feet. Springs of second magnitude are Squaw Creek and Fall Lake.

The source of the large quantity of water discharged by these springs is discussed as follows by Waring:[67]

> The springs rise at the southern border of an extensive lava field. They are locally considered to be the outlet of Tule or Rhett Lake at the northern border of the State. The water may, however, be furnished by the precipitation on the lava fields to the north, for much the greater part of the water that falls on these fields sinks into the crevices and caverns in the rock, and there is very little direct surface run-off. A continual flow of 1,500 second-feet would be furnished by an annual run-off of about 1 second-foot per square mile, or 13½ inches a year in depth of water over an area of 1,500 square miles. This is not excessive for the region under consideration, where the annual precipitation is 20 to 40 inches, for it represents both a normal run-off and the amount that usually sinks into the ground. There is an area of nearly 2,000 square miles of lava beds extending from northeast to northwest of Dana, and the topography of this area is favorable to the theory that it may furnish the water of the springs at the head of Fall River. The temperature of the water, 53° to 54° F., indicates that it is of essentially surface origin.

Rising River Springs.—Rising River is a spring-fed stream about 2 miles long which flows into Hat Creek from the east at a point just south of Cassel, Calif. It is described by Waring[68] as follows:

> The water rises in the lake and adjacent meadow, and its flow, which in July, 1910, was approximately 250 second-feet, is nearly uniform. * * * The source of the springs of Rising River is not so evident as is that of the springs on Burney Creek, but the water is locally (and plausibly) believed to be derived from Butte or Lost Creek, which flows from Lake Bidwell or Butte Lake to Porcupine Flat, where it sinks about 12 miles southeast of the head of Rising River.

A gaging station was maintained on Rising River by the Geological Survey from August 15, 1911, to September 30, 1913, at the highway bridge in sec. 8, T. 35 N., R. 4 E., about 1¼ miles south of Cassell and about half a mile above the mouth of the stream. The daily records show a discharge during this period of 25½ months that ranged between 275 and 490 second-feet and averaged about 370 second-feet.[69]

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[67] Waring, G. A., Springs of California: U. S. Geol. Survey Water-Supply Paper 338, pp. 326–327, 1915.

[68] Idem, p. 328.

[69] U. S. Geol. Survey Water-Supply Papers 298, pp. 115–117, 387, 1912; 361, pp. 282–283, 1916.

The following additional information has been furnished by R. C. Briggs, of the Geological Survey:

Daily discharge records of Rising River are now available from March 10, 1921, to September 30, 1922. They indicate the normal flow of the springs to be between 275 and 300 second-feet. Hat Creek carries considerable snow run-off in addition to its spring flow. At high stages it overflows into Rising River about 3 miles above the junction of the two streams, and it is very probable that discharges of Rising River in excess of 300 second-feet are due to the excess Hat Creek water.

Great Springs.—The Great Springs are near the middle of the east boundary of T. 32 N., R. 4 E., on the west side of Hat Creek, at the base of a southward-facing fault scarp in basalt that crosses the creek at this point. Apparently the ground water, percolating in the direction of the creek, is forced to the surface when it reaches the fault. The springs are described by Waring[70] as follows:

Great Springs issue for a distance of about a quarter of a mile along the southwestern bank of Hat Creek, at the northern base of the mountain mass that culminates in Lassen Peak. The greater part of the headwaters of Hat Creek is conducted westward by a power ditch, so that in July, 1910, there was a flow of only about 2 second-feet in its channel above Great Springs. Below the springs the stream was 50 to 75 feet wide and 2 or 3 feet deep and a float measurement indicated a discharge of 280 second-feet.* * * The water of Lost Creek normally sinks at a distance of about a mile above its junction with Hat Creek, or about 2½ miles in a direct line west of south from Great Springs, and it is locally believed that the creek reappears in the springs. The position of the springs at the northern base of slopes that rise to Lassen Peak and the fact that the water issues almost entirely on that bank of Hat Creek which is toward the mountains indicate, however, that the supply comes mainly from melting snow on the slopes to the south, though a part is perhaps derived from Lost Creek. The yield of the springs is said to vary somewhat with the season, a characteristic of springs that have near-by sources of supply.

A gaging station was maintained by the Geological Survey from August 15, 1911, to August 9, 1913, on Hat Creek at the Hawkins ranch, in sec. 5, T. 33 N., R. 5 E., about 8 miles downstream from the Great Springs. During this period the discharge at the Hawkins ranch ranged between 111 and 257 second-feet and averaged about 170 second-feet. Some water was diverted between the spring and the gaging station, and there is no information as to whether there was any flow from above the Great Springs or from springs or tributary streams between the Great Springs and the gaging station. The daily records, however, indicate relatively uniform discharge such as is characteristic of springs rather than of streams that carry much direct run-off. Measurements made by E. A. Garland on November 1, 1923, showed that the flow of Hat Creek was 9 second-feet above the springs and 134 second-feet at the road crossing about

[70] Waring, G. A., op. cit., pp. 328–329.

half a mile below the springs, indicating a flow of 125 second-feet from the springs. On July 19, 1926, when the springs were visited by the writer, the temperature of the water was 44° F.

Burney Creek Springs.—The Burney Creek Springs are described by Waring[71] as follows:

During periods of normal and low water Burney Creek sinks at a point 5 or 6 miles north of Burney Valley (Burney post office), but a short distance above Burney Falls, which are about 1½ miles above the junction of the creek with Pit River, the water issues again as large springs. The greater part of the water goes over the falls, but a large part also issues from fissures in the lava cliff, some distance below the crest of the falls. Although the water is apparently only that of the creek, which sinks below Burney Valley and rises again farther down the course of the stream, it may be properly considered to issue as a spring, whose chief difference from similar springs in the lava region is that the immediate source of the water seems to be evident.

Burney Creek was measured below the falls by the Geological Survey on September 9, 1903, when it had a discharge of 210 second-feet, and on September 25, 1910, when it had a discharge of 246 second-feet. On September 25, 1910, the flow of the creek 1½ miles above Burney post office and several miles above the falls was only 20 second-feet, indicating that the flow of 246 second-feet below the falls came chiefly from the springs. However, complete information as to the source of the water that was measured is not available.

The following information was recently furnished by Mr. Briggs:

Discharge records for Burney Creek at Burney Falls, near Burney, are now available from April 1, 1921, to November 24, 1922. They show that the increased flow in Burney Creek at the falls, due to spring flow, is about 150 second-feet. This record is very reliable and would seem to indicate a considerable falling off from the flow as measured in 1903 and 1910.

Crystal Lake Springs.—Crystal Lake is a spring-fed body of water about 1½ miles northwest of Cassel, Calif., and is tributary to Hat Creek. It is described by Mr. Briggs as follows.

Crystal Lake is in sec. 31, T. 36 N., R. 4 E., about 1½ miles northwest of Cassel, and is tributary to Hat Creek between the power houses of the Pacific Gas & Electric Co. known as Hat Creek No. 1 and Hat Creek No. 2. On March 14, 1922, the outlet of this lake was measured by G. C. Green, of the Pacific Gas & Electric Co., and was found to carry 114 second-feet, entirely spring flow. F. G. Baum, consulting engineer, upon whose property this spring is located, states that it ordinarily flows about 160 second-feet. The water can be seen bubbling up in several places around the margin of the lake, which is about one-fourth mile in diameter and similar to Rising River Lake. It narrows to a stream about 200 feet wide at the outlet, where the water falls several feet over a lava dike. A few hundred yards beyond these falls the stream joins Hat Creek. Mr. Baum has a small hydroelectric plant at

[71] Idem, p. 328.

the falls. He stated that there are two other springs tributary to Hat Creek near Crystal Lake, flowing between 20 and 25 second-feet each.

Dotta Spring and other springs in the Big Meadows.—There are many large springs in the lava-covered areas in the upper parts of the Feather River basin. Perhaps the largest are found in the Big Meadows, near Plattville, Calif., and are tributary to the North Fork of the Feather. Large springs at the northeast edge of the Big Meadows, about 5 miles northeast of Plattville, are described by Waring[72] as follows:

> The water issues from basaltic lava, a few feet above the meadow level, in an area of willows and quaking aspens about 100 yards in diameter. After flowing down over riffles of coarse lava gravel it forms a sluggish stream 100 yards or more in width in the meadow. A very rough float measurement at the riffles indicates that the discharge is about 56 second-feet. The water is cold (46° F.) and of very good quality.

It is not evident from the descriptions whether these are the same as Dotta Spring which is described by McGlashan and Henshaw[73] as being about 3 miles east of Plattville, near the mouth of the Big Meadows. The following nine measurements of Dotta Spring, made by the Geological Survey in 1902, 1905, and 1906, give an average discharge of about 90 second-feet.

Discharge, in second-feet, of Dotta Spring, Calif.

September 9, 1902	109	October 18, 1905	90
June 12, 1905	50	December 14, 1905	77
July 3, 1905	99	June 21, 1906	122
August 5, 1905	84	August 3, 1906	94
September 2, 1905	89		

Springs that were estimated to yield perhaps 20 second-feet issue from a small basalt escarpment about 2 miles east of Rock Creek and not very far from Dotta Spring.[74]

Salmon Creek Springs.—Salmon Creek, also called Fish Creek, is tributary to Pit River on the left bank, about 12 miles below Fall River Mills, in the SW. ¼ sec. 2, T. 36 N., R. 3 E. It is only about half a mile long and has its source in two large springs which plunge out of the lava rock at the foot of the bench land bordering the Pit. The noise of the rushing water can be heard for about half a mile. A measurement of this creek by the Pacific Gas & Electric Co. in August, 1921, showed a flow of about 50 second-feet.

Sisson Springs.—About 1 mile north of Sisson, at the western base of Mount Shasta, are two springs, about 400 feet apart, which yielded about 27 second-feet when examined by Waring. These springs

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[72] Op. cit., pp. 330–331.

[73] Hoyt, J. C., McGlashan, H. D., and Henshaw, F. F., Water resources of California, Part I, Stream measurements in Sacramento River basin: U. S. Geol. Survey Water-Supply Paper 298, pp. 21–22, 1912.

[74] Waring, G. A., op. cit., p. 331.

form the largest tributary at the head of Sacramento River and are sometimes referred to as its source.[75]

SPRINGS IN THE DESCHUTES RIVER BASIN, OREGON

GENERAL FEATURES

The Deschutes River basin, Oreg., is underlain mainly by very permeable volcanic rocks. The river is fed chiefly by large perennial

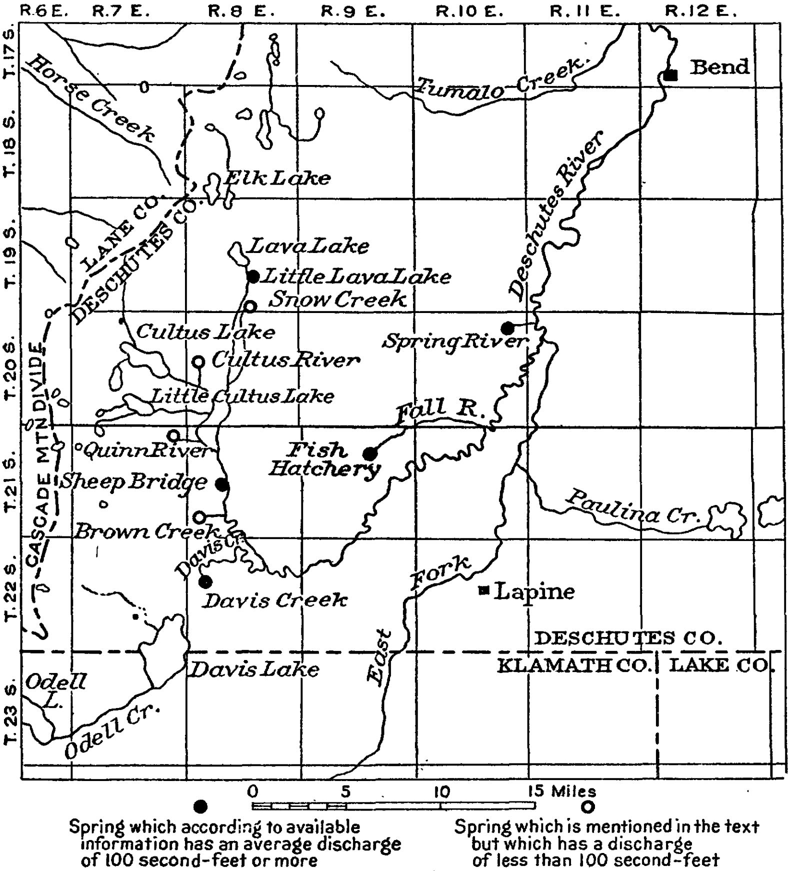


FIGURE 18.—Map showing large springs in upper part of Deschutes River basin, Oreg.

springs, and, according to Henshaw and Dean,[76] its flow is more nearly uniform than that of any river in the United States comparable with it in size, its maximum discharge being only about six times its minimum. Evidence of this uniformity of flow is presented by the low grass-grown banks between which the river runs. The fol-

[75] Idem, p. 332.

[76] Henshaw, F. F., and Dean, H. J., Surface water supply of Oregon, 1878–1910: U. S. Geol. Survey Water-Supply Paper 370, pp. 304–305, 1915.

lowing description of the large springs tributary to the Deschutes is compiled almost entirely from manuscript furnished by F. F. Henshaw and H. T. Stearns. Many of the discharge measurements in the Deschutes and Klamath River basins were made by E. O. Hokanson, of the United States Geological Survey. The available discharge data of the principal springs and spring-fed streams in the basin are summarized in the following table. (See also figs. 17 and 18.)

Discharge, in second-feet, of large springs in the Deschutes River basin, Oregon

Spring	Length of record	Discharge		
		Lowest	Highest	Approximate average
Little Lava Lake (measured 6 miles below lake).	Summers of 3 years	52	213	95
Snow Creek (measured near mouth of creek).	do			28
Cultus River (measured less than 1 mile below springs at head of river).	Summers of 2 years and part of another.	43	70	54
Quinn River (measured just below springs at head of river.	do	8	36	18
Sheep Bridge:				
Springs at the bridge	Estimated			300
Entire group	7 measurements	278	348	323
Brown Creek	Summers of 2 years	23	47	35
Davis Creek:				
Springs near head of creek	1 measurement			201
Creek near mouth	1 year and 9 miscellaneous measurements.	174	258(?)	223
Fall River:				
Fish hatchery (at head of Fall River)	1 measurement			103
River about 6 miles below fish hatchery	10 measurements	113	126	119
Spring River:				
Springs at head of river	Estimated			125
River near mouth	22 measurements	142	299	197
Black Butte	2 measurements	100	122	111
Roaring Creek	do	45	54	50
Heising	do	90	128	109
Metolius River (water practically all derived from large springs):				
At Allingham ranger station, 3 miles below head of river.	2 years	307	566	376
At Allen's ranch, 10 miles below head of river.	2 measurements	1,040	1,100	
At Riggs or Montgomery ranches, below practically all tributaries.	4 years	1,330		
Gilchrist	Estimated			25
Opal	do			130
Crooked River (all springs in 15-mile stretch above mouth, including Opal Spring).	Summers of 7 years	970(?)		1,000+

In the Deschutes River basin, as in other regions, the magnitude assigned to many of the springs depends on their grouping, which is based on insufficient information, and would necessarily be somewhat arbitrary even if complete information were available. The springs in this basin that are tentatively recognized as springs of the first magnitude are the Opal, Sheep Bridge, Davis Creek, Spring River, Fall River, Little Lava Lake, Black Butte, and Heising.

DETAILED DESCRIPTIONS

Large springs near head of Deschutes River.—The stream that is considered to form the head of Deschutes River rises in Little Lava

A. BIG SPRINGS, IDAHO

Photograph by O. E. Meinzer

B. BIG SPRINGS, NEAR LEWISTOWN, MONT.

Photograph by W. R. Calvert

A. VIEW LOOKING DOWN ON WOOD RIVER SPRING, OREG., FROM THE FAULT ESCARPMENT

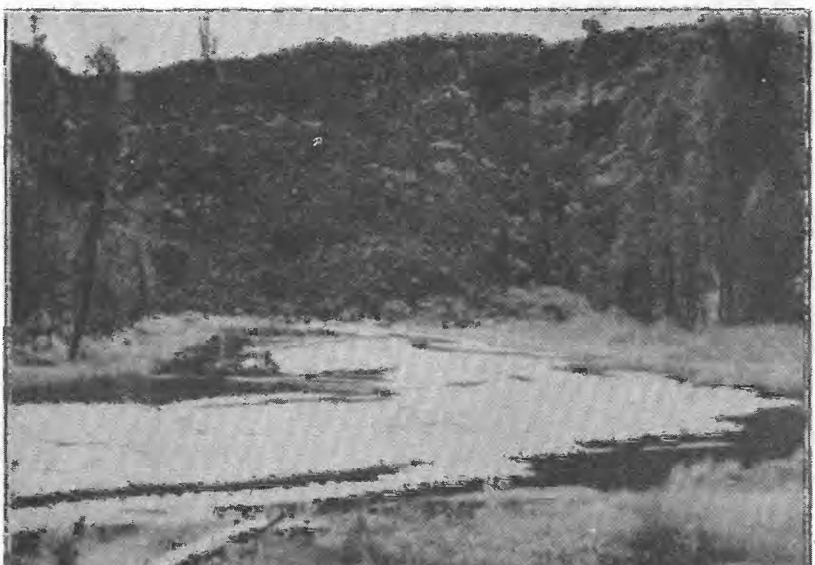
Photograph by H. T. Stearns

B. NORTHERN VENT OF SHEEP BRIDGE SPRING, OREG.

Discharge about 45 second-feet. Photograph by H. T. Stearns

A. HEAD OF BROWN CREEK, OREG.

View from footbridge in sec. 30, T. 21 S., R. 8 E. Photograph by H. T. Stearns

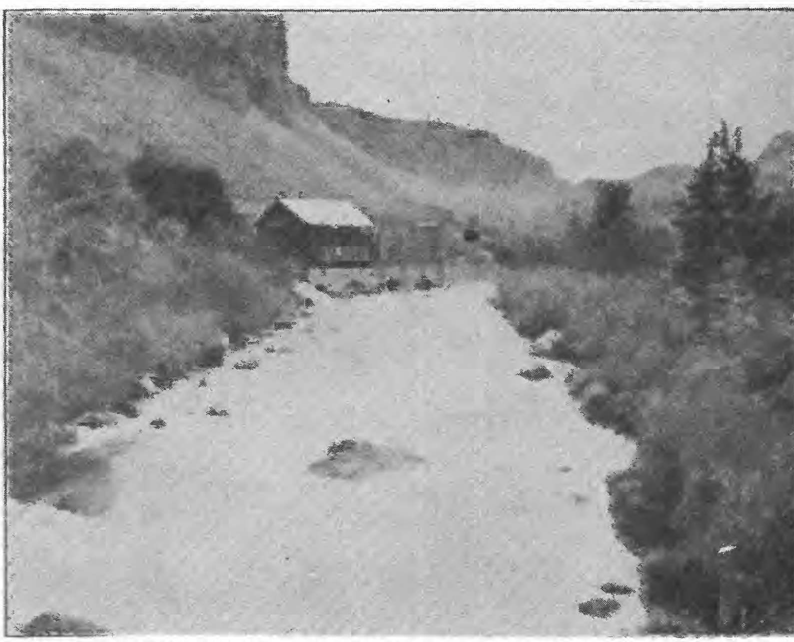


B. SPRING ISSUING FROM RECENT LAVA AT HEAD OF DAVIS CREEK, OREG.

In sec. 18, T. 22 S., R. 8 E. Discharge about 50 second-feet. Photograph by H. T. Stearns

A. CROOKED RIVER 12 MILES ABOVE OPAL SPRING, OREG.

At this point the stream is nearly dry

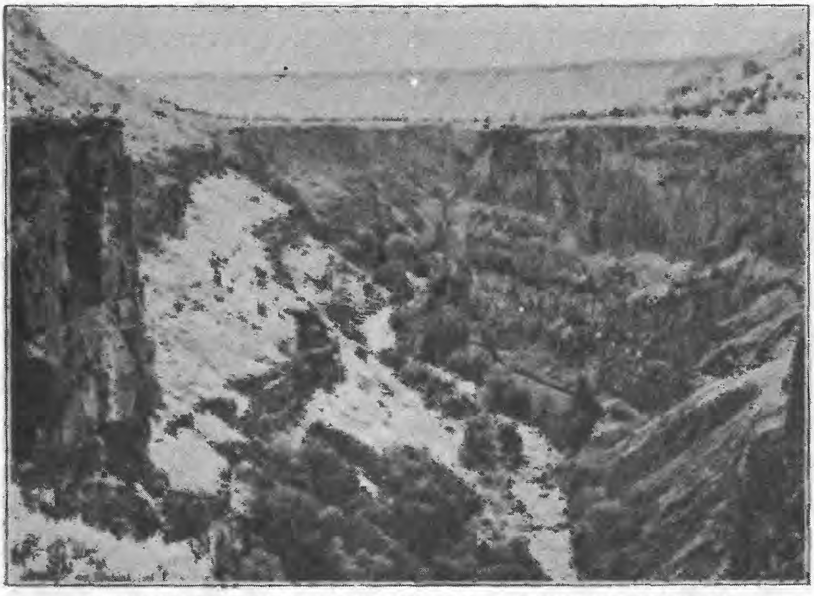


B. CROOKED RIVER 4½ MILES BELOW OPAL SPRING, OREG.

Here the stream flows more than 1,000 second-feet, practically all derived from large springs. Photographs *A* and *B* taken on same day by W. W. Laxton

A. NEAR VIEW

Discharge about 130 second-feet

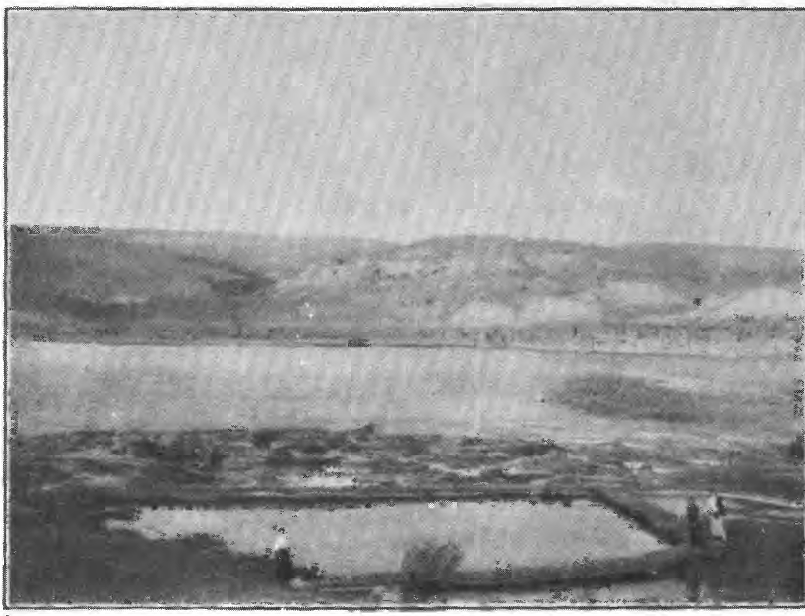


B. CROOKED RIVER CANYON, SHOWING POSITION OF SPRING (X)

The cliff back of the spring consists of alternating beds of permeable basalt and relatively impermeable sedimentary rocks. In most of the canyon this series of beds is covered by more recent lava, which forms the cliff on the opposite side of the river

OPAL SPRING, OREG.

Photographs by H. T. Stearns



A. GENERAL VIEW

Missouri River in background

B. NEAR VIEW

GIANT SPRINGS, NEAR GREAT FALLS, MONT.

Photographs by C. A. Fisher

Lake, in sec. 22, T. 19 S., R. 8 E. Willamette meridian. This lake, which, according to the United States Forest Service map, has an area of about 80 acres, has almost no surface inflow and is, therefore, in a sense a large spring pool. North of this spring is an area of exceedingly permeable lava and volcanic débris which has rather copious precipitation but virtually no surface drainage. The water that falls in this area is largely absorbed and percolates underground to Little Lava Lake or other large springs. In its underground course the water appears in a number of lakes that have no considerable surface intake and no surface discharge. One of these is Lava Lake, which discharges into Little Lava Lake underground. (See fig. 18.)

In the following table is given a summary of the discharge of Deschutes River recorded at a gaging station maintained by the United States Geological Survey at a point about 6 miles below Little Lava Lake, above Snow Creek and other important tributaries. The record, which covers the period from June, 1922, to September, 1924, shows a discharge ranging from 52 to 213 second-feet and averaging 95 second-feet. There is an annual fluctuation in discharge, the high stage of the stream lagging a few months behind the period of maximum annual intake from rains and melting snow. The high stage of the river occurs during the summer with a peak coming about the middle of August. Thereafter the flow decreases gradually until April or early in May, thus giving a minimum at a time when most streams are approaching their highest stage of the year.

Snow Creek, the uppermost tributary of Deschutes River, rises in large springs about 2 miles south of Little Lava Lake (fig. 18). It flows nearly parallel to the Deschutes and not more than half a mile from it for almost its entire course of about 6 miles. Its flow, as measured during the summer months of 1922–1924 at a gaging station near its mouth, is nearly constant and averages about 28 second-feet. (See table below.) It showed little reduction even during the low-water year of 1924, when the discharge of Little Lava Lake decreased notably.

Cultus River has its source in a group of large springs in the SW. ¼ sec. 17, T. 20 S., R. 8 E. (fig. 18). Its discharge, as measured at a gaging station less than a mile below the springs (see table below), has ranged from 43 to 70 second-feet and averaged 54 second-feet. The Cultus River Springs have a variation in discharge similar in character to that of Little Lava Lake but much less in degree.

Quinn River is a short stream that is supplied entirely by springs at its head (fig. 18). The discharge as measured during the summer months of 1922–1924 at a gaging station just below the springs has ranged from 8 to 36 second-feet and averaged 18.4 second-feet. Thus these springs fluctuate in discharge even more than Little Lava Lake.

Monthly mean discharge, in second-feet, of large springs at or near the head of Deschutes River

Month	Deschutes River about 6 miles below Little Lava Lake and above mouth of Snow Creek	Snow Creek	Cultus River less than a mile below its source	Quinn River
1922				
June	135	29.4	----------	[a] 20
July	145	27.7	----------	[a] 26
August	204	26.9	----------	[a] 27
September	187	27.9	----------	[a] 24
October	140	28.5	70	[a] 20
1923				
June	107	29	67	29.4
July	115	29	69	35.2
August	151	29	69	34.7
September	175	29	65	32.5
October	152	29	62	31.5
1924				
June	56.9	28	46	14.5
July	67.0	27	46	13.6
August	72.6	27	46	12.2
September	62.1	27	46	9.2

[a] Estimated.

Sheep Bridge Springs.—A large flow of water enters Deschutes River from springs about 4 miles below the mouth of Quinn River, in the vicinity of the so-called Sheep Bridge, near the southeast corner of sec. 20, T. 21 S., R. 8 E. (fig. 18). The water issues from coarse glacial morainal débris, but its true source is undoubtedly the underlying basalt. On November 19, 1925, the discharge of the north vent was found to be 38 second-feet (pl. 13, *B*) and that of the south vent 51 second-feet. On August 30 the water from the north vent had a temperature of 40° F., and that from the south vent 38° F. On the east side of the river there are several springs with a temperature of 45° F. and a combined discharge of about 50 second-feet. This temperature, which is a few degrees above the normal for the region, suggests that the water of the east-side springs comes largely from the leaky Crane Prairie Reservoir. This reservoir lies less than 2 miles upstream from the springs. During the summer its water is much warmer than normal ground water. The total spring inflow to the river at the bridge is about 300 second-feet. A group of small springs issues from a thick pumice bed overlying basalt in the SE. ¼ sec. 12, T. 22 S., R. 7 E., the largest of which flows about 15 second-feet. On August 30, 1925, the water of these springs had a temperature of 39° F. Conditions are such that the discharge of the entire group can not be measured directly, but it can be estimated closely by deducting from the flow of Deschutes River at Graft's bridge (about 4 miles below the Sheep Bridge Springs), the flow of the river at the Crane Prairie Dam (about 1½ miles above the Sheep Bridge Springs), and the flow of Brown Creek, which discharges into the Deschutes between the Sheep Bridge and Graft's bridge. The flow of the entire group of Sheep Bridge Springs, according to estimates based on seven sets of measurements recorded in the following table, has ranged from 278 to 348 second-feet and averaged 323 second-feet.

Discharge, in second-feet, at three stations near Sheep Bridge Springs, and discharge of the springs computed from these records

Date	Deschutes River at Crane Prairie Dam	Brown Creek	Deschutes River at Graft's bridge	Other inflow between Crane Prairie Dam and Graft's bridge, chiefly that of Sheep Bridge Springs (calculated)
July 28, 1915	160	[a] 40	478	278
July 10, 1922	348	40	732	344
July 17, 1922	337	41	699	321
Aug. 3, 1922	337	42	717	338
Nov. 21, 1922	196	42	581	343
Apr. 25, 1923	4	[a] 39	334	291
Sept. 17, 1923	20	44	412	348

[a] Estimated.

Brown Creek Springs.—Brown Creek, which is less than 3 miles long, flows into the Deschutes from the west. It has its source in a group of springs that issue from crevices in basalt in sec. 30, T. 21 S., R. 8 E. Its measured discharge has ranged from 23 to 47 second-feet and averaged 39.3 second-feet in 1923 and 30.4 second-feet in 1924. On August 30, 1925, the spring water had a temperature of 40° F. (See pl. 14 *A*.)

Davis Creek Springs.—Davis Creek, which is about 6 miles long, rises in a group of springs, the largest of which are in sec. 18, T. 22 S., R. 8 E. The springs issue from the base and margin of a bed of barren Recent andesitic lava which in this vicinity fills the ancient valley and has formed the dam that has given rise to Davis Lake. (Fig. 18.) These springs are obviously the outlet of an underground stream that rises in Davis Lake. At several places on the lava it is possible to hear the water running underground, and cold air issues from crevices in the lava at these places. On November 17, 1925 (see pl. 14, *B*), the largest single spring was discharging 54 second-feet and had a temperature of 48° F. This temperature, which is about 10° F. above the average of springs in this region, furnishes additional evidence that the springs are fed from Davis Lake, in which the water warms up somewhat during the summer. Other large springs enter Davis Creek from the north. On November 20 a spring entering about 1 mile below the head discharged 79 second-feet and another a little farther downstream discharged 68 second-feet. The temperature of both was 39° F. Davis Creek, although generally receiving all its water from springs, fluctuates considerably in discharge. It has been measured from time to time at Graft's ranch, near its mouth, in sec. 10, T. 22 S., R. 8 E., but only during 1924 has a complete year of record been obtained. In that year its minimum flow was 174 second-feet and its average flow 203 second-feet.

Discharge, in second-feet, of Davis Creek at Graft's ranch

November 2, 1914	208	August 4, 1922	255	April 25, 1923	228
July 1, 1922	258	August 24, 1922	251	June 25, 1923	249
July 13, 1922	250	November 21, 1922	237	September 24, 1923	224

Fall River.—Fall River heads in a group of springs, the largest of which issue from crevices in basalt in sec. 10, T. 21 S., R. 9 E. The discharge from the two vents at the fish hatchery on November 21, 1925, was found to be 103 second-feet. The temperature of the spring water on that date was 41° F. The operator of the hatchery stated that the temperature does not vary throughout the year.

From the head springs Fall River flows about 6 miles in a fairly straight course to the falls and thence tortuously to its mouth. Measurements made of this stream near the falls from time to time since 1912 indicate a remarkable regularity of discharge. In the 10 measurements recorded below the flow ranged only from 113 to 126 second-feet and averaged 119 second-feet.

Discharge, in second-feet, of Fall River near Pringle Falls

July 19, 1912	118	May 28, 1922	126
June 7, 1913	122	August 7, 1922	114
August 23, 1913	113	August 30, 1922	113
June 1, 1914	121	November 20, 1922	117
May 5, 1922	126	June 26, 1923	120

Spring River.—Spring River rises in a group of springs in the SW. ¼ sec. 1, T. 20 S., R. 10 E., about 1 mile west of Deschutes River and 10 feet above the river. All the water of this group issues from three main vents in an area of about 100 square feet.

On August 28, 1925, these springs were discharging about 125 second-feet. The temperature of the water from all vents on that date was 45° F. The springs issue from basalt, the water probably being collected at this place by a lava tube or lava tongue.

Spring River has been measured at intervals for nearly 20 years at a point near its mouth, in the NW. ¼ sec. 6, T. 20 S., R. 11 E. Its discharge varies much more widely than that of Fall River, ranging from 142 to 299 second-feet and averaging 197 second-feet in the 22 measurements recorded in the following table:

Discharge, in second-feet, of Spring River near its mouth, in the NW. ¼ sec. 6, T. 20 S., R. 11 E.

April 13, 1907	299	November 2, 1914	222
March 26, 1908	271	December 16, 1914	182
April 23, 1909	228	February 1, 1915	188
February 25, 1912	194	February 18, 1915	176
October 21, 1912	158	July 30, 1915	155
June 9, 1913	226	October 1, 1915	163
August 23, 1913	248	August 11, 1916	200
October 29, 1913	167	August 28, 1920	149
April 2, 1914	224	October 27, 1920	142
June 1, 1914	204	August 7, 1922	150
August 15, 1914	195	February 7, 1924	189

Springs on Metolius River.—Metolius River is fed by a great number of large springs. It rises in Black Butte Springs, at the base of Black Butte, which is a large volcanic cone about 10 miles east of the main Cascade Range. On August 24, 1908, the flow of this spring was 100 second-feet, and on November 24, 1925, it was 122 second-feet. The volume of the river is augmented rapidly downstream by inflow from other springs. A gaging station was maintained for several years at the Allingham ranger station, 3 miles below the head of the river and below the mouth of Lake Creek. At this station the flow of the river ranged in 1911 and 1912 between 307 and 566 second-feet and averaged 376 second-feet.

Jack Creek, which enters the river about 2 miles below the ranger station, has a low-water flow of about 30 second-feet, mostly from one spring. Canyon Creek, which enters less than a mile below the mouth of Jack Creek, has a flow which is practically never less than 50 second-feet, derived from a series of springs. Roaring Creek, the largest of these springs, had a discharge on June 22, 1915, of 44.5 second-feet, and on November 25, 1925, of 54 second-feet.

Heising Spring enters the river near the mouth of Jack Creek. It flowed 128 second-feet on March 26, 1912, and 90 second-feet on November 24, 1925. At Allen's ranch, about 3 miles below the mouth of Canyon Creek and about 10 miles below the head of the river, the flow was 1,040 second-feet on March 26, 1912, and 1,100 second-feet on June 22, 1915. Below this point enter Jefferson Creek, with 100 second-feet or more, and other creeks with large low-water flow. The resulting flow of Metolius River, as measured at the Riggs and Montgomery ranches, below practically all tributaries, has never been less than 1,300 second-feet. The minimum for the four years of record at the Riggs ranch was 1,330 second-feet. As the area apparently tributary to the river at this station covers about 347 square miles, the discharge amounts to an average of 3.83 second-feet per square mile.

Springs on Crooked River.—Crooked River, the principal eastern tributary of the Deschutes, rises in a group of warm springs in a belt about 2 miles long at the north end of Gilchrist Valley, in Oregon. These springs have temperatures ranging between 60° and 87° F., and their combined discharge was roughly estimated by I. C. Russell at 20 to 25 second-feet. In its upper course the stream grows rapidly by inflow from springs, but farther down it loses by seepage into the lava and also by diversions for irrigation, and below Prineville it frequently becomes dry in late summer.[77] The flow at the bridge on the Dalles-California highway, generally known as Trail Crossing, is reduced in summer and fall to the amount contributed by return waters from irrigation along the river and from Ochoco Creek, near Prineville. In the 15 miles below this crossing, however, the river receives a flow of more than 1,000 second-feet from springs. (See pl. 15.) On November 28, 1925, the flow was 110 second-feet at Trail Crossing, above Opal Spring, 841 second-feet below Opal Spring, and 1,190 second-feet near the mouth of Crooked River.

Monthly mean discharge, in second-feet, of Crooked River near its mouth, 1918–1924

Year	June	July	Aug.	Sept.	Oct.	Year	June	July	Aug.	Sept.	Oct.
1918	1,130	1,100	1,110	1,100	1,110	1922	1,210	1,110	1,110	1,120	1,150
1919	1,110	1,080	1,100	1,110	1,060	1923	1,200	1,240	1,130	1,150	1,180
1920	1,060	1,060	1,060	1,090	1,120	1924	1,110	1,110	1,110	1,110	....
1921	1,300	995	970	1,030	1,100						

Opal Spring is in the NE. ¼ sec. 33, T. 12 S., R. 12 E., on the east bank of Crooked River, at 1,969 feet above sea level. Its discharge was estimated at about 130 second-feet. On August 24, 1925, the spring water had a temperature of 54° F. Part of the spring issues from talus about 5 feet above the river, and the re-

[77] Russell, I. C., Preliminary report on the geology and water resources of central Oregon: U. S. Geol. Survey Bull. 252, pp. 18, 19, 55, 56, 1905.

mainder rises in a pool at the edge of Crooked River (pl. 16). The true source of the water has not been definitely determined, but there are good reasons to believe that the water comes from a bed of basalt interstratified with tuffs and partly consolidated sediments. Opal Spring is said to derive its name from the fact that it brings up grains of opal from the basalt.[77a]

SPRINGS IN THE KLAMATH RIVER BASIN, OREGON AND CALIFORNIA

GENERAL FEATURES

The upper part of the Klamath River basin is underlain chiefly by permeable lava rock and fragmental volcanic débris. The streams tributary to the Klamath are to a great extent fed by large springs that issue from these permeable materials. The following table summarizes the discharge data in regard to the springs that are described. Two of these, Spring Creek (near Chiloquin) and the spring at the head of Wood River, are doubtless springs of the first magnitude. The following descriptions are based chiefly on data furnished by F. F. Henshaw, H. T. Stearns, and E. O. Hokanson.

Discharge, in second-feet, of large springs in the Klamath River basin, Oregon and California

Spring	Record	Discharge		
		Lowest	Highest	Approximate average
Big Spring (on Williamson River)	19 measurements	12	62	36
Spring Creek (on Williamson River; entire spring-fed creek).	16 measurements	279	500	330
McCready (on Sprague River)	2 measurements	46	67	56
Wood River (spring at head of river)	1 measurement			208
Beetles Rest	4 measurements	24	26	25
Bonanza (on Lost River)	1 measurement			67
Little Shasta	Estimated and 1 measurement.	14	20	

DETAILED DESCRIPTIONS

Big Spring.—Big Spring Creek enters Williamson River from the west in that part of the river's course where it flows through Klamath Marsh. The creek rises in large springs only a short distance from the edge of the marsh, and measurements of its discharge have been made from time to time in sec. 22, T. 30 S., R. 8 E., at a point just within the marsh.

[77a] Idem, p. 19.

Discharge, in second-feet, of Big Spring Creek, on Lenz ranch, in sec. 22, T. 30 S., R. 8 E.

April 24, 1914	61	October 29, 1920	21.1
August 12, 1914	62	April 29, 1921	30.3
June 28, 1915	57	June 23, 1921	31.0
May 30, 1916	58	September 1, 1921	25.9
October 13, 1916	50	October 31, 1921	30.2
June 15, 1917	52	August 9, 1922	26.4
April 30, 1918	44.7	May 3, 1923	27.9
August 27, 1919	33.5	June 27, 1923	24.9
July 5, 1920	27.8	September 3, 1923	22.4
August 20, 1920	24.0	November 10, 1925	11.6

Spring Creek.—Spring Creek is about 2½ miles long and also empties into Williamson River. It has its source in a beautiful pool of clear blue water a few miles from Chiloquin, Oreg. Numerous springs bubble up in the pool from crevices in lava rock, which is either basalt or andesite. Not far east of these springs there is a 400-foot fault scarp. The flow of Spring Creek has been measured several times in the last 20 years. In the 16 miscellaneous measurements recorded in the following table the flow ranged between 279 and 500 second-feet and averaged 330 second-feet. Most of this water comes from the big spring at the head of the creek, but the flow is augmented by other springs in the bed of the creek, nearly all of which are within about half a mile of the head. The temperature of the water on November 6, 1925, was 42° F.

Discharge, in second-feet, of Spring Creek near Chiloquin, Oreg.

August 13, 1905	362	August 16, 1920	301
September 27, 1908	473	August 30, 1921	291
October 1, 1909	500	August 12, 1922	300
October 27, 1914	337	May 3, 1923	293
June 27, 1915	320	October 19, 1923	294
June 2, 1916	343	February 18, 1924	279
June 26, 1917	315	May 20, 1924	290
August 23, 1919	297	October 10, 1924	282

McCready Spring.—Measurements on Sprague River show that its flow at low stages would be about 300 second-feet if no water were diverted for irrigation. Practically all the tributaries of Sprague River are fed by springs. The largest of these springs is in the vicinity of the McCready ranch, in sec. 30, T. 34 S., R. 9 E. A measurement of this spring on August 13, 1920, showed a flow of 67 second-feet, and one on October 31, 1925, showed a flow of 46 second-feet. The temperature of the water on October 31, 1925, was 52° F.

Wood River Spring.—Wood River rises in spring pools a few miles north of Fort Klamath, in sec. 26, T. 32 S., R. 7½ E. These pools are fed largely by two groups of springs about 1,500 feet apart. On November 7, 1925, they discharged 208 second-feet. The temperature of the water was 42° F. at the north group of springs and 48° at the south group. The water is clear and very blue so that the spring is known locally for its beauty. The water bubbles up from glacial gravel and pumice at the foot of an andesite fault scarp which trends north (pl. 13, *A*). Discharge records have been obtained since 1911 at a gaging station at Fort Klamath, below the mouth of Sun and Anna Creeks. Anna Creek has been measured since 1922 and has a low-water flow of about 40 second-feet, largely from springs within the Crater Lake National Park. Sun Creek is a similar but smaller stream. The flow at the gaging station has probably been materially reduced in June and July of each year by diversions for irrigation. The mean flow during five summer months of each year, so far as records are available, is given in the following table:

Mean monthly discharge, in second-feet, of Wood River at Fort Klamath, Oreg.

Year	June	July	Aug.	Sept.	Oct.	Year	June	July	Aug.	Sept.	Oct.
1911	-------	-------	320	291	280	1919	222	228	225	240	256
1913	315	334	313	290	293	1920	170	163	168	183	219
1914	345	295	[a] 280	[a] 275	[a] 290	1921	-------	310	294	276	305
1915	257	265	256	282	245	1922	-------	-------	-------	-------	[a] 300
1916	[a] 270	[a] 325	293	282	-------	1923	[b] 255	229	189	[a] 218	[a] 240
1917	253	274	260	232	231	1924	158	146	146	158	-------
1918	212	189	199	205	237						

[a] Estimated. [b] Partly estimated.

Beetles Rest Spring.—The Beetles Rest Spring, on the Klamath Indian Reservation half a mile north of the Klamath Agency, is typical of a large number of springs of the second magnitude in the Klamath River Basin. The water issues in one well-defined spring that has been walled up with brick. The country around the spring is covered with pumice. No rock is exposed near the spring, but the water probably comes from shattered lava. On September 1, 1925, the water had a temperature of 49° F. The spring has been measured by the Geological Survey[78] with the following results: August 7, 1907, 25 second-feet; March 23, 1908, 26 second-feet; April 27, 1908, 25 second-feet; October 1, 1909, 24 second-feet.

Bonanza Springs.—Lost River discharges into Tule Lake, which lies on the Oregon-California State line. Tule Lake is only a few miles east of Lower Klamath Lake, which forms a part of the Klamath River system, but it has no surface outlet. Lost River derives its flood flow from a large area, but its low-water flow comes almost entirely from copious springs rising in the vicinity of Bonanza, Oreg. Bonanza Springs issue from numerous vents in basalt, in the S. ½ sec. 10, T. 39 S., R. 11 E. On September 2, 1925, the springs

[78] Henshaw, F. F., and Dean, H. J., op. cit., p. 818.

had a temperature of 59° F., and on November 4, 60°. On November 4, 1925, Lost River was measured by Mr. Hokanson at points about 4 miles below and 2 miles above Bonanza Springs. The lower measurement showed 68.2 second-feet, and the upper only 1.4 second-feet, indicating an increase in flow of 66.8 second-feet, mainly from vents in an area about 1,200 feet long. These vents together constitute the Bonanza Springs.

Measurements have been made of Lost River near Merrill and Olene for the last 20 years, but since about 1918 the records convey no adequate idea of the natural flow because of extensive diversions by pumping for irrigation not far below the Bonanza Springs. The flow for the five low-water months of each year up to 1918 is given in the following table:

Mean monthly discharge, in second-feet, of Lost River near Merrill and Olene, Oreg.

Year	June	July	Aug.	Sept.	Oct.	Year	June	July	Aug.	Sept.	Oct.
1905	138	125	125	102	102	1912	144	101	87.3	98.9	114
1906	240	113	93.7	87.0	87.0	1913	111	123	120	110	102
1907	227	142	109	117	128	1914	117	115	88.7	95.0	104
1908	126	96.0	101	96.0	110	1915	103	81.2	87.7	91.9	[a] 90
1909	119	104	107	116	109	1916	72.7	78.8	80.2	63.2	121
1910	97.5	89.5	89.5	103	103	1917	144	98.8	90.7	89.2	92.6
1911	110	94.4	109	105	108	1918	95.1	82.8	87.8	[a] 85.0	124

[a] Estimated.

NOTE.—Discharge measurements beginning May, 1912, include Lost River diversion canal and "G" canal and have been reduced by an amount diverted from Upper Klamath Lake into Lost River.

Little Shasta Spring.—Several large springs issue near the head of Little Shasta River, in California. One of these, about 13 miles east of Montague, rises from basalt and has a relatively constant flow of about 14 second-feet, according to Waring.[79] This is probably the same as the "Little Shasta Spring," which, according to a measurement made by the Geological Survey, yielded 20 second-feet on August 29, 1905.[80]

SPRINGS IN THE WILLAMETTE, UMPQUA, AND ROGUE RIVER BASINS, OREGON

GENERAL FEATURES

A number of large springs are found in the lava-covered region on the west slope of the Cascade Mountains in Oregon, of which five are apparently springs of the first magnitude. The first-magnitude springs are Clear Lake Spring, Lower Falls Spring, Olallie Creek Springs, and Lost Creek Spring, which discharge into McKenzie River, a tributary of the Willamette, and Spring River, which dis-

[79] Waring, G. A., op. cit., p. 331.

[80] U. S. Geol. Survey Water-Supply Paper 177, p. 245, 1906.

charges into the North Umpqua. The information that is given in regard to these springs was furnished by H. T. Stearns, K. N. Phillips, and B. E. Jones, all of the United States Geological Survey, who have recently made a reconnaissance survey of the water resources of the region.

DETAILED DESCRIPTIONS

Clear Lake Spring.—Clear Lake, which was visited by Mr. Stearns on September 5, 1926, lies in T. 14 S., R. 7 E., near the head of McKenzie River. It is a beautiful green lake about a mile long and is reported to be 190 feet deep at one place. A gaging station is maintained at the outlet of the lake. On September 5 the discharge was approximately 200 second-feet, all of which rose in the bottom of the lake except about 20 second-feet that issued from Great Spring, 100 feet from the east shore of the lake, and about half a second-foot that entered through a tributary creek. According to Mr. Stearns, the lake owes its origin to a basalt flow that entered the valley of McKenzie River and formed a dam in the valley. On September 5, 1926, the temperature of the water of Great Spring was 39° F., and that of the lake was 50° to 52° F.

Spring at Lower Falls of McKenzie River.—A beautiful spring pool occurs at the foot of the Lower Falls of McKenzie River, in sec. 31, T. 14 S., R. 7 E. This pool discharges about 250 second-feet of water at times when there is no surface flow in the river above the pool. A few springs issue from crevices in the basalt about 10 feet above the water surface, but most of the water rises in the pool below the water level. Mr. Stearns reports that the spring is due to a recent basaltic lava flow that entered the gorge of the McKenzie in sec. 29 and flowed down the gorge. In normal stages the entire river sinks into this basalt, and the water reappears about 1½ miles farther down the gorge in the spring pool.

Olallie Creek Springs.—Olallie Creek discharges into McKenzie River, in sec. 13, T. 15 S., R. 6 E. The entire flow at low stages comes from springs about 1½ miles above its mouth, which issue from basalt. The information in regard to these springs was furnished by Mr. Jones, who examined them in July, 1926.

Nearly all the water comes from three spring areas. Two of these are on the creek about a quarter of a mile apart and have a difference of altitude of 30 to 40 feet. Their combined flow was estimated at about 60 second-feet. The third spring issues at somewhat lower altitude, at the head of a branch a quarter of a mile long that discharges into the creek a short distance below the other two. It also discharges approximately 60 second-feet. The flow of the creek below the spring branch was 137 second-feet, according to a measurement by Mr. Jones on July 20, 1926. Practically all the water came from these three springs and several smaller springs in the same locality. As the flow of streams in this region was exceptionally low in the summer of 1926, the discharge of these springs was probably also below the average. It appears, therefore, that the Olallie Creek Springs may be regarded as a spring of the first magnitude.

Lost Creek Spring.—Lost Creek Spring rises chiefly from one large irregular pool at the end of a basalt flow in sec. 24, T. 16 S., R. 6 E. The water flows northeastward through Lost Creek into McKenzie River. The temperature of the water on September 7, 1926, was 42° F. According to measurements made by Mr. Jones 3 miles below the spring the flow was 175 second-feet on August 9, 1926, 172 second-feet on September 6, and 166 second-feet on September 22. This spring owes its origin to the burial of an ancient stream channel by a lava flow.

Spring River.—Spring River, which is only a mile or two long and discharges into North Umpqua River, forms the outlet for two large springs which may together be regarded as a spring of the first magnitude. These springs are situated near the west boundary of the unsurveyed T. 26 S., R. 6 E., in Douglas County, Oreg. The two springs are less than a mile apart. The western one, which is somewhat the larger, issues from the base of a lava bed about 100 feet thick. The water is clear and had a temperature of 40° F. on July 29, 1926. In the bed of the stream where the spring issues Mr. Stearns observed waterworn cobbles, which suggest that the water issues from the bed of an ancient river that was buried by the lava flow. The eastern spring issues from the same lava bed. Its water on the same day had a temperature of 42° F. This slightly higher temperature may be due to relatively warm water from Thirsty Creek, near by, that may percolate to the spring. Evidently the water of Spring River is the underground drainage of a large area of permeable rocks in the Cascade Mountains, to the southeast. The flow of Spring River below both springs was 177 second-feet on May 20, 1926, and 174 second-feet on July 17, 1926, according to measurements made by Mr. Phillips.

About a mile north of the eastern spring, on the north bank of North Umpqua River, is a spring known as Cold Spring, which on July 29, 1926, according to Mr. Stearn's estimate, discharged about 25 second-feet from openings in basaltic rocks. On the same day the temperature of the water was 39° F.

Measurements made by Mr. Phillips showed that the flow of North Umpqua River just below the mouth of Spring River was 284 second-feet on May 21, 1926, and 248 second-feet on July 17, 1926. A measurement at the same place by J. N. Partridge on September 12, 1924, indicated a flow of 251 second-feet. All the water measured on July

17, 1926, is known to have come from springs. It was estimated that more than 200 second-feet of spring water issued from an area of 1 square mile.

Springs on Clearwater River.—Clearwater River, which discharges into the North Umpqua some miles below Spring River, is fed by large springs near its source. The flow of a group of springs in Toolbox Meadows, at the head of the Clearwater, was estimated by Mr. Stearns on July 28, 1926, at 25 second-feet, and the flow of Lava Creek, a spring-fed tributary, at 20 second-feet. Several measurements have been made on the river about 4 miles below the head springs. Flows of 112 second-feet on October 18, 1924, and 128 second-feet on July 18, 1926, consisted almost exclusively of spring water that issued in the upper 4 miles of the river valley.

Big Butte Springs.—The Big Butte Springs consist of a number of springs within several hundred feet of one another, in secs. 20 and 21, T. 35 S., R. 3 E., Jackson County, Oreg. The water issues from openings in basalt and flows into the South Fork of Big Butte Creek, a tributary of Rogue River. Some of the water is to be diverted as a supply for the city of Medford. In 16 measurements made from 1923 to 1926 the discharge of the largest group of springs ranged between 12.2 and 16.9 second-feet. In 7 measurements in 1925 and 1926 the total spring flow below the junction of the spring branches ranged between 43 and 59 second-feet and averaged about 53 second-feet.

SPRINGS IN THE INTERIOR BASINS OF OREGON

Ana River Springs.—Ana River rises in springs in sec. 6, T. 30 S., R. 17 E., and is the principal feeder of Summer Lake, which it enters from the north through a channel about 5 miles long.[81] There are five vents close together that are now at times flooded by water impounded by a dam. They issue from Pliocene lake beds at the north end of the great fault valley occupied by Summer Lake. The origin of the springs has not been definitely determined, but, as suggested by Waring, the water probably comes from permeable lava rock and is brought to the surface through the agency of the fault. A temperature of 66° F., reported by Waring, suggests a deep origin of the water.

On July 27, 1925, Mr. S. Mushin, of Lakeview, Oreg., measured these springs and found them to be discharging 130 second-feet. Ana River has been measured from time to time for the last 22 years at a point below the lowest of the large springs. In the 29 measurements recorded in the following table the flow has ranged from 106 to 165 second-feet. The discharges of 106 and 109 second-feet were

[81] Waring, G. A., Geology and water resources of a portion of south-central Oregon: U. S. Geol. Survey Water-Supply Paper 220, pp. 54, 56, 1908.

measured at times when a diversion dam constructed just above the measuring section had raised the water to a height of 30 or 40 feet above the bed of the stream. The minimum measured before this dam was constructed or thereafter when the water was not impounded behind the dam has been 114 second-feet. The flow of the springs in the 27 measurements exclusive of these two has, therefore, ranged from 114 to 165 second-feet and has averaged about 135 second-feet.

The measurements show that in addition to small seasonal variations there has been a moderate secular fluctuation due to a cycle of relatively wet and dry years. From a maximum measured flow in 1904 there was a more or less persistent decline to 1920, followed by a partial recovery in the next five years.

Discharge, in second-feet, of Ana River near Summer Lake, Oreg.

July 17, 1904	165	April 29, 1918	124
July 18, 1904	155	March 28, 1919	120
March 28, 1905	148	August 31, 1919	121
April 6, 1905	149	May 24, 1920	115
June 8, 1905	148	August 6, 1920	114
April 8, 1906	141	March 7, 1921	131
January 14, 1909	134	August 23, 1921	122
May 2, 1909	150	October 19, 1921	128
September 25, 1910	141	April 4, 1922	130
February 7, 1912	140	August 17, 1922	[a] 106
August 2, 1914	137	January 29, 1923	[a] 109
December 12, 1914	131	July 10, 1923	129
May 17, 1915	134	September 20, 1924	130
October 3, 1915	132	July 27, 1925	130
April 20, 1917	132		

Springs in Warm Spring Valley.—A group of rather large springs is situated in Tps. 26 and 27 S., R. 29 E., near the Double O ranch, in Warm Spring Valley, just west of Harney Lake, Oreg. (fig. 17). They rise in the lowland, at or near the bordering bluffs of lava. Waring[82] states that in those places where the immediate source of the spring was seen the water issues from coarse tuffaceous material that is interbedded with the lava rock. The temperature of several springs in this group ranges, according to observations, from 53° to 73° F., which is somewhat above the normal. Eleven measurements of the main Double O Spring, in sec. 34, T. 26 S., R. 28 E., made between 1916 and 1924 show a discharge ranging between 8.4 and 16.4 second-feet, and five measurements of the Hughet Spring, in sec. 10, T. 27 S., R. 29 E., in 1916 and 1917, showed a discharge

[a] Water raised by dam above measuring section.

[82] Waring, G. A., Geology and water resources of the Harney Basin region, Oreg.: U. S. Geol. Survey Water-Supply Paper 231, pp. 35, 39, 40, 63, 1909.

ranging between 12 and 14.5 second-feet. In six sets of measurements, three made in 1916 and three in 1917, the discharge of the entire group of springs ranged from 39.7 to 44.4 second-feet and averaged about 42 second-feet.

SPRINGS IN OWENS VALLEY, CALIFORNIA

The Fish Springs are at the west edge of Owens Valley, about 3½ miles south of Big Pine, Calif., or 27 miles north of Independence. They form a large pond at the side of a lava ridge that extends for some distance into the valley.[83] Measurements made on these springs by the Geological Survey gave 29 second-feet on December 4, 1905, 36 second-feet on December 7, 1906, and 25 second-feet on February 8, 1907.[84]

Black Rock Spring, about 9 miles north of Independence, is the largest of a group of springs in this part of Owens Valley. Its water rises in a pool 30 to 50 feet in diameter, at the base of a low lava ridge. The water comes out of the lava or possibly out of the alluvium just above the lava. Its temperature is reported to be 56° or 57° F. The yield of the spring was reported to be 21 second-feet by Waring[85] and 23 second-feet by Lee.[86]

INTERMITTENT SPRING, WASHINGTON[87]

Near Trout Lake, Wash., in the drainage basin of White Salmon River, in the SW. ¼ sec. 13, T. 5 N., R. 10 E., is a spring known as Intermittent Spring, which had a discharge of 50 second-feet when it was measured on July 1, 1913, and 33 second-feet when it was measured on July 3, 1914, but was dry on September 16, 1914. This spring is in the region underlain by basalt, but no description of it is available. Its behavior does not appear to be that of typical basalt springs.

SPRINGS IN MONTANA

GENERAL FEATURES

Four springs of unusual size are known to occur in Montana—the Giant Springs, near Great Falls; the Big Springs southeast of Lewistown; Warm Spring, north of Lewistown; and the Big Spring near Toston (fig. 19). The Giant Springs, which discharge about 600 second-feet, rank among the very largest springs in the United States; Warm Spring and the Lewistown Big Springs are also springs of the first magnitude; the Toston Big Spring, which

[83] Waring, G. A., op. cit., p. 322.
[84] U. S. Geol. Survey Water-Supply Paper 300, p. 393, 1913.
[85] Waring, G. A., op. cit., p. 320.
[86] Lee, C. H., An intensive study of the water resources of a part of Owens Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 294, p. 45, 1912.
[87] U. S. Geol. Survey Water-Supply Papers 362, p. 749, 1917; 394, p. 174, 1917.

in a single measurement discharged 64 second-feet, is apparently the fourth largest spring in the State.

These springs are in different parts of the State, issue from different formations, and are due to different structural features. The Giant Springs, Warm Spring, and the Lewistown Big Springs issue from sandstone; the Toston Big Spring doubtless issues from limestone. Warm Spring, the Lewistown Big Springs, and possibly also the Giant Springs are related to faults. The Giant Springs and the Toston Big Spring are believed to derive their large flows

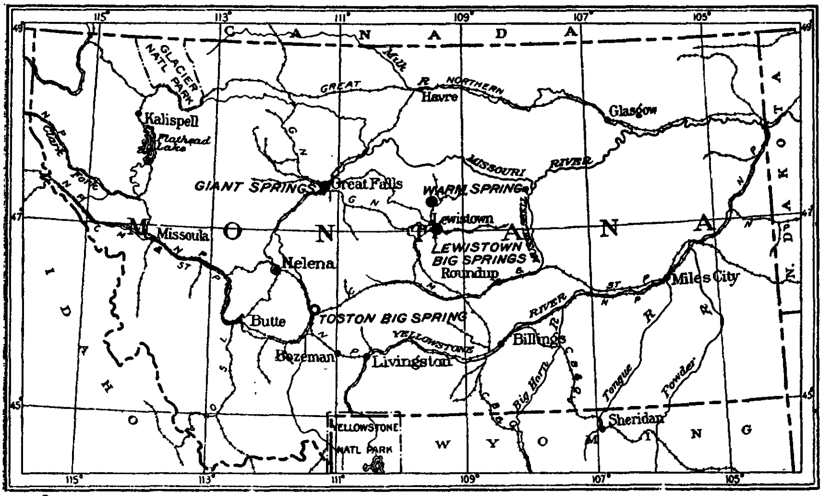


FIGURE 19.—Map of Montana showing the location of large springs. The Giant Springs, Warm Spring, and the Lewistown Big Springs are springs of the first magnitude; the Toston Big Spring discharged 64 second-feet when measured, and is therefore rated as a spring of the second magnitude

as a result of natural diversions from Missouri River at points upstream from the springs.

DETAILED DESCRIPTIONS

Giant Springs.—The Giant Springs,[88] on the south bank of Missouri River about 3 miles below Great Falls, Mont. (fig. 20), were discovered by Capt. Meriwether Lewis, of the Lewis and Clark Expedition, 1804, and in his description were spoken of as the "largest fountain in the United States."

The water appears at the surface through large joints in a medium to coarse grained sandstone belonging to the Kootenai formation (Lower Cretaceous). It boils up with considerable force, is clear

[88] Fisher, C. A., Geology and water resources of the Great Falls region, Mont.: U. S. Geol. Survey Water-Supply Paper 221, pp. 37–39, pl. 6, 1909. Letter by W. A. Lamb, district engineer, U. S. Geol. Survey.

and blue, contains only a moderate amount of dissolved mineral matter, and has a temperature of about 50° F. No spring deposits are found in the vicinity of the springs.

There is one large spring on the right bank near the edge of the river which discharges about 200 second-feet (pl. 17). It discharged 202 second-feet according to a measurement made September 11, 1904, and 192 second-feet according to a measurement made September 14, 1912. On both sides of the main spring for a short distance are smaller springs flowing from the joints, and directly opposite it in

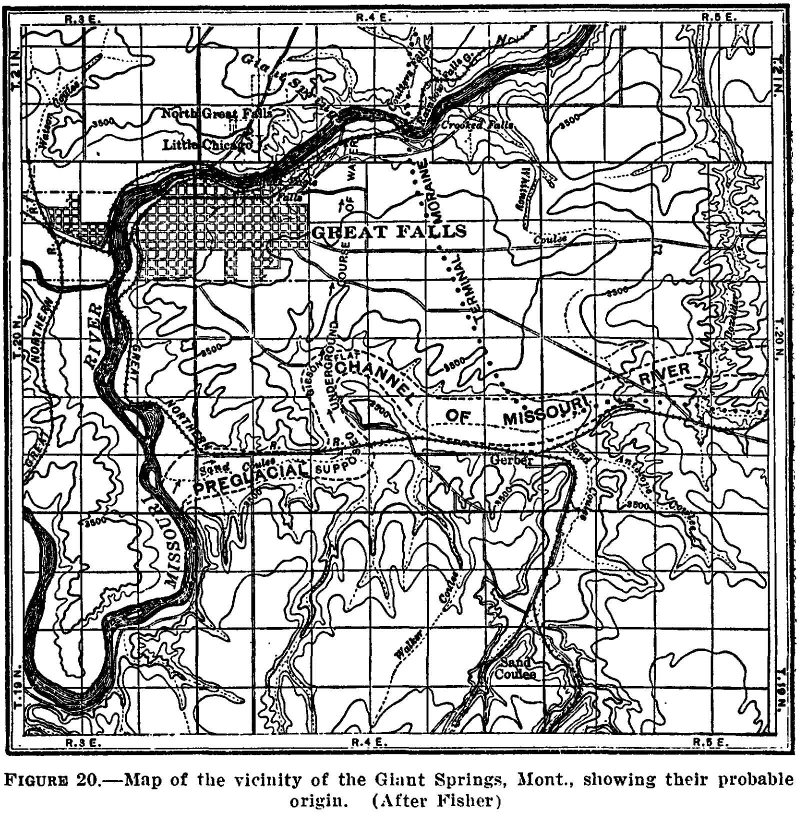


FIGURE 20.—Map of the vicinity of the Giant Springs, Mont., showing their probable origin. (After Fisher)

the bed of the river there is a large spring which can be seen during low stages of the river. According to measurements made by Nettleton[89] in 1891, the flow of Missouri River was 3,885 second-feet above the springs and 4,523 second-feet below the springs, giving a calculated discharge of 638 second-feet from all the spring openings in this locality. In recent years the Montana Power Co. has made measurements which have determined that in the vicinity of the

[89] Nettleton, E. S., Artesian and underflow investigations (final report): 52d Cong., 1st sess., Ex. Doc. 41, pt. 2, p. 77, 1892.

springs there is an increase in the flow of the river of about 600 second-feet, all of which must come from the springs.[90]

The following explanation of the origin of the Giant Springs is given by Fisher:

It is believed that the water of Giant Springs is derived from the subriver flow of the Missouri which leaves the valley of that stream near the mouth of Sand Coulee as an underflow and passes down its preglacial channel, which extends up Sand Coulee, into Gibson Flat, an oxbow in the old river channel (fig. 20). From here by a subterranean passage through porous Cretaceous sandstone and sandy shale, which dip in a favorable direction for its transmission, it makes its escape to the present Missouri River, where it appears in the form of Giant Springs. It is further believed by the writer that the jointing, which is here well developed, with the major joint planes extending in a north-south direction, is an important factor in the underground movement of the water. It is also possible that a fault in this vicinity further facilitates the underground passage of the water, but no positive evidence of this was seen. Well borings in lower Sand Coulee and Gibson Flat demonstrate that the materials filling the old valley are largely coarse river sediments, well adapted for rapid percolation of water.

Warm Spring.—Warm Spring is about 12 miles north of Lewistown, in the NE. ¼ sec. 19, T. 17 N., R. 18 E., and is the principal source of Warm Spring Creek, a tributary of Judith River. Calvert,[91] who made a geologic survey of the region in 1907, reported that the spring has a nearly constant flow of about 140 second-feet, but according to later information obtained by George M. Hall, who examined the spring in 1923, measurements made by the Barnes-King Development Co., indicate a flow of 180 to 190 second-feet. The water has a temperature, as observed by Hall on July 24, 1923, of 68° F., and contains 647 parts per million of dissolved solids, as shown in an analysis by H. B. Riffenburg. It has deposited practically no mineral matter. The water is used in part by the Barnes-King Development Co. for power in mining and milling operations. Some of the water is also used for irrigation.

This large spring apparently owes its existence to a fault, as is indicated in the following quotation from Calvert.[92] (See fig. 21.)

Structural relations in the vicinity of the Warm Spring make it evident that the spring issues on a fault line which to the east seems to follow the valley, curving around into Moccasin Creek, and to the west gradually passes to the north of the stream. Just to the southwest of the spring a few feet of sandstone is exposed in the cut bank, which appears to be the sandstone overlying the coal [Kootenai]. To the northwest and below the spring the top of the Ellis sandstone is exposed, and in the immediate vicinity of the spring the varicolored shales of the Morrison form the north bank. The downthrow of the fault, therefore, is on the south side, and the vertical dis-

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[90] Information furnished by W. A. Lamb, district engineer, U. S. Geol. Survey.

[91] Calvert, W. R., Geology of the Lewistown coal field, Mont.: U. S. Geol. Survey Bull. 390, p. 55, 1909.

[92] Idem, pp. 54, 55.

placement is the same as the interval between the base of the Morrison and the top of the massive sandstone just above the coal—about 200 feet. One-half mile below the spring a second fault meets that described above. This has a downthrow on the west, extends northeast, and is finally concealed beneath the travertine of The Park.

The Park, mentioned by Calvert,[93] is the largest of several areas in this region that are underlain by travertine. It covers about 6 square miles and extends within half a mile or so of Warm Spring

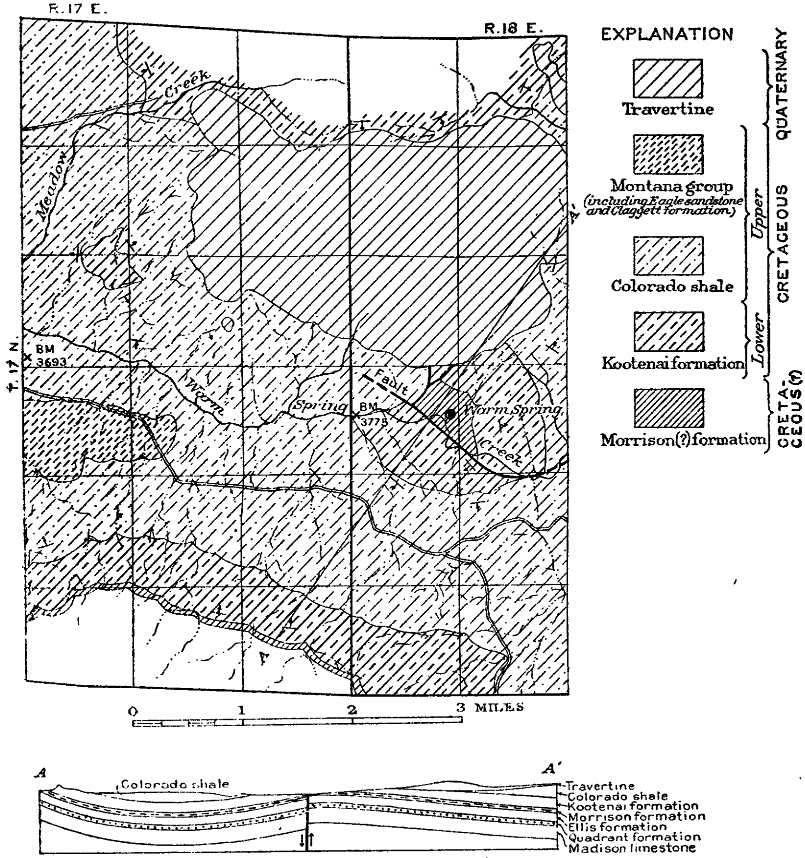

FIGURE 21.—Map and section of the vicinity of Warm Spring, Mont., showing its relation to the structure of the rocks. (After Calvert, op. cit., pl. 1.)

(fig. 21). The travertine, which is estimated to have a maximum thickness of about 250 feet, is believed by Calvert to have been deposited in early Quaternary or possibly in pre-Quaternary time by hot springs which owed their origin to laccolithic intrusions of the Moccasin Mountains. "Heated waters, probably charged with carbonic acid—a most natural solvent for calcium carbonate—may have

[93] Idem, pp. 35–40.

passed through the Madison limestone and, finding means of access through fractures developed in the process of doming, deposited the travertine at the surface upon release of pressure and decrease of temperature." Calvert does not believe, however, that Warm Spring represents the last phase of general hot-spring activity, but rather that it is due to artesian structure, which carries the water to sufficient depths to raise its temperature moderately, and to the fault, which provides the artesian water with a natural means of escape. His discussion of the subject is in part as follows:

If the spring does represent the last phase of such [igneous] activity, it would seem highly improbable that it should be the only one in the entire district whose temperature is noticeably above the average. Likewise, it would seem strange that not even this spring is depositing lime. In fact, field analysis of its waters shows that they contain no more than the average of carbonates for that region. It might also be argued that the temperature is a result of recent faulting, and the fact that the spring is directly on a fault line gives weight to that assumption. However, numerous other faults, apparently contemporaneous, occur in the region, and since springs near them are not affected as regards temperature, it would seem that some other cause should be sought to account for the exceptional temperature of the water of Warm Spring.

A much more probable theory regarding the elevated temperature of the spring water is that it has come from a considerable depth. The drainage area of Warm Spring Creek is largely a structural basin, the underground waters of which would find an outlet through the syncline between North Moccasin and South Moccasin Mountains and find access to the surface on the plane of the fault. The principal water-bearing stratum of this region is the massive sandstone which overlies the coal and which is exposed along the flanks of the Judith and Moccasin Mountains on the rim of the structural basin. A mile southeast of the spring this sandstone is buried by practically the entire thickness of the Colorado shale, which, in addition to the 400 feet of Kootenai sediments that comprise the interval between the sandstone in question and the Colorado formation, would fix the depth to the water zone in the above locality at about 1,800 feet. Since the temperature of the spring water is about 70° F., and that of the average spring of the district about 50° F., an increase of 1° for each 90 feet of depth will account for the temperature of the water in question.

Lewistown Big Springs.—The Lewistown Big Springs are in sec. 5, T. 14 N., R. 19 E., about 7 miles southeast of Lewistown, on Big Spring Creek, a tributary of Judith River. They furnish the water supply for the city of Lewistown. The water has a temperature, as observed by George M. Hall on September 2, 1922, of 52° F., and contains 446 parts per million of dissolved solids, as shown in an analysis by H. B. Riffenburg. According to Calvert,[94] they have a nearly constant flow and yield about 140 second-feet, as measured by Robert Follansbee, of the United States Geological Survey. They issue from the Ellis formation, a massive sandstone of Juras-

[94] Calvert, W. R., Geology of the Lewistown coal field, Mont.; U. S. Geol. Survey Bull. 390, p. 53, 1909.

sic age, and are believed by Calvert[95] to be due to the damming effect of a fault, as is explained in the following quotation (see fig. 22):

It appears that the Big Springs owe their origin to the faults above described. South of the fault block the strata dip to the northwest, away from the Big Snowy uplift, and underground waters naturally follow this dip. On meeting the fault plane, however, their tendency would be to flow to the north-

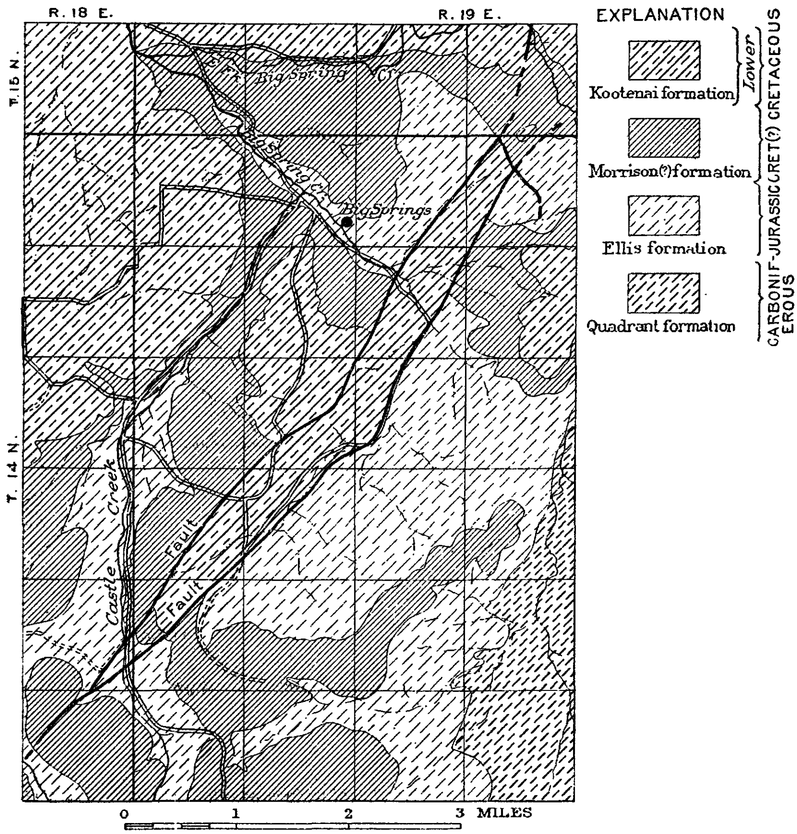

FIGURE 22.—Map of the vicinity of Lewistown Big Springs, near Lewistown, Mont., showing their relation to faults. (After Calvert, op. cit., pl. 1.)

east along the fault, since the throw is such as to bring the massive Ellis sandstone, the most likely water-bearing stratum in this vicinity, against the more impervious shales in the lower part of the Kootenai. On reaching the cross fault which ends the block the water could readily pass across to the Ellis sandstone again, then follow the dip, which is here westward, and find a vent where the sandstone is cut by the stream valley. The springs probably represent, therefore, the underground water which is stopped by the fault block.

[95] Idem, p. 53.

Toston Big Spring.—The Toston Big Spring, known also as Mammoth Spring, is situated on the right bank of Missouri River about 5 miles south of Toston (fig. 23). Its flow, which is said to remain fairly constant throughout the year, amounted to 64 second-feet when it was measured on May 18, 1922, by W. A. Lamb, of the United States Geological Survey. The following description of this spring is given by Pardee [96] (see also fig. 23):

Big Spring, which includes the water escaping at several places along a distance of 200 feet or more, issues from talus and gravel below a steep slope and collects in a beautiful transparent blue pool alongside the track of the Northern Pacific Railway. * * * In July, 1921, the temperature of the water discharged at one of the larger openings was 59° F. By means of a concrete dam and a canal, part of the water is diverted to irrigate lands near Toston; the remainder falls directly into Missouri River. The talus and gravel from which the water escapes evidently form a shallow deposit that overlies limestone belonging to the older group [Madison limestone, Carboniferous]. Doubtless the water is discharged from an extensive solution channel in this rock. The spring is at the lower end of a horseshoe bend in Missouri River, the upper end of which is at Lombard, a distance of 1¼ miles in a straight line, or 5½ miles following the course of the river. At Lombard is the mouth of Sixteenmile Creek, which drains the country back of the spring. Beds of limestone occur in the area between the spring and Lombard and extend into the area crossed by Sixteenmile Creek. At Lombard Missouri River is about 30 feet higher than the spring. These relations suggest that most of the water discharged by this spring may come through underground channels that tap the river or Sixteenmile Creek in the neighborhood of Lombard.

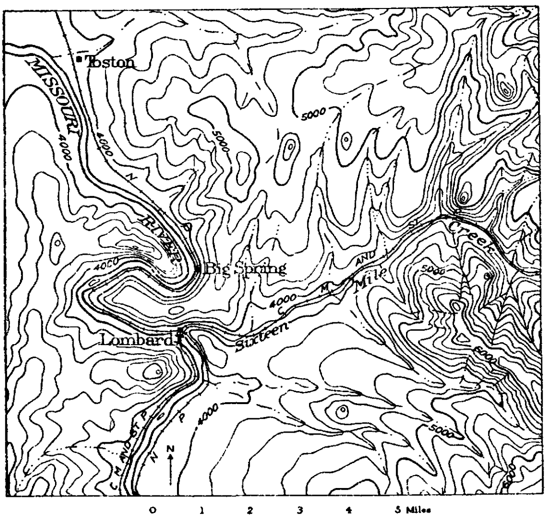

FIGURE 23.—Map of the vicinity of Toston Big Spring, Mont., showing relation of the spring to Sixteenmile Creek and to the bend in Missouri River

SPRINGS IN THE BASIN AND RANGE PROVINCE OF NEVADA AND UTAH

In Nevada and western Utah, which lie in the Basin and Range province, there are numerous large springs, many of which yield

[96] Pardee, J. T., Geology and ground-water resources of Townsend Valley, Mont.: U. S. Geol. Survey Water-Supply Paper 539, pp. 46–47, 1925.

warm or even hot water, but they do not rank with the very large springs that have been described in this paper. Some of them issue from limestone, lava, or other bedrock, and others issue from the valley fill. Many of these springs are related to large faults, and some of those that issue from valley fill probably have their source in the faulted bedrocks.

Good examples of these springs are the Hiko, Crystal, and Ash Springs, in Pahranagat Valley, Nev.,[97] which issue from limestone along the east side of the valley. The water of Hiko Spring and probably also of the others is warmer than the normal for the region. According to estimates made by Carpenter in 1912, Hiko Springs discharged about 9 second-feet, Crystal Spring about 7 second-feet, and Ash Spring about 20 second-feet, but according to estimates made by A. D. Ryan, of the United States Geological Survey, in 1921, Crystal Spring discharged 20 to 30 second-feet, and the three springs together discharged about 65 second-feet.

The Big Spring[98] just west of the Nevada-Utah line, at the head of Lake Creek, about 10 miles up the valley from Burbank, Utah, issues from gravel, but its ultimate source is probably the limestone that crops out not far away. The temperature of the water is 63.5° F., which is somewhat above the normal for the region. The flow of this spring together with smaller ones that issue farther downstream was reported in 1908 to be about 18 second-feet, but in 1921 the flow was estimated by Ryan at about 27 second-feet.

SPRINGS IN LIMESTONE IN SOUTHEASTERN IDAHO AND NORTHEASTERN UTAH

A number of large springs issue from limestone in southeastern Idaho and northeastern Utah. Some of these are very variable in their flow. According to the best information that is available, none of them has an average flow of as much as 100 second-feet. The information in regard to these springs was obtained from H. T. Stearns, A. B. Purton, C. G. Paulsen, G. R. Mansfield, and William Peterson.

Several large springs issue from limestone at the base of the Aspen Range, near the town of Soda Springs, Idaho. The largest are Woodall Spring, or Tule Lakes, in the S. ½ sec. 27 and N. ½ sec. 34, T. 7 S., R. 42 E., and Formation Spring, near the line between secs. 28 and 29, T. 8 S., R. 42 E. Both of these springs issue from carboniferous limestone, apparently along fault lines. The water is very clear but has a distinctly bluish color and has deposited great

[97] Carpenter, Everett, Ground water in southeastern Nevada: U. S. Geol. Survey Water-Supply Paper 365, pp. 26, 56, 1915.

[98] Meinzer, O. E., Ground water in Juab, Millard, and Iron Counties, Utah: U. S. Geol. Survey Water-Supply Paper 277, p. 129, 1911.

quantities of travertine. The entire flow of Formation Spring comes out of the base of a hill in one channel. According to measurements made by C. G. Paulsen, the discharge of Woodall Spring—that is, the total discharge from the Tule Lakes—was 23.5 second-feet on June 1, 1923, and 29.0 second-feet on July 18, 1923. According to measurements made in 1923 by C. G. Paulsen, A. G. Fiedler, and Berkeley Johnson, all of the Geological Survey, the discharge of Formation Spring was 23.9 second-feet on June 3, 26.4 second-feet on June 25, 24.9 second-feet on July 17, and 25.4 second-feet on August 30.

Several large springs issue on the west side of the Bear River valley, among which are the springs at the head of Paris and Bloomington Creeks, in Idaho, and the spring at the head of Swan Creek, in Utah. They probably issue from limestone of Cambrian age. According to measurements by the Utah Power & Light Co., the flow of Swan Creek Spring ranges from 30 or 35 second-feet in the winter to 200 second-feet or more in May.

A large spring on Ashley Creek, about 10 miles northwest of Vernal, Utah, in sec. 1, T. 3 S., R. 20 E., was measured by the Geological Survey on January 23, 1922, when it had a flow of 30.5 second-feet, and on September 5, 1922, when it had a flow of 50 second-feet. The minimum flow of the Ashley Creek Spring is probably not over 20 second-feet, as records on Ashley Creek show the creek to have a minimum flow of 26 second-feet or less.

Purton also mentions a large spring on the South Fork of Ogden River, a large spring on the upper Blacksmith Fork, and a large and well-known spring, called Ricks Spring, on the upper Logan River. Ricks Spring has, however, at times gone absolutely dry.

SPRINGS IN GLACIAL GRAVEL IN QUINCY VALLEY, WASHINGTON [99]

Many large springs in various parts of the country issue from deposits of sand and gravel. The Portneuf Springs, near Pocatello, Idaho, issue largely from gravel and may be the largest gravel springs in the country, but the source of their water is probably the basalt underlying the gravel (p. 51). In so far as information is at hand, the other sand and gravel springs do not belong to the class that yield more than 100 second-feet. This is probably due to the fact that the ground water is more generally distributed in sand and gravel than in limestone or volcanic rock, and hence its discharge is less localized.

[99] Schwennesen, A. T., and Meinzer, O. E., Ground water in Quincy Valley, Wash.: U. S. Geol. Survey Water-Supply Paper 425, pp. 153–155, 1919. U. S. Geol. Survey Water-Supply Papers 292, pp. 146–148, 1913; 312, pp. 170–171, 1915; 332, pp. 195–196, 275, 1916.

Rocky Ford Creek, in Quincy Valley, east of Ephrata, Wash., is fed by springs in T. 21 N., R. 27 E., that issue from coarse glacial outwash gravel, into which the waters of Crab Creek sink. A gaging station was maintained on Rocky Ford Creek by the Geological Survey during parts of 1910–1913 at a point in sec. 8, T. 20 N., R. 27 E., where essentially all of the stream consists of water derived from these springs. According to measurements made at this gaging station the discharge fluctuates at least between 38 and 88 second-feet and averages about 60 second-feet. Drumheller Spring, about 4 miles south of Moses Lake, in Quincy Valley, in sec. 32, T. 18 N., R. 28 E., also issues from unconsolidated sand or gravel. According to several measurements its discharge is about 15 to 20 second-feet.

SPRINGS IN GRAVEL IN PAHSIMEROI VALLEY, IDAHO

A good example of large springs that issue from gravel is afforded by the springs of Pahsimeroi Valley, Idaho.[1] According to the water master, in the high stage of August, 1921, a total of about 140 second-feet of water issued from the gravel along a 25-mile stretch of Pahsimeroi River, of which 85 second-feet issued along a stretch of about 8 miles. The average discharge is not known but is also large.

SPRINGS IN CARBONIFEROUS LIMESTONE AND GYPSUM IN PECOS VALLEY, NEW MEXICO[2]

Several springs of the pool type occur near Roswell, N. Mex., in the valley of Pecos River, about 75 miles north of Carlsbad. These springs, which are known as Berrendo Springs (secs. 9, 14, 16, and 17, T. 10 S., R. 24 E.), North Springs (NE. ¼ sec. 36, T. 10 S., R. 23 E.), and South Springs (S. ½ NE. ¼ sec. 22, T. 11 S., R. 24 E.), issue from valley fill underlain by Permian gypsum and limestone. They were formerly springs of the first magitude or nearly of that size, but their flow has declined greatly as a result of the extensive use of artesian water in the Roswell basin.

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[1] Meinzer, O. E., Ground water in Pahsimeroi Valley, Idaho: Idaho Bur. Mines and Geology Pamphlet 9, pp. 28–29, 1924.

[2] The information regarding the springs near Roswell, N. Nex., was obtained from Newell, F. H., Hydrography of the arid regions: U. S. Geol. Survey Twelfth Ann. Rept., pt. 2, p. 285, 1891; Fisher, C. A., Preliminary report on the geology and underground waters of the Roswell artesian area, N. Mex.: U. S. Geol. Survey Water-Supply Paper 158, 1906; and unpublished data furnished by W. A. Wilson, county surveyor of Chaves County, N. Mex., and by A. G. Fiedler, hydraulic engineer, U. S. Geological Survey. The information in regard to the Major Johnson and Carlsbad Springs was obtained from Meinzer, O. E., Renick, B. C., and Bryan, Kirk, Geology of the No. 3 Reservoir site of the Carlsbad irrigation project with respect to water-tightness: U. S. Geol. Survey Water-Supply Paper 580–A, 1926.

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The combined flow of all the openings of the Berrendo Springs prior to the drilling of the artesian wells was doubtless more than 100 second-feet, according to W. A. Wilson, county surveyor of Chaves County, and was estimated at 50 second-feet in February, 1889, according to Newell. In 1926, however, the North Berrendo Spring flowed only 5 second-feet and the Middle Berrendo Spring only 3 second-feet, while the South Berrendo Spring was entirely dry.

The North Springs had an estimated discharge of about 50 second-feet in February, 1889, according to Newell, and 77 second-feet November 6, 1901, according to a measurement made by Mr. Wilson. In 1901 a distribution of the water of North Spring River was made on a basis of 70 second-feet. Mr. Wilson estimated that prior to the drilling of any artesian wells the discharge of these springs was between 100 and 150 second-feet. In 1926 the North Springs were entirely dry.

The original discharge of the South Springs was probably between 60 and 75 second-feet, according to the estimate of Mr. Wilson. The discharge in February, 1889, was 73 second-feet according to Newell's report. The flow failed rapidly after the drilling of artesian wells had begun. A measurement made in February, 1902, showed a flow of only 28 second-feet, and the springs practically went dry between 1902 and 1904.

The Major Johnson Springs occur along Pecos River, about 15 miles northwest of Carlsbad, N. Mex., chiefly in sec. 16, T. 20 S., R. 26 E. The water comes from one large opening in the bed of the river and from numerous smaller openings on the river banks or in its bed. The springs issue from crevices in a limestone member of the Chupadera formation, which is of Permian age. The discharge of these springs has been measured for many years by the United States Bureau of Reclamation and has been found to range from about 40 to at least 272 second-feet. The average discharge was estimated to be about 140 second-feet in the period from 1912 to 1915, about 100 second-feet in 1918, and about 230 second-feet in the period of 1921 and 1922. It has been demonstrated that the flow in excess of the minimum of 40 second-feet is due chiefly to leakage from the McMillan Reservoir, a few miles upstream, into sink holes in a bed of gypsum that underlies the limestone. On account of this artificial augmentation of the flow, the Major Johnson Springs are not included in this paper with springs of the first magnitude.

When all the water of Pecos River is stored or diverted at the Avalon Reservoir, several miles upstream from Carlsbad, about 80 second-feet of ground water appears in the river bed in a stretch of about 3 miles immediately above Carlsbad, between the large flume and the Tansel power dam. Several second-feet of this flow is contributed by the Carlsbad Spring proper, which is a beautiful spring of clear water. The water of this entire group of springs evidently issues from the same bed of limestone that supplies the Major Johnson Springs.

SPRINGS IN PALEOZOIC LIMESTONE IN OR NEAR THE GRAND CANYON OF ARIZONA

The tributaries of Colorado River in the vicinity of the Grand Canyon have cut deep through Carboniferous limestone and other Paleozoic rocks, and they receive much of their perennial flow from large springs that issue from the limestone. The following table gives the results of measurements of tributaries of the Colorado made by E. C. La Rue, hydraulic engineer, of the Geological Survey party that descended Colorado River in 1923. Mr. La Rue states that no doubt all these streams are spring-fed, although there is no information available as to the size of any individual springs except those at Lava Falls Rapids. None of the streams were affected by storms at the time they were measured, and therefore the measurements represent the low-water flow, which is no doubt the amount furnished by the springs.

Discharge, in second-feet, of spring-fed streams tributary to Colorado River in Arizona

[Measurements made by E. C. La Rue]

	Date (1923)	Discharge		Date (1923)	Discharge
Nankoweap Creek	Aug. 12	3.13	Havasu Creek	Sept. 13	74.5
Bright Angel Creek	Aug. 25	32.8	Group of Springs at Lava Falls Rapids	Sept. 20	[a]15.0
Shinumo Creek	Sept. 3	15.3	Diamond Creek	Oct. 4	2.24
Tapeats Creek	Sept. 9	93.9	Spencer Creek	Oct. 11	4.43
Deer Creek	Sept. 10	8.21			
Kanab Creek	Sept. 11	3.84			

[a] Estimated.

A spring of first magnitude has been reported near the mouth of Little Colorado River, but this report has not been verified. Unfortunately the Little Colorado was in flood in August, 1923, when the Geological Survey party passed its mouth, and hence it was impossible to obtain any information as to the amount of ground water that it discharges.

LARGE SPRINGS IN OTHER COUNTRIES

Large springs in other countries are beyond the scope of this paper. However, it is interesting to compare the famous Fontaine de Vaucluse, the largest spring in France, with the springs in the

United States. It issues almost from a single opening in a cliff of limestone at the head of a valley. According to Pochet,[3] the discharge of this spring ranged during a period of 10 years (1894–1903) from about 160 to about 5,300 second-feet and averaged about 800 second-feet. Thus its maximum discharge is probably much larger than that of any spring in the United States, and its average discharge is larger than that of any limestone spring in the United States. It fluctuates, however, through a wider range than any of the American springs for which data have been given, and hence with respect to minimum yield a number of American springs rank above it. According to computations by Keilhack[4] it discharges about 60 per cent of the water that falls as rain or snow upon its catchment area of 1,650 square kilometers, or 637 square miles.

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[3] Pochet, Léon, Études sur les sources, p. 424, Paris, Ministère de l'Agriculture, 1895.
[4] Keilhack, Konrad, Lehrbuch der Grundwasser und Quellenkunde, p. 317, Berlin, 1912.

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