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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGY AND GROUND-WATER RESOURCES OF THE SNAKE RIVER PLAIN IN SOUTHEASTERN IDAHO

Prepared in cooperation with the
IDAHO BUREAU OF MINES AND GEOLOGY
and the
IDAHO DEPARTMENT OF RECLAMATION

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BY

HAROLD T. STEARNS, LYNN CRANDALL
AND WILLARD G. STEWARD

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GEOLOGY AND GROUND-WATER RESOURCES OF THE SNAKE RIVER PLAIN IN SOUTHEASTERN IDAHO

By Harold T. Stearns, Lynn Crandall, and Willard G. Steward

ABSTRACT

The part of the Snake River Plain above King Hill, Idaho, is about 250 miles long and has a general eastward trend. This region and the alluvial valleys immediately tributary to it contain about 16,000 square miles. The principal cities in the region are Pocatello, Idaho Falls, and Twin Falls. The discharge of the Snake River at King Hill averages about 9,000,000 acre-feet a year.

The chief purpose of the investigation here recorded was to obtain data regarding the source, movement, and disposal of the ground-water supply of the lava plains that occupy most of the region. By assembling and correlating numerous well records obtained in this and related investigations, tied together by a system of levels, it has been possible to prepare a map of the region showing contours of the water table. This map (pl. 19) shows the direction of movement of ground water in all parts of the region and hence largely indicates the source and disposal of the water. As the altitude of most places in the region is known, this map makes it possible to predict the depth necessary for a well to obtain water. The total annual ground-water supply of the Snake River Plain is here estimated at 4,000,000 acre-feet, of which only a small part is now utilized for irrigation. One result of the study is the conclusion that, in order to conserve this supply, it is desirable so far as practicable to confine future irrigation development to the southeast side of the Snake River above Milner, so that the seepage water may return to a stretch of the river where it will be available for reuse. By heeding this hydrologic condition more land can be irrigated with the remaining available water supply than will be possible if the water is used on the northwest side of the river, because most of the return flow from the northwest side enters the river at too low an altitude to be used again.

The geology of the region in its relation to water supply has been studied with care, and much new information of many kinds has been obtained. One of the principal results of this study is the conclusion that the exceptionally large springs along the canyon of the Snake River owe their existence to the fact that the modern canyon intercepts a series of roughly parallel former canyons of the river that are now filled with especially permeable lava and hence serve as channels for ground water. The coves present where many of the springs emerge are thought to have been formed to some degree by solution. Light is thrown on other peculiarities of the behavior of ground water in basalt by a study of the exceptionally well exposed and very recent volcanic area of the Craters of the Moon National Monument.

The losses and gains in different stretches of the Snake River are estimated on the basis of available stream-flow records. An inventory of the water supply of the plain and its tributary valleys is made. The springs in and near the Snake River Plain are described, and all available records of their discharge are tabulated. Many of the heretofore unpublished ground-water conditions in both the plain and the tributary valleys are summarized.

INTRODUCTION

LOCATION AND AREA

The Snake River, the largest of the tributaries of the Columbia, is the drainage channel for the greater part of the State of Idaho. The South Fork enters southern Idaho from its source in Wyoming and contributes an average annual discharge of nearly 5,000,000 acre-feet. Henrys Fork, which rises in Henrys Lake and derives its waters chiefly from sources in Idaho, contributes an average of fully 1,250,000 acre-feet annually. Below the junction of the two forks the river takes first a southwestward and then a westward course through southeastern Idaho. In addition to the surface stream, a great quantity of water percolates underground, largely through the system of ancient channels of the Snake River that are now filled and covered with permeable lava, and reappears in many large springs in the canyon of the river above King Hill. The total discharge of these springs amounts to about 4,000,000 acre-feet a year. At Weiser, where the Snake River leaves southern Idaho, it has an average annual discharge of about 13,000,000 acre-feet. For more than 200 miles north of Weiser it forms the boundary between Idaho and the neighboring States of Oregon and Washington, and after receiving the inflow from the Salmon and Clearwater Rivers and from tributaries in Oregon and Washington, it leaves Idaho at Lewiston, where its average annual discharge is about 40,000,000 acre-feet. Plate 1 shows the major features of the topography of this part of Idaho. The waters of the Snake River have aptly been called the lifeblood of Idaho. The river with its tributaries furnishes water for irrigating about 2,000,000 acres of land in this State.

This report deals with the part of the Snake River Plain above the town of King Hill and with the valleys immediately tributary thereto. According to the official definition by the United States Geographic Board, this plain comprises the broad valley of the Snake River, which has a rather gently rolling surface mainly underlain by Snake River basalt and related sediments, beginning near the towns of Spencer, Kilgore, and Ashton, in northeastern Idaho, and extending south and west across the entire State to the point where the valley narrows sharply in the vicinity of Huntington, Oreg. In the region covered by this report the Snake River Plain is about 250 miles long, averages 70 miles in width, and covers about 12,500 square miles. The tributary valleys, whose conditions are described in this report, cover an additional area of about 3,000 square miles. The principal cities in the region and their population, according to the census of 1930, are Pocatello, 16,471; Idaho Falls, 9,429; and Twin Falls, 8,787. As shown in plate 4, the region is traversed by two main lines of the Union Pacific Railroad, one extending westward and one northward from Pocatello. Several branch lines connect with these two main lines.

PURPOSE AND HISTORY OF THE INVESTIGATION

The main purpose of the present investigation was to determine the direction of movement of the ground water in the Snake River Plain above King Hill and the respective amounts of water contributed to the great underground reservoir by seepage from the Snake River and tributary streams, from precipitation on the plain itself, and from irrigation water that percolates below the root zone. Efforts were made also to ascertain where the water lost from certain stretches of the Snake River returns to the river and the time involved in the passage of this water underground. The geology of the region was studied to show the occurrence of the ground water and the geologic structure that affects its movement. (See pls. 4, 5, and 6.) To determine the direction in which the ground water is moving in different parts of the region, the position of the water table (or upper surface of the body of ground water) was found by measuring the depth to the water level in as many wells as possible and by connecting the reference points at the wells with a network of levels. From these data the contours of the water table given in plate 19 and the lines showing depth to ground water in plate 18 were drawn. All reliable records of wells were assembled and studied to determine the changes in the water levels in the wells as a result of differences in precipitation and irrigation development. Dye was used in open cuts and in wells to show the rate of ground-water movement. The movements of ground-water crests through certain areas were studied for the same purpose.

The investigation was begun by the United States Geological Survey May 1, 1928, and was under the general direction of O. E. Meinzer, geologist in charge of the division of ground water. It was conducted in cooperation with the Idaho Bureau of Mines and Geology and the Idaho Department of Reclamation. The North Side Canal Co., the Twin Falls Canal Co., the Minidoka and Burley irrigation districts, and the Idaho Power Co. cooperated financially through the Idaho Department of Reclamation.

During recent years investigations have been made by private and governmental agencies relating in large part to the ground-water conditions of this region, but practically none of the results of these investigations have yet been published. One of the main tasks of the present investigation was the assembling and interpretation of the data in the unpublished reports on these investigations.

Mr. Crandall, now district engineer of the United States Geological Survey at Idaho Falls, spent about 15 years investigating the duty of water, canal losses, and ground-water conditions on the North Side Twin Falls tract and in the Big Lost and Little Lost River Valleys. Much of his work is published here for the first time. He is the author of the text concerning losses and gains in the Snake River, the inventory of the water of tributary valleys, and the inventory of the surface and ground waters in the Snake River Plain above King Hill, except the part relating to the economic use of water and portions of the text relating to consumptive use of water by crops, which were written by Mr. Steward. Mr. Crandall is joint author with Mr. Stearns of the text describing the valleys of the Big Lost, Little Lost, Big Wood, and Little Wood Rivers. In addition he wrote the part relating to the climate and the rate of flow of the ground water. He compiled most of the discharge measurements of the big springs in the Snake River Canyon.

Mr. Steward was responsible for the immense task of collecting, assembling, and checking all well data. In this work he was assisted by H. G. Haight, L. H. Perrine, John McDonnell, J. H. Boone, B. D. Alvord, Jr., and L. T. Burdick. Mr. Steward gave much valuable advice, based chiefly on his long experience in studying ground-water problems during the 20 years he was a member of the United States Bureau of Reclamation engaged largely in research problems in Idaho. He is also author of the text relating to ground water on the Minidoka project and part of that on the South Side Twin Falls tract.

The ground-water conditions on the Blackfoot-Fort Hall and Aberdeen-Springfield tracts were in part described by Mr. Haight. In addition he collected many of the trees and wrote much of the section on tree rings in relation to climate, although all three authors contributed to this section. He aided also in the preparation of the illustrations and in many other ways. C. L. Gazin contributed the data regarding fossils in the Hagerman lake beds. M. N. Short, formerly of the United States Geological Survey, examined the thin sections of the rocks in this region, and prepared a brief report on them which was utilized in this paper.

J. L. Saunders, of the United States Geological Survey, compiled the base maps and plotted the well data on them. This was a difficult task because the well records for each project had a different datum—a condition which required the adjustment of all measuring points to the sea-level datum of the United States Coast and Geodetic Survey.

Prior to this investigation Mr. Stearns spent most of 1921, 1922, and 1923 and parts of 1925 and 1926 in geologic field studies in and immediately adjacent to the region covered by the present report, and all pertinent results of his work during this period are incorporated herein except for the Soda Springs and Mud Lake areas. Mr. Stearns wrote all the text not specifically credited above to his collaborators. In connection with the present investigation, from 1928 to 1930, he mapped in detail the geologic formations along the canyon of the Snake River between King Hill and a point 10 miles downstream from Blackfoot in order to determine the relations of the older Pleistocene and Tertiary rocks, which in the greater part of the region are hidden under a cover of later Pleistocene basalt and of loess. Because of the lack of adequate base maps for areas at a distance from the river, this work was confined to a strip generally less than 2 miles wide. All available geologic data are incorporated in generalized fashion on plate 4 and those portions of the canyon of the Snake River whose geology cannot be adequately shown on this small-scale map are represented in plates 5 and 6.

ACKNOWLEDGMENTS

The writers are indebted to the personnel of various irrigation projects in the region for many valuable well records and maps. The work was facilitated by the generous and helpful attitude of the late Mr. Burton Smith, former manager of the Twin Falls Canal Co.; Mr. E. B. Darlington, superintendent of the Minidoka Irrigation Project; Mr. R. E. Shepherd, manager of the North Side Canal Co.; and Mr. W. C. Paul, president of the Minidoka irrigation district—all of whom gave a considerable amount of their time and that of their staff. The Oregon Short Line Railroad, the Idaho Department of Public Welfare, the United States General Land Office, and the United States Forest Service furnished most of the data from which some of the base maps in this report were compiled. Numerous residents and drillers in the region supplied records of wells, and several of them donated fossils that were valuable for the determination of the age of the formations. Mr. Elmer Cook, of Hagerman, pointed out significant fossil localities in the Hagerman lake beds. Acknowledgments pertaining to particular areas are made in several places in this report.

Valuable criticisms of the manuscript were made by Messrs. O. E. Meinzer, C. P. Ross, and G. R. Mansfield of the United States Geological Survey.

GEOGRAPHY

SURFACE FEATURES

SNAKE RIVER PLAIN

The Snake River has its source on the Continental Divide, in the southern part of Yellowstone National Park. It flows southward through Wyoming for about 75 miles, enters Idaho, and at Heise emerges from its mountainous headwater area, into the great Snake River Plain. A short distance farther downstream it is joined by its major tributary, Henrys Fork, which drains the upper part of the Snake River Plain. This plain extends for more than 300 miles entirely across southern Idaho, roughly along the arc of a circle. The Snake River flows near the southern boundary of the plain, a position that has been forced upon it by lava flows, which cover the region between the present river and the northern edge of the plain and which have displaced the stream from its ancient channel in the axis of its valley. Plate 2 shows the locality where the river enters a canyon cut in the lava at Milner. The canyon becomes deeper westward until near Twin Falls it is bounded by precipitous lava cliffs about 600 feet high. The Snake River continues in a canyon nearly to King Hill, a distance of about 90 miles. The topography of the region is illustrated by the relief map, plate 1.

Irrigated lands adjoin the river on both sides, extending for a distance of 10 or 12 miles and leaving the major part of the uninhabited plain as a great curved segment between the irrigated sections on the south and the mountains that border the plain on the north. Although this region presents from afar the appearance of a great level valley floor it has been built up by successive lava flows from numerous vents within the valley itself. Its topography is determined by the source and extent of these lava sheets and not by erosion, except that the Snake River and several tributary streams have cut deeply into it.

Though vegetation in one form or another covers much of the area, the desolate black lava flows, the drifting white sand dunes, and the bleak, bare lake beds serve to impress upon the traveler the desert character of the country. Throughout many square miles in the central part of the plain water can be found only in the ice caves in the lava flows or at some stock well at which the water is pumped hundreds of feet. With the increase in the area irrigated on the plain the people inhabiting the area have come more and more to refer to the irrigated part of the plain as the "Snake River Valley." About 1,000,000 acres is now under irrigation in "the valley," and not a small part of it lies hundreds of feet above the Snake River, on the surface of the plain. In the section of the report treating the irrigation development it is convenient to use the term "the valley" to refer to irrigated parts of the plain.

The altitude of the Snake River at Heise, where the stream first emerges from the foothills, is about 5,000 feet. At King Hill, about 250 miles downstream, the altitude is 2,500 feet. The stream thus descends at an average rate of about 10 feet to the mile. About 500 or 600 feet of this difference in altitude between Heise and King Hill, however, is concentrated in falls at Idaho Falls, American Falls, Twin Falls, Shoshone Falls, and other places, so that the average grade of the stream exclusive of these falls is about 8 feet to the mile. The altitude of the plain into which the river canyon is incised ranges from 5,100 feet at Ashton to 3,200 feet near King Hill and averages about 4,400 feet.

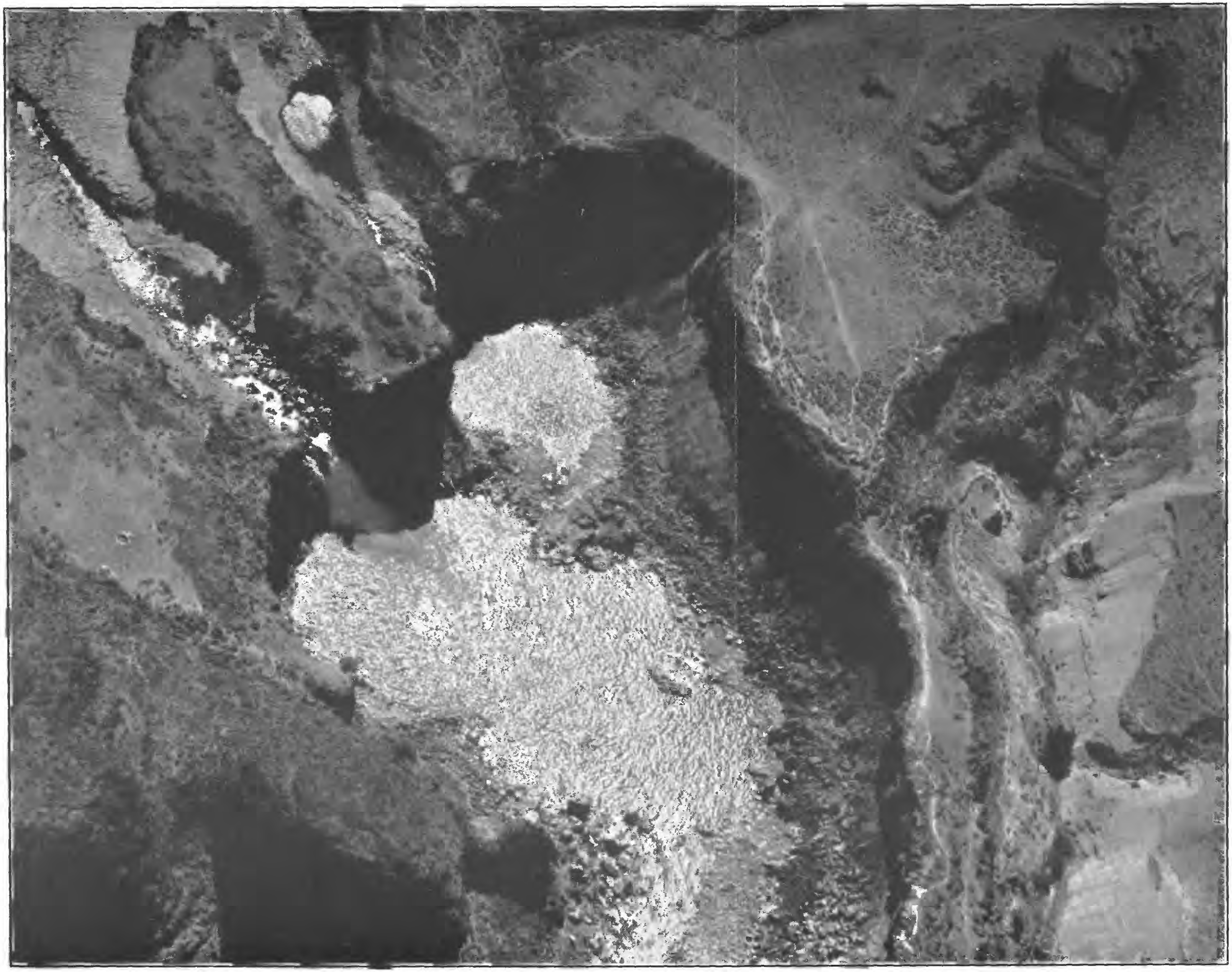
BUTTES

The generally flat appearance of the plain is relieved by several buttes, chief among which are Big Southern Butte, West Twin Butte, and East Twin Butte, which stand prominently above the general land surface about 30 miles northwest of Blackfoot. Big Southern Butte rises 2,350 feet above the surrounding plain. It is called by the

RELIEF MAP OF THE SNAKE RIVER PLAIN AND ADJACENT VALLEYS.

AIRPLANE VIEW OF MILNER LAKE, THE TWIN FALLS CANALS, AND THE CANYON OF THE SNAKE RIVER.

Photo by U. S. Army Air Corps.



AIRPLANE VIEW OF TWIN FALLS AT A LOW STAGE OF THE RIVER.

A resistant basalt bed 120 feet thick causes the falls. The sand banks in the gulch on the right are mined for flour gold and have yielded bones of extinct animals. Photo by U. S. Army Air Corps.

AIRPLANE VIEW OF SHOSHONE FALLS ON SNAKE RIVER SHOWING THE MASSIVE ANDESITE FLOW THAT FORMS THE FALLS.

The falls are dry because the entire flow of the river has been diverted for irrigation. The power plant on the left utilizes all the spring water and return flow that reaches the river below Milner. Photo by U. S. Army Air Corps.

Indians "Be-ah Car-did" (great stay), referring to its permanence. It may be seen from points over 100 miles distant. East Twin Butte rises about 1,100 feet and West Twin Butte about 800 feet above the adjacent plain.

There are many lower buttes scattered over the lava plain, all of which, unlike the three just mentioned, are extinct basaltic volcanoes (pl. 4). Among these may be mentioned Notched Butte; Sugar Loaf Butte, south of Shoshone; Big Cinder Butte, in the Craters of the Moon National Monument west of Arco; and the Menan Buttes, near Roberts. Besides the cones that are prominent enough to have been individually named, there are innumerable minor elevations that can be discerned if the surface of the plain is viewed against the sky line. These features rise to heights of 100 to 300 feet, but their bases, commonly 4 to 6 miles or more in diameter, are so broad that their slopes merge gradually into each other or into the surrounding plain. These minor elevations are also volcanic vents, and from those now visible as well as from many others buried by later eruptions, vast quantities of highly fluid lava formerly flowed in all directions.

FALLS OF SNAKE RIVER

There are many falls along the Snake River, some of which are large and spectacular. However, so much of the water is being used for irrigation that many of them are dry in the summer. The locations of most of the falls and principal rapids are shown on plates 4, 5, and 6. Shoshone and Twin Falls are by far the largest. The former is 200 feet high and results from the superposition of the river on the Shoshone Falls andesite as a result of displacement from its former channel by the Sand Springs basalt. The fall at a period of low water is shown in plate 7. Twin Falls is caused by the river's tumbling over a massive bed of basalt 120 feet thick (pl. 3). The other falls along the Snake River within the region studied are 45 feet or less in height.

TRIBUTARY STREAMS

Many perennial streams, of which the largest are the Blackfoot and Portneuf Rivers, flow into the Snake River from the south, but between the mouth of Henrys Fork, in the extreme northeastern part of the area, and the mouth of the Big Wood River, near Bliss, in the southwestern part, a distance of about 250 miles measured along the stream, the Snake River does not receive a single surface tributary from the north. The drainage area north of the plain is occupied by lofty mountains which rise to altitudes as great as 12,500 feet and the run-off from which forms many streams that sink at the north edge of the lava plain. Part of this run-off flows beneath the lava sheets near the mouths of the valleys through the gravel deposits which were laid down by the ancestral tributary streams and which underlie or are interstratified with the lavas, and a part passes through the lavas that fill these ancient valleys. The flood waters usually form shallow ponds or lakes in depressions on the surface of the Snake River Plain, from which the water not lost by evaporation sinks to the deep underlying water table. Big Wood and Little Wood Rivers are the only streams that succeed in crossing the lava plain, principally because of the more favorable topography along these rivers and the narrowness of that part of the belt of lavas that separates the mountains from the Snake River.

CLIMATE

TEMPERATURE

The mean annual temperature of the Snake River Plain east of King Hill ranges from 41° F. at Ashton (altitude 5,100 feet) to 50° at Bliss (altitude 3,270 feet). In parts of the mountainous areas bordering the plain the mean annual temperature is probably lower. A table showing the mean monthly and annual temperatures at 16 stations on the Snake River Plain is given below.

Temperatures in southern Idaho (° F.)

[From records of the U. S. Weather Bureau]

Station	Length of record (years)	January	February	March	April	May	June	July	August	September	October	November	December	Yearly mean
Arco	--------	14.8	20.1	29.9	36.3	58.9	61.1	65.0	64.0	54.7	44.8	31.6	18.6	41.7
Blackfoot	32	21.9	26.5	38.9	44.9	53.2	61.6	65.3	66.1	56.5	45.4	34.5	22.8	44.7
Boise	65	29.4	34.9	42.7	50.4	57.1	65.3	72.9	71.8	61.9	51.1	41.0	32.1	52.3
Buhl	21	28.0	33.3	40.1	48.1	55.8	64.3	72.9	66.2	60.2	49.6	39.6	28.4	49.2
Burley	11	27.3	32.3	38.8	45.6	55.9	64.3	72.5	69.0	59.5	48.4	38.0	27.7	48.2
Caldwell	24	28.7	35.4	43.2	50.5	57.4	65.3	73.1	68.8	60.7	50.3	39.5	30.7	50.3
Emmett	22	29.3	36.3	44.0	51.5	58.8	67.0	75.1	72.6	63.3	52.2	40.8	30.2	52.4
Fort Hall	14	21.2	28.6	36.2	44.4	53.4	61.8	69.9	66.4	57.0	46.4	35.0	23.4	45.3
Glenns Ferry	20	27.7	35.5	44.0	50.7	58.9	69.0	78.5	74.6	62.5	49.8	39.3	28.7	51.6
Gooding	19	24.2	29.2	39.0	46.7	55.2	63.3	71.4	68.5	58.8	48.1	37.4	25.7	47.3
Idaho Falls	34	19.6	23.4	33.6	44.4	53.9	60.5	68.5	66.5	56.8	45.9	43.5	22.2	44.0
Mackay	--------	17.2	20.9	31.0	41.8	51.0	59.4	67.2	64.6	55.3	44.6	31.0	19.6	42.1
Milner Dam	18	27.1	31.0	39.8	47.0	55.0	61.7	70.9	69.5	60.4	48.6	[1] 37.8	26.4	47.9
Oakley	35	28.6	31.8	38.7	46.2	53.9	62.4	70.7	69.2	59.4	49.2	38.8	28.7	48.2
Rupert	22	25.5	30.7	38.6	46.6	54.7	61.9	70.9	67.7	58.1	48.4	37.7	26.5	47.4
Twin Falls	23	27.8	32.4	39.5	47.2	54.9	62.4	70.6	67.9	58.9	48.3	38.0	27.9	47.9
Mean	25.7	26.2	31.5	39.6	47.4	55.6	63.7	71.7	68.9	59.8	48.7	38.6	27.2	48.3

[1] Mean of Burley and Rupert.

At Ashton the average date of the last killing frost in the spring is June 7 and that of the first killing frost in the fall is September 11. At Bliss the dates are May 10 and October 4. July is the month of maximum temperature, the mean for that month ranging from 71° at the lower altitudes to 63° at the higher altitudes on the plain. January is generally the month of minimum temperature, with a range in the mean temperature from 28° to 18° at different stations on the plain.

Like other continental interior areas of fairly high altitude, the Snake River Plain has a large daily range of temperature. The difference between the mean daily maximum and mean daily minimum is about 20° during the winter and about 38° during the summer, but occasionally much greater variations are experienced. The summers are characterized by hot days and cool nights. Now and then the temperature is 100° or more for a few days at a time, and it has reached a maximum of 106°. On account of the dryness of the atmosphere, however, the daytime heat is less oppressive than it is in more

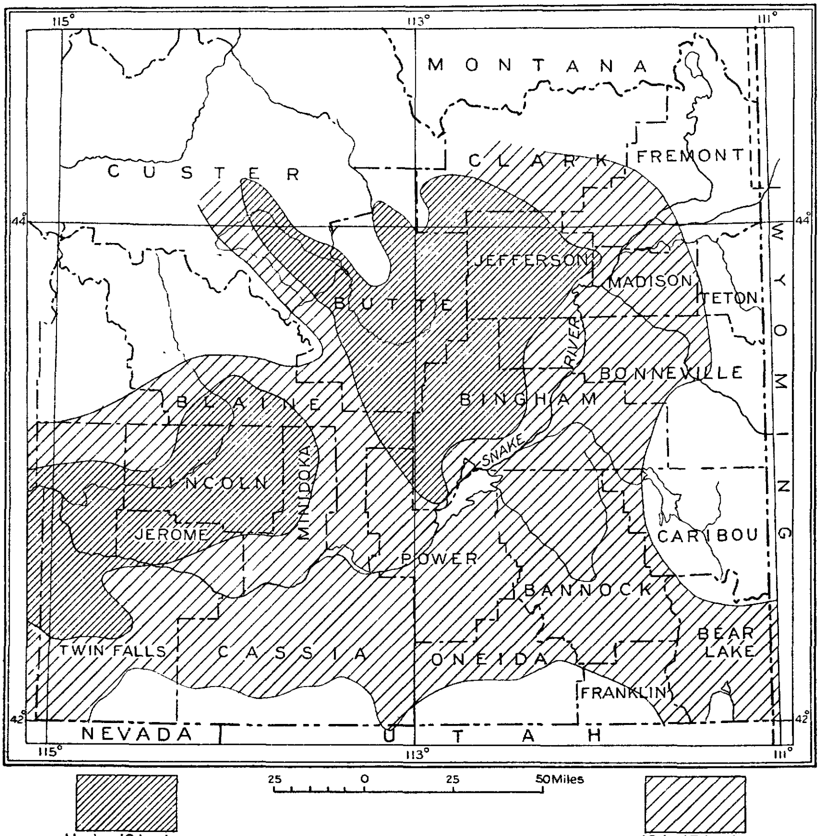


FIGURE 1.—Map of southeastern Idaho showing distribution of precipitation. Areas without pattern have an average annual precipitation of more than 15 inches.

humid regions, and as the clear summer nights allow rapid radiation from the heated land surface, the temperatures become comfortably cool shortly after darkness falls. During the winter the temperature frequently falls below zero and has dropped as low as 40° below zero at the entrances to some of the tributary valleys. In ordinary winters the minimum temperature reached on the plain is from 10° to 20° below zero. In the small area within the Snake River Canyon below Twin Falls and including the Hagerman Valley the temperature at all times is noticeably higher than on the adjacent uplands, doubtless because of the sheltered location and lower altitude of these lands.

PRECIPITATION

Precipitation on the Snake River Plain ranges from an annual average of less than 9 inches in some areas of the north-central and western parts to about 14 inches in some of the eastern, southern, and northeastern areas. Toward the mountain areas that contain the head-

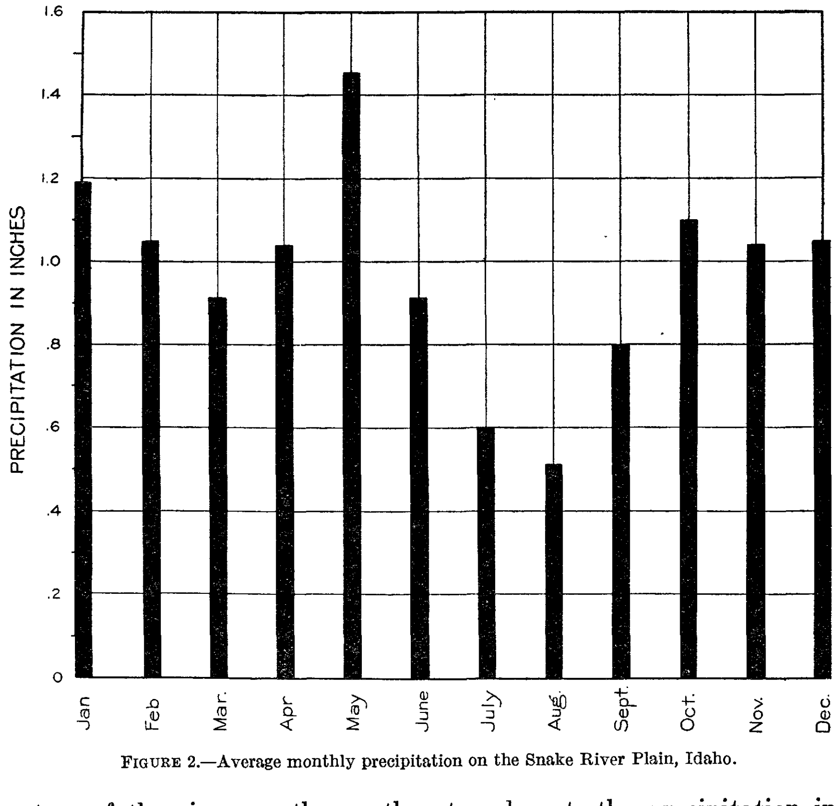


FIGURE 2.—Average monthly precipitation on the Snake River Plain, Idaho.

waters of the river on the northeast and east, the precipitation increases, exceeding 20 inches at high altitudes.

The general distribution of the precipitation is shown in figure 1. Records are lacking to show the precipitation at high points between the tributary valleys, hence there are probably local areas of higher precipitation than are indicated on this map. Unlike many other semiarid regions, the Snake River Plain is favored with a fairly uniform distribution of precipitation throughout the season, as shown by figure 2. The relatively high precipitation during the spring and early summer is probably in large part of local origin and supplied by the reprecipitation of the moisture evaporated from the melting snow fields in the foothills and mountains during these months.

Continuous records of precipitation in the upper part of the plain are not available for the years prior to 1891, but the average annual precipitation at American Falls, Ashton, Blackfoot, Idaho Falls, Oakley, and Pocatello, six stations with long-time records, is shown in figure 3

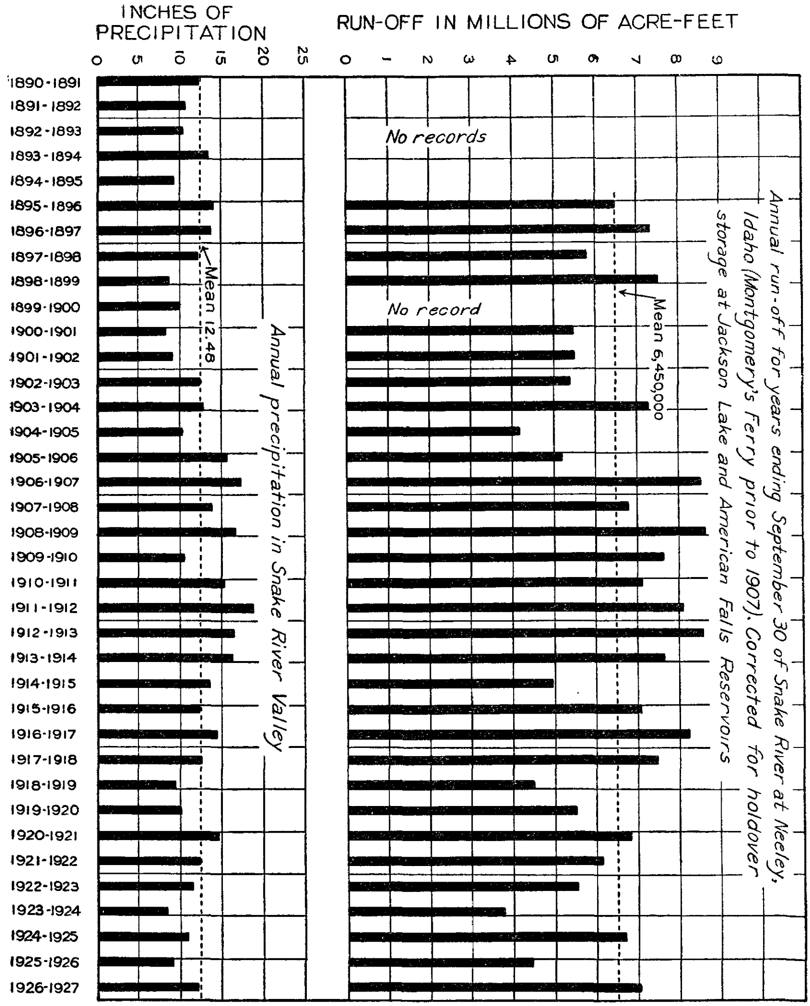


FIGURE 3.—Average annual precipitation and run-off in the Snake River Plain, by years ending September 30, 1891–1927.

together with the discharge of the Snake River at Neeley, corrected for storage hold-over at Jackson Lake and American Falls during the years of record. The table on page 12 gives the mean monthly and annual precipitation at these and other stations for years of record from 1891 to 1927.

The years of high precipitation from 1906 to 1917 constituted the period of great development of dry-farm wheat lands on the Snake River Plain, especially north of the Snake River between Idaho Falls and Minidoka. Most of these lands have been abandoned since 1918, owing to inadequate rainfall and it would thus appear that an average annual precipitation of about 15 inches is essential to successful dry farming in this region.

Mean monthly and annual precipitation, in inches, at stations in the Snake River Plain and tributary areas, 1891–1927

Station	Length of record (years)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Albion	13	1.20	1.35	1.18	1.28	1.60	1.09	0.64	0.40	0.71	1.58	1.48	1.29	13.80
Almo	8	1.58	1.43	.37	.92	1.95	2.88	1.63	1.01	1.25	2.09	1.42	.80	17.33
Aberdeen	14	.53	.71	.65	1.07	1.28	.63	.62	.47	.82	1.02	.74	.59	9.13
American Falls	35	1.50	1.21	1.43	1.33	1.66	.94	.64	.54	.70	1.25	1.23	1.41	13.84
Arco	25	1.13	.59	.92	.83	1.38	1.16	.59	.53	.58	.67	.65	.87	9.90
Ashton	24	1.90	1.41	1.22	1.20	2.02	1.35	.91	.58	1.16	1.51	1.26	1.66	16.18
Blackfoot	31	.93	.79	.86	.94	1.41	.80	.74	.64	.83	1.11	.79	.85	10.69
Bliss	11	1.25	1.12	.63	.90	1.06	.26	.13	.17	.44	.90	1.27	.99	9.12
Buhl	20	.99	.96	.59	.96	1.23	1.01	.48	.22	.54	1.02	.99	.96	9.95
Burley	10	.78	.80	.45	1.54	1.02	.81	.41	.78	.74	1.12	.98	.89	10.32
Fort Hall	13	.58	.65	.92	1.34	1.34	.60	.71	.74	.92	1.12	.72	.67	10.31
Gooding	18	1.18	1.16	.53	.95	.83	.51	.40	.25	.52	.97	1.57	.98	9.84
Hailey	24	2.53	2.16	1.34	1.08	1.51	.91	.51	.46	.79	1.12	1.60	1.86	15.87
Hazleton	10	.99	1.27	.77	1.01	2.05	.58	.22	.51	.59	1.03	1.10	1.25	11.37
Hollister	16	.70	.88	.47	1.19	1.29	.80	.42	.44	.61	1.09	.81	.78	9.48
Idaho Falls	33	1.37	1.07	1.25	1.01	1.49	1.18	.65	.69	.90	.95	.85	1.15	12.56
Irwin	25	1.35	1.12	1.13	.98	1.87	1.22	1.00	.91	1.33	1.34	1.15	1.20	14.60
Jerome	12	.90	1.06	.65	1.03	.92	.45	.18	.32	.40	.95	1.01	.99	8.86
Mackay	19	.95	.84	.45	.69	1.18	1.06	.93	.78	.92	.70	.51	.73	9.74
Martin	6	2.06	1.28	3.14	.91	2.16	.80	.20	.32	.77	.63	1.79	1.54	15.60
Mud Lake	5	.60	.35	.53	.49	1.43	.61	.76	.81	.61	.72	.24	.85	8.00
Oakley	34	.81	.76	.85	1.13	1.36	1.05	.64	.63	.81	.98	.78	.58	10.38
Pocatello	28	.66	.95	1.65	2.02	2.20	.99	.63	.56	.88	.98	.55	.86	12.93
Richfield	13	1.40	.97	.67	.92	1.02	.70	.27	.20	.63	.91	1.22	.93	9.84
Rupert	21	1.20	1.04	.82	1.09	1.26	.87	.54	.53	.78	1.16	1.18	1.17	11.64
Shoshone	13	1.57	1.17	.55	.68	.91	.51	.24	.11	.70	.95	1.45	1.03	9.87
Spencer	6	1.38	1.64	1.38	1.06	2.48	.75	1.48	.80	1.68	1.61	.91	1.76	16.93
Springfield	19	1.02	.81	.64	1.03	1.31	.74	.69	.47	.87	1.13	.94	.85	10.50
Sugar	20	1.13	.82	.61	.84	1.71	1.13	.78	.46	1.10	1.16	.57	1.18	11.49
Twin Falls	22	1.24	1.01	.84	.97	1.14	.90	.43	.26	.70	.93	1.17	1.10	10.69
Wendell	18	1.46	1.15	.66	.99	.93	.81	.26	.21	.51	1.19	1.41	.86	10.44
Average		1.19	1.05	.91	1.04	1.45	.91	.60	.51	.80	1.09	1.04	1.05	11.65

The stream run-off reflects in a general way the fluctuations in precipitation from year to year, but the relation is not definite, probably in part because precipitation at the stations within the valley is not always an index to precipitation on the headwater areas, from which the stream run-off is principally supplied. The precipitation generally takes the form of snow during December, January, and February, and at the higher altitudes often also in November, March, and even April. The snow cover during the winter ranges from a few inches to several feet or more at different places and in different seasons and often melts during warm weather in the winter, particularly at the lower altitudes. The deep snows in the high mountains melt during May, June, and July and then form the source of the water supply that is used for irrigation in the valley.

The mean relative humidity at Pocatello averages about 50 percent for the year, with a daily range from 25 to 60 percent during the summer and 70 to 80 percent during the winter. The average wind velocity at Pocatello is 8.8 miles an hour, and the recorded maximum 58 miles an hour.

EVAPORATION AND TRANSPIRATION

Records of evaporation from water surfaces have been obtained at several stations in the region, principally in connection with studies of losses from reservoirs. Some are records from floating lake pans, others from pans of the standard class A type of the United States Weather Bureau. The annual evaporation as disclosed by these records ranges from less than 3 feet to about 6 feet, according to the location and type of the evaporation pan. The accompanying tables show total evaporation—that is, the sum of the measured loss plus the rainfall.

JEROME

Fragmentary records of evaporation during 1916 are available for Jerome, in Jerome County. Beginning in 1917 records were obtained from a standard class A Weather Bureau land pan in an irrigated blue-grass pasture in the vicinity of Jerome, in sec. 18, T. 8 S., R. 17 E. Boise meridian.

Evaporation data at Jerome, 1916–27

[Altitude 3,780 feet. From records of North Side Canal Co., Jerome]

Month	Mean air temperature (° F.)	Precipitation (inches)	Evaporation (inches): Land pan 6 feet in diameter, top flush with ground	Evaporation (inches): Pan 27 inches square, floating in canal
1916				
June	60.4	0.01	6.60	5.30
July	69.9	.40	7.60	4.95
August	68.2	.00	6.35	4.50
September	59.8	.00	5.07	3.36
Total or average	64.6	.41	25.62	18.11

Month	Mean air temperature (° F.)	Precipitation (inches)	Evaporation from U. S. Weather Bureau class A pan (inches)	Wind velocity (miles a month): Top of 20-foot building	Wind velocity (miles a month): Ground surface	Mean relative humidity (percent)
1917						
April	42.2	2.43	4.23			
May	52.9	1.34	6.40			
June	62.2	.00	9.17			
July	74.3	.09	8.20			
August	69.8	.00	7.03			
September	62.6	.54	3.60			
October	49.6	.00	2.40			
Total or average	59.1	4.40	41.03			
1918						
April 17–30	46.7	0.82	3.15	[1]6,544		46
May	53.0	1.37	9.39	5,827		48
June	71.2	1.15	8.92	4,060		51
July	73.8	.42	10.17	4,040		56
August	66.0	.42	7.53	4,965		58
September	61.8	.95	4.23	4,015		57
October	50.4	.96	2.13	4,730		72
November	36.0	.42	1.41	6,420		69
December	30.6	.54	.70	4,766		72
Total or average	54.4	7.05	47.63	5,041		59

[1] For full month.

Evaporation data at Jerome, 1916–27—Continued

Month	Mean air temperature (° F.)	Precipitation (inches)	Evaporation from U. S. Weather Bureau class A pan (inches)	Wind velocity (miles a month) Top of 20-foot building	Wind velocity (miles a month) Ground surface	Mean relative humidity (percent)
1919						
January	29.9	0.39	0.52	5,925		67
February	30.7	1.47	.45	6,199		77
March	38.6	1.21	1.65	6,625		63
April	50.0	.69	5.09	6,382		64
May	59.0	.05	7.50	6,739	2,510	46
June	66.0	.00	10.51	4,300	1,860	47
July	73.7	.00	9.37	4,805	1,550	42
August	72.9	.00	9.64	4,604	1,655	40
September	62.4	.70	5.35	5,383	2,081	49
October	42.6	.92	1.89	4,799		68
November	35.8	.97	1.09		2,320	69
Total or average	51.1	6.40	53.06	5,576	1,996	57
1920						
February	34.7	0.48	0.67	4,628		70
March	38.8	.68	2.65	4,223		72
April	44.3	1.15	4.31	7,995		59
May	54.8	.00	6.34		2,539	46
June	63.8	.44	6.97	4,653	1,523	38
July	74.9	.05	9.90	4,450	1,530	44
August	70.5	.28	6.42	4,640	1,490	43
September	61.8	.48	2.73		1,040	63
October	48.2	1.81	1.83		1,360	68
Total or average	54.6	5.37	41.82	5,098	1,580	56
1921						
April	44.3	1.16	3.96		2,876	
May	55.4	3.16	4.88		1,726	
June	65.6	.46	6.29		860	
July	72.0	.03	7.71		941	
August	70.9	.06	5.02		958	
September	54.8	.06	2.61		1,289	
October	52.2	.03	1.61		1,137	
Total or average	59.3	4.96	32.08		1,398	
1922						
April	42.6	1.64	3.89		3,127	
May	54.1	.74	6.63		2,449	
June	67.0	.87	6.65		683	
July	70.8	.05	6.51		966	
August	71.8	1.07	3.77		748	
September	61.6	.01	2.65		923	
October	53.1	.34	1.75		1,275	
Total or average	60.1	4.72	31.85		1,453	
1923						
April	47.1	1.35	3.72		1,384	
May	56.4	1.30	6.51		1,146	
June	61.2	1.03	6.50		701	
July	74.4	.08	9.79		691	
August	70.1	.27	7.64		484	
September	63.4	1.37	5.76		541	
October	47.2	2.02	3.10		983	
Total or average	60.0	7.42	43.02		847	
1924						
April	47.3	0.03	5.69		1,522	
May	61.6	.15	10.08		1,367	
June	65.8	.20	[1] 9.02		1,277	
July	73.8	.00	9.54		945	
August	71.0	.00	8.28		765	
September	63.5	.02	4.98		877	
Total or average	63.8	.40	47.59		1,125	

[1] Partly estimated.

Evaporation data at Jerome, 1916–27—Continued

Month	Mean air temperature (° F.)	Precipitation (inches)	Evaporation from U. S. Weather Bureau class A pan (inches)	Wind velocity (miles a month)		Mean relative humidity (percent)
				Top of 20-foot building	Ground surface	
1925						
June	64.3	0.70	7.87	----------	544	----------
July	76.8	.41	8.64	----------	479	----------
August	69 7	1.17	7.12	----------	683	----------
September	60.4	.35	4.16	----------	601	----------
Total or average	67.8	2.63	27.79	----------	577	----------
1926						
May	59.4	0.19	4.39	----------	964	----------
June	70.4	.03	6.87	----------	1,314	----------
July	76.0	.52	8.56	----------	1,030	----------
August	73.5	.15	8.82	----------	826	----------
September	56.2	.04	7.43	----------	1,039	----------
October	51.8	.25	4.83	----------	955	----------
Total or average	64.5	1.18	40.90	----------	1,021	----------
1927						
June	66.4	0.02	8.85	----------	898	----------
July	74.2	.00	8.42	----------	658	----------
August	70.6	.05	6.46	----------	474	----------
September	59.0	.41	5.49	----------	753	----------
Total or average	67.5	.48	29.22	----------	696	----------

Average evaporation at Jerome, 1917-27 from U. S. Weather Bureau class A evaporation pan

[Records from North Side Canal Co., Jerome]

Month	Relative humidity (percent)	Mean temperature (° F.)	Precipitation (inches)	Evaporation (inches)	Wind velocity (miles a month)	
					20 feet above ground surface	Ground surface
January	67	26.7	0.90	0.52	5,925	----------
February	73	32.2	1.06	.56	5,414	----------
March	67	38.3	.65	2.15	5,424	----------
April	57	47.2	1.03	4.26	6,974	2,227
May	47	56.4	.92	6.90	6,283	1,814
June	45	65.7	.45	7.96	4,338	1,073
July	47	73.7	.18	8.80	4,432	977
August	47	70.5	.32	7.07	4,736	898
September	57	60.4	.40	4.45	4,699	1,016
October	69	49.8	.95	2.44	4,764	1,142
November	69	38.5	1.01	1.25	6,420	2,320
December	72	28.9	.99	.70	4,766	----------
Total or average	60	49.0	8.86	47.06	5,348	1,433

PIONEER IRRIGATION DISTRICT

Evaporation and transpiration data are available for the Pioneer irrigation district, near Caldwell, in Canyon County. Pan A was a galvanized-iron tank 4 feet square and 3 feet deep, set about 2 feet in the ground in a swamp and surrounded by water from 0.3 to 0.4

foot deep. The space within the pan was planted to cattails or tules, which grew abundantly in the surrounding area. The pan was filled with water twice a week to maintain conditions similar to those in the surrounding swamp.

Pan B was of the same dimensions as pan A. It was set in the ground about 2.8 feet, in a water-logged area, and was filled with soil to the same level as the surrounding ground. In the pan were planted strips of blue grass about 8 inches wide, with intervening 8-inch strips of bare soil. The water level in the pan was maintained from 1.5 to 2 feet below the surface by means of pipes that supplied the water from beneath, so that it rose in the soil from below, as under ordinary field conditions in water-logged areas.

Pan C was a standard Weather Bureau class A evaporation pan, 4 feet in diameter and 10 inches deep, set on a platform of 2- by 4-inch planks resting on the ground.

Evaporation and transpiration in the Pioneer irrigation district, 4 miles southeast of Caldwell, Boise Valley, Idaho [1]

[Altitude 2,370 feet]

Date	Mean temperature (° F.)	Precipitation (inches)	Evaporation and transpiration from soil (inches)		Evaporation from free water surface (pan C) (inches)
			Pan A	Pan B	
1918					
June 12-30	73.6	0.25	6.01	4.23	4.60
July	73.8	.50	13.00	6.23	7.26
August	67.2	.24	14.10	4.13	4.70
September	64.8	1.87	7.20	2.91	2.83
October	54.0	1.47	3.25	1.28	1.28
The period	66.7	4.33	43.56	18.78	20.67
1919					
April 3-30	53	0.85	4.84	4.09	4.77
May	57	.00	6.70	5.60	8.27
June	67	.00	8.92	5.80	8.15
July	74	.00	14.27	6.37	8.30
August	72	.00	13.10	4.20	6.10
September	63	.37	7.86	2.38	3.83
October	45	.52	2.99	2.14	2.29
The period	62	1.74	58.68	30.58	41.71

[1] Steward, W. G., and Coffin, M. H., Experiments conducted to show the comparative evaporation from swamped areas in the Pioneer irrigation district": U. S. Bur. Reclamation unpublished report, Boise, Idaho, 1920.

MILNER

Records of evaporation have been obtained at Milner, in Twin Falls County, in sec. 29, T. 10 S., R. 21 E. The land pan at this point is a standard class A Weather Bureau pan surrounded by bare uncultivated soil. The lake pan is 4 feet in diameter and 10 inches deep, floated on a raft in Milner Lake.

Evaporation at Milner [1]

[Altitude 4,200 feet. From records of Twin Falls Canal Co.]

Month	Monthly mean temperature (° F.)	Precipitation (inches)	Evaporation (inches)		Wind movement per month (miles)
			Land	Floating pan	
1927					
April	45.0	1.02	4.53	4.02	2,790
May	52.0	2.14	6.24	5.79	2,940
June	64.8	.40	8.48	7.27	1,832
July	73.7	.00	10.60	9.20	1,631
August	68.6	.19	8.09	7.20	1,015
September	58.8	.92	5.31	6.69	1,247
October	51.2	.48	3.71	4.11	1,569
November	42.2	1.08	1.41		2,124
Total or average	57.0	6.23	48.37	44.28	1,893
1928					
March 17-31	41.1	0.99	1.00		
April	44.1	.41	6.43	5.66	3,445
May	61.0	.14	8.14	7.38	2,013
June	60.2	1.43	8.34	7.27	2,241
July	72.8	.00	8.70	10.14	1,226
August	67.7	.00	9.00	10.06	1,230
September	61.9	.00	5.49		927
October	49.6	.72	2.53		
Total or average	57.3	3.69	49.63	40.51	1,847

[1] During several of the months shown in the table the lake-pan results at this station are higher than the land-pan results, owing to some undetermined cause. The land-pan results are believed to be more reliable during such periods than those from the lake pan. During the period from Dec. 1, 1927, to Mar. 17, 1928, the land pan was frozen and received precipitation of 1.65 inches, mostly in the form of snow. When the snow and ice had melted, on Mar. 17, 1928, the amount of water remaining in the pan indicated a total evaporation since Dec. 1, 1927, of 0.71 inch. This result may have been affected by snow blown in or out of the pan by winds.

STERLING

Records of evaporation were obtained at Sterling, in sec. 33, T. 4 S., R. 32 E., adjacent to the American Falls Reservoir, in Bingham County. The land pan was a standard United States Weather Bureau class A evaporation pan resting on a frame of 2- by 4-inch planks fully exposed to sun and wind and surrounded by bare ground. The lake pan was 4 feet in diameter and was placed on a small raft chained within a larger raft near the west shore of the American Falls Reservoir near Sterling.

Evaporation at Sterling [1]

[Altitude 4,400 feet]

Month	Mean temperature (° F.)	Precipitation (inches)	Evaporation (inches)	
			Land pan	Lake pan
1927				
May	50.2	1.80	7.95	
June	61.8	.28	10.95	7.73
July	69.1	.11	13.03	9.72
August	64.6	.74	9.83	7.70
September	55.2	1.43	6.65	4.78
October 1-15	47.4	.06	2.60	2.11
Total or mean	58.0	4.42	51.01	32.04
1928				
June	57.0	.78	9.90	7.37
July	68.8	.45	11.76	8.48
August	64.2	.10	11.00	7.91
September	58.0	.13	6.87	4.76
October 1-17	45.8	.47	2.40	1.58
Total or mean	58.8	1.93	41.93	30.10

[1] Newell, T. R., Segregation of water resources, American Falls Basin and American Falls Reservoir: Unpublished repts. to Committee of Nine, Water District 36 ,1927-28.

AMERICAN FALLS AND MICHAUD

Records of evaporation were obtained at American Falls and Michaud, in Power County. The pans at both places are standard United States Weather Bureau class A land pans, situated adjacent to the American Falls Reservoir. The American Falls pan is in sec. 20, T. 7 S., R. 31 E., and the Michaud pan is in sec. 1, T. 6 S., R. 33 E. Both pans are surrounded by uncultivated ground and are about 4,400 feet above sea level.

Evaporation at American Falls and Michaud [1]

[Altitude 4,400 feet]

Month	Mean temperature (° F.)	American Falls		Michaud	
		Precipitation (inches)	Evaporation (inches)	Precipitation (inches)	Evaporation (inches)
1928					
June	57.0	1.49	9.50	1.16	9.26
July	68.8	.63	11.48	.30	10.58
August	64.2	.25	11.04	.39	10.17
September	58.0	.21	7.12	.23	6.80
October 1-17	45.8	.50	2.60	.39	2.33
Total or average	58.8	3.08	41.74	2.47	39.14

[1] Newell, T. R., Segregation of water resources, American Falls Basin and American Falls Reservoir: Unpublished repts. to Committee of Nine, Water District 36, 1927-23.

MUD LAKE REGION

Evaporation and transpiration records have been obtained at Mud Lake, in Jefferson County, and are included in the report on that region.[1]

SUMMARY OF EVAPORATION LOSSES

It is well known that evaporation as measured by land pans or even by floating lake pans is greater than the evaporation from large water surfaces.[2] In the following table the figures for the open-water months are based on measured evaporation from the lake pans at Milner and American Falls, multiplied by a coefficient of 90 percent to give reservoir evaporation losses, and those for the winter months on the Jerome records for evaporation from ice and snow surfaces.

Computed average evaporation and loss from large water surfaces in the Snake River plain

[+ indicates gain]

Month	Evaporation (inches)	Precipitation (inches)	Net gain or loss (inches)	Month	Evaporation (inches)	Precipitation (inches)	Net gain or loss (inches)
January	0.52	1.19	+0.67	August	6.91	.51	−6.40
February	.56	1.05	+.49	September	4.73	.80	−3.93
March	2.15	.91	−1.24	October	2.95	1.10	−1.85
April	4.36	1.04	−3.32	November	1.25	1.04	−.21
May	5.70	1.45	−4.25	December	.70	1.05	+.35
June	6.67	.91	−5.76				
July	6.88	.60	−7.28	The year	44.38	11.65	−32.73

[1] Stearns, H. T., Bryan, L. L., and Crandall, L., Geology and water resources of the Mud Lake region, Idaho: U. S. Geol. Survey Water-Supply Paper 818 (in press).

[2] Am. Soc. Civil Eng. Trans., vol. 90, p. 266, 1927.

POSSIBLE EFFECT OF EVAPORATION AND TRANSPIRATION ON PRECIPITATION AND STREAM FLOW

The large amount of water lost by evaporation from reservoirs and transpired and evaporated from the irrigated land is not necessarily a total loss of water to the region. It has long been recognized that areas remote from the ocean receive a considerable part of their precipitation from water lost by evaporation from the land.[3] On account of the topography of the Snake River drainage basin the prevailing west and southwest winds carry a part of the moisture that is evaporated on the Snake River Plain to the mountainous headwater area on the east side of the basin. There, on account of the greater altitude, the moisture of the ascending winds is in part precipitated and may reappear as stream flow.

TREE RINGS IN RELATION TO CLIMATE

The period for which records of precipitation, stream flow, and other conditions are available in the Snake River Plain is relatively so short that a study was made of tree rings in an endeavor to obtain an idea of climatic conditions prior to 1868, when records of precipitation were first started in Idaho.

The careful studies of tree rings in their relation to climate made by Douglass [4] have demonstrated that, although there are many factors which tend to affect the formation of these rings, precipitation has so predominant an influence that it is safe to assume that tree rings form an approximate measure of the rainfall. He finds a 70 percent correspondence between tree-ring growth and rainfall in a dry climate, and a much closer agreement if the degree of conservation of moisture can be taken into account. Although data from a considerable number of trees in a given region greatly increase the accuracy of the conclusions by permitting allowance for variable factors, Douglass' work demonstrates that study of even a single tree gives results of considerable reliability provided it grows fast enough.[5]

The only native tree that has a wide distribution over the Snake River Plain is the juniper, which occurs generally wherever the annual precipitation exceeds 13 to 14 inches. This is somewhat unfortunate in the present connection, as Douglass [6] found that in Arizona juniper was less satisfactory than some other kinds of trees, particularly yellow pine. The native junipers in Idaho usually do not live to be more than 150 to 200 years old, especially where rooted in soil; if rooted largely in lava rock they have a longer life, smaller annual ring width, more heartwood, and less tendency to decay. Several

[3] Visher, S. S., Climatic laws, p. 82, 1924.

[4] Douglass, A. E., Climatic cycles and tree growth: Carnegie Inst. Washington Pub. 289, 1919.

[5] Douglass, A. E., A method of estimating rainfall by the growth of trees, in Huntington, Ellsworth, The climatic factor as illustrated in arid America: Carnegie Inst. Washington Pub. 192, p. 109, 1914.

[6] Douglass, A. E., Some aspects of the use of the annual rings of trees in climatic study: Smithsonian Inst. Ann. Rept., 1922, p. 226.

specimens were found that ranged from 350 to 600 years old, and one, in the Fifield Basin, grew for 1,600 years before finally falling a victim to a farmer's need for fuel. Several pines from 300 to 400 years old were found near the edge of the valley, where the plains merge into the adjacent foothills.

In all 20 specimens were cut from different trees scattered over the Snake River Plain. (See pl. 8.) Pertinent data regarding these specimens follows:

1. Craters of the Moon. Limber pine. Taken from Craters of the Moon National Monument, Idaho. Cut by Harold T. Stearns in 1926. Tree dead when specimen taken, having been killed by lightning about 2 years before. Needles still hung from the branches. Grew in a crack at the edge of a recent lava flow where there would be a tendency for a little water to accumulate but for snow to linger. The rock is so permeable that rain and melting snow would seep away rapidly.

2. Massacre Rocks. Juniper. Taken 10 miles west of American Falls, Idaho, on the north side of the Snake River, near the place commonly known as "Massacre Rocks." Cut by Harold T. Stearns and W. G. Steward in the fall of 1928 from a living tree. Grew on a high lava bluff overlooking the river. The lava is partly covered with blow sand, and many juniper trees are growing here. Moisture is retained in the blow sand, which fills the lava cracks, for longer periods than it would remain, where not so much fine sand or soil is present. Center of tree decayed.

3. Black Lava. Western juniper. Taken from a point about 12 miles southwest of Idaho Falls, Idaho, in the Fifield Basin area. Cut by Steve Krolik from living tree and hauled to his ranch in the NE¼ NE¼ sec. 26, T. 2 N., R. 36 E., in the winter of 1927 or 1928. Specimen cut from tree by W. G. Steward in the spring of 1929. Conditions surrounding the place where this tree stood are not known except that it was cut on the bare lava beds.

4. Fifield. Western juniper. Taken from the bare lava beds about 15 miles southwest of Idaho Falls, Idaho, in the Fifield Basin area. Cut by Steve Krolik from a living tree and hauled to his ranch, in the winter of 1928. Specimen sawed from tree by Harold T. Stearns, W. G. Steward, and H. G. Haight in the spring of 1929. Grew in a crack at the margin of a lava ridge. By far the oldest and best specimen of juniper known to have been taken in Idaho.

5. Woodville. Western juniper. Taken about 12 miles southwest of Idaho Falls, Idaho, in the Fifield Basin area. Cut by Steve Krolik from a dead tree and hauled to his ranch in the winter of 1927 or 1928. Specimen taken from tree by W. G. Steward in the spring of 1929. Conditions surrounding the place where this tree stood are not known except that it was cut on the bare lava beds.

6. Wapi I. Western juniper. Taken 20 miles due west of American Falls, Idaho. Cut by W. G. Steward and H. G. Haight in October 1931 from a living tree. Grew at foot of lava ridge and approximately at central western edge of a grove of junipers estimated to cover 160 acres. Would receive benefit of drifted snow. Lava very broken and permeable. Seepage would carry any rain or melting snow away rapidly. Center of tree decayed.

7. Wapi II. Western juniper. Taken 20 miles west of American Falls, Idaho. Cut by W. G. Steward and H. G. Haight in October 1931 from a living tree. This tree grew about 150 feet west of Wapi I, farther from the foot of the ridge. Center of tree decayed.

8. Wapi II. Western juniper. Unpolished.

9. Wapi III. Western juniper. Taken 20 miles west of American Falls, Idaho. Cut by W. G. Steward and H. G. Haight in October 1931 from a living tree. This tree stood 200 feet southwest of Wapi I, farther from the foot of the high ridge that encircles this grove. Conditions same as described under Wapi I. Center of tree decayed. At the time these specimens were cut, a few posts had been cut from this grove by nearby dry-farmers. Late in the fall of 1932 most of the trees in this grove had been taken for fuel.

10, 11, 12. Graham Canyon. Mountain mahogany. Taken 4 miles west of Almo, in what is called locally "Graham Canyon." Cut by W. G. Steward and H. G. Haight in November 1931 from living trees. Grew on a steep hillside of decomposed rock with a slope to the southwest. Would retain little moisture. Rings of these specimens could not be counted or measured, except for short disconnected periods, because of an overlapping or blurred growth.

13. Minidoka. Western juniper. Taken 24 miles west of American Falls, Idaho. Cut by Viggo Christofferson and Lars Larsen in December 1931 from a living tree. Grew in the center of a small grove of juniper trees on silt-covered lava bed that was sheltered by a high lava ridge.

14. Almo. Piñon. Taken in Graham Canyon 4 miles west of Almo, Idaho. Cut by H. G. Haight and H. G. Haight, Jr., in October 1932 from a living tree. Grew on the southwest slope of a steep hillside of decomposed rock. This slope is exposed to the hot summer sun, and little moisture would be retained. Rain and melting snows would no doubt run off rapidly.

15. Cedar Creek. Western juniper. Taken on the south rim of Cedar Creek, 2 miles below Cedar Creek dam and about 8 miles southwest of Roseworth, Idaho. Slightly decayed at center. Cut by H. G. Haight and Stella Perrine Haight in October 1932 from a living tree. Grew on a rock shelf 12 feet below the top of the rim of Cedar Creek Canyon, which is about 200 feet deep at this point. Partly protected and subject to some snowdrift. Otherwise in a decidedly dry location. The only tree for miles around except those in the bottom of the canyon.

16. San Jacinto I. Juniper. Taken 14 miles southeast of San Jacinto, Nev., on Trout Creek. Cut by H. G. Haight and H. G. Haight, Jr., in October 1932 from a living tree. Decayed at center. Grew on the top of a high rocky ridge overlooking Trout Creek. A large number of junipers in this vicinity. Three selected from the decidedly unfavorable location. No place to collect or hold precipitation and at the mercy of the winds and temperature.

17. San Jacinto II. Juniper. Taken 14 miles southeast of San Jacinto, Nev., on Trout Creek. Cut by H. G. Haight and H. G. Haight, Jr., in October 1932. This tree killed by fire and decayed at center. Grew on the steep side of a rocky gulch about 600 feet southeast of San Jacinto I.

18. San Jacinto III. Juniper. Taken 14 miles southeast of San Jacinto, Nev. Cut by H. G. Haight and H. G. Haight, Jr., in October 1932 from a living tree. Slightly decayed at the center. Grew in a pass between two higher ridges. Stood apart from the other trees. About three-quarters of a mile southwest of San Jacinto I and II.

19. Bliss. Sage brush. Taken about 8 miles northwest of Bliss, Idaho, near the Elmore County line. Cut by H. G. Haight in October 1932 from a living shrub. About 104 years old. This is one of several samples that have been gathered for study in the future.

20. Blue Lakes alcove. Western juniper. Taken 5 miles north of Twin Falls, Idaho, on the north side of Snake River Canyon and the south side of the Blue Lakes Cove. Cut by H. G. Haight and Stella Perrine Haight in October 1932 from a living tree. Decayed at center. Grew on a large shelf 60 feet below the main rim of the Snake River Canyon and on a sharp nose of rim rock that projects

between Snake River Canyon proper and the Blue Lakes Cove. This was one of four trees that grew on this dry rocky shelf. Conditions are anything but favorable—dry, hot, and windy.

A silvanometer constructed by W. G. Steward and H. G. Haight was used to measure the ring widths of all the specimens. The different parts are a heavy hardwood piece grooved for runners; a steel rod 28 by 5/8 inches, threaded with 20 threads to the inch; a 12-inch wheel from a Stevens water-level recorder, divided into 10 equal parts, which in turn are subdivided into 10 equal parts; an indicator point; a main movable platform, which is connected to the threaded rod and moves on hardwood runners; a specimen board to which the specimen is fastened by small countersunk screws driven in from the under side; an adjustable arm for holding magnifier; a three-legged low-power compound magnifying glass with eyepiece of heavy brown paper glued to the upper surface of the upper lens and an auxiliary lens with gross marks scratched on the lower surface fitted into and held between the legs of the magnifier; a small light attached to the magnifier arm and equipped with a reflector, which throws light onto the specimen at the measuring point; and a counter attached to the outside center of the wheel for recording revolutions.

By the use of the silvanometer, the total ring widths were measured for each 10-year period for a selected number of specimens and are shown graphically in plate 8. The specimens were selected for clearness of the annual growth, locality, and freedom from distorted growth.

The growth record of the Fifield juniper (pl. 8, specimen 4), on account of its great length, affords a basis of comparison with other graphs. Practically all the other trees examined began their life during a favorable growth period, as indicated by the Fifield record. Most of the trees show a larger growth in 10-year periods during their early life, say, the first 100 years. Several, particularly specimens 13 and 14 (pl. 8), show a steadily decreasing growth with advancing age, which probably arises in considerable part from other causes than lack of moisture. Variation in growth of nearby trees is shown by specimens 6, 7, and 9—all representing growth of trees within a few hundred feet of one another.

To eliminate the effect of erratic growth records of individual trees, as well as more rapid growth during the early years of the life of the trees, a composite diagram showing mean ring width of the various specimens for the last 300 years was prepared (pl. 8). In preparing this figure specimens 13 and 14 were excluded because their growth apparently had been affected to a great extent by causes other than precipitation. All growth records prior to 1640 A. D. were eliminated to avoid distortions due to early age growth of some of the specimens. Plate 8 also shows precipitation at Boise, the only station adjacent to the region having a long-time precipitation record, and the run-off of

the Snake River at Moran, above irrigation diversions, for years of available records. The precipitation and run-off trends are in substantial agreement. The precipitation record and the mean ring-width record both show a general downward trend from 1870 to date, although the two records do not always show the same relation between adjacent decades.

According to the mean ring-width diagram (pl. 8), the decade 1920–30 was less favorable than any similar period during the last 300 years, although many of the individual tree diagrams (pl. 8) show decades less favorable than that of 1920–30.

SOIL

Nearly half a million acres of the Snake River Plain consists of bare, broken, and fissured lava with practically no soil covering, and a still larger area consists of lava with a scant covering of wind-blown soil that ranges in depth from only a few inches to a foot. Considerable portions of the region, however, are underlain by soils of good depth, in some places 6 to 8 feet.

The soil that covers the lava plain between the river and the mountains on the north is a fine loess, consisting essentially of minute particles of quartz with slight amounts of calcium carbonate as a cementing material. The loess originated chiefly as dust blown by the prevailing westerly winds from the lake beds to the west, but some of the dust was derived from the alluvium of tributary streams and from volcanic ejecta. Its slow rate of accumulation is indicated by the fact that the most recent lava flows in the region, probably not less than 1,000 years old, are still free of soil. Only the cracks in their surface show evidence of some desposits of wind-blown material.

As a rule the soils in the region are fertile and are very productive when irrigated. Several studies of the soils in the region have been published.[7]

Along the borders of the plain, near the mouths of tributary streams, and along the Snake River, occur extensive gravel deposits which yield considerable road-surfacing material and gravel for concrete. In this gravel, particularly in the section of the main river channel from Blackfoot to the mouth of the Big Wood River, near Bliss, appreciable

[7] Russell, I. C., Geology and water resources of the Snake River Plains of Idaho: U. S. Geol. Survey Bull. 199, pp. 136–137, 1902.

McLendon, W. E., Soil survey of the Blackfoot area, Idaho: U. S. Dept. Agr., Bur. Soils, Field Operations, 1903, pp. 1027–1044, 1904.

Lewis, H. G., and Peterson, P. P., Soil survey of the Portneuf area, Idaho: Idem, 1918, pp. 1–52, 1921.

Youngs, F. O., Baldwin, Mark, Kern, A. J., and McDole, G. R., Soil survey of Minidoka area, Idaho: Idem, 1923, pp. 859–902, 1928.

Baldwin, Mark, and Youngs, F. O., Soil survey of the Twin Falls area, Idaho: Idem, 1921, pp. 1367–1394, 1925.

Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713, p. 118, 1920.

Poulson, E. N., and Thompson, J. A., Soil survey of the Jerome area, Idaho: U. S. Dept. Agr., Bur. Chemistry and Soils, ser. 1927, no. 16.

quantities of gold are found, and extensive placer-mining operations were carried on in former years. The gold is so fine, however, that its recovery proved difficult, and the placers were abandoned. In recent years, however, attempts to obtain gold from these placers have been renewed. Above American Falls the irrigated lands on both sides of the river have soils that are mainly of alluvial origin.

South of the Snake River, from a point near Pocatello to a point beyond King Hill, occur extensive lake beds, in places more than 1,000 feet thick. Except in a few favorable localities the benches underlain by these lake beds are not readily susceptible of irrigation because of their topography and height above the river.

Residual soils formed by the decay of the underlying rocks occur to some extent in the mountains bordering the Snake River Plain, but the basalt that underlies most of the plain is relatively so recent in origin that it has not disintegrated sufficiently to make any appreciable contribution to the soils of the region. The basalt eroded from the Snake River Canyon has contributed only in minor degree to the alluvial deposits along the river except at the downstream sides of former lava dams as in Hagerman Valley or near King Hill.

In a few areas shifting material consisting mostly of quartz sand forms the surface soil. Most prominent is the sand-dune area between the Birch Creek Sink and the Big Bend Ridge. In this area migrating sand hills attain heights of 100 feet or more and cover many square miles. From Wendell southward to the Snake River Canyon the soil is mainly silt or fine sand, on the whole well adapted to cultivation under irrigation. There are small areas of shifting "blow sand", not so adapted. Similar areas of blow sand occur locally in other areas. From King Hill eastward isolated sandy knolls rise 10 feet or more above the plain and support a sufficient cover of vegetation to prevent shifting of the sand.

CROPS AND VEGETATION

Irrigated lands on the Snake River Plain produce a wide range of diversified crops common to the intermountain region, among which the staples are alfalfa and other hay crops, wheat, oats, barley, potatoes, corn, beans, sugar beets, garden vegetables, and some tree and bush fruits. The largest acreage is in alfalfa. Of the principal crops potatoes have yielded the highest average acre value. Much of the hay and grain crop is used locally for stock feed. Crops entering into interstate commerce include potatoes, onions, beans, clover, small grains, alfalfa seed, peas, and head lettuce. Along the borders of the plain and in the tributary valleys up to the zone where frosts are likely to occur in any month of the year, irrigated areas are devoted largely to the growing of alfalfa, native grasses, small grains, and garden vegetables.

Much of the uncultivated area of the plain supports considerable native vegetation, some of which is valuable for grazing. Sagebrush (*Artemisia tridentata*) predominates and lends a dusty-green hue to the landscape. At the lower limits of rainfall the moisture naturally available for plant growth is so little that practically desert conditions prevail, and the natural growth includes transition desert shrubs, of which rabbitbrush is the most conspicuous. At the higher limits of rainfall a considerable undergrowth of grass is associated with the sage. Where the rainfall is from 15 to 25 inches a year the natural vegetation consists principally of the Idaho and wheat bunch grass and shrubs that furnish excellent spring, summer, and fall range. Grain crops, principally wheat, have been raised without irrigation on large areas of this type.

GEOLOGY AND WATER-BEARING PROPERTIES OF THE ROCKS

SUMMARY

The Snake River Plain is commonly regarded as a structural depression that has been filled mainly by Pliocene and later basalt and kindred volcanic rocks which are locally intermingled with sediments. Subsidence continued intermittently until Pleistocene time, so that the older rocks filling the depression are down-warped in varying degree and locally broken by faults. The basalts covering the surface of the plain are nearly all Pleistocene and Recent and they are practically undisturbed. This great mass of volcanic rock, about 95 percent of which is in the area described in this report, is termed the "Snake River basalt."[8] In numerous places on the borders of the plain rhyolitic flows and pyroclastic and related rocks emerge from beneath the basalt. Locally there is evidence that similar rocks extend well under the plain. Estimates as to the age of the rhyolitic rocks by different authors and in different localities range from early Pliocene to late Oligocene. This wide range in age assignment results in part from inadequate data. It may well be, however, that exposures in different parts of this large region, even though broadly similar in lithology and stratigraphic relations, may record eruptions at materially different times. Beneath the Tertiary strata in the nearby mountains lies a complex aggregate of sedimentary rocks of which the oldest is generally of pre-Cambrian age, and the youngest is either Carboniferous or Mesozoic. The youngest are extensively exposed in the mountains bordering the plain. These rocks are locally interbedded with and intruded by igneous rocks of several different kinds and ages.

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[8] Russell, I. C., op. cit., p. 59.

Volcanism and deformation have thus played dominant parts in the development of the present Snake River Plain, although locally stream erosion by the Snake River and its tributaries, as in the Snake River Canyon, and wind action, as in the Mud Lake region, have had noticeable effects. These diverse processes, the results of which can as yet be evaluated in detail only in certain small areas, have, in a general way, produced a great basin floored with relatively impermeable rock and filled with a variety of materials, many of which are readily permeated by ground water. The many streams issuing from the mountains and the Snake River itself provide a large supply of water for the filling of the partly enclosed underground reservoir thus created. As volcanic processes are inherently catastrophic, intermittent, and irregular, their results in this region have introduced many complexities into the behavior of the ground water. Consequently, an especially thorough understanding of geologic details is required in connection with the study of problems of water supply. Over large areas of the Snake River Plain the lack of stream incisions renders it impossible to examine any but the most recently formed rocks, so that many local details are undecipherable. It so happens, however, that most such areas are of relatively small agricultural value, and large stretches of them are unsuited for cultivation of any kind, so that the incompleteness of knowledge in regard to them is of comparatively minor economic importance.

The salient features of the geology of the Snake River Plain are shown in plate 4. This map is based primarily on data gathered by H. T. Stearns during the present study and related investigations. For areas not covered in the course of these studies, mainly along the mountain border, other data, principally in published reports of the United States Geological Survey and the Idaho Bureau of Mines and Geology, have been utilized. The mapping of the northeastern portion of the area shown in plate 4 is based on a geologic map of the Mud Lake region, one of the parts of the plain studied in especial detail, to be published elsewhere.[9] The geology along the canyon of the Snake River from a point below Blackfoot to King Hill was mapped in detail, and those sections of the canyon along which the data obtained are too complex to be adequately portrayed in plate 4 are shown on a larger scale in plates 5 and 6.

The first of the two following tables is intended to aid in grasping the outstanding features of the stratigraphy of the Snake River Plain. The second table summarizes the stratigraphy along the part of the canyon of the Snake River that was studied in detail.

[9] Stearns, H. T., Bryan, L. L., and Crandall, Lynn, Geology and water resources of the Mud Lake region, Idaho: U. S. Geol. Survey Water-Supply Paper 818 (in press).

Generalized stratigraphic section of the Snake River Plain east of King Hill, Idaho

Geologic age	Geologic unit	General character	Water-bearing characteristics
Recent.	Dune sand and loess (not distinguished in mapping from the rock it covers).	Light-colored wind-blown sand, consisting chiefly of round quartz grains and some particles of ash. The loess is somewhat intermingled with soil. Dunes are rare except locally, as in the area east of Mud Lake, but loess covers most of the Snake River Plain to depths of about 10 feet or less. Still in process of formation.	Generally above the water table. Where the loess lies in the zone of saturation, it is so fine-grained as to be relatively impermeable. Extensive deposits in such situations commonly act as confining or perching beds. Dune sand in the zone of saturation carries water but generally causes trouble in drilling by running into the well.
	Landslides and talus.	The landslides form hummocky topography, mainly in canyons, and the talus forms aprons at the foot of cliffs. Both consist largely of jumbled blocks of rock. They are mapped only along the canyon of the Snake River.	Unimportant with relation to water because of the small size of individual masses.
	Younger alluvium (not separated from older alluvium on the maps).	Sand and gravel derived from the erosion of preexisting rock and alluvial deposits, confined to the small recent flood plains along present stream channels. Locally contains unfossilized bones of mammoths and extinct bison.	Commonly contains considerable water at shallow depths, but because it occupies small areas it is of little value as a source of water supply.
	Black basalt and associated fragmental deposits.	Fresh black basaltic flows and fragmental deposits associated with them. The flows consist of about equal amounts of aa and pahoehoe and are free from covering of soil or loess. The lava in the Craters of the Moon National Monument is the youngest of all.	All these recent lavas lie above the water table. They are very permeable and serve as intake areas for ground-water recharge. Locally they contain pools of water in caves and crevices, derived from melting ice, which are valuable as watering places in the desert.
	Local		
Pleistocene.	Older alluvium (not differentiated from younger alluvium in mapping).	Floors most of the tributary valleys as well as the canyon of the Snake River. Consists of sand, gravel, and locally boulders. Differs from the younger alluvium chiefly in lying topographically higher on terraces. In numerous places contains bones of elephants, camels, sloths, and bison, as yet scarcely fossilized.	A good water-bearer wherever the topographic situation is suitable. Commonly contains water at shallow depths.
	Lake beds.	Largely clay and silty clay. Locally sandy where stream deposits are included. In part at least as young as the older alluvium, but in part interfingers with Pleistocene basalt, mostly made up of flows high in the sequence. Locally interbedded with basalt and tuff. Distinguished only near Terreton, Market Lake, and American Falls.	Yield water to wells only in the local sandy parts, mostly nearly impermeable. Intercalated basalt flows are permeable and locally cause springs.

Generalized stratigraphic section of the Snake River Plain east of King Hill, Idaho—Continued

Geologic age	Geologic unit	General character	Water-bearing characteristics
Pleistocene—Con.	Pre-Wisconsin glacial deposits.	The only deposits of glacial origin mapped within the region are those near Ashton. Outwash plains occur near Island Park and in Camas Meadows. These consist of bedded sand and gravel, commonly overlain by gumbo clay.	Except where clayey yield water copiously to shallow wells.
Late Pleistocene and possibly locally early Recent. In part contemporaneous with Pleistocene sediments listed above.	Younger basalt flows and related cones, older than the black lava listed above (not everywhere distinguished from the older flows).	Mainly basaltic lava. Flows are locally mantled by and interbedded with loess and soil. Many of the buttes on the plain, some of which are composed of cinders, are the source of these flows. Along the canyon of Snake River several members have been distinguished.	Highly permeable because of the presence of numerous openings of diverse kinds.
	Local.		
Earliest Pleistocene.	Tuff.	Tuff and unconsolidated lapilli interbedded with basalt. Mapped only in and near Menan Buttes, western Madison County.	Yields water satisfactorily to wells where suitably situated.
	Local.		
	Basalt flows.	Blue and gray basalt, with and without feldspar and olivinephenocrysts. Dominantly pahoehoe; contains numerous caves. Thin and restricted loess and clay beds locally intercalated in the basalt. Most of the flows originate from definite cones north of the Snake River, and some fill old tributaries of the river.	Highly permeable and constitute valuable aquifers. Almost without exception water is present in them, the depth depending on the position of intercalated or underlying impermeable beds or other local conditions.
	Unconformity.		
Pliocene and Pliocene(?).	Lake beds and other sediments.	Sedimentary beds at several horizons, older than the Pleistocene basalts. Mainly clay, silt, and sand, with local gravel deposits. In part consist of reworked tuff. A little basalt and tuff intercalated locally. Some of the beds contain Pliocene vertebrate fossils. The age of others is less precisely fixed by their relations to other formations. Mapped near Medicine Lodge Creek, in Clark County, and at several places along the canyon of the Snake River, especially in Hagerman Valley.	The fine-grained beds, which predominate, are relatively impermeable, but the gravel and intercalated basalt constitute aquifers.
Pliocene.	Basalt and related volcanic rocks.	Mainly blue, black, brown, and greenish weathered basalt. Some tuff and other pyroclastic rocks and locally a little intercalated clay and gravel.	Much of the basalt and coarser pyroclastic rocks are permeable and constitute fair aquifers.
	Unconformity.		
Miocene(?).	Intrusive rocks.	Granite and related porphyrites, which cut the Challis volcanic rocks in Blaine and Butte Counties and may be the sources of some of the rhyolitic flows.	Not so situated as to have any appreciable effect on the ground water of the Snake River Plain.

Generalized stratigraphic section of the Snake River Plain east of King Hill, Idaho—Continued

Geologic age	Geologic unit	General character	Water-bearing characteristics
Miocene(?)—Con.	Flows and related rocks.	Include the so-called "rhyolitic rocks" and also the Challis volcanics (Oligocene?) where that formation has been traced into the regions here discussed. Mainly latitic, rhyolitic, and andesitic flows, with large amounts of pyroclastic material commonly welded and locally basalt. Within this region the age is not positively fixed, except that the beds are everywhere older than the contiguous basalt flows of the Snake River Plain.	Not very permeable, except where fractured.
	Great unconformity.		
Pre-Miocene rocks (early Tertiary?, Mesozoic, Paleozoic, and pre-Cambrian?).		The sedimentary and intrusive rocks that compose the mountains and doubtless underlie the Snake River Plain below the Tertiary volcanic rocks.	Relatively impermeable, except where fractured. Form the containing walls of the ground-water reservoirs of the Snake River Plain.

Detailed stratigraphic section of the rocks along the Snake River between King Hill and Blackfoot, Idaho [1]

Geologic age	Formation	Thickness (feet)	General character	Water-bearing characteristics
Pleistocene.	Wendell Grade basalt.	25±	A dense black olivine pahoehoe basalt with a soil cover too thin for farming. It covers many square miles near Wendell and is later than the Snake River Canyon, because three branches of this flow cascaded over the rim at Hagerman Valley.	Very permeable but lies above the zone of saturation.
	Local.			
	Minidoka basalt.	30±	A vesicular blue pahoehoe basalt containing tiny crystals of olivine and feldspar and thinly covered with loess. It overlies alluvium at Minidoka Dam and crops out for 5 miles along the north shore of Lake Walcott Reservoir. It displaced the Snake River to the south.	Very permeable and causes leakage from Lake Walcott Reservoir.
	Local.			
	Sand Springs basalt.	500±	A prominent pahoehoe lava flow, which enters the Snake River Canyon near Sand Springs. From this place it flowed downstream for at least 14 miles and is now preserved as lava benches along the river. It fills a former deep canyon of the Snake River from Paul to Sand Springs. (See pl. 9.) On the upstream side of this lava dam were deposited the Burley Lake beds, which underlie the Minidoka project and are overlain by the Minidoka basalt.	Very permeable and serves as a channel for the movement of ground water under the North Side Twin Falls tract. Many of the large springs are fed by it. Below Thousand Springs water is found in the bottom of the basalt except where it forms isolated small benches along the Snake River. These benches do not contain water. The Burley Lake beds are in part permeable, but water does not move through them fast enough to prevent drainage problems on the Minidoka project.
	Local.			

[1] Each formation along Snake River is underlain by a local erosional unconformity but superposition in the table does not necessarily mean superposition in the field.

Detailed stratigraphic section of the rocks along the Snake River between King Hill and Blackfoot, Idaho—Continued

Geologic age	Formation	Thickness (feet)	General character	Water-bearing characteristics
Pleistocene—Continued.	Bliss volcanics.	100±	Form dikes, a cone, and a flow. The dikes are dense, narrow, and short, and the cone is composed of comminuted basaltic glass and black cinders. Pillow structure and fragmental glassy porphyritic lava characterize the flow. Phenocrysts of olivine and feldspar occur in a glassy brown groundmass free from pyroxene. It crops out at numerous places for 7½ miles downstream in the Snake River Canyon below Malad River.	Sullivan, Bliss, and several unnamed springs issue from this basalt. It is very permeable but is only locally a water bearer, because it occurs as isolated patches above the water table in most places, and even these springs probably have their source in the Madson basalt.
	—Local.—			
	McKinney basalt.	500±	A decidedly porphyritic grayish-black pahoehoe basalt containing phenocrysts of fresh green olivine and long laths of plagioclase. It covers an extensive area north of Bliss and displaced parts of the Big Wood and Snake Rivers between Bliss and King Hill.	Except where it fills an ancient canyon of the Snake River it lies above the zone of saturation, and all indications point to a very small amount of ground water, even in the part occupying the buried valley. This is not due to lack of permeability but to inadequate intake area.
	—Local.—			
	Thousand Springs basalt.	100±	An olivine basalt occupying a buried canyon of the Snake River north of the present one and shallower. It is filled with tubes, and open contacts occur between successive layers.	This basalt is very permeable and is the source of Sand Springs, Thousand Springs, and all other springs downstream to Riley Springs.
	—Local.—			
	Malad basalt.	400±	A black basalt containing feldspar, olivine, and pyroxene. It fills an ancient canyon of the Snake River north of the present one. Sufficient soil rests on its surface to make good farm land.	A very permeable basalt. The source of Malad Springs and of the springs that feed Billingsly Creek. Water occurs in it everywhere from 50 to 400 feet below the surface.
	—Local.—			
	Madson basalt.	200±	An extremely fine grained black basalt in places very evenly jointed. It fills a former canyon either of Snake River or Big Wood River carved in the Hagerman lake beds.	Too tightly jointed in most places to be a prolific water bearer but at the base it is open and permeable. It is probably the source of Steele, Madson, Sullivan, and Bliss Springs.
	—Local.—			
	American Falls lake beds.	150±	Buff even-bedded clay and sand, only partly consolidated. Near the top occur local pebbly lenses, and about 60 feet below the top there is a 6-foot bed of laminated basic tuff. The deposits change northeastward into coarser sediments. Between American Falls and Gibson Butte along the north side of the Snake River aphanitic gray pahoehoe about 10 feet thick is interstratified with the sediments.	The finer-grained beds are relatively impermeable, but near Springfield a flowing well yields a small supply of water from the coarser beds. The intercalated basalt member is the source of numerous large springs on the Springfield-Aberdeen tract.
	—Local.—			
	Cedar Butte basalt.	200±	An aphanitic blue pahoehoe basalt with fresh green olivine phenocrysts. It dammed and displaced the Snake River near Massacre Rocks and now forms imposing cliffs along the Snake River and Lake Channel. Its surface supports considerable vegetation.	Permeable but in most places lies above the zone of saturation. However, along Lake Channel springs issue from it, indicating that water occurs in its lowest part, or in general about 200 feet below the surface.
	—Local.—			

Detailed stratigraphic section of the rocks along the Snake River between King Hill and Blackfoot, Idaho—Continued

Geologic age	Formation	Thickness (feet)	General character	Water-bearing characteristics
Pleistocene—Continued.	Early undifferentiated basalts.	500±	Blue and gray basalt flows, generally containing phenocrysts of olivine and feldspar and covering most of the Snake River Plain and forming a considerable part of the Snake River Canyon. Few individual beds exceed 50 feet in thickness. They contain numerous caves and are predominantly pahoehoe. A few thin and local loess beds are found intercalated in the series. The undifferentiated basalt shown in plates 5 and 6 originated chiefly from cones on the south side of the Snake River and in places fills ancient tributaries of the river.	These flows are valuable aquifers of southern Idaho. Almost without exception water is found in them at different depths, depending upon the depth to the intercalated or underlying impermeable beds.
	Erosional unconformity.			
Upper Pliocene.	Hagerman lake beds.	600±	Nearly level and partly consolidated buff to white clay and silt beds which in most places contain a gravel cap 20 feet thick and in some places pebbly lenses and sandy beds near the top. Along a considerable part of the Snake River Canyon between Salmon Falls Creek and King Hill there is a thin intercalated basalt flow 200 feet below the top, or a basaltic tuff bed at about the same altitude. Near the mouth of Salmon Falls Creek a bed of diatomite 20 feet thick occurs only a little above the tuff bed. The lake beds contain in places well-fossilized bones of mammals and numerous fresh-water shells.	The sedimentary parts of the series are impermeable and poor aquifers, but the intercalated basalt contains water and gives rise to landslides, segments of it sliding on the saturated clay beneath it during wet periods.
	Banbury volcanics.	300±	Extensive outcrops of this basalt occur along the canyon walls between Salmon Falls Creek and Blue Lakes. It is dark brown but commonly has a greenish hue. Its color is due largely to weathering, and even in a hand specimen it is easily distinguished by its iron stains from any younger basalts. The flows are massive and continuous. Closely associated with it is the tuff of the Riverside Ferry cone. At one place a bed of pebbly alluvium containing a fossil camel bone was found interstratified with it.	A relatively poor water bearer, but numerous seeps have issued from it since irrigation started on some of the land above it. In some places it forms the basement of the great underground reservoir of the Snake River Plain.
	Unconformity			
Middle (?) Pliocene.	Raft lake beds.	200±	Partly consolidated buff-colored beds of clay, silt, and sand, generally in lenticular form and in places filled with concretions. Weather to a brown sandy loam and are eroded into rounded rolling hills except along the Snake River, where they form a terrace.	Contains water in small quantities except where it forms benches above the water table along the Snake River.
	Rockland Valley basalt.	250±	Series of even-bedded blue and black basalts that show considerable weathering. Intercalated with them is at least one bed of clay 15 feet thick. All are tilted about 4° NW.	Permeable but has not been studied sufficiently to determine its water-bearing value.
	Unconformity			

Detailed stratigraphic section of the rocks along the Snake River between King Hill and Blackfoot, Idaho—Continued

Geologic age	Formation	Thickness (feet)	General character	Water-bearing characteristics
Pliocene (?) (lower Pliocene?).	Massacre volcanics.		Massacre Rocks is a neck or feeder of a former large cone composed chiefly of pyroclastic debris and a few lava flows. The cindery tuff is exposed for a distance of 11 miles upstream from Massacre Rocks along the Snake River but for only 2 miles downstream. It is well consolidated and is red to brown. In places it contains angular fragments of the underlying older formations. Faulting has greatly disturbed this series. There is one persistent fine-grained blue basalt flow 23 feet thick at the base of the series underlain by 6 inches to 2 feet of partly baked loess soil.	The coarser tuff and the flows are permeable and doubtless waterbearing. Davis and Mary Franklin Springs issue from the basalt member.
	——Local.——			
	Eagle Rock tuff.	35±	Well-defined sequence of rhyolitic tuffs crops out at different places along the Snake River between American Falls and Massacre Rocks. The sequence from top to bottom consists of red felsitic welded pumice 6 inches thick, welded obsidian tuff 21 feet thick containing spherulites and lithophysae; black comminuted glass only partly consolidated at the bottom, grading upward into a hardened dull obsidian tuff 4½ feet thick; banded gray to white tuff of fine texture 9 feet thick, in places pisolitic. The whole was evidently laid down in rapid succession by a series of explosions from the same volcano.	Only slightly permeable, but since the construction of American Falls Reservoir small amounts of water are found seeping through them.
	Neeley lake beds.	100±	Flesh-colored to brown lacustrine deposits consisting partly of reworked tuffs. Evenly bedded and commonly sandy in texture. Their base is not exposed.	Relatively impermeable.
	Unconformity—			
Miocene (?) (upper Miocene?).	Pillar Falls mud flow.	40±	Red and black andesitic waterworn pebbles and boulders intermingled with compact ash and soil. The top few inches is baked by the overlying basalt. Fills the irregularities in the underlying andesite.	Only slightly permeable.
	Erosional unconformity			
	Shoshone Falls andesite.	200±	Black and purple glassy porphyritic columnar jointed or platy andesite; weathers pinkish brown. On it is a dark soil about 1 foot thick.	Impermeable.
	Unconformity—			
Paleozoic.	Carboniferous.	Not measured.	Isolated outcrops of blue and buff compact limestone.	Contains water in joints and crevices but has no well-defined water table.

ROCK FORMATIONS AND THEIR WATER-BEARING PROPERTIES

PRE-MIOCENE ROCKS

The pre-Miocene rocks in the mountains bordering the Snake River Plain include a great variety of sedimentary and igneous rocks. They are alike in being thoroughly consolidated and, in comparison with any of the younger rocks of the plain, poorly permeable. Except along faults and other fractures, they appear everywhere to be unable to transmit water with sufficient readiness to have any material bearing on problems of water supply in the Snake River Plain.

MIOCENE (?) ROCKS

GENERAL CHARACTER

In the mountains on both sides of the Snake River Plain there are large quantities of lava and associated pyroclastic rocks, for the most part materially older and more silicic than the basaltic flows that underlie most of the plain. Part of the rocks of this character north of the plain belong to the Challis volcanics.[10] In most places the Challis volcanics are dominantly latitic and andesitic, with basalt locally abundant and considerable rhyolite high in the formation. In several places clastic beds composed dominantly of tuff are associated with the flows and locally make up a large part of the formation. The only rocks of this character distinguished on plate 4 are those near the head of Pass Creek, in the Lost River Range. The small mass here may have been brought to its present relatively low altitude by faulting. Most similar beds are beyond the area mapped. The total thickness of the formation is commonly several thousand feet and locally over a mile. Fossils from beds high in the sequence in Custer and Lemhi Counties, according to unpublished studies by R. W. Brown, indicate that the Challis volcanics here are of late Oligocene or early Miocene age. This tentative assignment accords with the stratigraphy and structure of the formation in Custer, Blaine, and Lemhi Counties and adjacent areas.[11]

Along the borders of the Snake River Plain and in scattered exposures within its area, there are large quantities of dominantly silicic volcanic rocks, in part belonging to and in part probably younger than the Challis volcanics, which may for convenience be grouped as Miocene (?) rhyolitic rocks and are thus shown on plate 4. Most geologists who have described portions of the region have loosely referred to these rocks as "rhyolite." Some have applied such local designations as "Mount Bennett rhyolite",[12] "Owyhee rhyolite",[13] and "Tertiary late lava" [14] to portions of the group. Although a considerable part of this lava is correctly termed rhyolite much of it

[10] Ross, C. P., Geology and ore deposits of the Seafoam, Alder Creek, Little Smoky, and Willow Creek mining districts, Custer and Camas Counties, Idaho: Idaho Bur. Mines and Geology Pamph. 33, p. 2, Mar. 1930.

[11] Ross, C. P., The geology and ore deposits of south-central Idaho: U. S. Geol. Survey Prof. Paper — (in preparation).

[12] Russell, I. C., op. cit., p. 42. Piper, A. M., Ground water for irrigation on Camas Prairie, Camas and Elmore Counties, Idaho: Idaho Bur. Mines and Geology Pamph. 15, p. 8, [1926].

[13] Kirkham, V. R. D., Igneous geology of southwestern Idaho: Jour. Geology, vol. 39, no. 6, pp. 564-591, 1931.

[14] Kirkham, V. R. D., A geologic reconnaissance of Clark and Jefferson and parts of Butte, Custer, French, Lemhi, and Madison Counties, Idaho: Idaho Bur. Mines and Geology, Pamph. 19, pp. 33-38, 1927.

is actually quartz latite [15] or has even more calcic composition and differs little from that of many flows in the Challis volcanics where that formation was originally described. Few of the many isolated exposures of the rhyolitic rocks in and bordering the Snake River Plain exhibit direct evidence as to their age other than the fact that they are all probably older than the Snake River basalt, the main bulk of which is regarded as Pliocene or later. In the few places in which the Challis volcanics have been traced to the vicinity of the plain it has been found that the rhyolitic and associated beds belong to the upper part of that formation.[16] On the other hand it is probable that some of the rhyolitic flows are as young as Pliocene, although for the region mapped on plate 4 evidence in support of this suggestion is at present scanty.[17] There is reason to believe that some, at least, of the rhyolite southeast of the Snake River may be as young as Pliocene. It appears from Mansfield's descriptions [18] that this rhyolite has different relations and is probably much younger than the Challis volcanics. It may be that some of the rhyolitic rocks farther north are similar in relations and age. In southern and southwestern Idaho the rhyolitic rocks are tentatively regarded in the most recent reports [19] as Miocene or Pliocene.

In relation to ground-water problems the different rhyolitic and related rocks are mainly of interest in elucidating structure. Their presence at any locality is evidence that the base of the basalt flows of the Snake River Plain has been reached. The rocks themselves, except where much fractured, are not readily permeable and in few places are so situated that water for irrigation has been sought in them. In the region south of the canyon of the Snake River, where the rocks dip northward and contain intercalated tuffaceous beds, they locally also contain water under artesian pressure.

In areas studied during the present investigation nearly all the nonbasaltic volcanic rocks are included in the Miocene (?) rhyolitic rocks, as the term is here used. The basalt of Big Southern and West Twin Buttes has geologic relations akin to those of the Miocene (?) rhyolitic rocks and consequently may be grouped with them. On the other hand, the rhyolitic Eagle Rock tuff is regarded as younger than most of the Miocene (?) rocks. Available data regarding each

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[15] Kirkham, V. R. D., op. cit. (Pamph. 19). Anderson, A. L., Geology and mineral resources of eastern Cassia County, Idaho: Idaho Bur. Mines and Geology Bull. 14, pp. 60–66, 1931. Stearns, H. T., Geology and water resources of the Mud Lake region, Idaho: U. S. Geol. Survey Water-Supply Paper 818 (in press). Also unpublished data by C. P. Ross.

[16] Ross, C. P., op. cit. (Pamph. 33), p. 23. Also unpublished data.

[17] Stearns, H. T., Volcanism in the Mud Lake area, Idaho: Am. Jour. Sci., 5th ser., vol. 11, p. 361, 1926.

[18] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, p. 119, 1927; Geography, geology, and mineral resources of the Portneuf quadrangle, Idaho: U. S. Geol. Survey Bull. 803, p. 42, 1929.

[19] Kirkham, V. R. D., Igneous geology of southwestern Idaho: Jour. Geology, vol. 39, no. 6, pp. 564–591, 1931. Anderson, A. L., op. cit., p. 66.

of the areas of Miocene (?) rhyolitic rocks studied in connection with this and related investigations are summarized below.

RHYOLITIC ROCKS IN AND NEAR THE MUD LAKE REGION

Rhyolitic rocks, chiefly welded tuffs, but containing subordinate amounts of agglomerate, andesite, latite and basalt are extensively exposed in the Centennial Mountains, the southern part of the Beaverhead Mountains, Big Bend Ridge, Juniper Buttes, and smaller neighboring hills. These rocks have been described elsewhere.[20] As these flows may in part interfinger with overlying sediments tentatively supposed to be Pliocene, the flows may also be of this age. Whatever their exact age they have the same general relation to the basalt of the plain as the rest of the Miocene (?) rhyolitic rocks. Kirkham [21] has described similar flows on both sides of the valley of the Little Lost River.

RHYOLITE OF BIG SOUTHERN BUTTE

Three great buttes in the lava fields between Arco and Blackfoot form prominent landmarks. Big Southern Butte, about 5 miles in diameter, the largest of these masses, reaches an altitude of 7,658 feet and rises nearly 2,500 feet above the Snake River Plain, 21 miles southeast of Arco.

The butte is composed of basaltic and rhyolitic flows of different textures. The main mass is a light-colored porphyritic rock containing large quartz crystals, which was identified megascopically as a rhyolite. The bulk of the material is glassy or pumiceous and obviously accumulated as explosive debris on the summit of a volcano. If a crater formerly existed, it has been completely dissected by erosion. The summit is made up largely of huge blocks of white pumice among which are a few obsidian bombs. Some of the obsidian is spherulitic. In places beneath the coarse ejectamenta beds of white ash and agglomerate crop out.

Near the mouth of the largest gulch that drains the north side of the butte there is a playa that formerly contained water throughout much of the year. Prior to the drilling of wells this playa was the only water hole between the Fort Hill Bottoms and the Big Lost River, and for many years all stage roads led to it. More recently a stock ranch has replaced the old stage station, and the owner has developed about a third of a second-foot of water by tunneling into the alluvium at the mouth of the gulch. When visited in 1921, the tunnel was 532 feet long and reached bedrock. Water from the coarse alluvium seeps into the tunnel through most of its length. The water is piped about a mile to a small reservoir. After stock and domestic

[20] Stearns, H. T., Bryan, L. L., and Crandall, Lynn, Geology and water resources of the Mud Lake region, Idaho: U. S. Geol. Survey Water-Supply Paper 818 (in press); Volcanism in the Mud Lake area: Am. Jour. Sci., 5th ser., vol. 11, pp. 360-362, 1926.

[21] Kirkham, V. R. D., op. cit. (Pamph. 19), pp. 33-38, 1927.

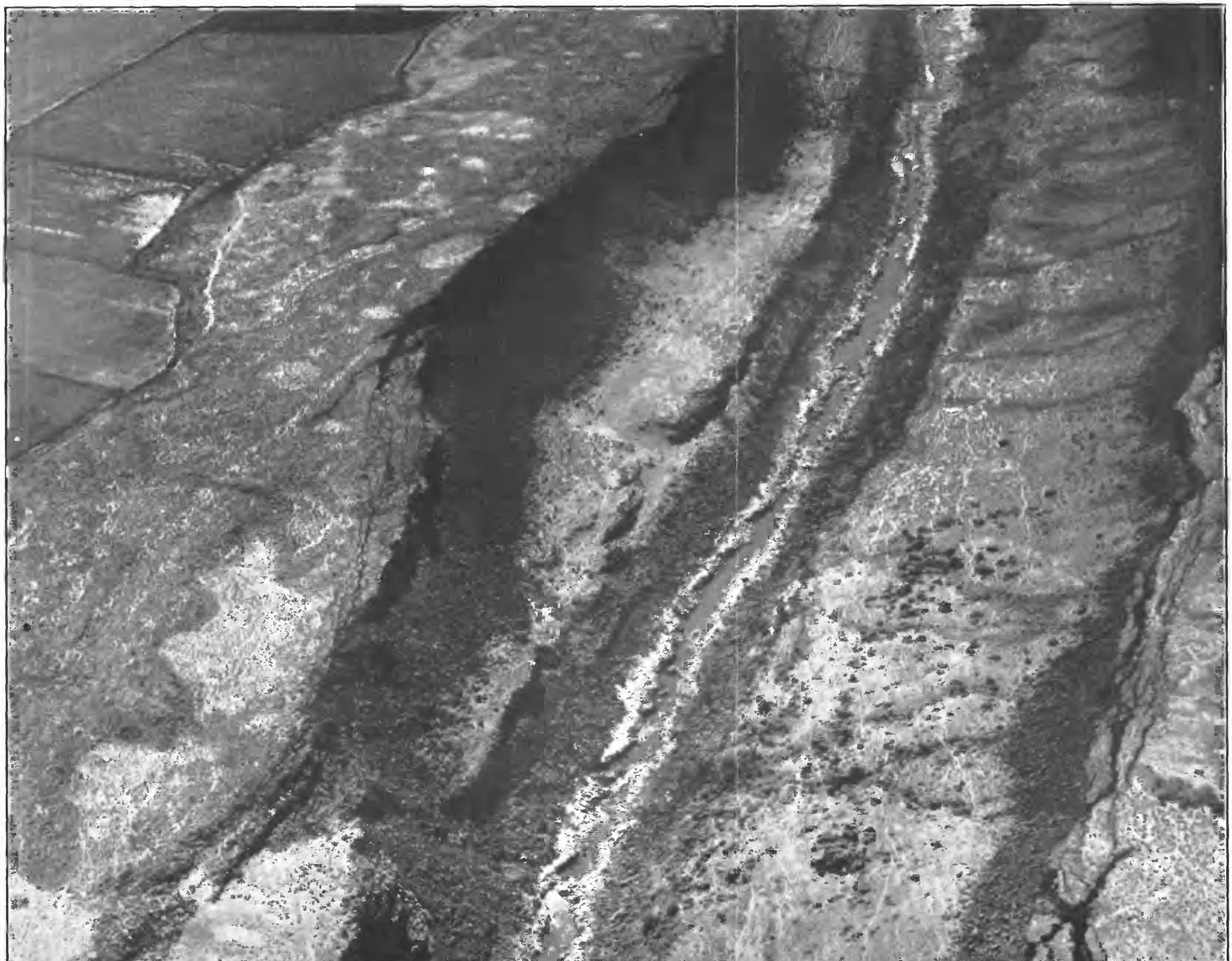
requirements are met, the surplus is used to irrigate a small patch of alfalfa. The tunnel simply recovers the underflow of the gulch. The fact that most of the water was encountered near the contact of the alluvium and bedrock indicates that the water recovered is following the old bedrock surface. The success attained in this gulch suggests that similar developments might be made at the mouths of other gulches around the butte, but is is doubtful if the drainage areas of the others are large enough.

In ascending the gulch above the tunnel a porphyritic basalt containing phenocrysts of feldspar and olivine was found. It is deeply weathered and appears to be of the same age as the rhyolite and extruded from the same crater, although this could not be definitely established. Farther up, the narrow gulch opens into an amphitheater that may have been originally a crater. In this amphitheater occurs a remnant of an asymmetric basaltic red cinder cone. The feeding dike of aphanitic basalt can be traced down the side of the gulch from beneath the cinders. The fresh character of this basalt and the associated pyroclastic material, together with its topographic position, shows that it is much younger than the weathered porphyritic basalt described above. A bed of aphanitic vesicular basalt flowed northward over the rhyolite from this cinder cone. It is now detached from the cone by erosion. This eruption is definitely younger than the rhyolite and seems to be associated with some of the older basaltic eruptions of the plain. However, as the flow has been removed by erosion from the side of the butte it must be older than the late basalts encompassing it. The topographic relation of the flow and cone to the gulch suggests that the amphitheater is a crater and that the basic eruption took place prior to the breaching of the crater by erosion.

TRACHYTE OF EAST TWIN BUTTE

The Twin Buttes rise above the lava plain 15 miles northeast of Big Southern Butte. They are about 4 miles apart. The East Twin Butte, locally known as East Butte, rises about 1,100 feet above the plain, and its light color forms a strong contrast to the surrounding dark lava fields.

The beds of trachyte, pumice, and obsidian of which the butte is composed dip about 30° S. and strike east. The trachyte, which is the most abundant, has phenocrysts of glassy feldspar (mainly orthoclase) and a few of quartz, in a fine-grained white groundmass composed mainly of orthoclase. The butte is deeply eroded, like Big Southern Butte, and on the south side an alluvial fan stretches southward for nearly a mile. No vestige of any crater remains on the summit, but the character of the rocks indicates that they accumulated near the top of a volcano. Inclusions of porphyritic basalt in the trachyte show that all the lavas of this cycle were not highly



AIRPLANE VIEW OF ROCK BENCH BORDERING BOTH SIDES OF SNAKE RIVER AND FORMING A CONSPICUOUS FEATURE NEAR KIMBERLY.

Note the gaping parallel cracks of incipient landslides in the basalt along the rim of the canyon. Photo by U. S. Army Air Corps.

siliceous. The butte is much older than the encompassing basalt and as viewed from a distance appears to surmount an elevated platform.

East Twin Butte may be an eroded fault block of silicic lava, but irrespective of its structure its lava flows appear to belong to the same eruptive cycle as those in Big Southern Butte.

BASALT OF WEST TWIN BUTTE

West Twin Butte or Middle Butte rises nearly as high above the plain as East Twin Butte and lies about 4 miles west of it. The butte is composed entirely of basalt that dips 10° S. and has well-defined columnar jointing. A thin section examined by Mr. M. N. Short contained abundant feldspar, olivine, and pyroxene, with a little interstitial, partly recrystallized brown glass. Abundant calcite has filled vesicles and replaced the glass. The minerals are all very fresh. Although the texture of this basalt, like that of most of the younger ones described below, is ophitic, the coarser, more abundant feldspar and nearly colorless pyroxene give it a distinctly different appearance. The abundance of calcite is another distinctive characteristic.

The most plausible theory to account for this single block of tilted basalt rising above the surrounding basalt fields is that of differential erosion of a range made up of acidic and basic lavas. The southerly dip of the beds in both East Twin Butte and this one suggests that a fault block several miles long was uplifted and tilted to the south along an eastward trending fault, but faulting is not essential to this theory. Subsequent erosion of this block, followed by the eruption of later basalt, left the two buttes as "kipukas."[22] The presence of basalt inclusions in the trachyte of East Twin Butte and the ancient basalt flow on Big Southern Butte show that here as elsewhere basalt flows accompanied the silicic eruptive rocks.

SHOSHONE FALLS ANDESITE

The Shoshone Falls andesite is a massive porphyritic vitreous mass of unknown thickness. It has an exposed thickness of about 200 feet, and a typical outcrop of it is shown in plate 7. Both Shoshone Falls and Pillar Falls owe their origin to the resistance of this rock to erosion as compared with that of the weaker ancient basalts downstream from the falls. A specimen from the foot of the Perrine Grade was examined under the microscope by Mr. Short, who has described it as follows:

> The rock consists of large tabular crystals of oligoclase and andesine in a groundmass that is composed of a mat of tiny feldspar laths in a brown glass. The feldspar phenocrysts reach 5.0 millimeters in length and are proportionately wider than in other specimens. Magnetite grains ranging from 0.1 to 1.0 millimeters in diameter are fairly common.

[22] A kipuka is defined as an island of older rock in a lava flow.

Most of the andesite is massive, with numerous large irregular-shaped vesicles, whose size is increased by weathering. Locally it is platy and exhibits flow structure. Along its upper contact the rock is black and glassy.

The andesite is exposed along the Snake River only from the foot of Twin Falls downstream as far as the Perrine ranch, a distance of 6 miles by river. (See pl. 5.) It terminates so abruptly downstream as to suggest the possibility of faulting, but a thick flow of this composition might well come to rest with a similarly steep front. The abundance of glass, especially near the top, and the vesicles and flow structure suggest that this rock is a flow, although the evidence at hand does not preclude an intrusive origin. The base of the andesite is not exposed. The rock is separated from the overlying rocks by an erosional unconformity. A lateritic soil at least a foot thick was formed on its irregular surface before being covered by the next succeeding formation, the Pillar Falls mud flow. The andesite is megascopically similar to the rock in Mount Bennett,[23] 30 miles to the northwest.

In the Twin Falls Cemetery well in the SE¼SW¼ sec. 14, T. 10 S., R. 17 E., the basalts of the plain were passed through at 270 feet, below which was 23 feet of boulders, probably the Pillar Falls mud flow. From 293 to 750 feet the well is in hard rock except for thin streaks of clay 2 to 3 feet thick. A fragment of rock recovered from the well is typical Shoshone Falls andesite, and a specimen of the so-called clay at 600 feet is a brown greasy material resembling a chemical deposit of some sort rather than clay. This 8-inch hole is reported to have yielded only about 45 gallons a minute at 270 feet. This well indicates that the andesite extends southeast at least 3 miles farther than mapped and if all the rock below 293 is Shoshone Falls andesite then it is more than 450 feet thick.

PILLAR FALLS MUD FLOW

From Shoshone Falls downstream the Pillar Falls mud flow rests on the eroded surface of the Shoshone Falls andesite. Upstream from these falls basalt rests directly on the andesite, indicating that the mud flow was either local in occurrence or else was removed by erosion prior to the eruption of the basalt. The latter hypothesis is favored, because the mud flow is also absent from some of the high points of the andesite downstream. The mud flow was not differentiated from the andesite in plate 5 because its outcrops are found only in the vertical walls of the canyon, and hence in the horizontal plan of the map their area is negligible. Furthermore, this material

[23] Russell, I. C., Geology and water resources of the Snake River Plain of Idaho: U. S. Geol. Survey Bull. 199, p. 44, 1902. Piper, A. M., Ground water for irrigation on Camas Prairie, Camas and Elmore Counties, Idaho: Idaho Bur. Mines and Geology Pamph. 15, p. 8 [1926].

appears to have no important bearing on the occurrence of ground water.

The mud flow consists of well-rounded gravel and huge boulders several feet in diameter composed of silicic extrusive material in a gray matrix of sand, ash, and soil. The lack of sorting indicates that the material was deposited by a stream overloaded with ash derived from a volcanic explosion. In the exposure examined angular explosion blocks were absent, indicating that the source of the ash was not nearby. Some of the soil on the underlying andesite is intermingled with the mud flow. The upper several inches of the mud flow is dull gray to red as a result of baking by the overlying basalt. In a few places the mud flow is sufficiently consolidated to overhang, but in other places it is easily removed with a pick. Russell [24] was apparently the first to note it, although the underlying andesite was described earlier by King.[25]

Probably at some time subsequent to the eruption of the Shoshone Falls andesite a deposit of ash was spread widely over the surrounding country. Torrential rain concurrent with or following shortly after the ash shower swept the incoherent material off the slopes in amounts so great as to form a pasty flow of mud, which shoved or floated everything movable in its path. The soil on the andesite shows that considerable time intervened between the eruption of this lava and its covering by the mud flow. On the other hand, the absence of fragments of basalt in the mud flow indicates that it was probably deposited before the episode of basaltic eruptions, which began in late Pliocene time. As the break at the top seems greater than that at the base the mud flow is tentatively assumed to be of Miocene rather than Pliocene age.

RHYOLITIC ROCKS SOUTH OF SNAKE RIVER

In the area between the canyon of the Snake River and the southern boundary of Idaho and extending as far east as the Malta Range there are large areas of rhyolitic rocks, most of which have been studied only in reconnaissance fashion. In the course of the present work these rocks were seen in many places but not mapped.

The valley of Salmon Falls Creek above the dam that forms the reservoir is carved in silicic lava and associated pyroclastic material. Farther north these Miocene (?) rocks are largely covered by later beds. Near Castleford a silicic layer 25 feet thick, possibly a welded tuff, is exposed beneath the Pleistocene basalt. Under this layer is 6 to 8 feet of reddish soil, which in turn rests on massive rock, probably an andesite flow, with an exposed thickness of 100 feet.

[24] Russell, I. C., op. cit., p. 43.

[25] King, Clarence, U. S. Geol. Expl. 40th Par. Rept., vol. 1, pp. 592–593, 1878.

Still farther downstream at a point a third of a mile south of the Salmon Falls Hot Spring in sec. 31, T. 8 S., R. 14 E., an exposure bearing on the relation of an andesite flow to the Hagerman lake beds and the Banbury volcanics occurs. Although this flow is doubtless not the same one as at Shoshone Falls, probably it has essentially the same age. At this point on the east bank of Salmon Falls Canyon, 60 feet of platy andesite occurs with its bottom going below creek level. Above it is 30 feet of bedded sand and clay with the top 5 feet of clay baked red by an overlying weathered basalt flow 50 feet thick, vesicular at the top and typical of the Banbury volcanics. Above this basalt is 30 feet of lake beds. The basalt dies out on the west side of the canyon and in that side the andesite is overlain by 200 feet of lake beds which are capped with a later basalt. The basalt on the east bank appears to have flowed from the north and east and the andesite from the south. The andesite terminates about 800 feet south of the hot spring. Its contact with the overlying sediments is not exposed but one gets the impression it ends either in a natural margin or by erosion, rather than by faulting. However, it is obvious here as it was not at Shoshone Falls, that the andesite underlies the Hagerman lake beds and Banbury volcanics.

Near the heads of Deep, Cottonwood, McMullen, Rock, and Dry Creeks, successively farther east, occur thin widespread even-bedded fluidal pink rhyolitic rocks with glassy tops, apparently largely welded tuffs, and intercalated ash beds. This series of rocks dips north and along the border of the Snake River Plain is apparently much disturbed by faulting, with the downthrow generally to the north.

Similar rhyolitic rocks continue eastward into the valley of Goose Creek. Here Piper [26] distinguished early Miocene (?) rhyolite and late Miocene (?) lacustrine beds with "intercalated and capping flows of rhyolitic lava."

Rhyolitic tuff and lava flank Marsh Creek, the next stream to the east, on both sides. On the west these beds rest on Paleozoic (?) quartzite. Near the mouth of the valley the tuff is quarried for use locally as building stone. The ridge on the east, which separates this valley from that of the Raft River, is composed chiefly of rhyolite and obsidian with here and there a white tuff bed capped by a persistent glassy rhyolite. The mountains east of the Raft River Valley, at least on their east side, contain volcanic rocks of several kinds resting on Paleozoic sedimentary beds. Presumably the volcanic rocks are to be correlated in part with those farther west. From this vicinity east and northeast rhyolitic, andesitic, and related flows and pyroclastic rocks continue to be exposed at intervals. Most of them have

[26] Piper, A. M., Geology and water resources of the Goose Creek Basin, Cassia County, Idaho: Idaho Bur Mines and Geology Bull. 6, pp. 26–35, 1931.

been described by Mansfield [27] and were not closely examined during the present work. The information available indicates that the thick sequence of rhyolitic rocks, and associated beds west of the Malta Range either originally thinned out rapidly immediately to the east of this range or else has been largely obliterated as a result of subsequent events. The silicic volcanic rocks in the area between the Raft River and the vicinity of Pocatello differ somewhat in appearance and thickness from those to the west.

SOURCES OF RHYOLITIC AND RELATED ROCKS

The amount of rhyolite and associated volcanic rocks in and on the borders of the Snake River Plain is much greater than can be accounted for by known vents in this region. Within the region examined there is a small cone near Fort Hall [28] and several near the Blackfoot Reservoir,[29] but no other cones that appear to be suitable sources for the rhyolitic lava are known. Indian Creek Butte [30] in Clark County instead of being a cone, as formerly thought, may consist of a hill of older rock blanketed with welded tuff.

Some of the vents from which these silicic volcanics issued may be buried beneath the copious Pliocene and later basalt flows. The hypothesis that one of the major sources of the silicic flows was a chain of volcanoes extending from the Yellowstone National Park toward Boise along the axis of the Snake River Plain accords with the known facts within this region, although it is supported by little direct evidence. It is clear from the descriptions which follow that the Pliocene and Pleistocene basalts locally attain an aggregate thickness of at least 1,000 feet, and the maximum thickness is probably much greater. Even this minimum figure is sufficient, especially if some allowance is made for erosion and possible down-warp prior to the basaltic eruptions, to account for the burial of rhyolitic cones of considerable size. Kirkham [31] has presented evidence tending to show that near the west end of the Snake River Plain the bottom of the depression that was filled with Tertiary beds may perhaps now be as much as 20,000 feet below sea level. However, his evidence of downwarp in the area studied is chiefly based on the dip of the silicic volcanics, which he considered as flows. Because many of them are welded

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[27] Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713, pp. 57–61, 1920; Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, pp. 116–130, 1927; Geography, geology, and mineral resources of the Portneuf quadrangle, Idaho: U. S. Geol. Survey Bull. 803, pp. 40–45, 1929. Mansfield, G. R., and Ross, C. S., Welded rhyolitic tuffs in southeastern Idaho: Am. Geophys. Union Trans., pt. 1, pp. 308–321, 1935.

[28] Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713, p. 72, 1920.

[29] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, p. 362, 1926.

[30] Stearns, H. T., Volcanism in the Mud Lake area, Idaho: Am. Jour. Sci., 5th ser., vol. 11, p. 362, 1926.

[31] Kirkham, V. R. D., Snake River downwarp: Jour. Geology, vol. 39, no. 5, pp. 473–479, 1931.

tuffs their dip may have resulted from the topography on which they fell and not on subsequent tilting.

The differences in the character of the rhyolitic rocks in different parts of the region accord with the concept that they came from separate vents arranged more or less parallel to the axis of the plain rather than that they flowed widely from a single area, such as the Yellowstone National Park, where rhyolitic flows are abundant.

Whether or not the buried volcanoes suggested above furnished some of the flows, evidence is rapidly accumulating [32] that there are many intrusions in the mountains of south-central Idaho which are of suitable age and petrographic character to have been the source of a large part of the lavas older than the basaltic flows of which the Snake River Plain is built up. Some of these intrusions in the Lava Creek [33] and Alder Creek [34] districts are shown in plate 4. Numerous others, some of which are much larger, are exposed in the mountains farther north and west.[35] Erosion has been so active in this high region since most of the intrusive rock now exposed became solid at depth that any original connection with surface flows has been eroded away or otherwise obscured. Recently Udell [36] has found that there are in the Muldoon mining district, Blaine County, not far from the border of the Snake River Plain, two lines of vents or craters which he regards as the sources of much of the Challis volcanics of this locality. He further finds that there are in the Muldoon district granitic and other intrusions comparable in age and character to those above referred to, and that some of the rhyolitic dikes here are materially younger than the granitic masses. This accords with the concept, expressed above, that the rhyolitic flows of the region may be of more than one age.

PLIOCENE ROCKS

OCCURRENCE AND CHARACTER

Over most of the region mapped on plate 4 rocks as old as Pliocene, if present, are deeply buried. Locally, at the base of the Centennial Mountains, along the canyon of the Snake River and in and near Hagerman Valley, rocks are exposed which may, with different degrees of certainty, be referred to the Pliocene. Some of these are lacustrine and fluviatile deposits, most of which contain fossils,

[32] Ross, C. P., Mesozoic and Tertiary granitic rocks in Idaho: Jour. Geology, vol. 36, no. 8, pp. 682–884, 692–693, 1928. Anderson, A. L., Geology and ore deposits of the Lava Creek district, Idaho: Idaho Bur. Mines and Geology, Pamph. 32, pp. 21–25, 1929.

[33] Anderson, A. L., op. cit. (Pamph. 32), pp. 21–25.

[34] Ross, C. P., Geology and ore deposits of the Seafoam, Alder Creek, Little Smoky, and Willow Creek mining districts, Custer and Camas Counties, Idaho: Idaho Bur. Mines and Geology: Pamph. 33, pp. 13–14, 1930.

[35] Ross, C. P., Mesozoic and Tertiary granitic rocks in Idaho: Jour. Geology, vol. 36, no. 8, pp. 682–684, 1928.

[36] Udell, Stewart, The geology of the Muldoon mining district, Blaine County, Idaho: Idaho Bur. Mines and Geology Pamph. — (in preparation).

although thoroughly diagnostic collections have been made only in Hagerman Valley. More or less closely associated with the different sedimentary units are beds of basalt and other volcanic rocks whose stratigraphic position (so far as determinable) and degree of weathering indicate that they are of approximately Pliocene age. It appears from the data summarized below that in the region here considered Pliocene rocks make up a relatively small part of the great mass of beds accumulated subsequent to Miocene time.

Four units have been mapped for whose age positive evidence is lacking but whose relations suggest that they are mainly older than the definitely recognizable upper Pliocene rocks and younger than the Miocene (?) rocks above described. These rocks are here grouped as lower Pliocene (?) and are described below. All but those in Clark County lie along the Snake River from American Falls to the east side of the Raft River, and they are considerably disturbed by faulting and in general dip northward, away from the foothills. The Rockland Valley basalt and Raft lake beds appear younger than these rocks but older than the upper Pliocene. They are therefore grouped as middle (?) Pliocene. The Banbury volcanics and Hagerman lake beds may on stratigraphic and paleontologic grounds be confidently assigned to the upper Pliocene.

LOWER PLIOCENE (?) ROCKS

TERTIARY SEDIMENTS IN CLARK COUNTY

A considerable area in the vicinity of Medicine Lodge Creek in northwestern Clark County is covered by fanglomerate and kindred material which overlies and may in part interfinger with the rhyolitic flows so abundant in this area.[37] Most or all of these deposits are stream-laid, and they are evidently but little younger than the rhyolitic flows of the vicinity. Pieces of thoroughly fossilized camel bone from a well in the gravel were regarded by J. W. Gidley as suggestive of Pliocene age. The sediments have therefore been tentatively referred to the Pliocene, although if the rhyolitic flows should prove to be as old as some of the similar flows in other parts of Idaho these sediments may likewise be pre-Pliocene.

NEELEY LAKE BEDS

In the bluffs of the Snake River near Neeley, 5 miles southwest of American Falls, a series of lake beds has an exposed thickness of 100 feet, but its base is concealed, hence it must be thicker. (See pl. 6.[38]) These beds consist of flesh-colored to brown sandy lacustrine deposits

[37] Stearns, H. T., Bryan, L. L., and Crandall, Lynn, Geology and water resources of the Mud Lake region, Idaho: U. S. Geol. Survey Water-Supply Paper 818 (in press).

[38] The geology on this map was originally plotted on a U. S. Bureau of Reclamation map. In replotting on the new U. S. Geological Survey base the géology was adjusted to fit the new base, and this may have given rise to errors.

composed partly of reworked and subaqueously deposited basic tuffs presumably accumulated behind a lava dam. The deposits are even-bedded and dip 3°–5° N. except where disturbed by faulting. They are sufficiently indurated to form steep bluffs wherever they have been eroded.

Although this formation is coarser than some of the other lake beds it is not sufficiently coarse to yield much water. No wells are known to derive their supply from this formation, and no perennial springs issue from it.

EAGLE ROCK TUFF

The Eagle Rock tuff, named from Eagle Rock, near American Falls, is exposed at the base of the American Falls. The following section was measured at this place, the type locality:

Section of Eagle Rock tuff on north bank of Snake River at American Falls

	Feet
Red felsitic tuff containing feldspar crystals 2 to 4 millimeters in length	0. 6
Welded rhyolitic obsidian tuff containing spherulites and lithophysae. Some of the lithophysae are 3 inches in diameter	20. 8
Even-bedded coarse black ash, composed of shards of rhyolitic glass. The top layer is compact and breaks into dull obsidian fragments and grades downward into ash that can be readily removed with a knife	4. 5
Even-bedded gray to white rhyolitic ash, in places pisolitic	9. 3
	35. 2

The following descriptions are based partly on microscopic studies by M. N. Short:

> The top bed is a fused rhyolitic tuff which contains large crystals of albite and owes its red color to the numerous minute hematitic inclusions. The 20-foot bed of obsidian tuff next below is less thoroughly fused. It contains a few rounded crystal fragments of microcline and oligoclase but with these exceptions is entirely glassy. The rock lacks joint planes and shrinkage cracks and presents an unusual appearance because of the honeycomb structure produced by the lithophysae and the weathering out of the spherulites from the matrix. In places where hollow spherulites or lithophysae predominate over the tiny symmetrical spherulites the matrix is pink. Small subangular obsidian pellets also weather out between the spherulites, and in these localities the matrix is easily removed with a pick. The next lower bed at the type locality is a compact dark-gray vitreous tuff, which consists of light-brown rhyolitic glass (refractive index 1.497) whose structure indicates welding and flowage. At another exposure along the Oregon Trail this bed is even more compact and megascopically gives no indication of its fragmental structure. The white ash in the lowest bed differs from the ash in the top bed only in its unconsolidated character. It consists of fragments of glass with only a few scattered grains of feldspar.

This formation has a uniform thickness except where eroded. Its component beds are so similar in composition and so closely comparable as to indicate that they followed one another in rapid succession and came from the same volcano. The presence of pisolites in the ash suggests subaerial deposition. The absence of cross-bedding and lamination indicates that the beds were formed from ash showers without appreciable sorting by wind or streams. Wind-blown soil at the top of the formation if deposited soon after the tuff accumulated would indicate that these rocks were laid down on dry land.

This formation has been recognized only in the canyon walls along the Snake River. Beyond it is buried by younger formations. It extends for several miles along the river southwest of American Falls. On the west side of Rockland Valley, about 12 miles south of American Falls, there is an exposure of white consolidated pumice and ash 100 feet thick which may correspond to the white ash of the Eagle Rock,

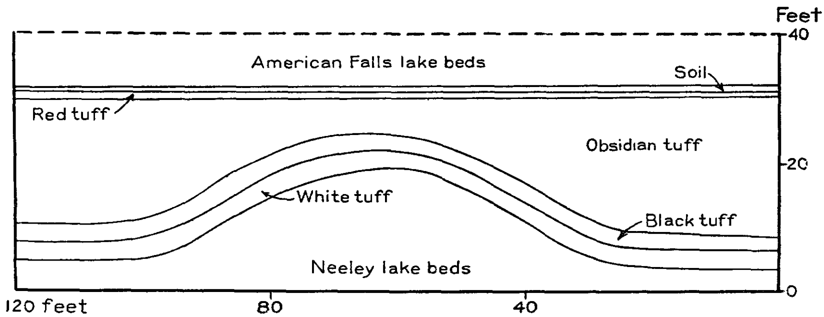


FIGURE 4.—Local unconformity between the Neeley lake beds and the Eagle Rock tuff.

and its greater coarseness and thickness here may be due to its being nearer the source. The pumice at this particular exposure weathers easily and is filled with cavities.

On the west bank of the Snake River in the NW¼ sec. 22, T. 8 S., R. 30 E., a slight variation occurs in the thickness of the beds. At this place a small mound a few feet high in the Neeley lake beds is overlain by the white and black ash beds retaining their usual thickness and conforming to the surface of the mound. The obsidian tuff above the ash thins sufficiently in passing over the mound to make its upper surface level. Consequently on top of the mound there is only about 4 feet of obsidian tuff, as compared with about 18 feet on each side. Above the obsidian tuff is the usual thin bed of red tuff and a few inches of soil containing scattered red basaltic cinders. On top of the soil rest the American Falls lake beds, which are much younger and which are described below. Figure 4 shows the relation of the obsidian to the underlying tuff and lake beds. These relations, coupled with the texture of the obsidian tuff, indicate that the fragments composing the tuff were molten when they fell and consequently coalesced into a mass sufficiently fluid to adjust itself to minor topographic irregularities. This suggests distribution as a hot avalanche or nuée ardente, as at Mont Pelée in the West Indies in

1902, or like the hot sand flow of the Valley of Ten Thousand Smokes [39] in 1912.

MASSACRE VOLCANICS

In the center of sec. 6, T. 9 S., R. 30 E., is a group of knobs of dense basalt. They are named "Massacre Rocks" because in 1862 the Indians massacred an emigrant train at this point. The rocks represent the denuded feeder of an ancient volcano. The wide distribution and coarseness of the pyroclastic rocks from this vent suggest that in comparison with similar less dissected cones in other regions, the original cone here may have been a thousand feet or more high and perhaps several miles in diameter. Its explosive products and flows were spread over more than 20 square miles. The products of this volcano, which are here named the "Massacre volcanics", are much older than the other basalts that now form the canyon wall on the north side of the Snake River opposite the historic spot.

The volcano was mainly explosive during its history, for the basaltic ash, cinders, and bombs greatly predominate in quantity over the lava flows. A few blocks of basalt, spherulitic obsidian, clay, and limestone torn from the underlying basement are intermingled with these fire-fountain deposits. The beds are brown, red, or black, the color depending upon the state of oxidation of the iron present in them. They are all consolidated and readily distinguished from the underlying Eagle Rock tuff. In general they dip away from Massacre Rocks, but many of the beds have been tilted considerably by subsequent faulting. In the SW¼ sec. 21, T. 8 S., R. 30 E., a peculiar bed of cinders crops out about 20 feet above the northwest bank of the Snake River. It contains numerous red concretionary balls of practically pure calcite as much as 4 inches in diameter.

Beds belonging to the Massacre volcanics are exposed at intervals on both banks of the Snake River upstream from Massacre Rocks as far as Eagle Rock, a distance of about 11 miles. (See pl. 6.) At this place they are cut off by a fault. Downstream they are exposed to a point only 1½ miles from Massacre Rocks, where they are faulted down out of sight.

In the SW¼ sec. 22, T. 8 S., R. 30 E., on the south bank of the river, which there makes a right-angle turn to the northwest, the fire-fountain deposits are in contact with the underlying Eagle Rock tuff. A similar contact can be seen on a neighboring island in the river. Here the deposits rest on 4 feet of loess soil containing angular rock chips derived chiefly from the red felsitic tuff, which here is only 1 foot thick and lies on the spherulitic obsidian. This contact shows that sufficient time elapsed between the obsidian flow and the eruption of the Massacre volcanics to form deep soil and also that the

[39] Fenner, C. N., The origin and mode of emplacement of the great tuff deposit of the Valley of Ten Thousand Smokes: Nat. Geog. Soc., Contributed Tech. Papers, Katmai ser., no. 1, pp. 70-74, 1923.

eruption took place on dry land. In places thin layers of basalt, which was erupted from the Massacre Rocks volcano, cap the fire-fountain deposits and are interbedded with them. The prominent hill that rises about 500 feet above the Snake River in sec. 5, T. 9 S., R. 30 E., is capped with weathered porphyritic basalt that may have come from this vent.

Another flow from the Massacre Rocks vent makes a prominent cliff along the highway just northeast of the mouth of Rock Creek, in sec. 12, T. 9 S., R. 29 E. A few thin flows interspersed with the cinders have not been differentiated on plate 6. Although these flows are thin where exposed, they are close to the source, where the lava was extremely liquid and was flowing down the cone slope. Therefore they may represent the upper ends of originally extensive flows.

On the north bank of the Snake River near the foot of American Falls the soil above the obsidian is overlain by a fine-grained blue basalt flow 25 feet thick. This flow caps the rhyolitic tuffs for 5 miles downstream, except where it has been removed by erosion. As it occupies the same stratigraphic position as the Massacre volcanics, it may have been erupted from the Massacre Rocks vent.

MIDDLE (?) PLIOCENE ROCKS

ROCKLAND VALLEY BASALT

On the west side of Rockland Valley even-bedded basalt flows are exposed in the deep, narrow canyon of Rock Creek. In sec. 8, T. 9 S., R. 30 E., about 250 feet of these lava flows is exposed. The flows exhibit the usual columnar jointing and are all of the pahoehoe type. They are considerably weathered, and their state of decomposition readily distinguishes them from the adjacent later basalts that cover the Snake River Plain. The uppermost flow near the mouth of Rock Creek is 40 feet thick and rests with apparent conformity on light-colored clay beds 15 feet thick, which in turn overlie basalt. Although the lavas do not exhibit subaqueous phases, they were evidently laid down at about the same time as the lake-bed clays. These clays appear to be playa deposits, hence they may have been dry when the lava covered them. This suggestion receives some support from the fact that the clay beneath the 40-foot lava flow is not baked red near the top by the basalt.

In the north end of Rockland Valley most of the lavas are buried by later deposits. The lavas extend toward Table Mountain, a high butte to the south, and it is possible that the vents lie in that direction. These lavas appear to have been tilted gently to the northwest. Apparently the Massacre Rocks cone was too high to be covered by them, for no remnants of them overlie the tuff; hence the cone was probably a kipuka during the lava floods.

The total thickness of the Rockland Valley basalt may be exposed somewhere in the Rockland Valley. The driller of the Burley city well 5, about 40 miles west of the mouth of Rock Creek, reported in the bottom of the well 647 feet of basalt, which occupies the stratigraphic position of the Rockland Valley basalt. (See p. 50.) Because basalts are poured out over the land as semifluids, a flow may be 1,000 feet thick at an outcrop, where it fills an old canyon, but a mile away the same flow may be absent or be only a few feet thick. The notable variation in thickness of basalts from place to place, as contrasted with the relatively uniform thickness of sedimentary deposits, may involve considerable errors in correlation and doubtless causes some of the great difference in the logs of wells drilled within a small area.

In spite of its extensive weathering, this basalt is fairly permeable, and several domestic wells probably derive their supply from it.

RAFT LAKE BEDS

Lake beds, here named the "Raft lake beds" (pl. 6), extend westward from the mouth of Rock Creek along the south shore of Lake Walcott as far as the mouth of the Raft River. The beds in this formation appear to have uniform thickness when seen in any one exposure, but individual layers are traceable for only short distances. The beds are buff to pale yellow and consist of partly consolidated silt, sand, caliche, and gravel. At the mouth of Fall Creek lens-shaped beds of coarse gravel and hardpan are plentifully intercalated in them. Nodular concretions, as much as 10 inches in length, are characteristic of the beds, but tuffaceous beds are uncommon.

Near the mouth of Rock Creek the lake beds rest on the Rockland Valley basalt. A small outlier of them is seen in a depression in the Massacre volcanics a mile northeast of this creek, on the south side of the highway, and possibly another occurs beneath the Cedar Butte basalt on the north bank of the Snake River near Bonanza Bar, at the mouth of Lake Channel. In the Rockland Valley these beds form rounded hills covered with rich brown soil that is extensively dry-farmed. At the head of Fall Creek, in secs. 27 and 28, T. 9 S., R. 29 E., a basal conglomerate of the formation crops out and includes talus blocks from the adjacent Paleozoic limestone. The beds rest unconformably on ancient limestone in sec. 9, T. 10 S., R. 28 E.

The Raft lake beds are about 200 feet thick near Fall Creek, and there they also rise about 200 feet above the Lake Walcott Reservoir. At the Raft River, 8 miles to the west, they rise only about 50 feet above the reservoir. Their surface also rises gently toward the southeast and forms a plateau cut only by a few ephemeral streams. The plateau is capped here and there by gravel deposits, which probably are the alluvial fans deposited by similar ephemeral streams tributary to the ancient lake. The whole formation has been tilted to the northwest, so that the beds dip in this direction about 5°. They form a precipitous bluff along the Lake Walcott Reservoir, and at one time they evidently extended much farther north into the Snake River Plain. Although these lake beds were possibly removed by the Snake River, they may be terminated on the north by an eastward-trending fault or series of faults.

The presence of several warm springs in sec. 19, T. 9 S., R. 28 E., issuing at the base of the bluff, suggests faulting as the cause of the escarpment, but similar bluffs have been carved by the Snake River in the Hagerman lake beds in many places. Furthermore, the underlying Massacre volcanics and possibly even the Raft lake beds crop out on the north bank of the Snake River, and if a fault terminated the lake beds the tuffs should have been carried down out of sight. The Raft lake beds end abruptly on the east side of the Raft River, beyond which they have been removed by erosion and replaced by recent basalts.

From exposures near the mouth and from well records farther south, much of the Raft River Valley, under a cover of alluvium, seems to be filled with Raft lake beds. Warneke's well, in the NE¼SE¼ sec. 32, T. 13 S., R. 27 E., is reported to have penetrated 48 feet of gravel and then remained in fine-grained stream and lake deposits to its bottom, at a depth of 800 feet. A composite sample from the cutting dump shows that the last material drilled was arkosic sand.

In T. 15 S., R. 24 E., 6 miles due south of Almo and 5 rods from the Raft River, the Oasis Oil Co., of Burley, started a well for oil. According to the log furnished by A. T. Wilcox, of Almo, this well is 375 feet deep and below 5 feet of soil penetrated gravel and sand, with some clay.

The Raft lake beds are younger than those in the adjacent valley of Goose Creek, described by Piper [40], because they overlie instead of underlie the rhyolite, and they are quite different lithologically. According to Anderson [41], however, there are on both sides of the Raft River Valley sedimentary beds which are capped by and locally intercal ted with rhyolitic flows. He maps these rocks only in the range east of the valley and in a small area south of Almo but notes their presence in small exposures in numerous other localities, particularly beneath the rhyolitic flows of the Malta Range.

City well 5 at Burley is 1,115 feet deep and between 255 and 468 feet below the surface penetrated 213 feet of lake beds with some basalt above them. The driller's description indicates that these beds are probably the Raft lake beds, because they occupy the proper strati-

[40] Piper, A. M., Geology and water resources of the Goose Creek Basin, Cassia County, Idaho: Idaho Bur. Mines and Geology Bull. 6, pp. 27-31, 1923.

[41] Anderson, A. L., Geology and mineral resources of eastern Cassia County, Idaho: Idaho Bur. Mines and Geology Bull. 14, pp. 35-44, 1931.

graphic position. Beneath the lake beds is 647 feet of basalt, variations in which indicate that it may comprise nearly 50 separate flows. The surface of the lake beds slopes about 18 feet to the mile westward from the mouth of Fall Creek to the mouth of the Raft River. Burley is about 30 miles due west of the Raft River. If this same gradient is maintained these beds should lie about 550 feet below the surface at Burley instead of 255 feet. A fault on the west side of the Raft River is postulated on page 106. If this fault moved again subsequent to the deposition of the lake beds it would account for this difference of 295 feet.

The lithology of the Raft lake beds points rather conclusively to shallow-water conditions during most of the lake's existence. It is highly probable that these sediments were laid down behind a lava dam in a depression that was fed by mountain streams, which filled certain parts of it at different times during the year, and that the water escaped through the dam or was evaporated. That is, the beds were formed in a playa rather than a lake, although in exceptionally wet years a temporary lake may have existed. Many of the fine-grained sedimentary beds that have accumulated in different places in southern Idaho were formed under similar conditions.

The Raft lake beds are, as a whole, poor water bearers. No perennial springs except the warm springs mentioned above are known to issue from them. However, wells drilled about 200 feet into them have obtained domestic supplies. The beds in the Burley well 5 supposed to belong to this formation did not yield appreciable amounts of water.

UPPER PLIOCENE ROCKS

BANBURY VOLCANICS

Flows.—The Banbury volcanics, named from the thick exposure near Banbury Hot Springs, in sec. 33, T. 8 S., R. 14 E. (see pl. 5), extend from the Perrine ranch, in sec. 28, T. 9 S., R. 17 E., at an altitude of 3,250 feet above sea level, down the Snake River 63 miles to the vicinity of King Hill, at an altitude of 2,500 feet. They crop out fairly continuously as a series of even-bedded massive basalt flows over 300 feet thick. Basalt belonging to this formation extends up Salmon Falls Creek also.

The basalt of this formation, wherever it is exposed, weathers to a dark brown, often with a greenish cast. By this color and its relative softness it is readily distinguished from the younger hard blue basalts that locally lie in juxtaposition with it. A fossil bone (specimen E-15) collected from a bed of gravel and sand 30 feet thick and of fluviatile origin, halfway below the rim of the south canyon wall of the Snake River in the SW¼NE¼ sec. 9, T. 9 S., R. 15 E., and interstratified with the Banbury volcanics, was identified by J. W. Gidley as the tibia of a large camel of either Pleistocene or Pliocene age. Because these lavas are intimately associated with the overlying lake beds, which contain late Pliocene fossils, their age is fixed with considerable certainty. The bottom of the basalt series was not observed. The fact that the basalts crop out at a higher altitude to the east than to the west may be due to their being gently downwarped toward the west or to their having accumulated in a greater thickness in one end of the basin than in the other. That these lavas were not spread uniformly over the entire basin is attested by the local variations in them.

Near the crossing of Salmon Falls Creek known as "Castleford" the Banbury volcanics rest on and are back-filled against an abrupt face of Miocene (?) lava, probably andesite. The Banbury volcanics are again exposed about three-quarters of a mile south of a hot spring in sec. 31, T. 8 S., R. 14 E., and continue to a point a few yards north of the spring, where they are abruptly terminated apparently by a fault and brought into contact with the upper part of the Hagerman lake beds.

The flows of this formation are massive, and such openings as exist are largely filled with soil as a result of weathering. Consequently they are less permeable than most other basalts, and only small supplies of water have been obtained from the formation. One exception occurs on the Twin Falls project, where a drainage tunnel about 100 yards long in this formation developed about 1 second-foot of water.

Riverside Ferry cone.—On both sides of Snake River at the old Riverside Ferry in secs. 20 and 29, T. 8 S., R. 14 E., are cliffs 125 feet high exposing steeply dipping bedded dark-gray and reddish-black cinders and thin layers of weathered brown basalt typical of a dissected cone. It is cut through by the Snake River, but erosion has not yet bared the feeder, as at Massacre Rocks. The gravel, older basalt blocks, and porcelain-like fragments of baked clay hurled out during the eruption and deposited with the cinders indicate that these rocks underlie the cone. The tuff exposed at Thousand Springs, 1¼ miles downstream, is probably from this cone. Some of the flows in the adjacent Banbury basalt appear to have originated at this vent. The cone deposits are cut off by a steep erosional unconformity on the north side of the river and overlain by the Sand Springs basalt. On the south side of the river the cinders are in juxtaposition with lake sediments possibly as a result of faulting. They are not exposed on the east bank of Snake River south of Box Canyon.

Because the deposits from Riverside vent form an integral part of the Banbury volcanics there can be little doubt that individual cones were the source of part, if not all, of the Banbury basalt. The character of the deposits from this cone suggests that it formed beneath the waters of a lake. The tuffs from this cone are not differentiated on plate 5 from the Banbury basalt, but the cone is shown by a separate pattern.

HAGERMAN LAKE BEDS

The Hagerman lake beds rest on the Banbury volcanics and form prominent bluffs along the Snake River in Hagerman Valley, as shown in plate 10, *A*. They comprise a series of white to buff, partly consolidated clays and silts, and are named from the fine exposures in this valley. Intercalated with the fine sediments are a few gravelly lenses and basic tuffs and flows. Some of the clay beds are gypsiferous, and near the mouth of Salmon Falls Creek a 20-foot bed of diatomite occurs in the series. A gravel bed 20 feet thick, laid down as the lake was drained, forms the capping member. The beds are nearly horizontal, and dips of only 2° to 3° were recorded except in areas where the beds had been disturbed by landslides. They are exposed from Melon Valley, north of Buhl, for many miles to the west and south, and only a small part of them is included in the area mapped.

The top of the Hagerman lake beds reach an altitude of about 3,400 feet, and because of the practically undisturbed condition of the beds it is judged that this altitude represents approximately the highest shore line of the lake. The types of sediments indicate that this lake was more persistent than the playa lake in which the Raft lake beds were deposited. Nevertheless, the character of the vertebrate fossils and of the beds containing them, described below, shows that the area was not submerged by a lake throughout the time during which the Hagerman beds were accumulating. Some of the beds are stream-laid, and others appear to have been formed in a swamp, but they occur almost exclusively in the upper part of the section. Only three or four lava flows were intercalated in these sediments in this area during the long time in which they were being laid down.

A flowing well that was drilled to obtain hot water for a natatorium on the north side of the highway near the center of sec. 7, T. 5 S., R. 11 E., about half a mile east of King Hill, penetrated 970 feet into these beds, and the log is given below.

Driller's log of well at King Hill

[E. B. Hughes, driller. Altitude 2,550 feet]

	Thickness (feet)	Depth (feet)
Boulders and sand (first surface water at 70 feet)	70	70
Clay	80	150
Hard rock	130	280
Clay	70	350
Clay and sandrock (small flow of about 15 gallons a minute [1] over casing at 350–360 feet; temperature 72° F.)	100	450
Sandrock (large flow of about 100 gallons a minute [1] at 450–480 feet; temperature 78° F.)	140	590
Hard rock	40	630
Soft sandrock (flow of about 200 gallons a minute [1] at 680–690 feet; temperature 83° F.)	60	690
Boulders and shale	110	800
Clay and boulders (last water at 820–840 feet; flow of about 300 gallons a minute;[1] temperature 92° F.)	170	970

[1] Driller's estimates of flow all believed to be too great.

A. TYPICAL EXPOSURE IN THE HAGERMAN LAKE BEDS ON THE WEST SIDE OF SNAKE RIVER IN HAGERMAN VALLEY.

B. BLISS BASALT CONTAINING TALUS BLOCKS OF A FORMER CLIFF (a) AND OVERLAIN BY VITREOUS VOLCANIC SAND (b) AND OLDER ALLUVIUM (c).

The well started in alluvium, and the hard rock struck at 150 feet is probably intercalated basalt. The basalt at the mouth of Clover Creek shown in plate 5 is evidently eroded completely away at the well site. The bed of hard rock 40 feet thick that is reported at 590 feet, presumably basalt, is the only other interstratified lava to a depth of 970 feet. The mouth of the well is about 2,550 feet above sea level; hence the drill penetrated to an altitude of 1,580 feet. It is evident from the log that sediments similar to the Hagerman lake beds were encountered to a depth of 690 feet, but the boulders and clay for the remaining 280 feet are difficult to interpret. The log of this well indicates a greater thickness of lake beds at King Hill than is exposed in Hagerman Valley.

An upper Pliocene age for the Hagerman lake beds is indicated by the fossil vertebrates that have been found in the bluffs along the west side of the Snake River near the town of Hagerman. Stearns while hunting for fossils heard that Elmer Cook, a farmer living in Hagerman, had some fossils in his yard and was shown the source by Mr. Cook. Recognizing the importance of this rich fossil deposit, Stearns excavated several hundred pounds and sent a representative collection to the National Museum in 1928. He suggested that someone be sent to make further excavations. Parties from the Smithsonian Institution under Dr. Gidley in the next two summers and under N. H. Boss in 1931 obtained a large quantity of fossil material from this locality. The great bulk of the collection consisted of horse remains and was uncovered in a quarry located on a hill in the NW¼ sec. 16, T. 7 S., R. 13 E., about 30 feet below the top of the lake series.

The equid material has been described by Dr. Gidley as *Plesippus shoshonensis* [42] and includes a large number of skulls, lower jaws, and other skeletal parts. Much of the material was disarticulated, but several nearly complete articulated skeletons are included in the collection, and also some articulated limb and vertebral portions. *P. shoshonensis* represents a stage between that of the typical Pliocene *Pliohippus* and Pleistocene *Equus*. The Idaho form was noted by Dr. Gidley to be more advanced than the *P. simplicidens of* the Blanco formation of Tesas and *P. proversus* of the upper part of the Etchegoin of California, suggesting a closer relationship to *Equus*.

The environmental conditions indicated by the fauna from the *Plesippus* quarry are described in the following quotations from Gidley's second report [43] on his explorations in Idaho:

It [the quarry deposit] is evidently the remnant of a stream-channel deposit made up of cross-bedded layers of coarse and fine sand with occasional pebbles and here and there patches and lenses of almost pure clay, forming a part of the horizontally laminated beds of the Idaho formation [Hagerman lake beds of this

[42] Gidley, J. W., A new Pliocene horse from Idaho: Jour. Mammalogy, vol. 11, no. 3, pp. 300–303, 1930.

[43] Gidley, J. W., Continuation of the fossil horse round-up on the Old Oregon Trail: Explorations and Field Work Smithsonian Inst. in 1930, pp. 33–40, 1931.

report]. The bone deposit was evidently at the time of its formation a boggy, springy terrane, perhaps a drinking place for wild animals in a semiarid country, where water holes were not abundant. * * * Springs and swampy conditions are indicated from the fact that there are in the deposits the remains of frogs, fish, swamp turtles, beavers, and other water-loving animals, and an abundant evidence of vegetation, as shown by remnants of coarse grass stems, leaves, and even small pieces of wood. * * * In the lower stratum of this deposit the sand is heavily stained, and many of the fossil bones are encrusted and stained with light accumulations of bog iron.

The bed that yielded the fossils is a light-yellow partly consolidated cross-bedded sandstone, capped with a layer of clean gravel. Locally the sand is tightly cemented in large irregular lumps by either calcareous or limonitic cement. The limonite points to boggy conditions, suggestive of swampy water holes and shallow ground water. The conglomerate contains mostly water-worn gravel of red and other dark colors derived chiefly from the silicic extrusive rocks that crop out in the mountains to the south. Most of the pebbles in the gravel are less than 3 inches in diameter.

The hill in which the fossils occur has been subjected to erosion, but 30 feet of light-yellow loess, which has accumulated since the lake was drained, caps the gravel on the adjacent plateau.

In addition to the forms mentioned above as obtained from the quarry, this and other localities in the vicinity of Hagerman have yielded remains of mastodon, camel, peccary, sloth, cat, otter, hares,[44] aquatic birds,[45] and a rodent of the muskrat group. The presence of the otter, the muskratlike rodent, and aquatic birds adds materially to the evidence indicating the environment suggested by Gidley.

Considerable silicified wood has been found along Clover Creek near King Hill in these same lake beds. The following invertebrate fossils, identified by W. C. Mansfield, of the United States Geological Survey, were collected by Stearns from a highly fossiliferous sandstone member of the Hagerman lake beds along the King Hill canal at a large siphon about 5 miles upstream from King Hill:

Goniobasis taylori (Gabb)
Lithasia antiqua Gabb
Latia dalii White
Sphaerium sp.

Besides these fossil shells, large fresh-water clam shells that evidently belong to the *Unio* family were noted along the canal road farther upstream. All these fossils indicate that these beds were laid down in fresh water.

The interstratified basalt members of the Hagerman sediments are shown in plate 5. They occur as relatively thin basalt flows of remarkable continuity, indicating extreme fluidity at the time of extrusion. The lower contact zone is commonly stained yellow to

[44] Gazin, C. L., Fossil hares from the late Pliocene of southern Idaho: U. S. Nat. Mus. Proc., vol. 83, no. 2976, pp. 112–121, 1934.

[45] Wetmore, Alexander, Pliocene bird remains from Idaho: Smithsonian Misc. Coll., vol. 87, no. 20 (Pub. 3228), pp. 1–12, 1933.

reddish brown and usually consists of comminuted and fragmental glassy lava. The flows are considerably jointed and in a few places change into "pillow" lava, or balls of lava surrounded by a vitreous rind, a common feature of subaqueous basic flows. In places these intercalated volcanic beds are tuffaceous, especially near the mouth of the Salmon Falls Creek and near Bliss. Both lava and tuff occur sparingly in the Hagerman lake beds, indicating that the tranquil waters of this lake were not often disturbed by volcanic eruptions.

The upper basalt layer in the Hagerman lake beds in the NW¼ sec. 18, T. 6 S., R. 13 E. (pl. 5), consists of 30 feet of columnar-jointed deeply weathered pahoehoe with the upper part showing the usual horizontal parting planes and vesicles. Nothing is present to indicate a subaqueous origin. About half a mile to the southeast the basalt is only 10 feet thick and rests on 12 feet of horizontal thin bedded basaltic tuff. Some layers of the tuff contain lapilli and others sand-sized particles, but foreign ejecta are scarce. This tuff is similar to that in the tuff craters of Oahu, Hawaii, and may have resulted from phreato-magmatic blasts.[46] The basalt pinches out a short distance southeast of this point and the tuff gets thicker. This tuff and lava indicates a vent not far away.

A deposit perhaps indicating a vent is exposed in the SE¼ sec. 20, T. 6 S., R. 13 E., but it is certainly unlike any volcanic deposit either at a vent or elsewhere known to Stearns. It crops out along the ditch road in the south side of the river in an exposure about 200 feet high. It is a decomposed dark-brown crumbly mass containing streaks and small balls of dense hard basalt intermixed with chunks of clay and streaks of agglomerate. The latter consists chiefly of weathered older basalts, and no andesite or quartzite fragments were noted. The whole deposit is overlain by 6 feet of laminated buff clay, which is distorted and so badly jumbled that its significance could not be determined. The whole mass dips to the northwest. To the southeast is another great mixture of rocks mapped as a landslide (pl. 5). Perhaps both have the same origin.

The Hagerman lake beds are in general so impermeable, because of their fine texture, that water occurs only sparingly in them. Most of this formation is traversed by canyons, hence precipitation falling on its outcrop appears as surface run-off. Perennial springs discharging over a few gallons a day do not occur, and small perennial seeps are few and far between. At the west end of the Twin Falls South Side tract these beds are saturated with irrigation water and yield water rather high in mineral content. The Banbury hot well, described on page 167, obtains its water from tuff and basaltic flows, intercalated with the lake beds. Wells penetrating the Hagerman

[46] Stearns, H. T., and Vaksvik, K. N., Geology and ground-water resources of the island of Oahu, Hawaii: Hawaii Dept. Public Lands, Div. Hydrography, Bull. 1, pp. 16–17, 1935.

lake beds will be unsuccessful for the most part, but if drilled deep enough they will probably find sufficient supplies from the sandy members or the interstratified basic tuffs and lavas. One of the wells of the Oregon Short Line Railroad at Bliss, after penetrating 56 feet of Pleistocene lava and clay, entered the Hagerman lake beds and obtained a good supply of water at 517 feet. At 235 feet enough water was struck in the clay for drilling, but the main supply was obtained from sandy layers between 456 and 470 feet. The water rose to a level 350 feet below the top of the well. The well is cased to 422 feet and on October 17 and 18, 1917, was tested with a steam pump and yielded 80 to 100 gallons a minute. The draw-down during this test is not known.

PLEISTOCENE ROCKS

OCCURRENCE AND CHARACTER

All the volcanic and sedimentary materials that were laid down in the Snake River Plain from the end of the Hagerman epoch to the end of the deposition of the older alluvium are assigned to the Pleistocene epoch. (See table, pp. 27–32, and pl. 4.) The lava flows, which make up by far the greater part of the Pleistocene rocks, might be further subdivided roughly into early and later groups, each group comprising the products of numerous eruptions. Available data do not permit differentiation of the flows in the greater part of the plain, partly because, in the absence of dissection, the youngest flows in each locality tend to conceal those previously erupted. The comparatively excellent exposures along the canyon of the Snake River between Blackfoot and King Hill have permitted the distinction of 11 local Pleistocene formations which for the most part correspond in age with the younger group of basalts. These are, named in order of decreasing age, Cedar Butte basalt, American Falls lake beds and intercalated basalt, Madson basalt, Malad basalt, Thousand Springs basalt, McKinney basalt, Bliss basalt, Sand Springs basalt, Burley lake beds, Minidoka basalt, and Wendell Grade basalt. Their distribution is shown in plates 5 and 6. Similar local subdivisions of the Pleistocene sequence have been made in the Mud Lake region and elsewhere.

SOURCES OF THE ERUPTIONS

The principal vents from which the Pleistocene and later basalts issued are shown on plate 4. Altogether about 300 vents are mapped, and probably about 400 occur in the entire plain. Most of the vents not shown lie in the desert between Idaho Falls and Kimama, and a reconnaissance through this area on the few existing roads indicates that only about a third were mapped. Except for the cluster in the Craters of the Moon and the group north of St. Anthony, the vents are rather evenly distributed. No definite rift pattern is discernible, although here and there short cone chains occur. The vents that supplied the recent black lavas have not been differentiated by a separate symbol on plate 4 because generally their close relation to these lavas is evident from their position. However, a few of the cones are older and stand like islands in the areas of black lavas. About 50 of the Recent cones are shown on plate 4.

Near the foothills along the north side of the Snake River Plain, cinder cones 50 to 200 feet high predominate. Over most of the plain the greater number of the vents are broad lava domes, each usually about 100 feet high and with the related flows covering an area of about 30 square miles. The broad dome is capped by a smaller dome which has slightly steeper slopes and is generally about 50 feet high. Deep craters in the domes are usually absent, and in many places only a suggestion of a crater rim was left when activity ceased. Small spatter cones 10 to 50 feet high occur in some places, but beds of basaltic tuff indicative of explosive eruptions are rare. The lava rose to the surface through fissures or tubular vents and welled out quietly and profusely. Unlike most volcanic cones of the central-vent type, nearly all these cones had only one period of activity. When volcanic activity was resumed in the neighborhood of one of these cones a new opening poured out lava, usually only a short distance away.

It is obvious that the copious flows in the region must have interfered with drainage greatly and intermittently through a long period of time. Several examples of such interference are described in subsequent parts of this paper. The present channel of the Snake River through most of the region here considered lies close to the southeastern and southern margin of the plain, a position which leads to the inference that many of the Pleistocene vents were so situated that eruptions from them forced the river to shift in this direction instead of remaining more nearly in the median portion of the plain, where presumably it originally flowed. The fact that many of the early Pleistocene flows now recognizable lie in the southern part of the plain supports the concept that later lava came largely from vents farther north and thus covered the older flows there. The early lava along the Snake River west of the Minidoka Dam issued in large part from cones on the south side of the river and from buttes near Eden, a short distance north of the canyon. The fact that the streams which reach the plain from the north now have no channelways connecting them with Snake River also constitutes evidence in favor of this concept. It would seem that when the major drainage pattern of the region was originally established these streams must have been directly tributary to the Snake River.

There is direct evidence that flows from cones to the south tended locally to shift the channel northward also. Examples are known near

Yale, in the Raft River Valley, and also in the South Side Twin Falls tract.

WATER IN THE PLEISTOCENE BASALT

The basalts of the Snake River Plain are in general very permeable, and their usefulness as aquifers is indicated by the large amount of water discharged from them in the form of springs between King Hill and Milner. In 1902 these springs discharged about 3,900 second-feet, and in 1918, as a result of irrigation, they had increased to about 5,100 second-feet. Wells that have penetrated the water table in these basaltic areas, almost without exception, yield abundant supplies of water for domestic and municipal use, with but slight draw-down. Yields of more than 50 gallons a minute for each foot of draw-down are not uncommon, and yields of more than 500 gallons a minute for each foot of draw-down are recorded. The Ralph Raumaker well, near Hamer, is about 50 feet deep, and the draw-down is only a few inches when the well is pumped with a 5-inch centrifugal pump that discharges about 450 gallons a minute. The Pleistocene basalts are fresh, and the cavities in them are as a rule open. The openings that allow ground water to move through the lavas are the clinkery contacts of one flow with another and the vertical joints or shrinkage cracks that characterize these flows. The open spaces in extrusive basalt through which water can move, exclusive of those due to later disturbances of the rocks, are listed in approximate order of usefulness as follows:

Large open spaces at the contact of one lava flow with another or of a lava flow with the underlying formation.

Interstitial openings in cinders, aa, and subaqueous lava formed during deposition.

Open spaces in joints formed by shrinkage of the basalt in cooling.

Tunnels and caves produced by liquid lava flowing out from under a hardened crust.

Vesicles and cavities due to the expansion of gases during the cooling of the lava.

Tree molds, resulting from lava surrounding a tree and solidifying before the tree has burned away.

The upper crust of a lava is generally rough and broken because of movement within the flow after the crust has formed. Inundation by another lava flow never completely fills these irregularities. Consequently many openings, some of which are extensive and capable of holding or transmitting large quantities of water, occur between successive beds. Beds of cinders are not extensive in the Snake River Plain and occur chiefly as buried cones. Drillers often report red cinders in drilling, but generally they refer to beds of red doughy masses that lie at the bottom of a lava flow or to the fragmental part of aa lava. Aa lava flows are the most permeable of the lava beds. This brecciated rock produced by granulation of the lava stream while in motion is, prior to weathering, probably the most permeable rock formation on the face of the earth. The blocks are rough and angular and resemble talus. They cover an appreciable area of the Snake River Plain, and drillers report the aa clinkery lava in wells.

Subaqueous lava, of which the Bliss basalt is typical, differs considerably from aa but is also brecciated and permeable. In many places where lava flows rest on older sediments they exhibit a subaqueous phase at the contact. Thousand Springs and most of the other large springs in the Snake River Canyon issue from basalt of this type. Cinders, aa, and subaqueous basalts, because of their fragmental character, yield readily to weathering and hence are commonly the first to become watertight with age.

Lava tubes are common in the Snake River Plain, and it is through a system of ramifying tubes that the pahoehoe type of lava was distributed from the vents. On relatively steep slopes these tubes are left open after the flow stops, and the lava drains out of them. Some of these tubes are as much as 50 feet in diameter and several thousand feet long. The Sand Springs basalt, which is about 300 feet thick near Thousand Springs, contains many open tubes. Lava tubes are sometimes encountered in drilling. Stearns was lowered on the drilling cable into the new Idaho Falls city well, near the mouth of Willow Creek to examine a cavity about 8 feet in diameter that was struck about 100 feet below the surface. In the J. A. Melton well, west of Mud Lake, a lava tube full of water was encountered. Large tubes full of water were also encountered in the Wilkinson and Cox drainage tunnels on the South Side Twin Falls tract.

Joint cracks due to shrinkage of the basalt at the time of cooling range from a fraction of an inch to several feet in width and in general are nearly vertical. They are useful in the transmission of water from one lava flow to another one below and doubtless are the means by which irrigation water in many places percolates readily downward to great depths. The Goyne sump, in sec. 10, T. 9 S., R. 23 E., serves as an outlet for drainage water on the North Side Minidoka project. It is about 100 feet deep and 8 feet in diameter, and all except the upper few feet is in basalt. About 22 second-feet of water will sink continuously in this pit, but when 25 second-feet is allowed to enter, the pit fills up, because its transmission capacity has been reached. Wells drilled into the lava on this project and near Roberts have been used successfully for drainage. The fact that many of the wells drilled in basalt blow and suck air with changes in barometric pressure is further evidence of the connected systems of cracks and caverns that occur in these lavas.

Vesicles and cavities caused by the expansion of gases during the cooling of the lava are usually disconnected, and hence water cannot move readily through them. Near the top of a lava flow these vesicles are commonly so numerous as to give the crust a spongy appearance, and this part is generally more permeable than the main mass of the flow. Drillers frequently state that this spongy lava yields large volumes of water. The spongy or vesicular lava is in fact commonly not the source of these large yields, however, but its presence indicates that the drill has passed from one flow to the top of another. The water is obtained largely from the open spaces at the contact of the lava beds or from the numerous joint cracks which occur at the top of the flow rather than from the vesicles.

In places where lava flows have entered forests tree molds are common and form an appreciable amount of the voids in the lava. In the Craters of the Moon National Monument there are certain small areas where tree molds are plentiful, and molds full of water have been encountered in drainage tunnels on the Twin Falls tract. However, if the Snake River Plain was nearly treeless during the accumulation of the lava flows, as it is at present, it is not likely that tree molds are sufficiently numerous to be very useful in the movement of ground water.

In small areas in the valley water in the basalts is confined by impermeable beds of clay and loess, of sufficient extent to produce slight artesian heads. This condition occurs in the vicinity of Mud Lake, where there are flowing wells with large discharge and large specific capacity.

A somewhat similar artesian condition has been developed in small areas in the Aberdeen-Springfield and Twin Falls South Side tracts as a result of irrigation. In the Twin Falls South Side tract flowing wells have proved effective in the drainage of swampy land. These wells, like those at Hamer, have low head but yield abundantly.

Dike systems and sills have not been recognized in any of the water developments except at Bliss Spring, although they must exist in some parts of the Snake River Plain. From the wide distribution of the vents and the absence of dikes in the walls of the Snake River Canyon they are probably too scattered to affect the circulation of water except locally.

The rate of flow of the water through the basalt is dependent on the geologic structure. Thus in the Twin Falls South Side tract, which lies from 50 to 300 feet above the Snake River, on a bench bordering the Snake River Canyon, swampy tracts have resulted through irrigation, whereas on the opposite side of the canyon, where also irrigation water is applied in large amounts, there are virtually no seeped areas and the water table lies far below the surface. This condition is interpreted as being caused by loess beds on the south side, which are intercalated with the lava flows and which form artesian wedges, whereas on the north side these loess beds have been cut through by former channels of the Snake River. These ancient canyons were later filled with permeable basalt and now form V-shaped wedges in which no loess occurs. The Sand Springs basalt (pl. 5) fills such a canyon, and from it issue many of the largest springs. Thus the north side is favored with natural drainage channels, but the Snake River has never cut a channel farther south than the present one in the vicinity of Twin Falls. This means that the South Side tract has none of these lava-filled canyons through which ground water can move rapidly away from the project. Furthermore, a study of the geology and water table indicated that the greater part of the Snake River Plain from Big Bend Ridge, near Ashton, to King Hill is cut by these ancient canyons through which the ground water moves freely.

The rate at which the water moves through the basalt is difficult to determine because it varies from place to place according to the permeability of the lava, the geologic structure, and the hydraulic gradient. The daily records of the flow of Blue Lakes Spring in sec. 28, T. 9 S., R. 17 E., from 1917 to 1920 afford a basis for estimating the rate of movement of the ground water tributary to it. The contour map of the water table (pl. 19) shows that the water that supplies these springs passes under Wilson Lake and the First Segregation of the North Side tract at Hazelton. There is no irrigated area between this First Segregation and Blue Lakes, and therefore a time interval for underground travel between the two points can be determined by comparing the observed flow of Blue Lakes Spring with fluctuations in the use and hence the seepage loss of water on the North Side project and the amounts of water in Wilson Lake, which loses at a heavy rate when containing much storage water.[47] The records of canal diversions and of storage in Wilson Lake are plotted by 15-day averages in plate 11. During the early part of each irrigation season Wilson Lake drops rapidly, with corresponding decreases in percolation losses. On the other hand, there is an increase in losses during the same period from increased irrigation diversions. Records are not available for Wilson Lake during the winter.

The sudden increase in diversions and lake storage during the first half of May 1917 is clearly reflected by the increased discharge of Blue Lakes Spring during the first part of August, 3 months later, as shown in plate 11. The time between the average of the summer irrigation diversions in that year and the corresponding peak in the flow at Blue Lakes Spring in 1917 was about 3½ months. A similar interval occurred in 1918. In 1919 the time between the seasonal peaks was only 2 months. That year, however, was one of deficient water supply, causing deliveries to the First Segregation to be less than half the average in normal years, hence contributions to the

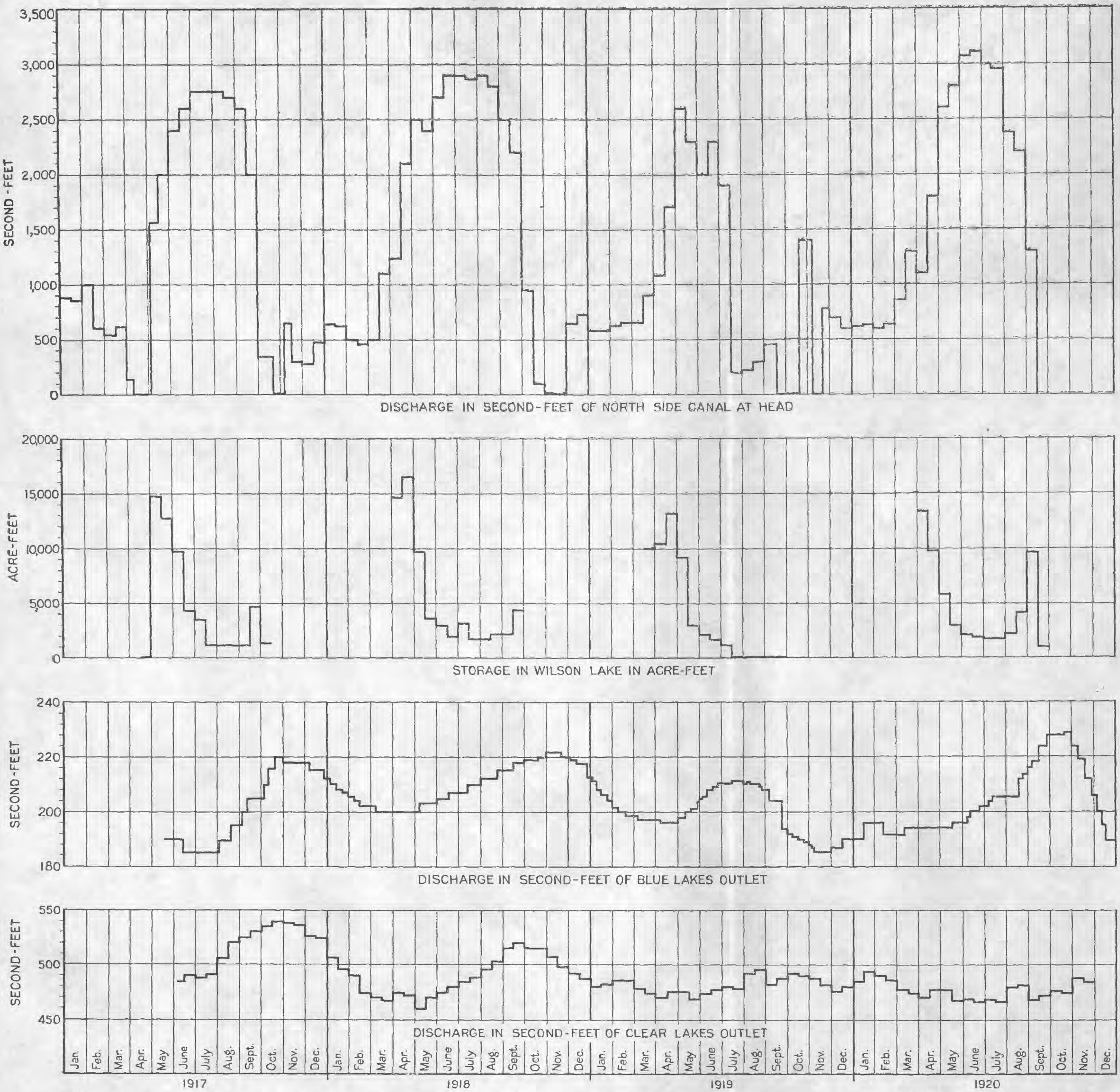
[47] Stearns, H. T., Success and failure of reservoirs in basalt: Am. Inst. Min. Met. Eng. Tech. Pub. 215, p. 112, 1929.

water table from irrigated lands were very small. The seasonal peak flow of Blue Lakes Spring in 1919 was about 3 to 3½ months later than the peak at Wilson Lake, and probably the fluctuations in that year reflected the ground-water contributions from Wilson Lake to a much greater extent than the contributions from irrigated lands.

The large amount of water diverted through the canal late in October 1919, after the canal had been dry for a month, clearly caused the increased flow at Blue Lakes Spring 3 months later. (See pl. 11.) The time between the peak diversions in 1920 and the maximum flow of the spring was about 3½ months, although the period when the canal was dry in the later part of September 1920 could be detected only 3 months later at Blue Lakes Spring.

It thus appears that the time interval between seasonal peaks is about 3½ months but that sudden large increases in the contributions to the water supply require only about 3 months to travel from Wilson Lake and the First Segregation to Blue Lakes Spring. A point half a mile south and 1½ miles west from Hazelton is about the center of ground-water contributions from the First Segregation and the Wilson Lake region. This point is 15 miles east of Blue Lakes Spring. Thus about 3½ months is required for the ground water to move 15 miles. The average seasonal rate of movement of ground water between the two points is therefore about 750 feet a day, whereas under certain conditions it apparently travels about 850 feet a day through the same permeable basalts underlying this area.

The altitude of the water surface in the town well at Hazelton was 3,836.2 feet on July 2, 1917, whereas that of the outlet of the spring that supplies Blue Lakes is about 3,300 feet. The difference in the water surface between the two points, 16½ miles apart, is therefore 536 feet, and the average slope is 32.5 feet to the mile. It appears from the ground-water contours of this section on plate 19, however, that the water table from Hazelton toward Blue Lakes has an average fall of only about 20 feet to the mile, which in 16½ miles would amount to 330 feet, or about 206 feet less than the total difference in altitude between the water table at Hazelton and that at Blue Lakes. This drop in the water table of 206 feet is probably concentrated in a short distance above the springs. The springs are about 160 feet higher than the Snake River and about three-quarters of a mile from it, making an average fall from the spring outlet to the river of 214 feet to the mile. If the ground-water cascade of which Blue Lakes Spring is the outlet continues on this gradient it would thus extend for about a mile in an easterly or northeasterly direction before reaching the main underground flow, which is moving westward under the plain north of the Snake River.



RELATION BETWEEN THE USE OF IRRIGATION WATER ON THE TWIN FALLS NORTH SIDE TRACT AND THE FLOW OF BLUE LAKES AND CLEAR LAKES SPRINGS.

Additional evidence of the relatively rapid rate of ground-water flow in this region is afforded by the fact that the ground-water contributions of more than 600,000 acre-feet annually from the North Side tract disappear each year as underground run-off without causing a progressive rise in the water table under the project. The average annual fluctuation in the water table amounts to about 6 feet, resulting from recharge from irrigation water, but each year the water surface in the wells returns to practically its former level, which is several hundred feet below the ground surface.

The discharge of Clear Lake outlet, the only spring beside Blue Lakes Spring for which daily records are available, is shown by plate 11. The fluctuations recorded at the Clear Lake gage do not afford a basis for calculating the rate of flow, because the irrigated area that contributes to the water that emerges at this point extends for many miles northeast and is not localized enough to indicate the source of Clear Lake water. The low flow of this spring in 1919 was caused by a deficient water supply for irrigation, but the failure of the spring to rise as high in 1920 as it was in 1917 and 1918 is probably due to the abandonment of the Jerome Reservoir in the fall of 1919, part of the large losses from that reservoir evidently having contributed to the flow of Clear Lake.

UNDIFFERENTIATED BASALT

A large proportion of the flows throughout the Snake River Plain belong to the early Pleistocene group, but in many areas these are effectively concealed beneath later deposits, and in others it is impossible, with the available data, to distinguish definitely between the two groups. In the Mud Lake region, and to some extent elsewhere, the relations to glacial and other deposits and the degree of weathering show that most of the flows in the vicinity of the present surface (exclusive of those grouped as Recent black lava) are as young as late Pleistocene, and some are possibly Recent. Along the Snake River between the Minidoka Dam and King Hill the flows grouped as "undifferentiated basalt" on plates 4 and 5 are older than the Pleistocene flows described individually. Upstream from the Minidoka Dam the basalt thus grouped includes flows both younger and older than those downstream.

The Pleistocene flows in general are readily distinguished from the older basalts by their comparative freshness. In most outcrops of Pleistocene basalt weathering has penetrated less than an inch. This basalt is commonly gray to black, fine-grained, and vesicular, and in many exposures has small feldspar and olivine phenocrysts visible to the unaided eye. Most of the flows are pahoehoe, whereas many of the Recent black lavas are aa. One of the few aa flows in the series overlies the American Falls lake beds north of American Falls and thus belongs to the later Pleistocene flows. Samples of drill cuttings taken at intervals of 1 to 5 feet in the Yarnell well, a dry hole north of Minidoka, were examined by H. T. Stearns, with the results given below. Drillers' logs of other wells scattered over the region show broadly similar variations in the character of the flows.

Log of Yarnell well, north of Minidoka

	Thickness (feet)	Depth (feet)
Soil consisting of loess and wind-blown quartz sand	2	2
Blue basalt, red at base, containing olivine crystals 1 to 3 millimeters in diameter. Vesicular at top and base of flow	37	39
Loess soil	.2	39.2
Blue basalt flow with phenocrysts of olivine and feldspar. The uppermost and lowermost 3 feet are composed of red vesicular lava	16.3	55.5
Loess soil, baked red	.5	56
Reddish-brown basalt, changing downward into extremely dense basalt except at 68 and 72 feet and at the base of the flow, which is vesicular	22	78
Blue-black basalt flow, with vesicular rock at 88 to 94 feet. Number of olivine grains greatly increases in densest part of flow, which is at 98 feet	22	100
Wind-blown soil	Trace	100
Blue basalt containing small amount of olivine and extremely dense at 110 feet	23	123
Wind-blown soil	.3	123.3
Olivine basalt	6.7	130
Wind-blown soil	Trace	130
Brownish-blue basalt, with abundant olivine discolored by weathering	20	150
Wind-blown soil	Trace	150
Reddish vesicular olivine basalt except for dense rock at 173 feet	24	174
Wind-blown soil	Trace	174
Gray-blue basalt, with olivine and clear feldspar crystals in abundance and a dense streak at 182 to 194 feet. At 197 feet the cuttings change to red vesicular rock, indicative of base of flow	26	200
Olivine basalt with only a thin vesicular band at top and bottom	42	242
Wind-blown sand	.5	242.5
Blue basalt, extremely dense in lower 15 feet; evidently bottom of hole is near the bottom of the flow but not quite through it	55.5	298

This well, if continued deeper, will encounter water, but it was drilled to discover gold ore, which, of course, does not exist interbedded with the basalts as the driller believed.

Individual flows are commonly 10 to 75 feet thick, but where a flow piles up in a preexisting drainage channel its thickness may abruptly increase. In the early lavas exposed in the walls of the canyon beyond the Minidoka Dam local thickenings resulting from such fills are relatively small. The aggregate thickness of the early flows exposed in this vicinity is 600 feet. Northwest of St. Anthony a well 1,050 feet deep failed to reach rock recognizable as pre-Pleistocene. In Laidlow Park, a short distance south of the Craters of the Moon National Monument, a well penetrated 918 feet of basalt before reaching the older silicic lava. It is probable that over much of the central part of the Snake River Plain the Pleistocene flows aggregate fully 1,000 feet in thickness.

SEDIMENTARY BEDS IN THE LAVA

Loess and clay are intercalated in the Pleistocene flows. In a few places, as near Trail Springs, there is also some gravel. In the canyon of the Snake River these materials are especially plentiful near the new Twin Falls bridge. The sedimentary beds are everywhere thin as compared to the basalt. Some are thick enough to indicate intervals of quiescence of considerable length between eruptions. The products of any single eruption covered only a small part of the plain, and meanwhile soil accumulation continued undisturbed elsewhere. The thickness of an individual loess bed depends more on its nearness to a source of supply than on the time interval between eruptions. For example, only a short distance west of the Twin Falls area extensive outcrops of incoherent lake beds have long been exposed to the wind. During the time required to accumulate a foot of loess on lava in this vicinity only an inch or two will probably be deposited on the basalt 50 miles to the northeast. In spite of variable factors of this sort it appears to be broadly true that the depth and uniformity of cover of loess soil on a given area of basalt is an index of the age of the flows. On this basis it is postulated, for example, that the basalt south of the river near Twin Falls, which is almost everywhere covered by deep soil, is materially older than that north of the river in the same locality, where numerous areas of lava are exposed and most of the soil is comparatively thin.

In some places masses of sedimentary material, so thick or extensive that they can be separately mapped, are associated with the Pleistocene flows. Each of these masses that has so far been recognized is described on succeeding pages.

PLEISTOCENE FORMATIONS ABOVE THE CANYON OF SNAKE RIVER

LAVA FILLS

The numerous displacements of the Snake River and its tributaries by lava flows have caused it to aggrade behind the dams thus caused, to cut down through these dams, and to build accumulations of boulders short distances beyond them. The local formations discriminated along the present canyon of the river and described below (pp. 65–84) have all resulted more or less directly from such episodes.

The Snake River before displacement by the Sand Springs basalt, for example, was flowing in a basaltic canyon 500 feet deep with nearly vertical walls. The inflowing lava was pahoehoe basalt that came in great volume from a cone on the north side of the river. This lava had first spread laterally on the plain above, but when part of it reached the north rim and cascaded into the canyon it temporarily built up a lava delta. The sudden change in grade of the surface on which the lava flowed accelerated the draining of the feeding tube leading from the vent and tended to make this the master drain. Thus, from the time the lava began cascading into the canyon the flow tended to cease spreading laterally, and most of the lava flowed toward the canyon.

Although canyon lava fills in this area are impressive because of their length and thickness they do not ordinarily represent greater outpourings than occurred elsewhere on the plain. Instead of sheets, V-shaped lava fills were formed.

As some of these lava fills are 50 miles long and 300 to 500 feet thick, it is obvious that they must have retained much heat. Here as elsewhere [48] this was doubtless accomplished by movement of the lavas through tubes of its own construction beneath an insulating crust. In all localities where the Snake River was displaced the flow filled the canyon at the original point of entry and then because of topographic control spread along it, chiefly but not exclusively downstream. The lava rarely extends more than a fraction of a mile on the south side of the canyon, except where it fills tributary valleys owing to the easier escape down the canyon.

In all places studied in detail the lava had completely obliterated the preexisting canyon for several miles. Then it had become confined between the walls of the canyon for a few miles and stopped. The Sand Springs flow, for example, obliterated the Snake River Canyon for 50 miles downstream beyond its point of entry and stopped 10 miles farther down. The ends of the flows are not now exposed except where they are cut through by the Snake River. They are generally about 20 feet high, or the same height as if the flow had spread out on the plains, even though the lava fill upstream may be 500 feet thick.

During such an accumulation of lava in the canyon, especially in the early phases of an eruption, the margin of a flow advancing upstream was continually entering ponded waters and producing local steam explosions. One such explosion is definitely known to have formed a cinder and ash cone more than 200 feet high. Most of the products of these explosions were later buried by the sediments deposited behind the lava dam; hence they are seldom found.

It is not unusual to find lava several miles upstream from the point where the flow entered the canyon. The downstream advance of such a flow was accompanied by many activities and changes. The following hypothesis is offered to account for the pillow lava and glassy brecciated pahoehoe at the base of the lava fills.[49] Where the stream bed was underlain by saturated gravel or other permeable materials the lava that flowed over such wet ground was comminuted or brecciated by steam explosions. This extremely permeable phase of the pahoehoe made the dam start leaking at the outset. The leakage was continually available for minor explosions and for the formation of pillow lava at the downstream margin. To a less extent the same permeable material is found at the contact of the lava with the canyon wall, apparently because steam rising in most places along

[48] Stearns, H. T., Geology and water resources of the middle Deschutes River basin, Oreg.: U. S. Geol. Survey Water-Supply Paper 637, pp. 145–146, 1931.

[49] Stearns, H. T., Origin of the large springs and their alcoves along the Snake River in southern Idaho: Jour. Geology, vol. 44, p. 440, 1936.

the contact was available for the disruption of the lava. As the hydraulic gradient of the water moving through the lava dam was probably somewhat steepened by the damming effect of the debris caused by the steam explosions at the downstream margin and by the progressive widening of the dam, the water table in the lava dam may have risen simultaneously with the accumulation and cooling of the lava, so that it may have been fairly close to the hot lava at all times.

Because of the narrowness of the canyon, the newly created lake had small storage capacity, hence it may have overflowed even while the eruption was in progress, unless leakage through the dam with the added effect of steam explosion was sufficient to dissipate the inflow. These agencies, however, could not have sufficed to dispose of the inflow of so large a river as the Snake during prolonged eruptions. In fact, a dam 50 miles wide and only a mile across would be entirely different from any known engineering structure. As the dam was permeable, the seepage, instead of following a few well-defined crevices, must have built up a water table with a fairly uniform slope from the surface of the impounded lake to the toe of the dam.

At the moment of overflow the great volume of water in the Snake River was sufficient to establish a course along the southern margin of the new lava flow until it reached the point where the lava no longer filled the canyon. At this point the water tumbled back into its former course and formed a cascade on the surface of the lava fill until the end of the flow was reached, where it again returned to normal grade in its prelava channel. The river was influenced by topographic irregularities near the margin of the lava and at some places did not follow that margin very closely. For example, it established a course half a mile to 5 miles south of the Sand Springs lava fill from the lake it created near Burley to Shoshone Falls. Here it again returned to the edge of the lava, which it followed to Salmon Falls Creek and then reentered its former canyon.

On the irregular surface of the lava fill the river took a meandering course that soon became established. As the downcutting proceeded remnants of the fill were left first on one side of the river channel and then on the other as detached benches. While the new channel was being established there was doubtless considerable leakage into the lava. In at least one place this leakage was sufficient to give rise to large springs at the toe of the dam.

When the Snake River was displaced by lava flows and had taken its new course it faced the great task of draining the lakes so formed and of resuming its former grade. While the outlets of the lakes were being cut down the debris carried by the river was settling in the quiet waters behind the lava dams. In some of the lakes this process of sedimentation was more rapid than the cutting, so that the lakes filled with silt before the outlets were appreciably reduced. In others, where the new course was in relatively weak lake beds and one abutment of the newly formed lava dam was in lake beds also, the outlet was reduced so rapidly that there was time for only a thin veneer of gravel to form in the lake bottom. Thus, the texture of the lake sediments would be dependent in some measure upon the size of the lake and the weakness of the dam.

While a lava-dammed lake was being filled with sediment and its outlet lowered, the Snake River actively aggraded its bed at the toe of the dam. The river cascading down the dam with a gradient in some places as much as 150 feet to the mile, loosened huge blocks of lava and rolled them to the toe, where the sudden flattening of the grade made them drop. The jointing in basalt permitted ready plucking, so that water-worn boulders 5 to 12 feet in diameter are common. During the early stages the debris accumulated rapidly enough to form a steep fan overlapping the toe of the dam and extending a mile or more downstream. With the flattening of its gradient and the subsequent reduction in quantity of debris supplied, the river ceased to build its fan and began to destroy it. The decreased velocity of the river at this stage permitted only the smaller material to be removed, and the large boulders are left as a residual concentrate much like that seen at hydraulic placer mines. Spectacular groups of boulders formed in this way can be seen in Hagerman Valley and near King Hill. They resemble the coarsest of morainal deposits. The alluvial fan near King Hill was only partly reworked by the river and now forms steeply sloping alluvial terraces that border the river. Boulder deposits of this type served as valuable field criteria in determining the location and number of the places where the Snake River had been ousted from its channel by lava. Such groups of boulders occur at the mouth of Rock Creek in connection with the lava dam at American Falls, and there are several similar occurrences in Hagerman Valley (pl. 12, *A*) and near King Hill.

Where a lava fill, such as those described above, has been largely removed through reexcavation of the canyon, its former presence is commonly recorded by benches composed of residual masses of the fill clinging to the canyon walls. Similar topographic forms, however, can be produced in other ways. Where a series of essentially flat beds of different degrees of resistance to erosion is cut into by a stream, a bench of somewhat similar appearance commonly results. Where the canyon of the Snake River is cut in basalt alone, the flows are of so nearly equal resistance that only a single conspicuous example of this type of bench was noted. This bench commences near Milner Dam, where it is so small as to be hardly noticeable. It increases in size in a short distance downstream, and between Murtaugh and Shoshone Falls is a conspicuous topographic feature on both sides of the river.

(See pl. 9.) The part of this bench above Shoshone Falls lacks the billowy surface commonly characteristic of a youthful intracanyon flow. Good exposures near Twin Falls seem to show that the bench was formed because of the resistance of a massive layer of basalt at a time when a temporary base level was established by the resistant andesite now exposed at Shoshone Falls. Benches of this kind can be distinguished from remnants of intracanyon fills by the absence of any unconformity at the junction of bench and canyon wall.

CEDAR BUTTE BASALT

In secs. 22, 23, 26, and 27, T. 8 S., R. 29 E., there are two buttes, one of them known as "Cedar Butte" (pl. 6), which are former vents of a large basaltic dome. Like most of the great lava producers of the Snake River Plain both of them lack well-formed craters. The basalt spread southward from the cones as massive pahoehoe, with lesser amounts of aa. The lava is an aphanitic blue basalt containing phenocrysts of fresh green olivine as much as 3 millimeters in diameter. On the eastern knob of the northern butte there are a few cinders.

Prior to the eruption of the Cedar Butte basalt, the Snake River occupied a course roughly parallel to the present one but a few miles north of it, between a point near Blackfoot and the mouth of the Raft River. The Cedar Butte eruption filled at least 20 miles of this channel, damming the river and forming a lake about 40 miles long and 12 miles wide, which extended from Massacre Rocks nearly to Blackfoot (pl. 4).

AMERICAN FALLS LAKE BEDS

Sedimentary beds.—Along the Snake River from Springfield nearly to Massacre Rocks stretches a series of yellowish-white to buff lake beds, which are regarded as produced by sedimentation back of the dam described above. (See pls. 4, 6.) They form steep bluffs about 150 feet high along the north bank of the river from the American Falls Dam to the Narrows, a distance of about 5 miles. They consist of even-bedded, partly consolidated silt, clay, and sand, with local pebbly lenses near the top and a 6-foot bed of laminated basic tuff 60 feet below the top of the series southwest of American Falls. Large parts of them have been removed by erosion from the south bank of the Snake River below the dam. Along the north side of American Falls Reservoir just at the shore line, or about 100 feet below the highest deposits of the lake, basalt is interstratified with the sedimentary beds.

Although the precise stratigraphic relations between the tuff and basalt were not established because of the lack of adequate topographic maps and the distance between their outcrops, it seems likely that the tuff resulted from explosions caused by the basalt entering water.

The absence of tuff cones in the adjacent area supports the idea of its local origin.

Near the junction of the Low Line and High Line canals on the Aberdeen-Springfield project large basalt blocks lie scattered over the surface of the lake beds 100 feet or more from their parent outcrop. These blocks were presumably plucked from the basalt along the shore of the ancient American Falls lake and rafted away on ice cakes. The altitude of this place of plucking is 4,450 feet, which tends to establish the altitude of the shore line of the ancient lake. In some places a definite shore line exists near the High Line canal of the Springfield-Aberdeen project, but in others the lake beds grade imperceptibly into the loess covering the basalt of the plains. A well 178 feet deep in sec. 7, T. 4 S., R. 31 E., did not penetrate any sedimentary beds, hence the lake did not extend this far to the northwest. The exposure of the sedimentary rocks farthest downstream is in sec. 9, T. 8 S., R. 30 E., about 2½ miles above the point where the Cedar Butte basalt crosses the present canyon of the Snake River at Massacre Rocks. Remnants of the basalt crop out about 170 feet above the river on both sides a quarter of a mile below this point.

The completion of the American Falls Reservoir has caused the submergence of the lower part of the lake beds upstream from American Falls, but wave action has undermined the banks, exposing the upper beds. From American Falls to the mouth of the Portneuf River, along the southeast side of the reservoir, the top layer becomes progressively coarser and grades from fine shot-sized gravel through all sizes to huge boulders near the mouth of the Portneuf River. Red and white quartzite gravel predominates, suggesting that most of the gravel was derived from the Portneuf and adjacent tributary streams rather than from the Snake River. From the Portneuf River around the head of the reservoir to a point south of Springfield younger gravel at or slightly above the reservoir level obscures the lake beds, if they are present. The upper surface of the lake beds on the south side of the Snake River, with its veneer of later gravel, corresponds to the Gibson terrace described by Mansfield.[50]

A flowing well in the center of sec. 15, T. 4 S., R. 32 E., is reported by the driller to have encountered 265 feet of clay and silt with some beds of colored gravel. A 36-inch log of redwood was drilled through at 190 feet. One piece of bone, too small to be identified, was found in the lake beds. It was not fossilized like those from the Hagerman lake beds. Leo Lee, of Aberdeen, obtained several bones and teeth, which he states were removed from these beds during the excavation of the west abutment of the American Falls Dam. They have been identified by J. W. Gidley, of the Smithsonian Institution, as being

[50] Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713, pp. 16–17, 1920.

bones of *Elephas* sp., of Pleistocene age, probably late Pleistocene. These beds rest on the eroded and deformed Eagle Rock tuff and Massacre volcanics and are unconformable on some of the basalt of the plains. In a general way they resemble the Hagerman lake beds in their lithology and undisturbed condition, but their shore line is 4,500 feet above sea level, or about 1,050 feet higher than that of the Hagerman beds.

The American Falls lake beds are generally so fine grained as to be poor water bearers, but in the vicinity of the reservoir the more sandy members carry sufficient water for domestic use.

Basalt member.—Gibson Butte rises several hundred feet above the Snake River in sec. 32, T. 3 S., R. 32 E., and is among the largest and most prominent basalt domes on the Snake River Plain. Its surface is heavily veneered with loess, but the character of the butte is shown by a few small outcrops of scoriaceous aphanitic gray basalt and a broad, shallow crater on its summit.

Young alluvium mantles the south and west sides of the butte, but on the southeast and east it abuts against the ancient alluvium of the Gibson terrace, which corresponds to the upper part of the American Falls lake beds. Across the Snake River and practically at the foot of the butte occurs a basalt flow whose sparse soil cover indicates youth. This condition and the fact that it seems to have come from the north indicates that it had no connection with the eruptions from Gibson Butte. Farther downstream much basalt is definitely intercalated with the American Falls lake beds. Other patches of basalt similar in character and stratigraphic position extend as far downstream as American Falls. The most southwesterly of these outcrops differs from the rest in that it contains tiny phenocrysts of olivine. Although this difference by itself does not prove that this basalt had a different origin from the rest, such an assumption is strengthened by the fact that there is some evidence that the basalt fills a depression cut in the lake beds instead of being merely intercalated in them.

So far as can be judged, the basaltic member lies at an average depth of 100 feet below the top of the lake beds. The basalt thickens northeastward toward Gibson Butte, with corresponding thinning of the overlying sediments suggesting that Gibson Butte is the source of this lava. Near the old shore line the basalt is only 1 to 10 feet thick and locally has the characteristics of lava that flowed under water. As much of the basalt does not have these characteristics, the lake may have been shallow at the time of eruption.

The basalt was, at least in part, buried under lake beds and alluvium at the time the lake was tapped by the Snake River, and therefore it had no effect on the original position of the channel cut by the river. The river started to cut down along the north shore of the former lake, on the side opposite the tributaries, where no inflow occurred and consequently where less sediment was deposited. A well-defined terrace about 30 feet high bordering the High Line canal cut in the lake beds marks this stage. When the river reached the level of the intercalated basalt, however, the cycle of down cutting was halted, and lateral erosion became most effective. During this episode the river shifted slowly southeastward, exposing a considerable portion of the basalt and leaving behind it several short, shallow gravel-filled channels cut in the lava. The Leo Lee gravel pits, east of Aberdeen, are in some of these channels. Finally during this shifting stage the river reached the margin of the intercalated basalt and began to work in the soft lake beds. This began a new phase of entrenchment, which lasted until a new base level was established when the river encountered a resistant ledge of older lava at American Falls. At this level the river channel began again to shift laterally. With the aid of the Portneuf River it excavated the Fort Hall Bottoms, now almost entirely submerged by the American Falls Reservoir.

MADSON BASALT

A fine-grained black basalt, so dense as to resemble a slate, crops out directly above the talus and beneath basalts in the east wall of the Snake River Canyon near Steele Springs, half a mile downstream from the mouth of the Big Wood River. It is here named the "Madson basalt", after Madson Spring, which issues from the alluvium some distance below outcrops of the basalt. As shown in plate 5, this lava forms also two isolated patches of rim rock resting on the Hagerman lake beds on the opposite canyon wall, about 500 feet above the river.

The basalt is about 400 feet above the Snake River and shows remarkably regular and tight columnar jointing, resembling an intrusive rock. This structure was evidently induced by the slow rate of cooling that led to the holocrystalline texture. No other basalt exposed in the Snake River Canyon shows such regular jointing or diabasic texture. According to a microscopic examination by M. N. Short the basalt here is very fresh, contains scattered phenocrysts of green glassy olivine, and is holocrystalline. The mass of the rock consists of olivine in grains as much as 1.5 millimeters in diameter and thin plagioclase laths as much as 1 millimeter long embedded in brown pyroxene with many inclusions, probably mainly ilmenite.

The observed relations of the scattered outcrops of this basalt to the older rocks suggest that the Madson basalt may fill an old canyon cut in the Hagerman lake beds by either the Snake River or the Big Wood River. The west side of the supposed filled canyon has been cut into by the present canyon of the Snake River. Variations in texture and jointing in the different exposures of the Madson basalt tend to support this view. Southeast of Steele Springs toward the Big Wood River (beyond the limits of pl. 5), this lava with tight regular jointing grades into more open and permeable basalt. Likewise, the jointing is more normal in the outcrops on the opposite (western) wall of the canyon. However, the small discharge of both Madson and Steele Springs, which apparently issue from this basalt, indicates that such a buried canyon, if it exists, is either drained by one of the big springs upstream or does not extend far to the southeast.

On the east and west sides of the Bliss Grade in sec. 7, T. 6 S., R. 13 E. (see pl. 5), black aphanitic basalt lies stratigraphically above the Hagerman lake beds and is overlain by the McKinney basalt. Erosion has exposed it and shows it filling an ancient canyon several hundred feet deep carved in the Hagerman lake beds. The bottom of the lava fill is about 300 feet above the Snake River. The narrow strip of this basalt shown in plate 5 at a point about half a mile south of Bliss, is a sliver of the northeast side of the fill. As this sliver occurs below the top of the Hagerman beds at Bliss the lava at this point did not completely fill the ancient channel.

The basalt in this channel is diabasic. That on the east side of the Bliss Grade contains small olivine phenocrysts, recognizable megascopically, and in that on the west side minute crystals of feldspar are visible. Rock from both places, examined microscopically, is seen to consist mainly of plagioclase with abundant olivine and thin plates of hematite. The groundmass of the rock from the west side has been only partly recrystallized as pyroxene, whereas in that from the east side pyroxene is as abundant as olivine. The Pleistocene basalts of this vicinity are characteristically nondiabasic and contain easily visible feldspar phenocrysts. The petrographic resemblance of the basalt near the Bliss Grade to that near Madson and Steele Springs leads to the correlation of these scattered outcrops as the Madson basalt. As the old channel exposed near the Bliss Grade is in an appropriate position and contains lava regarded as Madson, it is assumed to be a portion of that postulated to lie east of Steele Springs.

The source of the Madson basalt was apparently in Little Gooding Butte, about 9 miles northeast of Steele Springs, near the town of Gooding. Mr. Short examined a specimen from this butte and reported the lava to be identical in thin section with a specimen from the lava fill on the east side of Bliss Grade except for a more complete crystallization of the groundmass into brown pyroxene and hematite.

As Little Gooding Butte is close to the Big Wood River it seems likely that the flow from this butte coursed down the Big Wood to the Snake River, where it formed a lava dam and thence flowed down an ancient canyon of the Snake River to a point beyond Bliss. Outcrops indicate that this flow did not completely fill the ancient canyon at Bliss Grade, hence the flow was probably not sufficiently voluminous to displace the Snake River from its course. The shifting of the river in this stretch probably occurred later and was caused by the Malad basalt, a much larger flow. Consequently Steele, Madson, and probably Bliss Springs are fed by the drainage from a buried former channel of the Big Wood River filled by the Madson basalt. That Bliss Spring has its source to the east rather than upstream along the Snake River is indicated by muddy water appearing in this spring when irrigation water is wasted in certain sink holes on the land to the east. Furthermore, the Big Wood Canyon is sufficiently deep to intercept any ground water moving toward this group of springs from points upstream along the Snake River.

MALAD BASALT

Closely following the extrusion of the Madson basalt there came a very extensive voluminous lava flow that displaced the Snake River for at least 9 miles between the Big Wood River, formerly and still locally called the "Malad River", and Sand Springs Creek. Near Sand Springs Creek the boundary of this formation swings eastward beyond the limits of the area shown on plate 5 and is covered by a loess soil so thick as to obscure its contacts. On the north it wedges out between the Madson and McKinney basalts near Steele Springs. It has been named the "Malad basalt" from the thick exposures in Malad Canyon, the deep gorge at the mouth of the Big Wood River. According to M. N. Short, a specimen of this formation from the top of the Justice Grade in sec. 12, T. 7 S., R. 13 E., has long feldspar phenocrysts in a fine-grained groundmass with ophitic texture. The rock consists of abundant feldspar (labradorite-bytownite) and olivine and augite in equal amounts embedded in opaque glass that shows no devitrification. Near the Malad power plant this basalt forms a cliff about 400 feet high, and its bottom is obscured by talus. On the south bank a quarter of a mile above the power plant the Malad basalt rests on the Hagerman lake beds. Along Billingsly Creek also it assumed the same position, although its contact is invariably mantled with talus. The Hagerman and Kearn tunnels, near Hagerman, shown in plate 5, penetrate this lava near the contact and recover considerable water. In these tunnels 20 to 25 feet of pillow lava is exposed, and in the Kearn tunnel the lava rests on an eroded surface carved in loess. The pillow lava grades upward into the normal jointed Malad basalt. The Kearn dry tunnel is driven for 300 feet into a thick deposit of loess on which rests 40 to 50 feet of Malad basalt, with the usual pillow structure at the contact. The dry, mealy character of the loess and its high position near the top of the plain favor the opinion that it was dry at the time of burial by the

Malad lava; hence the moisture that caused the pillow structure probably rose as steam along the contact. The Malad basalt thickens northward toward the Big Wood River, where it fills an ancient canyon of the Snake River. The bottom of the canyon is not exposed, and the steep unconformity with the Hagerman lake beds near the power plant points to a canyon as deep as the present one occupied by the Snake River, if not deeper. This buried canyon must have an extensive collection system, for it supplies the entire flow of the springs that feed Billingsly Creek, Cove Creek Spring, and the enormous springs in Malad Canyon. Malad Canyon is essentially a spring alcove that has receded from the present Snake River at right angles and intercepted the flow of the buried canyon.

The Malad basalt disappears in a quarter of a mile downstream from Malad Canyon beneath the McKinney basalt and is not exposed anywhere farther down the Snake River. Its absence along Bliss Grade suggests that the buried canyon containing it passes north of Bliss, and the logs of the two railroad wells at Bliss support this hypothesis. The well close to the railroad station penetrates mainly basalt to a depth of 235 feet, whereas the one three-quarters of a mile to the east passes through sedimentary beds with only three widely spaced layers of basalt to a depth of 517 feet. If most of the sediments in this well belong to the Hagerman lake beds, as is probable, a steep erosional unconformity is indicated between this well and the well close to the station.

Although Big Gooding Butte, near Gooding, may be one of the sources of the Malad basalt, the springs issuing from this formation are so large as to suggest that the canyon it fills may be so long as to extend to the vicinity of Jerome. If so, the canyon may have been in part filled by lava from one of the cones there.

THOUSAND SPRINGS BASALT

The Thousand Springs basalt, named from the famous springs that issue from it, forms the rim rock of Snake River Canyon from Riley Springs, at the southeast end of Hagerman Valley, to Sand Springs, as shown in plate 5. It constitutes the filling of an ancient river channel carved in the Hagerman lake beds. Near Sand Springs the Thousand Springs basalt leaves the river and extends beyond the area mapped.

At Thousand Springs the formation consists of three flows of pahoehoe with feldspar phenocrysts. Numerous large cavities occur at the contacts of each of the flows, probably the result of the removal of loose material by springs before the adjacent canyon of the Snake River had been cut below the base of the basalt and allowed the water to escape from the bottom of the formation. In all exposures the contact with the underlying beds is characterized by the development of comminuted glassy rock or pillow lava. Above this material, however, lies normal jointed pahoehoe, which, according to M. N. Short, consists of feldspar (labradorite), olivine, and light-brown glass. Some feldspar laths are as much as 5 millimeters long and are well formed. The olivine grains average about 0.25 millimeter in diameter and in part show crystal outlines. The rock is absolutely free from alteration. Pyroxene may be present in the central part of the flows.

A possible source for the Thousand Springs basalt is Trail Butte, near Jerome, about 15 miles east of Thousand Springs. The formation is sufficiently old to be well covered with loess and sand. The high level of the outlet of Thousand Springs and of the end of the basalt near Riley Springs is conclusive evidence that the valley filled by the basalt was relatively shallow, hence much shorter lived than the present valley of the Snake River. It was excavated by the Snake River in the Hagerman lake beds after the displacement of the stream by the Malad basalt. Thus the Thousand Springs lava is later than the Malad basalt, and as it forms the rim rock of the ancient canyon of the Snake River now filled with the Sand Springs basalt it is older than the Burley Lake beds and Sand Springs basalt.

McKINNEY BASALT

McKinney Butte, a typical lava dome about 4 miles across, rises about 300 feet above the adjacent plain, at the foot of the mountains in sec. 31, T. 4 S., R. 14 E. Prolific pahoehoe flows from it, here named the "McKinney basalt", spread over an area of more than 80 square miles between the Big Wood River and King Hill. The cone, built during a single great eruption, is surmounted by a shallow, insignificant crater. Little domes extend southwest from it for about 6 miles, an arrangement which suggests that the lava was extruded along a fissure. On the south side of the road crossing over the butte is a tube 30 feet high and 50 feet wide through which one of the main streams of lava flowed. The surface of the flows is partly covered with loess and a fair stand of sagebrush, but the pressure domes and other features in relief on the lava surface are well exposed. The soil is not deep enough to till, hence the country occupied by the McKinney lavas is still an uninhabited waste.

The rock is decidedly more porphyritic than any other basalt along the Snake River and is characterized by long laths of feldspar and conspicuous fresh green olivine phenocrysts. The groundmass, according to M. N. Short, consists of feldspar and olivine embedded in pyroxene with which platy iron oxide is associated.

The lava from this butte not only spread over the plains but reached the edge of the Snake River Canyon a short distance from the Big Wood River, as shown in plate 5. For at least 6 miles downstream from Malad Canyon the lava did not reach the rim in sufficient volume to affect the position of the Snake River, but not far west of Bliss it completely obliterated the Snake River Canyon and made a fill 600 feet thick for an additional distance of 6 miles. Thence the lava rapidly thins out, and 1½ miles west of Ticeska the surface of the flow falls below the former lake-bed rim of the Snake River. At this point it made a fill nearly 2 miles wide and about 500 feet thick. Downstream from this point, as shown in plate 5, the fill narrows and finally disappears beneath alluvium. A fine cross section of this enormous fill, extending slightly below the river, can be seen in sec. 33, T. 5 S., R. 11 E. About 1½ miles north of this point, in sec. 28, another branch of the same flow entered the Snake River Canyon through a small tributary gulch. About 6 miles north of Bliss part of the rim of some former canyon projects above the McKinney basalt. This may mark the position of the Big Wood River prior to the eruption. The Oregon Trail Highway follows the edge of this lava stream to the plains above the canyon. (See pl. 5.) This branch was a minor affair, and the several miles of McKinney basalt along the Snake River between this gulch and Clover Creek is a continuation of the main branch that flowed down the Snake River.

The McKinney lava created a temporary lake in the Snake River Valley and moved the Big Wood River and Dry Creek eastward into their present position. From a point about 2 miles west of Bliss the Snake River was forced to carve a new canyon in the adjacent Hagerman lake beds along the southern margin of the flow. The remnant of Hagerman lake beds at Ticeska indicates that the former channel of the Snake River probably lies north of the railroad in this stretch. When the ponded water overflowed along this new course it fell 700 feet in 7 miles. A temporary base level existed at this time at King Hill, where the Snake River resumed normal grade.

The weak sedimentary deposits offered little resistance to these swift waters, and during this stage a great alluvial fan containing huge boulders was built near the end of the lava fill. Finally a turning point occurred when the Snake River ceased fan building and passed from an overloaded depositing stage to a degrading stage. It was during the early part of the degrading stage that Hollywood Valley, an abandoned overflow channel of the Snake River in the King Hill project, was excavated. Simultaneous with this erosion the fan deposit was reworked, but the progressively decreasing velocity of the river made it more and more incompetent to remove the boulders previously deposited, so that now near King Hill there are extensive fields of boulders resembling those left in the path of hydraulic placer operations. When viewed from above, distinct parallel curving ridges of the larger boulders occur where they were concentrated by the river as it shifted laterally on the McKinney basalt.

Near the center of sec. 4, T. 6 S., R. 11 E., the river in its new position has exposed a basalt dike, one of the few known in the Snake River Plain. (See pl. 5.) The dike causes rapids in the river, and its weathered condition suggests that it supplied one of the upper interstratified lava beds in the Hagerman formation.

A small spring issues from the McKinney basalt at the river's edge in sec. 4, T. 6 S., R. 11 E. The absence of a large spring at the place where the Snake River dissects this great lava fill is not surprising in view of the fact that the supply for this spring is dependent upon recharge from local rainfall. The Snake River does not supply water to this spring, because it is incised in the relatively impermeable Banbury volcanics throughout its course along the edge of this fill upstream.

The age of the McKinney lava in relation to the other rocks mapped is difficult to ascertain. It rests on Hagerman lake beds and on the Malad basalt, but many incidents connected with volcanism occurred during the interval of time represented by these two formations. The bareness of the flow suggests that the McKinney eruption took place a short time prior to the extrusion of the Sand Springs basalt.

BLISS VOLCANICS

Bliss cone.—The Bliss cone, in sec. 11, T. 6 S., R. 12 E., is about 300 feet high and is composed entirely of fragmental lava, including cinders, vitreous volcanic sand, and a few bombs. The ash from this cone is overlain by 100 feet of coarse alluvium on the south bank of the river. The basalt is decidedly porphyritic and contains crystals of olivine and laths of white feldspar. The cone rests on 2 feet of soil, which covers a steep erosional slope of the Banbury volcanics. From its shape and position the cone was evidently formed in the canyon of the Snake River. Near the Bliss bridge, 1½ miles to the east, a vitreous sand caps subaqueous pillow and brecciated lava that is probably of the same age as the Bliss cone. This flow is consequently here named the "Bliss basalt." The sand may have originated in the cone, but more probably it was produced by local small explosions of the lava. The cone may have been a vent for some of the subaqueous lava, but its close resemblance to the cones formed by lava flowing into the sea in Hawaii strongly suggests that this cone resulted merely from explosions owing to a lava stream entering water.

Associated dikes.—A most remarkable group of dikes is associated with the Bliss subaqueous basalt. They range in thickness from 1 to 50 feet and form conspicuous ledges along the Oregon Trail Highway between Malad River and Bliss. Nine dikes striking N. 80° E. crop out in the talus at the foot of the canyon wall near Sullivan Spring in sec. 21, T. 6 S., R. 13 E. They consist of olivine-feldspar porphyritic blue basalt with smooth but bumpy surfaces, generally glassy. Glassy fragments of this lava were found among the talus all the way to the base of the rimrock, but it could not be ascertained whether it underlay the rimrock or whether it had been hurled against that rock during the eruption. About three-quarters of a mile northwest along the highway springs issue from the base of two more similar dikes. A tunnel 15 feet above the road penetrates one of the dikes. Definite pillow lava is associated with the dikes, which are very irregular and pockety. About a mile northwest is another group of dikes from which Bliss Spring issues. Two tunnels have been driven into the dikes to develop water, and they show that the dikes penetrate the talus. In an excavation on the northeast side of the dike, near the west tunnel, interstices in the talus are filled with wind-blown sandy soil, and fragments of olivine-feldspar porphyry do not occur among this material. Above this is 1½ feet of steeply dipping loose sandy loess, indicating a subaerial surface like the present one. Above this loess is 2 feet of granulated and ball type glassy Bliss porphyry. Since the McKinney olivine feldspar porphyry forms the rimrock above this place and both it and the Bliss porphyry are absent from the talus below the loess, the dikes and the McKinney basalt must be late arrivals, after the canyon had reached essentially its present form.

In the roof of the east tunnel the interstices in the talus not filled with loess are filled with crumbly glass, some of which adheres to the talus. The talus is not fused. A horizontal tube 3 feet long and 1½ feet in diameter occurs in the dike above the west tunnel.

Because these structures cut older formations and inject interstices in the talus there can be little doubt that they are real dikes. The loose loess underlying the glassy lava at the spring would have been washed away if a body of water had existed long at this site. Five conditions that favor the presumption that the Bliss volcanics were contemporaneous with the McKinney basalt and are probably part of it are: (1) The similarity in texture and phenocrysts; (2) the dikes always occur below where the rim is capped with McKinney basalt; (3) the exposures at Bliss Spring indicate both were the last volcanic events to occur at this place; (4) the Bliss glassy lava can be traced up the talus slope to the base of the McKinney basalt; and (5) the McKinney basalt would have made a dam for the Bliss lava to accumulate behind.

The problem whether the dikes are true vents or pseudovents due to some condition not understood is yet unsolved. The coincident seems too grea; that lava would break out simultaneously from vents in Snake River Canyon and in the foothills miles away and that the latter lava would reach Snake River canyon directly above the dikes. It is believed that they will turn out to be pseudovents and were caused in some manner by the McKinney basalt spilling over the rim at this place into a lake dammed by the same lava farther downstream.

The basalt flow.—The Bliss flow is entirely fragmental in character. It is decidedly fresh and porphyritic and has a distinct blue color, commonly iridescent. Pillows produced by the lava cooling in clots under water occur locally. According to M. N. Short, the rock contains large well-formed phenocrysts of plagioclase (labradorite) and olivine in a dark-brown groundmass free from pyroxene. The Bliss basalt has a maximum exposed thickness of 75 feet and forms cliffs near the highway bridge in Malad Canyon and also at the Bliss bridge. At the former place it rests on an erosion slope of the Banbury volcanics, and at the Bliss bridge, as shown in plate 10, *B*, it is in contact with talus. About 100 feet of coarse alluvium rests on the lava at several places. As the Bliss basalt occurs over 150 feet above the bottom of the valley it appears to have formed in a lake. Its subaqueous origin was recognized by Russell.[51]

This lava is a notable water-bearer in most places and is intimately associated with several springs, notably Bliss Spring and the unnamed spring an eighth of a mile southeast. The lava itself is not sufficiently extensive to have an intake area adequate to account for the flow of the springs from it.

A tunnel 80 feet long near Sullivan Spring, penetrating only the subaqueous lava has not recovered any water. The lava is easily removed with a pick but stands well without cribbing because of the angularity of its constituents. This tunnel was started about 40 feet above Sullivan Spring with the hope of tapping the spring flow at a higher level. There is still a chance of obtaining the objective in such a scheme, and it is advisable to continue the tunnel until the contact of the subaqueous basalt with the old valley wall is struck.

SAND SPRINGS BASALT AND BURLEY LAKE BEDS

The Sand Springs basalt forms large flat-topped detached benches on the north side of the Snake River from the mouth of Cove Creek, in sec. 2, T. 7 S., R. 13 E., for 14 miles upstream, or to the point where Sand Springs, from which it is named, cascades into the Snake River. It is a fresh gray pahoehoe basalt flow containing feldspar (labradorite) and iron-rich olivine phenocrysts. It has the usual ophitic texture, with interstitial dark-brown glass. Although there are local textural differences, the lava probably consists entirely of one flow which has a characteristic pressure-dome surface. It is vesicular and jointed and in the thick section near Thousand Springs is filled with tubes, many of which appear to have carried water at one time. Near the base of the bluff at this place spring water issues

[51] Russell, T. C., Geology and water resources of the Snake River Plains: U. S. Geol. Survey Bull. 199, pp. 113-116, 1902.

from it. The altitude of the bench near Cove Creek is about 2,850 feet, or about 100 feet above the river. The surface of the bench rises steadily from this point to Thousand Springs, where it reaches an altitude of 3,200 feet and is 300 feet above the river. (See pl. 5.) Numerous contacts show that these benches are wedge-shaped remnants of a lava flow which at one time partly filled the Snake River from Thousand Springs to Cove Creek. At the head of the Devils Wash Bowl and Blue Lakes alcoves the steep angular unconformity between the Sand Springs basalt and the ancient buried canyon walls is exposed. Invariably the basalt at the contact is brecciated and contains pillow lava, which indicates solidification in the presence of moisture. The bottom of the old channel filled by this flow is evidently below the present river level, for it is nowhere exposed. At Cove Creek, the lowest point at which it is recognized, a thickness of slightly more than 100 feet is exposed, indicating that the flow once extended farther downstream. Possibly the Bliss basalt represents the downstream extension of this flow, although there is little evidence in support of such a concept.

From Sand Springs downstream to Cove Creek the Snake River cut its canyon along the west side of the flow at the contact of the lava and the older, softer Hagerman lake beds. This accounts for the absence of Sand Springs basalt on the west side of the river in this stretch with the exception of a small remnant filling a gulch in sec. 19, T. 8 S., R. 14 E. Between this remnant and the large wedge on the opposite bank is the point where the Snake River, diverted from its channel many miles upstream, again tumbled back into its old course. The Sand Springs basalt from this point turns eastward, and within a short distance all suggestion of the former rim of the Snake River Canyon is obliterated by this lava.

The Sand Springs basalt borders the Snake River on the east and north from Sand Springs Creek to the Devils Wash Bowl Spring, a distance of 32 miles, with few and short exposures of other rocks between it and the alluvium of the present stream. At Cedar Draw, in sec. 14, T. 9 S., R. 15 E., several remnants of the Sand Springs basalt are preserved as benches in a reentrant on the south rim. From Blue Lakes eastward the pressure ridges on the surface of the Sand Springs basalt and the general absence of soil make it readily traceable. It was followed as far east as Eden, where it was lost in a maze of young flows. A reconnaissance of the buttes in this region points to Rocky Ridge, a broad lava dome between Kamama and Hazelton, as the probable source of the flow.

As the Sand Springs basalt filled the Snake River Canyon for about 50 miles, it made an effective dam. The impounded waters covered practically the same area as that now included in the Minidoka project. In fact, the level agricultural land free from rock that was chosen for the site of this project resulted from the deposition of sediments in the lake. For convenience the deposits of this lake are called the Burley lake beds. Because they are concealed by later deposits they are not mapped. The log of the city well at Burley indicates that 150 feet of alluvium was deposited in the lake. The Burley lake beds are essentially horizontal and are capped on the south and east by gravel deposited by the Snake River and Goose Creek. They have not been disturbed by diastrophism since they were deposited, and as they reach nearly to the old shore line the lake must have practically silted up before it was drained.

Like other basalt dams the Sand Springs basalt was so permeable that before silting of the basin was far advanced the leakage may have equaled the inflow. Boulders along the margin of the flow between Eden and Hazelton suggest that Burley Lake overflowed there, but the final outlet of the lake was established farther south. The present channel of the Snake River from a point near Milner to the Devils Wash Bowl, which was established at that time, is 6 to 8 miles south of the margin of the Sand Springs basalt, but the topography readily accounts for this peculiarity. The position of the buried channel of the Snake River is indicated by the ground-water contours west of Rupert, shown in plate 19. This channel, which is deeper than the present canyon of the Snake River, is separated from the present canyon along the stretch between the Devils Wash Bowl and Box Canyon by a divide made up of either the impermeable Shoshone Falls andesite or the Banbury volcanics capped with permeable later basalts. As the canyon filled with Sand Springs basalt is carrying great volumes of ground water, low saddles in the impermeable part of the divide become spillways from which water escapes into the present canyon in the form of great springs, as shown in plate 25. Many of these low saddles are places where northward-flowing streams from the mountains to the south had notched the rim of the canyon that preceded the eruption of the Sand Springs basalt.

About 2½ miles downstream from Blue Lakes a deep V-shaped section of the Sand Springs basalt is exposed in the wall of the Snake River Canyon, and as practically no water escapes from it the aquifer must be drained by Blue Lakes Spring unless the bottom of the Sand Springs basalt lies considerably below the Snake River at this place. However, farther west numerous springs discharge from it; hence additional water is probably supplied to the Sand Springs basalt from similar buried canyons to the north. The idea that such tributary canyons exist is supported by the fact that during the existence of Jerome Reservoir, Clear Lake Springs increased in flow, whereas Blue Lake did not. If this condition prevails the water-bearing structure paralleling the Snake River for so many miles could be utilized for hydroelectric development. Tunnels driven into the north wall of the canyon at advantageous locations would bring out water that now discharges as springs farther downstream. Thus the flow could be concentrated at certain power sites.

MINIDOKA BASALT

A late pahoehoe basalt flow, the Minidoka basalt, extends along the north shore of Lake Walcott Reservoir upstream from the dam. It supports only a sparse growth of vegetation and is only partly covered with loess. Most of the high-pressure domes are bare and exhibit the original ropy structure and cracks characteristic of such flows. The margin of this flow borders the east side of the Minidoka project and forms a rocky wall about 25 feet high. The flow was not traced to its source, but presumably it issued from one of the cones near Minidoka. In hand specimens the basalt is blue and vesicular and shows tiny crystals of feldspar and olivine. Beneath the Minidoka basalt a bed of gravel about 11 feet thick rests on an older somewhat weathered basalt. This older basalt forms the foundation and south abutment of the dam and is porphyritic. The olivine is oxidized, and the feldspar phenocrysts are darker than those in the Minidoka basalt. This older basalt can be traced southward toward one of the cones near the mouth of the Raft River Valley, from which it apparently came. The Minidoka basalt is mapped on plate 4.

The gravel between these basalts is continuous with the gravel exposed on the north bank of the river just beyond the west margin of the Minidoka basalt. As this gravel was deposited after the Burley lake beds, the Minidoka basalt must be later than the Sand Springs basalt, which impounded the ancient Burley Lake. In the interstratified gravel in the north abutment fossils were discovered by F. C. Horn during the excavation for the dam.

A. M. Gilbert describes the section as loose soil, 6 inches; lava (Minidoka basalt), 12 feet; sand, 12 feet; semicemented, comparatively loose gravel containing bones, 2 feet; and lava of unknown thickness. Hay [52] identified *Bison alleni*, *Camelops minidoka*, *Elephas* of undetermined species, and *Equus* of undetermined species. Without examination of the locality Hay states that he "sees no reason for doubting that these deposits and the animals belong to the first interglacial stage of the Pleistocene." Unquestionably the fossils are Pleistocene, but the mere fact that the gravel is overlain by a lava flow is not adequate evidence upon which to assign these mammals to the first interglacial stage, especially as the appearance of this flow indicates that it is not as old as many in the vicinity.

[52] Hay, O. P., The Pleistocene of the western region of North America and its vertebrated animals: Carnegie Inst. Washington Pub. 322B, p. 264, 1927.

WENDELL GRADE BASALT

Where the road from Hagerman to Wendell leaves the Snake River Valley, in sec. 19, T. 7 S., R. 14 E., there is a steep ascent known as the "Wendell Grade." Near the top a fairly recent black basalt crops out which is here named the "Wendell Grade basalt." This rock, according to M. N. Short, contains abundant vesicles 7 millimeters or less in diameter, some of which are lined with clay, probably beidellite, formed by superficial alteration of the basalt. Olivine is abundant, and some crystals are as much as 3 millimeters in diameter. Laths of plagioclase feldspar with an average length of 0.5 millimeter are embedded in slightly devitrified brown glass.

The basalt at this place occupies a slight depression where a small gully formerly notched the valley rim. It flowed over the rim and part way down the valley wall before the flow ceased. The angular unconformity thus produced shows conclusively that this basalt is younger than the Snake River Valley. It is underlain by the Malad basalt and the Hagerman lake beds. As shown in plate 5, two other branches of the same flow cascaded over the rim of the valley within the next 3 miles upstream. These branches unite a few miles east of the rim in a broad hummocky pahoehoe sparsely covered with soil and vegetation. This area is crossed by the highway from Wendell to Bliss and is conspicuous because of the abrupt change from intensely cultivated farms to stony uninhabited lava fields. Without the aid of a topographic map it becomes more and more difficult to trace the flow away from the Snake River. Near Shoshone it is covered with drifting sand. In spite of this covering it seems probable to one standing on Notch Butte that the flow came from this cone. Thus, the Wendell Grade basalt shown in plate 5, is about 25 miles from its source, and in view of the vast area inundated by this pahoehoe it is not surprising that advance tongues barely reached Hagerman Valley.

A very vesicular specimen collected from the summit of Notch Butte, examined by Mr. Short, differs from the one from Wendell Grade in that the feldspar crystals are larger and those of olivine smaller, and the groundmass has crystallized into brown pyroxene containing plates of iron oxide.

The recent appearance of this lava flow and the almost inappreciable change that has occurred in the rim of Hagerman Valley since this basalt cascaded over it place the Wendell Grade basalt among the youngest lavas along the Snake River and probably later than the Sand Springs basalt. In freshness it closely resembles the Minidoka basalt, which was poured out long after the Sand Springs basalt. However, this Wendell Grade flow does not compare in youthful appearance with the black lavas in the Craters of the Moon National Monument but rather resembles the oldest of them.

PLEISTOCENE BASALT IN TRIBUTARY VALLEYS

Basalt flows extend short distances upstream from the mouths of several of the valleys on the borders of the Snake River Plain and in a few valleys have filled long stretches. The character and geologic relations of the different flows indicate that they are probably all of Pleistocene age and that most of them were erupted relatively late in that epoch.

Salmon Falls Creek.—Two sets of such flows appear to have occurred along Salmon Falls Creek. The older set extends from a point near the downstream end of the reservoir to a point about 2 miles above the mouth of the creek. The flows issued from local vents, several of which are marked by domes in the vicinity of the creek. Two of the largest domes, the Castleford Buttes, lie on the east side of the Castleford crossing of Salmon Falls Creek near the town of Castleford. The name was suggested by the pedestal rock in the Miocene (?) silicic lava, to the west of the ford. In this part of the valley the relatively early basaltic flows rest unconformably on the Miocene (?) lava and the Hagerman lake beds and fill a broad former valley of Salmon Falls Creek eroded in these older rocks. Near the Snake River this old valley was not completely filled with basalt, as is shown by the presence near Lucerne, on the east side of the present canyon, of part of the old valley rim rising above the basalt. This rim remnant is composed of the capping member of the Hagerman lake beds and now serves as a source of gravel for the Buhl highway district.

The sheets of basalt near Castleford are even-bedded and attain a thickness of about 75 feet. One thin bed of loess intercalated in the flows indicates that there was at least one pause in the eruptive activity. The adjacent lake beds furnish so abundant a source of supply that such a bed of loess may well have accumulated in a short time.

After the extrusion of the early set of basalt flows a narrow canyon was incised into the flows and older rocks to a depth of about 600 feet. Then, from a group of rugged spatter cones half a mile from the east abutment of Salmon Falls Dam, a voluminous basalt flow was poured out. This lava partly filled the canyon for about half a mile upstream from the present dam and for many miles downstream. The canyon was not entirely filled, so that the creek returned to it after the eruption and established a meandering course over the billowy lava crust. Subsequent erosion has entrenched these meanders and left the basalt in a series of prismatic vertical-faced remnants whose surfaces form a conspicuous bench about 150 feet above the creek, as shown in plate 12, *B*.

Goose Creek.—Near the head of Goose Creek and extending southward to Little Goose Creek there are exposures of basalt at high altitudes, capping the Paleozoic rocks.[53] This basalt was tentatively regarded by Piper as Pliocene on the assumption that most similar rock in the region was of that age. According to the classification here adopted it is presumably Pleistocene. If so, it appears to have been erupted at an altitude much above that of the kindred flows elsewhere in the region.

Raft River.—Near the mouth of the Raft River Valley there are basaltic domes from 50 to 200 feet high, surmounted by four shallow craters. Lava from these domes choked the valley and now hides it from the view of the tourist on the Oregon Trail Highway (pls. 4, 29). These flows probably nowhere exceed 100 feet in aggregate thickness except in the vicinity of the cones. They displaced the Raft River from its former channel and caused it to flow around them on the east, where it has cut into the Raft lake beds, forming a terrace about 50 feet high between Yale and the Snake River.

Portneuf River.—The valley of the Portneuf River from a point near Lava Hot Spring to a point near Pocatello (pl. 4) was at one time largely filled by basalt, which may have originated at least in part from inconspicuous cones near Alexander, on the Bear River. Basaltic flows from Tenmile Pass northeast of Bancroft, and somewhat nearer, may have been contributed to the filling of the lower canyon of the Portneuf. However, a distinct terminal margin of the last flow from Tenmile Pass occurs near Bancroft.

Ancestral Marsh Creek apparently once joined the Portneuf near McCammon. Basalt from the valley of the Portneuf extended up that of Marsh Creek to a point within a mile of Arimo, where it terminated in a steep front, 30 to 50 feet high, against a ledge of limestone, which may have been the former rock divide between Marsh Creek and the Bear River. After the eruption the Portneuf River reestablished itself on the east side of the lava fill, and Marsh Creek flowed down the west side. Consequently the two streams are approximately parallel to each other for 14 miles, separated only by a peninsula of basalt. Some time later Lake Bonneville [54] overflowed through the pass at the head of Marsh Creek.

The small channel of Marsh Creek on the west side of the lava fill was not of sufficient carrying capacity to allow the discharge of Lake Bonneville to pass entirely through it; hence the water overflowed and cut a canyon 20 to 50 feet deep and 100 to 400 feet wide across the lava fill. When the overflow waters of Lake Bonneville subsided, Marsh Creek reverted to approximately its former channel, because the softer material beyond the lava was more susceptible of erosion.

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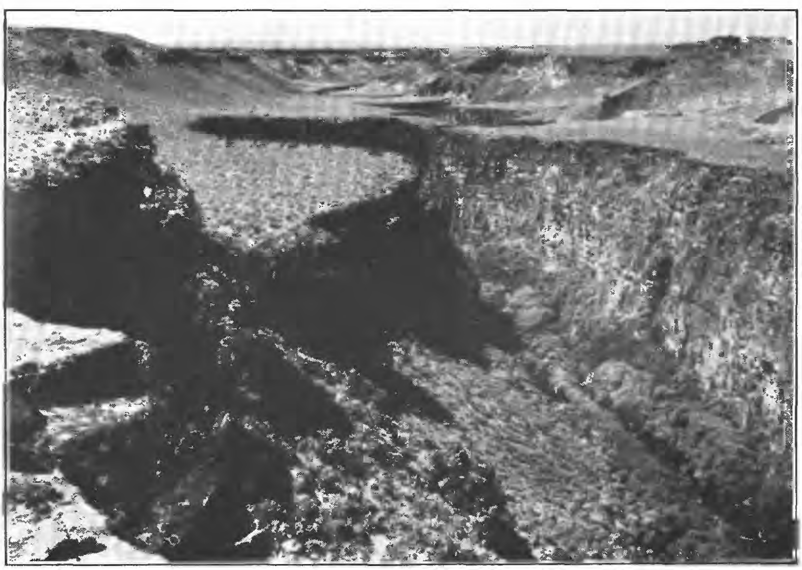
[53] Piper, A. M., Geology and water resources of the Goose Creek Basin, Cassia County, Idaho: Idaho Bur. Mines and Geology Bull. 6, pp. 31–32, 1923.

[54] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, pp. 171–180, 1890.

A. BOULDER DEPOSIT IN HAGERMAN VALLEY LAID DOWN AT THE TOE OF A LAVA DAM.



B. VIEW LOOKING DOWN SALMON FALLS CREEK SHOWING ENTRENCHED MEANDERS AND INNER BENCH FORMED BY AN INTRACANYON LAVA FLOW AND OUTER BENCH OF OLDER LAVAS.

The intercanyon lava in the Portneuf Valley appears to consist of two flows. Peale [55] describes a tunnel in the basalt near Lava Hot Springs, where a gravel bed was exposed between two layers of basalt. The apparent conformity of the flows and the absence of a continuous intervening soil bed is evidence, however, that the time interval between their extrusion was short. The upper flow has not been recognized downstream from a point about a mile below Pocatello, but the lower basalt persists farther downstream. It seems probable that the basalt from which the Portneuf Springs issue may be an extension of that in Portneuf Canyon. The erosion of the two flows has produced two sets of rock terraces along the Portneuf above Pocatello.

Fossils collected from a highway gravel pit near McCammon in sec. 18, T. 9 S., R. 33 E., were determined by J. W. Gidley to include Pleistocene horse, bison, camel (*Camelops* cf. *C. kansanus*), elephant, and bear. As this gravel is apparently younger than the lava, the lava is presumably of rather early Pleistocene age.

Blackfoot River.—At some early time the Blackfoot River carved for itself a canyon more than 300 feet deep in Tertiary sedimentary rocks and associated lava and tuff. This valley was half a mile or more wider than that of the present stream. Volcanic eruptions in the middle and upper stretches of this stream completely filled much of the valley with basalt. In the lower stretches the basalt did not apparently accumulate in sufficient thickness to obliterate the prebasalt canyon. The Blackfoot River, on returning to its former course, incised a canyon in this lava fill.

Although this early basalt fill of the Blackfoot River Canyon rests unconformably upon the Tertiary rhyolite and associated deposits, it appears considerably older than any of the basaltic intracanyon lava flows in other valleys tributary to the Snake River. From its weathered and deeply eroded appearance it can be correlated tentatively with the Rockland Valley basalt in the Rock Creek Valley, described on page 47. It appears that subsequent erosion carved a new canyon in this intracanyon basalt, which in turn was partly filled for a distance of at least 40 miles by a stream of lava from one of the numerous vents near the Blackfoot Reservoir, in the Willow Creek lava fields. In the lower stretches the basalt accumulated to a thickness of about 200 feet and caused the rejuvenation of the Blackfoot River. The eroded remnants of the older intracanyon basalt fill now remain as high-level benches strung along the river and generally 250 feet above it, whereas the last lava flow forms similar benches at a level of 60 to 200 feet above the river bed. In plate 61, *B*, of United States Geological Survey Professional Paper 152 the relation of these two sets of benches to the Blackfoot River is shown. The absence of soil beds in the younger basalt cliffs indicates that the lava was prob-

[55] Peale, A. C., Report on the geology of the Green River district: U. S. Geol. and Geog. Survey Terr. 11th Ann. Rept., p. 564, 1879.

ably poured out during a single eruption.[56] When it reached the Snake River Plain, such a voluminous flow doubtless spread out in the form of a large delta of lava. If now present this basalt is buried beneath alluvium. Wells in this vicinity penetrate basalt beneath the top coating of gravel.

Upper Snake River.—The late geologic history of the valley of the Snake River above Heise as interpreted by the writer is much like that of the Blackfoot. After a valley had been carved in the older rocks and the acidic eruptive rocks of Tertiary age there came a thick basaltic flow down the valley, which filled it several hundred feet deep. Subsequent erosion left the remnants of this early basalt flow as high benches along the river. Later another basalt flow between 75 and 100 feet thick coursed down the new canyon and in time was partly removed by the Snake River. Remnants of this basalt flow are found here and there as narrow benches along the river, commonly at the foot of the higher basalt bench.

Between Heise and the confluence with Henrys Fork the Snake River has built an extensive alluvial fan. On the west side of this fan for several miles below the mouth of the canyon is a basaltic terrace, which is a remnant of the former lava delta that was built when the earlier intracanyon basalt flows spilled out upon the Snake River Plain.

LAKE BEDS NEAR TERRETON AND MARKET LAKE

Two masses of lake sediments are associated with the Pleistocene basalt of the Mud Lake region.[57] As shown on plate 4, the largest of these masses is in the general vicinity of Terreton and the present Mud Lake, although extending much beyond the limits of the lake. A smaller but otherwise similar mass is exposed near the present Market Lake, a short distance farther south. Both masses consist largely of horizontal clay beds with lesser amounts of silt and sand. They are covered in many places by loess and sand dunes. Those near Mud Lake interfinger northward with the alluvium of tributary streams. Basalt flows are locally intercalated with them. Well logs indicate that the beds near Terreton have a maximum thickness of 200 feet, and those near Market Lake have a thickness of at least 148 feet. Scanty fossil evidence and the relations to other rocks indicate that both masses may have begun to accumulate early in the Pleistocene epoch and that deposition has continued into Recent time.

Most of these lake beds are so fine grained as to be practically impermeable except where they grade into and are interleaved with

[56] Detailed studies indicate that this valley has a complex erosion history only an abstract of which has yet been printed. See Mansfield, G. R., Blackfoot Valley—a typical valley system in southeastern Idaho: Geol. Soc. America Proc., 1936, p. 402, 1937.

[57] Stearns, H. T., Bryan, L. L., and Crandall, Lynn, Geology and water resources of the Mud Lake region, Idaho: U. S. Geol. Survey Water-Supply Paper 818 (in press).

stream deposits. Downward percolation through them is so slow that perched water tables occur in the areas underlain by the lake beds. In irrigated areas shallow wells have obtained meager domestic supplies from these beds. Where permeable basalt flows are intercalated in them local artesian pressures are set up and flowing wells have been obtained.

GLACIAL DEPOSITS

Pleistocene glaciation was widespread in the mountains, but few of its products reached the Snake River Plain in distinguishable form. East of Ashton, on Henrys Fork of the Snake River, there is an extensive deposit of bedded sand and gravel, commonly overlain by gumbo clay, which appears to have formed in the outwash plain of a pre-Wisconsin glacier.[58] Outwash deposits also occur in Camas Meadows near Kilgore and in the Island Park Basin.

OLDER ALLUVIUM

The older alluvium was not differentiated in mapping from the younger alluvium because the younger occupies so small a part of the area. The older differs from the younger only in that it forms stream-laid terraces at various heights as much as 300 feet or more above the streams. A casual examination of the alluvial deposits along the Snake River would lead to the view that they were deposited chiefly during an aggrading stage induced by glaciers existing in its headwater region during Pleistocene time. However, detailed studies of the part of the river mapped on plates 5 and 6 show conclusively that essentially all the material was laid down either in impounded waters behind lava dams or as fans at the toes of these dams. The extensive gravel deposits near Springfield and Blackfoot and those near the Minidoka Dam were formed behind lava dams. These deposits are far less striking and usually contain finer gravel than the great deposits formed at the toes of the dams. Immense boulders, such as those shown in plate 12, *A*, many of them 6 to 8 feet in diameter, characterize this fan type of alluvium. They occur at Bonanza Bar, in Hagerman Valley, at the mouth of the Malad River, and near King Hill. Similar coarse alluvium is left in the wake of large receding spring alcoves and falls—for instance, near Blue Lakes.

Another type of alluvium along the Snake River results from deposition by the streams tributary to the south side. Conspicuous deltas of gravel occur at the mouths of the Portneuf River, Dry Creek, Rock Creek, and Salmon Falls Creek. Even some of these deltas were built at the toes of lava dams, formed by the thick flows that formerly filled the valleys of the Portneuf River, Salmon Falls Creek, and other streams.

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[58] Stearns, H. T., Bryan, L. L., and Crandall, Lynn, Geology and water resources of the Mud Lake region, Idaho: U. S. Geol. Survey Water-Supply Paper 818 (in press).

Most stream valleys tributary to the Snake River Plain contain older alluvium, and many are floored by large quantities of it. Some of the canyons in the southwestern part of the region, cut into Miocene (?) lava, have little space for the accumulation of alluvium, but in valleys such as that of Goose Creek this material is plentiful. In that valley much of the material is derived from erosion of Tertiary lacustrine deposits and is exceptionally fine grained.[59] Much of the silt of this sort is mixed with wind-blown material from areas near the Snake River and produces good soil. Locally, especially near its head and on its borders, the valley of Goose Creek contains coarse gravel.

Stream-laid deposits cover considerable areas along the Snake River from Heise to Milner. Some of these deposits have been mapped on plate 4, but there are large areas not shown. The gravel deposits of the Snake River form a continuous surface mantle from Heise to American Falls, especially on the east and south sides of the river. Most of the streams entering the Snake River Plain have built extensive fans of gravel, especially the streams on the north side. The gravel as a rule is very permeable, and wells obtain abundant supplies from it. A large well dug in gravel only about 18 feet deep in the Raft River Valley yields enough water to irrigate 320 acres. The deposits of alluvium that underlie the Minidoka projects are less permeable than most others in the valley, because at shallow depths they become fine-textured and grade downward into the Burley lake beds. The Burley well penetrated 158 feet of these deposits, and the log shows a considerable part of them to be clay beds. This clay gives rise to the drainage problems on the North Side Minidoka project because irrigation water cannot percolate rapidly enough through it and into the underlying permeable lavas to prevent seeped areas.[60]

In the section that extends upstream from the American Falls Reservoir to the foothills at the head of the Snake River Plain there are extensive gravel beds that yield water freely for domestic use and in certain sections discharge considerable water as ground-water inflow to the stream. In some places this gravel overlies the basalt, but in others it is intercalated with the basalt or is rather thick and rests on the older rocks. Some tests of the rate of movement of the ground water at its surface in this area were made in 1916. A slight depression was excavated into the zone of saturation and charged with fluorescein, and the time required for the colored water to appear in one of several similar holes arranged on the circumference of a circle about 4 feet in diameter with the first hole as a center was noted.

[59] Piper, A. M., op. cit., pp. 35–36.

[60] For a detailed discussion of the occurrence of water in alluvium see Meinzer, O. E., Occurrence of ground water in the United States: U. S. Geol. Survey Water-Supply Paper 489, pp. 117–118, 1923.

Half a dozen tests of this kind in the vicinity of Firth, in coarse clean gravel, gave velocities averaging about 5 feet an hour. Similar tests in material of the same kind on the north bank of the Snake River opposite the mouth of the Blackfoot River gave results of about 4 feet an hour, and tests in a black sand 3 miles east of Blackfoot showed a velocity of 1.9 feet an hour. These observations, of course, apply only to the rate of movement of the surficial part of the ground water for a short distance and do not necessarily indicate the average rate of ground-water movement. They do furnish, however, some idea of the relatively rapid rate at which the ground water may move through the coarse gravel of the upper Snake River Valley.

The high yield of shallow wells sunk into this gravel is shown in the results of the following tests, reported by W. G. Sloan, of wells at Arco, sunk into the gravel at the mouth of the Big Lost River.

Yield of shallow wells at Arco, August 1927

Well	Diameter of well (feet)	Yield (gallons a minute)	Draw-down (feet)
Arco city well	2½	300	2
Arco railroad well	16	157	1

The Raft River Valley likewise has extensive deposits of older alluvium, described on pages 210–212. In many of the valleys farther east and northeast the widespread filling by Tertiary deposits and by Pleistocene basalt has greatly limited the amount of alluvium.

On the whole, the tributary valleys north of the Snake River Plain contain more alluvium than those to the south. Much of this alluvium is coarse gravel and sand with comparatively thin beds of clay and of hardpan consisting of gravel with a calcium carbonate cement. In some places, as in the Big Lost River Valley near the Mackay Dam, cemented gravel is extensive and has been eroded into hills of some size. However, this material is probably older than the comparatively unconsolidated alluvium. In the general vicinity of Mud Lake, Jefferson County, the older alluvium interfingers with and grades into lacustrine deposits. Further details as to the distribution and character of the older alluvium are given in the description of several of the tributary valleys (pp. 205–262).

In numerous places along the canyon of the Snake River vertebrate remains are abundant in the alluvial deposits. Similar fossils exist in some of the valleys in the nearby mountains, but little is as yet known about them. Hay[61] in 1927 published descriptions of the Pleistocene vertebrate fossils in the National Museum. These fossils

[61] Hay, O. P., The Pleistocene of the western region of North America and its vertebrated animals: Carnegie Inst. Washington Pub. 322B, 346 pp., 1927.

included a considerable number from the vicinity of the Snake River. With the scanty data available to him, Hay made such interpretations of the geologic relation of the fossils as he could. He requested Stearns to review these in the field, and, in consequence, comments on some of his statements and revisions of them are given below. He supposed that many of the fossils described by him came from the Idaho formation,[62] and as the fossils were clearly Pleistocene he believed it necessary to refer the Idaho formation to that epoch.[63] The Hagerman lake beds of the present report are equivalent to part at least of the Idaho formation, which is more extensively exposed farther west. It is shown below that the fossils on which Hay's conclusion was based came from the older alluvium and not from the Hagerman lake beds or any similarly old formation. Some of the fossils he described came from the younger alluvium, as that term is used in the present report.

In a gravel pit in the older alluvium near the east end of American Falls Dam numerous fossil bones have been found. Mr. J. Ayers saved many specimens from this pit. Bones of extinct Pleistocene camels, horses, bison, elephants, and other animals, mostly waterworn and slightly fossilized, are abundant, and in 1929 J. W. Gidley unearthed in this pit a nearly complete skeleton of a new species of ground sloth. One large horn core recovered from this pit was regarded by him as possibly representing a new species akin to *Bison alleni*. Flooding by the American Falls Reservoir makes the relation of this deposit to the Snake River rather difficult to establish, but the type of pebbles and its position suggest deposition by a stream tributary to the Snake River from the south.

W. C. Mansfield, of the United States Geological Survey, identified shells associated with the bones in this pit as *Fluminicola fusce* Haldeman and *Sphaerium* cf. *S. sulcatum* Lamarck. He states that both of these species inhabit fresh water and that their age does not appear to be earlier than late Pleistocene.

A considerable number of bones have been unearthed by workmen in the Acequia gravel pit, in the SE¼ sec. 7, T. 9 S., R. 25 E. Among the bones from this pit, now in the Rupert High School, are the larger part of an elephant skull and tusks (*Elephas*) and the upper part of a bison skull with horn cores that have a spread of 51 inches. It was identified by Dr. Gidley as a new species of bison. Several elephant bones and one buffalo skull collected from this pit were obtained for the Smithsonian Institution from the Rupert Record, at Rupert. In the Rupert Record collection were the horn cores and part of the skull of a new species of musk ox. The bones of *Bison alleni* and of

[62] Lindgren, Waldemar, The mining districts of the Idaho basin and the Boise Ridge, Idaho: U. S. Geol. Survey 18th Ann. Rept., pt. 3, pp. 627–628, 1898.

[63] Hay, O. P., op. cit., p. 269.

Elephas imperator mentioned by Hay[64] as reported to come from the vicinity of Rupert are from the same locality as those just mentioned. The gravel here is continuous with that under the Minidoka basalt at the Minidoka Dam and overlies the Burley lake beds. Hence it is among the youngest deposits of the older alluvium.

Hay[65] mentions horse remains from Minidoka which he thinks do not belong to *Equus idahoensis*. If these bones are part of the collection whose geologic relations are described on page 126 of his report they are to be correlated with those just mentioned.

The remains of *Bison alleni* reported by Hay[66] to have been dredged from the Snake River just above the old town of American Falls were assumed by him[67] to have been washed out of early Pleistocene beds. This derivation seems improbable, for similar remains, including nearly complete skeletons, according to local reports, are known to be abundant in the older alluvium of the vicinity. Bones are so common in every excavation that they have ceased to arouse comment. For example, bones of extinct elephants, horses, and bisons, mostly fragmentary, are plentiful in a pit on the shore of American Falls Reservoir, 6 miles northeast of Aberdeen. Leo Lee, of Aberdeen, states that he found a complete skeleton of an elephant in a gravel pit about 4 miles from Aberdeen. Ben Cotant, of American Falls, reports that 10 years ago, before blow sand covered the locality, he saw a complete mammoth skeleton exposed in the American Falls lake beds near a ledge of lava in sec. 10, T. 8 S., R. 30 E.

A great many bones have been found in the older alluvium, especially when placer mining was carried on extensively along the Snake River. A few of these bones are in the State Historical Society exhibit at Boise, but many tons of them have rotted away in the yards of private collectors. The bones in the gravel pits show that both the extinct mammoth, *Elephas columbi*, and the largest elephant that ever lived, *Elephas imperator*, frequented the Snake River Plain during the time of deposition of both the older and younger alluvium. The abundance of these and other remains suggests that animals were plentiful here during this part of the Pleistocene. Many of the bones are in an excellent state of preservation, hence their careful exploitation by paleontologists seems warranted.

RECENT DEPOSITS

OCCURRENCE

Certain of the volcanic and other deposits in this region appear to be so young that they are regarded as of Recent age. In some places definite fossil or other evidence is available on which to base

[64] Hay, O. P., op. cit., p. 44.
[65] Idem, p. 74.
[66] Idem, p. 126.
[67] Idem, p. 264.

this assignment. In those areas in which volcanic activity or sedimentation continued without recognizable interruption from the Pleistocene into the early part of the Recent epoch, differentiation is commonly impossible, and the Recent beds have been mapped and described with their Pleistocene associates.

BLACK BASALT AND ASSOCIATED CONES

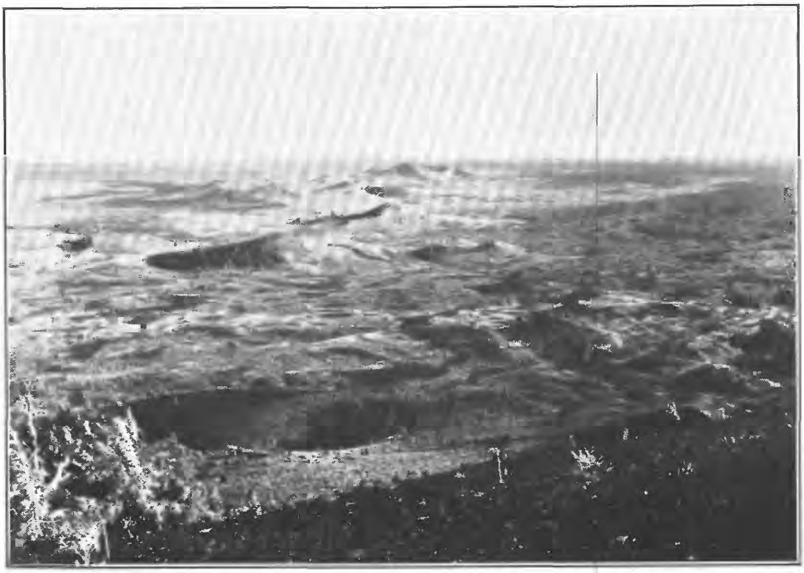
Four areas in the Snake River Plain are covered with young basalt, whose dense black color contrasts strongly with the gray, blue, and brown tones of the underlying Pleistocene basalt, a contrast that is emphasized by the scantiness of the soil and vegetation on the young flows. These areas, as shown in plate 4, are Hell's Half Acre, which covers about 180 square miles a short distance west of Idaho Falls; the Wapi lava field, which covers about 160 square miles about 15 miles west of American Falls; the Shoshone lava field, which covers 18 square miles and lies about 15 miles north of Shoshone; and the Craters of the Moon field, with a total area of about 125 square miles, of which about 80 square miles is included in the Craters of the Moon National Monument. Another similarly recent lava field, only partly shown in plate 4, fills much of the valley of the Little Wood River just within the border of the mountains.[68]

These recent lava fields are striking features of the landscape and are of much interest to tourists. They are of value also as unmarred and readily studied illustrations of the characteristics of the older, similar rocks that underlie much of the Snake River Plain. The Craters of the Moon National Monument is the only one of these areas that has as yet been studied in detail.[69] Plate 13 is modified from a larger-scale geologic map of this area, which is based on the topographic map issued by the United States Geological Survey.

Practically all of the vents in this area are situated in a strip of land slightly less than 2 miles wide at the north end and only 1 mile wide at the south end. It extends S. 50° E. from the foot of the mountains for a distance of about 13 miles and is known as the Great Rift Zone. It is studded with 55 cones that have given vent to lava and rent by 14 fissures bordered by spatter cones (pl. 13 and pl. 14, *A*) and dies out to the southeast in several gaping cracks. The cones in part of this zone are shown in plate 14, *A*. About 5 miles southeast of Vermilion Chasm, outside of the national monument and in line with these cracks, is a large black cinder cone called Black Butte (outside the area shown in pl. 13) that also may belong to the Great Rift Zone.

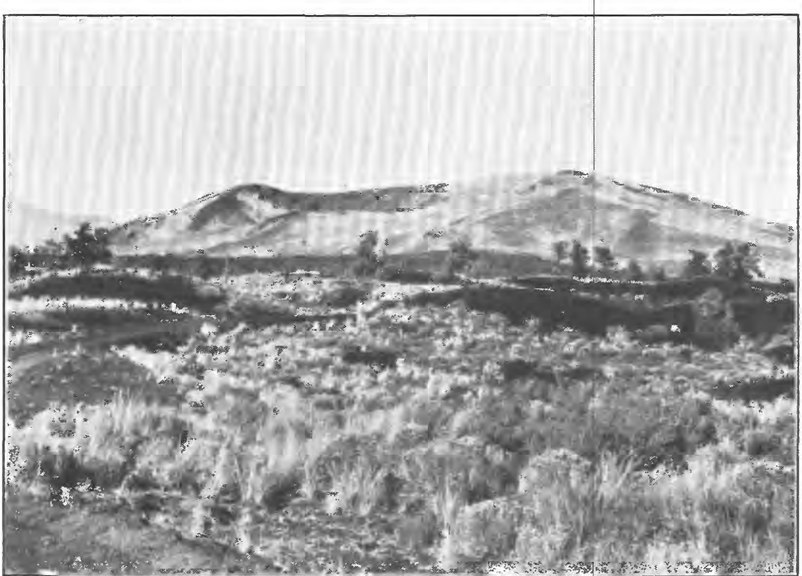
[68] Umpleby, J. B., Westgate, L. G., and Ross, C. P., Geology and ore deposits of the Wood River region, Idaho: U. S. Geol. Survey Bull. 814, pp. 60–61, 1930.

[69] Stearns, H. T., Guide to Craters of the Moon National Monument, Idaho: Caldwell, Idaho, Caxton Printers, 59 pp., 2d ed., 1936.



A. VIEW LOOKING SOUTHEAST FROM THE SUMMIT OF BIG CINDER BUTTE SHOWING THE LINE OF CONES IN THE GREAT RIFT ZONE.

Symmetrical crater bowl in foreground.



B. VIEW LOOKING NORTHEAST FROM THE IDAHO CENTRAL HIGHWAY NEAR GRASSY CONE ACROSS THE DUNELIKE TOPOGRAPHY TO SUNSET CONE.

A. PERFECT CRATER BOWL IN THE SUMMIT OF A VERY SYMMETRICAL CONE AT THE NORTH END OF TWO POINT BUTTE.

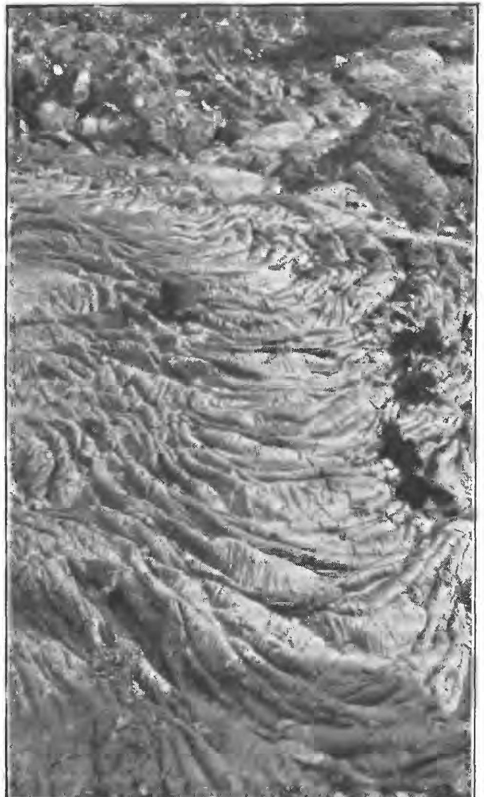
Fissure and Sheep Trail Buttes are in the background.

B. THE LINE OF SPATTER CONES ALONG CRYSTAL FISSURE.

The top of the small cone in the foreground is the entrance to Ice Cave. Big Cinder Butte is in the background.

A. VIEW OF NORTH CRATER AND THE LAST PAHOEHOE FLOW WHICH ISSUED FROM IT.
Cinder Crag in foreground.

B. VIEW OF MALAD SPRING COVE.



A. ROPY LAVA ON THE SURFACE OF THE NORTH CRATER PAHOEHOE FLOW.

B. AA LAVA FLOW AT THE HOODOO WATER HOLE NEAR ROUND KNOLL.

In 1926 two cones were found in the mountains near Martin that appeared to be on a northward extension of the Great Rift. Anderson [70] has since found that these vents, which are separated by a high ridge from the national monument, are in line with the cones in the Great Rift, although fractures do not occur in the intervening stretch. He finds that the Great Rift has the same trend as the strike of the Paleozoic formations and is parallel to the axis of an overturned fold and other tectonic lines of Tertiary age.[71]

In its subsurface structure the Great Rift Zone is believed to consist of an old land mass and subsequent lava flows penetrated by numerous parallel dikes 2 to 5 feet in width, which may have followed a preexisting zone of faulting. These dikes were the feeders of the flows. The estimate of the thickness of the dikes is based chiefly upon the width of the trenchlike fissures from which the lava was extruded and upon a comparison with the dikes that have produced similar fissure eruptions on basaltic volcanoes elsewhere.

There are 27 distinct cinder cones in the Great Rift Zone, and many remnants of older partly buried cones exist among them. The most prominent cone in the Great Rift Zone is Big Cinder Butte, a double cinder cone that rises about 800 feet above the adjacent lava flows. The other cinder cones range in height from 50 to 600 feet and 13 of them exceed 300 feet in height. Probably many of the lower ones are partly buried by lava of later date.

Most of the cinder cones are asymmetric, showing a pronounced elongation toward the northeast. This condition developed chiefly during the eruption, the prevailing southwest winds causing an accumulation of debris on the northeast side of the vent. The cones in the northern part of the area, near the spur of the mountains, show a more pronounced elongation than elsewhere, doubtless because they were exposed to stronger winds during their formation. The cinders are too heavy to drift before the wind as dunes, hence the asymmetry must have been largely original and not due to subsequent wind action.

During eruptions the lighter pumiceous material drifted several miles with the wind, as shown by thick deposits of lapilli at the foot of the mountains, 2 miles northeast of Sunset Cone. The only dunelike topography in the area occurs along the highway on the northeast side of Grassy Cone and is shown in plate 14, *B*. However, these mounds are not true dunes, for they lack the typical cross-bedding of dunes. An artificial cut exposes lapilli and cinders that are even-bedded, showing that they were dropped from the air during an eruption and not drifted into dunes by the wind. The bedding is curved parallel to the surfaces of the mounds, which are 10 to 20 feet high and 20 to 40 feet long. The presence of lava in the top of a few of the mounds

[70] Anderson, A. L., Lava Creek vents, Butte County, Idaho: Northwest Science, vol. 3, p. 17, 1929.

[71] Idem, p. 18.

indicates that some of them were formed by the deposition of cinders on a hummocky lava flow.

Practically all the cinder cones are surmounted by craters, many of which are breached on one side. In places craters are nested, the smaller ones having been formed inside of larger ones by closing eruptions of lesser intensity. Some of the cones have compound craters because of the slight shifting of the fire fountains or because several fountains were active simultaneously. Some of the craters have been deepened and enlarged by collapse after the subsidence of the lava column beneath the cones. The crater and crater rims that are discernible in the area are shown in plate 13. Many of the cinder cones were produced by fire fountains along a fissure, and their craters in places are linked together. Five linked craters occur in Big Craters Butte, and four in Sheep Trail Butte. Some fissures are marked by small but well-formed spatter cones, such as those shown in plate 15, *B*.

In a few places vertical ejections of cinders occurred when the wind was not blowing, so that perfectly rounded cones were formed, with very symmetrical bowl-shaped craters in their summits, as shown in plate 15, *A*. Grassy Cone, Big Cinder Butte, and Two Point Butte have such craters. On Sheep Trail Butte a round crater is encircled by narrow concentric rings of cinders that increase in height progressively outward. The eruptions at this vent were sufficiently violent to produce cinders, hence the rings, only a few feet apart, could not have been formed by successive explosions at the same vent, because cinders erupted in later explosions would tend to cover and conceal those erupted earlier. The fact that the rings decrease in height toward the center of the crater suggests that they were formed by periodic concentric collapse around the vent as the lava subsided. Such rings tend to show that the lava column supporting the cinders fell in successive steps.

The craters in the cinder cones range in diameter from a few feet to nearly half a mile and in depth from 10 feet to more than 200 feet. If the depth is measured from the highest part of the rim several craters exceed 300 feet. Deep craters occur in Grassy Cone, Sunset Cone, Paisley Cone, Big Crater Butte, Big Cinder Butte, Echo Crater Butte, Crescent Butte, Fissure Butte, Sheep Trail Butte, and Two Point Butte.

Although the lava flows of this area appear smooth from a distance, closer inspection shows them to be astonishingly rough and covered with jagged fragments of lava or transported crags of cinders from the source cones as shown in plate 16, *A*. In places there are smooth billowy patches which glisten in the sun, but elsewhere the lava forms a chaotic mass bristling with formidable points. Great areas of the lava are black and fresh-looking, and they stand in sharp contrast to the soil-covered lavas over which they have flowed. To the casual observer the great fields of black and nearly bare lava, especially in the northern part of the area, appear to be one great continuous lava flow. However, careful study shows that this great lava field consists of many flows discharged from numerous vents at many different times. Some of these flows have sufficient individual characteristics to differentiate them from adjacent flows. Others, however, either issued from different vents at the same time and merged as one flow or are so similar in appearance that they are inseparable. Within the area studied in detail 88 vents and 39 lava flows were distinguished. One, termed the "Serrate flow," is distinguished by the fact that it contains numerous inclusions of more or less gneissic coarse-grained hypersthene-quartz diorite, presumably carried up from the underlying basement rocks during eruption.

Few of the lava flows exceed 25 feet in thickness. Both aa and pahoehoe lava flows occur in about equal amounts. The contrast between these two kinds of flows is brought out in plate 17. A few pahoehoe flows are much thinner than 25 feet, and several aa flows are more than 50 feet thick. The average gradient during their flow was about 50 feet to the mile, to judge from the present topography. Lava tubes and cones are numerous in different parts of the area. Molds of trees are found in some of the flows.

Specimens of lava from this area, examined microscopically by Howel Williams, proved without exception to be olivine basalt abnormally rich in magnetite. The olivine probably contains much iron. In different specimens the feldspar in microliths and small phenocrysts ranges in composition from calcic andesine to sodic labradorite. The groundmass is glassy and is rendered opaque by magnetite. It rarely makes up less than 50 percent of the rock and commonly forms as much as 70 percent. In addition to the magnetite in the glassy groundmass somewhat larger crystals of this mineral are scattered through the rock. Dark volcanic glass (tachylyte) forms iridescent or blue skins on the pahoehoe flows and also occurs in thin beds in cinder crags.

The cavernous fissured surface of the lava is not conducive to the accumulation of soil. Aeolian dust and finer volcanic detritus and also the granular fragments of the crust do not accumulate on the surface but are blown into the crevices and sift downward toward the base of the flow, leaving the surface free from dust or soil. Occasional rains tend to wash the soil farther downward and into places unfavorable for seed germination. The semiarid climate of the area, coupled with the great permeability of the lava, is not favorable for plant reproduction, hence the flows have remained relatively bare and fresh for centuries. Nevertheless, close inspection shows more vegetation on them than would be expected at first sight. In contrast to the general lack of vegetation on the flows the parent cinder cones support numerous stout pines and aspens on their slopes, especially in the shaded spots, where the snow lies late in the spring and where there is some protection from the strong southwest winds.

The bare expanse of rock occasioned by these two factors gives the visitor an impression of even greater youth than is probably correct. Russell [72] supposed that the time since the last eruption was probably "no more than 100 or possibly 150 years" previous to his visit in 1901. He based this estimate in part on the small size (20 to 24 inches in diameter) of the trees growing on the cones. However, limber pines of this size should in this area be 250 to 300 years old. Fallen trees of this kind as much as 30 inches in diameter and in an advanced stage of decay are now lying on some of the cones. With due allowance for the long time required for vegetation to start on a newly formed cone in this semiarid region and also for the time required for such thorough decay, these trees indicate that even the youngest cones are probably over 400 years old. The comparatively freshly charred trees on some cones and on the borders of certain flows are thought by some to record very recent volcanic activity, but the larger trees growing at the margins of recent flows are charred only on the sides away from the lava, indicating that they were burned by fires in the brush on the nearby cinders.

A count of the growth rings of a tree felled in the SW¼SE¼ sec. 3, T. 1 N., R. 24 E., indicates that the fresh black lava which poured out of the side of the Big Craters and which lies southeast of Silent Cone issued prior to 1463 A. D. This tree grew in a crevice near the margin of the lava. Other trees, which were even larger than this one and which died probably a hundred years ago, lie rotting on the surface of this same flow, and hence the flow is more than 500 years old. The lava from the breached cinder cone called "North Crater" overlies this flow and hence must be younger. However, trees at least 250 years old lie rotting on the surface of the North Crater Cone. It is known that this cone has given vent to more than one lava flow and that each flow was separated from the preceding one by a considerable interval of time. If the last pahoehoe flow issued quietly and was not preceded by an ejection of cinders the vegetation on the cone may have survived the last eruption. Such an eruption could have occurred, for the last lava flow from North Crater is pahoehoe basalt, a type of lava that sometimes wells out quietly, unaccompanied by ejection of spatter or cinders. (See pl. 16, *A*.) The fresh-looking bombs that lie scattered over the surface of North Crater Butte appear to be younger than the main mass of the cone. If they are younger the vegetation on the cone would have been destroyed by the last eruption, and the last North Crater flow would therefore be more than 250 years old, to judge from the age of the trees on the cone. If

[72] Russell, I. C., op. cit. (Bull. 199), p. 105.

no ejection of cinders occurred the age of this flow remains unsolved, for in that event the vegetation on the cone is not an index to the age of this last eruption.

The only traces of organic remains in the rocks themselves are the molds of trees. Some encased standing trees and still rise several feet above the surface. Others are merely impressions of charred logs. In spite of careful search, no charcoal has been found in any of the tree molds. As charcoal in large tree molds of this character has been known to last fuliy 100 years under similar conditions, its absence here is evidence that the flows are not extremely young.

The effect on a compass needle of the magnetism of the basalt was studied as of possible aid in fixing the age and order of eruption of the flows. Chevalier [73] has shown that there is a tendency for the lines of magnetic force in a lava flow to be permanently oriented parallel to the lines of terrestrial magnetic force existing at that locality when the flow consolidated. By laboratory studies, aided by the long historic record at Mount Etna, in Sicily, he was able to show accord between the magnetic fields set up by the flows and the magnetic declination at the date of their eruption. Data regarding variations in magnetic declination in that region are on record since about 1560. Extrapolation of the curve of variation for 4 centuries prior to the earliest records on the basis of the data obtained from the lava yields a logical continuation of the known curve.

Records both of historic events and of the secular change in the magnetic declination for the region containing the Craters of the Moon are short and incomplete as compared to those of Sicily. For this reason and because of the impracticability of devoting much time to this phase of the investigation, the data obtained are scanty. At 14 points in the area determinations were made of the angle between the reading of a compass set on a flat pahoehoe surface and true north as determined from the topographic map. This procedure gives an approximation to the magnetic declination brought about by the flow tested. The readings obtained vary from due north to N. 44° E. The mean magnetic declination for the locality in 1926, when the observations were made, was 19°45′, and the annual change at that time was a decrease of about 1′. As was to be expected there was close correspondence in readings taken at different points on the same flow. The similarity in readings strengthens the concept obtained from other observations that a flow from the spatter cones in which Crystal Pit is located was erupted at the same time as flows from the southeast and southwest sides of the Big Craters. Unfortunately with the present scanty knowledge regarding variations in declination the observations yield no clue as to the exact age of the flows.

[73] Chevalier, Raymond, L'aimantation des laves de l'Etna et l'orientation du champ terrestre en Sicile du XVIII^e siècle: Annales de physique, sér. 10, vol. 4, pp. 5–162, 1925.

Consideration of the different lines of evidence outlined above leads to the conclusion that the last volcanic eruption probably occurred more than 250 years ago but perhaps not more than 1,000 years ago. In any event, it seems clear that the flows of this area and the similar lava in the four other areas listed above are so young, in a geologic sense, that most of them must be regarded as of Recent age. It is possible, however, that these eruptions began in Pleistocene time.

The other areas of Recent lava mapped on plate 4 have characteristics broadly similar to those of the Craters of the Moon, just described, except that cones are less abundant. The flows of the Shoshone field disturbed the Big Wood and Little Wood Rivers, which apparently once joined between Shoshone and Richfield. A recent pahoehoe flow from a cone north of the site of Richfield completely filled this channel and spread out for a mile on each side as far as Gooding, causing the two streams to establish new courses on its flanks. This is apparently the explanation of the fact that the two streams now flow for about 25 miles in roughly parallel courses, which in few places are more than 2 miles apart.

WATER IN THE RECENT BASALT

All the persistent pools of water in the caves and at and near the surface within the areas of Recent lava are perched upon impermeable bodies of ice. Small pools of water collect here and there in depressions on broad cakes of pahoehoe, but these pools do not last throughout the summer unless they are fed from a body of ice nearby. The fresh chaotic aa, the fissured, cavernous pahoehoe, and the loose angular cinders together form one of the most permeable formations to be found anywhere. They constitute a great sieve, for all of the precipitation except that lost by evaporation and transpiration sinks into them. Wells near the Craters of the Moon have shown that ground water is to be expected here only at depths in excess of 1,000 feet. The principal accumulations of water perched on ice are in the lava tubes, some of which form caves of considerable size. Water of essentially similar source occurs also in cracks and depressions in the lava and in craters.

Water occurs during part of the year in practically all the main lava tubes, but in dry years few retain any as late as September. When plentiful, the ice occurs as low heaps or small sheets, usually at the rear of the tubes. The water is found in small pools on the ice or in depressions in the adjacent blocks of lava. During the spring and frequently until late in the summer, large clear blue icicles hang from the roofs of the caves. The slow thawing of these icicles furnishes much of the water found during the summer. Snow accumulated during the winter melts in the spring, and water trickles through crevices in the cave roofs. Because the air in the interior is not exposed to the direct rays of the sun its temperature remains below freezing, especially at night, long after the snow on the surface above has disappeared. Hence, during most of the spring the water that percolates through the roof freezes as it encounters the cold air of the cave, forming icicles. Even when the caves are warmed to the melting point during the day, water trickling down the icicles in the daytime is cooled nearly to the freezing point, so that if it drips on the floor it may be frozen by the slight but critical drop of the temperature during the night. The ice thus formed tends to seal fissures in the floors of the caves, retarding escape by leakage downward. In this way the accumulation of the ice continues, and because freezing temperatures occur during 7 months of the year, considerable ice is stored before the air temperature rises too high. As late as September 27, 1926, with the temperature in the shade on the surface about 75° F., the air temperature in Surprise Cave in the Craters of the Moon (pl. 13) was only 40° F. The temperature in the other main caves was within 1° or 2° of this figure. During July and August the icicles melt and add considerably to the pool on the floor. Any surplus water that does not remain perched on the ice percolates to the main water table. Here and there a block of basalt on the floor is sufficiently impermeable to perch a few gallons in depressions upon its surface. The amount of ice stored in the caves in any given year is not so much dependent upon the depth of the snowfall as upon the rate of melting. Thus a heavy snowfall if dissipated within a few days, might percolate rapidly, and much of the water would be lost through the crevices in the floor before it could be frozen. In years when conditions are favorable, large masses of ice generally remain in the caves throughout the year. In Shoshone Ice Cave, near Shoshone, the ice has accumulated to such an extent that it completely fills a portion of the cave from floor to ceiling.

In addition to the lava tubes there are many localities in the areas of Recent basalt where the conditions outlined above exist. In favorably situated and shaped fissures, craters, and caves, formed by spatter cones or otherwise, there are open spaces sufficiently protected from the sun so that water from melting snow is refrozen and later more or less thoroughly protected from remelting. Some of these spaces are so situated that snow sifts or is blown into them during the winter. Several perennial water holes occur in depressions in the roughest aa. They too must be perched on ice and supplied by melting ice in the interstices between the adjacent and underlying blocks, because of the low temperature of the water and because the rocks in which they occur are loose, shattered, and permeable, excluding any other possible origin.

A conservative estimate, based upon observation, places the yield of one water hole in the Craters of the Moon National Monument during 1926 at about 5,000 gallons. The visible storge at no time during the year exceeded 50 gallons, hence it is apparent that considerable underground storage must have existed. The temperature of the water in this water hole during September and October 1926 never exceeded 34° F., and during part of the time the pool was covered with ice. The water hole is in a depression in the aa lava of the Paisley Cone. The surface of the water was exposed to the sun most of the time, but evaporation is probably low because of the temperature of the water. Greenish-brown algae lived in the water. The presence of ice filling the interstices of the cinders in the adjacent North Crater Butte was demonstrated by S. A. Paisley, who unearthed ice 2 feet below the surface in the cinders on July 14, 1926. The cinders are so loose that they serve as an insulator, like sawdust in an icehouse. The yield of this water hole compares favorably with that of many springs, hence it might be considered an ice-perched spring. It is certainly an unusual type of spring to be found in a semiarid desert. The following year this water hole went dry overnight. The basement of ice apparently melted from the interstices below, presumably because of overdraft.

WIND-BLOWN DEPOSITS

A light cream colored to buff loess covers most of the lava and older alluvium of the Snake River Plain. It is unconsolidated and obviously of recent origin but differs little from the more thoroughly compacted loess intercalated with the Pleistocene flows. Locally it contains limy hardpan layers resulting from the leaching action of percolating water. Similar leaching and subsequent evaporation produce the white caliche coating on most of the lower surfaces of lava fragments lying on the soil in the desert.

The wind derives the material mainly from the fine-grained and poorly indurated sedimentary deposits of Pliocene and later age and in part from accumulations of ash and decomposed pumice. The process of spreading and rearranging this material is still going on. In a few places, such as the vicinity of Mud Lake, the quantity moved by the wind is so great that sand dunes as much as 200 feet high have been formed.

Wind-blown sand where present within the zone of saturation in sufficient quantity will yield water to wells, but most of the larger masses are above the level of the water table. Where unconsolidated sand of this character is encountered between lava flows in drilling a well it may give trouble because of its tendency to cave and run into the well. Most of the loess between the older flows is somewhat compacted and so intermingled with clayey residual soil from the basalt as to be comparatively impermeable.

YOUNGER ALLUVIUM

The younger alluvium, not differentiated in mapping, forms the bars and beaches along the Snake River and floors the present channels of this stream and its tributaries. It usually comprises sand, silt, and clean water-worn gravel. It is in general reworked older alluvium and in many places consists to a large extent of cobbles of older silicic lavas and resistant rocks from the mountains bordering the plain.

At the foot of American Falls on the east side of the river, in a sand pocket in a spring pool, several skeletons of mammoths were removed about 1904, when an excavation was made for the first power house built on this bank. This sand is to be correlated with the younger alluvium. Charles Johnson, an employee of the Idaho Power Co., who saw the bones removed, states that the remains of seven animals were found. One tusk 15 feet long and 15 inches in diameter at the base was found here. Some of these bones collected by J. H. Burley, of Boise, are now in the State Capitol. About 500 pounds was shipped to the University of Iowa by W. H. Bernhardt. A few large bones from this pit are in J. F. Kosanke's office at American Falls and have the fresh appearance characteristic of those known to come from the younger alluvium. Mr. Kosanke donated one tooth to the Smithsonian Institution, and it was identified by Dr. Gidley as belonging to *Elephas columbi*.

Hay [74] described remains of *Elephas columbi* reported by W. H. Bernhardt as coming from beneath 50 feet of lava during the excavation of the American Falls power plant. The writer believes, after careful inquiry at American Falls, that these bones are part of the collection above referred to and did not come from under the lava.

Hay reports remains of *Elephas imperator* from the NW¼ sec. 10, T. 10 S., R. 18 E., near Twin Falls. From the meager data sent in with the bones he concluded that they had been found beneath 700 feet of lava. According to C. N. Beatty,[75] who found the bones, they were unearthed in sand near the high-water mark of the Snake River at the foot of the canyon wall. These bones are consequently of the same age as those from the foot of American Falls just described and from the adjacent Syster mine, referred to below.

In the reentrant in the NW¼ sec. 4, T. 10 S., R. 18 E., near the foot of Twin Falls, as shown in plate 3, is an old quicksand deposit that served as a death trap for animals in the past. W. O. Syster, of Twin Falls, who mines this sand extensively as a placer, has found many bones of prehistoric animals embedded in it. The bone-bearing material at and near this spot is slightly compacted sand, in part of eolian and in part of fluviatile origin. The bones are not water-worn and most of them appeared to be part of one skeleton. Mr. Syster saved only the larger bones and teeth for exhibition. He has now in his possession several hundred pounds of teeth, leg, and thigh bones of elephants. One tooth sent to the Smithsonian Institution for identification was too much worn to determine the species with cer-

[74] Hay, O. P., op. cit., p. 39.
[75] Personal letter to H. T. Stearns.

tainty, but it seems to be that of *Elephas imperator*. He also found a considerable part of *Mammut americanum* [76], and Stearns found the skull of an extinct bison in the same deposit.

The bones as a whole are very recent looking and in color and age closely resemble those found at the power plant at American Falls. The question arises as to how much time has elapsed since these animals disappeared from Idaho. The writer believes that because of the freshness of the bones, their stratigraphic position, and comparison with other recent discoveries in the western United States, they may have lived until rather recently.

LANDSLIDES AND TALUS

The talus and landslides have not been differentiated from each other on plates 5 and 6 because the landslides cover such a relatively small area. They are common in favorable situations throughout the region. Talus aprons cover many significant contacts and commonly conceal the geology of the outlet of the large springs along the canyon of the Snake River. In many places sand blown from the adjacent river bed hides the talus from view.

The most noteworthy landslides are associated with the Hagerman lake beds. There is a large comparatively old one, however, in sec. 7, T. 6 S., R. 13 E., exposed in the road cuts along the Bliss Grade. This has not been shown in plate 5, because to do so would obscure the relations of the underlying rocks. In one place along the Bliss Grade there is a fault that displaces the beds 6.5 feet. Numerous strike and dip observations in the vicinity of this fault show that large blocks of compact bedded clay have slid down the valley slope comparatively intact. A thin bed of tuff is interstratified with the Hagerman lake beds near the top of the Bliss Grade. The saturation of this bed and the underlying clays with water, and the subsequent sliding of the tuff on the slippery clay may have caused the slide. A similar slide, likewise not mapped, was caused by the same tuff and lava on the opposite bank, in the NW¼ sec. 18, T. 6 S., R. 13 E.

In the SE¼ SW¼ sec. 7, T. 6 S., R. 13 E., there is a landslide that involves the alluvium and underlying older formations; it is shown in plate 5. For about half a mile upstream there are incipient landslides, and the house shown on the map near this slide had to be moved away from the rim because it was in danger of sliding into the canyon. These landslides are recent and result from the saturation of the slippery clay beds by irrigation.

Another slide covering nearly half a square mile in secs. 20, 21, 28, and 29, T. 6 S., R. 13 E., is shown in plate 5. Like those near Bliss it originated from the interstratified tuff member of the Hagerman lake beds slipping on the underlying clay. Still another slide of

[76] Hay, O. P., op. cit., p. 21.

similar origin in sec. 18, T. 8 S., R. 14 E., near the mouth of Salmon Falls Creek, is shown in plate 5. Apparently the large slide near Buhl on the bank of this creek which occurred in 1937 was caused by basalt sliding on saturated clay.

STRUCTURE

The Snake River Plain is a depression occasioned, to some degree perhaps, by isostatic adjustment resulting from its long-continued filling by lava and sediments and the denudation of the adjacent mountains by erosion. The extrusion of such large quantities of lava from vents within the plain, so far as such a process produces withdrawal of support to the crust, may have partly caused the depression. Many geologists are agreed that the depression now filled by the Snake River basalt is a product of flexure or warping,[77] although the exact causes that led to the development of this great structural feature remain in doubt. Except that wells show a thickness of at least 1,000 feet of basalt, there is no direct evidence within the region here considered as to the depth of the depression. Near the western border of Idaho there is some evidence, according to Kirkham,[78] suggesting that the surface on which the Columbia River basalt rests may be as low as 20,000 feet below sea level in the middle of the depressed area. At Ontario, Oreg., a well has been drilled to a point 2,300 feet below sea level and, according to Kirkham's interpretation, is still in the Idaho formation.

The Tertiary beds on the borders of the plain commonly dip at low angles toward its axis. Within the region studied no other folds and only locally minor faults were observed. If folds exist, they are apparently everywhere concealed beneath the cover of comparatively recent flows. Kirkham [79] records folding in Columbia River basalt and the Payette and Idaho formations in the extreme western part of the Snake River Plain.

The depression of this great area was accompanied by some faulting. As shown in the following descriptions, most of the known faults are in the pre-Pleistocene beds, and there is evidence of several periods of such deformation. The plain trends transverse to the major structure in the intensely deformed pre-Tertiary rocks in the neighboring mountains, but here and there along the margins the lava or associated sediments seem to be faulted down against the old rocks in such fashion as to suggest that fractures may have played a part in outlining the depression. For example, the Neeley lake beds in secs. 28 and 29, T. 9 S., R. 29 E., have so straight a contact with Paleozoic limestone as to suggest faulting, a hypothesis which is sup-

[77] Kirkham, V. R. D., Snake River downwarp: Jour. Geology, vol. 39, no. 5, pp. 456–482, 1931.

[78] Idem, pp. 477–479.

[79] Kirkham, V. R. D., Revision of the Payette and Idaho formations: Jour. Geology, vol. 39, no. 3, pp. 201–213, 1931.

ported by the warm springs that issue from the base of the limestone scarps. To the north of the plain, especially west of the region here considered, the mountain front is so steep as to suggest faulting,[80] but supporting evidence of this hypothesis is lacking.

Ample evidence of the relative uplift of mountains of southern Idaho in relation to the Snake River Valley in post-Miocene time is visible everywhere on the north, east, and south sides of the valley. Mansfield [81] has found evidence of regional uplift at the end of the Miocene and a similar uplift of 1,000 to 1,500 feet at the end of the Pliocene, for the entire mountainous region of southeastern Idaho.

Some of the rhyolitic rocks on the borders of the plain and the Challis volcanics have been flexed and broken by faults, a few of them of large throw.[82] Although, as already noted, these beds on the margins of the plain tend to dip toward it, this dip may be largely acquired from the topography on which these volcanics accumulated. The major faults and flexures in them within the mountains, as recorded in the papers above cited, lie for the most part at considerable angles to the axis of the plain. Evidence suggestive of faulting in them has been observed in the present studies. In the Malta Range, west of the Raft River Valley, which is composed mainly of Miocene(?) rhyolitic rocks, there are local transverse faults, revealed by the displacement of a conspicuous bed of white ash. It is thought that movement along faults of this kind, subsequent to the development of the northward-trending major valleys, deflected the Raft River and Cassia Creek across the Malta Range to unite with Clear Creek. The range as a whole is thought to be a rotated block terminated on the east by a major fault. It may be that the range to the east, which has not yet been closely studied, is a similar block with the fault on its west side, which implies that the intervening Raft River Valley is a graben. The lake beds in this valley appear to terminate abruptly against either the rhyolitic rocks of the Malta Range or older rocks immediately underlying them. Probably they were laid down in the depression formed by the supposed graben. Their great thickness suggests that subsidence continued during their deposition. The Rockland and Bannock Creek Valleys, farther east, are thought to be similarly bounded by normal faults.[83] On the north side of the plain,

[80] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Boise folio (no. 45), 1898. Russell, I. C., op. cit. (Bull. 199), p. 48.

[81] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper, 152 pp. 202-203, 1927.

[82] Umpleby, J. B., Westgate, L. G., and Ross, C. P., Geology and ore deposits of the Wood River region, Idaho: U. S. Geol. Survey Bull. 814, pp. 66-73, 1930. Anderson, A. L., Geology and ore deposits of the Lava Creek district, Idaho: Idaho Bur. Mines and Geology Pamph. 32, pp. 26-27, 1927. Geology and mineral resources of eastern Cassia County, Idaho: Idaho Bur. Mines and Geology Bull. 14, pp. 80-88, 1931. Ross, C. P., Geology and ore deposits of the Casto quadrangle, Idaho: U. S. Geol. Survey Bull. 854, pp. 77-80, 1935.

[83] Piper, A. M., Possibility of petroleum in Power and Oneida Counties, Idaho: Idaho Bur. Mines and Geology Pamph. 12, pp. 6-12, 1924.

especially in the valleys of the Big Lost and Little Lost Rivers, the abrupt and fairly straight mountain fronts are suggestive of faulting.

The Pliocene (?) rocks exposed in the canyon of the Snake River are broken by numerous faults, of which the largest and best exposed are shown in plate 6. Wherever these beds are exposed between Rock Creek and American Falls they are broken into small blocks. The displacement of the faults in this stretch is generally less than 50 feet, although in a few places it is as much as 100 feet. They have two general trends, one northwest, the other northeast.[84] The faults break the Neeley lake beds, the Eagle Rock tuff, and the Massacre volcanics but do not disturb any of the later deposits lying on these beds. The multiplicity of small blocks apparently resulted from the brittleness of the volcanic rocks involved, especially the obsidian tuff bed in the Eagle Rock tuff. The fact that the epoch of faulting followed the formation of the Massacre Rocks cone suggests that the deformation may have been due to collapse after the period of cone building and thus the faulting may resemble that around great calderas of subsidence. However, the Pliocene (?) beds as a whole appear to be down-faulted and down-warped toward the northwest, a condition that suggests regional disturbance rather than simple collapse around a volcanic center.

The Raft lake beds along the south shore of Lake Walcott are not, so far as known, disturbed by faulting such as characterized the deformation of the Neeley lake beds. Both these formations, with their constant dip toward the Snake River Plain, were clearly involved in the regional depression.

The Hagerman lake beds as a whole are remarkably horizontal, and dips of more than 3° are found only where landslides have disturbed large blocks of clay beds. The small dips of 3° or less show that the Snake River Plain has been depressed slightly since the beds were laid down, but to a much less degree than is indicated by the dips in the older formations.

An area of complex faulting occurs near the mouth of Salmon Falls Creek near Riverside Ferry Cone. Beds of diatomite believed to have been originally continuous with some that crop out in the bench near Buhl appear to have been dropped 250 feet and brought in juxtaposition with the tuff of the cone. The fault on the south side of this downdropped block can be traced northwestward through the sediments from the point where Salmon Falls Creek leaves its canyon. On the east bank of Snake River in sec. 28, T. 8 S., R. 14 E., two east-west faults with 30-foot throws bound a small upthrown block. Two basalt flows with a clay bed between are exposed in this block and a spring yielding about 12 cubic feet per second issues from the north

[84] The trend of these faults on plate 6 is probably not exact because they were originally mapped on a poor base and were adjusted in 1937 to fit the new survey of the Snake River.

fault. The bottom of the lower basalt is not exposed. Other fault blocks occur on the west bank but the details were not worked out.

Another fault displacing the Banbury volcanics may exist near the mouth of Deep Creek, in sec. 10, T. 9 S., R. 14 E., but time was not available to investigate it. The slight occurrence of faulting in the Hagerman lake beds and the definite collapse structure at Riverside Ferry Cone suggest that the engulfment occurred over a volcanic reservoir, a process similar to that which causes a caldera of subsidence, though a more concentric pattern of collapse might have been expected. It is probably more than a coincidence that the two areas of faulting in the Hagerman and underlying formations are associated closely with large explosive volcanic cones. Possibly considerable support for the crust at these localities was removed during the eruptions.

The Pleistocene basalt on the plain is remarkably free from faults. Parallel lines of cracks en échelon, with displacements of 5 feet or less, are the only faults observed. They trend N. 45° W. (magnetic) and extend for several miles northwest and southeast across T. 4 S., R. 27 E. In places they gape several feet, and that they have served as death traps for animals during centuries is shown by the abundant bones of buffalo and other animals at a depth of 30 to 40 feet. Toward the northwest the cracks disappear beneath later flows. This type of cracking commonly accompanies volcanic eruptions in Hawaii, and that it occurs so rarely in Idaho is surprising. Cracks of this type, however, are common in the Craters of the Moon area and in Soda Springs Valley. In those areas, such as the Mud Lake region, where the Pleistocene flows have been studied in detail, it appears that many were erupted from fissures that may be the surface expression of buried faults.

The Recent lava of the Craters of the Moon was erupted along a zone of fracture. Several faults parallel to this zone as well as some with other trends have been recognized (pl. 13). In addition to those mentioned below, minor faults and cracks associated with the eruptions are plentiful.

The highway from the national monument to Carey for a distance of a little over a mile northeast of the southwest corner of sec. 34, T. 2 N., R. 24 E., lies at the edge of a vertical cliff 25 to 50 feet high, facing toward the south (pl. 13), which was formed by normal faulting prior to the extrusion of the last North Crater lava flow and the northwest flow from the Big Craters. The fault cuts off the southeast part of the Highway flow and isolates a small sliver of a still older lava on the southeast side of Grassy Cone. Blocks that fell from the escarpment have been transported 20 to 50 feet by the later flows. In the SE¼NE¼ sec. 35, T. 2 N., R. 24 E., one end of the fault displaces and breaks asunder an old cinder cone and disappears under later lavas from North Crater. The other or southwest end dies out in the cinders on the south side of Grassy Cone.

A similar and parallel fault scarp, facing northward, bounds the north side of North Crater. It is in the S½ sec. 35, T. 2 N., R. 24 E., and is about half a mile long. It displaces the north side of Big Crater Butte and is of the same age. These two escarpments bound a graben a little over a quarter of a mile wide and from 25 to 50 feet deep, now partly filled by later lava from North Crater.

On the north and east sides of Broken Top, in sec. 12, T. 1 N., R. 24 E., there are two escarpments 5 to 25 feet high that face toward the butte. The lava nearby is so tilted that faulting along the dipping basalt escarpments is suggested, although other explanations are possible.

Faulting has displaced vertically the entire northeast side of Fissure Butte, forming an eastward-facing escarpment a mile long traversing the cone in a northwest direction. (See pl. 13.) Parallel to it and an eighth of a mile to the east, at the foot of the same cone, is another eastward-facing escarpment, marked by a trench 20 to 30 feet deep. The total maximum displacement along these two faults is about 75 feet. Lava has issued along a part of the upper fault crack and obscures much of the original displacement.

GROUND-WATER LEVELS

METHOD OF INVESTIGATION

In the investigation of ground-water levels at least one well was recorded for each square mile in areas where wells were numerous, so as to have them evenly distributed. In outlying districts, especially in the desert part of the plain, where wells were few or where unusual ground-water conditions were anticipated, all wells where the depth to the water level could be ascertained by report or measurement were recorded. The records are published separately.[85]

FORM OF THE WATER TABLE

The water table is the upper surface of the zone of saturation, except where that surface is formed by an impermeable body.[86] Below this surface all the spaces not occupied by rock are filled with water. Thus, the part of a well that extends into the zone of saturation is filled with water, and the water surface in the well may be regarded as the water table at that point, provided the water is not under artesian pressure.

[85] Stearns, H. T., Crandall, L., and Steward, W. G., Records of wells on the Snake River Plain, southeastern Idaho: U. S. Geol. Survey Water-Supply Paper 775, 139 pp., 1936.

[86] Meinzer, O. E., Outline of ground-water hydrology: U. S. Geol. Survey Water-Supply Paper 494, p. 32, 1923.

In a few places the water table may be a level surface, but under most areas it has a gentle gradient. As Meinzer and Hare[87] have so aptly expressed it:

> A knowledge of the elevation and topography of the water table gives information in regard to the source, movement, and disposal of the underground water and in areas with little development gives a basis for forecasting the depth to water. It also gives a basis for future estimates of the effects of heavy pumping. A knowledge of the position of the water table relative to the land surface is important in its bearing on the cost of drilling and pumping, the quantity of underground water returned to the atmosphere, and the accumulation of alkali in the soil.

The form and altitude of the water table in most of the Snake River Plain and in the main tributary valleys of the Snake River is shown on plate 19 by 10-foot contours. In a few places, as on the North Side and South Side Twin Falls tracts, the water table is so steep that 50-foot contours were used, with the 10-foot contours indicated between them by short lines. As the culture on the base map used for plate 19 is slightly in error in some places, a few wells, in order to be shown on the correct side of a railroad, road, or stream, are plotted in the 40-acre tract adjacent to the one they are in and thus may differ slightly from their description published in Water-Supply Paper 775. However, so few wells are shown in each section that this should cause no difficulty in locating them.

The list of wells below supplements and corrects Water-Supply Paper 775.

Wells either not included in Water-Supply Paper 775 or incorrectly listed therein

NE¼ sec. 3, T. 3 N., R. 34 E., reported depth to water 650 feet; altitude about 5,150 feet.

SE¼SE¼ sec. 4, T. 5 N., R. 29 E., should read SW¼SE¼.

SE¼NE¼ sec. 36, T. 6 N., R. 32 E., Second Owsley, drilled 286 feet; reported depth to water about 230 feet; altitude about 4,795 feet.

SE¼NE¼ sec. 36, T. 6 N., R. 36 E., should read SE¼NE¼ sec. 36, T. 6 N., R. 33 E.

SW¼ sec. 33, T. 6 N., R. 38 E., should read SE¼ sec. 33.

SW¼SW¼ sec. 24, T. 7 N., R. 32 E., Robert Stubbs; drilled 232 feet, depth to water 224.1 feet, Nov. 13, 1929; altitude base of pump at surface 4,804.6 feet.

NE¼SW¼ sec. 4, T. 7 N., R. 36 E., should read NE¼SE¼.

NE¼NW¼ sec. 35, T. 7 N., R. 36 E., should read NE¼NW¼ sec. 33.

NW¼SE¼ sec. 18, T. 7 N., R. 37 E., should read NW¼SW¼.

NE¼NE¼ sec. 22, T. 7 N., R. 39 E., should read NE¼SE¼.

SW¼SW¼ sec. 3, T. 7 N., R. 41 E., should read SW¼NW¼.

NE¼SE¼ sec. 24, T. 8 N., R. 36 E., should read NE¼SE¼ sec. 24, T. 8 N., R. 35 E.

SE¼SE¼ sec. 28, T. 8 N., R. 36 E., depth to water July 22, 1921, was 14.07 feet.

NW¼NE¼ sec. 28, T. 8 N., R. 36 E.; A. I. Sugg; dug 22 feet; altitude of surface 4,811.6 feet; depth to water measurements are listed in Water-Supply Paper 775, p. 92, under SE¼SE¼ sec. 28, T. 8 N., R. 36 E.

[87] Meinzer, O. E., and Hare, R. F., Geology and water resources of Tularosa Basin, N. Mex.: U. S. Geol. Survey Water-Supply Paper 343, p. 103, 1915.

NE¼SE¼ sec. 33, T. 8 N., R. 36 E., should read NW¼SE¼.
NW¼NW¼ sec. 24, T. 11 N., R. 35 E., should read NW¼NW¼ sec. 27.
SW¼SW¼ sec. 11, T. 11 N., R. 39 E., Laird, drilled 572.8 feet, depth to water 509.6 feet Aug. 30, 1922; altitude by barometer 6,210 feet.
SE¼SE¼ sec. 36, T. 1 S., R. 25 E., should read SE¼SE¼ sec. 16, T. 2 S., R. 31 E.
NW¼NE sec. 16, T. 2 S., R. 28 E., Cox, drilled 777 feet, reported depth to water 740 feet, altitude about 5,000 feet.
SE¼NW¼ sec. 5, T. 8 S., R. 39 E., should read SE¼NE¼.

The most striking feature of the water table under the plain is the gentle gradient between Idaho Falls and Minidoka. Between these two points, about 90 miles apart, the gradient of the water table is less than 4½ feet to the mile, whereas east of Idaho Falls and west of Minidoka the average gradient is about 25 feet to the mile. Relatively flat impermeable rock that may be gently tilted lake-bed deposits probably underlies the part with the gentle gradient. However, the meager data gathered from deep wells indicate that much of the basement rock of the plain is probably composed of siliceous volcanics. In any event, the low gradient of the water table indicates that the prebasalt floor had a gentle gradient to the west and was probably in a mature geomorphic stage at the time of burial.

The contour lines show that a definite ground-water cascade exists between the mouth of Birch Creek and Idaho Falls, along a curved line passing through the south side of Mud Lake and the west side of Market Lake. Some large faults pass into the region of this cascade from the adjacent mountains and become buried by Pleistocene flows. Faults may cause this ground-water cascade by the downward displacement of the impermeable basement in this area, but it is more probably caused by the ending of clay beds or other perching formations. Also this is a recharge area, where streams from the mountains sink to the water table, the gradient of which is determined by the prebasalt floor of the ancestral Snake River Valley. Mud Lake and Market Lake are both perched bodies of water, and the gentle gradient of the water table between Egin Bench and these lakes, as well as its shallow depth, have been produced largely by irrigation on Egin Bench,[88] aided by the presence of fine-grained lake beds at slight depth, as shown by wells. From 1905 to 1932 the water table under the area adjacent to Mud Lake rose. In 1921 about 31,000 acres was submerged in the vicinity of Hamer, largely by discharge from newly formed springs fed to a considerable extent by irrigation water from Egin Bench, 20 miles away. In 1930 there was about 125 square miles in the Mud Lake region where ground water lay within 50 feet of the surface (pl. 18).

At the foot of the Beaverhead Mountains, between Shotgun Valley and Medicine Lodge Creek, there is a steep ground-water cascade,

[88] Stearns, H. T., Bryan, L. L., and Crandall, Lynn, Geology and water resources of the Mud Lake region, Idaho: U. S. Geol. Survey Water-Supply Paper 818 (in press).

where the streams leave the mountains and sink in the basalt that overlies the impermeable rocks of the mountain mass.

Near the confluence of Henrys Fork with the South Fork of the Snake River there are large springs that discharge into the river or into sloughs adjacent to it. Instead of being springs with restricted outlets, like those in the Fort Hall bottoms or in Hagerman Valley, these are really infiltration channels that collect the ground water through the area which they traverse. The ground-water contour lines indicate that these sloughs are fed primarily by seepage from the alluvial fan of the South Fork and from irrigation on the alluvial fan in the vicinity of Rexburg.

A few miles downstream from Roberts the water table passes beneath the Snake River with a steep gradient and does not again become tributary to it until the Fort Hall bottoms, near American Falls Reservoir, are reached. Losses in the river between Roberts and a point below Shelley, as well as seepage water from irrigation, move westward and reappear in the large springs in Hagerman Valley. The numerous springs that discharge into American Falls Reservoir derive their water from the Portneuf and Blackfoot Valleys, from irrigation on the east side of the Snake River, and from seepage losses from the river below Shelley. (See pp. 139–142.) The shape of the water table between Blackfoot and American Falls Reservoir, as shown by the contour lines on plate 19, illustrates clearly the source of these springs.

Irrigation on the Springfield-Aberdeen tract has caused the ground-water contour lines to be elongated to the south. This condition indicates that a ridge of saturated soil has been caused by the irrigation. The contours show that some of the water reaches American Falls Reservoir but that the rest moves northwestward into the desert. A small part of the ground water discharged from this tract finds its way southward from the end of the project into Davis and Rueger Springs, near American Falls. A larger part of the ground water moving westward from Aberdeen eventually turns southward and discharges into the Lake Channel country and into the upper part of Lake Walcott at Gifford Springs and the other springs nearby. Between Lake Channel, where these springs discharge, and Minidoka there is a turning point in the ground-water contours. Unfortunately in this area there are not enough wells to determine the ground-water contours definitely. Sufficient data exist, however, to show that ground water ceases to move toward the Snake River between the springs near the mouth of the Raft River and the Minidoka Dam, and that instead the ground water moves northward from the western part of Lake Walcott toward the desert and does not reappear until it reaches the large springs near the Hagerman Valley. It is reported that a well drilled near the Minidoka Dam prior to construction found the water table below the altitude of the surface of the Snake River.

Sufficient wells exist on the desert immediately north of the Minidoka project to establish definitely the position of the 4,100-foot water-table contour line. It is irregular in shape, indicating that the ground-water conditions here are dissimilar to those that occur upstream, where the contours are regular. Apparently there is a ground-water cascade at this place much like that which occurs in the vicinity of Roberts and Mud Lake. Steep hydraulic slopes of the water table or ground-water cascades in the Snake River Plain signify either steeply sloping impermeable basement rock beneath the basalt or rocks of low permeability. The cascading of water lost in Camas and Beaver Creeks where they leave the mountains and the cascade in the vicinity of Idaho Falls are apparently examples of the steeply sloping impermeable basement rock, and the cascades represented by the contour lines south of Mud Lake, west of Market Lake, and north of the Minidoka project result from rocks of low permeability.

The shape of the 4,100-foot contour line suggests a lava-filled valley north of Rupert into which the ground water cascades. At any rate, from this line westward there is a pronounced change in the gradient of the water table, indicating that there has been a change in the slope of the impermeable basement rock and the character and permeability of the rocks above it. The North Side Minidoka project is underlain by relatively impermeable clayey Burley lake beds, hence the water table under this project is perched. On the north and west sides of the project there is a steep ground-water cascade where the water seeping away from the tract descends to the main water table. From this tract downstream to the Thousand Springs power plant the Snake River is flowing in a geologically recent channel. Its previous channel was filled with the Sand Springs basalt, which is supposed to have issued from a cone between Hazelton and Paul. This last major disturbance of the position of the Snake River has greatly affected the ground-water conditions in this vicinity, because the Sand Springs basalt-filled canyon acts as a collecting channel and serves as a great underground drain.

In the area between Rupert and Eden very little is known regarding the shape of the water table, because there are few wells. Likewise there is an absence of data to the north, in the lava field between Kimama and Eden. West of Eden the water table has a uniformly steep gradient toward the springs in the Hagerman Valley. All the ground water collected in the desert portion upstream from this place must appear on the surface here, because the lavas end against impermeable lake beds of great thickness, and all the lava-filled channels of the ancestral Snake River are here cut through and drained.

The water table on the South Side Twin Falls tract has been greatly built up as a result of irrigation, hence the hydraulic gradient was much gentler previously. The postulated filled channels under the North Side Twin Falls tract are doubtless separated by low, comparatively impermeable divides. However, these buried canyons fail to show in the ground-water contours because the water table stands higher than the impermeable divides between the canyons, creating in place of narrow streamlets a great underground reservoir that overflows at openings here and there along the Snake River.

The form and altitude of the water table in the desert on the north side of the plain, along the foot of the mountains between Richfield and Arco, are unknown. A few wells have been drilled in this area, but all except one failed to obtain water, even though one of them was drilled to a depth of 1,700 feet. It is difficult to explain why wells are not more successful in this area. One well was drilled through the basalt into the underlying siliceous lava that forms the basement of the basalt-filled valley. The water in the one successful well occurred at a lower altitude than would be expected if the ground-water contour lines were projected theoretically into the area from the south side of the plain where they are known. This implies some sort of an underground impermeable divide. Well data along the Oregon Short Line branch from Blackfoot to Mackay show that a definite water table exists to a point as far northwest as Cerro Grande. Between this point and Arco, at the mouth of the Big Lost River Valley, data are lacking. Possibly the Twin Buttes and Big Southern Butte are the tops of a buried mountain range of relatively impermeable rock, which may continue for some distance on both sides of the buttes beneath the basalt, constituting the buried divide suggested. Such a range would also help to account for the peculiar hydrologic condition that exists at the mouth of the Big Lost River Valley and in Laidlow Park, south of the Craters of the Moon, where deep wells have been drilled and where one obtained water below the general level of the main water table, but it would not alone be adequate to account for the failure of the water from the streams to the north to build a water table behind it. It may be that the Big Lost River cut a gorge through the impermeable ridge and that all of the ground water is escaping through this buried gorge.

RELATION OF WATER TABLE TO LAND SURFACE

The water table under much of the Snake River Plain lies more than 400 feet below the surface. In general it is not less than 200 feet below the surface except in the vicinity of irrigated tracts, where it has been built up artificially by irrigation, as illustrated on plate 18 by the lines showing depth to water. In most of the main perennial stream valleys tributary to the Snake River the depth to water is less than 50 feet. It is, however, not uncommon to find the water table more than 200 feet below the surface where these streams debouch upon the plain. This condition is particularly well exemplified by Birch Creek and by the Big Lost and Little Lost Rivers. A few miles above the mouths of these streams the water table is very close to the surface, and along some of them numerous copious springs occur. There is no change in the topographic character of the valley floor where they issue, but investigation reveals the buried geologic structure to which they are due.

The water table lies close to the surface along the axes of the valleys except in the Big Lost River Valley, where a few sinks occur. These sinks are described on page 246.

The ground-water cascades at the mouths of these valleys are caused by the abrupt steepening of the impermeable rock floors that underlie the gravel upstream and the occurrence of permeable basalt that interfingers with the alluvium near the mouths, thus offering a ready escape for the underground water. As the basalt offers little resistance to the downward passage of the ground water at the mouths of these valleys, the water continues to travel along the impermeable basement rock into the bottom of the Snake River Plain.

At some of the headwaters of the tributary streams there are lava flows which because of their permeability and their thickness allow the water to sink to considerable depth. Just south of the Blackfoot Reservoir and in the vicinity of Alexander the depth to water is more than 100 feet, owing to the thick lava fills in these places.

In a few localities the depth to water under the Snake River Plain is 1,000 feet. It appears that the ground-water recharge in the great mass of permeable basalt, which has a probable thickness of more than 1,000 feet, is not adequate to build up a high water table. The percolating water from rainfall, the water lost from the Snake River and other streams, and the water percolating away from irrigated areas sinks rapidly through the lava until it reaches the impermeable basement rock, along which it travels toward the west until it is discharged through the great springs in the Hagerman Valley.

The largest area of shallow ground water is along the Snake River between the mouth of Henrys Fork, near Menan, and American Falls. This land is intensively cultivated, and large quantities of water are applied each year, which aid considerably in maintaining the shallow water table as is indicated by the shape of the lines showing depth to water on plate 18. On the north and west sides of the irrigated belt the lines showing depth to water lie parallel and close to one another, indicating a ground-water cascade toward the desert. In the vicinity of Idaho Falls the rocks are so permeable that all the water lost from the extensive irrigation and from the Snake River itself is not adequate to maintain a shallow water table. In the new city well at Idaho

Falls, close to the bank of the river, which was completed in 1930, the depth to water is more than 100 feet.

Prior to irrigation in the Snake River Plain the shallow-water areas must have been very small and limited to places where spring inflow to the Snake River occurred. Thus, shallow water would probably have been found only in the vicinity of the confluence of the South and Henrys Forks of the river near Lorenzo, in the Fort Hall Bottoms, at the upper end of the Lake Walcott Reservoir in the so-called "Lake Channel country", and in the Hagerman Valley, where the Thousand Springs discharge. In view of the great number of perennial tributaries to the Snake River and the large flow in this stream itself, the great depth to water under most of the plain is an impressive and large-scale illustration of the permeability of the basalt. Thus, even with the irrigation of 1,000,000 acres of land in this valley there is only 425,000 acres, or less than 5½ percent of the entire area of 7,886,000 acres, where the depth to water is less than 50 feet. In the principal valleys tributary to the Snake River the water table is within 50 feet of the surface under 180,000 acres, by far the largest part of which is underlain by gravel, sand, and clay.

RELATION OF WATER TABLE TO IRRIGATION

ALLUVIAL FAN OF SNAKE RIVER

In 1923 R. I. Meeker made a manuscript report to the Committee of Nine of the Snake River Water Users' Association dealing with losses, delivery, and return flow of the water of the Snake River on the alluvial fan between Heise and Henrys Fork. On plate 20 is shown the location of the river and canals and the wells measured. All data for this plate except the water-table contours for August and September 1928 were obtained from a map in the Meeker report.

The fan of the Snake River is composed of silt, sand, and gravel dropped by the river as it debouches upon the Snake River Plain. The depth to water is a little over 100 feet at the mouth of the canyon, near Heise, but decreases downstream to a point near the mouth of Henrys Fork, where the water table is practically at the surface and where great quantities of ground water are discharged into the river and sloughs. The river flows near the crest of the fan, but when it is in flood it breaks up into several distributaries. The sloughs are the abandoned distributaries. In 1929 the Engineer Corps of the United States Army made a survey of the fan to determine methods for flood prevention. At times there is danger that the river will find a new channel that would seriously upset the present irrigation system as well as endanger life and property.

Farming is practiced successfully over the entire fan, and this was one of the first tracts in the Snake River Plain to be placed under irrigation. Considerable fluctuation of the water table occurs annually as a result of recharge by irrigation, as much as 10 acre-feet to the acre being used to irrigate some of the gravelly land. Moreover, several hundred thousand acre-feet are lost annually by the Snake River in the 10-mile stretch between Heise and Lorenzo. The great ground-water recharge of the fan is shown by the average gain of about 341,000 acre-feet annually between Lorenzo and Shelley.

In plates 20 and 21 a map and three longitudinal sections and four cross sections are given to illustrate the fluctuations of the water table and its relation to the river and fan. The ground-water contours in this plate are characteristic of a water table in an alluvial fan crossed by a large stream. The cross sections indicate that the river flows on the crest of an asymmetric ground-water ridge. The low water table on the south side of the sections is in part caused by the rapid movement of ground water through the thick permeable material on this side on its way to the undergound cascade near Idaho Falls, shown in plate 19.

In general the water table stood higher in August 1928 than in August 1923, but fluctuations of this sort result from seasonal variations in the flood run-off and in the starting of the irrigation season. No data are available regarding the water table prior to irrigation, but its position during the last decade indicates that it has reached approximately an equilibrium.

ABERDEEN-SPRINGFIELD TRACT

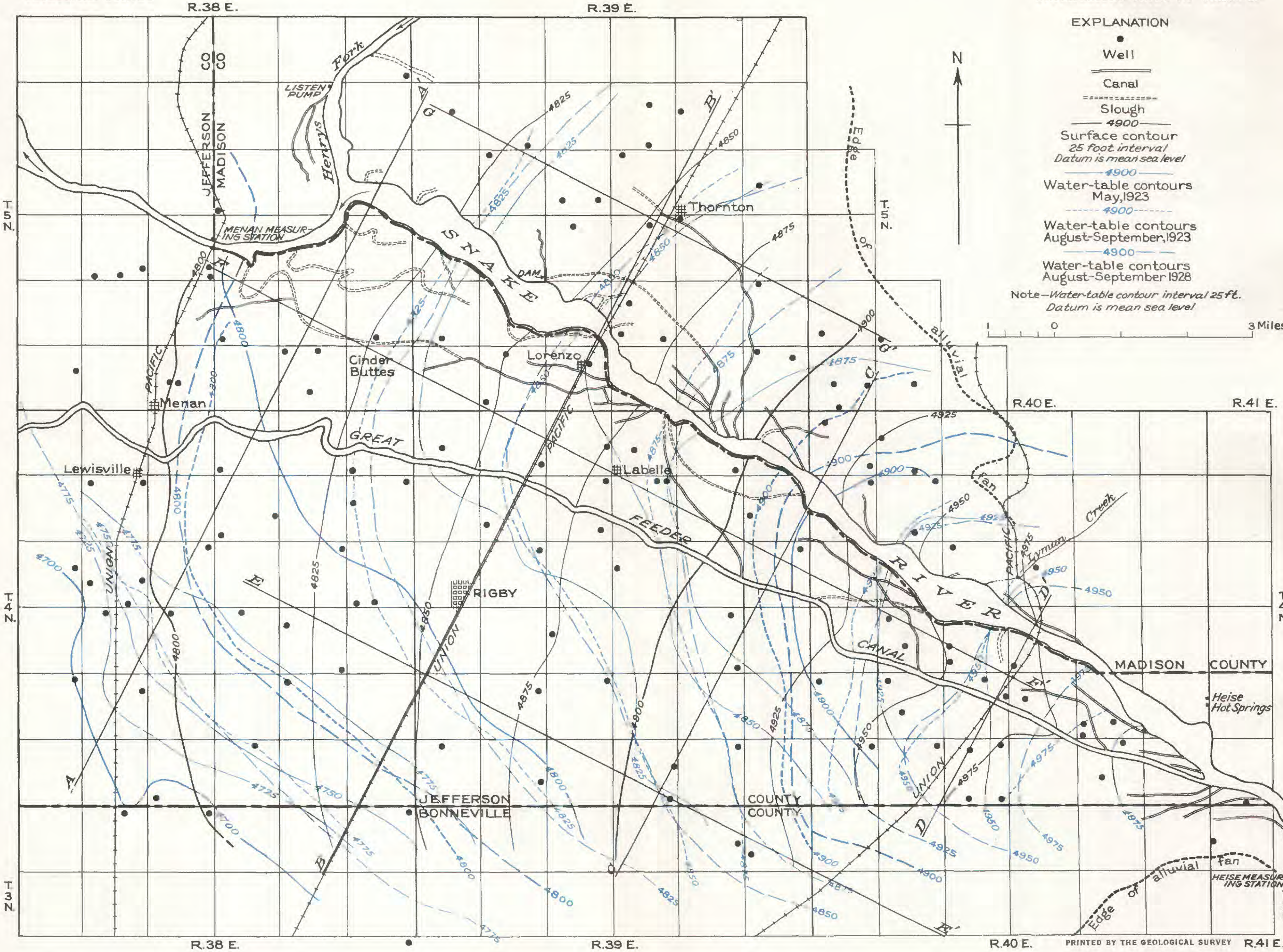
The form of the water·table under the Aberdeen-Springfield tract during or prior to the early years of irrigation is practically unknown and can be based only on meager reports or deduced from water-table conditions now existing in the desert areas bordering the project. During the construction of the Aberdeen-Springfield canal, in 1907, a well was dug by Mr. Shaw in sec. 7, T. 4 S., R. 32 E., in which water was first encountered at 20 feet and a permanent supply was found at 25 feet.

The earliest data regarding ground water on this project were gathered by the United States Bureau of Reclamation in 1919 and 1920, and two ground-water maps were prepared on the basis of the records made at that time. During 1922 and 1923 about 70 wells were recorded in this tract. As only one or two of the original wells located in 1919 and 1920 have been measured monthly since 1922 it is difficult to ascertain the detailed changes in ground-water conditions.

The water table under the Aberdeen-Springfield project forms a part of the large ground-water basin that now surrounds the American Falls Reservoir. Its slope ranges from 10 feet to the mile in the vicinity of Aberdeen to 40 feet to the mile in the part of the area near Sterling. (See pl. 19.) The geologic structure in the Aberdeen-Springfield project plays an important part in the movement and disposal of ground water. The rocks consist essentially of stratified sand, silt, and clay of the American Falls lake beds, with a layer of intercalated basalt that has been here and there exposed by subsequent erosion. On the north and east sides of the area the lake beds are in part covered by later basalt. The intercalated basalt is the chief aquifer of the area, and from it the numerous large springs issue. As this aquifer is either at or above the present shore line of the American Falls Reservoir, the movement and hydraulic gradient of ground water in it have not been affected by the storage of water in the reservoir. Prior to inundation the sedimentary rocks below this basalt cropped out along the Snake River in the side of the terrace that now forms the bank of the reservoir. It is well established that no appreciable quantity of water drained from these rocks into the river, and it is known that they had a fine texture. Consequently, the immersion of these rocks in the reservoir has not disturbed the equilibrium of ground water beneath the Aberdeen-Springfield project except perhaps locally, where percolation from irrigated lands along the shore has been slightly arrested. If the American Falls Dam had been built high enough to drown the springs issuing from the intercalated basalt, considerable land on the project might have become seeped. It is evident, however, that under present conditions the seeped areas on the project have resulted from irrigation and not from the construction of the American Falls Reservoir. Records showing the depth to water indicate that the only deleterious effect of the reservoir has been to raise the water table under the inhabited part of the old town of American Falls, on the opposite side of the reservoir from the Aberdeen-Springfield project.

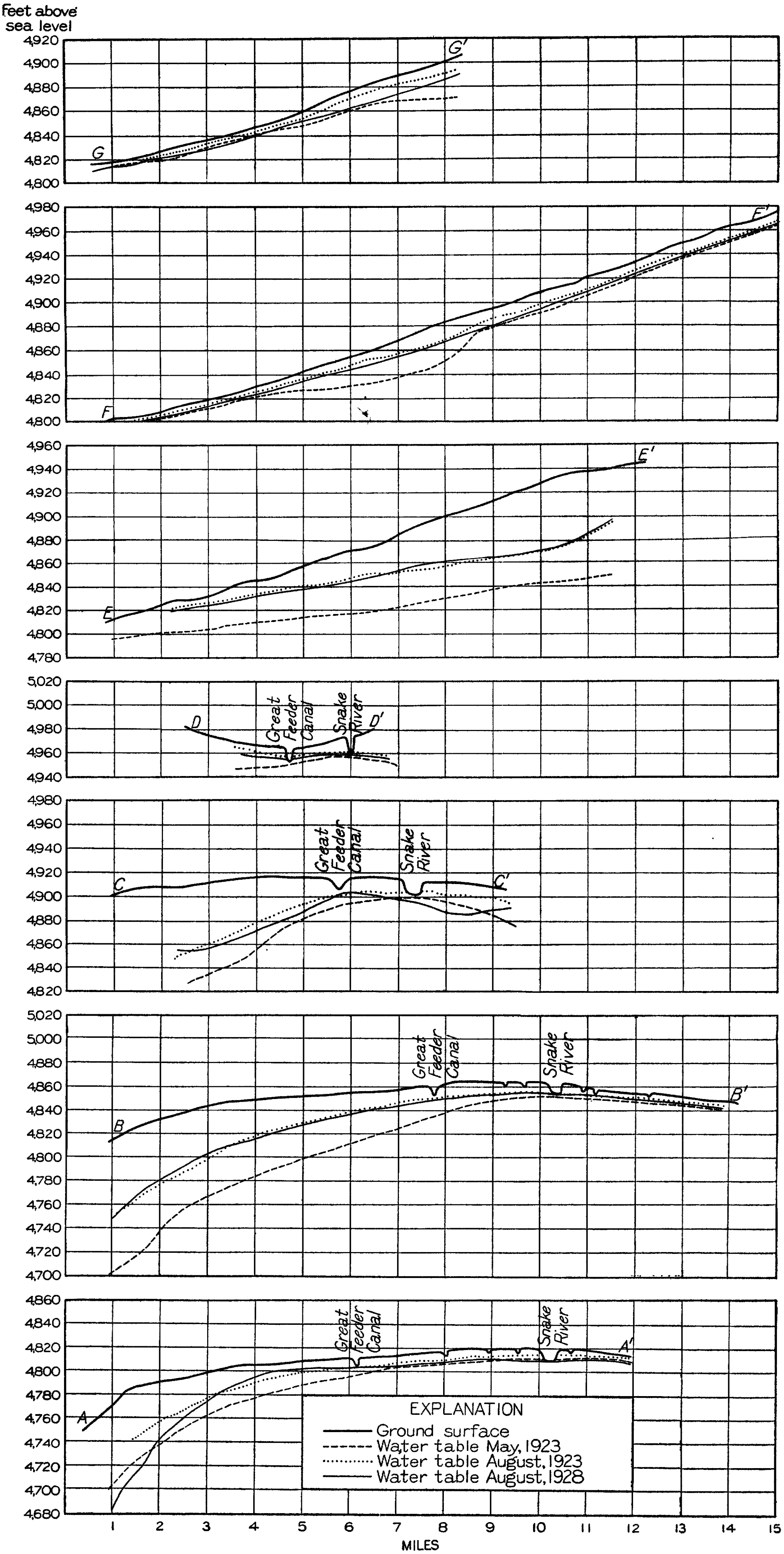
A comparison of the water-table contours for 1919 with those for 1927 shows very little change in the general shape of the water table throughout most of the area. A noticeable decrease in the depth to water has occurred northeast of Sterling. As the springs near Sterling discharge above the flow line of the reservoir, this change must have resulted from irrigation on higher lands. The contours for 1919, prior to the construction of the American Falls Reservoir, indicate a rather steep gradient of the water table north and west of the reservoir site, between Aberdeen and a point 4 miles north of the present dam. The gradient of this part of the water table has not been changed by the filling of the reservoir. Examination and comparison of measurements of depth to water made in 1920, 1923, 1926, 1927, and 1928 show that there has been little or no change in the water table east of Springfield and in the vicinity of Pingree.

An appreciable fluctuation of the water table occurs from year to year, but this fluctuation is probably due entirely to irrigation, as is indicated by the following table:



MAP OF SNAKE RIVER ALLUVIAL FAN SHOWING GROUND-WATER CONDITIONS

1938



SECTIONS OF SNAKE RIVER ALLUVIAL FAN SHOWING GROUND-WATER CONDITIONS.

Water used on the Aberdeen-Springfield tract and depth to water levels in 12 representative wells

Year	Water diverted for irrigation (acre-feet)	Average depth to water (feet)
1923	236,000	23.3
1926	166,000	24.5
1927	243,000	20.5
1928	288,000	19.7

The monthly well measurements in 1923 and 1926 show the annual fluctuation of the water table to be about 3.5 feet. The water table is lowest during April or May and reaches its highest level in September or October.

A large area in the vicinity of Sterling is affected by seepage, which has steadily increased since the beginning of irrigation. It is reported that the water table in this vicinity, even in the early stages of irrigation, was only about 8 to 20 feet below the surface. Moreover, several large springs issued here prior to irrigation—namely, Danielson, Crystal, Tanner, Hull, and Artesian Springs. These springs emerge at a considerable distance from the present reservoir flow line and at a higher altitude, and they reflect the shallow depth to water in this area. The ground-water contours show that a short distance northwest of Sterling the water table is sloping toward the southeast. Irrigation of the land has added large quantities of water to the zone of saturation and has thereby raised the water table.

In most parts of the Aberdeen-Springfield area there has not been any great rise in the water table. In the area east of Springfield and in the vicinity of Pingree the rise has been only slight. In the vicinity of Aberdeen the water table has risen about 5 feet since 1919, but in a small area in the vicinity of Sterling and Springfield a 20-foot rise of the water table has occurred during the period between 1919 and 1928. The application of additional water during 1927 and 1928 has no doubt contributed materially to this rise.

Work has already begun on this project to drain the seeped areas. Drainage by pumping from wells is being tried. Fortunately most of the seeped areas are near the upper end of the project, and the water pumped from the drainage wells can be delivered into the main canal and used on the lower end of the project. As the delivery of water to the farmers at the lower end of the two canals is now difficult because of the inadequate carrying capacity of the canals for the land served, this method of drainage may obviate increasing the size of the canals. Shallow wells drilled into the basalt near Sterling will yield copiously, and the pumping lift will probably not exceed 30 feet.

FORT HALL AND BLACKFOOT TRACTS

The Fort Hall project occupies all of the Gibson terrace, which is bounded on the north by the Blackfoot River, on the east by the foothills, on the south by the Portneuf River, and on the west by the Fort Hall Bottoms and the Snake River. In the project at the present time (1938) there are 30,000 acres of irrigated land and 39,000 acres of nonirrigated land. The larger portion of the nonirrigated land lies between an east-west line through Gibson and Gibson Butte and an east-west line through Fort Hall. This land is mostly very sandy, and much of the surface is covered by shifting dunes. The part of the Blackfoot irrigated tract that was studied in detail lies between the

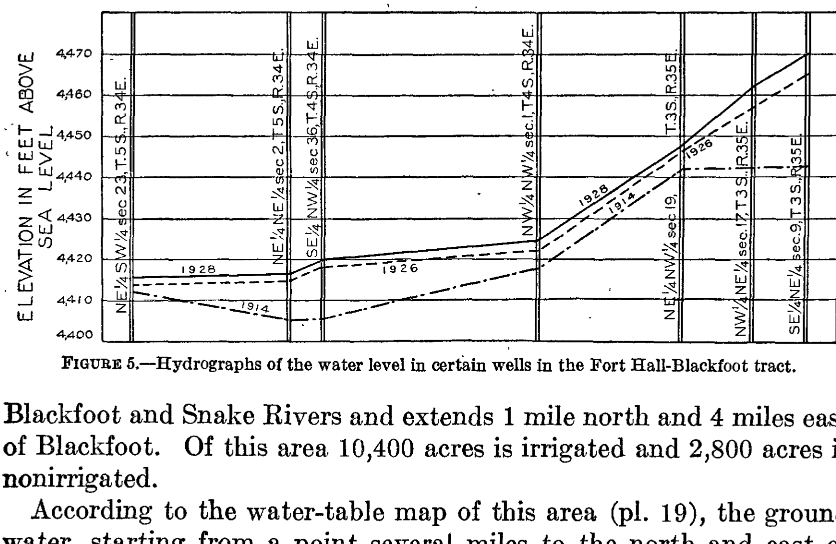


FIGURE 5.—Hydrographs of the water level in certain wells in the Fort Hall-Blackfoot tract.

Blackfoot and Snake Rivers and extends 1 mile north and 4 miles east of Blackfoot. Of this area 10,400 acres is irrigated and 2,800 acres is nonirrigated.

According to the water-table map of this area (pl. 19), the ground water, starting from a point several miles to the north and east of Blackfoot, moves in a southwesterly direction into the American Falls Reservoir basin and the Portneuf River. A ground-water dome in the vicinity of Fort Hall is shown on plate 19. It appears to be caused by leakage from a partly confined aquifer, which produces subartesian wells.

A group of wells on the Fort Hall and Blackfoot tracts were measured in the fall of 1914.[89] The rise in the water level between 1914 and 1928 is shown graphically for certain wells in figure 5. Measurements made in the fall of 1928 on several of the same wells show an average rise in the water table in these wells of 11 feet during the 14 years, or an average of 0.8 foot a year. By assuming 25 percent of voids in the soil, such a rise over the project area of 69,000 acres would require 13,800 acre-feet of water a year, or 19 second-feet of continuous inflow. North and east of Blackfoot considerable land that was formerly

[89] Heroy, W. B., in Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713, p. 135, 1920.

covered with desert vegetation is now badly seeped. However, even before irrigation began the ground water was probably shallow in this area. Practically all the wells in the Fort Hall and Blackfoot areas are comparatively shallow, very few wells having been dug to a depth of 100 feet. Reports of the ground-water conditions on the Fort Hall project and Blackfoot tract covering the three irrigation seasons of 1926, 1927, and 1928 have been made by the Twin Falls Canal Co., and copies of the reports are on file in the offices of that company, the Fort Hall project, and the United States Geological Survey at Idaho Falls.

The yearly fluctuations of the water table in this area are large, as is shown by the following table. Some of the wells just south of the Blackfoot River have an annual fluctuation of 25 feet or more. The large fluctuations seem to be caused by a large underground recharge that comes from some locality outside of the project.

Source and disposal of water in the Fort Hall tract, in acre-feet

[Gross area, 69,000 acres; cultivated area, 29,910 acres; uncultivated area, 39,090 acres]

Date, 1928	Surface application			Surface disposition			Subsurface disposition					Return flow		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Water diverted for irrigation	Precipitation on cultivated area	Total water applied	Surface waste	Evaporation and transpiration from cultivated area	Waste, evaporation, and transpiration (column 5+ column 6)	Deep percolation (column 4 — column 7)	Ground-water recharge	Underground inflow	Withdrawn from ground storage	Effluent seepage	Return flow May 1 to Oct. 1, 1928 (column 5+ column 12)	Water in ground storage Oct. 1, 1928 (column 9— column 11)	Total return flow for year ending May 1, 1929 (column 13+ column 14) [1]
May	30,038	3,290	33,328	3,267	7,178	10,445	22,883	35,362	12,479			3,267		
June	35,717	3,589	39,306	5,006	8,973	13,979	25,327	31,912	6,585			5,006		
July	53,553	748	54,301	2,630	11,665	14,295	40,006	36,225			4,080	6,710		
August	51,113	538	51,651	4,454	10,768	15,222	36,429	15,520			20,909	25,363		
September	35,572	299	35,871	4,303	6,281	10,584	25,287			32,180	57,467	61,770		
Total	205,993	8,464	214,457	19,660	44,865	64,525	149,932	119,019	19,064	32,180	82,456	102,116	86,839	188,955

[1] Available only if water table returns to altitude of May 1, 1928.

Source and disposal of water in the Blackfoot tract, in acre-feet

[Gross area, 10,900 acres; cultivated area, 8,500 acres; uncultivated area, 2,400 acres]

Date, 1928	Surface application			Surface disposition			Subsurface disposition					Return flow		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Water diverted for irrigation	Precipitation on cultivated area	Total water applied	Surface waste	Evaporation and transpiration from cultivated area	Waste, evaporation, and transpiration (column 5+column 6)	Deep percolation (column 4—column 7)	Ground-water recharge	Underground inflow	Withdrawn from ground storage	Effluent seepage	Return flow May 1 to Oct. 1, 1928 (column 5+column 12)	Water in ground storage Oct. 1, 1928 (column 9—column 11)	Total return flow for year ending May 1, 1929 (column 13+column 14)
May	9,412	1,019	10,431	1,043	2,038	3,081	7,350	16,350	9,000			1,043		
June	8,331	1,469	9,800	980	2,547	3,527	6,273	5,995			278	1,258		
July	14,054	255	14,309	1,431	3,311	4,742	9,567	7,085			2,482	3,913		
August	9,880	233	10,113	1,011	3,056	4,067	6,046	4,905			1,141	2,152		
September	5,028	85	5,113	511	1,784	2,295	2,818			3,270	6,088	6,599		
Total	46,705	3,061	49,766	4,976	12,736	17,712	32,054	34,335	9,000	3,270	9,989	14,965	[1] 31,065	[2] 46,030

[1] Available through effluent seepage.

[2] Available if water table returns to altitude of May 1, 1928.

It appears that a large part of the flow of the springs discharging in the American Falls Reservoir basin passes under the Fort Hall and Blackfoot areas and that there is added to that flow most of the return flow from these areas. It is also apparent that with an increase in the irrigation diversions for the Fort Hall project there will be a constantly increasing amount of return flow until such time as new development ceases and the ground-water conditions again reach equilibrium.

At the present time the average depth to water over the area is about 30 feet. Between Tyhee and Pocatello the depth to water is from 50 to 60 feet. In the area 4 miles east of Blackfoot the depth ranges from zero to 2½ feet, so that during most of the year this land is fully saturated. Drains are now (1928) being built to relieve the lands north and west of Fort Hall.

MINIDOKA PROJECT

The Minidoka area embraces all lands along the Snake River from Lake Walcott west to the dam at Milner. Within this area are the North Side Minidoka project and the South Side Minidoka project.

The North Side Minidoka area lies at an average distance of about 14 miles southwest of the town of Minidoka. It extends along the north side of the Snake River downstream from Lake Walcott for about 20 miles and has an average width of about 6 miles. The South Side Minidoka area lies on the opposite side of the Snake River and has an average width of a little more than 4 miles. These two projects taken together are usually called the "Minidoka project." (See pl. 19.)

The areas on both sides of the river include 106,000 acres of irrigated land. This land lies at an average altitude of about 4,150 feet and has a gentle slope to the west of about 1 foot to the mile. All the land is underlain by lava at various depths. Overlying this lava are lake and stream deposits of gravel, sand, and silt, upon which rests a cover of windblown material of irregular thickness. Under large areas on the north side lie beds of clay that produce perched water tables when the areas are irrigated. This condition has made it necessary to construct an extensive system of surface drains, most of which discharge into the Snake River. Part of the drains are run to the north and west and discharge into drainage wells, which carry the water downward to the deep ground water in the lava beds under the project. This deep ground water moves westward at a much lower altitude than the water in the river, even at Milner; hence the ground water derived from these sumps does not return to the river above the Milner Dam.

The most effective drainage well on the project is the Goyne sump, in sec. 10, T. 9 S., R. 23 E. It is in a small playa at the margin of the lava and is 6 feet in diameter and about 90 feet deep. Most of the pit was blasted into basalt and red clinkery lava. The water enters the pit after passing through a settling tank and a wooden screen. Occasionally the leaves and sticks that enter the pit are cleaned out, but otherwise it requires no attention. For years it has been taking 22 second-feet of muddy waste and drain water. The bottom of the pit is above the main water table. Tests indicate that an inflow of more than 22 second-feet will exceed the drainage capacity of the pit and that it will fill up. The 6-inch wells occasionally become clogged. The Goyne sump is so successful that in the future other pits should be used for draining this part of the project.

The projects receive their water through canals heading in Lake Walcott. A large part of the water diverted to the South Side project is pumped to lands too high to be supplied by gravity canals, the power being generated at the Minidoka Dam. The average annual discharge of the main North Side Canal from 1916 to 1927 amounted to 440,360 acre-feet. The average annual discharge of the main South Side Canal in the same period was 269,000 acre-feet.

Discharge, in acre-feet, of wasteways and drains on the Minidoka project for 1927 [1]

Month	North Side	South Side	Total	Average in second-feet
January	2,650	1,350	4,000	65
February	2,100	1,020	3,120	56
March	2,300	770	3,070	50
April	4,334	952	5,286	89
May	7,637	1,116	8,753	142
June	9,438	1,056	10,494	175
July	11,043	1,453	12,496	202
August	13,343	1,797	15,140	244
September	9,439	2,029	11,468	191
October	6,875	2,325	9,200	149
November	4,600	2,300	6,900	115
December	3,450	1,870	5,320	86
Total	77,209	18,038	95,247	

[1] Computed from measurements and extension of seasonal discharge curves (see fig. 6).

Average daily discharge, in second-feet, of wasteways and drains on the Minidoka project

Month	From project data			Measured by Twin Falls Canal Co., 1927	Mean	
	1914	1915	1916		Second-feet	Acre-feet per month
January	74	56	65	65	65	4,000
February	65	26	74	56	55	3,060
March	46	42	69	50	52	3,200
April	56	59	82	89	72	4,280
May	84	165	132	142	131	8,060
June	124	180	188	177	167	9,940
July	167	206	210	208	198	12,180
August	179	207	223	247	214	13,160
September	164	175	218	193	188	11,190
October	123	119	121	149	128	7,870
November	89	85	91	116	95	5,650
December	77	62	71	86	74	4,550
Total						87,140

The preceding tables give the discharge of drains and wasteways on the project. The discharge for 1927 was computed from measurements and the extension of the seasonal-discharge curves in figure 6. The average annual discharge is about 87,000 acre-feet.

In order to arrive at the amount of ground-water recharge from this project a special study was made for the 11-year period 1916–27, the results of which are given in the following table. The seepage gains on the river were obtained from the mean monthly gains as shown by the

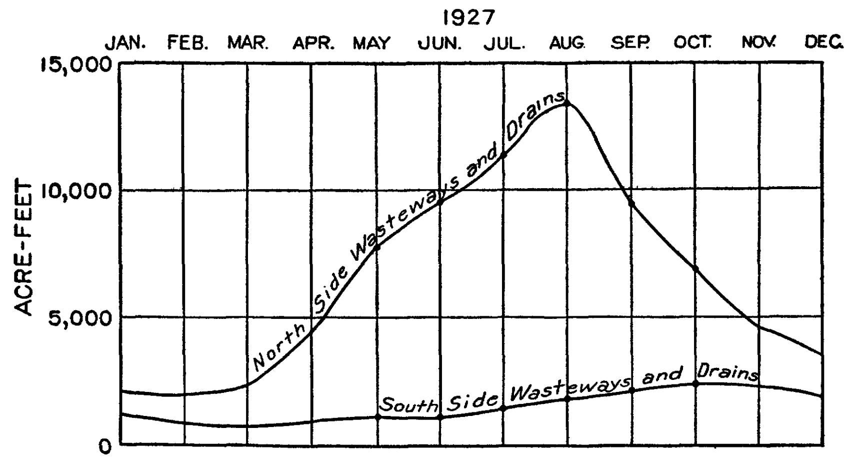


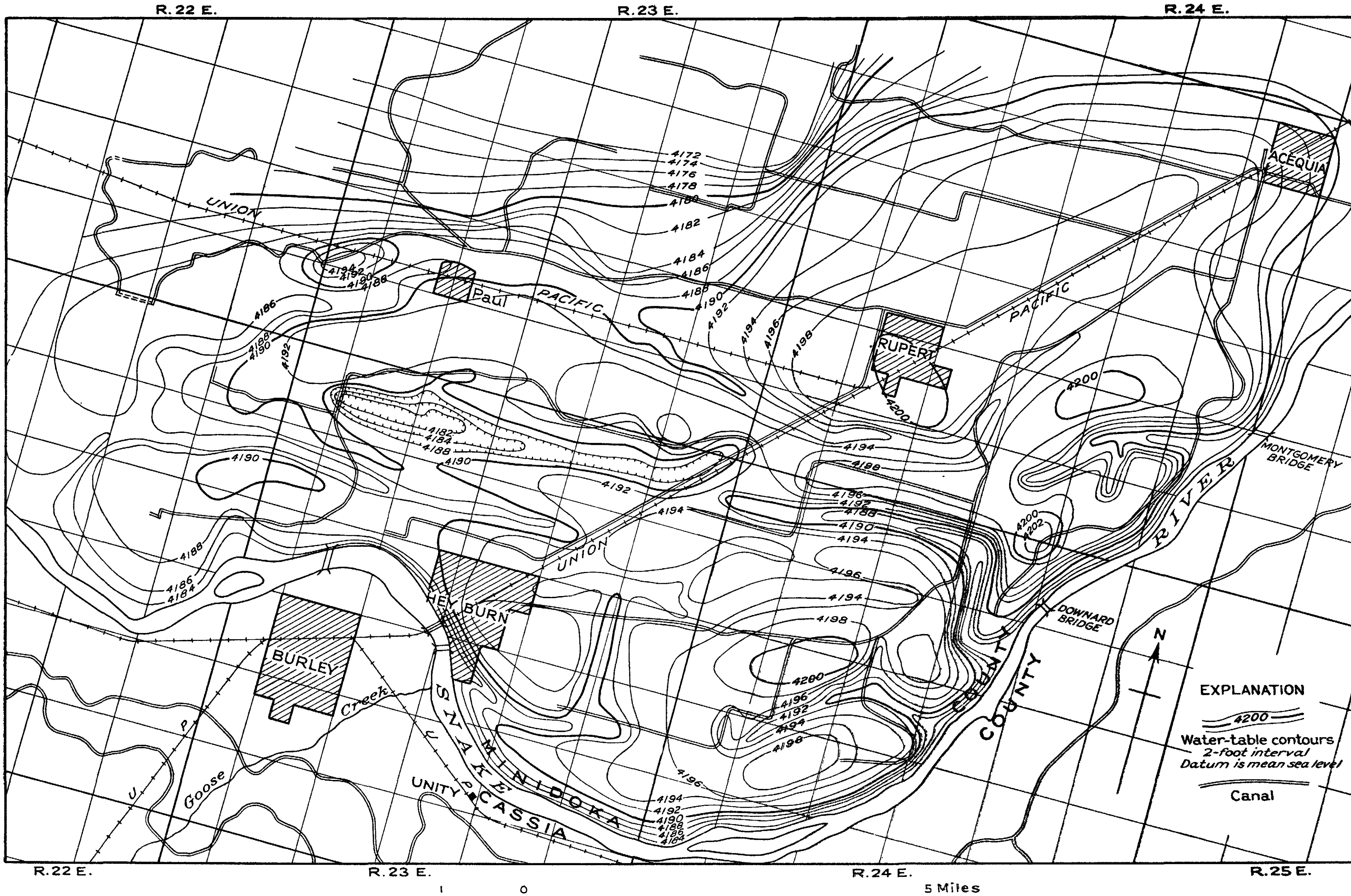
FIGURE 6.—Curves showing discharge of wasteways and drains from the Minidoka project for 1927.

United States Geological Survey records of the flow at the Minidoka and Milner stations. The deep percolating water that joins the underflow of the Snake River Plain amounts to about 233,360 acre-feet annually.

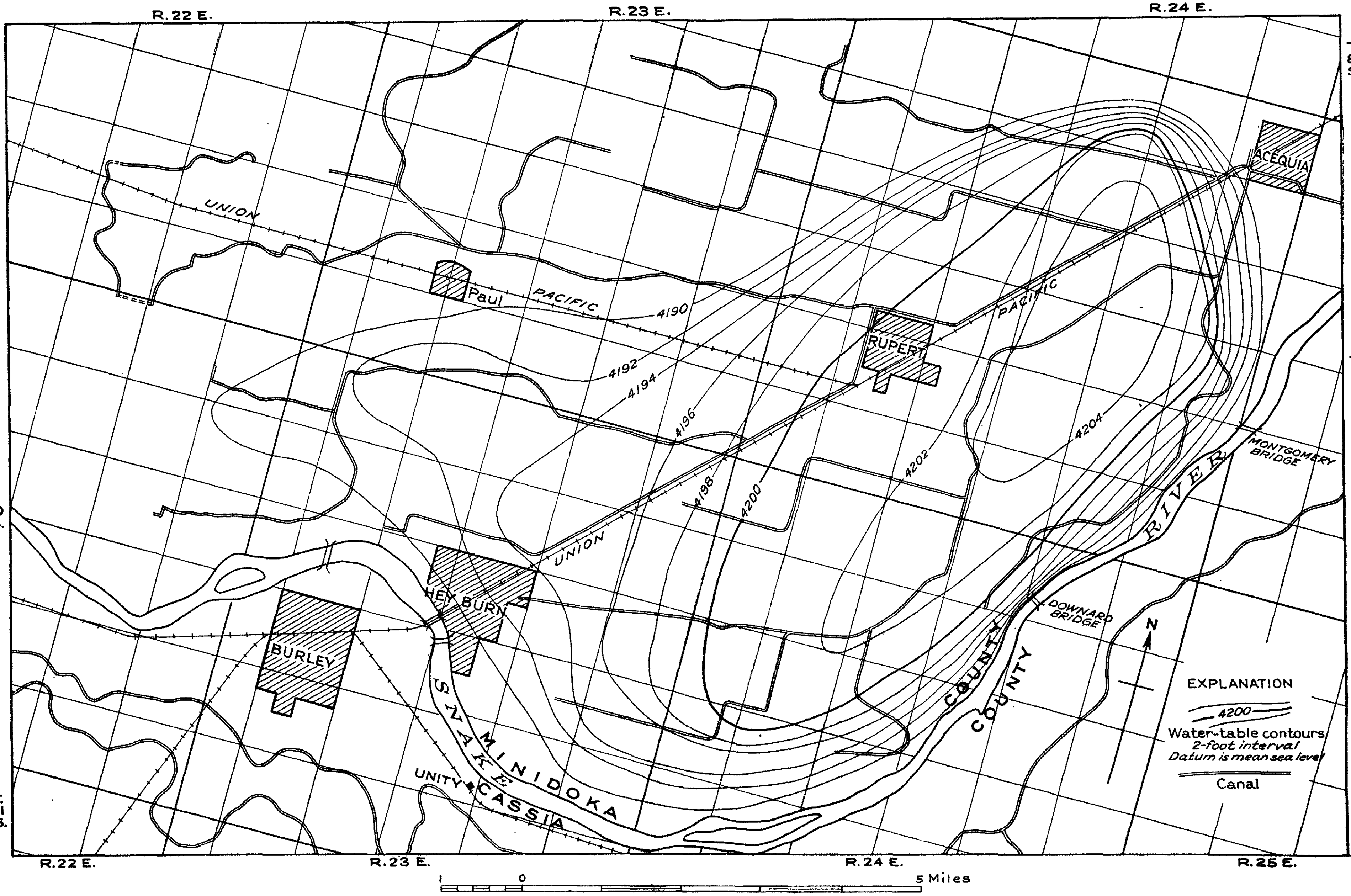
Application and disposal of water on the Minidoka project exclusive of rainfall, 1916–27

		Acre-feet
Application:		
Mean discharge main North Side canal	440, 360	
Mean discharge main South Side canal	269, 000	
Total applied		709, 360
Disposal:		
Crop use at 1.70 acre-feet per acre on 103,000 acres	175, 100	
Waste and drainage from entire project	87, 000	
Seepage gains to river	213, 900	
Total visible disposition		476, 000
Deep percolation		233, 360

On account of the sandy soil on the Minidoka project it seemed necessary to use large quantities of water to get the lands under irriga-



WATER-TABLE CONTOUR MAP OF THE NORTH SIDE MINIDOKA PROJECT FOR 1910.



WATER-TABLE CONTOUR MAP OF THE NORTH SIDE MINIDOKA PROJECT FOR 1915.

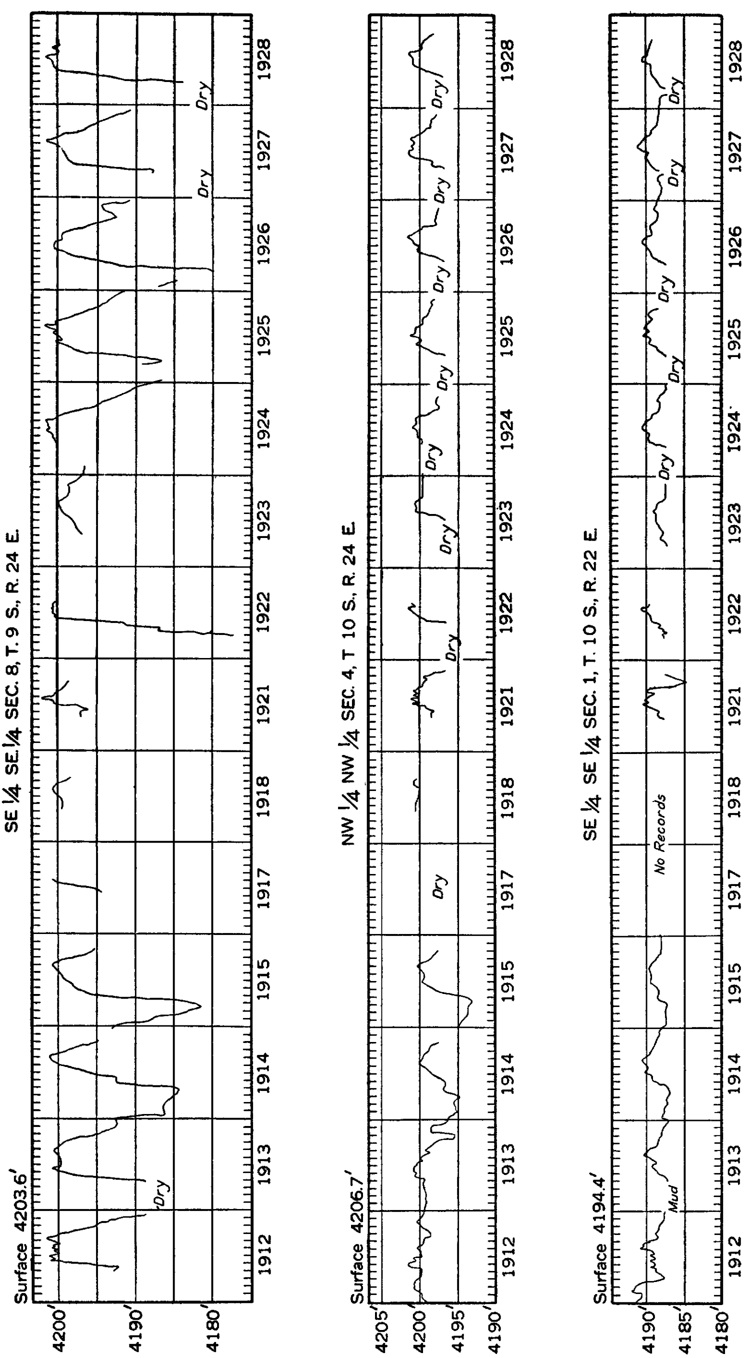


FIGURE 7.—Hydrographs of three typical wells on the North Side Minidoka project.

tion. This excessive use of water caused a rapid rise of ground water, so that within a short time after water was turned on the project, crops on large portions of the project were subirrigated, and later considerable areas became seeped. The first ground-water map of the project, made in 1910 (pl. 22), shows that most of the land which has since been drained was either seeped or in danger of being saturated at that time. Drainage operations were continued until 1915, when the system was considered complete and was turned over to the settlers. The ground-water conditions existing on the North Side project in September 1915 are shown on plate 23. In 1915 F. N. Cronholm wrote a detailed report of the drainage work done on the Minidoka project, copies of which are on file in the Burley, Rupert, and Washington offices of the United States Bureau of Reclamation.

From 1915 until 1927 a few measurements were made each year on observation wells scattered over the more critical parts of the project to determine the ground-water conditions, but no complete study was made until 1927. At that time, in connection with the present investigation, measurements were made on about 150 wells and water-surface points on the North Side Minidoka project. From these measurements the water-table contours in plate 19 were drawn, showing the condition in September 1927. These maps and the hydrographs of three typical wells in figure 7 show that while changes in local conditions more or less vital to the project have occurred, there has been no great change in the ground-water conditions on the project since 1910.

The ground-water contour map of 1927 indicates that aside from the surface drainage very little water gets into the Snake River from the North Side project. The greater part of the ground water travels to the north and west, beyond the project.

TWIN FALLS SOUTH SIDE PROJECT

During the early period of irrigation on the Twin Falls South Side project it was generally believed that there would never be a drainage problem on that project because the area was cut diagonally in several places by creek beds that formed what were then believed to be natural deep drainage channels, the creeks and the Snake River were flowing from 50 to 500 feet below most of the lands, and the depth to water in the first drilled wells was 50 to 400 feet.

Irrigation water was turned on the Twin Falls project in 1905, and the first appreciable seepage appeared in 1912 on lands south and west of Twin Falls. The question of possible future development of seepage was investigated during 1912 and 1913, and an extensive report was written in 1914 on conditions at that time.[90] This report made good suggestions as to the proper methods to be used in the

[90] Heroy, W. B., Geology and ground-water investigations of the Twin Falls South Side project (unpublished report, U. S. Geol. Survey, Washington office, 1914).

prevention of seeped areas and in the reclamation of the area already seeped. From 1914 to 1916 W. G. Sloan,[91] of the United States Department of Agriculture, made an extensive study of the canal losses, surface waste, drainage run-off, and effect of drains on about 12,000 acres lying south and west of Rock Creek. His report is also very complete and outlines remedial measures similar to those given in the Heroy report. Data contained in both reports are utilized in the following review.

Prior to the completion of the project canals the seasonal run-off of the creeks crossing the project was not great. Only small tracts were irrigated along Dry Creek, Rock Creek, and Deep Creek.

From information available and from present conditions it is believed that prior to 1905 the water table under the Twin Falls tract stood on an average more than 250 feet below the surface. So far as known there was no well on the tract prior to the opening of the project, in 1905. The earliest wells of record were drilled in 1908. In the Johnson well, in the SE¼NE¼ sec. 20, T. 10 S., R. 17 E., when drilled in 1908, the depth to water was 210 feet, but in less than 5 years the water level had risen 186 feet, or an average of more than 37 feet a year. If the same rate of rise existed under the project in the first 3 years of irrigation the water table was originally about 320 feet below the surface in the vicinity of Twin Falls. The water level in the Buhl well, in the center of sec. 36, T. 10 S., R. 14 E., was 129 feet below the surface in 1908. The water in this well rose 47 feet in 4 years, or nearly 12 feet a year, suggesting a pre-irrigation water table about 225 feet below the surface at Buhl. In wells drilled in the Castleford territory in 1908 to 1911 the depth to water was from about 100 to 450 feet. Of the 40 wells recorded by Heroy that gave sufficient data for computation, 29 showed an average depth to water of 190 feet in the period 1909 to 1912, and the average rise in these wells was 25 feet a year during the same period, as shown in the following table. Remeasurements of 17 of these wells in 1928 showed an average rise of only 3.8 feet a year from 1913 to 1928. A computation of the rate of rise of the ground water over the entire project for the 8 years 1920–28 gives an average of about 4 feet a year. It is probable that about 6,000,000 acre-feet of water has been absorbed as permanent ground-water storage in this area from 1906 to 1928.

[91] Sloan, W. G., Report of investigations on the Twin Falls South Side project, Twin Falls, Idaho (unpublished report, U. S. Dept. Agr., Office of Public Roads and Rural Eng., 1916).

Rise of water table due to irrigation on the Twin Falls South Side tract, as shown in wells

Well No.	Location				Original measurement		1913				1928			Average rise per year 1913 to 1928 (feet)
	Quarter	Section	T. S.	R. E.	Date	Depth to water (feet)	Date	Depth to water (feet)	Total rise (feet)	Average rise per year (feet)	Date	Depth to water (feet)	Total rise 1913 to 1928 (feet)	
1	SE¼SW¼	24	9	14	1911	32	Dec. 4	37	−5	−2	Sept. 26	16	21	2
2	S½NE¼	29	9	14	1911	83	Dec. 5	57	26	13				
3		36	9	14	1908	129	Nov. 29	82	47	9				
4	SW¼SE¼	20	9	15	1912	169	Dec. 4	130	39	39				
5	SW¼SE¼	34	9	15	1909	180	Dec. 3	163	17	4				
6	SW¼SW¼	35	9	15	1909	132	Dec. 3	100	32	8	Sept. 28	51	49	3
7	SW¼SE¼	35	9	15	1910	40	Dec. 3	23	8	2				
8	NE¼NW¼	29	9	16	1909	182	Dec. 2	165	17	4	Oct. 22	76	89	6
9	SE¼NW¼	34	9	16	1909	170	Dec. 2	114	56	14				
10	SW¼NW¼	35	9	16	1909	185	Dec. 2	127	58	14				
11	SW¼SE¼	36	9	16	1912	130	Dec. 13	86	44	44	Sept. 29	34	52	4
12	SE¼SE¼	25	10	13	1912	430	Dec. —	411	19	19				
13	NE¼NE¼	14	10	14	1910	479	Dec. 13	353	126	42	Nov. 22	54	299	20
14	NE¼SE¼	3	10	15	1911	171	Dec. 4	107	64	32				
15	NW¼NW¼	9	10	15	1909	180	Dec. 5	110	70	18	Sept. 27	92	18	1
16	SW¼SE¼	12	10	15	1910	130	Dec. 6	64	66	22	Nov. 22	36	28	2
17	NE¼SW¼	18	10	16	1910	165	Dec. 6	128	37	12				
18	NW¼NE¼	25	10	16	1909	315	Dec. —	246	69	17	Nov. 22	39	30	2
19	SW¼SW¼	3	10	17	1909	158	Dec. —	40	118	30	Nov. 20	24	16	1
20	SE¼NW¼	8	10	17	1912	102	Dec. 13	73	29	29				
21	SE¼NW¼	14	10	17	1912	120	Dec. —	80	40	40	Nov. 21	54	26	2
22	SE¼SE¼	17	10	17	1910	180	Dec. 13	18	162	46	Oct. 1	16	2	0
23	SE¼NE¼	20	10	17	1908	210	Dec. 13	24	186	37	Oct. 1	5	19	1
24	SE¼NW¼	35	10	17	1910	315	Dec. —	48	267	76				
25	NW¼NE¼	25	10	18	1909	315	Dec. 11	246	69	17	Oct. 3	247	−1	0
26	NE¼NE¼	28	10	18	1909	190	Dec. 11	189	1	0	Oct. 2	173	16	1
27	NE¼SE¼	5	11	14	1912	415	Dec. —	372	43	43	Sept. 25	153	119	8
General average										24+				3.2

In the vicinity of Twin Falls and toward the east end of the project the ground water has been in a nearly stable condition for several years, owing to the construction of drains and to the underground drainage into the Snake River and Rock Creek. The area of most rapid rise at the time of this investigation was in Tps. 10 and 11 S., Rs. 13 and 14 E., near Castleford, but even in this area there is a decided slowing down in the rate of rise. Four wells in this area on which there is a record for 9 to 18 years show an average rise of 27 feet a year. The average rise in 32 of the wells in the most critical parts of this area in 1928 was about 15 feet and the average depth to water was between 40 and 60 feet. Figure 8 shows the rate of rise in 12 representative wells of the project on which there are sufficient data for study. In all these wells except three in the Castleford area the present rate of rise is exceedingly slow, and this rise can be checked by a reduction in the amount of water applied or by constructing drains.

The general slope of the water table under the project (see pl. 19) is to the north and west and conforms closely to the slope of the land surface. The deep canyons across the project make drainage feasible, so that no considerable area of the project will ever become seeped. Although the drainage of some of these lands may be expensive, there is no reason to believe that they cannot all be drained.

At first open drains were tried, but these were not effective. Soon, however, it was discovered that shallow wells along the bottoms of the ditches, drilled into the basalt underlying the saturated loess soil of the seeped areas, would yield water by artesian flow. This method of drainage by means of flowing wells became the established practice for the next decade. The wells were connected to tile, with gravel placed at the joints, and the trenches were back-filled. In recent years many of these drains have ceased functioning because roots have filled the tiles, and many of the drains that still function have tiles so small that they are unable to carry away the present increased seepage.

About 1927 Burton Smith, then manager of the project, started tunnels to drain favorably situated seeped areas. This method has in most places met with success when augmented by wells. The tunnels have the advantages over tile drains that they are not clogged up by roots, they can carry additional water during wet seasons, and they can be extended whenever necessary.

Much drilling has been done in connection with the drainage work, but the logs of the test wells are mostly valueless because no effort was made to standardize the description of the rocks encountered. The drillers when interviewed reported numerous "openings" through which the percussion drill fell rapidly, but investigation showed that these so-called "openings" were saturated unconsolidated beds of

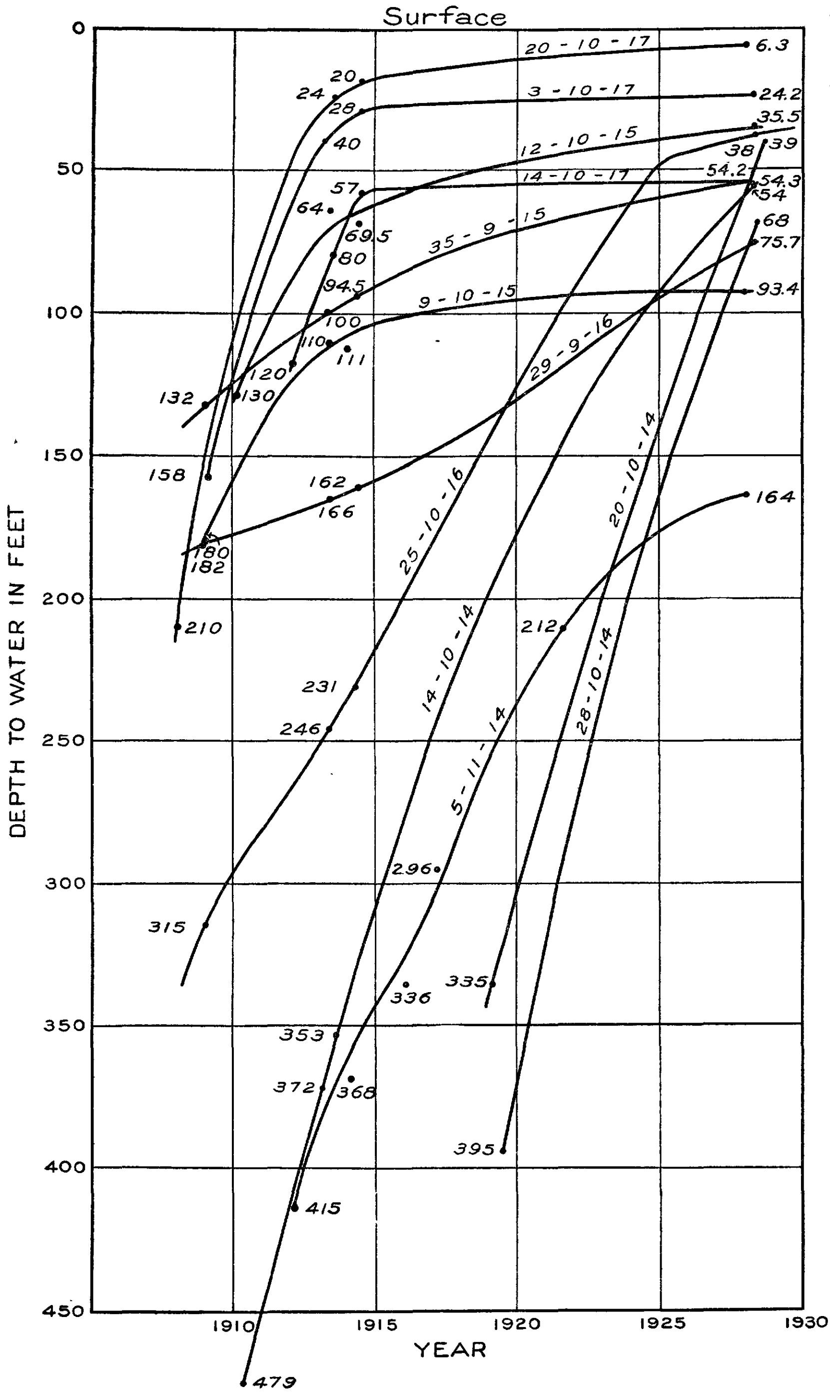


FIGURE 8.—Rate of rise in wells on the South Side Twin Falls project. The location of the well is indicated by numbers like 20-10-14, which signify sec. 20, T. 10 S., R. 14 E.

loess intercalated with the basalt. These beds, which were deposited by the wind on a hummocky lava surface, are very irregular and range from a few inches to about 8 feet in thickness.

The practice in 1929 was to drive a tunnel under the seeped area from the side of a gulch, paying no attention to geologic structure in

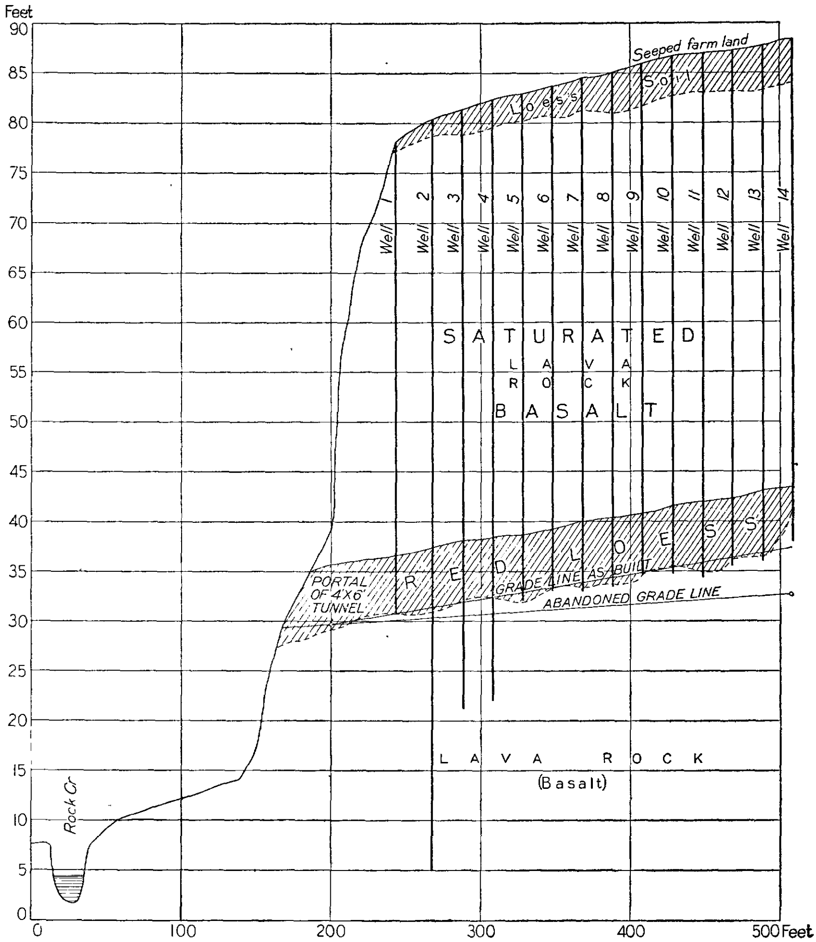


FIGURE 9.—Longitudinal section of the Fargo drainage tunnel, Twin Falls.

the position or grade of the tunnel. Naturally some of the tunnels are too low and others too high to tap the saturated and permeable beds most effectively. If the tunnel passes beneath the aquifer, holes are drilled through the roof to let the water down into the tunnel. If the tunnel is above the aquifer, holes are drilled into the floor, and the water rises and overflows into the tunnel.

Figure 9 illustrates the Fargo drainage tunnel in the NE¼SE¼ sec. 17, T. 10 S., R. 17 E., and the topographic relation of a seeped area to the adjacent deep gulch. This tunnel on June 9, 1928, was discharging about 2 second-feet of water at a temperature of 53° F., but it is reported that in September, at the end of the irrigation season, the discharge visibly increases. Nearly all the water drained by the tunnel enters through the 14 holes drilled through the roof to the overlying saturated lava. As the tunnel collects very little drainage water except what enters from these holes, it is evident that the water is perched above it. An examination of the logs of the holes discloses two more loess beds above the one penetrated by the tunnel. The data were inadequate to enable them to be shown in figure 9. Although these beds are less than a foot thick they serve as imperfect confining beds. Perhaps at a distance from the tunnel they are thicker.

Prior to the construction of the Fargo tunnel, another was driven 20 feet into the basalt 5 feet farther south and 15 feet higher. This tunnel was abandoned when the lower loess bed, where tunneling would be cheaper, was discovered. It started in a bed of basalt but within a few feet exposed the margin of another lava flow. This tongue of lava has a trace of loess on its surface and is underlain by a bed of loess a few inches to 3 feet in thickness.

The presence of the soil beds indicates that a basalt flow about 15 feet thick spread over the 6-foot loess bed of the Fargo tunnel. Then came a period of quiescence during which another bed of loess accumulated. Next the lava flow whose border is exposed in the upper tunnel arrived, and this in turn was followed by more soil and a third lava flow.

The following hypothesis is given to explain the hydrologic conditions. The flows thicken southward toward the cones from which they were extruded. Seepage from the canals and irrigated fields to the south enters these flows and percolates downward. Some of this water is arrested at the base of the flows by the underlying loess and percolates northward down the ancient surface over which the lava flowed. As the flow narrows both laterally and vertically away from its source the number of fissures correspondingly decreases. Eventually the volume of ground water moving through the basalt may exceed the carrying capacity of the fissured rock—a condition that will tend to build up artesian pressure. As the loess that forms the confining beds is somewhat permeable, leakage results. In most places the water can escape only upward, producing a seeped area unfit for farming. The condition is aggravated by the increase in alkali that results from evaporation of the seepage water.

Some of these seeped areas are on the canyon rim 600 feet above the river. As the Snake River probably flows farther south now than formerly, the artesian structure has not all been dissected. The numerous small springs along the wall of the canyon, however, prove that some of the structure has been crosscut. The beds that cause the drainage problems are in general near the surface but appear to have escaped tapping by the deep canyons of tributary streams because the courses of these streams tend to follow the margins of the late flows.

Even with the aid of this explanation of the drainage problems, much further study supplemented by drilling may be necessary before it will be possible to select favorable sites for the tunnels. At present, it seems best to drive the tunnel under a seeped area on a steep grade and as deep beneath it as possible. The overlying saturated beds can then be drained into the tunnel by wells. Wherever possible the tunnels should be run in the loess in order to lower the cost of excavating and to cut through one of the confining beds. The need of a steep grade is illustrated by the South Park tunnel, near Twin Falls, which encountered about 16 second-feet of water. The grade is so flat that the water is too deep in the tunnel for men to work. Not enough is known about the problem to determine whether the tunnels

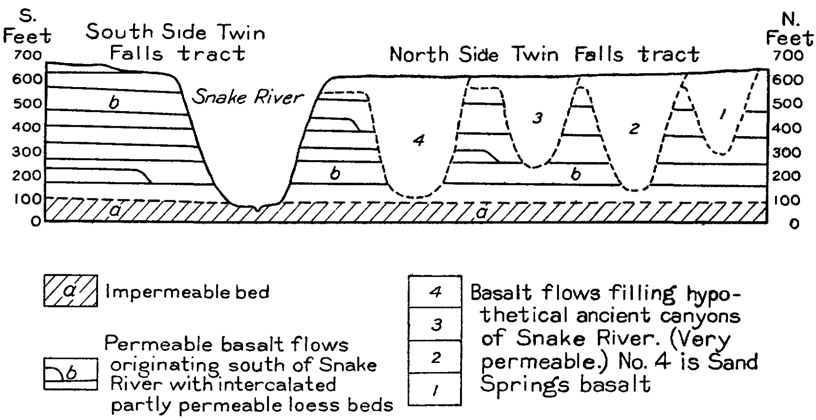


FIGURE 10.—Diagrammatic section showing postulated conditions beneath the North Side Twin Falls tract.

should be run at right angles to the water-table contours of the seeped areas or parallel to them. In places the bedding of the lava flows and the presence of the adjacent Snake River Canyon suggest that drainage may be successfully accomplished by drilling wells that will allow the water to drain downward to permeable aquifers that crop out in the canyon walls. Pumping, where the lift is low, may also be practical as a means of drainage.

TWIN FALLS NORTH SIDE TRACT

The ground water under the Twin Falls North Side tract moves toward the west, as shown in plate 19. Unlike the South Side Twin Falls tract, on the opposite side of Snake River Canyon, the North Side tract has no seeped areas resulting from irrigation, even though more than 600,000 acre-feet is annually contributed to the water table, as shown by the records of the use of water on this project.

The data obtainable indicate that the water table has risen only about 5 feet under the project since irrigation began and that recently there has been little or no rise.

The tract is underlain by permeable basalt; but, unlike that under the Twin Falls South Side tract, this basalt does not occur entirely in thin flows with intercalated loess beds. Instead, many of the flows are believed to occur as V-shaped fills as much as 500 feet thick, occupying former canyons of the Snake River, as shown in figure 10. The basalt in these fills is very permeable, and therefore the water moves rapidly through them, especially along the contacts. They serve as extensive drains, and the water escapes from them in the form of immense springs in the Hagerman Valley.

SPRINGS

OCCURRENCE AND CHARACTER

The region contains many springs, some of which are among the largest in the United States. Several are grouped along the margins of the Fort Hall bottoms, now in part flooded by the American Falls Reservoir. The large quantity of water in the basalt of the Snake River Plain, obtained through percolation from the Snake River and its tributaries, including that similarly lost during irrigations, moves westward and is in large part discharged through the numerous springs along the river below American Falls, especially between Milner and King Hill. The available data concerning the lava-filled channels that are mainly instrumental in collecting the water and delivering it to the springs are given in the geologic description (pp. 65–85). Many of these springs now issue from deep embayments termed "spring coves." Most of the minor springs and seeps along this section of the river have come into existence since irrigation began and derive their water largely from percolation losses from nearby projects. General data in regard to the source of the water and the origin of the spring coves are given below, followed by descriptions of individual springs from the Fort Hall bottoms successively downstream.

In addition to the different kinds of cold springs there are numerous hot springs scattered over the region. Available data regarding these springs are also summarized below. Many of these springs can, with more or less certainty, be shown to be related to faulting. The Mud Lake region contains a considerable number of both cold and thermal springs, which are described in the forthcoming report on that region and are not further discussed here. For data regarding the hot springs and hot wells in Goose Creek Valley, Cassia County,[92] and in Camas County [93] the reader is referred to Piper's published accounts. The

[92] Piper, A. M., Geology and water resources of the Goose Creek Basin, Cassia County, Idaho: Idaho Bur. Mines and Geology Bull. 6, pp. 60–73, 1923.

[93] Piper, A. M., Ground water for irrigation on Camas Prairie, Camas and Elmore Counties, Idaho: Idaho Bur. Mines and Geology Pamph. 15, pp. 15–30, 1924.

descriptions of tributary valleys at the end of this report include data on springs within them.

SPRINGS IN THE FORT HALL BOTTOMS

GENERAL FEATURES AND DISCHARGE

Springs rise at intervals for a distance of 10 miles or more along the Fort Hall bottoms and adjacent to the Portneuf River near its mouth. Most of these springs rise on the valley floor at heights of 10 to 15

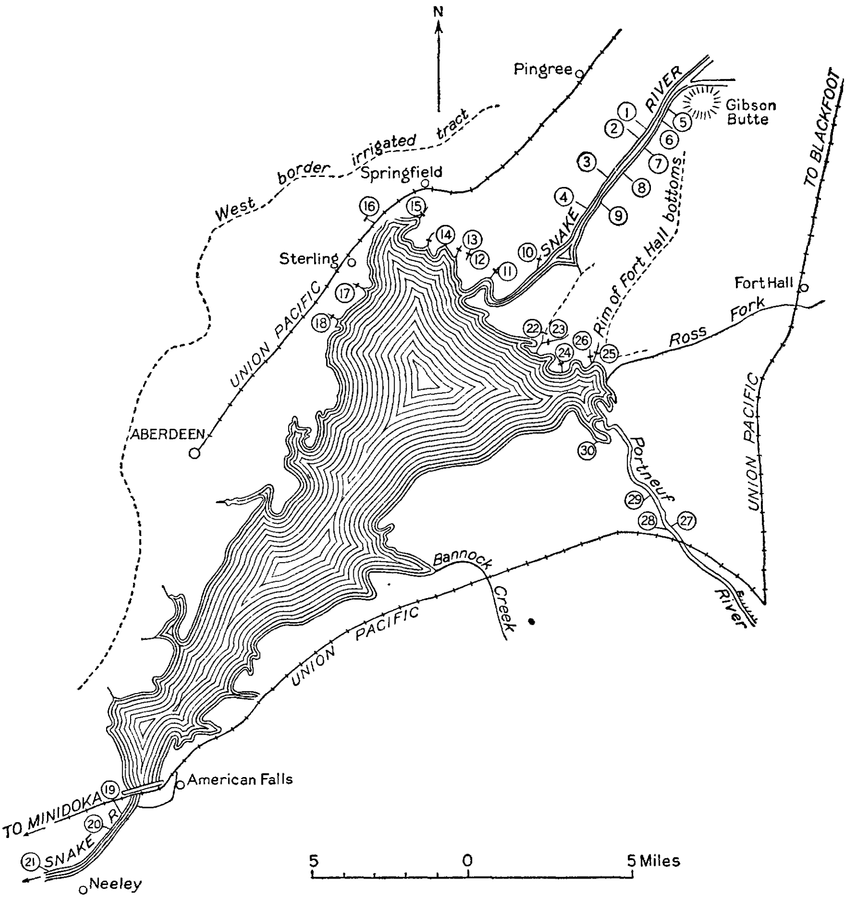


FIGURE 11.—Sketch map showing the location of spring-measuring stations in the vicinity of the American Falls Reservoir. (See table, p. 138, for explanation of numbers.)

feet above the river. They have a fairly uniform aggregate discharge of about 1,400 second-feet, and most of them issue from basalt which underlies the alluvium in this area. The flow and the names of 30 of the larger springs in the vicinity of the American Falls Reservoir are given below. The location of the stations where the flow from these springs was measured is shown in figure 11. Additional details will be found on plate 19. Most of the stations are on creeks formed from a series of springs that are known under a common name.

Mean discharge, in second-feet, of springs in the vicinity of American Falls Reservoir, Idaho

No. on fig. 11	Name	Discharge	No. on fig. 11	Name	Discharge
1	Rich	18.6	16	Artesian	5.5
2	Johannes	7.2	17	Sterling	6.2
3	Thorn	20.2	18	Colburn	3.2
4	Log Cabin	34.9	19	Ruger	23.9
5	Indian No. 1	47.4	20	Davis	
6	Indian No. 2	21.9	21	Franklin	
7	Indian No. 3	163.5	22	Big Jimmy	37.6
8	Indian No. 4	3.8	23	Big Spring	448.0
9	Indian No. 5	19.3	24	Kinney	29.3
10	Pyle	14.0	25	Clear	130.0
11	McTucker	26.4	26	Ford	7.4
12	Hull	7.1	27	Pocatello City	
13	Tanner	2.2	28	Batise	50.0
14	Crystal	32.8	29	Fish Hatchery	75.0
15	Danielson	51.1	30	Wide	60.0

On September 14, 1925, Batise Spring, on the west side of the Portneuf River about 4 miles northwest of Pocatello, discharged about 50 second-feet,[94] and the Fish Hatchery Springs, about 1½ miles downstream from Batise Spring, about 75 second-feet.[95] Wide Creek, which is among the largest of the spring-fed streams in this area, a tributary to the Portneuf River from the south, had an average discharge during 1926 of 60 second-feet at a point near the center of the W½ sec. 26, T. 5 S., R. 33 E.[96] The largest spring-fed tributary to the Portneuf River is Big Spring Creek, which had an average discharge of 442 second-feet of spring water during the irrigation season of 1926 at a point in the SE¼ sec. 9, T. 5 S., R. 33 E.[96] This stream rises in spring pools on the south side of Gibson Butte and flows into the Portneuf River from the north. Clear Creek, also spring-fed, had an average discharge during 1926 of 120 second-feet at a point in the SW¼ sec. 11, T. 5 S., R. 33 E.[96] This stream flows into Ross Fork and thence into the Portneuf. Ford Creek is a tributary to Clear Creek from the west and has an average flow of about 7 second-feet. Another spring-fed tributary to the Portneuf from the north is Kinney Creek, which had a discharge of about 28 second-feet during 1926 at a point near the center of sec. 15, T. 5 S., R. 33 E.

The ground-water contours (pl. 19) indicate that the springs bordering the Fort Hall bottoms should be divided into two groups. Batise Spring, Fish Hatchery Spring, and Wide Creek, in the Portneuf Valley form one group, and Big Spring Creek, Clear Creek, and Kinney Creek, the waters of which come from the valley of the Snake River north and east of Fort Hall, form the other group.

94 Meinzer, O. E., Large springs in the United States: U. S. Geol. Survey Water-Supply Paper 557, p. 52, 1927.

95 Idem, p. 52.

96 Smith, T. R., Hydrometric report on the American Falls Reservoir area for 1926 (unpublished rept., U. S. Bur. Reclamation, American Falls, Idaho, 1927).

In addition to these springs, 230 second-feet of water is discharged by 13 springs in the Aberdeen-Springfield area. (See fig. 11.) These springs issue from the basalt of Gibson Butte, which collects the water from under the irrigated areas to the northeast and from seepage from the Snake River. At most of the spring vents this basalt is overlain by the American Falls lake beds or by alluvium, as shown in plate 4.

The Portneuf and the Snake Rivers are also augmented by smaller springs and by inflow rising in the stream channels themselves. The location of the larger of these small springs as determined by Smith [97] are given in figure 11. The Snake River between the mouth of the Blackfoot River and American Falls, a distance of about 30 miles, has a total gain, exclusive of surface run-off from the upper Portneuf, of about 2,500 second-feet, nearly all of which is supplied by springs.

SOURCES

The origin of the springs in the Fort Hall bottoms, which discharge about 1,400 second-feet, or about 1,000,000 acre-feet annually, has been variously attributed to three sources—(1) ground-water flow down the valley of the Portneuf River, with an original source in the drainage basin of that stream and augmented by ground-water contributions from the drainage basins of the Bear River and the Blackfoot River; (2) precipitation on the lava beds north of the Snake River; (3) underflow along the Snake River. In the following pages an analysis is made of the possible supply derivable from each of these sources.

POSSIBLE SUPPLY FROM PORTNEUF RIVER BASIN

The average annual run-off of the Portneuf River at Pocatello for the years 1920 to 1927 was 217,000 acre-feet, equivalent to a depth of 0.26 foot over its drainage area of about 825,000 acres. Study of the records for the Bear and Blackfoot Rivers and Willow Creek leads to the conclusion that, with due allowance for storage holdovers, the average run-off from the drainage basins of these streams in the same period was equivalent to a depth of about 0.32 foot. The smaller relative run-off of the Portneuf drainage basin thus indicated may be assumed to represent underflow discharged through the springs near the mouth of the river. A depth of water of 0.06 foot over the Portneuf drainage area is equivalent to only about 49,500 acre-feet, or only about 5 percent of the total discharge of the springs in the Fort Hall bottoms.

A possibility of a slight error occurs in the computations of run-off. The Blackfoot River is flowing from the Blackfoot Reservoir to Snake River Valley in a canyon cut in two intracanyon flows. As the gaging stations measuring the run-off are situated in this canyon, ground water moving past the upper gaging station as underflow might not be measured at the lower station. A somewhat similar

[97] Smith, T. R., op. cit.

condition exists on the Portneuf River. The gaging station at Pocatello was used for the computations for the Portneuf drainage. A considerable gain occurs in the Portneuf River at the Topaz gaging station, part of which is derived from contributions from Gem Valley. Although all gains from Gem Valley must appear as surface flow at the narrows at the Lava Hot Springs, yet an opportunity exists for some of this surface water gain from Gem Valley to become underflow of the Portneuf above the Topaz station and hence pass beneath the Pocatello gaging station as a contribution for the springs near the mouth. Because the computed 49,500 acre-feet of ground-water contribution from the Portneuf drainage basin is only adequate to supply Batise and part of Fish Hatchery Springs, the remaining spring flow must come either from unmeasured Gem Valley contributions or from the irrigated lands to the northeast.

POSSIBLE SUPPLY FROM PRECIPITATION NORTH OF SNAKE RIVER

According to the view adopted in the present report, most of the ground water under the plain north of American Falls is tributary to springs in the area between Milner and King Hill, more than 100 miles downstream. There is a narrow strip of desert area north of the river for a few miles, the precipitation on which would contribute slightly to the springs on that side of the river, but contributions to any of the springs by ground-water accretions from precipitation on the adjacent area are insignificant compared to their total flow.

The possibility that ground-water recharge from precipitation on the desert to the north may pass under the Snake River and issue in the springs in the Fort Hall bottoms was suggested by Heroy.[98] However, the basalt in the American Falls lake beds, which is the chief aquifer on the north bank of the Snake River, terminates at the reservoir, and the low permeability of the underlying lake beds, which pass under the river, excludes them as possible conduits.

POSSIBLE SUPPLY FROM UNDERFLOW OF SNAKE RIVER

The ground-water contours (pl. 19) in this section of the plain indicate that water lost from the Snake River below the vicinity of Firth returns in these springs. Likewise, the springs are augmented by recharge from all the irrigated lands downstream from Firth and possibly from lands even farther up the valley. If the area bordering the Snake River between Heise and Neeley is considered as a unit, the following relation between available supply and water accounted for is indicated:

[98] Heroy, W. B., in Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713, p. 141, 1920.

Average annual water supply of the Snake River Valley between Heise and Neeley, 1920–27

	Acre-feet	
Average annual water supply entering the area:		
Henrys Fork near Rexburg	1, 340, 000	
Snake River at Heise:		
Surface flow	5, 132, 000	
Underflow	53, 000	
Riley ditch	4, 000	
Willow Creek	128, 000	
Sand Creek	2, 000	
Blackfoot River	218, 000	
Pocatello, Ross Fork, and Lincoln Creeks	7, 000	
Portneuf River at Pocatello:		
Surface flow	217, 000	
Underflow	49, 000	
		7, 150, 000
Average annual amount of water accounted for:		
Snake River at Neeley	5, 476, 000	
Stored in American Falls Reservoir	174, 000	
Evaporation loss from American Falls Reservoir	21, 000	
Used by crops on irrigated lands (estimated 1.7 acre-feet per acre on 327,747 acres)	557, 000	
		6, 228, 000
Average annual excess of supply over water accounted for		922, 000

It thus appears that the amount of surface inflow along this section of the Snake River which through irrigation and river losses becomes ground water is sufficient to account for all of the spring flow between Blackfoot and Neeley and still leave an excess of 922,000 acre-feet annually for the period 1920–27 in addition to any contributions to the water table from precipitation on the area. The excess, according to the ground-water contours in plate 19, moves west under the desert between the mouth of Henrys Fork and Firth. During the period studied over 2,000,000 acre-feet was diverted annually on 328,000 acres of irrigated land in the Snake River Valley between Heise and Neeley, of which about a quarter is used by vegetation and evaporation from the soil, leaving 1,500,000 acre-feet to return to the Snake River as surface waste or to be contributed to the underlying water table. River-channel losses between Heise and the mouth of Henrys Fork cannot be definitely calculated, on account of lack of winter stream-flow records, but the information available for the irrigation season indicates that they are likely to be of the magnitude of several hundred thousand acre-feet annually. It thus appears evident that the springs in the Fort Hall bottoms are mainly supplied by this great underflow of the Snake River Valley.

Coarse clean gravel deposits and basalt suitable for the accumulation of ground water underlie the river and the irrigated tracts upstream from the springs, but near Blackfoot the gravel deposits grade into relatively impermeable lake-bed silts and clays of the American

Falls Basin. As a consequence the ground water that is carried by the gravel deposits tends to be forced into the basalt, which is the only available material of sufficient permeability, and practically all the springs issue from basalt.

In summary, all three of the possible sources that are considered probably contribute to the supply of the springs in the Fort Hall bottoms, but analysis of the stream-flow records and study of the local geology favor the conclusion that most of the supply comes from the underflow of the Snake River.

SPRINGS BETWEEN AMERICAN FALLS AND KING HILL

SOURCES

As shown in the following descriptions, nearly all the springs along the Snake River below American Falls are on the north side of the river and may consequently be presumed to derive their water from that side. The movement of ground water under the Snake River Plain accords with this position of the springs. The Snake River between Heise and Neeley, the Henrys Fork, and the tributary streams that reach the north border of the plain between Henrys Fork and Camas Prairie contribute a total of 2,400,000 acre-feet to the ground water. Percolation losses of about 1,640,000 acre-feet from Lake Walcott and the Minidoka and North Side Twin Falls projects should be added to this amount, making a grand total of about 4,040,000 acre-feet annually available for discharge. As the following summaries show, this figure is in close agreement with the amount of water discharged in this section of the river.

The springs that issue between American Falls and Milner are relatively small and have an aggregate flow of less than 50 second-feet, but those between Milner and King Hill are very large. The data regarding the discharge of these large springs are summarized in the following table. Most of them occur at 140 to 200 feet above the river level, but a few issue at or just above the river level. On account of the large volumes of water discharged by these springs in this semiarid region and the cascades that many of them produce, the springs have long been noted as among the most picturesque features of the United States (pl. 26). Their water is used in part for both irrigation and the development of power. Their further use for irrigation without pumping is limited by lack of available land at suitable altitudes, but further developments for power are possible. The largest of the individual springs have a discharge of more than 1,000 second-feet. In 1902, prior to any considerable irrigation on the bench lands north and east of the canyon, these springs had a combined discharge of about 3,800 second-feet, or about 2,800,000 acre-feet a year. By 1917, owing to irrigation, the discharge had increased to more than 5,000 second-feet, or 3,600,000 acre-feet a year, and since 1917 there has been a small decline in discharge.

VIEW LOOKING TOWARD SNAKE RIVER FROM THE HEAD OF BLUE LAKES COVE SHOWING THE GENERAL ABSENCE OF TALUS APRONS.
Photograph by I. C. Russell.

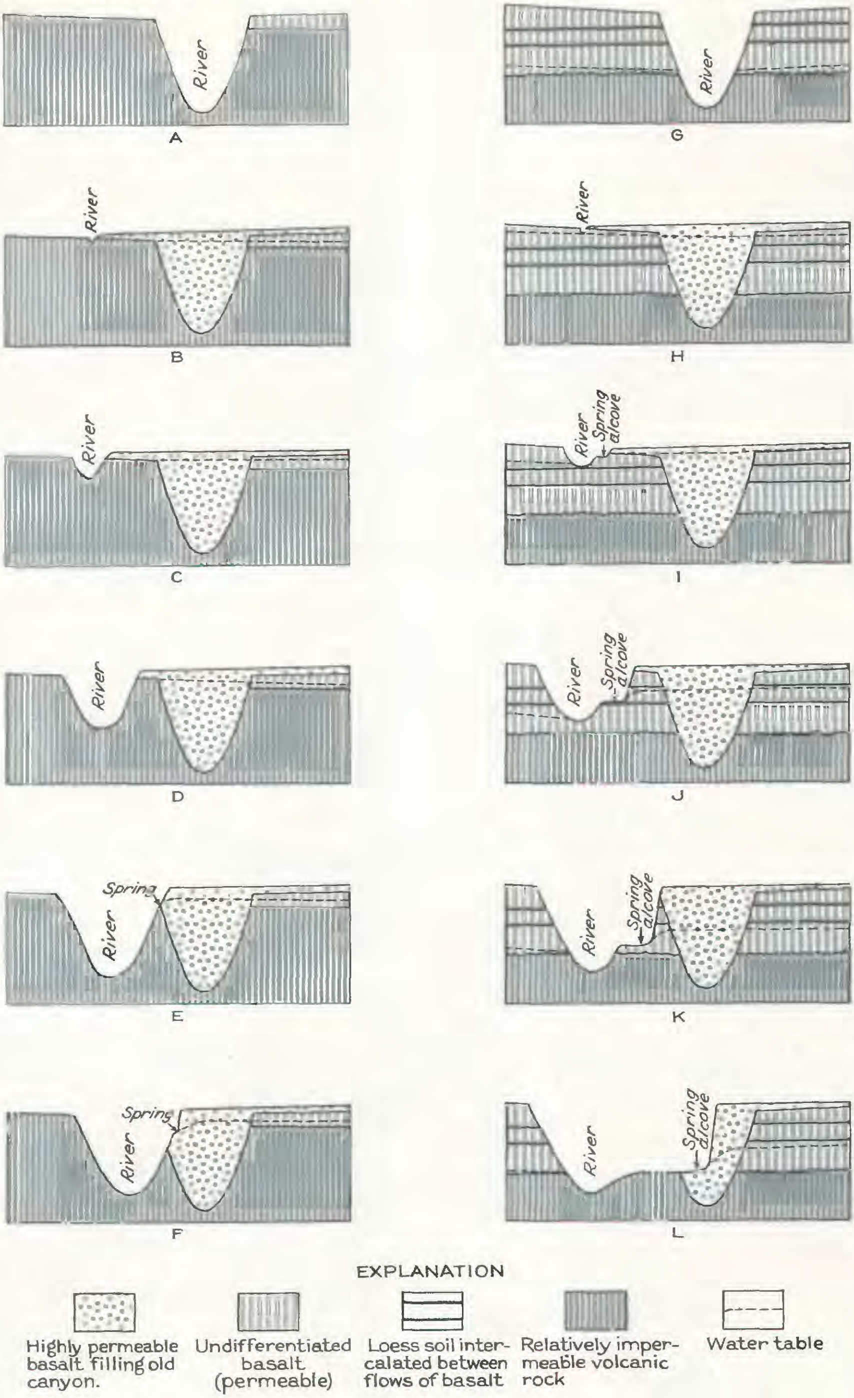


DIAGRAM SHOWING DEVELOPMENT OF SPRINGS FED THROUGH LAVA-FILLED CANYON

1938

PRINTED BY THE GEOLOGICAL SURVEY

THOUSAND SPRINGS BEFORE POWER DEVELOPMENT.
Photograph by I. C. Russell.

Discharge from springs on north side of Snake River Canyon, in second-feet

	1902	1917	1924
Total discharge of springs between Milner and Blue Lakes	90	[1] 110	[1] 116
Total discharge of Blue Lakes	80	192	195
Total discharge of springs between Blue Lakes and Crystal Springs	25	33	[1] 33
Crystal Springs	336	536	468
Niagara Springs	107	242	222
Clear Lake Springs	150	504	497
Briggs Spring	77	128	114
Banbury Springs	66	124	100
Blind Canyon	2	12	[1] 10
Box Canyon	[1] 450	[1] 461	[1] 406
Springs at river level below Box Canyon	[1] 94	[1] 90	[1] 90
Total discharge of Blue and Riverside Springs	63	75	[1] 70
Sand Springs	51	80	80
Total discharge of Thousand Springs group, including Bickel Springs	797	982	935
Total discharge of springs from Bickel ranch to Malad Canyon	344	[1] 350	[1] 300
Total discharge of Malad Springs	1,090	1,133	1,192
Total discharge of springs between Malad Canyon and Bliss	[1] 25	[1] 33	[1] 30
Total	3,847	5,085	4,858

[1] Partly estimated.

The increase in the flow of these springs from 3,847 to 5,085 second-feet between 1902 and 1917 is undoubtedly due to the irrigation of large areas on the uplands north and east of the Snake River Canyon, particularly on the North Side Twin Falls tract. The decrease in the recorded flow of the springs to 4,858 second-feet in 1924 may be due partly to the fact that 1924 was a year of deficient water supply for the Snake River projects. The elimination of the Jerome Reservoir from the canal system of the north side tract since 1920 accounts for a reduction of about 60,000 acre-feet a year in the seepage losses contributed to the ground-water flow.

The Snake River in this stretch also receives other inflow of considerable extent, principally from seepage springs and waste from the South Side Twin Falls project but partly from seepage on the north side. During the period August 7 to September 15, 1923, the gain in the flow of the river, in addition to observed spring inflow from the north side, was 2,160 second-feet, distributed as shown in the following table. This is equivalent to an annual contribution of about 1,550,000 acre-feet.

Gain, in second-feet, in Snake River from Milner to King Hill, Aug. 7 to Sept. 15, 1923, exclusive of measured spring inflow from the north side

[Records furnished in part by the Idaho Power Co.]

Section of river	Average discharge at head of section	Spring inflow from north side	Average discharge at lower end of section	Gain
Milner to Murtaugh bridge	12	0	48	36
Murtaugh bridge to point ½ mile below Twin Falls	48	60	488	380
Point ½ mile below Twin Falls to Shoshone Falls	488	66	583	29
Shoshone Falls to Perrine bridge	583	0	679	96
Perrine bridge to Owsley Ferry, near Hagerman	679	3,370	5,442	1,393
Owsley Ferry to King Hill	5,442	[1] 1,372	7,040	226
Total				2,160

[1] Includes diversion of 290 second-feet for King Hill project.

SPRING COVES

ORIGIN

Between American Falls and the mouth of the Big Wood River (Malad Canyon) there are in the north wall of the canyon of the Snake River numerous short, deep box canyons or coves enlarged at their heads into amphitheaters. Springs gush up in the heads of many of the coves, but others are dry and partly filled with alluvium or wind-blown sand. The best-developed spring coves include Lake Channel, 12 miles southwest of American Falls; Blue Lakes, north of Twin Falls; Box and Blind Canyons, in secs. 27 and 28, T. 8 S., R. 14 E.; and Malad Canyon, near Hagerman. (See pls. 16, *B;* 24.) More or less similar topographic forms are common in many regions.[99] They are formed wherever conditions favor undermining of a relatively resistant mass of such character that cliffs are produced by the resultant slumping.

Along the Snake River the coves of this character are generally formed at points where the present canyon intersects or clearly approaches lava-filled former canyons. The coves have nearly vertical walls, in places more than 300 feet high, and some of them are as much as 2 miles long and 2,000 feet wide. They tend to be enlarged into amphitheaters at their heads, and in these places talus is conspicuously less abundant than it is along the walls nearer the main canyon. Many of the coves are floored with varying quantities of fine white sand. The floors of these subsidiary canyons are at different heights above the Snake River, their position depending largely on the altitude of the lowest point in the lava-filled valley exposed in the wall of the modern canyon. In several places springs that have not yet had opportunity to form coves issue directly from the canyon wall.

Russell [1] described these features in detail and recognized that they were formed through the undermining action of the springs issuing from them. He assumed that here, as in many other places, undermining was initiated by the presence of a weak bed under a more massive one, and he supposed that the sand in the bottoms of many of the coves was brought up by the spring water from such an underlying bed of poorly consolidated sand or silt. There is, however, no evidence of the presence of such material in suitable locations. The sand flooring of the coves is essentially similar to the wind-blown sand on the adjacent river flood plain. The Malad and Blue Lakes coves are underlain by dense basalt belonging to the Banbury volcanics. The Devils Corral and several other canyons between the Twin Falls

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[99] Lubbock, John (Lord Avebury), The scenery of Switzerland and the causes to which it is due, p. 116, 1896. Berthaut, H. M. A., Topologie, étude du terrain, vol. 1, p. 144, 1919. Wilson, A. W. G., Shore-line studies on Lakes Ontario and Erie: Geol. Soc. America Bull., vol. 19, p. 496, 1907. Freeman, O. W., The origin of Swimming Woman Canyon, Big Snowy Mountains, Mont., an example of a pseudo-cirque formed by landslide sapping: Jour. Geology, vol. 35, pp. 75–79, 1925.

[1] Russell, I. C., Geology and water resources of the Snake River Plains of Idaho: U. S. Geol. Survey Bull. 199, pp. 127–130, 1902.

and the Blue Lakes are underlain by Shoshone Falls andesite. Some of them are dry and high above the river, so that the sharp contact between the basalt and the andesite can be readily observed. Tunnels driven in several places to tap the spring water have encountered it moving through interstices in the basalt and held up by the relatively impermeable rock below.

In the opinion of the writer (Stearns), chemical weathering played a major part in disintegrating the large masses of basalt that have been removed, although mechanical weathering must also have had its influence. Talus is scarce at the heads of the coves where the springs issue, but not along the walls of the canyons through which the water flows. The accumulation of talus is a slow process, and the heads of the canyons have obviously been exposed to it for a shorter time than the downstream walls. In addition, disintegration of the talus blocks by chemical or other means must be more effective where talus falls directly into the spring water than in the lower reaches of the canyons, where the talus piles are commonly some distance away from the channels that carry the spring water.

Mechanical disintegration is caused largely by variation in temperature. Expansion and contraction of the rocks as they are alternately heated and cooled and the wedging action of ice contribute to the loosening of fragments of the basalt. The large diurnal and seasonal fluctuations in temperature in this region aid both these processes. On the other hand, fine-grained rocks, such as basalt, are much less susceptible to mechanical weathering than those of coarser grain. Both processes would be relatively ineffective on blocks sunk in the spring water, whose temperature is very uniform.

It is well known that basalt is especially susceptible to chemical attack by water containing atmospheric gases or such other constituents as organic acids. Clarke [2] in his summary of the effect of chemical weathering on common rock minerals shows that augite, olivine, and plagioclase are more soluble than orthoclase, the micas, and quartz. Disintegration begins with partial solution of the more susceptible minerals, with liberation of colloidal silica and the formation of carbonates and other salts. The iron carbonate tends to be promptly oxidized and redeposited as rusty coatings of the hydroxide. Next the undissolved residues are hydrated. The double process of solution and hydration results in increase in volume, which may, under suitable circumstances, aid disintegration. The accessory minerals commonly present in a basalt are for the most part resistant to chemical attack. In particular ilmenite, which appears to be abundant in the Pleistocene basalts of this region, commonly accumulates with little alteration in the sandy rock residues. The Pleistocene basalts contain large proportions of glass, which is unstable under

[2] Clarke, F. W., The data of geochemistry, 5th ed.: U. S. Geol. Survey Bull. 770, pp. 479–494, 1924.

atmospheric conditions and may contribute materially to the effectiveness of chemical disintegration.

The water discharging from the spring coves, as shown by the chemical analyses on page 174, is not appreciably higher in mineral content than the ordinary ground water of the region. The volume of this spring water is, however, a considerable factor in the problem. For example, Malad Spring discharges annually somewhat more than 1,000 second-feet, or about 1,000,000,000 tons of water. According to the analysis on page 174, this water contains 252 parts per million of dissolved mineral matter. Therefore, the total amount of mineral matter carried away in solution by this spring each year is computed to be about 250,000 tons, which is equal to about 3,500,000 cubic feet of basalt. Even if only a very small part of this material has been derived at or near the spring opening it is quantitatively adequate to account for the excavation of the Malad Canyon within the probable time since the spring began its work. Moreover, in every cubic foot of rock disintegrated by chemical weathering there is considerable material that is carried away in suspension—indeed, the quantity carried away in suspension may be as great as the quantity carried away in solution.

Whatever the precise agencies that have been most effective in forming the coves, it seems clear that the location of the springs and the position and size of the coves have been determined by the character of the rock bordering the buried channels that supply the ground water and by the relation between these channels and the present canyon. Where the lava-filled channel supplying the water was carved mainly in a poorly permeable rock, such as the basalt of the Banbury volcanics, leakage into the canyon now occupied by the Snake River has obviously not taken place as readily as where the channel was in permeable rock, such as most of the Pleistocene basalt. The result in general is that springs formed under the first set of conditions issue relatively high in the wall of the present canyon and have as yet formed no coves or, at most, only small ones. The different steps in the process of development of springs under the two sets of conditions are illustrated in plate 25.[2a] Each of the springs fed through buried channels along the Snake River corresponds in development to some one of the stages represented diagrammatically in this illustration. For example, Clear Lake corresponds essentially to the final stage developed where impermeable rock predominates, and Blue Lakes to the final stage developed mainly in permeable rock.

Immediately after a channel was filled by lava, the displaced river water, except such portions as may have been dammed, flowed over the plain, generally along the margin of the lava flow, some distance south of the old channel (B and H, pl. 25). However, this water soon began the excavation of a new canyon (C and I). Where the interven-

[2a] The position of the water table in sections C and D, pl. 25, should be the same as in section B.

ing rock was sufficiently permeable, leakage from the lava-filled channel began to cause springs in the new canyon as soon as the canyon was cut into the water table (I). In impermeable rock springs could not form until the widening of the new canyon removed enough of the barrier at points where it was either especially low or especially vulnerable to attack under the conditions governing erosion of the new canyon. Although spring water issuing as indicated in E and F, plate 25, has a steep gradient and may have large volume, it is unarmed with abrasive sand and cannot deepen its outlet as fast as the river deepens its canyon. As a result the lower part of the old fill is not tapped and can carry considerable water westward to supply other springs. Where erosion is proceeding in permeable rock, approach to impermeable material at depth tends to hold up the water table, as shown in L and K, plate 25. When the impermeable material is reached, as in L, downcutting by the spring water is greatly retarded, although headward progress of the cove may continue.

COVE PIRACY

Piracy by which one of the spring-formed canyons is robbed of its tributary underflow by another has been a continued process along this section of the Snake River. The principal known results of this process are described below.

When the Sand Springs basalt was erupted the Snake River was displaced from half a mile to 5 miles south of its old canyon and forced to find a new channel. Then the river began to erode a canyon to the baselevel of the river bed at the downstream end of the Sand Springs basalt, near the mouth of the Big Wood River. The water table in the Sand Springs basalt adjusted itself to the point of discharge, which at first was where the river tumbled back into its former partly lava-filled canyon. This place was shown by geologic mapping to be at the mouth of Salmon Falls Creek, near Thousand Springs. Here the first springs should have developed, because upstream from this point the river was presumably flowing above the water table on the surface of the lava plain. It therefore is not surprising to find at this point the best-developed coves—namely, Box and Blind Canyons, each over a mile long (pl. 5). Between this place and Blue Lakes numerous large springs, such as Clear Lake, issue, but they have not formed coves or have made only slight indentations in the canyon wall. It is believed that the absence of coves at these springs indicates that they are relatively young. This explanation is supported by the fact that the divide between the Snake River and the Sand Springs basalt-filled valley in this stretch is the relatively impermeable Banbury volcanics. At Blue Lakes the divide is formed by permeable basalts, and hence ground water had an opportunity to enter the river at this point early in the history of the present canyon. Accordingly, at this point a large cove exists similar to Box and Blind Canyons. The series of diagrammatic cross sections in plate 25 illustrate the differences in history according to my hypothesis of their development, if A to F are assumed to be stages in the development of Clear Lake and G to L of Blue Lakes Spring. Section A represents the geologic conditions in the vicinity of Clear Lake, Niagara, or Crystal Springs prior to the extrusion of the Sand Springs basalt and shows the Snake River Canyon incised in the relatively impermeable Banbury volcanics at the margin of younger basalt. Section G shows geologic conditions at the same stage in the vicinity of Blue Lakes. The important difference between the two sections is the presence of the thick series of permeable basalt beds overlying the relatively impermeable Banbury volcanics at Blue Lakes.

Sections B and H show the geologic conditions after the canyon was filled with the Sand Springs basalt and when the Snake River had just established a new course. The water table is close to the surface in the lava fill, because the baselevel of ground-water flow was established by the outlet of this water at Box Canyon Spring, near Hagerman Valley. The water-table conditions at Blue Lakes at this time were very similar.

Section C shows the conditions after the river had cut a canyon about 100 feet deep at the southern margin of the Sand Springs basalt. The banks of the river consist of the relatively impermeable Banbury volcanics, hence the ground water moving through the lava-filled channel is not affected by the new canyon and continues to flow westward toward Box Canyon, its nearest outlet. At the same stage (I) in the vicinity of Blue Lakes ground water in the lava-filled valley had already begun to escape into the river through the permeable basalt divide.

Section D shows a still later stage of river-cutting. In the vicinity of Clear Lake the water table was still in the same position, undisturbed by the presence of a fairly deep canyon adjacent to it because of the impermeable divide between them. At the same stage at Blue Lakes (J) a cove had already formed because water readily entered through the permeable divide between the old and new canyons. Considerable water was still moving westward through the lava fill, because the Blue Lakes outlet was still considerably higher than the bottom of the ancient canyon. West of Blue Lakes additional ground water probably entered the lava fill from the north, and this recharge accounted for the high level of the water table as shown in the section.

Section E shows the Snake River Canyon at Clear Lake in a more advanced stage than that shown in section D. In the process of deepening, the canyon had been widened sufficiently to reduce the impermeable divide slightly between the old and new canyons. Water in the lava fill found an outlet and began to overflow at low points in this divide in the stretch between Blue Lakes and Box Canyon, leading to the formation of Clear Lake and the adjacent springs. The level of the water table was consequently lowered by this overflow of ground water into the river. In the meantime, the Blue Lakes Cove was deepened slightly and migrated northward, as shown in section K. The old basalt divide has practically disappeared, but the deepening of the cove was arrested by the spring cutting down to the Banbury volcanics.

Section E shows the present stage of the Snake River Canyon at Clear Lake. The long erosional epoch has widened the canyon, thereby reducing the height of the impermeable inverted wedge-shaped divide between the old and new canyons. The springs have increased considerably in discharge, and the water table has been lowered. Probably the increase in the flow of these springs accounts in part for the drying-up of Blind Canyon, which was less favored by the underlying structural conditions than the adjacent Box Canyon. At Blue Lakes the cove has receded northward until a considerable part of the lava fill in the old canyon has been removed, as shown in section L. In spite of its steep gradient the Clear Lake water, being unarmed with abrasive sand, was not able to cut through the Banbury volcanics and keep the spring channel at the same level as the Snake River. For this reason considerable water is still moving westward through the unexposed parts of the lava fill and helping to supply the springs farther west. The deepening of the Blue Lakes Cove dried up the numerous coves upstream from it, because at these coves the impermeable Shoshone Falls andesite occurred at much higher levels than that of the Banbury volcanics at the Blue Lakes.

When, as described on page 69, the Cedar Butte basalt created a large lake near American Falls by damming the river, the basalt and the gravel beneath it proved so permeable that water leaked through it and created large springs. Early in the history of the lake the leakage may have equaled the inflow except during floods, but as the lake began to silt overflow became established. The section of this channel above Bonanza Lake (pl. 6), which has a maximum depth of about 50 feet and is now largely filled with wind-blown sand, was cut by the overflow water.

Progressive recession of what was then probably the main cove, with occasional assistance by overflow water from the lake, caused the excavation of the great amphitheater with a maximum depth of about 150 feet now occupied by Bonanza Lake and the Bonanza Sloughs. The great alluvial deposit of Bonanza Bar was left in the wake of this receding spring and now occupies the mouth of Lake Channel. By the time the main spring cove had receded to sec. 18, T. 9 S., R. 29 E., the underground leakage had established about four separate outlets. These in turn receded until two of them, more favored than the others, became the main spring vents. The northern one, coinciding with the lake-outlet channel and now occupied by Bonanza Lake, retreated more rapidly for a time because of the assistance rendered to it by the overflow waters of American Falls Lake. At the same time the southern vent was favored by the presence of weak lake beds on one side of its cove. Soon this cove began to capture the ground water tributary to a few of the coves to the north as is attested by the presence of a series of abandoned coves, shown in plate 6, in the north wall of the present Snake River Canyon near Massacre Rocks. As time elapsed this cove retreated to about the present mouth of Rock Creek, and here the decisive contest occurred. At this stage there were apparently two main coves receding toward the lake, both progressing at a rate largely dependent upon the supply of ground water. The struggle for the capture of the lake waters and the establishment of the future course of the Snake River was finally won by the southern cove, and the northern cove, in sec. 1, T. 9 S., R. 29 E., and sec. 36, T. 8 S., R. 29 E., is now abandoned and slowly filling with wind-blown sand. The northern cove was headed northward toward the main underflow channel, or pre-lava valley, of the Snake River, but the southern cove succeeded in draining the lake because it was working in the narrowest part of the dam adjoining Massacre Rocks. In plate 6 is shown a remnant of this dam on the south side of the river at this place.

In a relatively short time the waters of the lake, tumbling over the head of this amphitheater, must have cut down the narrow divide and turned loose the full erosive power of the Snake River on the soft, unconsolidated lake deposits and the underlying weak tuffs. Thus the present course of the Snake River channel was established. The numerous abandoned coves in the Lake Channel country now stand as mute evidence of a long battle of spring piracy. The present Bonanza Lake is spring-fed, drawing its water from continued leakage through the Cedar Butte basalt.

Devils Corral and Devils Wash Bowl are the largest of a group of box canyons, mostly dry, in the vicinity of Twin Falls, in Tps. 9 and 10 S., R. 18 E. (See pl. 5.) At the Devils Corral two coves about half a mile apart and both discharging into the Snake River receded from the river at right angles to each other, leaving an islandlike mass of basalt about 200 feet high surrounded by streams. (See pl. 5.) The eastern spring discharges the greater amount of water. It issues from basalt underlain at shallow depth by andesite, which crops out in the spring channel near the mouth of the cove. (See pl. 5.)

The abandonment or partial drying up of the springs between Twin Falls and Blue Lakes is the result of a long epoch of piracy by the Blue Lakes cove, which was favored by the geologic structure. Among other channels abandoned are a large blind canyon with its floor about 200 feet above the river, half a mile west of Blue Lakes, and a reentrant canyon about 75 feet deep that now hangs high and dry to the east of Blue Lakes. Both canyons were supplied by water flowing toward the west, and hence they were drained by the springs farther east.

The numerous springs between Blind Canyon and Blue Lakes have not formed spring coves, apparently mainly because of their youth. All these springs differ from those that have developed coves in that they form beautiful cascades. These cascades were caused by the high impermeable divide that separates the Snake River from its former lava-filled valley to the north, preventing the formation of springs until the divide was eroded, as illustrated in the first half of plate 25.

SPRINGS BETWEEN AMERICAN FALLS AND MILNER

Between American Falls and the Narrows, 4½ miles farther downstream, several springs enter the Snake River from the north bank.

Rueger Spring.—Rueger Spring, in sec. 31, T. 7 S., R. 31 E., issues in a swampy tract about 30 feet above the river in the American Falls lake beds. Basalt of the Massacre volcanics, broken by several faults, lies immediately below and is the most probable source of this spring. (See pl. 6.) Water is led by gravity, from the spring to American Falls, where it is pumped across the river to supply the city. A record of the discharge of this spring is given below.

Discharge of Rueger Spring, 1925–28 [1]

[Records from the U. S. Bureau of Reclamation]

Date	Gage reading (feet)	Discharge (second-feet)	Date	Gage reading (feet)	Discharge (second-feet)	Date	Gage reading (feet)	Discharge (second-feet)
1925			1927			1928		
June 18	0.57	14.00	Mar. 21	0.50	19.61	Apr. 18	0.50	16.90
July 21	.56	11.98	May 26	1.45	18.59	May 8	.71	21.44
Aug. 5	.56	10.39	June 5	.91	20.19	Aug. 2	.60	21.50
Aug. 24	.59	11.09	June 7	1.06	18.34			
			June 29	---------	19.00			
1926			July 15	.72	18.19			
Apr. 1	.49	11.28	Aug. 11	.65	17.14			
May 22	.49	13.53	Sept. 1	.58	19.69			
June 24	.49	6.26						
July 9	.50	11.82						

[1] The town of American Falls obtains its water supply from Rueger Spring. This would account for the irregularity of flow. The gage readings were much influenced by the presence of moss in the channel below.

Davis Springs.—Davis Springs issue in sec. 6, T. 7 S., R. 30 E. (See pl. 6.) There are two main vents and several smaller ones. The springs rise along traceable faults that displace the Massacre volcanics and the Eagle Rock tuff. The principal aquifer at this locality is the permeable basalt belonging to the Massacre volcanics. Although this basalt is not visible at the springs because of a cover of American Falls lake beds and recent landslides, it is probably the source of the water. The obsidian tuff that lies stratigraphically just below the Massacre volcanics forms the basement over which the springs discharge. Small seeps issue in some places from the obsidian tuff, but it is not sufficiently permeable to carry the volume of water that issues here. The water-table contours on plate 19 indicate that the water which is supplying the springs comes from the north and east. Some increase in their discharge and in the formation of new seeps and landslides has been reported since the American Falls Reservoir was built. The discharge of the springs is given in the table below:

Discharge, in second-feet, of Davis Springs, 1925–28 [1]

[Records furnished by U. S. Bureau of Reclamation]

June 25, 1925	1.04	June 7, 1927	3.06	September 1, 1927	3.13
July 19, 1926	2.35	June 29, 1927	3.27	April 18, 1928	3.55
May 6, 1927	2.91	July 15, 1927	5.29	August 2, 1928	3.58
June 5, 1927	6.67	August 11, 1927	3.73		

[1] The flow from Davis Springs during 1927 and 1928 varied materially with the stage of the American Falls Reservoir and probably with the use of water on the Aberdeen-Springfield project.

Mary Franklin Mine Springs.—In sec. 11, T. 8 S., R. 30 E., are the Mary Franklin Mine Springs, named from an old gold placer at this place. (See pl. 6.) Excavations show that the water issues from the permeable basalt of the Massacre volcanics, which rests as usual on the obsidian tuff of the Eagle Rock formation. Between the Mary Franklin Mine Springs and the Davis Springs occur several small seeps which together discharge only a few gallons a minute. The recent slumping of the unconsolidated American Falls lake beds along the bank where these seeps occur suggests that they result from leakage from the American Falls Reservoir. The discharge of the Mary Franklin Mine Springs is given in the table on page 153.

Mower Springs.—The Mower Springs comprise a line of seeps along the north bank of the Snake River opposite the mouth of Rock Creek. The total discharge is probably not more than 1.5 second-feet.

Springs near Lake Walcott.—Between the mouth of the Fall River and Lake Channel, on the north bank of Lake Walcott, are three groups of springs that enter along the shore and are easily distinguished during seasons of muddy water by the clear water they discharge. They issue from Pleistocene basalt and derive their water from the northeast. Liberty Hunt, who formerly lived in the part of the Snake River Canyon now flooded by Lake Walcott and subsequently moved into the adjacent Lake Channel, gives an interesting account of the history of the springs. According to him, Gifford Springs, at the mouth of Lake Channel, in sec. 16, T. 9 S., R. 28 E., came into existence about a year after the dam was completed. Little Gifford Spring, half a mile downstream, in sec. 17, formerly issued from under the rim rock and tumbled down into the Snake River. Nearby was Big Gifford Spring, which also issued from under the rim rock and discharged prior to the construction of the dam about 1,200 miner's inches (24 second-feet). A fourth spring, three-quarters of a mile downstream from Big Gifford Spring, discharged about 75 miner's inches (1½ second-feet), but it is now distinguished with difficulty, as it is nearly submerged. At an old rock cabin in sec. 19 a spring issued from under the rim rock and discharged about 600 miner's inches (12 second-feet). About a mile downstream, near the county line, was Keats Spring, now drained. It discharged about 30 miner's inches (0.6 second-foot). The Hunt Spring was 2¼ miles farther downstream along the rim. It yielded about 50 miner's inches (1 second-foot). Four miles below the Hunt Spring was the Smith or Foster Spring. It discharged about 100 miner's inches (2 second-feet) and is still visible along the shore. According to Mr. Hunt's recollection of his estimates, these springs had a combined discharge of about 2,055 miner's inches or (51 second-feet) prior to their flooding. As the tendency is to overestimate water, the total flow of these springs was probably about 25 to 35 second-feet. Considerable change has been wrought by the flooding of these springs. Numerous sloughs have appeared in Lake Channel, and Bonanza Lake at its head has steadily risen as a result of the rise of the ground water caused by the change in baselevel of the spring discharge and by irrigation of the Aberdeen-Springfield tract, as shown by the water-table contours on plate 19.

Discharge, in second-feet, of Mary Franklin Mine Springs and small seeps nearby 1925–28 [1]

[Records furnished by U. S. Bureau of Reclamation]

Date	3-foot weir gage reading (feet)	Discharge		
		Springs	Seeps	Total
1925				
Mar. 22	0.69	5.79		
Apr. 14	.68	5.66		
May 8	.72	6.17		
June 10	.70	5.92		
July 3	.70	5.92		
Aug. 8	.68	5.66		
Sept. 8	.68	5.66		
Oct. 13	.68	5.66		
Nov. 20	.68	5.66		
Dec. 1	.70	5.92		
1926				
Jan. 2	.68	5.66		
Feb. 16	.68	5.66		
Mar. 17	.68	5.66		
Apr. 1	.68	5.66	2.00	7.66
Apr. 11	.68	5.66		
May 19	.70	5.92		
May 22	.68	5.66	3.08	8.74
June 17	.70	5.92		
June 24	.68	5.66	2.42	8.08
July 9	.68	5.66		
Aug. 11	.68	5.66		
Sept. 14	.68	5.66		
Oct. 7	.68	5.66		
Nov. 9	.68	5.66		
Dec. 1	.70	5.92		

Date	3-foot weir gage reading (feet)	Discharge		
		Springs	Seeps	Total
1927				
Jan. 1	0.72	6.17		
Feb. 7	.74	6.43		
Mar. 2	.80	7.23		
Apr. 1	.80	7.23		
May 4	.84	7.78		
May 9	.84	7.78		
June 5	.89	8.48	2.02	10.50
June 7	.89	8.48	1.90	10.38
June 10	.88	8.34		
June 29	.96	9.50		
July 6	.86	8.06		
July 15	.90	8.62	1.59	10.21
Aug. 11	.90	8.62	3.87	12.49
Aug. 16	.88	8.34		
Sept. 1	.89	8.48	2.06	10.54
Sept. 16	.88	8.34		
Oct. 13	.88	8.34		
Nov. 6	.88	8.34		
Dec. 11	.88	8.34		
1928				
Jan. 19	.99	9.95		
Feb. 2	.98	9.80		
Mar. 3	.99	9.95		
Apr. 2	.99	9.95		
May 1	.98	9.80		
June 9	.90	8.77		
July 17	.88	8.34		
Aug. 3	.90	8.60	1.95	10.55
Aug. 15	.88	8.34		
Sept. 6	.87	8.20		
Oct. 16	.86	8.06		
Nov. 30	.84	7.78		

[1] After the filling of the American Falls Reservoir, in 1927, there was a decided increase in the discharge of the Mary Franklin Mine Springs. When the river was at a low stage there were several small springs that emerged below the main spring, and these were measured when practicable. At high water their flow was submerged.

With a view to studying the possible future seepage losses in the American Falls Reservoir the United States Bureau of Reclamation in 1921 installed a gage on the spring-fed Bonanza Lake, in sec. 21, T. 8 S., R. 29 E. The zero of this gage was 4,249.59 feet above sea level. The benchmark is cut on a big lava rock near the water's edge about 100 feet northwest of the gage, at an altitude of 4,250.99 feet. The records are given below:

Gage readings on Bonanza Lake, 1921–28

[Records furnished by U. S. Bureau of Reclamation]

	Feet		Feet		Feet
Dec. 15, 1921	[1] 0.39	June 17, 1926	0.22	Aug. 15, 1927	0.62
Dec. 27, 1921	[1] .29	July 9, 1926	.22	Sept. 13, 1927	.70
Apr. 27, 1922	[2] .19	Aug. 14, 1926	.8	Oct. 11, 1927	.90
May 30, 1922	.10	Sept. 14, 1926	.8	Nov. 11, 1927	1.02
June 19, 1922	.10	Oct. 7, 1926	.16	Mar. 15, 1928	1.64
July 21, 1922	.50	Nov. 9, 1926	.72	Apr. 12, 1928	1.66
Aug. 22, 1922	.40	Dec. 11, 1926	.44	May 15, 1928	1.60
Sept. 21, 1922	.50	Mar. 3, 1927	1.36	June 15, 1928	1.60
Oct. 18, 1922	.50	Apr. 18, 1927	1.30	July 17, 1928	1.38
Dec. 1, 1922	.50	May 9, 1927	.86	Aug. 15, 1928	1.36
Jan. 10, 1923	.02	May 17, 1927	[3] .80	Sept. 9, 1928	1.36
Jan. 14, 1926	[1] .56	June 7, 1927	[3] .85	Oct. 18, 1928	1.38
Feb. 16, 1926	.68	June 10, 1927	.82	Nov. 13, 1928	1.53
Mar. 17, 1926	.68	July 14, 1927	.62	Dec. 7, 1928	[1] 1.76
Apr. 12, 1926	.68	July 15, 1927	[3] .65		
May 19, 1926	.40	Aug. 11, 1927	[3] .55		

[1] Lake covered with ice.
[2] Water surface has been 0.3 to 0.4 foot higher.
[3] Measured by Twin Falls Canal Co.

The American Falls Reservoir was filled in 1926, and it is evident from the rise in the surface of Bonanza Lake since that time that leakage from the reservoir is reappearing in this lake. The water-table contours on plate 19 furnish additional evidence of this condition.

This lake is on the downstream side of the Cedar Butte basalt described on page 69, and were it not for the thick beds of silt and clay between the reservoir and this basalt the leakage would doubtless have been much greater.

SPRINGS BETWEEN MILNER AND BLUE LAKES

Minor springs.—In descending the Snake River Canyon below Milner, none of the larger springs that enter from the north are encountered until the Blue Lakes outlet, 4 miles north of the city of Twin Falls, is reached. There are several smaller springs in this section above Blue Lakes, however, on which measurements have been made as follows:

Discharge of spring in Snake River Canyon between Milner and Blue Lakes

[Records for 1902 and 1917 furnished by Twin Falls North Side Land & Water Co., Jerome, Idaho; for 1923 and 24 by Idaho Power Co., Boise, Idaho]

Date	Stream	Locality	Discharge (second-feet)
June 10, 1902	18 springs on both sides of Snake River.	Between Milner and Devils Corral	70.5
Sept. 17, 1917	Devils Wash Bowl outlet	NE¼ sec. 4, T. 10 S., R. 18 E., on north side of Snake River.	12.7
Aug. 20, 1923	do	do	19.7
July 22, 1924	do	do	16.7
Aug. 19, 1924	do	do	15.2
June 10, 1902	Devils Corral upper outlet	SE¼ sec. 32, T. 9 S., R. 18 E., on north side of Snake River.	20.7
July 30, 1923	do	do	37.3
Aug. 30, 1923	do	do	41.9
July 21, 1924	do	do	41.5
Sept. 12, 1924	do	do	43.6
June 10, 1902	Devils Corral lower outlet	Near center sec. 32, T. 9 S., R. 18 E., on north side of Snake River.	3.8
Aug. 6, 1923	do	do	8.4
Sept. 29, 1923	Spring	SW¼ sec. 31, T. 9 S., R. 18 E., on north side of Snake River above Shoshone Falls.	6.3
June 10, 1902	10 springs	Between Devils Corral and Shoshone Falls.	17.0

In addition to the inflow from the springs on the north side of the canyon between Milner and Blue Lakes as here listed, there is considerable inflow from the south side of the canyon, nearly all of which, according to local testimony, has developed since irrigation started on the Twin Falls tract. A detailed investigation of inflow in this section of the Snake River was made by C. E. Tappan, engineer for the Idaho Power Co., in the late summer of 1923, when no water except leakage was passing the Milner Dam, and the following data and remarks are based on his work.

The Snake River at the Murtaugh Bridge, in sec. 6, T. 11 S., R. 20 E., about 7½ miles west of Milner and just above the mouth of Dry Creek, had an average discharge of 48 second-feet from August 7 to September 15, 1923. The average discharge at the station below the Milner Dam for the same period was 12 second-feet, and the total gain between the two points was thus about 36 second-feet, most of which came from the south side of the river, within a mile or so upstream from the Murtaugh Bridge. During the same period, Dry Creek contributed an average flow of 22 second-feet to the Snake River, probably supplied by waste and seepage from the Twin Falls South Side tract. Below the mouth of Dry Creek the spring inflow from the south side became noticeably greater, and in sec. 18, T. 10 S., R. 19 E., several springs of considerable magnitude discharged from the south canyon wall, 75 feet or more above the river surface. Other springs in the same section appeared on the floor of the canyon, and numerous springs from the south, with discharges ranging from mere seepage to perhaps 20 second-feet, continued to flow into the river until a point a mile west of the Hansen Bridge, in sec. 11, T. 10 S., R. 18 E., was reached, where springs appeared on both sides of the stream. On the south side of the river above Twin Falls some springs were discharging 21.3 second-feet on September 22, 1923.

Measurements showed that during the period August 7 to September 15, 1923, the Snake River had an average discharge of 488 second-feet at a point about half a mile downstream from Twin Falls, in sec. 33, T. 9 S., R. 18 E., just above the upper outlet of Devils Corral. The average flow at the Murtaugh Bridge during the same period was 48 second-feet, and the indicated gain between the two points was 440 second-feet, of which, as previously stated, 22 second-feet was contributed from Dry Creek just below the Murtaugh Bridge station. Several miscellaneous measurements showed a total gain to the Snake River between the station half a mile below Twin Falls and Shoshone Falls of 95 second-feet. The average flow at Shoshone Falls August 7 to September 15, 1923, was 583 second-feet, indicating a total average gain of 571 second-feet from Milner to Shoshone Falls between these dates. The average flow of the Snake River at the Perrine Bridge, in secs. 28 and 33, T. 9 S., R. 17 E., just above the Blue Lakes outlet, during this period was 679 second-feet, indicating an average gain between Shoshone Falls and the Perrine Bridge of 96 second-feet.

Discharge of Blue Lakes springs

[Measurements made 200 feet below highway bridge near mouth]

Date	Authority [1]	Measured discharge (second-feet)	Date	Authority [1]	Measured discharge (second-feet)	Date	Authority [1]	Measured discharge (second-feet)
August 27, 1902	TF	80	November 1918	TF	221	September 1920	TF	220
August 27, 1910	TF	110	December 1918	TF	218	October 1920	TF	228
September 7, 1913	M	191	January 1919	TF	208	November 1920	TF	219
August 6, 1914	M	199	February 1919	TF	200	December 1920	TF	196
May 1917	TF	190	March 1919	TF	197	March 30, 1921	M	192
June 1917	TF	187	April 1919	TF	196	July 25, 1921	M	193
July 1917	TF	185	May 1919	TF	200	August 12, 1921	M	190
August 1917	TF	192	June 1919	TF	208	September 19, 1921	M	200
September 1917	TF	204	July 1919	TF	211	April 30, 1922	M	198
October 1917	TF	215	August 1919	TF	210	August 12, 1922	M	185
November 1917	TF	218	September 1919	TF	202	April 14, 1923	GS	209
December 1917	TF	215	October 1919	TF	190	May 5, 1923	GS	192
January 1918	TF	209	November 1919	TF	185	July 23, 1923	GS	210
February 1918	TF	203	December 1919	TF	188	November 1, 1923	GS	220
March 1918	TF	200	January 1920	TF	192	April 16, 1924	GS	186
April 1918	TF	200	February 1920	TF	192	May 18, 1924	GS	187
May 1918	TF	203	March 1920	TF	192	June 6, 1924	GS	193
June 1918	TF	206	April 1920	TF	194	July 21, 1924	IP	196
July 1918	TF	209	May 1920	TF	195	July 24, 1924	GS	192
August 1918	TF	212	June 1920	TF	199	August 19, 1924	IP	198
September 1918	TF	216	July 1920	TF	205	September 11, 1924	IP	194
October 1918	TF	219	August 1920	TF	209	November 1, 1924	IP	211

[1] TF, Twin Falls North Side Land & Water Co.; M, Meinzer, O. E., U. S. Geol. Survey Water-Supply Paper 557, pp. 45-46, 1927; GS, U. S. Geol. Survey unpublished records; IP, Idaho Power Co.

NOTE.—Measurement of Sept. 7, 1913, includes diversions. Where day of month is not given, the discharge is monthly average.

Blue Lakes.—The Blue Lakes, in sec. 28, T. 9 S., R. 17 E., are fed by springs. The water rises about 160 feet above the Snake River, and though some of the water from the outlet is used for irrigation on that portion of the Perrine ranch lying north of the Snake River, the greater part discharges directly into the river. The lakes, according to

Russell,[3] lie in a tributary box canyon cut into the wall of the main canyon, here about 700 feet high and nearly vertical. The tributary canyon is about 2 miles long and about 2,000 feet wide at the top and heads in a semicircular amphitheater with vertical walls about 300 feet high. This canyon has a relatively small amount of talus bordering the cliffs, especially in the headwater amphitheater. (See pl. 24.) One reason for the paucity of springs between Blue Lakes and Shoshone Falls is that the impermeable Shoshone Falls andesite retarded their development, as explained on pages 147–151, and permitted those which once existed to be drained through the more advantageously situated Blue Lakes. Discharge measurements of Blue Lakes springs are given in the table on page 156.

SPRINGS BETWEEN BLUE LAKES AND CRYSTAL SPRINGS

Between Blue Lakes and Crystal Springs, 10 miles downstream, several small springs issue from the basalt. The largest one is above Auger Falls, in the NW¼ sec. 29, T. 9 S., R. 17 E., a mile below the Blue Lakes outlet. It issues from talus blocks at the foot of the north rim and flows northwestward parallel to the Snake River for 1 mile before joining the river. (See pl. 5.) The discharge in 1902 may have been augmented by waste water from the Perrine ranch, as the measurement in 1917 showed only 16.5 second-feet at the point where the flow from this spring reaches the Snake River.

Trail Spring, about 5 miles below the Blue Lakes outlet, in sec. 15, T. 9 S., R. 16 E., issues at the contact of the basalt of the Banbury volcanics with the overlying Pleistocene basalt on the north side of the river. The discharge of this spring and others along this stretch of the river is given in the table below. It may be that the so-called "Auger Falls Spring" listed in the table below is this spring, for there is no other large one known in this vicinity.

Discharge of springs between Blue Lakes and Crystal Springs

[Measurements furnished by Twin Falls North Side Land & Water Co.]

Date	Spring	Point of measurement	Discharge (second-feet)
Oct. 9, 1917	Spring	2 miles below Blue Lakes outlet, in sec. 19, T. 9 S., R. 17 E.	16.5
Do	Trail Spring	6 miles below Blue Lakes outlet, in sec. 15, T. 9 S., R. 16 E.	5.5
Do	8 springs	Sec. 7, T. 9 S., R. 16 E	10.9
1902	Auger Falls	Not known	25

In sec. 17, T. 9 S., R. 16 E., a spring issues from talus at the base of the undifferentiated Pleistocene basalt and forms a small pool on a bench carved in relatively impermeable Banbury basalt. It was formed doubtless by irrigation on the Twin Falls South Side tract. On July 6, 1928, the spring had an estimated discharge of 6 second-feet.

In sec. 7, T. 9 S., R. 16 E., about a mile upstream from Crystal Springs, 8 small springs issue from the basalt on the north wall of the canyon. Their combined discharge amounts to about 10 second-feet.

[3] Russell, I. C., op. cit. (Bull. 199), p. 127.

SPRINGS BETWEEN CRYSTAL SPRINGS AND THOUSAND SPRINGS

Crystal Springs.—Crystal Springs are in sec. 12, T. 9 S., R. 15 E. They consist of numerous good-sized springs, which extend for over a quarter of a mile along the canyon side and are collected together artificially so that they flow into the river in two main channels. The springs are ponded by dams and utilized by a commercial fish hatchery.

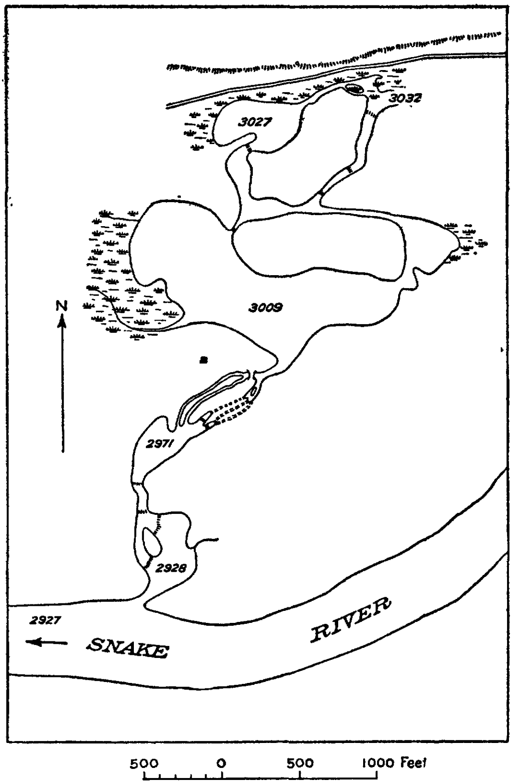


FIGURE 12.—Map of the vicinity of Clear Lake, which is fed by large springs. Altitude of water surfaces shown in feet above sea level. Surveyed by Warren Oakey in 1921.

They issue from the bottom of the Sand Springs basalt near the contact with the underlying impermeable Banbury basalt. (See pl. 5.) It is believed that these spring outlets are spillways for ground water moving through the ancient lava-filled canyon of the Snake River not far to the north, as illustrated in plate 25. Measurements of these springs are given in the table below:

Total discharge of Crystal Springs

[Records for 1902, 1907, and 1919 supplied by Twin Falls North Side Land & Water Co.; for 1924, by Idaho Power Co.]

	Second-feet		*Second-feet*		*Second-feet*
1902	304	July 22, 1924	433	Sept. 9, 1924	486
Oct. 11–12, 1917	536	Aug. 18, 1924	477	Nov. 1, 1924	479
Sept. 22, 1919	475				

Niagara Springs.—Niagara Springs are in sec. 10, T. 9 S., R. 15 E. They appear in a well-defined outlet under the canyon rim rock, about 130 feet above the river level. A portion of the flow is used for irrigation of orchards, and the rest flows directly into the Snake River. A small amphitheater is forming at their head. A tunnel driven into the canyon wall nearby shows that the water escapes along the contact of Banbury and Sand Springs basalts. (See pl. 5.)

Discharge of Niagara Springs

[Records for 1902–20 supplied by Twin Falls North Side Land & Water Co.; for 1924, by Idaho Power Co.]

Date	Discharge (second-feet)	Remarks	Date	Discharge (second-feet)	Remarks
1902	107		Aug. 17, 1924	226	At mouth. Does not include 36 second-feet diverted.
Sept. 8, 1917	242	At mouth.	Sept. 9, 1924	215	At mouth. Does not include 27 second-feet diverted.
Sept. 1, 1918	322	At mouth. Includes 12.5 second-feet diverted.	Nov. 1, 1924	231	At mouth. Does not include 19 second-feet diverted.
Sept. 23, 1919	250	At mouth. Includes 10 second-feet diverted.			
Sept. 16, 1920	252	At mouth. Does not include diversions.			
July 19, 1924	218	Do.			

Clear Lake.—Clear Lake, in sec. 2, T. 9 S., R. 14 E., is fed by numerous large springs flowing from the talus that lies at the base of the Sand Springs basalt, about 130 feet above the river. A detailed map of these springs is shown in figure 12,[4] and their origin is described on pages 147–149 and illustrated in plate 25. This spring has long been under consideration as a power site. Measurements made at the lake outlet, about a third of a mile from the river, are given below.

Discharge of Clear Lake

[Records furnished by Idaho Power Co. and Twin Falls North Side Land & Water Co. Records for 1917–20 are monthly averages]

	Second-feet		*Second-feet*		*Second-feet*
1902 (estimated)	150	May 1918	465	October 1919	492
April 1913	410	June 1918	477	November 1919	485
July 1, 1914 (510 second-feet at mouth of outlet stream)	437	July 1918	486	December 1919	477
June 1917	487	August 1918	498	January 1920	490
July 1917	489	September 1918	518	February 1920	489
August 1917	514	October 1918	517	March 1920	476
September 1917	527	November 1918	502	April 1920	473
October 1917	537	December 1918	489	May 1920	470
November 1917	538	January 1919	481	June 1920	467
December 1917	524	February 1919	487	July 1920	466
January 1918	500	March 1919	476	August 1920	480
February 1918	482	April 1919	473	September 1920	470
March 1918	469	May 1919	471	October 1920	476
April 1918	474	June 1919	477	November 1920	486
		July 1919	480	December 1920	475
		August 1919	496	July 19, 1924	501
		September 1919	485	Aug. 17, 1924	494

[4] Meinzer, O. E., Large springs in the United States: U. S. Geol. Survey Water-Supply Paper 557, fig. 16, 1927.

Briggs Spring.—Briggs Spring is in the SE¼ sec. 3, T. 9 S., R. 14 E. It issues from the talus at the foot of the canyon wall, undoubtedly from the contact of Banbury and Sand Springs basalts like the others upstream. It flows due west for about a mile before joining the Snake River. (See pl. 5.) Its discharge is given below:

Discharge of Briggs Spring

[Records for 1902–20 supplied by Twin Falls North Side Land & Water Co.; for 1924, by Idaho Power Co.]

	Second-feet		*Second-feet*		*Second-feet*
1902	77	Sept. 12, 1919	128	Aug. 17, 1924	110
Sept. 13, 1917	128	Sept. 17, 1920	122	Sept. 10, 1924	113
Sept. 30, 1918	130	July 16, 1924	110	Oct. 31, 1924	125

Banbury Springs.—On the east bank of the Snake River in sec. 33, T. 8 S., R. 14 E., a series of springs tumble down over a cliff of Banbury basalt from the contact of the overlying Sand Springs basalt. On the opposite bank is Banbury Hot Spring, described on page 167. The cold water is piped across the river for irrigation. The discharge of the cold springs is given below:

Discharge of Banbury Springs, Idaho

[Records for 1902–20 furnished by Twin Falls North Side Land & Water Co.; for 1924, by Idaho Power Co.]

Date	Discharge (second-feet)	Remarks	Date	Discharge (second-feet)	Remarks
1902	66		July 15, 1924	95.4	Does not include diversions.
April 1913	128	Total flow.	Aug. 16, 1924	93.7	Do.
Sept. 14, 1917	124	Includes 4 second-feet diverted.	Sept. 8, 1924	101	
Sept. 13, 1919	108	Do.	Oct. 31, 1924	108	
Sept. 17, 1920	117				

Box Canyon and Blind Canyon Springs.—Two large spring coves in secs. 27 and 28, T. 8 S., R. 14 E., near the mouth of Salmon Falls Creek, are shown on plate 5. They form narrow blind canyons extending east from the Snake River and are supplied with water from the Sand Springs basalt. They have an origin similar to that of Blue Lakes Cove (pl. 25). The rock exposed in their vertical walls is the typical Sand Springs basalt. Its great thickness locally is due to the filling of a valley-shaped depression cut in Banbury basalt. From its proximity to the mouth of Salmon Falls Creek this depression may be the place where this creek emptied into the ancient Snake River Canyon now filled with Sand Springs basalt. The springs in both coves issue nearly 200 feet above the Snake River. Most of the spring inflow enters at the head of Box Canyon, but more is received as the stream flows toward the Snake River. The discharge of Blind Canyon Spring at its mouth, as recorded by the Twin Falls North Side Land & Water Co., was 2 second-feet in 1902, 11.8 second-feet October 13, 1917, and 8.5 second-feet September 19, 1919. The discharge of Box Canyon Spring is given in the following table:

Discharge of Box Canyon Spring in sec. 27, T. 8 S., R. 14 E.

[Records for 1902–21 supplied by Twin Falls North Side Land & Water Co.; for 1924, by Idaho Power Co.]

Date	Discharge (second-feet)	Remarks	Date	Discharge (second-feet)	Remarks
1902	450	Discharge estimated at mouth.	Sept. 30, 1918	338	At falls, ¾ mile from river.
1911	465	At mouth.	Sept. 13, 1919	302	Do.
Sept. 14, 1917	341	Flow into Box Canyon between point of measurement and mouth estimated 120 second-feet additional.	Sept. 15, 1920	308	Do.
			July 13, 1921	356	Do.
			Aug. 16, 1924	309	Do.
			Sept. 8, 1924	264	Do.
			Nov. 2, 1924	277	Do.

A spring yielding about 12 second-feet of water issues in sec. 28, T. 8 S., R. 14 E., from a fault displacing basalt and clay beds a short distance upstream from Blind Canyon.

Blue Springs.—Several springs enter the river between Box Canyon and the mouth of Sand Springs. The largest is Blue Springs, which issues in a beautiful blue pool in the NW ¼ sec. 28, T. 8 S., R. 14 E., at the river's edge. Local residents state that similar springs issue in the river bottom between this point and the mouth of Box Canyon. Several small springs also discharge from the lava about half a mile below the old Riverside Ferry, and their discharge is listed below:

Discharge of springs between Box Canyon and Sand Springs

[Records supplied by Twin Falls North Side Land & Water Co.]

Date	Stream	Locality	Discharge (second-feet)
1902	Blue Springs	Sec. 28, T. 8 S., R. 14 E.	48
Oct. 13, 1917	do	do	61.5
Sept. 19, 1919	do	do	61.0
1902	Springs	½ mile below old Riverside Ferry, in sec. 20, T. 8 S., R. 14 E.	15.0
Oct. 13, 1917	do	do	13.2

Sand Springs.—The Sand Springs are in sec. 21, T. 8 S., R. 14 E. They rise about 250 feet above the river level, about 1½ miles east of the Snake River. Part of the flow is used for irrigation. The rest formerly spilled over the rim rock into the Snake River, but in recent years it has been diverted into the Thousand Springs feeder canal and utilized by the Thousand Springs power plant. The spring issues from the Sand Springs basalt at the foot of a bluff of Thousand Springs basalt about 50 feet high. This bluff is the unburied north rim of the ancient Snake River Canyon, which was filled nearly to the top at this place with the Sand Springs basalt. The springs issue too high to be supplied by water in the Sand Springs basalt, hence they are fed by ground water overflowing from the older canyon to the north filled with Thousand Springs basalt. The discharge of Sand Springs at the point of measurement in sec. 17, T. 8 S., R. 14 E., is given below:

Discharge of Sand Springs

[Records for 1902-21 supplied by Twin Falls North Side Land & Water Co.; for 1924, by Idaho Power Co.]

Date	Discharge (second-feet)	Remarks	Date	Discharge (second-feet)	Remarks
1902	46	Below diversions.	Sept. 21, 1920	80.7	Includes 8 second-feet diverted.
May 7, 1912	52	Do.	July 13, 1921	66.5	Does not include diversions.
April 1913	68	Do.	July 15, 1924	82.4	Includes 17.4 second-feet diverted.
Sept. 15, 1917	80.4	Includes 14.2 second-feet diverted.	Aug. 15, 1924	72.4	Includes 19.7 second-feet diverted.
Apr. 8, 1918	81.9	Includes 3 second-feet diverted.	Sept. 7, 1924	79.6	Includes 18.5 second-feet diverted.
Sept. 30, 1918	94.5	Includes 11.2 second-feet diverted.	Nov. 3, 1924	85.9	Includes 1.2 second-feet diverted.
Sept. 6, 1919	75.9	Includes 12.2 second-feet diverted.			
Oct. 19, 1919	66.6	Measured at head.			
Oct. 21, 1919	71.9	Does not include diversions.			

A small spring that enters the Snake River between Sand Springs and Thousand Springs, in sec. 17, T. 8 S., R. 14 E., had an estimated discharge of 4.2 second-feet on October 13, 1917, according to records furnished by the Twin Falls North Side Land & Water Co.

Thousand Springs.—The Thousand Springs, in sec. 8, T. 8 S., R. 14 E., consist of numerous large and small springs which issue about 30 feet below the top of the rim rock. Part of this water is collected by a canal about 2,500 feet long and utilized under a head of 186 feet to generate power. Snowbank Spring, one of the larger springs at the south edge of the series, formerly discharged down the talus slope into the Snake River, but during recent years it has been included with the other springs tributary to the collecting canal. These springs before they were diverted into the canal made a beautiful display, as shown in plate 26. Measurements have been made of the springs after the water has passed through the power plant and include the combined flow of water utilized for power together with leakage. The Thousand Springs group issues from an exceedingly permeable subaqueous phase of the Thousand Springs basalt, where it rests upon impermeable Banbury basalt. The water is derived from a lava-filled valley to the north carved in these rocks by the Snake River to a lesser depth than the present canyon. The north rim of this former canyon is visible in sec. 1, T. 8 S., R. 14 E. Billingsly Creek now flows approximately along the northward extension of the axis of this ancient valley where it was not filled with lava. It seems reasonable to suppose that all the water of this group of springs could be intercepted by one tunnel cross-cutting the Thousand Springs basalt at the contact. To do this, however, would require a tunnel at a lower level than the collection canal at the Thousand Springs power plant or a long tunnel driven to the base of the Thousand Springs basalt from the canal. Each spring from Sand Springs to Riley Springs is at a successively lower altitude, indicating that the buried channel is filled with water to a certain level and that each low place in the impermeable beds along the canyon wall serves as a spillway.

Discharge of Thousand Springs group of springs, Bickel to Snowbank Springs, inclusive

[Records for 1902–20 furnished by Twin Falls North Side Land & Water Co.; for 1924, by Idaho Power Co.]

Date	Discharge (second-feet)	Remarks
1902	797	
1910	818	
Sept. 17, 1915	836	Partly estimated.
Sept. 15, 1917	982	
Sept. 19, 1918	1,010	Do.
Sept. 6, 1919	850	Do.
Aug. 9, 1920	934	
July 14, 1924	[1] 1,006	Excludes 63 second-feet diverted from Sand Creek.
Aug. 15, 1924	[1] 891	Excludes 53 second-feet diverted from Sand Creek.
Sept. 7, 1924	909	Excludes 61 second-feet diverted from Sand Creek.

[1] Of this amount 509 second-feet came from Thousand Springs and Sand Springs above.

Measurements of individual springs downstream from the Thousand Springs power plant are shown in the following table, and the points of measurement are designated by letters in figure 13.

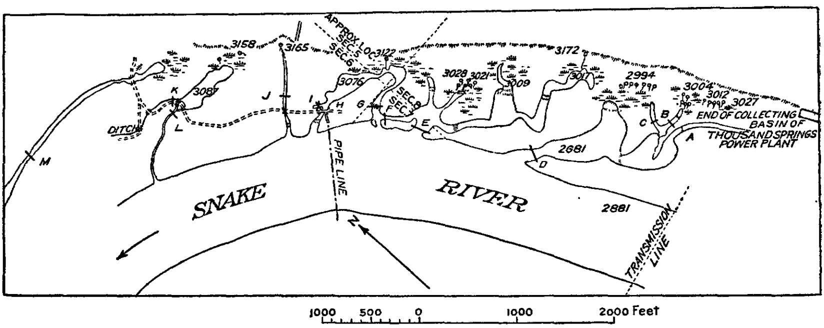


FIGURE 13.—Map of the Bickel Springs, or that part of the Thousand Springs group north of the Thousand Springs power plant. The letters indicate measuring stations, and the numbers indicate altitude of springs, spring outlets, and the river, in feet above sea level. Numerous springs occur between the escarpment and the river throughout the area, but only those for which altitudes are given are shown on the map. Surveyed by Warren Oakey in 1921. (After fig. 14, U. S. Geol. Survey Water-Supply Paper 557.)

Measurements of springs north of Thousand Springs power plant, in second-feet

Measuring section [1]	July 1921 [2]	July 1924 [3]	Aug. 1924 [3]	Sept. 1924 [3]	Oct. 1924 [3]
A	90.3				
B	39.7	38.2	39.0	40.2	36.8
C	10.9	10.7	11.2	8.1	10.0
D	163	252	244	238	254.0
E	114	107	104	120	
F	9.2				
F and G	16.2				
H	20	24.2	23.6	20.7	
I	23.9	24.0	21.4	21.7	
J	.8	.8	.7	2.0	
K	11.8	15.4	15.5	11.3	
L	5.7	7.9	2.4	5.2	
M [4]	45.9		57.0	67.7	

[1] The letters refer to place of measurement as shown on fig. 19.
[2] Measurements from unpublished records, U. S. Geol. Survey.
[3] Measurements furnished by Idaho Power Co.
[4] The discharge at point M is tributary to Riley Creek.

SPRINGS BETWEEN THOUSAND SPRINGS AND BLISS

Springs in Hagerman Valley.—Several springs rise under the canyon rim rock between the Bickel ranch and Malad Canyon, from 120 to 150 feet above the Snake River, and collect in channels that eventually reach the river after a portion of the water has been diverted for irrigation. These springs issue from the Malad basalt where it rests on the impermeable Hagerman lake beds and represent water collected in an ancient canyon of the Snake River north of that filled with the Thousand Springs basalt. Their location is shown on plate 5, and the measurements are given on page 165. There has been an increase of about 100 second-feet in these springs as a result of irrigation. Bliss and Woodworth Springs are downstream from the mouth of the Big Wood River. Woodworth Springs may be those known as "Sullivan Spring." There are several others in this stretch as shown on plate 5. Many of them issue from the Bliss basalt but are believed to be supplied from the ancient canyon filled with the Madson basalt.

Malad Springs.—The Malad Springs constitute the largest of the Snake River springs and indeed one of the largest known groups of springs in the world. The deep Malad Canyon which crosscuts an extensive ancient canyon filled with Malad basalt, acts as an efficient intercepting drain, and only a few minor springs appear along the banks of the Snake River below the mouth of Malad Canyon. The flow is used partly for the irrigation of the King Hill project and partly for power development at the Malad plant of the Idaho Power Co. The Malad Canyon is in reality a spring cove partly enlarged by landslides and river action. The Big Wood River empties into the head of the cove about 2½ miles from its mouth. At this point the Big Wood River has cut a narrow gorge in the basalt, but it has not been able to cut down as rapidly or remove as much rock as the clear spring water in the cove. Thus, in spite of carrying considerable silt at a steep gradient the Big Wood River tumbles nearly 50 feet from its narrow gorge into the amphitheater containing the spring pool at the head of Malad Canyon, as shown in plate 16, *B*. This contrast in erosive power may be in part the result of chemical weathering (pp. 144–147) but is chiefly due to the large addition to the volume of water contributed by the springs. It is estimated that the volume of the Big Wood River above the springs prior to irrigation was not over a fifth of the combined flow of the springs. The lower part of the cove has been materially enlarged by landslides caused by thin deposits of the Hagerman lake beds, which underlie the Malad basalt and overlie the Banbury volcanics at the mouth of the canyon. These impermeable beds form the western rim of the ancient canyon filled with the Malad basalt and serve as a divide causing the water to issue far above the Snake River. The Malad cove is the largest, and apparently the oldest, of all the coves in the valley.

Discharge of springs in Hagerman Valley

Date	Stream	Locality	Authority [1]	Discharge (second-feet)	Remarks
1902	Total of springs and creeks from Bickel ranch to Malad River.	Not known	TF	344	
Sept. 17, 1917	Riley Creek	Sec. 6, T. 8 S., R. 15 E. Near head	TF	62.4	Does not include 3 second-feet diverted.
July 13, 1921	do	do	TF	45.9	Does not include diversions.
Aug. 15, 1924	do	Near head of creek	IP	57.0	Do.
Sept. 6, 1924	do	do	IP	67.7	Do.
Sept. 17, 1917	Kearns Springs	Sec. 36, T. 7 S., R. 14 E	TF	91.8	
July 12, 1924	Tucker Springs	Near head	IP	79.0	
Sept. 17, 1917	Billingsly Creek	At State highway bridge, sec. 11, T. 7 S., R. 13 E	TF	159	Does not include 75.2 second-feet diverted upstream.
Sept. 24, 1919	do	do	TF	128	Does not include diversions.
July 10, 1924	do	do	IP	45.1	Do.
Aug. 13, 1924	do	do	IP	42.1	Does not include diversions amounting to 57.4 second-feet.
Sept. 5, 1924	do	do	IP	63.1	Does not include diversions amounting to 41.9 second-feet.
Oct. 29, 1924	do	do	IP	160	No diversions.
Sept. 17, 1917	Springs	Scattered between Billingsly Creek aud mouth of Malad Canyon.	TF	6.5	
Sept. 24, 1919	do	do	TF	20.5	
July 11, 1921	Woodworth Springs	6 miles below Hagerman	GS	7.7	
Do	Bliss Springs	7 miles below Hagerman	GS	2.0	

[1] TF, Twin Falls North Side Land & Water Co.; IP, Idaho Power Co.; GS, U. S. Geol. Survey Water-Supply Paper 533, p. 286, 1925.

Discharge, in second-feet, of upper Malad Springs

[Measuring section located 400 feet above upper dam in sec. 25, T. 6 S., R. 13 E.]

Date	Discharge	Remarks
Sept. 18, 1917	600	Records supplied by Twin Falls North Side Land & Water Co.
Apr. 25, 1920	621	Records supplied by Idaho Power Co.
June 4, 1920	608	Do.
Aug. 9, 1920	642	Do.
July 12, 1921	621	Records supplied by Twin Falls North Side Land & Water Co.
July 9, 1924	606	Records supplied by Idaho Power Co.
Aug. 12, 1924	620	Do.
Sept. 5, 1924	623	Do.
Oct. 28, 1924	638	Do.

Total discharge, in second-feet, of all Malad Springs at mouth of canyon in sec. 34, T. 6 S., R. 13 E.

Date	Discharge	Remarks
1902	1,090	Records supplied by Twin Falls North Side Land & Water Co.
1910	997	Do.
1911	998	Do.
Sept. 18, 1917	1,133	Do.
Sept. 26, 1919	1,145	649 second-feet in Malad flume and 496 second-feet in river. Records supplied by Twin Falls North Side Land & Water Co.
July 8, 1924	1,149	953 second-feet in Malad flume and 196 second-feet in river. U. S. Geol. Survey Water-Supply-Paper 593, p. 257, 1929.
July 17, 1924	1,198	1,020 second-feet in Malad flume and 178 second-feet in river. U. S. Geol. Survey Water-Supply Paper 593, p. 257, 1929.
Aug. 12, 1924	1,191	995 second-feet in Malad flume and 196 second-feet in river. U.S. Geol. Survey Water-Supply Paper 593, p. 257, 1929.
Sept. 5, 1924	1,190	975 second-feet in Malad flume and 215 second-feet in river. U. S. Geol. Survey Water-Supply Paper 593, p. 257, 1929.

The following diversions by the King Hill ditch were being made from the Malad flume at the time of the measurement in 1924: July 8, 293 second-feet; August 12, 301 second-feet; September 5, 274 second-feet. The remainder of the discharge in the Malad flume on those dates was passing through the Malad power plant.

Miscellaneous small springs.—The Twin Falls North Side Land & Water Co. reports estimates of 33 second-feet on September 18, 1917, and 14.8 second-feet on September 24, 1919, of the combined flow of various small springs between the Malad Canyon and Bliss.

THERMAL SPRINGS AND WELLS

WHITE ARROW HOT SPRING

White Arrow Hot Spring is about 16 miles northwest of Bliss, in the NE¼SE¼ sec. 31, T. 4 S., R. 13 E., at an altitude of about 3,100 feet. There are four vents on the north bank of a dry creek channel near the foothills on the north side of the Snake River Plain. The total discharge was estimated to be about 2½ second-feet on June 28, 1928. The hot water issues from basalt and is used partly for irrigation and partly to supply a natatorium. The temperature of the hottest vent on June 28, 1928, was 149° F. Considerable odorless gas bubbles up in the water.

BLANCHE CRATER WARM SPRING

About 2 miles east of White Arrow Hot Spring is Blanche Crater, in which is Soda or Lye Lake. Russell[5] states that the lake is bordered and underlain by a deposit of alkaline salts estimated to cover 3 acres to an average depth of about 15 feet. The temperature of the lake on June 28, 1928, was 70° F., and that of the small seeps on the southeast shore that help to feed the lake was 80° F. The lake appears to be shallow and is without visible outlet. The lye in it was once used for the manufacture of soap and is concentrated by the evaporation of the warm mineral water. There is a beach of soda sand about 5 feet high on the northeast side of the lake. The crater surmounts a small spatter cone that marks the site of the vent of a basalt flow which extends toward Clover Creek. A large partly collapsed lava tube leads away from Blanche Crater. This tube was the principal feeder of the flow. The appearance of the cone suggests that it is younger than the basalt intercalated with the sedimentary rocks nearby and is probably of late Pleistocene age.

TSCHANNEN WARM SPRINGS AND HOT WELL

About 2 miles southeast of White Arrow Hot Spring, in the Clover Creek Valley, there is a meadow fed by warm seeps whose temperature is reported to be about 110° F. R. T. Tschannen, who owns this meadow, drilled a well in it and obtained a flowing hot well, which is reported to yield about 20 miner's inches, or 180 gallons a minute.

BANBURY HOT SPRING AND HOT WELLS

Banbury Hot Spring is on the west bank of the Snake River in lot 6, NW¼ sec. 33, T. 8 S., R. 14 E., at an altitude of 2,950 feet, and is used to supply a natatorium. It issues from alluvium overlying the Hagerman lake beds close to a large fault. Two 6-inch wells have been drilled at the spring to increase the flow. The log of the first well, a few feet away from the spring, according to J. W. Banbury, the owner, is as follows:

Log of Banbury hot well

	Thickness (feet)	Depth (feet)
Boulders and gravel	8	8
Blue clay	75	83
Hardpan (struck water)	10	93
Rock	4	97
Clay (more water)	2	99
Rock	4	103
Clay (more water)	1	104
Rock	45	149
Clay	15	164
Ground and sand (caved).		

[5] Russell, I. C., op. cit. (Bull. 199), p. 70.

This well struck water at 93 feet but did not increase the amount of hot water until it reached a depth of 112 feet. At that depth the water rose and overflowed the top of the casing 3 feet above the surface of the ground. No further increase in the supply was obtained down to a depth of 164 feet, where caving gravel and sand made it impossible to drill further without casing, so the tools were pulled out and another hole 112 feet deep was drilled nearby. No water flowed out of this second hole, but it increased the discharge of hot water from the spring, which is reported to have trebled as a result of drilling these two wells. The total yield on September 14, 1923, was estimated to be about 75 gallons a minute. The log is typical of the Hagerman lake beds, and the rock from 104 to 149 feet is probably a basalt flow. Evidently the hot water is confined in it under artesian head. The "rock" strata above 104 feet are so thin that they are probably the basaltic tuff so common in the Hagerman formation rather than lava. According to Russell,[6] who visited them prior to the drilling, they had a temperature of 131° F. On July 5, 1928, the spring had a temperature of 136° F., possibly indicating an increase of 5° as a result of drilling.

RINGS HOT SPRING

Near the north line of sec. 31, T. 8 S., R. 14 E., on Salmon Falls Creek, about 1½ miles west of Banbury Hot Spring, is Rings Hot Spring. On September 14, 1923, it had a temperature of 125° near the edge of the bubbling spring pool. Considerable odorless gas bubbles up in the pool and brings up with it some quartz sand. Some black sand also occurs in the bottom of the pool. The discharge on September 14, 1923, was estimated to be 200 gallons a minute. The spring issues from the Hagerman lake beds and probably rises along a fault. (See pl. 5.)

UNNAMED HOT SPRING

About 100 yards south of the Oregon Trail Highway, on an island in Salmon Falls Creek, in sec. 30, T. 8 S., R. 14 E., is a small hot spring that discharges about 5 gallons a minute and has a temperature of about 130° F. The water brings up black sand and issues from two small fissures in the island. There is a small wooden bathhouse at the spring.

ARTESIAN CITY HOT SPRINGS AND HOT WELLS

A group of hot wells with a natatorium in sec. 6, T. 12 S., R. 20 E., is known as Artesian City. Originally there was a warm spring at this place which is reported to have yielded only a few miner's inches. In 1909 wells were drilled near the spring, and flowing hot water was struck at 360 feet. The flow was not increased by drilling deeper.

[6] Russell, I. C., Geology and water resources of the Snake River Plains of Idaho: U. S. Geol. Survey Bull. 199, p. 169, 1902.

The wells are at the foot of the mountains bordering the Snake River Plain, and the water is confined in some of the Tertiary sedimentary beds that dip toward the valley at this place. The deepest well is 600 feet deep. Altogether there are six wells on the Stoner ranch and one only a few feet away on the Moorman ranch. The water is used for irrigation as well as for the plunge, and the combined natural discharge of all the Stoner wells is about 1 second-foot. A 20-horsepower deep-well turbine is used to increase the discharge during the irrigation season. The temperature of the water on October 19, 1928, was 104° F.

According to F. J. Marshall, there was at first one 10-inch well and one 6-inch well which together discharged 232 miner's inches. Later a 10-inch well was drilled, which took all the water from the other two wells. In addition one well was drilled and abandoned because of being crooked, and two other wells were drilled on which Mr. Marshall has no data. When the Moorman well was drilled on the adjoining ranch it took away some of the flow from the Stoner wells. This led to extensive litigation, which was finally settled by the Supreme Court of Idaho. According to records made by a committee appointed by the court, the following temperatures were observed on April 22, 1926: Stoner's "large" well, 106° F.; Stoner's east 10-inch well, 86° F.; Stoner's 4-inch well, 100° F.; Moorman well, 98° F.

A test was then made to determine the effect of Moorman's well. Before closing Moorman's pump, both wells in Stoner's east pool were not flowing. The water in Stoner's "large" well was 4 inches from the top and 3½ inches from the top of the 4-inch well. Five minutes after shutting down the Moorman pump the 4-inch well began to flow. While the Moorman pump was operating there was 20 miner's inches of water rising around the large well casing, and the total flow, including that through the casing, was 52 miner's inches. At 12 minutes after stopping Moorman's pump the flow of the large well increased to 57 miner's inches, and 24 minutes later the discharge was 61.5 miner's inches. In the evening of the same day the discharge had increased to 69 miner's inches, and on the next morning, after Moorman's pump had been closed all night, the discharge was 77.5 miner's inches. On April 23, 1926, the natural flow at the end of Moorman's pipe line was 12 miner's inches. When the pump was operating the flow was increased to 53 miner's inches. Stoner's pump was not set up at the time when these observations were made.

On April 28, 1926, Stoner's pump was installed, and with both pumps operating the discharge of Stoner's pump was 94 miner's inches and Moorman's pump 39.5 miner's inches. Moorman's pump was stopped at 12:50 p. m., and the discharge of Stoner's pump at 1:40 p. m. was 99.5 miner's inches. The natural flow at the end of Moorman's pipe line at this time was 2.5 miner's inches. At

3:30 p. m. on the same day, with Moorman's pump still closed, the discharge of Stoner's pump had increased to 102.75 miner's inches.

The so-called "large" Stoner well was drilled in 1914 to a depth of 495 feet. The first 420 feet is 9¼ inches in diameter and the last 75 feet 7⅝ inches in diameter. It has about 18 feet of wooden casing. The 14-inch Stoner well is 370 feet deep and has 60 feet of 11⅝-inch casing. The reported log is 310 feet of sand and 60 feet of mud and sandstone. The 10-inch well in the east lane and the 4-inch well are both reported to be 363 feet deep. There is 100 feet of casing in each of these wells, and both were drilled through clayey material.

BRIDGER HOT SPRING AND WELLS

The following data regarding this hot spring and another unnamed one in Marsh Creek Valley near Albion were furnished by G. A. Waring.

Bridger Hot Spring issues about a quarter of a mile east and 50 feet above Marsh Creek in the NE ¼ NW ¼ sec. 11, T. 11 S., R. 25 E. It has a temperature of about 120° F. and a discharge of about 4 gallons a minute. A 6-inch well 260 feet deep a few yards away discharges about 4 gallons a minute. The flow of the well and spring are used for irrigation. Halfway between the spring and Marsh Creek, the Dewey southern well, 8 inches in diameter, discharges about 2 gallons of water a minute that has a temperature of 115° F. About 200 yards to the north the Dewey main well, 16 inches in diameter, discharges about 150 gallons a minute with a temperature of 100° F. The water is used for irrigation. The three wells and spring are probably close to the fault that borders the east side of the valley.

Another spring, with a temperature of 100° F. and a discharge of about 3 gallons a minute, seeps from alluvial material in sec. 22, T. 11 S., R. 25 E.

FRAZIER HOT SPRING AND WELL

There is a hot well in the NW¼NW¼ sec. 23, T. 15 S., R. 26 E., at an altitude of 4,930 feet, at the foot of the range on the west side of the Raft River Valley. Before the well was drilled there was a warm moist spot of ground at this place stained with spring deposits. C. W. Frazier, the owner, drilled a well 400 feet deep here and obtained a flow of about 120 gallons a minute with a reported temperature of 204° F. The temperature of the water a few feet away from the well was found to be 196° F. The well was drilled into alluvium, but its hot water may have ascended along a large fault that probably bounds the mountain range nearby. The well flows because of its high temperature and the included steam and is not necessarily indicative of the existence of an artesian basin. The high temperature of the water at the surface suggests that it is superheated not far below the bottom of the well. The water is used at present for irrigation.

WARM SPRINGS ON SOUTH SHORE OF LAKE WALCOTT

In the NE¼SW¼ sec. 19, T. 9 S., R. 28 E., are a group of warm springs, issuing from five definite vents. All had a temperature of 70° F. on October 4, 1928. They issue from the Raft lake beds about 15 feet above the level of Lake Walcott, possibly along a fault. Their discharge is about 1½ second-feet.

FALL CREEK WARM SPRINGS

The perennial supply of Fall Creek, a tributary to the Snake River, is derived from a group of warm springs in the center of sec. 29, T. 9 S., R. 29 E. They issue in the creek bed at the foot of a bluff of Carboniferous limestone, which is possibly a fault scarp. (See pl. 6.) The springs discharge about 20 second-feet and had a temperature of 62° F. on November 1, 1928. The water is impregnated with lime, which has been deposited as reefs in the channel. The reefs form the falls that give the creek its name.

INDIAN HOT SPRINGS

Indian Hot Springs are in the NW¼SE¼ sec. 19, T. 8 S., R. 31 E., about 4 miles south of American Falls. They issue from a light-colored limestone near the north end of the mountain spur that forms the east side of the Rockland Valley, presumably along a fault. The spring is reported to yield 1,500,000 gallons a day.

LAVA HOT SPRINGS

Near the town of Lava Hot Springs, in secs. 21 and 22, T. 9 S., R. 38 E., are numerous hot springs close to the banks of the Portneuf River, which flows in a narrow, deep canyon at this place. The mineral content of these natural hot springs and the excellent climate of this town combine to make the place a popular health resort. Several hotels and natatoriums, one of the largest of which is supported by the State of Idaho, are situated near the springs. The temperatures on August 28, 1929, of the group of springs on the north bank of the Portneuf follow: Magnesia Spring, 100° F.; Sanitarium Spring, 100°; Sulphur Spring, 144°; Iron Spring, 144°.

It was impracticable to take the temperature of the mud baths, because there were no definite vents. An unnamed spring near this group supplies the State plunge. It had a temperature of 102° F. on August 28, 1929. The total flow of these springs is about 3 second-feet. The water issues chiefly from tufa, although some of the springs issue from tan quartzite and from cemented angular fragments of quartzite that appear to be a fault breccia.

On the south bank of the Portneuf River near the Riverside Hotel is Ha-Wah-Na Spring, which on August 28, 1929, had a temperature of 132° F. and a discharge between 50 and 100 gallons a minute. It was impossible to estimate the discharge of this spring more closely, because it issues in a concrete box and flows thence through a pipe line to the hotel. A few hundred feet upstream from the first group of springs mentioned, but on the south bank of the river, is Chicken Soup Spring, which on August 28, 1929, had a temperature of 126° F. It supplies the hotel known as "the Spa" and another one nearby.

The following analysis of the water of Chicken Soup Spring is reported by the owners of the Spa Plunge.

Analysis of water of Spa Plunge

[Parts per million]

Silica	28	Calcium carbonate	280
Sodium sulphate	60	Calcium bicarbonate	4
Sodium chloride	276	Calcium chloride	Trace
Sodium carbonate	Trace	Alumina	3
Sodium bicarbonate	45	Barium carbonate	Trace
Potassium sulphate	68	Manganese carbonate	Trace
Potassium chloride	Trace	Iron carbonate	2
Lithium carbonate	Trace	Strontium	Trace

The spring discharges about 5 gallons a minute and issues from an intracanyon basalt flow. Only thin wedges of this basalt are preserved on the south bank at the narrows near Lava Hot Springs. The rest of the valley floor is covered with tufa and hill wash. The abundant deposits of tufa or travertine indicate that hot water has discharged here over a long period. The presence of the breccia near one of the springs suggests that the hot water is rising along deep faults.

HEISE HOT SPRINGS

The Heise Hot Springs are in sec. 25, T. 4. N., R. 40 E., on the north bank of the Snake River, near the mouth of the canyon. The main vent is on a mound of travertine about 30 feet above the river level. The springs have been partly enclosed, and the water is piped about 100 yards to the northeast, where it supplies a natatorium. The temperature of the water on April 27, 1930, was 122° F. The springs are in constant ebullition because of the escaping gas, which carries a strong odor of sulphur. The discharge is about 90 gallons a minute. Smaller springs seep out from the base of the bank of the high-water channel of the river nearby. The extensive deposits of travertine adjacent to the spring indicate the great antiquity of hot springs at this place. Beneath the travertine are gravel and hillside wash, and in the bluff behind the spring several tan rhyolite flows and some tuff are exposed. A hotel and post office is maintained in connection with the natatorium.

An analysis of the water furnished by the owner follows:

Analysis of water of Heise Hot Springs

	Grains	Percent		Grains	Percent
Silica	17	0.0290	Potassium sulphate	8	0.0138
Sodium carbonate	15	.0260	Sodium sulphate	50	.0860
Sodium chloride	180	.3100	Calcium carbonate	60	.1034
Magnesium chloride	15	.0260			

A well drilled in 1936 about 300 feet upstream from the spring and more than 300 feet deep encountered only sufficient seepage for drilling. Cuttings from the hole were gray, pink, and blue limestone typical of pre-Tertiary beds of this part of Idaho.

CONDIE HOT SPRINGS

Condie Hot Springs are at the southeast corner of sec. 14, T. 1 S., R. 21 E., near Carey. There are two vents about 500 feet apart with a combined discharge of about 1 second-foot. On September 5, 1928, the eastern vent had a temperature of 124° F. The water issues from alluvium at the north edge of the basalt of the Snake River Plain. It is used partly for irrigation and partly for a natatorium.

LAVA CREEK HOT SPRING

Lava Creek Hot Spring is in the bottom of Lava Creek Canyon, near the flow line of the Magic Reservoir, in Blaine County. The spring brings up considerable quartz sand, and odorless gas bubbles up in it at intervals. The spring discharges about 150 gallons a minute and has a temperature of 98° F. It is not used. Although this spring issues from the Pleistocene basalt, the large amount of quartz sand brought up by the water indicates that it originates in some other formation, below the basalt. On the opposite side of the reservoir this basalt is underlain by rhyolite.

QUALITY OF WATER

In 1930 a set of 16 samples of water were collected in the Snake River Plain and analyzed by S. K. Love, of the United States Geological Survey. An additional set of 28 analyses, mostly from railroad wells, were kindly furnished by Dr. W. M. Barr, consulting chemist of the Union Pacific System. He states that, though some of the analyses are old, recent tests show no change in the composition of the waters. These analyses are given in the accompanying tables.

Practically all the waters analyses of which are given in the two tables are calcium bicarbonate waters, such as are found more commonly than any other type throughout the United States. The main constituents are calcium, magnesium, and bicarbonate. The waters differ mainly in their content of these constituents.

The hardness of most of the waters is above 100 parts per million, which has been commonly accepted as about the upper limit of thoroughly satisfactory water for ordinary household use with soap. Where municipal supplies are softened it is customary to reduce the hardness to 100 or 80 parts per million. Laundries and steam-boiler plants find it advantageous to soften their supplies practically to zero hardness. Except for the hardness, these analyses show nothing that would have any harmful effect upon the use of these waters in the home or for irrigation. A large proportion of the public supplies from wells used by cities in the central and western part of the United States have hardness as great as 200 parts per million.

Sample 15 in the first table was obtained from a well in a seeped area near Twin Falls, and the high mineral content is due to the concentration of soluble material, chiefly sodium and sulphate, by evaporation of water previously used for irrigation. This sample is probably typical of the hard waters in the seeped areas of the Twin Falls tract. Sample 16 was collected at the portal of the South Park drainage tunnel and closely resembles the water in the seeped ground drained by it.

Analyses of waters in Snake River Valley, Idaho

[S. K. Love, U. S. Geological Survey, analyst. Parts per million]

No.	Total dissolved solids	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Total hardness as $CaCO_3$ (calculated)
1	376	33	0.04	55	22	37	4.6	201	67	52	2.5	228
2	380	34	.08	52	22	40	5.4	200	81	42	2.3	220
3	363	25	.04	59	19	31	4.3	195	66	50	1.2	225
4	312	21	.02	74	17	15	2.4	280	35	16	1.4	255
5	322	36	.02	49	19	30	4.2	189	48	44	1.7	200
6	296	43	.02	42	18	26	4.2	177	46	30	1.3	179
7	271	30	.06	47	16	23	3.6	188	42	28	2.3	183
8	279	35	.51	40	19	26	3.8	181	46	24	1.6	178
9	319	29	.02	36	18	25	3.4	172	44	23	.97	164
10	252	30	.04	42	15	22	3.2	195	29	13	2.5	166
11	234	20	.10	50	13	12	2.6	179	39	10	.30	178
12	239	35	.26	32	16	22	4.0	161	36	18	1.8	146
13	207	27	.04	37	14	15	2.6	171	24	8.0	1.2	150
14	206	24	1.44	55	5.7	9.0	1.8	196	7.2	4.0	1.8	161
15	791	54	.37	88	42	106	6.1	315	225	88	9.6	392
16	830	60	.06	91	43	116	4.8	329	247	84	6.4	404

1. Drilled well, 194 feet deep, 6 inches in diameter, in NE¼NE¼ sec. 12, T. 9 S., R. 16 E., owned by M. F. Grimes. Water from basalt. Temperature 58° F. Collected May 17, 1930.
2. Snake River at Owsley Bridge, near Hagerman, in SW¼NW¼ sec. 1, T. 8 S., R. 13 E. Temperature 58° F. Collected May 18, 1930.
3. West Danielson Spring, half a mile west of Springfield, in SE¼SE¼ sec. 10, T. 4 S., R. 32 E. Water from basalt. Temperature 50° F. Collected May 16, 1930.
4. Dug well, 20 feet deep, 6 feet in diameter, in NW¼NW¼ sec. 31, T. 4 N., R. 27 E., owned by city of Arco. Water from gravel. Collected June 8, 1930.
5. Blue Lakes Spring, at Blue Lakes Ranch, near Twin Falls, in SE¼NE¼ sec. 28, T. 9 S., R. 17 E. Water from basalt. Temperature 61° F. Collected May 17, 1930.
6. Clear Lakes Spring, near Wendell, in NE¼SE¼ sec. 2, T. 9 S., R. 14 E. Water from basalt. Temperature 58° F. Collected May 17, 1930.
7. Batise Spring, 100 yards downstream from Oregon Short Line pumping plant, near Pocatello, in NE¼ sec. 7, T. 6 S., R. 34 E. Water from alluvium. Temperature 55° F. Collected May 19, 1930.
8. Drilled well at Cedar Draw schoolhouse, in NW¼SW¼ sec. 29, T. 8 S., R. 15 E. Water from basalt. Temperature 58° F. Collected May 17, 1930.
9. Thousand Springs and Sand Springs combined, from power canal near Wendell, in SW¼SE¼ sec. 8, T. 8 S., R. 14 E., owned by Idaho Power Co. Water from basalt. Temperature 58° F. Collected May 17, 1930.
10. Malad Springs, near Hagerman, in NW¼NE¼ sec. 34, T. 6 S., R. 13 E. Water from basalt. Temperature 58° F. Collected May 17, 1930.
11. Snake River at Blackfoot, in SW¼SW¼ sec. 33, T. 2 S., R. 35 E. Temperature 53° F. Collected May 16, 1930.
12. Drilled well in SE¼NW¼ sec. 9, T. 8 S., R. 14 E., owned by Sand Springs ranch. Water from basalt. Temperature 58° F. Collected May 17, 1930.
13. Drilled well, 6 inches in diameter, near Hagerman, in SW¼ sec. 31, T. 6 S., R. 14 E., owned by C. H. Covell Water from basalt. Temperature 58° F. Collected May 17, 1930.
14. Spring in Craters of the Moon National Monument, in NE¼ sec. 28, T. 2 N., R. 24 E. Water from acid lava. Collected June 14, 1930.
15. Drilled well, 39 feet deep, 6 inches in diameter, near Twin Falls, in SW¼NE¼ sec. 21, T. 10 S., R. 17 E., owned by S. S. All. Water from basalt. Temperature 58° F. Collected May 17, 1930.
16. South Park drainage tunnel near Twin Falls, in NW¼NW¼ sec. 27, T. 10 S., R. 17 E. Water from basalt. Temperature 56° F. Collected May 17, 1930.

Analyses of waters from wells in and near the Snake River Plain, Idaho

[Oregon Short Line Railroad wells unless otherwise specified. Recalculated from results furnished by the consulting chemist, Union Pacific System, Omaha, Nebr. Parts per million]

Location: Town	Location: County	Well: Depth (feet)	Well: Diameter (feet)	Date of collection	Total dissolved solids	Silica (SiO_2)	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Total hardness as $CaCO_3$ (calculated)	Analyst
Ashton	Fremont	420		Oct. 13, 1925	304	36	3.9	44	16	34	231	25	15	16	176	W. M. Barr.[1]
Blackfoot	Bingham	174		June 13, 1929	415	16	4.8	88	24	28	346	49	25	9.8	318	Do.
Bliss (Joslin ranch well).	Gooding	216	½	Oct. 23, 1920	692	35	8.0	92	38	81	256	236	75		386	Do.
Burley (city wells)	Cassia			May 17, 1929	288	44	1.2	41	9.5	38	156	32	45		141	Do.
Camas	Jefferson	70	½	July 22, 1924	285	25	1.2	55	10	14	190	24	22		178	Do.
Drummond	Fremont	288		Oct. 15, 1925	200	24	2.1	36	13	15	186	11	8.1		143	Do.
Dubois (city well)	Clark	60	6	Apr. 13, 1922	240	10	.9	58	11	16	239	16	7.0	3.1	190	Do.
Eden	Jerome	406		Oct. 5, 1926	446	37	1.6	59	22	51	208	65	77		238	H. Harms.[2]
Firth	Bingham	44	20	July 21, 1924	362	11	1.0	76	22	8.4	300	34	13		280	Do.
Fort Hall	do	80	⅔	do	396	19		74	25	19	312	29	30		288	Do.
Gooding	Gooding	263	⅔	Apr. 25, 1929	226	24	.9	37	12	17	163	23	12	3.4	142	W. M. Barr.
Hammett	Elmore	149	6	Dec. 11, 1924	576	58	2.0	76	23	76	243	136	62	24	284	Do.
Jerome	Jerome	326		Oct. 5, 1926	304	25	1.1	40	17	28	162	44	39		170	H. Harms.
Kimama	Lincoln	420		Mar. 18, 1930	241	30	4.0	32	17	21	149	46	17	1.0	150	W. M. Barr.
King Hill (schoolhouse well).	Elmore	300	½	Oct. 8, 1920	356	42	3.3	13		103	293		11			Do.
Lorenzo	Jefferson	20	18	Oct. 14, 1925	248	9.9	2.1	61	15	5.9	195	44	14		214	Do.
Minidoka	Minidoka	390		Apr. 11, 1930	249	25	3.9	39	14	22	154	49	18	1.9	155	Do.
Mountain Home	Elmore	800	10	Jan. 24, 1925	120	19	5.1	12	4.0	19	75	15	7.0	1.1	46	Do.
Owinza	Lincoln	423	⅔	Apr. 25, 1929	196	22	.9	26	13	19	137	25	14	1.5	118	Do.
Plano	Madison	202	1	Oct. 14, 1925	130	20	8.1	16	4.8	17	100	5.8	6.0	2.5	60	Do.
Ririe	do	80	1	do	292	28	3.9	59	19	13	239	34	13	5.0	225	Do.
Roberts	Jefferson	20	13	July 21, 1924	485	20	1.5	98	21	31	358	58	32		331	H. Harms.
Taber	Bingham	339		Oct. 15, 1925	230	14	3.9	35	12	17	156	25	14	2.0	137	W. M. Barr.
Ucon	Bonneville	180	1	Oct. 14, 1925	223	3.9	2.1	28	25	17	166	48	17		172	Do.
Wapi	Blaine	355		Oct. 31, 1917	316	24	2.5	41	8.8	20	59	89	28		139	H. Harms.

[1] Consulting chemist, Union Pacific System, Omaha, Nebr.
[2] State chemist, Salt Lake City, Utah.

SURFACE AND GROUND WATERS IN SNAKE RIVER PLAIN ABOVE KING HILL

CONTRIBUTIONS FROM TRIBUTARY VALLEYS

In another part of this report are given the available data regarding the contributions from the tributary streams to the surface and ground-water supply of the Snake River Plain above King Hill for the period 1920 to 1927. The following table gives a summary of the measurements or estimates of these contributions, including the entire outflow, both surface and underground, from the tributary valleys.

Average annual contributions to surface and ground waters of Snake River Plain above King Hill, from tributary streams, in acre-feet, 1920–27

Cedar Creek	8, 000
Salmon Falls Creek	50, 000
Creeks between Salmon Falls and Goose Creeks	40, 000
Goose Creek drainage area	33, 000
Creeks between Goose Creek and American Falls	41, 000
Bannock Creek	13, 000
Portneuf River at Pocatello	217, 000
Portneuf River underflow	49, 000
Ross Fork and other creeks	7, 000
Blackfoot River	218, 000
Sand Creek	2, 000
Willow Creek	128, 000
South Fork of Snake River	5, 189, 000
Moody Creek	2, 000
Teton River	579, 000
Fall River	629, 000
Robinson Creek	91, 000
Warm River	164, 000
Henrys Fork above Warm River	757, 000
Camas and Beaver Creeks	41, 000
Medicine Lodge Creek	40, 000
Creeks between Medicine Lodge and Birch Creeks	20, 500
Birch Creek	57, 300
Little Lost River	36, 700
Big Lost River	226, 000
Creeks between Big Lost River and Carey Valley	5, 000
Big Wood River, ground water	354, 000
Big Wood River, surface water	70, 000
Clover Creek	12, 000
	9, 079, 500

The water that enters the Snake River Plain annually from the tributary streams as shown in the above table is disposed of in the following manner:

Discharge by the Snake River, as measured at King Hill.
Consumption by crops and evaporation from the soil on the irrigated lands.
Storage in surface reservoirs.
Losses by evaporation from water surfaces.
Storage in water-bearing formations.

WATER DISCHARGED BY SNAKE RIVER AS MEASURED AT KING HILL

For 100 miles upstream from King Hill the Snake River serves as a great drainage channel, collecting the tributary ground water in copious quantities from both sides of the valley. Ground-water inflow, however, ceases about 10 miles upstream from King Hill, where the river leaves the area of permeable basalts and enters a narrow valley underlain by more impermeable materials. Because of the geologic conditions, there is no appreciable underflow at King Hill. The surface discharge consists of the flow of the river at the King Hill gaging station plus the diversion through the King Hill ditch. The average annual discharge at this point from 1920 to 1927 amounted to 7,918,000 acre-feet, as is shown in the following table:

Discharge, in acre-feet, of Snake River at King Hill, Idaho, years ending Sept. 30, 1920–27

	Snake River at King Hill	King Hill Ditch [1]	Total		Snake River at King Hill	King Hill Ditch [1]	Total
1920	7,100,000	[2] 86,000	7,186,000	1925	8,260,000	95,549	8,356,000
1921	9,470,000	56,153	9,526,000	1926	7,240,000	97,000	7,337,000
1922	8,650,000	61,326	8,711,000	1927	7,120,000	94,183	7,214,000
1923	7,970,000	91,454	8,061,000				
1924	6,850,000	105,337	6,955,000	Average	7,832,000	86,000	7,918,000

[1] Records supplied by King Hill Irrigation District.
[2] Estimated on account of missing records.

WATER CONSUMED BY CROPS ON IRRIGATED LANDS

The total area under irrigation on the Snake River Plain above King Hill and below the points for which outflow from tributary valleys is given in the foregoing table was 900,525 acres in 1928, as determined by the Idaho Commissioner of Reclamation, chiefly from reports of the several canal companies. It is believed that the total acreage did not change greatly from 1920 to 1928, and therefore the 1928 acreage is assumed to be the average during the years 1920 to 1927.

A wide variety of results have been obtained by different experimenters on duty of water, and a review of the literature on this subject impresses the student with the idea that the question is an elusive one and not subject to exact or refined determination. Extensive experiments made by Bark[7] during a period of 4 years on many plots of land in southern Idaho showed an average net use on the clay loam and sandy loam soils of 2 acre-feet to the acre, in addition to the precipitation. The fields covered by these experiments were all well prepared, the water was carefully applied in economical heads, and losses by deep percolation were probably slight. In applying this figure to large irrigated areas allowance must be made for nonirrigated lands,

[7] Bark, D. W., Experiments on the economical use of irrigation water in Idaho: U. S. Dept. Agr. Bull. 339, 1916.

such as roads, buildings, and canals, which according to Bark's surveys of 36 square miles of irrigated lands in Idaho amounted to about 8 percent of the total area. To allow also for possible slight deep percolation during the tests, a total reduction of 15 percent has been made in the duty of water as determined by Bark, giving 1.7 acre-feet to the acre as the average annual "net duty", or consumptive use of water exclusive of the precipitation, applicable to the gross irrigated areas of the region under consideration. "Net duty", as used in this connection, is taken to mean the amount of irrigation water transpired by the plants or lost by evaporation from the soil, exclusive of precipitation.

Observations of soil moisture at Jerome [8] during 1917 and 1918 indicated that the crops used about 40 percent of the annual precipitation, or about 0.4 acre-foot to the acre. Thus 60 percent of the annual precipitation was left to be accounted for by run-off, deep percolation, and evaporation outside of the growing season. The average annual consumptive use from both precipitation and irrigation supplies would then be 2.1 acre-feet to the acre during the growing season, reckoned for gross irrigated acreages. The actual consumptive use varies somewhat for different parts of the region, chiefly because of differences in the length of the growing season, being greater at the lower altitudes and less at the higher altitudes. An independent study by W. G. Steward led to the comparable conclusion that the consumptive use is about 2.2 acre-feet to the acre, including precipitation.

The total amount of irrigation water, exclusive of precipitation, consumed annually by crops on 900,000 acres of irrigated land at the assumed rate of 1.7 acre-feet to the acre would be 1,530,000 acre-feet.

WATER STORED IN SURFACE RESERVOIRS

The only large reservoirs in the region are the American Falls Reservoir and Lake Walcott. The American Falls Reservoir was completed in 1926 and contained about 1,389,000 acre-feet of water on September 30, 1927. Lake Walcott contained about 16,000 acre-feet on September 30, 1919, and about 103,000 acre-feet on September 30, 1927. The total increase in storage in these two reservoirs during the period of 8 years, 1920 to 1927, was therefore about 1,476,000 acre-feet, which is equivalent to an average annual increase of about 185,000 acre-feet.

LOSSES BY EVAPORATION FROM WATER SURFACES

On the Twin Falls North Side canal system the area of the water surfaces was carefully determined from 1916 to 1920 and was found to be about 1 acre for each 60 acres of land irrigated. This ratio has

[8] Crandall, Lynn, Use of water on the Twin Falls North Side project: Unpublished report to the Twin Falls North Side Land & Water Co., 1923.

been used for the entire region and gives an area of about 15,000 acres of water surface in all the canal systems. The average water surface of the Snake River between Heise and King Hill, exclusive of the reservoirs, has been estimated from the best available information at 24,000 acres. Lake Walcott had an average area of about 11,500 acres exposed to evaporation during the years 1920 to 1927. Therefore the total area of water surface in the region under consideration, except that of the American Falls Reservoir, was about 50,000 acres. If the excess of evaporation over precipitation was 2.6 feet a year, as is estimated from the evaporation records given in other parts of this report, the annual net loss amounted to about 130,000 acre-feet. The American Falls Reservoir has been in operation only since March 1926. The net evaporation loss (evaporation minus precipitation) from that reservoir for the period April 15 to September 30, 1927, as determined by the investigations of T. R. Newell, was about 129,000 acre-feet. To this amount 37,000 acre-feet has been added as calculated loss in the period from March 1, 1926, to April 15, 1927, making a net loss from that reservoir during the period from March 1, 1926, to September 30, 1927, of about 166,000 acre-feet. This would be an average of about 20,000 acre-feet annually during the 8-year period, which added to the loss from the other water surfaces gives an average annual loss of about 150,000 acre-feet from all water surfaces in the valley during 1920 to 1927.

GROUND-WATER STORAGE

During the early years of irrigation in this region large quantities of water were added to the ground-water storage, and in some places the water table was raised greatly. The well records show that in some places on the South Side Twin Falls project the water table has risen more than 200 feet since the project was started in 1906, and it is estimated that several million acre-feet of water have gone into storage as ground water in this tract during the period that the project has been in operation. Records on the projects north of the Snake River Canyon show only a moderate rise of the water table, most of which occurred during the early years of irrigation. Owing to the permeable character of the underlying lava rocks, the additional contributions to the ground-water supply caused by irrigation found ready escape, and equilibrium of the ground-water levels was soon reached.

By 1920 the principal irrigation developments in this region had long been completed, and the only projects on which appreciable rise in the water table, other than seasonal fluctuations, has been noted since 1920 are the Twin Falls South Side, Salmon Falls, and Fort Hall projects. The average rise in the water table under the Twin Falls tract during these years has been about 4 feet a year according to the records of wells that were measured in 1920 and again in 1928. The rise in individual wells, however, has ranged from insignificant amounts to more than 20 feet a year. A similar rise under part of the Salmon Falls Creek Valley south of the Twin Falls tract was probably caused principally by seepage from the Twin Falls tract but doubtless also in part by seepage from the Salmon Falls project. The Twin Falls tract covers an area of 210,000 acres, and it is estimated that about 80,000 acres underlying the Salmon Falls Creek Valley has been affected by the ground-water rise. If an effective porosity of 15 percent in the underlying lava rocks and silt beds is assumed, the 4-foot annual rise over 290,000 acres is equivalent to an annual increase in ground-water storage of about 174,000 acre-feet. It has been estimated that the increase in ground-water storage under the Fort Hall tract averaged about 14,000 acre-feet annually from 1920 to 1927. There may also have been some additions to ground-water storage in other parts of the region, but they were doubtless small because practically all of the rise of the water table occurred prior to 1920. The average annual addition to ground-water storage in the entire region during the 8-year period is therefore estimated at 188,000 acre-feet.

SUMMARY OF SUPPLY AND DISPOSAL

A summary of the disposal of the surface and ground waters in the region is given in the following table:

Average annual disposal of water in the Snake River Plain above King Hill, in acre-feet, 1920–27

Discharge of Snake River at King Hill	7, 918, 000
Irrigation water consumed by crops or through evaporation from the soil	1, 530, 000
Increase of water stored in surface reservoirs	185, 000
Water lost by evaporation from streams, reservoirs, and canals	150, 000
Increase of water stored underground	188, 000
	9, 971, 000

As there was an estimated average annual contribution from the tributary streams of 9,079,000 acre-feet, the computed average annual excess of disposal over inflow amounted to 892,000 acre-feet. There are doubtless errors in the above estimates. However, a considerable contribution to the water supply is made by the precipitation upon the Snake River Plain, and this contribution is not included in the computations except insofar as it is represented by the apparent excess of disposal over inflow. This apparent excess of 892,000 acre-feet is equivalent to about 1.36 inches in depth of water over the entire area of the Snake River Plain above King Hill, or about 12 percent of the average annual precipitation on the area. Only a small part of the contribution by precipitation is made by direct run-off, the greater part being made through percolation to the water table and subsequent discharge by springs. In the bare, rough lava areas, which cover about 400,000 acres, a large percentage of the precipitation reaches the ground water, but in the rest of the area, which is mostly covered with soil, the recharge is proportionately much smaller and may easily be less than 10 percent of the precipitation.

ECONOMIC USE OF THE WATER

Much of the water discharged by the Snake River at King Hill enters the river downstream from Milner in the form of springs and wasteways at points so far below the rim of the canyon that it is not practicable under present conditions to pump the water up to the adjacent bench lands for irrigation. Another considerable part passes Milner during the periods of high water or during the nonirrigation season. From Ashton to King Hill practically no water enters the Snake River from the northwest side except in the form of springs along the river. These springs issue from the permeable lava rocks into which the tributaries on this side of the river disappear. On the other hand, practically all the water that enters the river from the south side between Pocatello and King Hill is in the form of surface streams, because the few springs on the south side of this stretch of the river issue at relatively high altitudes and at some distance from the river.

Except for a part of the Aberdeen-Springfield project and a part of the Minidoka project, the water on the irrigated lands on the northwest side of the river that sinks to the water table appears in the large springs in the Snake River Canyon at points so low that it cannot again be used for irrigation. On the other hand, a considerable part of the water that percolates to the water table from lands on the southeast side of the river from Firth to Milner returns to the American Falls Reservoir or to streams in localities where it can be used again for irrigation. Another important consideration is that much of the return flow from irrigation water used on the southeast side returns above the power plants on the Snake River at seasons of the year when good use can be made of it.

In the development of future irrigation projects in southeastern Idaho advantage should be taken of these conditions in order to obtain the greatest possible conservation of water. Other conditions being equal, a more beneficial use of water will be obtained by irrigating lands on the southeast side of the Snake River between Firth and Milner than by irrigating lands on the northwest side.

LOSSES AND GAINS IN SNAKE RIVER

GENERAL CONDITIONS

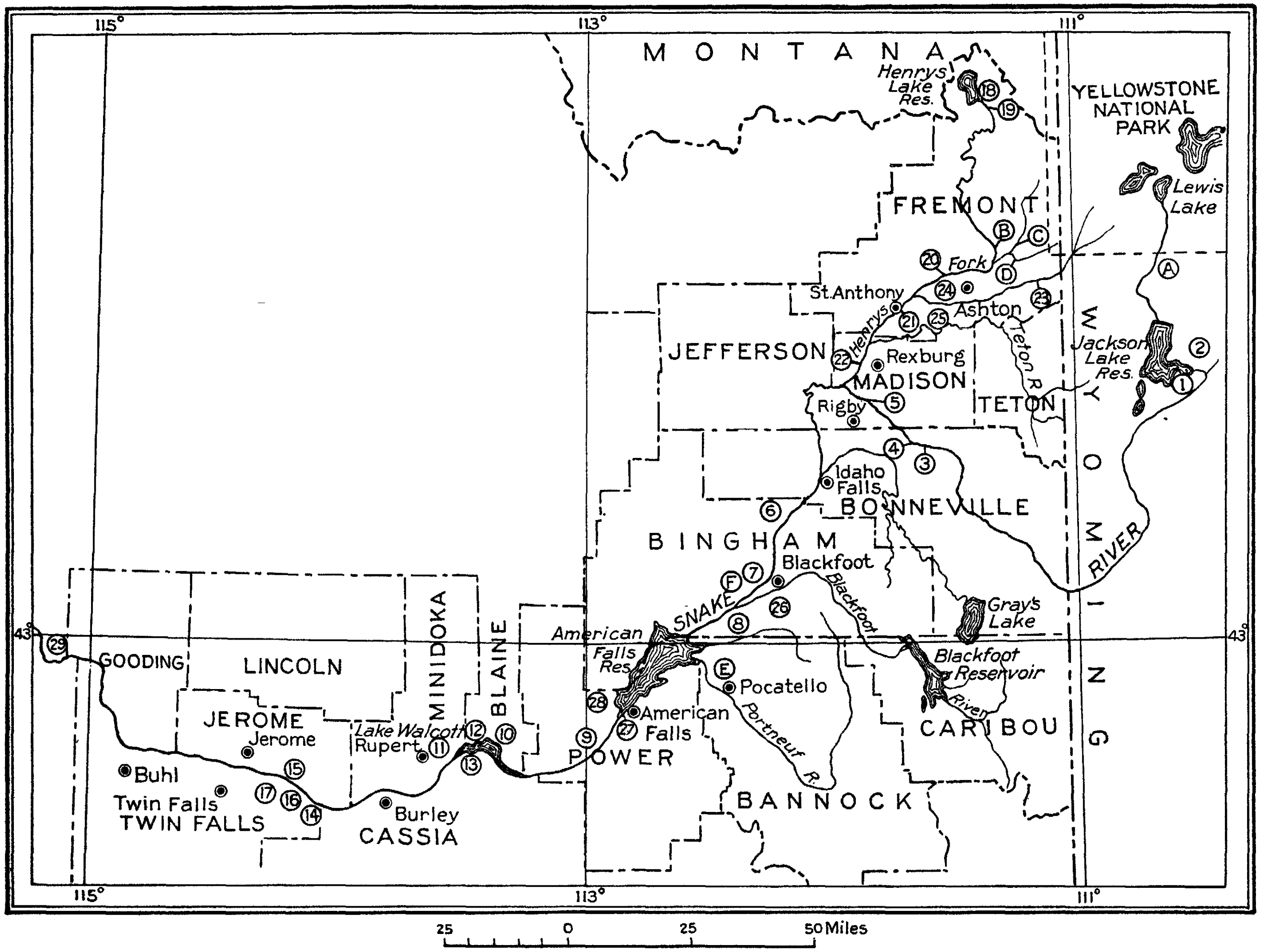
After the Snake River leaves the headwater areas, which have a high run-off, and starts across the valley floor, it has influent sections, in which losses occur, in alternation with effluent sections, in which the river gains. Wherever the underlying formation is permeable and the water table lies considerably below the river, water percolates readily downward to the zone of saturation. Thus in some stretches the Snake River flows for miles above the water table and loses large amounts of water. In other stretches the river cuts through the aquifers that carry ground water and drains them, thereby becoming a gaining stream. In certain sections the relation between the river surface and the height of the adjacent water table may be such that the stream loses water during high stages and gains during low stages. This condition apparently occurs along the Snake River between Alpine, near the Idaho-Wyoming State line, and Heise.

METHOD OF COMPUTATION

In computing the losses and gains in the Snake River by sections and as a whole, the following method was used. Published records at the gaging stations on the Snake River were adjusted to allow for time of transmission of the water through the section. The gain for the month in question was first determined from the stream records by taking actual differences betweeen the mean monthly discharges as published. If the stream had practically the same discharge at the end of the month as at the beginning, no correction was necessary for time of transit of the water between stations. If the discharge changed during the month, the total change was divided by the number of days in the month to give the average change per day. This quantity was multiplied by the ratio that the time interval between the stations bears to 24 hours, to give the correction to be applied to the gain or loss as first determined. On rising stages this correction is applied to increase gains and decrease losses; on falling stages it is applied to decrease gains and increase losses. The time intervals were those used by the Snake River water master or were determined by comparison of automatic gage records at the different stations. The locations of the stations is shown in plate 27.

LOSSES BETWEEN HEISE AND LORENZO

Between the gaging stations at Heise and Lorenzo, a distance of about 14 miles, the Snake River loses water as it flows over a gravel fan, which was built as a result of the change in gradient and the consequent drop of debris as the stream passes from its steep mountain



MAP OF SNAKE RIVER VALLEY ABOVE KING HILL, IDAHO, SHOWING LOCATION OF GAGING STATIONS.

Regular stations are indicated by numbers, auxiliary stations by letters.

GAGING STATIONS

1. Jackson Lake at Moran, Wyo.
2. Snake River near Moran, Wyo.
3. Snake River near Heise.
4. Great Feeder Canal near Ririe.
5. Snake River at Lorenzo.
6. Snake River near Shelley.
7. Snake River near Blackfoot (Blackfoot Bridge).
8. Snake River at Clough Ranch (formerly listed as near Blackfoot).
9. Snake River at Neeley.
10. Lake Walcott near Minidoka.
11. Snake River near Minidoka.
12. North Side Minidoka Canal near Minidoka.
13. South Side Minidoka Canal near Minidoka.
14. Lake Milner at Milner.
15. North Side Twin Falls Canal at Milner.
16. South Side Twin Falls Canal at Milner.
17. Snake River at Milner.
18. Henrys Lake Reservoir near Lake.
19. Henrys Fork near Lake.
20. Henrys Fork near Ashton.
21. Henrys Fork at St. Anthony.
22. Henrys Fork near Rexburg.
23. Fall River near Squirrel.
24. Fall River near Chester.
25. Teton River near St. Anthony.
26. Blackfoot River near Blackfoot.
27. American Falls Reservoir at American Falls.
28. Snake River at American Falls.
29. Snake River at King Hill.

A. Snake River at south boundary of Yellowstone Park.
B. Henrys Fork at Warm River.
C. Warm River at Warm River.
D. Robinson Creek at Warm River.
E. Portneuf River at Pocatello.
F. Snake River at Robertson Ranch.

course to the relatively level valley floor. The losses for this stretch of channel were computed as shown below, beginning with 1924, when records were first obtained at Lorenzo.

Average apparent loss, in second-feet, from Snake River between Heise and Lorenzo gaging stations

Year	May	June	July	August	September
1924		240	20	245	140
1925		830	180	460	350
1926	[1] 350	180	130	270	210
1927			440	280	
Average	350	417	193	314	233
Average loss, in percentage of discharge at Heise	3	3.0	1.5	3.8	5.3

[1] Part of month only.

The figures shown in the table above have been computed by adding the discharge of the Snake River near Lorenzo, Great Feeder Canal at head, Bannock Jim and Lower Sloughs at head, and diversions between Heise and Lorenzo, and subtracting the result so obtained from the discharge of the Snake River at Heise. Results as shown above are corrected to Heise dates by allowing a time interval of 4 hours between Heise and Lorenzo stations.

The losses during the irrigation season between Heise and Lorenzo amount to an average of 3.3 percent of the river discharge at Heise. Losses during the winter, when the water is colder, are probably less. Water losses on the Twin Falls North Side project during 1916–20 [9] were studied in detail, and the relation between the rate of loss over the entire canal system and the average temperature of the water in the canal system is shown by the following table:

Average monthly water temperature (° F.) and rate of loss of water (depth per day, in feet, over water-surface area) on North Side Twin Falls project

	April	May	June	July	August	September
1916: Temperature	49.2	52.0	61.5	69.0	68.3	60.0
Loss	.71	.75	.83	.90	.91	.84
1917: Temperature		53.1	60.0	69.0	68.0	59.0
Loss		.66	.72	.84	.90	.73
1918: Temperature	45.5	56.0	66.0	69.5	67.0	60.0
Loss	.69	.78	.83	.87	.86	.71
1919: Temperature	44.0	59.0	64.0	69.2		
Loss	.57	.79	.82	.87		
1920: Temperature	44.0	55.0	62.0	69.0	68.0	
Loss	.64	.78	.87	.99	.86	
Average: Temperature	45.7	55.0	62.7	69.2	67.8	59.7
Loss	.65	.75	.82	.89	.88	.76
Loss by evaporation	.01	.02	.02	.02	.02	.01
Seepage loss	.64	.73	.80	.87	.86	.75

[9] Crandall, Lynn, The use of water on the Twin Falls North Side irrigation project, Idaho, 1923 (unpublished).

The relation between water temperature and loss by seepage is shown diagrammatically by figure 14. The results for September are

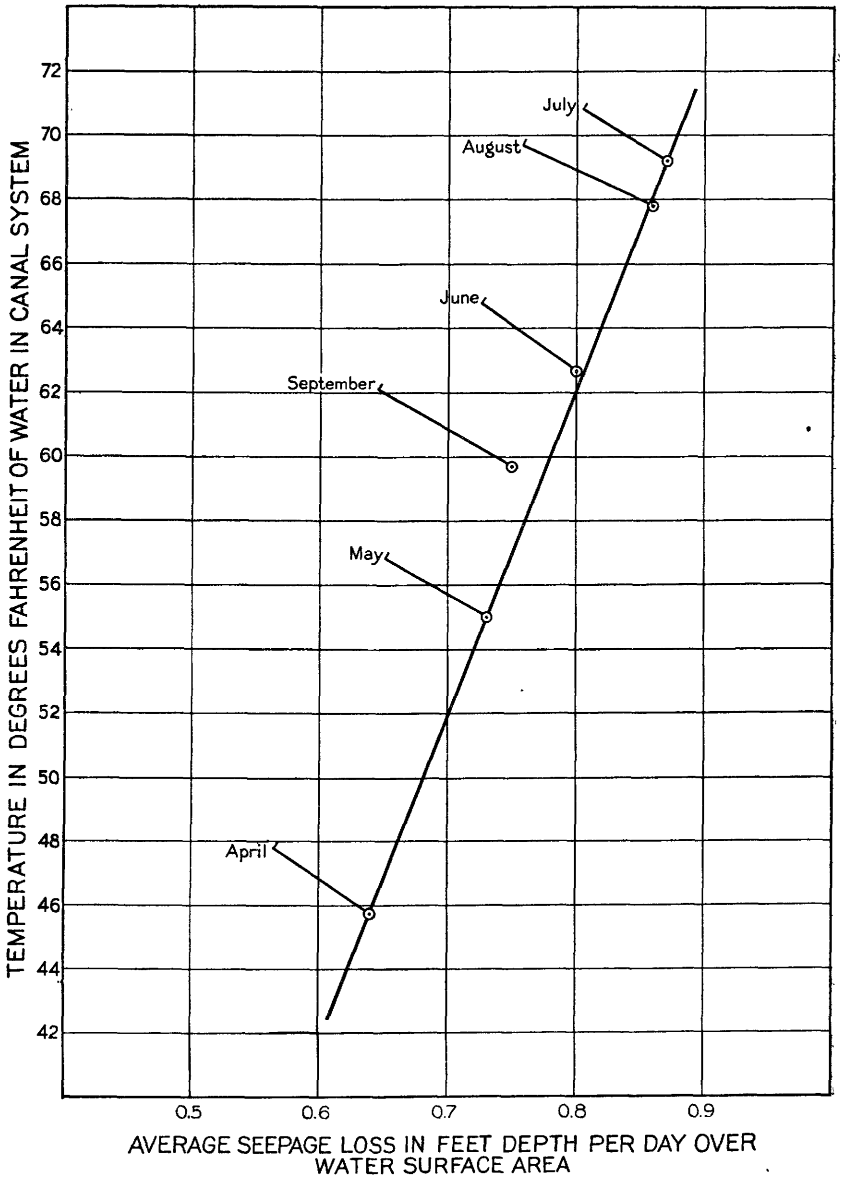


FIGURE 14.—Relation between water temperature and rate of loss by seepage on the North Side Twin Falls project. Average for 1916–20.

lower than in the other months, probably because the records for that month were the averages for 3 years only and because of water shortage in that month in the other years.

The average water temperature during the nonirrigation season, from October to April, inclusive, has been estimated to be 39° F. Applying the relation developed on the North Side project between water temperature and rate of loss to winter losses between Heise and Lorenzo, it appears that the losses during the nonirrigation season will be 70 percent of the summer losses for similar discharges of the stream, or 2.3 percent of the river discharge. If the loss from the average summer run-off of 3,790,000 acre-feet, as recorded at Heise, is 3.3 percent and the loss from the average run-off during the nonirrigation season of 1,340,000 acre-feet is 2.3 percent the average annual loss in the section between Heise and Lorenzo amounts to 156,000 acre-feet.

GAINS BETWEEN LORENZO AND SHELLEY

The gain from Lorenzo to Shelley, 50 miles downstream, from 1924 to 1927 is shown in the table. The average gain during the months from May to September amounts to 341,000 acre-feet. No records are available for the Shelley station outside of the irrigation season, and none are available for winter diversions between Heise and Shelley. Consequently, there is no basis for determining the gain in this section during the winter, but the gain is probably considerably less than it is during the summer, because there is less inflow from irrigation waste and the ground-water levels are lower.

The diversions from the Snake River between Heise and Shelley amount to about 1,700,000 acre-feet each year from May to September and are therefore equivalent to an average daily flow during that period of 5,600 second-feet. The area irrigated by these canals amounts to about 250,000 acres, the crops on which would not consume more than about one-fourth of the quantity of water that is diverted, leaving the rest to be contributed to the ground water or to be wasted into the Snake River.

Average apparent gain, in second-feet, in Snake River between the gaging stations at Lorenzo and Shelley

Year	May	June	July	August	September
1924		985	1,060	890	780
1925		1,800	1,580	1,410	1,130
1926	[1] 760	910	1,130	1,030	755
1927			2,140	1,710	
Average	760	1,230	1,480	1,260	888

[1] Part of month only.

The figures shown in the table above have been computed by adding the discharge of the Great Feeder at head, the Snake River near Lorenzo, Bannock Jim, and Lowder Sloughs at head, and Henrys Fork near Rexburg, and subtracting the result so obtained from the combined discharge of the Snake River near Shelley, diversions from the Great Feeder, and diversions from the Snake River between

Lorenzo and Shelley stations. The results as shown above are corrected to Lorenzo dates by allowing a time interval of 14 hours from Lorenzo to Shelley stations.

GAINS BETWEEN HEISE AND SHELLEY

It is about 64 miles between the Heise and Shelley gaging stations. Because records for Lorenzo, at an intermediate point, are available only for the years beginning with 1924, the gain for the entire stretch of channel was computed for the years 1915–27. The gain between Lorenzo and Shelley more than compensates for the loss from Heise to Lorenzo, and hence there is a net gain at Shelley.

Average apparent gain, in second-feet, in Snake River between the Heise and Shelley gaging stations

[− indicates loss]

Year	May	June	July	August	September
1915		[1] −500	540	175	[1] 940
1916		[1] 510	1,070	1,060	[1] 1,360
1917			[1] 630	860	[1] 1,150
1918			850	1,300	[1] 1,490
1919		−305	260	460	295
1920		−133	530	1,210	800
1921		−650	420	1,010	810
1922		450	980	1,060	580
1923		1,040	1,040	1,210	870
1924	[1] 503	745	1,040	645	640
1925	−409	970	1,400	950	780
1926	[1] 410	730	1,000	760	545
1927		700	1,700	1,430	1,000
Average	168	323	881	933	866

[1] Part of month only.

The figures shown in this table have been computed by adding the discharge of the Snake River at Heise to the discharge of Henrys Fork near Rexburg and subtracting the result so obtained from the combined discharge of the Snake River near Shelley and canal diversions between Heise and Shelley stations. The results as shown above are corrected to Heise dates by allowing a time interval of 18 hours between Heise and Shelley stations.

Part of the apparent gain between Heise and Shelley shown in the preceding table is supplied by surface waste into the stream. Complete records of this surface waste were obtained only during 1915, in which the average surface inflow was about 300 second-feet. Lack of records in other years made it impossible to segregate accurately the total apparent gains into gain from surface waste and gain from ground-water inflow.

Average surface flow, in second-feet, into Snake River from wasteways and drainage channels between Heise and Shelley gaging stations

[Records from report of special deputy State engineer, Boise, Idaho, 1915]

June 17–30, 1915	297
July 1–31, 1915	255
Aug. 1–31, 1915	282
Sept. 1–15, 1915	356

LOSSES BETWEEN SHELLEY AND CLOUGH RANCH

The Snake River loses water from Shelley to a locality a short distance above the mouth of the Blackfoot River, where springs appear in or near the river bed. Between the first of these springs and the Clough ranch, about a quarter of a mile below the mouth of the Blackfoot River, the spring inflow is 120 to 150 second-feet according to observations made at the Clough ranch when the Snake River was entirely dry for several miles below the town of Blackfoot.

The computed losses between Shelley and the Clough ranch are shown in the following table. These are the apparent losses, exclusive of surface irrigation waste into the river between these points. The actual loss is greater than this apparent loss by the amount of surface inflow between the stations. This has been measured at various times, and the results are shown in a subsequent table.

Records are not available for this section of the river during the winter, but if the losses shown in the following table are corrected for inflow between the stations during the summer and for lower discharge and colder water in the winter, the annual loss from the Snake River in this section is computed to be about 200,000 acre-feet.

Average apparent loss, in second-feet, from Snake River between Shelley and Clough ranch gaging stations

[+ indicates gain]

Year	May	June	July	August	September	Year	May	June	July	August	September
1915	------	[1] 274	240	435	[1] 564	1923	------	222	322	73	55
1916	------	[1] +225	+180	275	[1] 110	1924	[1] 311	346	349	183	123
1917	------	------	[1] +435	+67	[1] +10	1925	[1] 763	164	95	+84	+92
1918	------	------	335	185	[1] +40	1926	[1] 280	430	441	230	89
1919	------	358	427	326	226	1927	------	3	269	+49	+58
1920	------	411	248	101	[1] 19						
1921	------	491	271	124	+127	Average	451	278	195	124	67
1922	------	579	156	+119	12						

[1] Part of month only.

The figures in this table have been computed by adding the discharge of the Snake River at the Clough ranch to the diversions between Shelley and the Clough ranch, and subtracting the result so obtained from the combined discharge of the Snake River near Shelley and the Blackfoot River near Blackfoot. The results as shown above are corrected to Shelley dates by allowing a time interval of 12 hours between Shelley and the Clough ranch.

Surface flow, in second-feet, into Snake River on specified dates from wasteways and drainage channels between Shelley and Clough ranch gaging stations

July 28 to Aug. 2, 1921	136	Aug. 28–30, 1922	229	Aug. 30–31, 1926	22
Sept. 8, 1921	299	July 23–25, 1923	103	Aug. 10–11, 1927	300
July 13–15, 1922	76	Aug. 23–25, 1923	229		
Aug. 9–11, 1922	298	Sept. 12–14, 1924	44	Average	182
		Aug. 28–29, 1925	266		

The stretch of the river between Shelley and the Clough ranch has been divided into two sections since 1919 by an intermediate station near Blackfoot. From 1919 to 1923 the intermediate station was located at the Porterville Bridge, but in 1924 this site was abandoned and a station was established 2½ miles farther downstream, at the bridge west of Blackfoot. Records for these intermediate sections of the river are shown in the following tables:

Average apparent loss, in second-feet, from Snake River between the Shelley and Porterville Bridge gaging station

[+ indicates gain]

Year	June	July	August	September	Year	June	July	August	September
1919	290	237	322	309	1923	116	143	148	73
1920	143	282	182	[1] 109	Average	324	244	194	105
1921	388	192	156	+43					
1922	683	367	164	75					

[1] Part of month only.

The figures shown in this table have been computed by adding the discharge of the Snake River at the Porterville Bridge to the diversions from the river between the Shelley and Porterville stations, and subtracting the result so obtained from the discharge of the Snake River near Shelley. The results as shown above are corrected to Shelley dates by allowing a time interval of 6 hours between the Shelley and Porterville stations.

Average apparent loss, in second-feet, for Snake River between Porterville Bridge and Clough ranch gaging stations

[+ indicates gain]

Year	June	July	August	September	Year	June	July	August	September
1919	68	190	4	+83	1923	106	179	+75	+18
1920	268	+34	+81	[1] +90	Average	88	41	+93	+68
1921	103	79	+32	+84					
1922	+104	+211	+283	+63					

[1] Part of month only.

The figures shown in this table have been computed by adding the discharge of the Snake River at the Clough ranch to the diversions from the river between the Porterville and Clough stations, and subtracting the result so obtained from the combined discharge of the Snake River near Porterville and the Blackfoot River near Blackfoot. The results as shown above are corrected to Porterville dates by allowing a time interval of 6 hours between the Porterville and Clough stations.

Average apparent loss, in second-feet, from Snake River between Shelley and Blackfoot Bridge gaging stations

Year	May	June	July	August	September	Year	May	June	July	August	September
1924	[1] 184	332	322	293	228	1927		[1] 483	[1] 127	17	63
1925	[1] 725	352	172	69	92						
1926	[1] 240	336	391	286	173	Average	383	376	253	166	139

[1] Part of month only.

The figures shown in this table have been computed by adding the discharge of the Snake River at Blackfoot Bridge to the diversions from the river between the Shelley and Blackfoot Bridge stations, and subtracting the result so obtained from the discharge of the Snake River near Shelley. The results as shown above are corrected to Shelley dates by allowing a time interval of 8 hours between the Shelley and Blackfoot Bridge stations.

Average apparent gain, in second-feet, in Snake River between Blackfoot Bridge and Clough ranch gaging stations

[— indicates loss]

Year	May	June	July	August	September	Year	May	June	July	August	September
1924	[1] −127	−14	−27	110	105	1927		[1] 312	[1] −54	66	121
1925	[1] −38	188	77	153	184						
1926	[1] −40	−94	−50	56	84	Average	−68	98	−14	96	124

[1] Part of month only.

The figures shown in this table have been computed by adding the discharge of the Snake River at Blackfoot Bridge to the discharge of the Blackfoot River near Blackfoot and subtracting the total so obtained from the combined discharge of the Snake River at the Clough ranch and diversions from the Snake River between Blackfoot Bridge and the Clough ranch. The results as shown above are corrected to Blackfoot Bridge dates by allowing a time interval of 4 hours between Blackfoot Bridge and the Clough ranch.

Surface flow into Snake River, in second-feet, on indicated dates from wasteways and drainage channels between Shelley and Blackfoot Bridge gaging stations

July 28 to Aug. 2, 1921	85	Aug. 28–30, 1922	141	Aug. 30–31, 1926	8
Sept. 8, 1921	233	July 23–25, 1923	61	Aug. 10–11, 1927	207
July 13–15, 1922	64	Aug. 23–25, 1923	160		
Aug. 9–11, 1922	156	Sept. 12–14, 1924	34	Average	120
		Aug. 28–29, 1925	175		

Surface flow into Snake River, in second-feet, on indicated dates from wasteways and drainage channels between Blackfoot Bridge and Clough ranch gaging stations

July 28 to Aug. 2, 1921	51	Aug. 28–30, 1922	88	Aug. 30–31, 1926	14
Sept. 8, 1921	66	July 23–25, 1923	42	Aug. 10–11, 1927	93
July 13–15, 1922	12	Aug. 23–25, 1923	69		
Aug. 9–11, 1922	142	Sept. 12–14, 1924	10	Average	62
		Aug. 28–29, 1925	91		

GAINS BETWEEN CLOUGH RANCH AND NEELEY

In the 40-mile stretch between the Clough ranch and Neeley the river has a gain supplied chiefly from spring inflow but in part from irrigation waste and surface streams. The uniformity of this gain, about 2,500 second-feet, is noteworthy and indicates that the spring inflow in this section has a source far enough removed from its outlet to equalize by underground storage the major irregularities in the original contributions. The American Falls Dam, which creates a reservoir to store 1,700,000 acre-feet, was constructed on the Snake River in this section of the stream in 1925–26, and a small amount of water was stored in this reservoir during 1926 but not enough to affect these gains materially. Owing to the large amounts stored in 1927, however, and the consequent heavy evaporation losses, the gains were reduced during the summer of that year.

The earliest measurement of the gain in this section of the Snake River was made on August 11, 1905, and showed a discharge of 1,996 second-feet at American Falls while the Snake River was dry below Blackfoot.[10] The surface inflow from the upper Portneuf River was not measured at that time, but it is known from later measurements that in very dry years the low-water flow of the Portneuf at Pocatello is about 60 second-feet. The low-water flow at the Clough ranch on August 11, 1905, was probably about 120 second-feet, and Rueger Springs, tributary to the Snake River between American Falls and Neeley, probably discharged about 15 second-feet. This would make the gain between the Clough ranch and Neeley in August 1905 about 1,830 second-feet. During the month of August in sub sequent low-water years the gain was approximately as follows: 1915, 2,080 second-feet; 1919, 2,390 second-feet; 1924, 2,360 second-feet; 1926, 2,450 second-feet. It thus appears that the gain in this section of the Snake River during the month of August in dry years has increased persistently from 1905 to 1927.

[10] U. S. Geol. Survey Water-Supply Paper 178, p. 96, 1906.

Average daily gain, in second-feet, in Snake River between Clough ranch and Neeley gaging stations

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Yearly average
1912	2,440	2,670	2,740	2,740	2,930	2,730	2,630	2,170	2,770	2,770	2,570	2,930	2,670
1913	3,230	2,980	2,240	2,600	2,810	2,510	2,250	2,460	3,050	2,400	2,550	2,540	2,640
1914	2,750	2,640	2,500	2,750	3,050	2,920	2,520	2,570	2,150	2,080	2,050	2,050	2,500
1915	2,240	2,230	2,260	2,190	2,240	2,180	2,160	2,150	1,980	2,170	2,080	2,100	2,170
1916	[1] 2,080	[1] 2,190	2,300	2,080	2,410	2,560	2,200	2,450	2,140	2,330	2,280	2,350	2,280
1917	2,480	2,430	2,200	2,140	2,310	2,480	2,680	2,740	[1] 2,400	[1] 2,440	2,550	2,720	2,460
1918	2,540	2,520	2,550	2,410	2,110	2,540	2,490	2,470	2,150	2,880	2,570	2,380	2,470
1919	2,550	2,530	2,350	2,330	2,600	2,850	2,500	2,370	2,380	2,300	2,390	2,310	2,460
1920	2,330	2,460	2,340	2,390	2,500	2,600	2,640	2,490	2,690	2,340	2,370	2,450	2,470
1921	2,410	2,630	2,670	2,700	2,660	2,700	2,390	2,210	2,730	2,400	2,480	2,500	2,540
1922	2,440	2,450	2,420	2,540	2,530	2,870	2,760	2,510	2,640	2,460	2,650	2,500	2,570
1923	2,470	2,440	2,350	2,600	2,420	2,710	2,660	2,640	2,750	2,730	2,700	2,600	2,590
1924	2,720	2,790	2,590	2,460	2,610	2,730	2,580	2,360	2,210	2,220	2,360	2,380	2,500
1925	2,260	2,430	2,370	2,560	2,750	2,480	2,800	2,180	2,290	2,400	2,600	2,680	2,480
1926	2,610	2,640	2,590	2,540	2,690	2,670	2,580	2,370	2,460	2,400	2,450	2,510	2,540
1927	2,630	2,570	2,330	2,480	2,880	2,380	2,490	2,320	2,100	1,750	2,340	2,510	2,400
Average 1912–25 [2]	2,500	2,540	2,420	2,470	2,570	2,620	2,520	2,400	2,430	2,380	2,440	2,470	2,480

[1] Based on partly estimated records.
[2] For years prior to American Falls Reservoir construction.

The figures shown in this table have been computed by adding the flow of the Snake River at the Clough ranch to the flow of the Portneuf River at Pocatello, and subtracting the result so obtained from the flow of the Snake River at Neeley. The results as shown above are corrected to Clough ranch dates by allowing a time interval of 14 hours between the Clough ranch and Neeley. The records for 1926–27 include corrections for water stored in or released from the American Falls Reservoir but do not include corrections for evaporation from the reservoir or other reservoir losses.

The development of the Fort Hall tract, between Blackfoot and Pocatello, has undoubtedly contributed to the gain between the Clough ranch and Neeley. In the following table are given the records of the diversions and the cultivated area on this project for the years since 1908, also the estimated crop consumption, based on a duty of water of 1.7 second-feet, and the surface waste and ground-water contributions to the Snake River. On page 180 it is shown that 14,000 acre-feet a year, or 19 second-feet of continuous flow, has been absorbed as ground-water storage under the Fort Hall-Blackfoot area between 1914 and 1927. In the subjoined table no account is taken of this increase in ground-water storage.

Use of water on the Fort Hall project

Year	Total diversions from Snake River, Blackfoot River, and Ross Fork (acre-feet)	Cultivated area (acres)	Estimated crop consumption (acre-feet)	Surface waste and ground water contributed to Snake River	
				Acre-feet	Average (second-feet)
1908	10,000	1,885	3,210	6,790	9
1909	15,000	2,126	3,620	11,380	16
1910	18,000	2,700	4,590	13,410	18
1911	21,200	3,654	6,210	14,990	21
1912	56,970	8,540	14,500	42,470	59
1913	70,780	12,600	21,400	49,380	68
1914	77,300	16,432	28,000	49,300	68
1915	91,200	18,542	31,500	59,700	82
1916	109,600	19,563	33,300	76,600	106
1917	138,300	23,168	39,400	98,900	136
1918	173,000	23,917	40,700	132,300	183
1919	153,400	26,700	45,400	108,000	149
1920	158,600	25,232	43,000	115,600	159
1921	151,600	29,313	49,800	101,800	141
1922	159,900	24,988	42,500	117,400	162
1923	160,200	25,026	42,500	117,700	162
1924	150,300	24,743	42,100	108,200	149
1925	163,000	25,640	43,600	119,400	165
1926	207,800	27,527	46,900	160,900	222
1927	185,500	30,000	51,000	134,500	186
Average, 1920–27					168

The probable return flow to the Snake River from irrigation on the Springfield-Aberdeen project, north of the river, between the Clough ranch and American Falls, is shown in the following table. The net duty of water has been estimated at 1.7 acre-feet to the acre from irrigation water, exclusive of precipitation, except in years of deficient water supply, when a slightly larger amount has been used, based on water deliveries to the project. As some ground water percolates northward or westward away from the project and enters the Snake River many miles downstream, the contributions listed in the last column of the following table do not all reach the Snake River between the Clough ranch and Neeley.

Use of water on the Aberdeen project

Year	Diversions (acre-feet)	Cultivated area (acres)	Estimated crop consumption (acre-feet)	Surface waste and ground water contributed to Snake River	
				Acre-feet	Average (second-feet)
1912	120,000	20,000	34,000	86,000	119
1913	130,000	22,000	37,400	92,600	128
1914	140,000	24,000	40,800	99,200	137
1915	138,000	27,000	45,000	93,000	128
1916	158,000	28,000	47,600	110,400	152
1917	157,000	29,000	49,300	107,700	149
1918	209,000	30,000	51,000	158,000	218
1919	123,000	32,500	50,000	73,000	101
1920	216,000	36,400	61,800	154,200	213
1921	215,000	39,869	67,700	147,300	203
1922	217,000	41,171	70,000	147,000	203
1923	239,000	37,671	64,000	175,000	241
1924	175,000	36,207	57,000	118,000	163
1925	241,000	38,712	65,700	175,300	242
1926	176,100	40,145	62,000	114,100	157
1927	256,100	41,569	70,900	185,200	256
Average 1920–27					210

LOSSES BETWEEN NEELEY AND MINIDOKA DAM

The section of the Snake River between the Neeley and Minidoka gaging stations, a distance of 35 miles, is largely occupied by Lake Walcott, which backs water to a point about 3 miles below the Neeley station. Lake Walcott, formed by the Minidoka Dam, which is 65 feet high, contains about 160,000 acre-feet of water, of which about 55,000 acre-feet is dead storage and is not available for withdrawal. The lake when full covers 12,000 acres and extends for 30 miles along the stream. The dam serves as a diversion dam for the Minidoka canals and is also being used to develop power for irrigation pumping on the Minidoka project. The lake is maintained at its maximum stage during July, to provide sufficient head at the dam to meet the peak demands for power at that time, and it is not until the later part of the irrigation season, during September and October, that the water stored in the lake can be withdrawn. The full amount of the available storage is not usually withdrawn except in very dry years or when repairs to the power plant are necessary.

Springs having an aggregate flow of about 25 second-feet enter the river from the north near the upper end of the reservoir. Rock Creek, Fall Creek, and the Raft River are perennial tributaries from the south. During August 1905, prior to the construction of the dam, 33 second-feet of water, in addition to the inflow of the streams and springs above mentioned, was lost by evaporation and percolation between American Falls and Montgomerys Ferry, 7 miles below the Minidoka Dam.[11]

Losses in this section from 1909 to 1927 are shown in the following table:

Average apparent loss, in second-feet, in Snake River between Neeley and Minidoka gaging stations

[+ indicates gain]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Year
1909	210	50	+180	+260	105	70	350	430	1,220	1,490	710	180	365
1910	205	390	40	[1] +100	[1] +100	590	1,460	2,350	860	670	320	80	564
1911	75	+105	710	+1,110	+430	+360	+135	70	980	980	140	350	97
1912	+140	+340	240	[1] 100	40	170	130	+560	70	370	250	215	45
1913	+15	90	+90	+40	270	40	320	110	850	650	480	390	254
1914	+210	145	+200	+140	55	115	+50	300	210	100	+150	+10	14
1915	+10	590	810	+355	+285	+110	+20	+10	200	245	+105	+40	76
1916	+295	360	+245	+860	+450	+80	+550	190	90	625	200	195	+68
1917	+125	+100	+65	+260	+490	+440	+260	+200	460	1,250	330	180	23
1918	+110	0	+215	+390	+580	+10	180	450	+170	790	245	+130	5
1919	+95	100	65	+240	+110	30	360	350	550	315	125	+210	103
1920	+175	395	60	65	20	165	115	70	750	280	230	90	172
1921	+220	+40	+30	+105	+420	+15	+395	+940	500	270	210	+25	+101
1922	+360	35	+170	85	130	+250	80	+220	400	480	250	+40	35
1923	+380	+210	+290	+110	+325	10	+90	15	210	530	300	+270	+51
1924	+135	40	+170	155	+250	340	70	+70	200	250	20	+100	29
1925	+110	100	50	1,090	+15	+80	250	+150	150	520	280	65	179
1926	+25	10	+45	+160	+165	75	80	320	450	350	+10	+120	63
1927	50	+130	+260	+65	+85	70	50	+80	70	700	200	390	76
Average	+98	73	1	+142	+162	17	102	128	423	572	212	63	99

[1] Estimated.

[11] U. S. Geol. Survey Water-Supply Paper 178, p. 96, 1906.

The figures shown in this table have been computed by adding the discharge of the Snake River near Minidoka and diversions by the Minidoka canals, and subtracting the result so obtained from the discharge of the Snake River at Neeley. Results as shown above are corrected for changes in the water level of Lake Walcott and are adjusted to Neeley dates by allowing a time interval of 24 hours between Neeley and Minidoka stations.

These apparent losses should be increased by the inflow from tributaries between the stations to get the actual losses. Records of this inflow during the period 1909–27 are not available, but the following estimates for the years 1926–27 are based on occasional measurements and gage readings supplied by the Twin Falls Canal Co.:

Flow, in acre-feet, into the Snake River between Neeley and Minidoka Dam, 1926–27

Stream	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Year
Franklin Springs	794	[1] 806	806	780	728	930	900	831	858	880	862	798	9, 973
North Side Springs [2]	1, 550	1, 500	1, 550	1, 550	1, 400	1, 550	1, 500	1, 550	1, 500	1, 550	1, 550	1, 500	18, 250
Spring in sec. 19, T. 9 S., R. 28 E. [3]	93	90	93	93	84	93	90	93	90	93	93	90	1, 095
Rock Creek	992	1, 300	1, 100	1, 150	2, 200	1, 750	2, 250	361	30	0	30	330	11, 493
Fall Creek	919	1, 100	1, 000	1, 050	1, 400	1, 200	1, 440	955	648	595	776	816	11, 899
Raft River	979	[4] 1, 150	1, 100	950	1, 175	1, 050	1, 200	285	234	211	214	300	8, 848
Total	5, 327	5, 946	5, 649	5, 573	6, 987	6, 573	7, 380	4, 075	3, 360	3, 329	3, 525	3, 834	61, 558
Average flow in second-feet	87	100	92	91	126	107	124	66	56	54	57	64	85

[1] Inflow from November to March estimated from miscellaneous observation.
[2] Measured 15.5 second-feet Sept. 29, 1926. Estimated 9.5 second-feet additional.
[3] Estimated average discharge 1.5 second-feet.
[4] Inflow from November to March estimated by comparison with Goose Creek.

No records of evaporation losses from Lake Walcott have been obtained, but this reservoir is about midway between American Falls and Milner, at which evaporation records are available. The average of the Milner and American Falls evaporation records is assumed to apply to Lake Walcott.

Losses by evaporation and gains by precipitation at Lake Walcott

Month	Milner Lake evaporation (inches)		American Falls lake-pan evaporation (inches)		Average (inches)	Estimated reservoir evaporation (inches)	Precipitation [1] (inches)	Net gain or loss due to precipitation and evaporation (inches)	Average area submerged 1909–27 (acres)	Net gain or loss due to precipitation and evaporation	
	1927	1928	1927	1928						Acre-feet	Average (second-feet)
October	4. 11	[2] 2. 22	4. 00	2. 80	3. 28	[3] 2. 95	1. 18	−1. 77	10, 700	−1, 580	−26
November						[4] 1. 25	1. 10	−. 15	10, 900	−140	−2
December						[4] . 70	1. 15	+. 45	10, 900	+410	+7
January						[4] . 52	1. 14	+. 62	11, 000	+570	+9
February						[4] . 56	1. 00	+. 44	11, 000	+400	+7
March						[4] 2. 15	. 94	−1. 21	11, 100	−1, 120	−18
April	4. 02	5. 66			4. 84	[3] 4. 36	1. 43	−2. 93	11, 100	−2, 710	−46
May	5. 79	7. 38	[5] 5. 83		6. 33	[3] 5. 70	1. 34	−4. 36	11, 300	−4, 100	−67
June	7. 27	7. 27	7. 73	7. 37	7. 41	[3] 6. 67	. 88	−5. 79	11, 500	−5, 550	−93
July	9. 20	[2] 7. 66	9. 72	8. 46	8. 76	[3] 7. 88	. 52	−7. 36	11, 800	−7, 240	−118
August	7. 20	[2] 7. 92	7. 70	7. 91	7. 68	[3] 6. 91	. 66	−6. 25	11, 300	−5, 890	−96
September	6. 69	[2] 4. 83	4. 78	4. 75	5. 26	[3] 4. 73	. 72	−4. 01	11, 000	−3, 670	−62
Year						44. 38	12. 06	−32. 32	11, 100	−30, 620	−42

[1] Average of Burley and American Falls records.
[2] 88 percent of land-pan records based on relation between lake and land pans during April, May, and June.
[3] Taken as 90 percent of lake-pan records. Am. Soc. Civil Eng. Trans., vol. 90, p. 266, 1927.
[4] From winter records at Jerome.
[5] 74 percent of land-pan records based on relation between land and lake pans during other months of year.

According to records presented in the foregoing table, the average annual evaporation from the surface of Lake Walcott is 44.38 inches in depth, and the average annual loss by excess of evaporation over precipitation is 32.32 inches in depth, which amounts to an average annual loss from Lake Walcott of 30,620 acre-feet, equivalent to an average flow of 42 second-feet. The average apparent loss between Neeley and Minidoka Dam, calculated from the river records only, without regard to inflow, is 99 second-feet. If the inflow in 1926–27, amounting to an average for the year of 85 second-feet, is assumed to represent the average inflow, the total average loss is 184 second-feet. Of this, as above shown, 42 second-feet is caused by evaporation, leaving 142 second-feet to be accounted for by seepage into the underlying lavas. The seepage losses are greatest in July, doubtless because of the warm temperature and high stage of the lake. In many years the lake has been drawn down late in the season, which has resulted in lower losses during the latter part of the season and a gain during October from the return of bank storage. The indicated gains during January and February may be due to poor winter records at the river gaging stations or to unmeasured large inflows in certain years from the tributary streams, which sometimes are in flood stages during these months. More than 1,000,000 acres of drainage area is tributary to the Snake River between Neeley and the Minidoka Dam. In some years the snow covering this area is melted by "chinooks" during January and February, resulting in heavy run-off while the ground is still frozen. Such floods doubtless produce a much greater average inflow from tributaries during January and February than occurred during the winter of 1926–27, when the estimates of inflow were made. A comparison of the stream-flow records at Neeley and Minidoka Dam during the early years of operation of Lake Walcott indicates that large losses occurred.

Average losses and gains in Snake River between Neeley and Minidoka gaging stations, in second-feet

Month	Loss or gain indicated by records at Neeley and Minidoka Dam	Estimated inflow between Neeley and Minidoka Dam	Actual loss or gain	Net loss or gain in Lake Walcott due to evaporation from and precipitation upon this reservoir	Seepage loss or gain
October	−98	87	−11	−26	−37
November	−73	100	−173	−2	−171
December	−1	92	−93	+7	−100
January	+142	91	+51	+9	+42
February	+162	126	+36	+7	+29
March	−17	107	−124	−18	−116
April	−103	124	−227	−46	−181
May	−128	66	−194	−67	−127
June	−423	56	−479	−93	−386
July	−573	54	−627	−118	−509
August	−212	57	−269	−96	−173
September	−63	64	−127	−62	−65
Year	−99	85	−184	−42	−142

In April 1906 water was turned into a diversion channel, and the foundation of Minidoka Dam was laid.[12] On June 20, 1906, the water in the reservoir reached its maximum height for that year at an altitude of 4,237 feet, corresponding to 9,500 acre-feet above the dead storage level of 55,000 acre-feet. At that time 1,000 second-feet were passing through the rock-fill dam and escaping at its lower toe. In October 1906 the control gates were lowered, allowing water to rise in the reservoir, but a leak developed around the North Canal headgates, and the reservoir was again lowered to permit the driving of piles to stop this leakage. The gates were closed in November 1906.[13] The canal system was not completed until July 7, 1907, and apparently no water was diverted by the Minidoka canals prior to that time.

No records of canal diversions were made until the spring of 1909, but records of river discharge above and below the reservoir from 1906 to 1908 are shown in the following table:

Loss between Neeley and Minidoka Dam, 1906–8

	Run-off at Neeley (acre-feet)	Run-off below Minidoka Dam (acre-feet)	Loss (acre-feet)
1906			
March 17-31	160,000	160,000	0
April	451,000	425,000	26,000
May	1,070,000	892,000	178,000
June	1,300,000	1,250,000	50,000
July	547,000	546,000	1,000
August	186,000	178,000	8,000
September	283,000	225,000	58,000
October	288,000	317,000	+29,000
1907			
February 12-28	199,000	111,500	87,500
March	438,000	380,000	58,000
April	827,000	720,000	107,000
May	1,450,000	1,340,000	110,000
June	1,800,000	1,730,000	70,000
July	1,470,000	1,360,000	110,000
August	533,000	461,000	72,000
September	410,000	369,000	41,000
October	460,000	436,000	24,000
November	458,000	439,000	19,000
December	464,000	451,000	13,000
1908			
January	413,000	381,000	32,000
February	357,000	349,000	8,000
March	437,000	482,000	+45,000
April	590,000	482,000	108,000
May	781,000	695,000	86,000
June	1,400,000	1,270,000	130,000
July	726,000	621,000	105,000
August	351,000	280,000	71,000
September	336,000	328,000	8,000

The canal diversions in 1909, the first year of record, amounted to 314,000 acre-feet. The diversions started in July 1907, and from the meager information available it is estimated that 100,000 acre-feet may have been diverted in 1907 and 250,000 acre-feet in 1908. The

[12] Fogg, P. M., A history of the Minidoka project: U. S. Bur. Reclamation unpublished report, Burley, Idaho, 1915.

[13] U. S. Geol. Survey Water-Supply Paper 214, p. 74, 1907.

loss, as determined by subtraction of the Minidoka Dam records from the Neeley records for the period March 17, 1906, to September 30, 1908 (estimating the loss per month for the period November 1, 1906, to February 11, 1907, at 17,000 acre-feet), amounts to a total of 1,506,000 acre-feet. By adding the estimated diversions of 350,000 acre-feet in 1907 and 1908 and the water in storage in the reservoir on September 30, 1908, which has been estimated at 106,000 acre-feet including the dead storage, and subtracting the sum thus obtained from 1,506,000 acre-feet, the apparent loss during this period amounts to 1,050,000 acre-feet. Heavy apparent losses continued during 1909 and 1910 and are shown in the table as amounting to 264,000 acre-feet in 1909 and 408,000 acre-feet in 1910. The total apparent loss, neglecting inflow, from March 17, 1906, to September 30, 1910, is therefore computed to be 1,722,000 acre-feet. Inflow based on the records for 1927 would increase this amount by 270,000 acre-feet, making a total loss of 1,992,000 acre-feet in the 52-month period. Of this loss 137,000 acre-feet may be attributed to evaporation, leaving 1,855,000 acre-feet as seepage losses. Average seepage losses in later years amounted to 142 second-feet, equivalent to 463,000 acre-feet in 52 months. It thus appears that the seepage losses from Lake Walcott in the first 52 months of its existence were 1,392,000 acre-feet greater than the seepage losses for a like period in more recent years. Although this figure is only roughly approximate, because of the incomplete character of the records for a part of the period, it indicates that a very great amount of water went into permanent ground-water storage in the lava beds adjacent to Lake Walcott during the early years of its existence.

Evidence of this ground storage is afforded also by the testimony of Liberty Hunter, a rancher living on the Lake Channel, an ancient abandoned spring alcove several miles north of Lake Walcott. He reports that the ground water in the vicinity of his place began to rise about 18 months after the construction of Lake Walcott and began to appear in sloughs in the bottom of the Lake Channel in about 1909 at points as far as 5 miles from the shores of Lake Walcott.

GAINS BETWEEN MINIDOKA DAM AND MILNER

In the 35-mile stretch of channel between the Minidoka Dam and Milner there is a consistent gain in all years. The gains shown in the table below have been computed by subtracting the discharge of the Snake River at the Minidoka Dam from the combined discharge of the Snake River at Milner and the Milner Canal diversions. The results are adjusted to Minidoka dates by allowing a time interval of 14 hours from Minidoka to Milner. This time interval seems to represent the average time of transit between these stations better than the 24-hour period used by the Water District No. 36 during times of storage delivery. Prior to the summer of 1916 the measuring section on the Snake River at Milner was unsatisfactory except at very low stages, because of a large dead-water area with cross currents and upstream eddies. The measuring cable was moved to a more favorable location in September 1916, and on this account it is believed that the records obtained since 1916 are more reliable than those obtained prior to that date.

Average apparent gain, in second-feet, in the Snake River between the Minidoka Dam and Milner gaging stations

[– indicates loss]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Year
1910	1,600	1,380	–290	[1] 300	[1] 290	2,340	3,220	3,740	390	120	190	–130	1,090
1911	–120	–110	660	–270	–130	–320	–400	630	3,770	350	260	120	370
1912	250	–790	–540	150	250	30	480	320	1,730	–190	160	–380	120
1913	620	380	130	200	280	–40	470	1,280	720	390	580	510	460
1914	740	890	380	250	400	340	590	470	560	380	330	190	460
1915	1,490	2,380	300	200	530	470	160	450	820	250	310	400	650
1916	1,280	1,120	830	[1] 1,050	1,400	1,210	820	870	770	850	330	420	910
1917	410	390	[1] 320	[1] 320	[1] 290	[1] 340	580	200	330	100	160	490	330
1918	[1] 150	[1] 280	[1] 240	[1] 200	240	250	660	60	630	450	590	740	375
1919	130	310	270	260	90	400	740	160	370	320	170	210	285
1920	440	470	200	270	250	260	160	270	100	350	420	520	310
1921	410	300	130	180	210	210	170	340	–180	240	450	850	275
1922	300	370	300	270	300	320	440	90	10	250	690	550	325
1923	540	230	250	240	60	120	200	140	230	260	450	580	275
1924	740	265	200	80	190	20	–90	350	210	230	270	170	220
1925	200	270	160	310	225	90	320	490	150	120	440	660	285
1926	565	570	340	240	235	160	125	190	250	290	235	200	285
1927	300	300	470	100	180	70	240	270	500	100	300	640	290
Average	560	500	242	242	294	348	493	574	631	270	352	374	406
Average, 1917–27	380	341	262	225	206	204	322	233	236	246	380	510	296

[1] Partly estimated.

GAINS BETWEEN MILNER AND BLUE LAKES

Between Milner and Blue Lakes, a distance of 26 miles, the Snake River receives considerable inflow, of which about 115 second-feet is provided by springs from the north bank, and the rest by inflow from the south. In 1902, prior to irrigation on the south-side lands, the springs entering the river from the south in this section had a total flow of about 28 second-feet. The wasteway from the main Twin Falls South Side Canal, half a mile below Milner, at times discharges large volumes of water into this section of the river, of which no record is available.

The total gain from Milner to Blue Lakes from all sources is shown in the following table:

Average apparent gain, in second-feet, in Snake River between Milner and Blue Lakes

[— indicates loss]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Year
1912	1, 040	940	1, 230	[1] 720	720	820	460	630	−1, 450	100	510	960	560
1913	940	480	540	580	620	670	1, 200	1, 300	600	630	240	640	705
1914	940	370	490	960	680	770	910	1, 200	810	480	550	860	750
1915	40	−170	[1] 650	[1] 700	730	780	770	910	190	465	475	485	505
1916	590	360	230	[1] 240	380	380	220	320	390	370	740	850	420
1917	2, 320	2, 340	2, 040	1, 570	1, 320	1, 310	1, 320	1, 540	760	-----	-----	-----	-----
1919	-----	-----	-----	-----	-----	-----	-----	930	520	510	525	590	-----
1920	700	900	1, 030	850	840	650	630	830	1, 030	540	585	650	770
1921	1, 020	1, 220	1, 100	1, 270	1, 200	1, 300	1, 370	1, 820	1, 830	615	660	920	1, 190
1922	950	1, 310	1, 300	1, 180	1, 180	1, 380	1, 390	1, 940	1, 750	640	680	710	1, 200
1923	770	1, 290	1, 130	1, 000	980	830	880	940	1, 080	660	655	725	910
1924	1, 180	1, 270	1, 080	960	900	990	725	520	540	535	555	560	820
1925	585	1, 070	960	1, 870	950	970	1, 040	1, 270	990	860	690	950	1, 020
1926	1, 260	1, 310	1, 130	930	1, 010	920	930	535	560	590	605	650	870
1927	655	645	750	840	615	515	450	770	1, 170	740	750	780	720
Average	928	953	976	976	866	878	878	1, 030	718	553	587	738	840
Average 1917–27	1, 050	1, 260	1, 170	1, 160	1, 000	985	971	1, 110	1, 020	632	634	726	977

[1] Partly estimated.

The figures shown in the table above have been computed by subtracting the discharge of the Snake River at Milner from the discharge of the river at Blue Lakes ranch. The results are adjusted to Milner dates by allowing a time interval of 9 hours between stations. The actual time interval ranges from about 6 hours at high stages to about 20 hours at low stages, when the river is practically dry at Milner; the time of transit for average discharges is about 9 hours.

GAINS BETWEEN BLUE LAKES AND HAGERMAN

The inflow in the 30-mile stretch of channel between Blue Lakes and Hagerman is supplied mainly from springs. The measured spring inflow from the north amounts to about 3,220 second-feet; in addition there is surface waste from the North Side tract. Probably additional undeterminable spring inflow is also received from the north. Rock Creek, from the south, contributes about 200 second-feet at its mouth, mostly supplied by drainage and waste water from the Twin Falls South Side tract. From the south the river also receives additional seepage water and surface waste from the Twin Falls project as well as ground water contributions from the Salmon River drainage basin. So far as shown by the records in the following table, the average total in the section from all sources during the period from 1912 to 1928, inclusive, was 4,100 second-feet.

Average apparent gain, in second-feet, in the Snake River between Blue Lakes, near Twin Falls, and Owsleys Ferry, near Hagerman

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Year
1912	------	------	------	------	------	------	------	------	------	------	3,830	3,600	------
1913	3,430	3,550	3,760	3,470	3,380	3,490	2,810	2,470	2,950	3,720	5,600	5,700	3,690
1914	3,990	2,860	3,770	3,620	3,600	3,480	3,000	2,700	1,390	4,110	4,460	5,200	3,520
1915	3,450	3,460	3,900	3,280	3,590	3,740	3,190	4,240	4,140	3,700	3,890	4,160	3,730
1916	4,340	4,370	3,920	4,210	5,120	4,130	4,360	[1] 4,300	[1] 4,300	4,230	4,230	3,490	4,250
1917	[1] 3,850	3,960	4,020	4,080	4,540	4,070	3,970	3,990	3,400	------	------	------	------
1919	------	------	------	------	------	------	------	------	------	3,980	4,010	4,310	------
1920	4,430	3,740	3,640	3,980	3,680	3,700	4,350	3,150	3,440	4,240	4,490	4,540	3,950
1921	4,380	3,750	4,010	3,550	3,500	3,440	3,620	3,660	2,970	4,420	4,440	4,630	3,860
1922	4,540	3,380	3,490	3,300	3,640	3,580	3,260	2,760	3,220	4,350	4,790	4,800	3,760
1923	4,590	4,010	4,230	4,210	4,140	4,050	4,200	3,980	4,600	4,700	4,810	4,820	4,360
1924	4,760	4,740	4,670	4,660	4,650	4,360	4,890	4,580	4,460	4,450	4,200	4,480	4,570
1925	4,810	3,980	4,140	4,440	4,410	4,310	4,300	3,790	4,470	4,380	4,720	4,500	4,350
1926	4,690	4,360	4,290	3,890	4,160	3,920	4,250	4,230	4,280	4,390	4,300	4,420	4,270
1927	4,700	4,670	4,400	4,350	4,700	4,650	4,550	4,700	3,890	4,520	4,880	5,320	4,610
1928	5,170	4,540	4,460	4,230	4,250	4,280	4,310	3,550	4,410	4,820	5,050	5,280	4,530
Average	4,370	3,950	4,050	3,950	4,100	3,940	3,930	3,720	3,710	4,290	4,510	4,620	4,100

[1] Partly estimated.

The figures shown in this table have been computed by subtracting the discharge of the Snake River at Blue Lakes from the discharge of the river near Hagerman. The results are corrected to Blue Lakes dates by allowing a time interval of 9 hours between stations.

The increased gain in recent years as compared with the years prior to 1923 is probably due to a decrease in the amount of water absorbed as permanent ground-water storage on the Twin Falls South Side tract.

GAINS BETWEEN HAGERMAN AND KING HILL

The total measured spring inflow in the 30-mile section between Hagerman and King Hill amounts to about 1,520 second-feet, the greater part of which is supplied by the Malad Springs. Some surface inflow is also received from the Wood River area, amounting to an annual average of about 100 second-feet, although the inflow from this source differs greatly at different times. The King Hill ditch diverts an average flow of about 290 second-feet from the Malad Springs in this section during the peak of the irrigation season each year. The gain between these stations, neglecting diversions by the King Hill project, is shown in the following table and amounts to an annual daily average of 2,080 second-feet over a 14-year period.

Average apparent gain, in second-feet, in the Snake River between Owsleys Ferry, near Hagerman, and King Hill

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Year
1912	------	------	------	------	------	------	------	------	------	------	1,970	2,100	------
1913	2,230	2,050	2,000	2,070	2,200	2,660	2,670	2,350	2,340	[1] 1,200	[1] 1,200	1,030	2,000
1914	1,760	2,800	1,990	2,500	2,210	2,600	2,300	2,850	3,660	1,200	1,280	1,220	2,200
1915	2,320	1,940	1,530	2,220	2,030	2,800	2,020	1,700	1,770	2,070	1,910	1,760	2,010
1916	1,100	1,680	2,140	1,630	1,710	3,060	2,630	[1] 2,400	[1] 1,800	1,600	1,430	2,580	1,980
1917	[1] 2,400	2,500	2,280	1,780	1,930	2,200	4,450	4,350	4,720	------	------	------	------
1919	------	------	------	------	------	------	------	------	------	1,980	1,900	1,730	------
1920	2,100	2,330	2,300	2,210	2,090	2,140	1,750	2,100	1,910	1,740	1,470	1,910	2,000
1921	1,920	2,400	1,980	2,430	2,620	2,810	2,280	2,740	3,610	1,480	1,860	1,790	2,330
1922	2,220	2,490	2,480	2,820	2,320	3,260	3,100	2,770	2,660	1,580	1,660	1,780	2,430
1923	2,080	2,020	2,000	2,090	2,230	2,540	2,030	1,930	1,930	1,440	1,540	1,750	1,970
1924	2,070	1,900	1,900	1,900	2,110	2,020	1,490	1,110	1,230	1,150	1,360	1,320	1,630
1925	1,450	2,170	2,050	2,100	2,390	2,140	1,700	1,590	1,560	1,510	1,610	2,040	1,860
1926	2,120	2,100	2,500	2,980	2,000	2,350	1,790	1,460	1,390	1,620	1,540	1,730	1,960
1927	1,960	2,140	2,180	2,210	2,720	2,540	2,240	2,090	1,990	1,600	1,610	1,820	2,090
1928	2,080	2,790	2,360	2,310	2,100	2,090	2,220	1,350	1,670	1,600	1,530	1,720	1,980
Average	1,990	2,240	2,120	2,230	2,190	2,520	2,330	2,200	2,300	1,550	1,590	1,750	2,080

[1] Partly estimated.

The figures shown in this table have been computed by subtracting the discharge of the Snake River near Hagerman from the discharge of the river at King Hill. The results are corrected to Hagerman dates by allowing a time interval of 9 hours between stations. Actual gains during the irrigation season will be greater than those shown above by the amount of diversions by the King Hill ditch. The records of the King Hill ditch are not complete enough to warrant the calculation of actual gains.

Diversions, in acre-feet, by the King Hill ditch from the Malad Springs, 1921–28 [1]

Year	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Total
1921	0	0	6,035	12,277	14,813	12,778	10,250	0	0	56,153
1922	0	1,208	11,912	13,149	14,640	13,541	6,876	0	0	61,326
1923	0	5,191	16,169	16,493	17,032	15,981	14,262	6,326	0	91,454
1924	0	13,924	16,277	15,981	15,035	17,091	15,355	9,665	2,009	105,337
1925	------	------	------	------	------	------	------	------	------	95,549
1926	------	------	------	------	------	------	------	------	------	97,000
1927	0	7,933	13,928	15,917	16,036	20,477	12,750	7,142	0	94,183
1928	715	8,300	19,370	18,743	16,675	18,366	15,643	6,136	0	103,948

[1] Records supplied by King Hill Irrigation District, King Hill. Totals for the season only are available for 1925 and 1926. Diversions were started about 1909 or 1910, but records are lacking for the years prior to 1921.

LOSSES FROM HENRYS FORK OF SNAKE RIVER BELOW MOUTH OF WARM RIVER

The channel of Henrys Fork (locally called "North Fork") clearly occupies its present position as the result of the basaltic lava flows from cones to the west, which have raised the channel and pushed it eastward from the course occupied by the ancestral stream. To determine the amount of water that may be leaking from the present valley under these lavas into the ancient buried channel, a comparison has been made of the surface inflow and outflow from the valley. The surface outflow, according to the record for Henrys Fork near Rexburg, is as follows:

Run-off, in acre-feet, of Henrys Fork near Rexburg, years ending Sept. 30, 1920–27

	Observed run-off during open-water months	Estimated winter run-off	Total estimated run-off
1920	873,800	351,000	1,225,000
1921	950,000	680,000	1,630,000
1922	742,600	630,000	1,373,000
1923	623,000	520,000	1,143,000
1924	299,700	408,000	708,000
1925	1,314,400	438,000	1,752,000
1926	750,900	372,000	1,123,000
1927	1,415,200	315,000	1,730,000
Average			1,335,000

The flow of the stream varies but little during the winter, and therefore the winter estimates given above are believed to be fairly reliable, being based on comparison with the winter flow of Henrys Fork near Warm River, with the flow at the beginning and end of the frozen period, and with actual winter records obtained at the station during earlier years.

The tributary inflow has been previously estimated as follows:

Average annual surface flow, in acre-feet, into the valley of Henrys Fork of Snake River, 1920–27

Henrys Fork above Warm River	757,000
Warm River	164,000
Robinson Creek	91,000
Fall River	629,000
Teton River	579,000
Moody Creek	2,000
Total	2,222,000

On the basis of the records of the Idaho Department of Reclamation, it is estimated that about 115,000 acres was under irrigation in the Henrys Fork Valley in 1928. This area has the highest altitude in the valley of the Snake River, with a resultant shorter growing season and slightly greater precipitation than the average for the entire valley. On this account the net consumptive use on the gross average of irrigated lands in this area has been assumed to be only 1.6 acre-feet to the acre, exclusive of precipitation, giving a net crop use of 184,000 acre-feet a year. If this figure is subtracted from the 2,222,000 acre-feet of average annual inflow and the result is compared with the average annual outflow of 1,340,000 acre-feet as measured at the gaging station near Rexburg, it appears that there is an average ground-water movement out of the Henrys Fork Valley above the Rexburg gaging station of 698,000 acre-feet a year for the period 1920–27, exclusive of any contributions from precipitation in the valley that may reach the zone of saturation. Of this total ground-water outflow from the Henrys Fork Valley, 140,000 acre-feet has been estimated [14] as ground-water flow from a portion of the valley known as "Egin Bench", which moves northward and then southward toward Mud Lake.

In view of the facts that the Egin Bench area comprises 30,000 acres out of the total of 115,000 acres irrigated in the Henrys Fork Valley and that diversions to the Egin Bench amount to over 350,000 acre-feet annually, it appears probable that the total ground-water movement away from the Egin Bench, including percolation toward the west and southwest, may amount to considerably more than 140,000 acre-feet annually—possibly to twice that quantity.

FUTURE DEVELOPMENT OF GROUND WATER

Ground-water development in the Snake River Plain is especially feasible in the Mud Lake region, where the water can in part be recovered through drains and flowing wells,[15] and in the valleys of the Big Lost, Little Lost, and Raft Rivers. Some development of ground-water supplies could be made near Carey, along Fish Creek, Little Wood River, Silver Creek, and other streams that enter the Snake River Valley. These developments would for the most part be made by pumping from wells, and owing to the present (1933) low value of land and water rights it is doubtful to what extent such undertakings would be financially successful. Possibly 75,000 acre-feet annually may eventually be developed in these tributary valleys, principally by pumping in selected locations where existing surface supplies would not be materially depleted by pumping operations. This water would be used principally upon lands which now have surface water rights that yield inadequate supplies. However, even for such use, development must for the most part be deferred until there is a general improvement in the agricultural situation.

In the immediate vicinity of the Snake River there are large areas where the water table is relatively close to the surface. However, this high position of the water table is maintained chiefly by the diversions from the river, amounting to more than 6 acre-feet to the acre annually, not more than 30 percent of which is consumed by the crops. These large diversions and the resultant high water table produce a substantial return flow to the river in certain sections, and this return flow constitutes the supply for established water rights. The owners of these rights would not view with equanimity any procedure that might decrease their water supplies. The relatively low cost of water rights at present (1933) acts as a further deterrent

[14] 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–D, pp. 112–114, 1925.

[15] Stearns, H. T., Bryan, L. L., and Crandall, Lynn, Geology and water resources of the Mud Lake region, Idaho: U. S. Geol. Survey Water-Supply Paper 818 (in press).

to the development of ground water in the valley. In the area above Blackfoot natural-flow rights of early priority have in recent years been selling at prices ranging from $15 to $25 a miner's inch ($750 to $1,250 a second-foot). The American Falls Reservoir, which was the last large storage development on the Snake River, cost only $4.50 an acre-foot of storage. Stored water in recent years has been available for rental at an annual cost of 25 to 50 cents an acre-foot. Such low costs exclude the possibility of pumping water for irrigation in the Snake River Valley unless the irrigated acreage should be considerably extended.

In certain areas along the river, however, the rise of the water table has developed drainage problems, and in some of these areas a combination of drainage and ground-water development may become feasible. In an area of 200 square miles in the vicinity of the confluence of Henrys Fork and the Snake River, extending up Henrys Fork about 12 miles and down the Snake River on the south or east side nearly to Market Lake and Roberts, the water table each year rises within 10 feet of the surface. In parts of this area the water table is very near the surface, and the land could be made more productive by drainage. This could be accomplished largely by open drains, but pumping from wells would provide more effective drainage, though at a greater cost. Water developed either by surface drainage or by pumping in the Roberts and Market Lake portion of this area would result in the recovery of ground water, which now moves westward and passes beneath the Snake River Plain, eventually to reappear below Milner.

In recent years the water table has steadily risen under an area of about 30 square miles east and north of Blackfoot, and this land now needs draining. The ground-water supply for this region comes principally from irrigation along the east side of the valley between Idaho Falls and Blackfoot. The recent rise of the water table under the Fort Hall project has probably contributed to this condition by preventing the free underground drainage that formerly existed. Ground-water supplies obtained in this area by drainage installations could be used to supply existing canals and to relieve their present demands on the river flow.

Portions of the Springfield-Aberdeen project, which lies north of the Snake River between the mouth of the Blackfoot River and American Falls, are also in need of drainage. Water supplies obtained by drainage on this project could largely be used on the project to supplement existing surface-water supplies.

Ground water under portions of the Minidoka project is now being pumped for a supplemental irrigation supply and provides drainage at the same time. As shown elsewhere, there is considerable loss of ground water on the north side by northward percolation under the lava plains. If the need for water ever becomes urgent ground water can here be recovered by pumping from wells.

Considerable quantities of ground water have been developed on the Twin Falls South Side project, incident to the drainage of seeped areas. Most of this water is collected into drains and tunnels, either by direct inflow or by discharge from flowing wells. Some of the water is delivered to low-level canals, but the greater part escapes into the river. If the need should arise, substantial amounts of ground water could be recovered by pumping.

The diversion of water from the Snake River at a point near the mouth of Rock Creek, northwest of the city of Twin Falls, has been proposed for the irrigation of the low-lying portion of the Bruneau project, situated south of the Snake River between the Salmon Falls and Bruneau Rivers. The water supply at the proposed point of diversion is now limited to seepage water and spring inflow between Milner and that point, but it could be greatly augmented by driving a tunnel, just above the river level, northward from Blue Lakes for a few miles. Such a tunnel would probably intercept much of the large volume of water that will otherwise be naturally discharged into the Snake River Canyon through the large springs between Blue Lakes and Thousand Springs. If the proposed irrigation plan should not prove feasible, the same development might be made for the purpose of concentrating the spring inflow for generating power.

TRIBUTARY VALLEYS

GROUND-WATER SUPPLIES

Ground water moving down tributary valleys supplies much of the ground water of the Snake River Plain. Many of these streams flow in wide valleys where there is more arable land suitable for irrigation than can be supplied by the surface water. In recent years more and more interest has been displayed in the development of ground-water supplies for irrigation in these valleys, and consequently special studies have been made in several of the valleys. The resulting reports were promptly released to the public in manuscript form, but the principal data are incorporated in this paper. An investigation of the Raft River Valley was made in 1929, at the request of the Commissioner of Reclamation of Idaho and the president of the Minidoka Irrigation District. In 1930 a study of the Big Lost and Little Lost River Valleys was made, which included drilling and pumping tests. Much of the information regarding these two valleys was obtained by Mr. Crandall during the period from 1920 to 1929, when he was commissioner of the United States District Court in charge of investigations in the Big Lost River Valley. For the valleys in which such special studies have not yet been made the available data are comparatively meager.

The tributary valleys are described in order of their location, beginning on the south side of the Snake River opposite King Hill, extending eastward and northward to the head of the basin, and thence back on the north side to the vicinity of King Hill. (See pls. 1, 4.) The estimates of the contributions by each valley, either as surface-water or ground-water inflow, are utilized in the inventory on page 176. They were made in the following manner.

The average flow during the 8 years 1920–27 was used. This period is long enough to equalize or smooth out to a considerable extent the annual irregularities, and the stream-flow records are more nearly complete for this period than for any other group of years. For a few minor streams, the records for other years were used because records were not available for the period 1920–27. The stream-flow records are taken from the following sources unless otherwise stated:

1920. U. S. Geol. Survey Water-Supply Paper 513, 1924.
1921–22. Idaho Dept. Reclamation 2d Bienn. Rept., 1922.
1923–24. Idaho Dept. Reclamation 3d Bienn. Rept., 1924.
1925–27. U. S. Geol. Survey Water-Supply Papers 613, 633, and 653.

SALMON FALLS CREEK VALLEY

Salmon Falls Creek, the first perennial tributary of the Snake River above King Hill on the south side, rises in Nevada. Throughout most of its course in Idaho it flows in a deep, narrow canyon where ground-water development is impracticable. The seepage from the Salmon Falls Reservoir flows through the interstices in the intracanyon basalt on the east abutment of the dam (p. 85). This leakage amounts to about 1,700 acre-feet a month during the high stages of the reservoir.

Records of the flow of Cedar Creek, a tributary of Salmon Falls Creek, at a point just below the Cedar Creek Reservoir, about 16 miles above the mouth of the stream, were supplied by the Utah-Construction Co., Ogden, Utah.

Annual discharge, in acre-feet, of Cedar Creek, years ending Sept. 30, 1921–28

1921	16, 642	1926	16, 642
1922	23, 811	1927	14, 472
1923	21, 080	1928	15, 190
1924	19, 482		
1925	18, 908	Average	18, 300

These records include diversions from Devil and Deadwood Creeks into the Cedar Creek Reservoir and represent the equalized reservoir outflow as affected by holdover storage from year to year. Deadwood Creek is a tributary of the East Fork of the Bruneau River. The area irrigated from Cedar Creek below the place of measurement during this period has averaged 6,700 acres. The water supply is scanty and has been spread over as large an area as possible, on account of which a consumptive use of 1.5 acre-feet to the acre, exclusive of precipitation, for gross irrigated acreage may be assumed instead of 1.7 acre-feet, as elsewhere in the Snake River Plain where the water supply is more ample. Applying this figure to the 6,700 acres gives a net consumption of 10,050 acre-feet, which subtracted from the average run-off leaves about 8,000 acre-feet as an average annual contribution to the Snake River from Cedar Creek.

Records of the flow of Salmon Falls Creek at a point near San Jacinto, Nev., above the Salmon River Canal Co.'s reservoir and Carey Act project, are available as follows:

Annual discharge, in acre-feet, of upper Salmon Falls Creek, years ending Sept. 30, 1920–27

1920	83, 100	1925	104, 000
1921 (partly estimated)	176, 000	1926	56, 500
1922	123, 000	1927	96, 300
1923	96, 700		
1924	80, 900	Average	102, 000

The land irrigated by this stream is slightly in excess of 30,000 acres, to which a small water supply is delivered. The net crop consumption plus the evaporation losses from the surface of the Salmon Falls Reservoir have been estimated at 52,000 acre-feet, leaving an average annual contribution to the Snake River of about 50,000 acre-feet. Perhaps about a third of this contribution is drainage water, which appears in the Salmon Falls Creek Canyon below the reservoir and flows directly into the Snake River. The rest was either contributed to the ground-water supply of the Snake River Plain or remained in storage as ground water under the Salmon project.

VALLEYS BETWEEN SALMON FALLS CREEK AND GOOSE CREEK

Deep, Cottonwood, McMullen, Rock, and Dry Creeks are ephemeral streams tributary to the Snake River between Salmon Falls Creek and Goose Creek. Where these creeks debouch upon the plain there is rather level arable land, and some attempts have been made to develop ground-water supplies for it. The meager well data indicate that artesian water occurs in a quantity sufficient to warrant development on a small scale. The presence of warm springs early encouraged drilling in the alluvium between the Miocene (?) rhyolite of the foothills and the basalt of the Snake River Plain. At the edge of the foothills, about 6 miles east of Hollister, in the drainage basin of Rock Creek, warm artesian water has been obtained from wells in a small swampy tract known as "Warm Springs." The yield of one of the 6-inch wells is about 45 gallons a minute, and on July 14, 1929, the water issued at a temperature of 101° F. About three-quarters of a mile to the northeast is the Jones well, which on July 14, 1929, had a temperature of 96° F. and yielded about 450 gallons a minute.

Russell [16] states that one other well was drilled on this ranch, and it is reported that the head has declined considerably since artesian water was first struck here in 1899. Water piped from this basin supplies Hollister.

About a mile northeast of the Jones well is the Olsen well, which yields about 50 gallons a minute of water with a temperature on July 14, 1929, of 98° F. A small wooden bathhouse near the well is still being used by local ranchers. Russell describes another well in this vicinity that had a head of 20 feet when drilled in 1899, but later the water ceased to flow because of defective casing. It is evident that small irrigation supplies can be obtained from wells in this area if care is taken to prevent leakage and waste from the wells. Russell [17] described other flowing wells in this area. The successful hot-water wells at Artesian City, near the mouth of Dry Creek, are described on page 168. Considerable drilling was in progress in this vicinity in 1928, and the record of one well is given below:

Driller's log of D. B. Moorman well, in SW¼SW¼ sec. 32, T. 11 S., R. 20 E.

[W. A. Moore, driller]

	Thickness (feet)	Depth (feet)
Soil	33	33
Black lava; crevice 5 feet wide at 95 feet	67	100
So-called hard granite sandstone, probably really rhyolite	70	170
Loose red sand	10	180

Water was encountered at 110 feet and rose 10 feet. The well had not been finished at the time this record was obtained.

The following estimates have been made of the discharge of the streams tributary to the Snake River between Salmon Falls Creek and Goose Creek.

Estimated average annual discharge, in acre-feet, of streams between Salmon Falls Creek and Goose Creek

Dry Creek	[1] 10,000	Cottonwood Creek	4,000
Rock Creek	[1] 28,000	Deep Creek	3,000
McMullen Creek	4,000		
			49,000

[1] Idaho State Engineer Ninth Bienn. Rept., pp. 436-439, 1912.

The land irrigated from the streams listed above has been estimated at 5,000 acres, on which a net duty of water of 1.7 acre-feet to the acre, exclusive of precipitation, has been assumed, leaving an average annual surface and ground-water contribution to the Snake River of about 40,000 acre-feet, most of which occurs as run-off during the flood period in the spring.

[16] Russell, I. C., Geology and water resources of the Snake River Plains of Idaho: U. S. Geol. Survey Bull. 199, p. 176, 1902.

[17] Idem, p. 177.

GOOSE CREEK VALLEY

The geology and ground-water conditions of Goose Creek Valley have been adequately described by Piper.[18] The valley contains an irrigation district that is supplied from the Oakley Reservoir. Artesian water occurs in the upper part of the valley, and most of the water from the artesian wells flows into the reservoir. In the lower part of the valley there is several thousand acres of arable land that is not irrigated because there is no available surface-water supply and the water table lies too far below the surface to make pumping from wells feasible.

The records of water supply and irrigation given in the following table were furnished by the Oakley Canal Co. The diversions from the reservoir in some years include hold-over storage.

Supply and disposal of water in Goose Creek Basin

Year ending Sept. 30	Diversions from Oakley Reservoir (acre-feet)	Deliveries at headgates (acre-feet)	Cultivated land (acres)	Estimated net crop consumption (acre-feet)	Contributions to water table (acre-feet)
1920	35,340	16,604	18,000	16,604	18,736
1921	87,868	51,476	21,000	31,500	56,368
1922	74,951	40,806	21,000	31,500	43,450
1923	63,144	32,347	18,849	28,300	34,844
1924	49,574	25,363	14,465	21,700	27,874
1925	48,316	25,883	17,987	25,883	22,433
1926	33,267	17,024	18,234	17,024	16,243
1927	41,857	24,152	16,368	24,152	17,705
Average					29,700

On account of the scanty water supply and high use of water on this project, the net consumptive use of water for the gross irrigated acreage was taken as 1.5 acre-feet to the acre, exclusive of precipitation, except in years when the deliveries were less than this amount, for which the amount delivered was used.

Birch Creek, Big Cottonwood Creek, and Little Cottonwood Creek, which drain into the Goose Creek Valley, lose some water by percolation before they discharge into the reservoir. These losses have been estimated at 3,300 acre-feet annually, making a total estimated contribution to the Snake River Plain of 33,000 acre-feet annually.

MARSH CREEK VALLEY

Marsh Creek Valley is a small valley between the Goose Creek and Raft River drainage basins. Between the foothills and the Snake River, at the mouth of the Marsh Creek Valley, the depth to water is too great to allow economical pumping from wells. The valley narrows rapidly upstream from the Snake River Plain, and practically all the available land is irrigated from the flow of the creek, which aggregates about 2,000 acre-feet annually.

[18] Piper, A. M., Geology and water resources of the Goose Creek Basin, Cassia County, Idaho: Idaho Bur. Mines and Geology Bull. 6, 1923.

The town of Albion, in which the State Normal School is situated, is in the upper part of Marsh Creek Valley and is supplied chiefly by shallow wells. The location of the wells in this valley is shown in plate 19. A dug well 30 feet deep in sec. 6, T. 12 S., R. 25 E., near the creek, yields a small flow of water. It appears to be simply the underflow of the creek developed into a spring, because the water surface is essentially the same as the level of the adjacent creek. A well 500 feet from the girls' dormitory at the Albion Normal School, according to Mr. Stevens, State superintendent of construction, penetrated mostly clay with some rock for the first 115 feet, then 235 feet of lava, and lastly 150 feet of clay and gravel. The well was drilled 24 inches in diameter for the first 115 feet, a 12-inch casing was inserted, and the intervening space was filled with lumnite cement to shut out shallow ground water. The next 235 feet was drilled 8 inches in diameter and the last 150 feet 6 inches. The lava and probably most of the clay reported in the log represent silicic eruptive material (Miocene?), with sedimentary beds. The pump is set at a depth of 135 feet and supplies 200 gallons a minute. It is reported that the main water-bearing bed is at a depth of 150 feet. The water rose about 100 feet when struck and now stands about 42 feet below the surface.

It is reported that about 1920 a test well for oil was drilled 505 feet deep near the northwest corner of sec. 17, T. 12 S., R. 25 E. The reported log shows 14 feet of boulders and gravel, 56 feet of blue clay, 55 feet of sandstone, 1½ feet of crystallized lime, 1½ feet of oil sand, 93 feet of quicksand, 12 feet of sandstone, 92 feet of gravel, clay, and sand, 33 feet of oil shale, 87 feet of gravel and sand, and 60 feet of gumbo clay. Water was encountered at 30 feet, between 126 and 221 feet and between 358 and 445 feet. Flowing water was not encountered. The log indicates that chiefly valley fill was encountered.

RAFT RIVER VALLEY

GEOGRAPHY

In the fall of 1928 Messrs. Stearns and Steward spent about a week and L. H. Perrine about a month in the Raft River Valley. Practically all the wells were recorded and connected by a network of levels, and statistics were obtained as to the area of irrigated land in the valley. A manuscript report covering the results of this work, with an estimate of the available supply of ground water, was released to the public in May 1929. It is published here in condensed and revised form. Mr. Frank Riblett, engineer at Malta, assisted generously, and many other residents of the valley, especially Messrs. E. H. Warneke, H. A. Shaw, and H. A. Shaw, Jr., supplied much useful information.

The Raft River rises in the Goose Creek Mountains, in Utah, near the Idaho line. It enters the main structural valley from the west and flows northeastward to a point 5 miles south of Bridge, where it is joined by Clear Creek, which rises to the south and occupies the axis of the upper part of the main structural valley. Thence the Raft River flows in a northerly direction about 30 miles and empties into Lake Walcott, on the Snake River. Cassia Creek, its principal perennial tributary below Clear Creek, rises in the mountains in the vicinity of Elba, on the west side of the valley, and empties into the Raft River near the village of Malta (pl. 28).

In the vicinity of the State line the Raft River occupies a north-south valley several miles wide, which is hemmed in on all sides by mountains. This valley is closed at the north, and the river leaves it by turning eastward and entering what is known as the Pass, about 8 miles above Bridge. The Pass is a rocky V-shaped gorge about 2 miles long. Northward from the junction with Clear Creek the Raft River flows along the axis of the main structural valley and occupies a broad but shallow inner valley. The structural valley has alluvial slopes on both sides which extend down to the inner valley. The alluvial fan made by Cassia Creek covers a considerable area, but the Raft River loses most of its debris upstream from the Pass. North of Idahome basalt flows overlie the alluvium. The bordering mountains in most places rise 3,000 to nearly 5,000 feet above the valley floor. Enough is known about the geology of the surrounding ranges to show that there is slight possibility that the ground water in the Raft River Valley is supplemented by percolation through the rocks of the mountains, a hypothesis that has been suggested. From the vicinity of Malta northward the structural valley is about 10 miles wide, and at the lower end, where it merges into the Snake River Plain, it is still wider.

The inner valley is a flood plain covered with silt and loess except for the lava at its mouth. During the irrigation season the whole river is diverted in the vicinity of Malta, and hence for a short distance the channel is dry. However, within a few miles sufficient water collects from irrigation waste and ground-water inflow to make it profitable to divert the river again for irrigation. This procedure is repeated several times before the river finally empties into Lake Walcott.

In the 24 miles from Strevell, which is about 5,440 feet above sea level, to Malta, which is about 4,500 feet above sea level, the smooth valley floor has an average gradient of about 40 feet to the mile. From Malta to Lake Walcott, the altitude of which is about 4,200 feet, the slope is about 13 feet to the mile. North of Malta the surface is so flat that during years of heavy spring run-off many hundred acres of land is flooded. The Raft River has several overflow channels, and from the Pass to the lava near its mouth its banks are only a few feet higher than the stream bed. The main channel is only a few feet wide, and the stream is insignificant compared with the broad valley in which it flows.

Near the channel of the Raft River, wherever the water table is at a shallow depth, the soil is a heavy black loam, in places peaty or clayey. A short distance from the river the soil consists of light sandy loam and loess, with a few streaks of gravel near dry washes that enter the valley from the adjacent mountains. Alkali ground is common in the areas of shallow ground water where the land is not in crops. Well logs show that coarse gravel underlies much of the valley floor at shallow depths, below which there are more fine-grained lake beds. About a mile from the Raft River channel, on both sides, the soil becomes gravelly, and thence toward the mountains it changes to angular rock chips and boulders.

Greasewood and rabbitbrush grow on the uncultivated land where the water table is not more than 30 feet below the surface. These plants are dependent during part of the season upon water derived from the zone of saturation.[19] In places where the water table is not more than 20 feet below the surface they attain an average height of about 2 feet. This area is shown on plate 29. In places where the water table is 20 to 30 feet below the surface the rabbitbrush disappears and stunted greasewood interspersed with sagebrush is found. In places where the water table lies at greater depths the greasewood also disappears and sagebrush predominates.

SURFACE WATER

Measurements of stream flow have been made at several stations in the Raft River Valley, mainly in the period from 1909 to 1915,[20] but few of the records are complete for an entire year at any of these stations. As shown on plate 28, one of the stations is on Cassia Creek, another on Clear Creek, and a third on the Raft River above both tributaries. Measurements have also been made at times on the lower Raft River, a short distance above its confluence with the Snake. The records for the upper stations are sufficient to give a basis for estimation of inflow to the valley only in the years 1910 and 1911. According to the published data, the station on the upper Raft River had a recorded discharge of about 27,800 acre-feet in the year ending September 30, 1910, with 17 days missing from the record and 56 days estimated. In the following year its recorded discharge was about 11,800 acre-feet, with 30 days missing and 19 days estimated. The station on Cassia Creek had a recorded discharge in 1910 of about

[19] Meinzer, O. E., Plants as indicators of ground water: U. S. Geol. Survey Water-Supply Paper 577, pp. 29–42, 1927.

[20] U. S. Geol. Survey Water-Supply Papers 272, pp. 292–299; 292, pp. 341–347; 312, pp. 310–317; 332, pp. 354–358; 362–B, pp. 104–107; 393, pp. 87–88; and 413, pp. 80–81.

2,300 acre-feet, with 52 days estimated. In 1911 its recorded discharge was about 18,900 acre-feet, with 55 days estimated. In the period January 20 to September 30, 1910, the station on Clear Creek had a recorded discharge of 9,070 acre-feet, with 30 days estimated. In the period October 1, 1910, to June 30, 1911, it had a recorded discharge of 8,420 acre-feet, with 17 days estimated. Apparently the upper Raft River and its two tributaries had an aggregate average annual discharge in these 2 years of about 55,000 acre-feet.

Records for the Raft River near its mouth are available only for part of 1927, as shown in the following table:

Discharge, in acre-feet, of the Raft River at its mouth, year ending Sept. 30, 1927

[Record furnished by Twin Falls Canal Co. Discharge for November to March estimated by comparison with Goose Creek]

October	979	May	285
November	1, 150	June	234
December	1, 100	July	211
January	950	August	214
February	1, 175	September	300
March	1, 050		
April	1, 200	Total	8, 848

The published records show that the discharge of Goose Creek in 1927 was 78 percent of its average discharge in 1910 and 1911. If the ratio was the same for the discharge of Cassia Creek, Clear Creek, and the upper Raft River, their aggregate discharge in 1927 was apparently about 43,000 acre-feet. For the computation, it was assumed that in the year ending September 30, 1927, the surface flow of the three principal streams into the Raft River Valley was 43,000 acre-feet and that the surface outflow was 9,000 acre-feet. Obviously the data were so meager that these figures can be regarded only as rough approximations. The available records of both precipitation and run-off for this general region indicate that 1927 was approximately an average year.

WELL RECORDS

All the wells in the vicinity of Malta were measured and their altitude was determined in the fall of 1928, and a few had been measured also in the spring of the same year. Small copper benchmarks, with the letters "U. S. G. S. W. R.", were placed at the measuring points for future identification. The wells in the area, with only a few exceptions, extend a few feet below the water table. Their location is shown on plates 19 and 29. The irrigation wells in the valley are shown by a separate symbol on plate 29. A tract of 320 acres in sec. 29, T. 14 S., R. 27 E., was irrigated with ground water by Harry Shaw in 1928. Mr. Warneke's well, in sec. 32, T. 13 S., R. 27 E., is 800 feet deep, and the water level in it is 8.5 feet lower than that in an adjacent shallow well. There is therefore not much hope for obtaining artesian water in the valley. The flowing well in sec. 13, T. 15 S., R. 26 E., yields boiling water, which is brought to the surface by the included steam on the principle of an air lift.

WATER TABLE

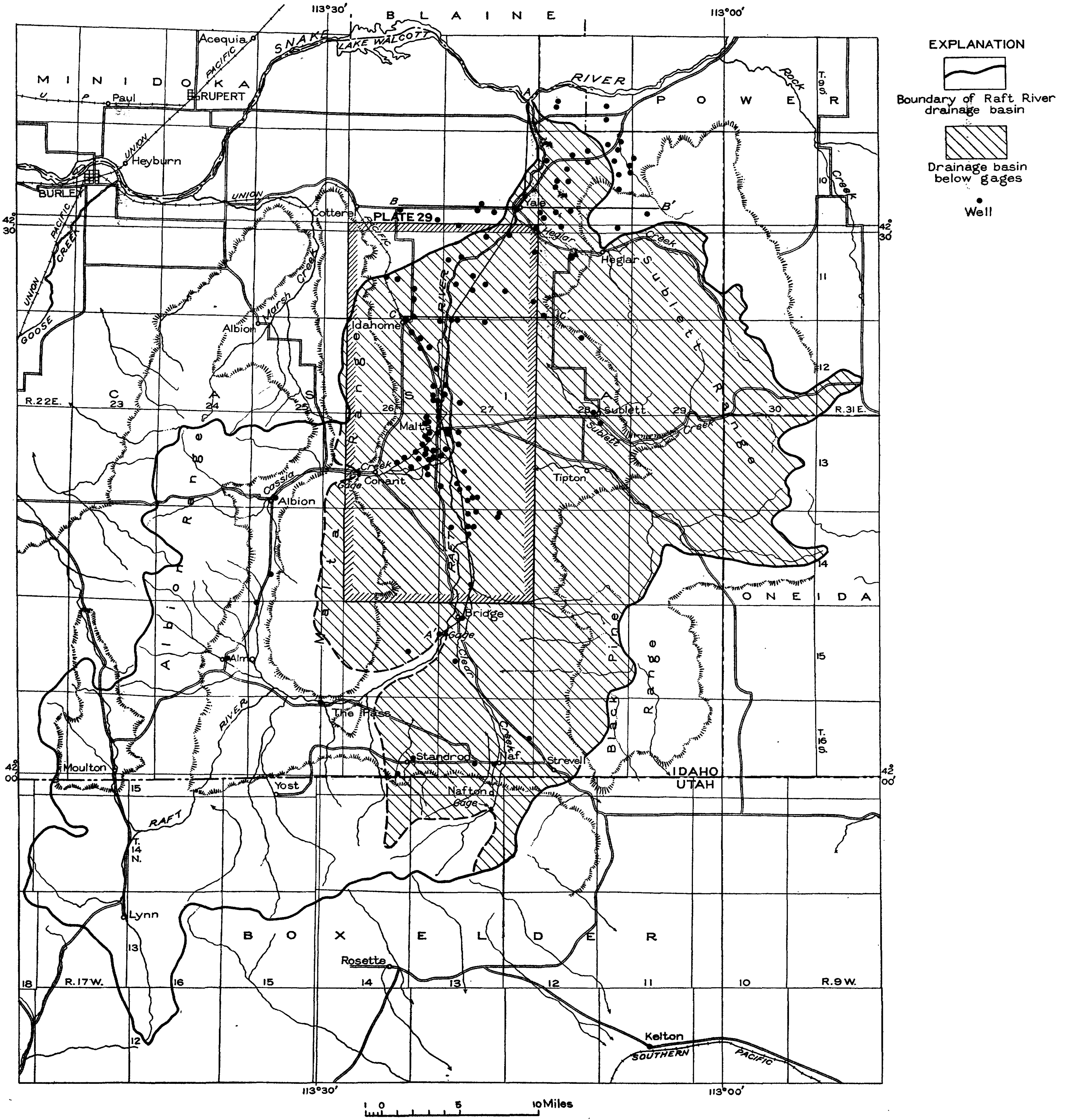
The results of the well measurements were used to determine the shape of the water table, which is represented on plate 29 by 20-foot contours. In general the contours cross the valley at regular intervals somewhat more than a mile apart and curve slightly upstream where they cross the axis of the valley, indicating that the ground water is moving northward under the valley floor. A pronounced bulge in the contours is produced by Cassia Creek near Malta, indicating that percolation losses from this stream are considerable. The slope of the water table at this place is about 40 feet to the mile, as compared with a slope of about 15 feet to the mile in the main valley. (See pl. 29.)

The steep slope of the land and of the water table on the alluvial fan of Cassia Creek has been utilized by Mr. Deardorff to develop ground water for irrigation by gravity. He has dug four ditches about half a mile southwest of Malta that maintain a grade slightly less than the slope of the land, so that within a distance of 1,000 to 2,000 feet they intersect the water table and collect ground water. The trenches have been lined with tile and back-filled. It is reported that these drains discharge considerable water in the spring, when the water table is high, but when visited by the writer in October 1928 the total discharge of the three drains completed at that time was considerably less than 1 second-foot. Most of the drains end within a short distance of Cassia Creek, and it is evident that if enough drains are built they will eventually decrease the discharge of that stream by lowering the water table, with consequent increase in percolation from the stream.

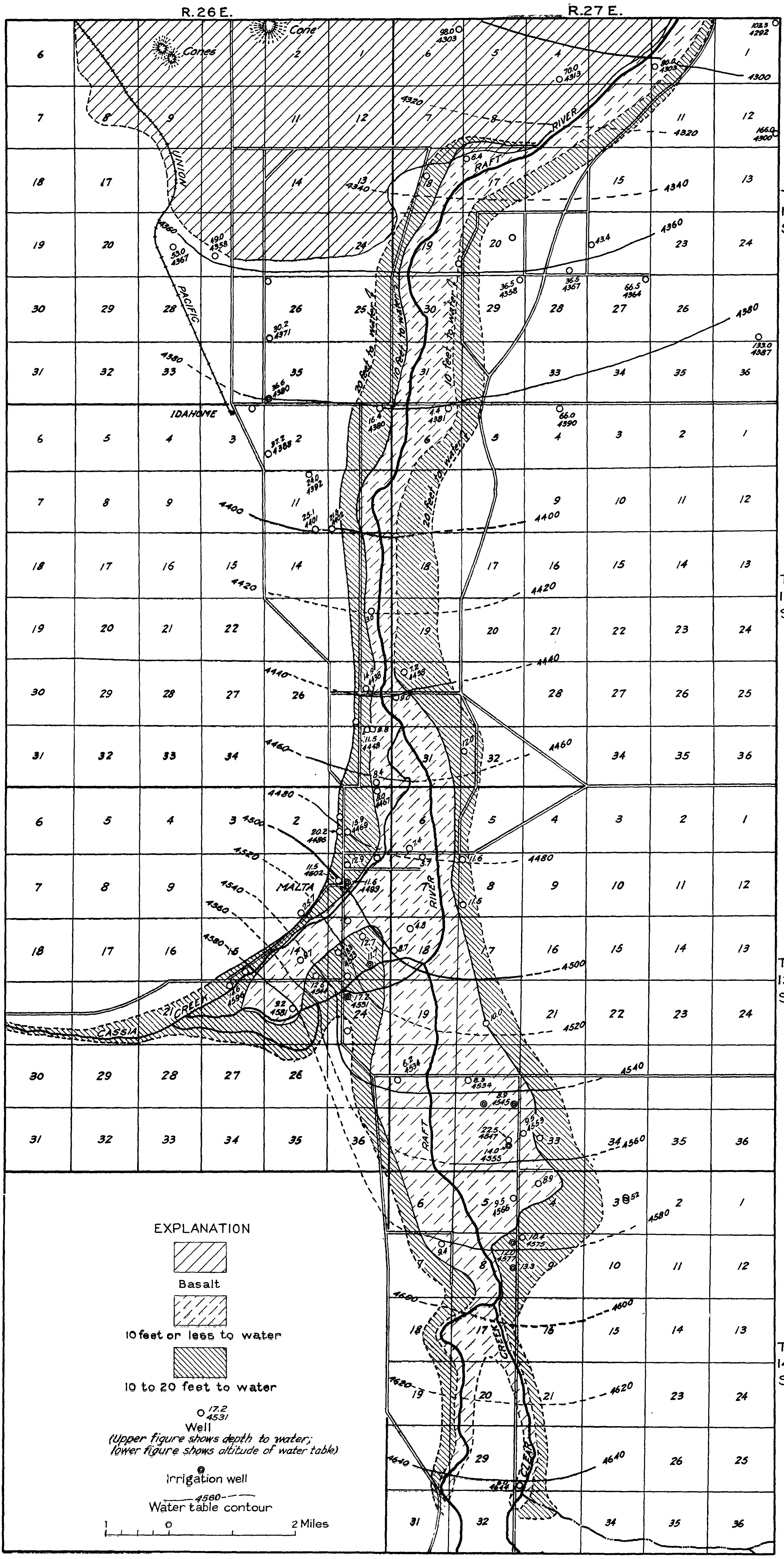
The profiles in figure 15, locations of which are given in plate 29, bring out the relation of the water table to the present topography.

Profile A–A′ is a longitudinal section that extends from the mouth of the Raft River to a point near Bridge and shows the low gradient of the valley floor and the uniformly shallow water that moves parallel to the surface of the land, down the axis of the valley, with a gradient of about 15 feet to the mile.

Profile B–B′, which extends from the northwest corner of sec. 34, T. 10 S., R. 26 E., across the valley in an eastward direction, illustrates the fact that a ground-water cascade exists 5 miles west of the Raft River, where the water, instead of moving down the valley as underflow of the river, moves westward and northward and at a much lower altitude than the water in the area to the east, adjacent to the Raft River. Measurements of depth to water in the vicinity of the Snake River near the Minidoka Dam show that the ground water moving



MAP OF RAFT RIVER DRAINAGE BASIN.



MAP OF RAFT RIVER VALLEY SHOWING WELLS, WATER-TABLE CONTOURS, AND DEPTHS TO GROUND WATER.

3660—38 (Face p. 214)

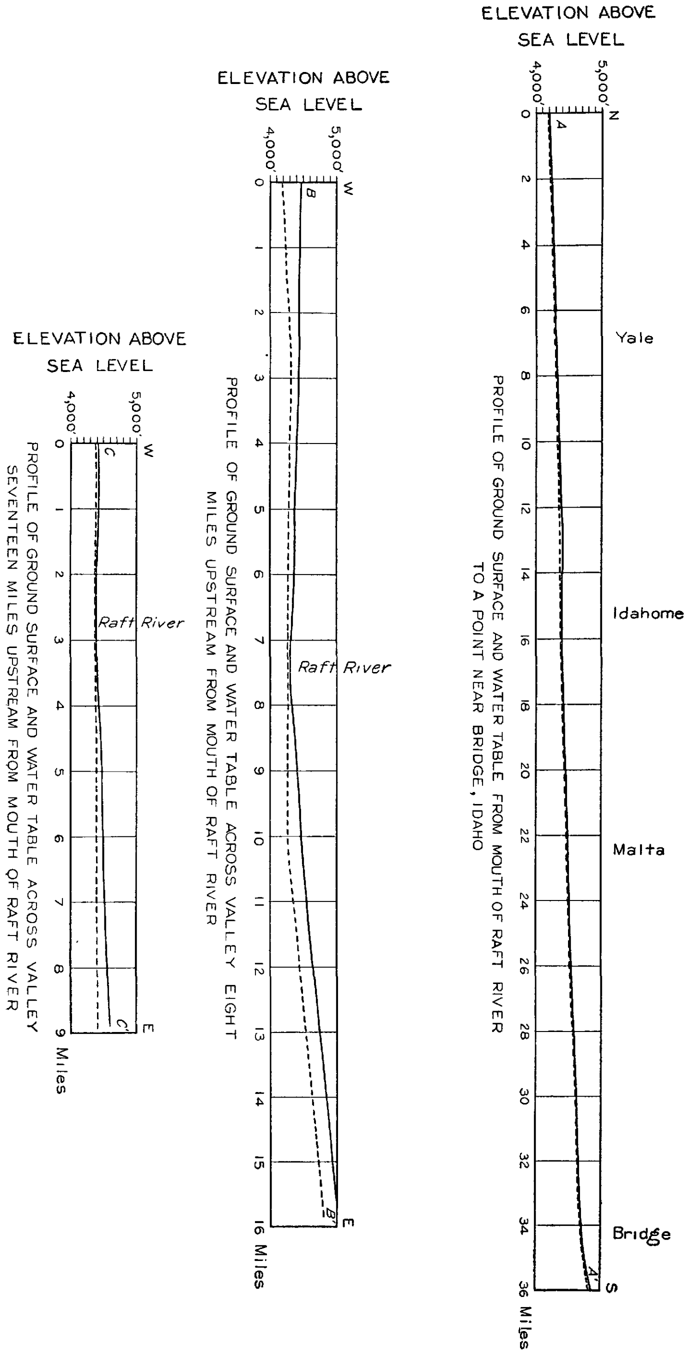


FIGURE 15.—Three profiles in Raft River Valley showing relation of the water table to the land surface.

northward from the west side of the Raft River Valley passes under the Snake River and joins the deep water table under the Snake River Plain. The water that follows this course is moving through the pre-lava channel of the Raft River mentioned on page 86.

The large size of the area in which the water table is near the surface and ground water is being discharged by evaporation and transpiration, and the presence of alkali water in many of the wells indicate that the rate of movement of the ground water out of the valley into the Snake River Plain is not rapid. The log of the Warneke well and other data indicate that the deep sediments are so fine grained that they do not carry much water out of the valley.

QUANTITY OF GROUND WATER

The underground reservoir in the Raft River Valley has a large storage capacity that can be utilized for conserving and equalizing the water supply, but the average annual amount of water that can safely be withdrawn from it is equal to only the average annual recharge less unavoidable losses by evaporation, transpiration, and underground outflow.

It is roughly estimated on page 213 that in 1927 the inflow to the Raft River Valley from the three principal streams was about 43,000 acre-feet and the outflow at the river mouth was about 9,000 acre-feet. There is about 9,000 acres of irrigated land in the valley above the point at which outflow was estimated. With an assumed consumptive use of 1.7 acre-feet of water this land would consume by evaporation and transpiration about 15,000 acre-feet, leaving, as computed, a contribution to the ground-water supply of about 19,000 acre-feet.

There is doubtless some unmeasured inflow to the valley. The underflow of Cassia Creek past the gaging station must be slight, for the station is in the mouth of a narrow pass, where the area of the cross section of permeable alluvium under the stream is small. Likewise the underflow of the Raft River at the gaging station is not large, because the gaging station was located close to The Pass. A somewhat greater underflow may occur in the Clear Creek region, because several small ephemeral streams enter the valley and sink before they reach Clear Creek.

The precipitation on the drainage area below the gaging stations does not contribute appreciably to the ground-water supply or to the run-off. There is about 500,000 acres in the drainage area below the gaging stations, and the precipitation on this area probably averages 10 inches. As no perennial stream enters the Raft River in this area the run-off is small. The only time there is any appreciable run-off is during warm rains in the winter, when the snow melts rapidly. At such a time the water enters the Raft River and is discharged into the Snake River. The ground is invariably frozen at such times and does not permit ground-water recharge. Later in the spring, water that sinks into the ground is largely used for plant growth.

Even moderate ground-water development would cause the water table under the axis of the valley to be lower than normal prior to the period of high run-off. Consequently, it is to be expected that with development a greater recharge would occur in those districts where water now stands on the surface during the floodwater season.

Although the Raft River Valley has an underground outlet to the Snake River Plain, the progress of the ground water toward the plain is so slow that a large proportion of the ground water is discharged by evaporation from the soil and transpiration from the vegetation in the shallow-water areas. Only a small part apparently escapes from the valley by percolation to the Snake River Plain. On plate 29 is shown an area of nearly 17,000 acres in which the water table is 10 feet or less below the surface, and an area of about 15,000 acres in which it is between 10 and 20 feet below the surface. There were not enough deeper wells to define the position of any other lines of equal depth to water. The area not covered by crops within the line of 20-foot depth to water is waste land, largely covered with greasewood and rabbit brush, which depend in part upon ground water. Some of this land is coated with alkali, and much of it is moist, especially where the depth to water is less than 10 feet. From the few measurements made in the spring of 1928 and from the fact that much of the land adjacent to the Raft River is submerged in the spring by floodwater, which causes the water table to rise to the surface, the average annual rise of this water table in the area enclosed by the contour showing 10-foot depth to water is estimated at about 4 feet. Thus the 10-foot line in the fall would approximate the position of the 6-foot line in the spring. During the spring in the middle part of this area, ground water has been observed on several thousand acres standing practically at the surface. Also numerous borrow pits and natural depressions only a few feet deep were kept supplied by ground water, even in the late fall, and hence the line of 10-foot depth to water was controlled by many observations of natural depressions and swampy tracts. Within much of the land of this area the depth to water is only 1 to 3 feet in the spring. The area of swampy ground comprises about 50 percent of all that is enclosed by the 10-foot line. The loss of ground water by evaporation and transpiration in this area is obviously heavy. Steward and Coffin [21] have shown an annual loss of 28.8 inches of ground water in the Boise Valley, Idaho, exclusive of precipitation from swampy tracts where the water was 2 feet below the surface. The remaining part of the land out to the 10-foot line does not lose so much water because it is not swampy.

[21] Steward, W. G., and Coffin, M. H., Experiments conducted to show the comparative evaporation from swamped areas in the Pioneer irrigation district: U. S. Bur. Reclamation unpublished report, Boise, Idaho, 1920.

On the basis of work done on the rates of evaporation and transpiration in other areas, it was estimated that the average annual discharge of ground water by evaporation and transpiration from the tract within the 10-foot line is probably about 1.7 acre-feet to the acre, or about 28,500 acre-feet.

The area of about 15,000 acres between the 10-foot and 20-foot lines is covered with greasewood and rabbit brush 2 to 3 feet high. Stunted greasewood is found a little beyond the 20-foot line to points where the water table is not more than 25 feet below the surface. However, because the slope of the valley floor near the foothills is steeper than in the axis of the valley the area of this stunted greasewood is small. White [22] found that in Escalante Valley, Utah, the water drawn by greasewood from the zone of saturation where the water table was 10 feet or more below the surface was only about 2 inches a year. At this rate the discharge of ground water from the area between the 10-foot and 20-foot lines would be about 2,500 acre-feet a year. Hence the total loss from the land in the part of the valley shown on plate 29 enclosed by the 20-foot line appears to amount to about 30,000 acre-feet. Of this total about 14,000 acre-feet is estimated to be lost from 8,000 acres of irrigated land that lies within this area, leaving about 17,000 acre-feet discharged from the uncultivated land. On the basis of a net duty of 1.7 acre-feet to the acre, this quantity of water would be sufficient to irrigate about 10,000 acres. Practically all the 2,500 acre-feet that is lost by transpiration from the land between the 10- and 20-foot lines is an unavoidable loss, because it would not be practicable to keep the land clear of greasewood. On the other hand, if ground water should be pumped for irrigation in considerable amount the resultant lowering of the water table would cause some increase in the recharge and also a reduction of ground-water outflow.

RELATION OF SURFACE WATER TO GROUND WATER

The water table of the valley is nearly everywhere tributary to or at a slight distance below the main stream channels. Whenever floods occur in the spring the water spreads over the level ground adjacent to the channel and recharges the ground water. As the floods subside the water drains off the land, and ground water stored in the valley alluvium during the flood begins to drain back into the channel. Cassia and Clear Creeks have deposited coarse alluvial fans where they enter the Raft River, and these streams lose water as they cross the fans. Irrigation diversions have probably accentuated these conditions.

Overdevelopment of irrigation by surface water has occurred in the past. During some of the wet periods in the last score of years the

[22] White, W. N., A method of estimating ground-water supplies based on discharge by plants and evaporation from soil—results of investigations in Escalante Valley, Utah: U. S. Geol. Survey Water-Supply Paper 659–A, p. 91, 1932.

increased run-off encouraged settlers to take up land and to make filings for water rights. In dry years the supply has been entirely inadequate, and some of the farmers left, but others remained, hoping for an additional supply of water. The water was finally decreed, and a water master placed in charge of distribution. During some of the recent dry years many of the people to whom flood-water rights were decreed have been entirely without water and some with old-established rights have had only enough water for one irrigation. This condition has caused some of the farmers to develop ground water, but the cost of pumping and equipment has made most of them abandon their wells or use them only occasionally. Thus, in 1928 there were 10 irrigation wells in the valley but only 1 of them was in use. However, the disuse of the wells has not been due to a shortage of ground water nor entirely to the cost of pumping but in part to the fact that in some areas in the valley where the water table is close to the surface alfalfa when once established will live from year to year as a result of its ability to draw moisture from the underlying zone of saturation without further irrigation.

The question immediately arises as to what effect additional ground-water development will have upon the surface streams. Such a development invariably causes the lowering of the water table either permanently or during a large part of the year. This condition may cause an increase in the rate of percolation from the stream beds to the zone of saturation and may thereby decrease the amount of surface water available. Consequently, to make a successful ground-water development, careful measurements of the flow of the creeks and of the amount of water delivered to each surface-water right should be made for several years in order that the exact effect of the ground-water development upon the losses from the streams can be ascertained.

A pooling of interests to permit the delivery of either surface or ground water in amounts proportioned to the rights of each rancher according to the most beneficial use of the water would give the ideal conditions for the maximum development of the valley. It may be that the best wells will be located on the land of the man who has the best surface-water right. Furthermore, if the surface water is used at the place where the streams enter the irrigation district instead of being allowed to flow for several miles through it, the spreading of this surface water by irrigation at the upper end will increase the amount available for pumpage in the lower end of the district. In the same way all the flood waters should be used on the higher lands to increase the amount of ground-water recharge. Provision might also be made for spreading the water on waste areas on the high gravelly land upstream from the irrigation district during years of high run-off. Most of this water would percolate to the water table and increase the supply of ground water. Even more successful than spreading to increase ground-water recharge would be to impound water by means of low "hesitation" dams where Cassia Creek and the Raft River flow through the Narrows. These dams would release the water slowly through percolation.

CONCLUSIONS

From the data at hand it is estimated that the ground-water recharge in the valley is adequate to irrigate about 10,000 acres of additional land. However, because of the brief periods covered by the records and the insufficiency of some of the other data on which this estimate is made, it is advisable to proceed conservatively with development. The initial ground-water development should probably not exceed 3,000 acres, including the land with inadequate flood-water rights, and further increase in the area irrigated by pumping from wells should not be undertaken if a progressive decline of the water table results from the initial development.

FALL CREEK VALLEY

More surface water is discharged by Fall Creek than can be used for irrigation, because there is no available agricultural land in the valley, hence ground water does not have an important economic use there. A flume and ditch, which are now out of repair, formerly diverted water from this creek, at first for placer mining and later to irrigate the narrow belt of arable land along the Snake River near the mouth of the creek. The warm springs at the head of Fall Creek are described on page 171. Should water become scarce in the future an additional supply could probably be developed by drilling near these springs. The water could be run into the Snake River, stored in Lake Walcott, and used farther downstream. The amount of water that can be developed in this manner will probably be small and at present is not of consequence. The discharge of Fall Creek from April to October 1927, as measured by the Twin Falls Canal Co., amounted to 6,150 acre-feet. The discharge in the winter has been estimated at 5,750 acre-feet, giving an estimated discharge in 1927 of 11,900 acre-feet.

ROCK CREEK VALLEY

Topographically and geologically the Rock Creek Valley is very different from the Raft River Valley. Its floor is hilly, and between the village of Rockland and the Snake River the creek has carved a canyon in places 300 feet deep in the Rockland Valley basalt. The Rock Creek Valley is partly separated from the Snake River Valley by a low range of hills known as the "Rockland Hills." Most of the wells are deep, and in the greater part of the valley the water table is more than 50 feet below the surface. (See pl. 18.) The thick soil which occurs in most places near the mouth of the valley and which is successfully dry-farmed appears to be a remnant of the once thicker cover of Raft lake beds.

With the land so rolling and with the water table so far below the surface, ground water will not be of importance for irrigation in this valley. However, sufficient water exists for domestic supply. The water levels in the wells show so great a lack of conformity in altitude that it was not possible to show water-table contours for this valley on plate 19, although numerous wells have been recorded. It is likely that some of the clay or ash beds locally present are sufficiently impermeable to allow the establishment of perched water tables.

The discharge of Rock Creek from April to October 1927 was 4,000 acre-feet, according to records supplied by the Twin Falls Canal Co. The discharge during the remainder of the year has been estimated as 7,500 acre-feet, which makes 11,500 acre-feet the total contribution to the Snake River in 1927.

BANNOCK CREEK VALLEY

The valley of Bannock Creek widens somewhat upstream, and at Arbon it is over 5 miles wide and has a fairly level floor. Few wells exist between Arbon and the Snake River. Except in a narrow belt of land bordering the creek, the depth to water is more than 50 feet. At Arbon School a well was being drilled in search for oil in 1929. The driller reported this well to be 3,600 feet deep, and the last 900 feet to be in green shale. At no horizon in this well was water encountered under sufficient head to rise to the surface.

From the mouth of the valley to the American Falls Reservoir the creek is entrenched about 50 feet below the alluvial plain. The land on this alluvial plain is topographically suitable for irrigation, and part of it is included in the proposed Michaud irrigation project. If these lands are reclaimed, irrigation will doubtless change the hydraulic gradient of the water table at the mouth of Bannock Valley and cause the water table to rise, so that pumping from wells for irrigation might be feasible. Adequate yields could probably be obtained from the gravel and sand beds that underlie the alluvial plain.

The discharge of Bannock Creek into the American Falls Reservoir, as given in the following table, was measured during each irrigation season from 1924 to 1932 in connection with investigations relating to the operation of the reservoir but was estimated for the rest of each year.

Annual discharge, in acre-feet, of Bannock Creek, 1924–28

Year	Measured discharge during summer	Estimated discharge during rest of year	Total
1924	3,800	8,000	11,800
1925	7,700	6,300	14,000
1926	7,400	5,000	12,400
1927	7,200	7,000	14,200
1928	1,700	11,000	12,700
Average			13,000

PORTNEUF RIVER VALLEY

The Portneuf River is the first large tributary on the south side of the Snake River upstream from King Hill. It discharges about 250,000 acre-feet annually into the Snake River, of which about 50,000 acre-feet comes from the Portneuf Springs, at the mouth of the valley. These springs are described on page 138.

The land northeast of the Portneuf River between the mouth of the valley and the Snake River is at present largely irrigated with water from the Blackfoot Reservoir, and hence ground water is not needed in this area. The Michaud Flats, which extend westward from the river between the mountains and the American Falls Reservoir, are suitable for irrigation, and at present this tract is included in an enlargement of the Fort Hall project. By the purchase of storage water and the exchange of it for water from the Portneuf Springs, the flow of which is now entirely appropriated, sufficient water could be pumped from these springs to supply these lands with 50,000 acre-feet of water with a lift of only about 30 feet. The proposed project contemplates a complicated exchange of water stored in the American Falls Reservoir and the Blackfoot Reservoir and the natural flow of the Snake River.

From Pocatello, at the mouth of the Portneuf Valley, to the Lava Hot Springs the valley approaches canyonlike conditions, with steep mountains rising from both banks of the river. In many places the river is faced by vertical lava cliffs, which are eroded remnants of a voluminous intracanyon lava flow (p. 86). Irrigable land in the valley is restricted to narrow isolated tracts along the river, and these are amply supplied by surface water. Dry farming is extensively practiced on the well-developed pediments several hundred feet above the river.

About 12 miles upstream from the Lava Hot Springs the canyon opens into a fertile valley about 8 miles wide (see pl. 1), which is partly irrigated with water stored in the Portneuf Reservoir of the Marsh Valley Canal Co., northeast of Chesterfield, which has a capacity of about 16,400 acre-feet. The water table is less than 50 feet below the surface under about 46 square miles of land in this part of the valley (pl. 18). An infiltration ditch recovers about 15 second-feet of ground water. There is doubtless an ample supply of ground water for the irrigable land in this shallow-water area that is not now irrigated.

The only large tributary of the Portneuf River is Marsh Creek, It rises about 25 miles north of the Utah line and flows northward in a broad open valley and joins the Portneuf River at Inkom. South and west of the lava, which partly blocks its valley, the creek flows in a flat swampy valley, and this characteristic marshiness gives the creek its name. Extensive gravel terraces that are chiefly dissected alluvial fans of tributary streams border its flood plain. An almost imperceptible divide, near the town of Oxford, in part underlain by gravel, separates the Marsh Creek drainage basin from the Bear River drainage basin.

The depth to water in the Marsh Creek Valley (see pl. 18) is practically nowhere less than 50 feet, except in the valley flood plain, which is naturally subirrigated and where there is no great need for developing ground water for irrigation. On the adjacent bench land there is much arable land, but almost everywhere under it the water lies between 50 and 100 feet below the surface. Hence pumping from wells for these lands is not considered economically feasible at the present time. Large water supplies could doubtless be obtained from the clean gravel that occupies this valley, and the underflow passing from it into the Portneuf is probably one of the sources of the water supply of the Portneuf Springs. The surface flow from this valley is small. At the mouth of the valley the present stream bed lies above the bottom of the lava-filled valley. As the basalt that forms the fill is permeable and doubtless overlies permeable gravel, the conditions are ideal for a considerable underflow to escape from the valley underground into the Portneuf.

The following table gives the discharge of the Portneuf River at Pocatello:

Annual discharge, in acre-feet, of the Portneuf River at Pocatello, years ending Sept. 30, 1920–27

1920	201,000	1923	224,000	1926	165,000
1921	299,000	1924	177,000	1927	200,000
1922	271,000	1925	199,000	Average	217,000

The ground-water contributions from the drainage basin of the Portneuf River that pass the Pocatello station as underflow have been estimated on page 139 as 49,500 acre-feet a year. Therefore, the total estimated annual contribution from this drainage basin to the Snake River Plain is 266,000 acre-feet.

Pocatello Creek and Ross Fork discharge below the Pocatello gaging station, and Lincoln Creek discharges below the gaging station on the Blackfoot River. The average annual contribution of these three creeks to the Snake River has been estimated at 7,000 acre-feet.

On plate 1 a broad undrained valley is shown between the Portneuf River near Chesterfield and the Bear River near Alexander. This valley is about 10 miles wide and 15 miles long and is known as the "Gem Valley." It is the Basalt Valley of Peale.[23] It is bounded on the east by the Soda Springs Hills and on the south by the Portneuf Range. Although the mountain areas tributary to it are small, yet the absence of run-off is significant and is due to the permeable mass of basalt which occupies it and which allows all the surface water as well as the precipitation on its surface to sink into it. The floor consists mostly of arable land that is suitable for irrigation. Much of this land is included in the proposed Empire irrigation district, which would obtain the water from storage created at the head of Soda Creek near Soda Springs. The water table in this valley everywhere except in the vicinity of Lund lies more than 100 feet below the surface, as is shown on plate 18. The water-table contours on plate 19 show clearly that the water is moving under most of this valley toward the Portneuf River, and in the fall of 1928 a divide less than 2 feet high and a little over a mile wide separated the ground water tributary to the Portneuf from that tributary to the Bear River. The geologic history and the hydrologic conditions of this valley are described in a forthcoming report on the Soda Springs Valley, with which it is intimately connected.

It has been suggested that water may enter the drainage basin of the Portneuf River by percolation through basalt from the Bear River and Soda Springs Valleys by way of the Gem Valley.[24] If so, most of it would be forced to the surface in the narrows at Lava Hot Springs. The walls of the canyon of the Portneuf here are composed of quartzite except for a thin wedge of basalt on the south side. Numerous hot springs rise to the surface in these narrows, and one of the hot springs discharges from the intracanyon basalt on the south bank. These springs are described on page 171. If any appreciable amount of ground water were moving through this part of the canyon it would dilute the rising columns of hot water and cool them off. It may be argued that the springs rise to the surface through insulated fissures lined with calcareous rock. Even if this condition exists the cross section of lava and other material filling this part of the canyon is too small to allow any large underflow. The presence of so many hot springs is proof that this fill is not very permeable.

That a considerable volume of water comes from the Gem Valley and possibly the Bear River is shown by the gain in the Portneuf River in the vicinity of Lava Hot Springs. No gagings have been made at this point, but a gaging station of the United States Geological

[23] Peale, A. C., Report on the geology of the Green River division: U. S. Geol. and Geog. Survey Terr. 11th Ann. Rept., p. 597, 1879.

[24] Meinzer, O. E., Large springs in the United States: U. S. Geol. Survey Water-Supply Paper 557, p. 52, 1927.

Survey is maintained at Topaz, 3 miles downstream. Benches of intracanyon lava are present in the Portneuf River Canyon between Lava Hot Springs and Topaz, hence opportunity exists for some of the water that passes the narrows at Lava Hot Springs as surface flow to enter the basalt and become underflow. The flow of the river at Topaz after deducting the flow of the hot springs and tributary inflow would therefore be less rather than greater than the discharge at Lava Hot Springs. No tributary inflow to the river occurs in this section in the dry season, and the entire yield of the hot springs is only about 5 second-feet. A measuring station was maintained at Gambles Bridge, in sec. 26, T. 7 S., R. 38 E., about 12 miles upstream from Lava Hot Springs, during 1925 by the Twin Falls Canal Co., and the data obtained there are given in the table below. The gain in the Portneuf River between this bridge and Topaz during the summer represents the return flow from irrigated lands in the Portneuf Valley above the bridge and the underground flow from the Gem Valley.

Gain in Portneuf River between Gambles Bridge and Topaz, in second-feet, in 1925

Month	Discharge at Gambles Bridge	Inflow from Pebble Creek	Diversions between stations	Discharge at Topaz	Net ground-water gain in section
May	90.3	[1] 30.0	31.5	325.9	237.1
June	93.3	22.1	30.5	246.0	161.1
July	85.5	9.7	27.6	202.9	135.3
August	102.8	.1	34.6	179.2	110.9

[1] Estimated.

The decline in the ground-water gain from May to August indicates that the return flow from irrigation is not the major component of the gain, or else the inflow would increase as the irrigation season advances. Part of the greater gain during the spring can be accounted for as direct run-off from the valley walls between the measuring points, but as this drainage area is small most of the water appears to be derived from the Gem Valley. The underground distance from the Gem Valley to the Portneuf is short, hence only a short lag should show between recharge and discharge. The thinning out of the intracanyon lava and the closing in of the bedrock walls at the narrows at Lava Hot Springs undoubtedly causes this large underflow to rise to the surface.

Underflow doubtless exists throughout the portion of the valley of the Portneuf that contains intracanyon basalt. In the vicinity of the probable downstream end of these flows, about 4 miles below Pocatello, there is a group of large springs, called the Batise Springs,[25] doubtless fed by this underflow.

[25] Meinzer, O. E., op. cit. (Water-Supply Paper 557), p. 52.

Subsequent erosion by the Portneuf River, after the intracanyon basalt came into position, has in part produced the great gravel and cobble deposit downstream from Pocatello. With the river gradient steepened by the lava fill and with large masses of material fed into it from the adjacent canyon wall, it is not surprising that the Portneuf River formed a great alluvial fan where it entered the Snake River Valley. The deposits of this fan were augmented by the cobbles rolled down the canyon by the flood waters from Lake Bonneville, the great Pleistocene lake in Utah. The huge boulders in this alluvial fan between Pocatello and the Snake River resemble the great boulder deposits in the Grand Canyon of the Colorado. The boulders are well rounded by abrasion and were deposited in such rapid succession that in many places there is no sand in the interstices. Such a deposit is exceedingly permeable, and through these deposits and the intercalated basalt the great volume of water that feeds the Portneuf Springs finds its way. In this alluvial fan blowing and sucking wells are numerous, indicating that large and connected voids exist beneath the surface. An excavation in these gravel deposits within the city limits of Pocatello exposed boulders 6 inches to 2 feet in diameter, and some of the interstices between the boulders were 5 to 6 inches across.

Further evidence of the great permeability of these gravel deposits is found in the record of the two wells that deliver water to Pocatello. They are at the foot of an eroded remnant of the lava fill, about 75 feet apart, on the north side of the railroad about 2 miles upstream from the city. The eastern well is reported to be 18 inches in diameter and 93 feet deep and to end in rock. The pump is reported to deliver 1,500,000 gallons daily from this well, with a draw-down of only 8 inches. During 1929 a third well, only 50 feet east of the eastern well, was being drilled. This well passed through the gravel into red quartzite, indicating that the basalt was entirely removed from the bottom of the valley at this point and that the valley was subsequently filled with boulders. The driller states that no additional water was obtained in the quartzite. The western well is reported to be 87 feet deep and, like the eastern one, is entirely in gravel. It is 18 inches in diameter and yields 1,000,000 gallons daily, with an unknown draw-down. It is significant that these two wells, yielding 2,500,000 gallons daily and only 75 feet apart, do not appreciably affect each other. The wells penetrate the gravel through which the water that feeds the Portneuf Spring passes, and hence additional wells would probably not materially affect the position of the water table. It therefore appears that Pocatello is assured of an ample water supply from underground sources.

BLACKFOOT RIVER VALLEY

The next large tributary to the Snake River north of the Portneuf River is the Blackfoot River. It rises in the mountains near the Wyoming line and flows northeastward toward the Snake River Plain, near which it abruptly turns to the southwest and flows along the foothills for about 15 to 20 miles. It finally crosses the alluvium that borders the Snake River and joins that river just upstream from the American Falls Reservoir. (See pl. 1.) At an altitude of 6,100 feet, in the upper stretches of the Blackfoot River, is the Blackfoot Reservoir, which is about 17 miles in length and over 5 miles in maximum width and has a capacity of about 200,000 acre-feet. Downstream from the reservoir the Blackfoot River enters a canyon which near the Snake River Plain reaches a depth of more than 300 feet.

As the Blackfoot River between the Blackfoot Reservoir and the Snake River Valley flows in a narrow canyon there is no need for ground-water development in this valley. The bench lands are mostly arable, but the depth to water is so great beneath them that pumping from wells to supply them with water is not feasible.

Leakage from Grays Lake into the Blackfoot River drainage basin has been considered by some as the possible source of some of the water supply of the Blackfoot River. The divide between these two drainage basins is composed of Carboniferous limestone,[26] which may allow some movement of ground water from Grays Lake into the Blackfoot drainage area. Several springs that issue from the Blackfoot River side of this divide may represent leakage from Grays Lake.

After the construction of the Blackfoot Reservoir it was found that considerable water leaked away from its south end through a permeable basalt divide and reappeared in the Fivemile Meadows, north of Soda Springs. Soda Springs Creek, a tributary of the Bear River, is fed by springs that derive a large part of their water from the Snake River drainage basin. Thus in the Soda Springs Valley, as in the Gem Valley, previously mentioned, the ground-water sources of the Snake River and the Bear River are very closely related.

The following table gives the annual contribution to the Snake River from the Blackfoot River.

Annual discharge, in acre-feet, of Blackfoot River near Shelley, above irrigation diversions, years ending Sept. 30, 1920–27

1920	207,000	1924	192,000	1927	[1] 97,841
1921	240,000	1925	[1] 103,260		
1922	341,000	1926	[1] 278,194	Average	218,000
1923	283,000				

[1] Records furnished by U. S. Indian Service.

[26] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, pl. 1, 1927.

The lands irrigated from the Blackfoot River below the Shelley gaging station are considered a part of the Snake River Valley acreage, as the larger part of the area receives its water supply from both the Blackfoot and the Snake Rivers.

The average discharge of Sand and Wolverine Creeks, small tributaries of the Snake River between the Blackfoot River and Willow Creek, has been estimated at 2,000 acre-feet annually.

VALLEYS TRIBUTARY TO UPPER SNAKE RIVER PLAIN FROM THE EAST

Willow Creek is the only large tributary of the Snake River between the Blackfoot River and Heise. The principal tributary of Willow Creek is Grays Lake Outlet. These creeks flow principally in narrow canyons carved in the mountains bordering the Snake River Plain, where there is not much irrigable land.

Annual discharge, in acre-feet, of Willow Creek near Ririe, above irrigation diversions, years ending Sept. 30, 1920–25

1920	146,000	1922	[1] 140,000	1925	[1] 123,000
1921	[1] 162,000	1923	[1] 123,000		
		1924	[1] 76,000	Average	128,000

[1] Partly estimated for winter months.

The lands irrigated from Willow Creek also receive water from the Snake River and are included in the Snake River Valley acreage on page 177.

Between Heise and the Wyoming boundary the Snake River flows between mountain ranges and locally has cut a narrow, steep-walled canyon, in many places over 500 feet deep. Small tracts of irrigable land that lie along the banks of the river are irrigated with water from the river. Copious underflow doubtless also exists but is not needed for irrigation.

Annual discharge, in acre-feet, of Snake River at Heise, years ending Sept. 30, 1920–27

	South Fork of Snake River at Heise	Riley ditch	Underground flow past Heise station	Total
1920	[1] 5,230,000	[2] 3,000	[3] 50,000	5,283,000
1921	5,800,000	3,000	[3] 58,000	5,861,000
1922	[1] 5,278,000	4,000	[3] 49,000	5,331,000
1923	[1] 5,248,000	4,000	[3] 48,000	5,300,000
1924	[1] 3,887,000	4,000	[3] 45,000	3,936,000
1925	5,530,000	5,000	[3] 61,000	5,596,000
1926	4,300,000	4,000	[3] 56,000	4,360,000
1927	5,780,000	5,000	[3] 59,000	5,844,000
Average	5,131,625	4,000	53,000	5,189,000

[1] Winter records estimated by comparison with Moran station to make these annual totals.
[2] From Snake River watermaster's records.
[3] Estimated from special investigation of losses in Snake River between Alpine and Heise during 1917–18, which show a change from a loss to a fairly uniform gain of about 250 second-feet between those points when the discharge drops below 8,000 second-feet. Unpublished reports of G. C. Baldwin, U. S. Geol. Survey, Idaho Falls, Idaho, 1917–18.

Moody Creek is a small stream that drains a low area east of Rexburg. The average annual run-off it contributes to the Henrys Fork Valley has been estimated at 2,000 acre-feet. Ground-water conditions in the Moody Creek Valley were not specially investigated, because in the mountainous part the depth to water is too great for pumping and in the stretch between the mountains and the Snake River the land is all under irrigation.

The Teton River Valley was not investigated except the part where the stream crosses the Snake River Plain. Ground-water contours for this part are shown on plate 19. Annual contributions from this stream to Henrys Fork are shown in the following table. The lands irrigated from Teton below the St. Anthony station are considered part of the Henrys Fork Valley irrigated acreage on page 202.

Annual discharge, in acre-feet, of Teton River near St. Anthony, for years ending Sept. 30, 1920–27 [1]

1920	574, 000	1924	408, 000	1927	725, 000
1921	684, 000	1925	700, 000		
1922	561, 000	1926	437, 000	Average	579, 000
1923	539, 000				

[1] Run-off estimated during winter months.

Falls River rises on the east side of the Teton Range and empties into Henrys Fork midway between Ashton and St. Anthony. Near its mouth it flows in a channel excavated in basalt. The average annual contribution from Falls River to the Snake River Valley is 629,000 acre-feet as shown below:

Annual discharge, in acre-feet, of Falls River, years ending Sept. 30, 1920–27

	Falls River near Squirrel	Diversions above Squirrel	Estimated inflow from Squirrel and Conant Creeks	Total discharge from Falls River into Snake River Valley
1920	499, 000	28, 000	45, 000	572, 000
1921	564, 000	29, 000	60, 000	653, 000
1922	564, 000	29, 000	44, 000	637, 000
1923	524, 000	24, 000	40, 000	588, 000
1924	394, 000	16, 000	20, 000	430, 000
1925	650, 000	27, 000	64, 000	741, 000
1926	492, 000	17, 000	39, 000	548, 000
1927	764, 000	29, 000	67, 000	860, 000
Average				629, 000

The lands irrigated from Falls River are considered part of the Henrys Fork Valley irrigated acreage, described on page 202.

Robinson Creek flows in a deep canyon which near the mouth is bordered by cliffs of basalt. It contributes an average of about 91,000 acre-feet to Henrys Fork Valley as shown by the following table:

Annual discharge, in acre-feet, of Robinson Creek at Warm River, years ending Sept. 30, 1920–27

1920	77, 400	1924	53, 100	1927	123, 000
1921	106, 000	1925	117, 000		
1922	89, 600	1926	80, 400	Average	91, 000
1923	82, 500				

The Warm River enters Henrys Fork in a deep canyon carved in basalt and contributes an average of about 164,000 acre-feet to the Henrys Fork Valley annually, as shown below.

Annual discharge, in acre-feet, of Warm River at Warm River, years ending Sept. 30, 1920–27

1920	162, 000	1924	141, 000	1927	176, 000
1921	185, 000	1925	165, 000		
1922	172, 000	1926	152, 000	Average	164, 000
1923	163, 000				

The run-off from the upper drainage area of Henrys Fork above Warm River is shown in the following table.

Annual discharge, in acre-feet, of Henrys Fork at Warm River, for years ending Sept. 30, 1920–27

1920	731, 000	1924	654, 000	1927	800, 000
1921	844, 000	1925	747, 000		
1922	802, 000	1926	738, 000	Average	757, 000
1923	738, 000				

VALLEYS NORTH OF MUD LAKE REGION

Camas, Beaver, and Medicine Lodge Creeks and several minor streams issue from the Centennial and Beaverhead Mountains and flow toward Mud Lake. Camas Creek is the only one of these that normally delivers water at the surface into Mud Lake or into the adjoining lakes and sloughs. All, however, contribute to the ground-water supply of this region. The estimates below of surface and underground contributions from these streams are based on data presented in the report on the Mud Lake region.[27]

All these streams have narrow and rocky canyons within the mountains, and little opportunity for irrigation exists along their mountain courses. The several branches of Camas Creek in the mountains unite in Camas Meadows, a high basin in which numerous springs issue. Below that basin the creek flows in a lava-walled canyon to a point a few miles above Camas. Below the canyon it flows over sand and gravel to Rays Lake and thence into Mud Lake.

Beaver Creek heads near the Continental Divide and flows in a mountain canyon to a point some distance below Spencer and thence in a lava gorge about 50 feet deep to Dubois, where the stream com-

[27] Stearns, H. T., Bryan, L. L., and Crandall, Lynn, Geology and water resources of the Mud Lake region, Idaho: U. S. Geol. Survey Water-Supply Paper 818 (in press).

mences to lose its water rapidly in coarse gravel. In flood periods it reaches Camas Creek, but at other times it loses all its flow before it gets more than 3 miles south of Dubois.

Annual discharge, in acre-feet, of Beaver and Camas Creeks for years ending Sept. 30, 1921–24

	Beaver Creek at Dubois	Estimated ground-water contributions from Beaver Creek above Dubois	Camas Creek near Dubois	Estimated ground-water contributions from Camas Creek above Dubois	Total
1921	44,000	8,000	91,000	6,000	149,000
1922	38,400	8,000	79,400	6,000	131,000
1923	31,800	7,000	68,000	5,000	111,800
1924	14,200	3,000	23,000	3,000	43,200
Average					109,000

Crop consumption on 15,000 acres is estimated at 24,000 acre-feet, and evaporation losses less precipitation on Mud Lake as 44,000 acre-feet, leaving 41,000 acre-feet contributed to the Snake River ground-water flow.

Medicine Lodge Creek rises in the southeastern part of the Beaverhead Range and is largely spring-fed. A little water is diverted from it for irrigation in narrow tributary mountain valleys. It loses water rapidly after reaching the plain and sinks entirely, even in the flood season, about 6 miles northwest of the Jefferson Reservoir, which is immediately north of Mud Lake. The annual discharge for the year ending September 30, 1922, was 47,500 acre-feet, and 51,500 acre-feet for 1923 or an average of 49,500 acre-feet. Assuming 9,600 acre-feet consumed by crops on 6,000 acres of irrigated land would leave about 40,000 acre-feet contributed annually to the Snake River plain.

BIRCH CREEK VALLEY

Birch Creek valley is deeply filled with alluvium and is bounded on both sides by high mountains. Great fans deposited by tributary streams flank both sides of the creek. A large basalt flow terminates near the Birch Creek Reservoir site. The lava has been spread over the alluvium, and subsequent erosion has brought the flow into relief as a plateau.

Where the stream debouches on the Snake River plain a large alluvial fan has been built, and at the south margin of the fan are the Birch Creek sinks, which are playas similar to those of Big Lost and Little Lost Rivers.

Birch Creek derives most of its water from a series of springs [28] and consequently has a comparatively uniform flow throughout the year. During the summer all the water is diverted for the irrigation of about

[28] Meinzer, O. E., Large springs in the United States: U. S. Geol. Survey Water-Supply Paper 557, p. 54, 1927.

1,200 acres, but in the rest of the year the creek persists as far as the sinks, about 20 miles from the springs.

The ground water is far below the surface at the mouth of the valley, as is shown by the well at the Reno ranch, in which the water level is 535 feet below the surface. Only a few people live in the Birch Creek valley, and they obtain their water from Birch Creek or some of its tributaries. Nothing is known regarding the shape of the water table in the valley, but presumably it is somewhat comparable to that of the adjacent Little Lost River valley.

The average annual contribution of ground water from the Birch Creek valley to the Snake River Plain has been estimated to be 57,300 acre-feet.

LITTLE LOST RIVER VALLEY [29]

GEOGRAPHY

The Little Lost River valley is about 50 miles northwest of Idaho Falls, in Butte and Custer Counties, Idaho. The principal village is Howe, which lies at the mouth of the valley and has about 25 inhabitants. Berenice is a post office about 5 miles north of Howe. (See pl. 19.) The valley trends southeast and has a length of about 40 miles, an average width of about 7 miles, and an average gradient of about 25 feet to the mile. It is bordered on the east by the Lemhi Range and on the west by the Lost River Range. Both of these mountain ranges are steep and narrow and rise over 10,000 feet above sea level, or about 4,500 feet above the valley floor.

The principal developments are near the mouth of the valley, where about 8,000 acres is under irrigation, about half of it Carey Act lands. About 1912 a large Carey Act project was promoted at the mouth of the valley, but an overestimate of the available water supply has caused its partial abandonment. Considerable land is under irrigation along the river in the upper part of the valley. The principal crops are alfalfa and grain, for the valley lies at an altitude between 5,000 and 6,000 feet, and the climate does not permit other crops. The area at the mouth of the valley, however, is one of deep fertile soil, and its location in close proximity to the adjacent range land has resulted in the development of a substantial livestock industry.

The Little Lost River is formed by several tributaries near its headwaters, and its flow is augmented here and there by inflow from spring-fed creeks. Diversions for irrigation are made from the stream at several places as it wends its way for about 40 miles in a southeasterly direction toward the Snake River Plain, and during the period from April to October of each year these diversions take the entire flow of

[29] A more detailed report was released to the public in mimeograph form on May 24, 1930.

the stream. During the winter the river flows out on the Snake River Plain a short distance from the mouth of the valley, where it spreads and freezes and because of deep percolation and evaporation is eventually dissipated. Formerly, when a lesser area was under cultivation in the valley, the floodwater often reached the "sinks", a flat, shallow depression at the north edge of the Snake River lava, but for several years the entire high-water flow has been diverted.

SURFACE WATER

On account of the considerable flow received by the Little Lost River from spring-fed creeks, the discharge shows relatively less variation from year to year than that of the Big Lost River and other streams to the west. The Howe gaging station is about 6 miles downstream from the Knollin ranch, where the ground-water flow of the Little Lost River Valley is forced to the surface, appearing in the form of spring inflow to the stream. Measurements indicate only a small loss in the stream channel between the Knollin ranch and the gaging station.

About 11,000 acres is irrigated from the stream below the gaging station, of which about 6,000 acres is within the project of the Blaine County Irrigation Co., with an average water supply of about 1.5 acre-feet to the acre. The only contribution to the water table from this project has been assumed to be the losses in its canal system, which amount to about 17 percent of the diversions for that tract. For the rest of the irrigated lands a consumptive use of 1.7 acre-feet to the acre, exclusive of precipitation, has been assumed for lands with full water rights and a lesser amount, depending upon the runoff, for lands with inferior rights. The winter flow that is discharged into the sinks has been estimated from the best available information. It is nearly all contributed to the ground-water supply of the Snake River Plain.

Estimated contributions, in acre-feet, to the ground water of the Snake River Plain by the Little Lost River, years ending Sept. 30, 1921–27

	Discharge of Little Lost River near Howe during irrigation season	Estimated crop consumption	Contribution to ground water during irrigation season	Estimated discharge of Little Lost River during winter	Total estimated contribution to ground water
1921	31,900	16,000	15,900	21,000	36,900
1922	39,855	16,000	23,855	23,000	46,855
1923	35,400	16,000	19,400	16,000	35,400
1924	26,880	14,000	12,880	18,000	30,880
1925	39,600	16,000	23,600	16,000	39,600
1926	30,380	15,000	15,380	15,000	30,380
1927	37,800	16,000	21,800	15,000	36,800
Average					36,700

GROUND WATER

The chief water-bearing formation in the Little Lost River Valley is the alluvium that underlies the valley floor. The logs of test wells given in this paper indicate that to the depths reached by these wells the alluvium is made up of alternating beds of sand, gravel, and clay, with streaks of hardpan. This hardpan is usually cemented gravel a few inches to 7 feet thick. A persistent bed of cemented gravel 4 to 7 feet thick underlies 5 to 7 feet of soil in the entire area tested for ground water.

Beneath the cemented gravel is usually a bed several feet thick composed of clean gravel, with pebbles ranging from half an inch to 3 inches in diameter, which yields water freely. Beneath the gravel are finer deposits, which in some of the test wells consist of impermeable clay that serves as an imperfect lower confining bed and together with the upper cemented gravel forms an imperfect artesian basin. The water thus confined has an artesian head of several feet, which is in places sufficient to make flowing wells. The spring-fed creeks tributary to the Little Lost River flow on this layer of cemented gravel and are fed by small artesian springs that rise through fissures in it. Thus, the creeks act essentially as collection ditches for artesian water.

About 9 miles above Howe, in T. 7 N., R. 28 E., there are numerous springs, and the water table is everywhere close to the surface. The land is covered with greasewood, a plant that sends its roots to ground water. Much of the land is swampy, and the discharge of ground water by evaporation and transpiration is evident. The investigation was concentrated on this area because it seemed to be the most promising place to develop water. Downstream from this tract the water lies farther and farther below the surface, and near Howe the water level in the wells lies at a depth of 200 feet. Early in the investigation it was recognized that ground water which was developed at the lower edge of the shallow-water area would represent a beneficial recovery of water that would otherwise escape from the valley. The principal purpose of the test drilling was to determine the geologic structure of the rocks underlying this area, the nature of the aquifers, and the amount of water moving underground. The available funds were too small to make pumping tests.

The ground-water supply of this area is derived from the Little Lost River and its tributaries above the area. Summit, Sawmill, Dry, and Wet Creeks are the main tributaries that enter the valley near its head to form the Little Lost River. (See pl. 19.) Summit Creek flows for several miles through a more or less swampy area where the water table is about at the creek level. During the irrigation season of 1925 measurements showed the average flow of Summit Creek at a point in sec. 33, T. 11 N., R. 26 E., just above the mouth of Sawmill ditch, to be about 11.5 second-feet. Of this amount about 7 second-feet was lost during the season of 1925 in the remaining 3½ miles of the Summit Creek channel to its confluence with Sawmill Creek.

Sawmill Creek, the largest tributary of the Little Lost River, in a distance of about 4 miles between the mouth of Sawmill Canyon and the river sustained losses during 1925 ranging from 14 second-feet at low stages to 27 second-feet when the stream discharge was 110 second-feet. This stream during periods of low and moderate discharge is now carried through the Sawmill ditch into Summit Creek, and thus at certain stages some of the losses that formerly occurred in the natural channel are prevented. The savings during 1925 ranged from zero when Sawmill Creek discharged 22 second-feet or less to 5.3 second-feet at a discharge of 100 second-feet. On the Basinger ranch, a mile or more downstream from the junction of Sawmill and Summit Creeks, the water table rises above the river level, resulting in an inflow of about 15 second-feet of ground water, probably supplied mainly by losses in Sawmill and Summit Creeks a few miles upstream.

Formerly Dry Creek entered the Little Lost River near the Basinger ranch, but its waters are now stored and diverted during the irrigation season into Wet Creek and thence into the Little Lost River. A substantial portion of the flow of Dry Creek during the winter and spring is lost by leakage from the Dry Creek Reservoir. This leakage amounts to about 20 second-feet when the reservoir is full.

During the irrigation season of 1923, when the flow was 60 second-feet, measurements indicated a loss of 8 second-feet in the canal that conveys Dry Creek water to Wet Creek. An additional average loss of 8 second-feet occurred during the same year in Wet Creek between the mouth of the Dry Creek canal and the Little Lost River. In more recent years the loss is reported to have increased. Some loss also undoubtedly occurs in Wet Creek above the mouth of the Dry Creek canal. During the irrigation season of 1923, when there was an average flow of 120 second-feet in the Little Lost River below the mouth of Wet Creek, there was an average loss of 17 second-feet in the river between the mouth of Wet Creek and the Blaine County canal, in sec. 11, T. 6 N., R. 28 E. Throughout this distance of 1.7 miles the river flows as a perched stream above the water table except for about a mile through the Knollin ranch, where during 1923 it received an average inflow of 3.5 second-feet from the Knollin Springs, in sec. 12, T. 7 N., R. 27 E.

In the stretch above the mouth of Spring Creek, in sec. 20, T. 7 N., R. 28 E., the Little Lost River flows along the west edge of the valley at a height in general from a few feet to 30 feet above the level of the water table. Along the east side of the valley, however, the ground water is higher and in places appears at the surface as springs. Spring Creek rises on the valley floor below the mouth of Badger Creek, in sec. 2, T. 8 N., R. 27 E. The water table drops below the bed of the creek about 2 miles downstream from the source, and the creek flows as a perched stream for about 4 miles parallel to and 1½ to 2 miles east of the river. For about 2 miles below this stretch Spring Creek receives the inflow from Whittaker Creek and a number of spring channels, the combined flow of which eventually reaches the Little Lost River.

Taney Creek and East Spring Creek (see pl. 30) rise also in sec. 21, T. 7 N., R. 28 E., on the east edge of the valley floor and are the farthest downstream of the tributaries in the valley. Southeast of the mouths of these creeks the water table drops rapidly as the Little Lost River approaches the Snake River Plain; in a distance of 3 miles it descends more than 200 feet. The area in the vicinity of East Spring Creek, Taney Creek, and the mouth of Spring Creek offers the most promising location for ground-water development in the valley, because any ground water moving down the valley past this area disappears and is permanently lost from the valley.

TEST DRILLING

During the winter of 1929–30 five wells, each 6 inches in diameter and about 60 feet deep, were drilled in this area, under contract by R. N. Wade, of Hamer, Idaho, who made good progress in spite of the severe winter weather. Plate 30 shows the locations of these test wells and contours of the water table. The casing was driven in each well so as to shut off the water in the higher strata.

Log of test well 1, NE¼SW¼ sec. 17, T. 7 N., R. 28 E.

[Altitude of surface at well 97.6 feet above assumed datum]

	Thickness (feet)	Depth (feet)
Fine sandy loam soil	7	7
Cemented gravel; quartzite and limestone pebbles as large as 1 inch in diameter in a limy matrix	4.5	11.5
Unconsolidated gravel; sample at 15 feet dirty ⅛- to ¼-inch gravel, in part subangular; sample at 20 feet clean quartzite and limestone gravel, ⅜ inch or less in diameter; sample at 25 feet similar to the clean gravel at 20 feet but coarser; sample at 30 feet still clean but coarser, some pebbles 2 inches in diameter; sample at 35 feet similar to sample at 25 feet	26.5	38.0
Loose sand	2	40
Unconsolidated gravel; sample at 41 feet coarse clean gravel as large as 2 inches in diameter; sample at 45 feet similar to one at 41 feet but less coarse; sample at 48 feet similar to one at 41 feet but slightly coarser	10	50
Gravel and sand; sample at 53 feet clean sharp sand and ⅛- to ¼- inch gravel	3	53

The water in this well was first encountered at a depth of 11 feet near the bottom of a layer of cemented gravel. The water was under a pressure head of 2 feet and rose to a level 9 feet below the surface when encountered.

The driller reports that considerable quantities of fine material were encountered between depths of 20 and 48 feet below the surface and were carried away by the water when the bailer was dumped.

At depths of 20, 30, 35, and 40 feet below the surface there was a low rate of inflow into the well. At 35 feet the normal water level stood 12.6 feet below the surface. When this level was lowered by bailing to 31 feet below the surface, it rose only at the rate of 2.3 feet a minute. The water pressure and inflow from a depth of 48 feet to the bottom of the well were reported to be considerably more than at lesser depths. Two weeks after the casing had been pulled the water level stood 6.4 feet below the surface.

Log of test well 2, NW¼NE¼ sec. 20, T. 7 N., R. 28 E.

[Altitude of surface at well 83.3 feet above assumed datum]

	Thickness (feet)	Depth (feet)
Fine sandy loam soil	6	6
Cemented gravel; samples at 7 and 12 feet similar dirty ⅛- to ¼-inch gravel, which prior to drilling was probably tightly cemented and with low permeability	6	12
Mixed sand and hardpan with some gravel in lenses 3 to 4 inches thick; sample at 15 feet coarse clean gravel as large as 1½ inches in diameter; sample at 18 feet fine silt with a few pea-sized pebbles; sample at 21 feet sharp clean coarse sand and gravel as large as 1 inch in diameter; sample at 24 feet medium sand and ½-inch gravel or smaller; sample at 27 feet coarse gravel as large as 2 inches in diameter; sample at 30 feet similar to one at 27 feet but slightly less coarse	18	30
Unconsolidated gravel containing considerable water; sample at 33 feet clean ⅛- to ½-inch gravel; samples at 36 and 39 feet coarse clean gravel ½ inch to 1½ inches in diameter	11	41
Sand with streak of gravelly hardpan containing no water	1	42
Sand, some water; sample at 45 feet fairly clean sand containing considerable quartzite in sharp grains	3	45
Clay	2	47
Gravel; sample at 48 feet clean sand and ⅛-inch gravel; sample at 51 feet coarse gravel as large as 2 inches in diameter; sample at 54 feet coarse clean sand and gravel	7	54
Coarse gravel; sample at 57 feet mostly gravel over 1 inch in diameter; sample at 60 feet coarse sand and ⅛- to ¼-inch gravel	6	60

Water was first encountered in this well at 13 feet and rose to a level 9.7 feet below the surface. At a depth of 12 to 30 feet water was found in the layers of gravel but not in the hardpan. The sand at 42 feet yielded no additional water, although some water was found in a similar formation at 45 feet. The clay at 49 feet did not yield water. Above this depth the water level remained stationary at about 9.7 feet below the surface during the drilling, but below the clay, in drilling from 50 to 60 feet, the water level in the well dropped. At 57 feet the depth to water was 13 feet, and at 60 feet it was 14.8 feet. At this depth the inflow of water was very strong, and the water level in the casing could not be noticeably lowered by repeated bailing with an 8-foot bailer 6 inches in diameter wrapped in burlap. By wrapping the bailer with burlap it fits tightly inside of the casing like a plunger and when raised brings out the water above it. The driller reports that in all the gravel below a depth of 50 feet the yield was so great that it was impossible to lower the water level by repeated bailing.

Log of test well 3, NW¼SW¼ sec. 21, T. 7 N., R. 28 E.

[Altitude of surface at well 56.1 feet above assumed datum]

	Thickness (feet)	Depth (feet)
Fine sandy loam soil	5	5
Cemented gravel; sample at 9 feet impermeable ⅛- to ¼-inch gravel in limy clay matrix; sample at 12 feet similar but appears to have been less cemented	7	12
Dirty, partly consolidated gravel; samples at 15 and 18 feet contain gravel as large as ½ inch across but look as if they would be impermeable prior to churning by drill	8	20
Gravel; sample at 21 feet mostly ⅛-inch gravel and sand; sample at 24 feet not very clean gravel but contains pebbles as large as ½ inch in diameter	4	24
Sand; sample at 27 feet sharp sand and gravel	3	27
Gravel; sample at 30 feet clean ¼- to ½-inch gravel	5	32
Sand; sample at 33 feet coarse fairly clean sand	2	34
Fine gravel; samples at 36 and 40 feet ⅛- to ¼-inch gravel in fine sand with a few larger pebbles	6	40
Clay	3	42
Gravel; sample at 42 feet clean ¼- to ½-inch gravel; sample at 44 feet coarse gravel as large as 1½ inches in diameter; sample at 47 feet clean ¼- to ½-inch gravel	7	49
Sand; sample at 51 feet coarse and fine sand containing ⅛-inch gravel	3	52
Gravel; sample at 54 feet like sample at 51 feet; sample at 57 feet clean gravel, as large as 1¼ inches in diameter; sample at 60 feet not quite so coarse as that at 57 feet	8	60

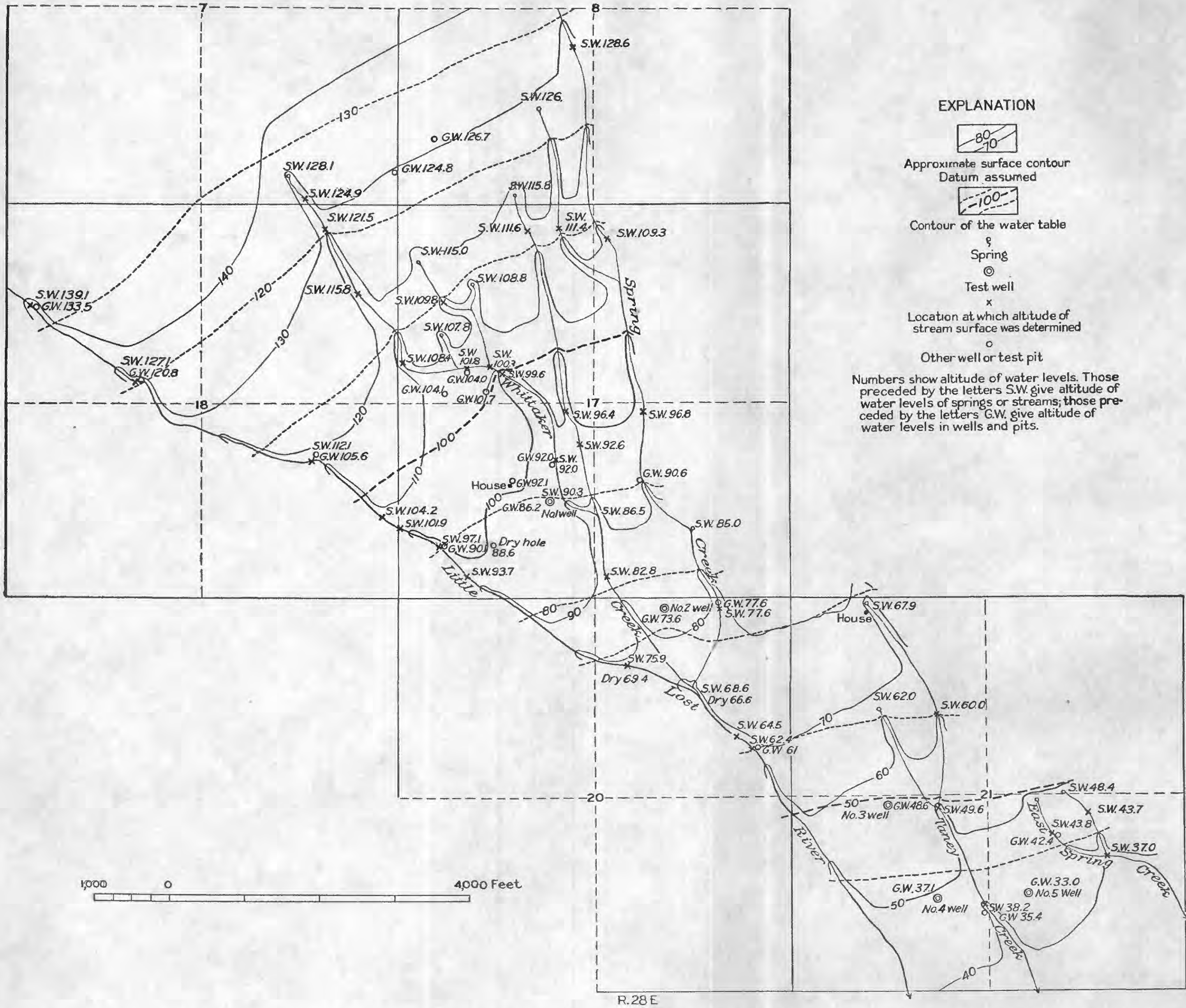
Water was first encountered at 11 feet and rose in the casing to 7.5 feet below the surface. The yield of water was small at 15 feet, and the formation did not yield water from 16 to 20 feet. At 21 feet the water level rose to 8.3 feet from the surface and could not be lowered by bailing. At 33 feet the water rose to 7.8 feet below the surface. The water pressure continued strong until the clay was reached at 40 feet. After the clay was passed at 43 feet the water rose only to 10.5 feet below the surface, although the inflow of water at depths from 43 to 60 feet was very strong, and it was impossible to lower the water level in the casing noticeably by repeated bailing. The driller reported that this well gave indications that it would yield the best of all the five test wells if pumped.

Log of test well 4, SE¼SW¼ sec. 21, T. 7 N., R. 28 E.

[Altitude of surface at well 49.1 feet above assumed datum]

	Thickness (feet)	Depth (feet)
Fine sandy loam	6	6
Cemented gravel; samples at 9, 12, and 15 feet ¼- to ½-inch gravel in a limy clay matrix	9	15
Gravel	1	16
Clay; sample at 18 feet like those from 9 to 15 feet; hence material at this depth is cemented gravel	5	21
Fine gravel; sample at 21 feet fairly clean sand and pea-sized gravel; sample at 24 feet a little finer than that at 21 feet; sample at 27 feet a little coarser than that at 21 feet; sample at 30 feet similar to those above but contains ½-inch gravel; sample at 33 feet still coarser and contains gravel as large as 1 inch in diameter	12	33
Clay, gravel, and sand; sample at 36 feet fairly clean sand and gravel as much as ½ inch in diameter; sample at 39 feet dirty pea-sized gravel; sample at 42 feet dirty ½-inch gravel; samples at 45, 48, and 51 feet dirty pea-sized gravel	18	51
Gravel; sample at 54 feet exceptionally clean gravel 1 inch or less in diameter, much of it poorly rounded; sample at 57 feet silty sand and coarse gravel, not very clean: sample at 60 feet good clean gravel as large as 1 inch in diameter	9	60

A small quantity of water was first encountered at a depth of 15 feet, and the water rose to 12 feet below the surface of the casing.



MAP SHOWING GROUND-WATER CONDITIONS IN THE SPRING CREEK AREA OF LITTLE LOST RIVER VALLEY, IDAHO.

There was very little water, however, until the clay was passed through at 21 feet. From 21 to 33 feet the yield of water was reported to be strong. At a depth of 51 feet the water stood 12.8 feet below the surface. A good supply of water was also reported from 51 to 60 feet.

Log of test well 5, SW¼SE¼ sec. 21, T. 7 N., R. 28 E.

[Altitude of surface at well 44.8 feet above assumed datum]

	Thickness (feet)	Depth (feet)
Fine sandy loam	6	6
Cemented gravel; samples at 12, 15, and 18 feet ⅛- to ¼-inch gravel in a limy clay matrix	14	20
Fine gravel; sample at 21 feet fine silt, sand, and ⅛- to ¼-inch gravel; sample at 24 feet a little cleaner sand than at 21 feet and ½-inch gravel	4	24
Gravel; sample at 27 feet fairly clean gravel as large as 1 inch in diameter; sample at 30 feet fairly clean gravel as large as 2 inches in diameter; sample at 33 feet fairly clean gravel ½ inch in diameter or smaller; sample at 36 feet sand and coarse gravel much of it over 1 inch in diameter; samples at 39 and 42 feet somewhat dirty fine sand with small gravel; samples at 40, 48, 51, 54, and 60 feet fine sand and silt with coarse gravel	36	60

Water first encountered at 12 feet, but the yield was slight until the cemented gravel ended at 20 feet. A strong yield of water was reported at practically all depths from 20 to 60 feet. At a depth of 32 feet the water level was 11.8 feet below the surface.

As a percussion drill was used, there was a tendency through washing during bailing for the coarser material to be concentrated and the samples to appear somewhat cleaner than in nature. The cleaner and coarser the gravel the better water bearer it is, but clean sand will generally yield more than dirty gravel. In spite of the washing and churning of the samples during the drilling there was a striking difference in the amount of fine material in the samples of gravel. Some of the samples of gravel were exceptionally clean, and the beds will prove to be good aquifers when pumped. The samples from well 5 were more consistently dirty than any others. However, there is a thickness of 40 feet of gravel in this well, which may compensate for the lower permeability.

In drilling the wells the casing was driven down a few inches, and after churning a short time the cuttings were bailed out. The driller averaged about 12 feet in an 8-hour day and pulled the casing from each hole in a little less than a day. He found that the casing was most easily pulled by lifting it by means of a lever while the bit was churning lightly at the bottom of the hole. This procedure kept the gravel and sand from closing in tightly against the bottom of the casing.

Of the group of five, wells 2 and 3 appeared to afford the best locations for wells of large size to develop water for irrigation, although wells at the other sites would doubtless yield substantial quantities of water.

Two wells of an exploratory nature were drilled privately during the summer of 1929 by R. N. Wade in the SW¼NW¼ sec. 17, T. 7 N., R. 28 E., at a distance of about 15 feet from the west fork of Whittaker Creek. The water level in these wells stood about 2 feet higher than the water level in the creek. When a trench was cut from the creek level to the wells, each of them flowed about 0.22 second-foot. About a quarter of a mile farther downstream a similar well was drilled, but the water in it stood at the same level as the water in the creek. In test well 1, a short distance farther downstream, the water level was 1 foot lower than the water level in the creek. It thus appears that near the heads of these spring-fed creeks the ground water drains into the creeks, but that a short distance farther downstream the ground-water level is lower than the creek bed, and the ground water is moving toward the mouth of the valley. The tendency of the water level to drop in several of the wells after the drill passed below a stratum of clay between 40 and 50 feet below the surface, together with the large amount of water encountered at such lower levels, indicates a free underground movement down the valley in this lower aquifer.

MEASUREMENTS OF THE SPRING-FED CREEKS

The yield of spring water from this area was determined on March 1, 1930, as follows:

Yield of Spring Creek area, Mar. 1, 1930, in second-feet

Outflow from area:	
Whittaker Creek where it discharges into Spring Creek	9. 64
Spring Creek above mouth of Whittaker Creek	18. 31
Taney Creek in SE¼SW¼ sec. 21, T. 7 N., R. 28 E	5. 60
East Spring Creek below forks in NE¼SE¼ sec. 21, T. 7 N., R. 28 E	3. 10
	36. 65
Inflow to area:	
Spring Creek on north line of sec. 8, T. 7 N., R. 28 E	15. 41
Net yield	21. 24

The flow of 15.41 second-feet in Spring Creek as it enters the area under consideration is the yield from another swampy area about 4 miles farther upstream.

The following additional miscellaneous measurements of the flow of some of these creeks have been made in connection with determinations of losses in the Little Lost River by Lynn Crandall and other engineers of the United States Geological Survey:

Miscellaneous measurements in the Spring Creek area, in second-feet

Spring Creek at mouth, below Whittaker Creek

July 14, 1921	25.46	Aug. 5, 1923	28.69
Sept. 12, 1921	27.65	Aug. 10, 1923	25.86
July 20, 1922	29.48	Aug. 18, 1923	26.48
July 8, 1923	27.65	May 5, 1926	28.54
July 15, 1923	27.68	June 4, 1926	25.36
July 24, 1923	28.28	Aug. 20, 1928	22.9

Whittaker Creek where it empties into Spring Creek

Sept. 12, 1921	12.24	Jan. 3, 1930	8.57

Whittaker Creek at weir in NE¼SW¼ sec. 17, T. 7 N., R. 28 E.

Oct. 11, 1929	8.18

Taney Creek a fourth of a mile above mouth

Sept. 12, 1921	6.61	June 4, 1926	5.85
Aug. 10, 1923	6.06		

East Spring Creek below forks, in NE¼SE¼ sec. 21, T. 7 N., R. 28 E.

Aug. 12, 1929	3.83

Spring Creek on north line of sec. 8, T. 7 N., R. 28 E.

June 4, 1926	12.45

Spring Creek above Fallert gate, in NW¼SE¼ sec. 17, T. 7 N., R. 28 E.

June 4, 1926	14.85

AVAILABLE GROUND-WATER SUPPLY AND METHOD OF RECOVERY

Records of the contributions of water to the zone of saturation of the Little Lost River Valley are incomplete. In addition to the channel losses in the several streams already cited, there are some contributions by seepage from irrigated lands above the Spring Creek area and from Badger, Deer, and Fallert Creeks, all of which reach the Little Lost River after flowing 3 or 4 miles across the gravelly slopes that border the valley. Some water is also undoubtedly received from the high mountains on each side of the valley, from which no surface water reaches the river. The available data are insufficient to justify an attempt to make a detailed tabulation of supply from these several sources, but a study of the records leads to the conclusion that probably from 25 to 50 second-feet of water passes the Spring Creek area underground and continues down the valley to join the underflow beneath the Snake River Plain. Not all of this water could be intercepted by pumping from wells unless the water level were lowered to the bedrock floor of the valley, which would obviously be impracticable.

A logical method for recovering part of the ground water would be first to sink a well somewhere in the vicinity of test well 2 or 3, which if properly developed may yield by pumping as much as a few second-feet; then from observations of the effects on the adjacent ground-water levels and on the flow of the springs produced by pumping this well, other wells could be located until the supply available at moderate lifts would be fully developed.

If flowing wells should be obtained they should be provided with suitable caps to close them during the nonirrigation season, in order to conserve the artesian water and maintain the artesian head. The shallowness of the water table, the presence of artesian conditions, and the occurrence of permeable aquifers less than 60 feet below the surface mean that the gound-water supply could be developed at relatively low cost. Moreover, a high-tension transmission line passes close to the area, and presumably cheap power would be available for pumping if this plan were carried out.

If a substantial volume of water were developed by such wells it might be feasible to excavate an infiltration ditch about 20 feet below the water table in this area. To supplement the water collected by this ditch, large-sized wells could be drilled in the bottom of the ditch. By continuing such a ditch for a mile or so down the valley the water could be delivered into the river by gravity without the use of pumps. The expenditure involved in such an undertaking would be large, however, and would certainly not be justified until the availability of a large perennial supply had been demonstrated by pumping a number of large-sized wells for several years. If an infiltration ditch of this character should be constructed, checks would be required in the ditch to impound the water during the nonirrigation season and thus allow the ground-water reservoir to become replenished.

The flow of the spring-fed creeks could be appreciably augmented by deepening them and drilling shallow wells through the cemented gravel over which they flow in the stretches of channel, shown on plate 30, where the water table is higher than the water surface of the creeks. These would be flowing wells and would yield water most of which now escapes from the valley. Additional wells could be drilled through the hardpan in the areas between the creeks where artesian water occurs, and short canals could be dug to convey the water thus obtained to the creeks. Such a development would decrease the flow of the springs but would increase the total recovery of ground water. Precaution should be taken to case the wells tightly with heavy casing and to cap them when not in use; otherwise there might be no increase in the total recovery during the irrigation season. Such development should preferably be made by the owners of the spring water, to avoid conflict. It would not be successful if enough pumping from wells were carried on downstream to reduce the slight head so that the wells in this area would no longer flow.

To obtain a substantial supply of water from wells or infiltration ditches it would doubtless be necessary to lower the water table until the flow of the springs would be diminished. Thus the total water supply would be increased but the flow from the springs would be diminished. Gaging stations should be established on the spring-fed creeks to determine their normal discharge in order that any diminution of their flow as a result of future withdrawals from wells or infiltration ditches can be determined and prior rights can be fully protected.

BIG LOST RIVER VALLEY [30]

GEOGRAPHY

The Big Lost River rises in the high mountainous region included in the Lemhi National Forest, Custer County, Idaho. On the rim of its drainage basin are Hyndman Peak, 12,078 feet above sea level, for many years considered to be the highest mountain in Idaho, and Mount Borah, which during 1929 was found by Lee Morrison, of the United States Geological Survey, to be 12,655 feet above sea level. The upper valley of the East Fork, known as "Copper Basin," is parallel to the main Big Lost River Valley and about 15 miles west of it, being separated from it by the White Knob Mountains (pl. 31). Below the East Fork the stream enters a gravel-filled valley averaging about 4 miles in width. Through this valley, known as the "Big Lost River Valley," it flows in a southeasterly direction for about 60 miles to the edge of the Snake River Plain below Arco. Thence it continues for about 40 miles, first in an easterly and then in a northeasterly and northerly direction to the Lost River "sinks," a shallow depression in the surface of the Snake River Plain, where the surplus waters in years of heavy run-off accumulate until they are lost by evaporation or by percolation into the underlying lava rocks. In the valley are the towns of Mackay (population 1,482 in 1930), Arco (population 834), and Moore (population 336), and the smaller settlements of Darlington, Leslie, and Chilly. (See pl. 31.)

In the section of the valley above Mackay the irrigated area, comprising about 10,000 acres, consists principally of wild-hay meadow lands devoted to raising livestock. Below Mackay about 40,000 acres has been irrigated, including the 6,000 acres of Carey Act lands lying at the mouth of the valley. This lower portion of the valley is used for general farm crops, principally hay and grain. The irrigated acreage, however, has been decreasing in recent years, owing to deficient run-off and decreasing precipitation. The altitude of the valley floor ranges from 5,300 feet at Arco to 6,300 feet at Chilly, 50 miles

[30] A more detailed report was released to the public in mimeograph form on June 23, 1930.

upstream. At Mackay, at an altitude of 5,900 feet, the mean annual precipitation is 9.74 inches and the mean annual temperature 42.1° F., according to the Weather Bureau records.

SURFACE WATER

The productive run-off of the Big Lost River comes principally from a relatively small area on its headwaters. The drainage area above the Howell ranch gaging station, in sec. 30, T. 8 N., R. 21 E., at an altitude of 6,600 feet, where the river first enters the enlarged valley, is 430 square miles. During the period 1921–29 the average annual discharge of the river at this station was 191,700 acre-feet. The drainage area above the gaging station below the Mackay Dam, 24 miles downstream from the Howell ranch station, is 790 square miles, and the average annual discharge at this station during 1921–29 was 207,900 acre-feet, a net gain between the two stations of only 16,200 acre-feet. If the crops on irrigated lands in the section between these stations consumed 1.7 acre-feet of water to the acre, a total of about 17,000 acre-feet was annually consumed on the tract of about 10,000 acres in the section.

The average annual run-off from the drainage area of 360 square miles between the two stations may have been more or less than the 33,200 acre-feet represented by the sum of the gain in flow and the water consumed on irrigated land, according as underflow at the Mackay station was greater or less than that at the Howell station. The actual run-off would also be greater than 33,200 acre-feet by the amount of water consumed by vegetation along the Thousand Springs Slough. (See p. 246.)

Below the Mackay Dam the river dwindles downstream through irrigation diversions and seepage losses. During the 3 years 1921–23, there was an average annual discharge of 47,000 acre-feet past the lowest canal diversion below Arco, but with this exception, there was no appreciable outflow from the valley during the 11 years 1919–29, although at Arco the river has a drainage area of 1,560 square miles.

The contributions from the Big Lost River to the ground-water flow of the Snake River Plain have been estimated by computing the total supply available from stream flow and deducting from it the quantity of water consumed on the irrigated land below the dam. The total supply available from stream flow was obtained by adding to the annual discharge of the river at the Mackay Dam the inflow from tributary streams below the dam. About 40,000 acres of land below the Mackay Dam was irrigated from the Big Lost River and tributaries below the points where they were measured during the years considered. The consumption of water by transpiration and evaporation of 1.7 acre-feet to the acre for the season, exclusive of precipitation, was assumed for the crops on these lands where water was available throughout the season. Many of the lands, however, have inferior water rights, which are filled only during part of the irrigation season, and on such lands a smaller consumption was assumed, the amount varying from year to year with the water supply in accordance with the record of water deliveries on the stream furnished by the watermaster.

Estimated contributions, in acre-feet, to the ground water of the Snake River Plain by Big Lost River, years ending Sept. 30, 1920–27

	Discharge of Big Lost River at Mackay Dam (acre-feet)	Tributary inflow below Mackay Dam [1] (acre-feet)	Total supply (acre-feet)	Estimated crop consumption and evaporation losses (acre-feet)	Contribution to supply of ground water of Snake River Plain (acre-feet)
1920	168,000	45,000	213,000	46,000	167,000
1921	268,000	102,000	370,000	64,000	306,000
1922	279,000	97,000	376,000	64,000	312,000
1923	235,000	80,000	315,000	58,000	257,000
1924	145,000	40,000	185,000	32,000	153,000
1925	237,000	61,000	298,000	58,000	240,000
1926	144,000	39,000	183,000	32,000	151,000
1927	212,000	65,000	277,000	56,000	221,000
Average					226,000

[1] Includes lower Cedar, Alder, Pass, and Antelope Creeks.

NOTE.—All records from unpublished data supplied by water commissioner for the Big Lost River, Mackay, Idaho.

GROUND WATER

The ground water is stored mainly in the alluvial valley fill. Some of this material is cemented, at least on the surface, and this is much older than the rest. Wells 80 feet deep fail to reach bedrock. From the size of the valley and the profiles of the exposed bedrock, the alluvium at some places may be 500 feet or more in thickness.

The alluvium is in part derived from the Big Lost River, but broad alluvial fans flank the mountains on each side of the valley. Most of the streams descending from the mountains sink into these fans and fail to join the Big Lost River except in times of cloudbursts or spring freshets. The river has been unable to maintain its course through the axis of the valley because these fan deposits have forced it first to one side and then to the other. Basalt flows from the Snake River Plain intermittently blocked or partly dammed the mouth of the valley thus causing the river to aggrade its floor. One of these flows issued in sec. 33, T. 4 N., R. 26 E., near Arco and forced the river to the east side of the valley. The main underflow of the valley escapes through the lava and follows the present surface channel only about 5 miles below Arco (pl. 19). As is shown below, the relation between the water table and the land surface differs from place to place in response to the geology.

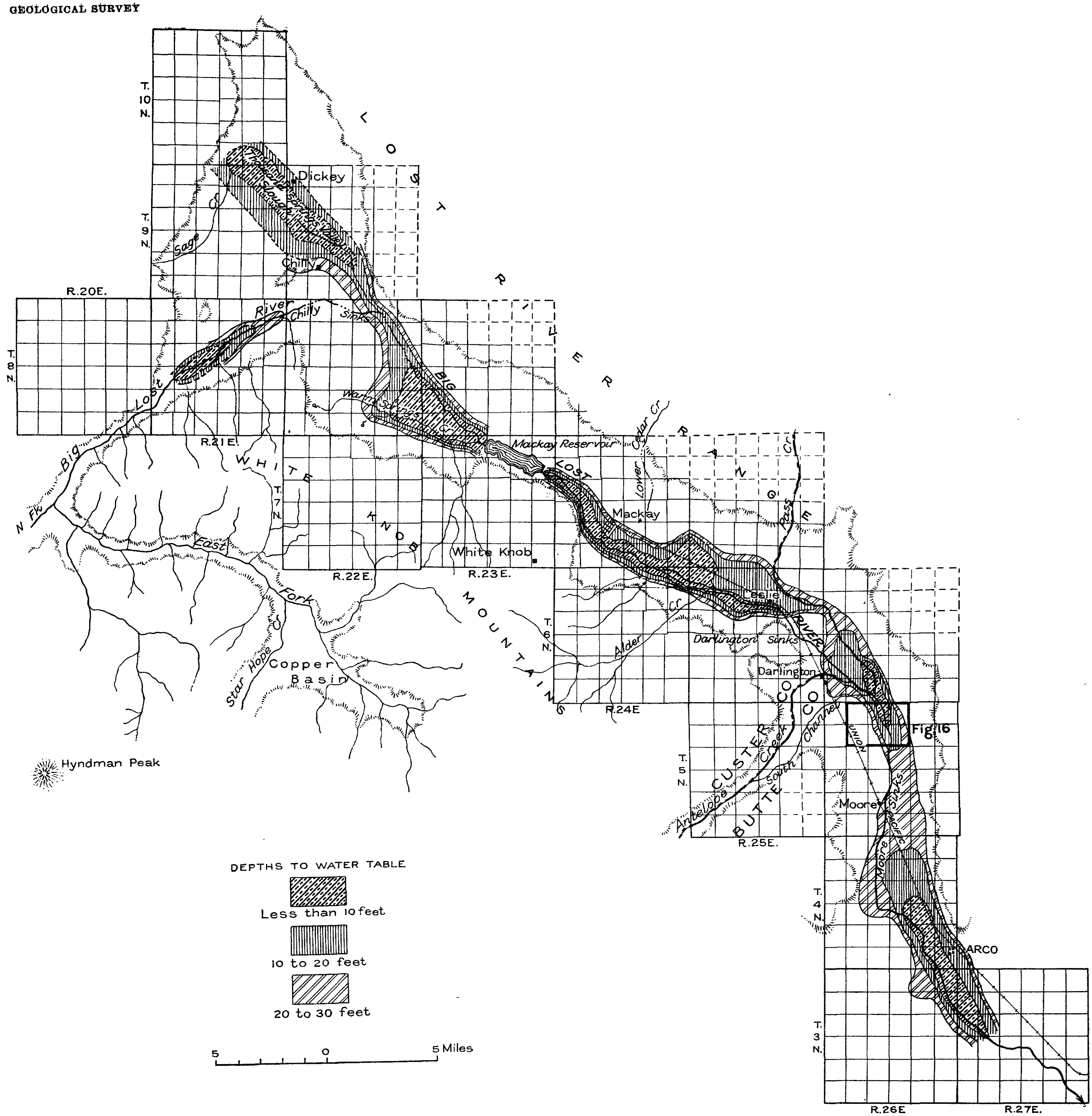
Since the earliest days of settlement in the valley the river has been noted for the "sinks" along its channel, and it no doubt takes its name from these features. Five sinks have been recognized and named. The uppermost one in sec. 15, T. 8 N., R. 21 E., consists of four small depressions in the land surface alined in a northeasterly direction. The southernmost of these depressions is the largest and has a width of about 50 feet and a depth of about 25 feet. It is thought that they may record the presence beneath the alluvial cover of a collapsed limestone cavern and that water entering this cavern may give rise to Thompson Spring, 5 miles to the southeast. The river losses in the section that contains the depressions are known to average about 30 second-feet; moreover, there is some contribution to the supply of ground water from irrigated land in the tributary drainage area.

The next three sinks downstream are not depressions but merely places where the river loses heavily in gravel and at times disappears. The lowest sink is a shallow basin or playa, where the river spreads out and is dissipated by evaporation and deep percolation.

The Chilly Sinks begin at a point in sec. 6, T. 8 N., R. 22 E., southwest of the village of Chilly, and extend thence about 9 miles downstream. The river has to attain a flow of about 750 second-feet at the Howell ranch before it is able to cross these sinks in the spring. However, once started, it will continue to flow at the surface in this stretch until it declines to a flow of about 300 second-feet at the Howell ranch. The river usually flows across the sinks for a period of 1 to 3 months in the spring and early summer of each year, and the channel is dry for the remainder of the year. During the spring, when the stream is first making its way across the sinks, the ground water in the adjacent gravel rises several feet daily, and water appears in wells and depressions a quarter of a mile or more from the river, keeping pace with the downstream advance of the water in the surface channel. Evidently there is much permeable alluvium in this stretch.

Thousand Springs Creek, which enters the Big Lost River about midway on the Chilly Sinks, has its source in springs that rise at the head of Thousand Springs Slough, about 10 miles from the point where it discharges into the river. The natural flow of these springs is largely absorbed during the summer by transpiration and evaporation on about 5,000 acres of swampy meadow. One of the largest springs feeding this creek rises in alluvium about half a mile from a limestone hill and discharges about 20 second-feet of water. During years of plentiful water supply the flow of the creek is augmented by seepage from the irrigated lands in the vicinity of Chilly, and at such times it may discharge as much as 75 second-feet into the Big Lost River. The creek usually dries up at its mouth early each winter, owing to the lowering of the adjacent water table.

Below the Chilly Sinks the river receives a considerable groundwater inflow, augmented by the flow of Warm Spring Creek. This creek has its source in two springs that rise on the west side of the valley



MAP OF BIG LOST RIVER VALLEY SHOWING DEPTHS TO GROUND WATER.

about 100 feet above the adjacent river level. The upper spring, which is Thompson Spring, in sec. 29, T. 8 N., R. 22 E., gushes forth from a fissured cherty limestone, overlain by Challis volcanics. The temperature of the water on October 9, 1929, was 46° F. The flow of this spring reaches a low point of about 22 second-feet during March of each year. It starts to rise during May and reaches a maximum of about 36 second-feet around August 1.

The lower spring, known as Boone Creek, in sec. 34, T. 8 N., R. 22 E., is about 15 feet lower in altitude than the upper spring. It issues from alluvium near a ridge capped with Challis volcanics. The water temperature on October 9, 1929, was 54° F. The lower spring reaches its minimum flow of about 26 second-feet during May and reaches a maximum of 33 second-feet during September.

Warm Spring Creek enters the main valley several miles above its mouth. The creek receives inflow from the ground water of the main valley, and at its mouth it usually discharges about 125 second-feet during low stages and considerably more during periods of high ground-water levels.

Below the mouth of Warm Spring Creek and 4 miles above Mackay is the Mackay Dam, a gravel-fill structure about 70 feet in height, which impounds 40,000 acre-feet. This dam is at the lower end of a stretch in which the river receives ground-water inflow. It abuts at both ends on hills of Paleozoic limestone, those on the northeast being mantled by the gravel sediments of upper Cedar Creek. Numerous minor faults with trends transverse to the valley appear to be present in the limestone in the southwest abutment, a fact which suggests that the limestone exposed farther northeast may be related to cross faulting. To the northeast the broad expanse of the valley is interrupted by hills composed largely of old alluvium, which dips gently westward. At the surface this alluvium is so thoroughly cemented as to be nearly impermeable but in the zone of saturation it may not be cemented. Whatever the precise structure or character in the underlying material, it seems clear that the hills which constrict the valley here, although far lower than the mountains on both sides, correspond to a restriction in the flow of ground water beneath them. This is believed to be the principal cause of the area of shallow ground water at and immediately above the Mackay Reservoir. (See pl. 31.)

The underground conditions are such that much water escapes under and around the dam. That this water returns to the river above the narrows, a mile below the dam, where the valley floor is greatly constricted by abrupt limestone spurs on each side, is proved by measurements at a station about 1½ miles below the dam and just below the narrows during periods when the gates at the dam are closed, as shown by the table following:

Discharge, in second-feet, of Big Lost River 1½ miles below Mackay Dam with the gates at dam closed

Gage height of reservoir (feet)	1918–19	1919–20	1920–21	1921–22	1922–23	1923–24	1924–25	1925–26	1926–27	1927–28	1928–29
10	(1)	(1)	43	50	(1)	(1)	30	(1)	30	30	28
15	(1)	(1)	47	52	(1)	(1)	42	(1)	40	38	36
20	68	(1)	59	63	(1)	60	50	(1)	47	46	46
25	76	(1)	69	75	(1)	65	64	(1)	53	63	55
30	87	85	85	84	(1)	71	76	59	67	76	66
35	94	94	100	95	97	77	87	69	78	85	78
40	111	(1)	122	103	102	89	101	85	90	89	98
45	121	(1)	135	112	106	105	115	96	108	112	113
50	137	(1)	(1)	135	113	112	(1)	108	(1)	130	130
55	(1)	(1)	(1)	(1)	123	131	(1)	135	(1)	(1)	(1)

[1] No record.

Between the narrows below the Mackay Dam and the village of Leslie, a distance of 10 miles, the ground water under the valley floor holds up to a level equal to or higher than the river level. During the irrigation season of the dry year of 1920 the river sustained an average loss of 15 second-feet in this section, but in years of plentiful supply it shows an average gain of about 20 second-feet during the irrigation season. Apparently the rate of underflow is nearly in equilibrium with the supply of water. Nearby spurs of limestone constrict the valley, and it is thought that bedrock may be closer to the surface under the alluvium here than in most other sections. These factors aid in maintaining the water close to the surface in the area between this point and Mackay.

Downstream from Leslie the valley again widens, and the ground-water level drops rapidly below the river level, and in the Darlington Sinks the river sustains losses ranging from 30 to 75 second-feet. About 2½ miles east and 1 mile south from Darlington water again rises and flows into the river channel, but all of it is diverted during low-water periods at the Moore diversion dam, in sec. 4, T. 5 N., R. 26 E. The rise here is aided by the constriction of the valley caused by Antelope Ridge, near Moore.

The average annual flow of the Big Lost River at the gaging station below the Mackay Dam in 1921–29 was about 208,000 acre-feet, to which may be added 64,000 acre-feet as the average annual inflow to the valley from Lower Cedar, Alder, Pass, and Antelope Creeks and minor tributaries between the Mackay Dam and the Moore Dam, making a total average annual supply of about 272,000 acre-feet. If there were no seepage loss and the consumption of water on the 17,000 acres of irrigated lands in this area is taken as 30,000 acre-feet annually, the average annual flow of the river at the Moore Dam should be about 242,000 acre-feet. However, during this period the average annual flow at the Moore Dam was only about 96,000 acre-feet, in addition to which there was an annual average of about 37,000 acre-feet carried by the Blaine Canal past the Moore Dam.

Hence it is inferred that approximately 109,000 acre-feet annually moved underground past the Moore Dam. Test drillings made during the winter of 1929–30 indicate, as shown below, that the groundwater level about half a mile west of the Moore Dam is about 18 feet

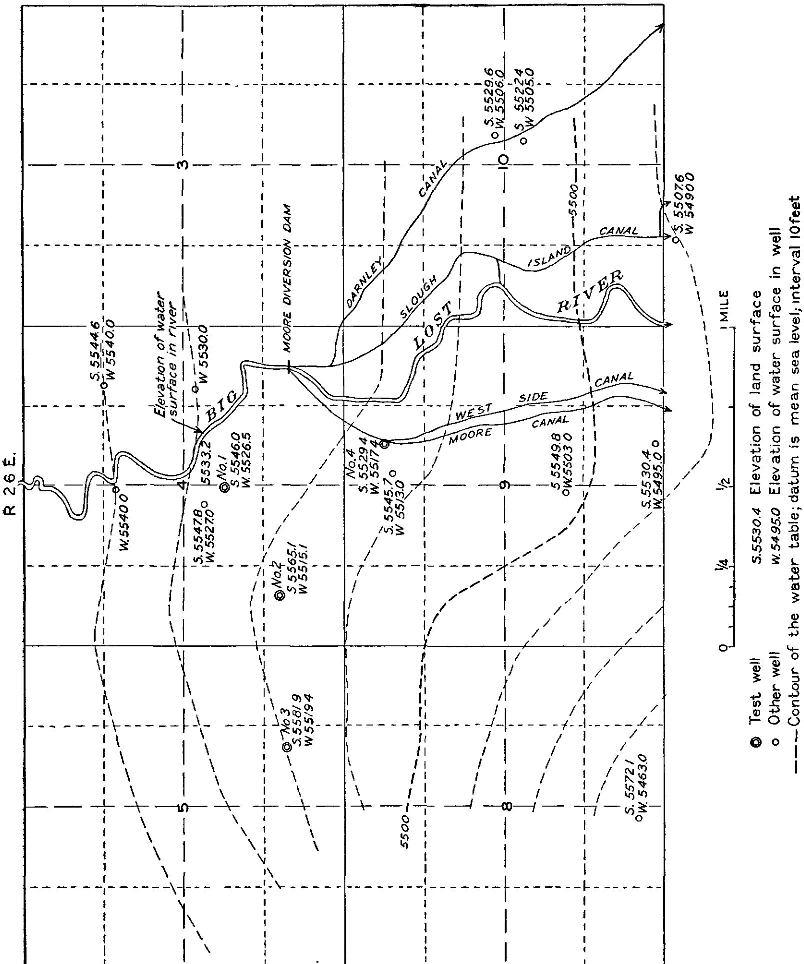


FIGURE 16.—Map showing location of test wells and contours of the water table in the vicinity of Moore diversion dam, Big Lost River Valley.

lower than the river level. This fact and the ground-water contours (pl. 19 and fig. 16) indicate that part of this underflow leaves the valley under the land of the Utah Construction Co., west of Arco, at great depth. The ground water may follow an old buried channel from which the river was diverted by basalt flows.

Between the Moore Dam and a point about a mile above Arco, a distance of 9 miles, the river flows across the Moore Sinks. In years of plentiful water supply, when the river runs through this section for several months and large volumes of water are used in the irrigation of adjacent lands, as much as 75 second-feet of return flow rises in the river channel and in several spring-fed creeks a mile or two above Arco. In dry years, however, this return flow decreases to practically nothing. When the ground-water levels are low in this section more than 200 second-feet must be discharged past the Moore Dam in order for any water to reach Arco.

At a point about 5 miles south of Moore the Big Lost River turns to the east and thence continues southeastward near the edge of a basalt flow for several miles. The main ground-water flow, however, continues southward beneath the lavas, its course being fairly well defined by the ground-water contours at the mouth of the valley (pl. 19). The area of shallow ground water in the vicinity of Arco appears to be supplied chiefly from the eastern side of the valley and the supply for this area is apparently not large.

TEST WELLS

WELLS NEAR MOORE DAM

During the winter of 1929–30 four test wells 4 inches in diameter were drilled in the valley in the vicinity of the Moore diversion dam, 3 miles upstream from the village of Moore. (See fig. 16.) A percussion drill was used, and the casing was carried down with the drilling. The casing was salvaged from all the wells except well 4. In the spring of 1930 a test well 20 inches in diameter was drilled in the vicinity of Arco and was pumped with a deep-well turbine centrifugal pump. The logs and descriptive notes of these wells follow:

Log of test well 1, NE¼SW¼ sec. 4, T. 5 N., R. 26 E.

[Altitude of surface 5,546.0 feet]

	Thickness (feet)	Depth (feet)
Sandy loam soil	3	3
Sandy silt; sample at 20 feet, sandy silt	17	20
Sand and fine gravel; sample at 25 feet, medium sand with a little ⅛-inch gravel	5	25
Clayey silt; sample at 27 feet, clayey silt with a little gravel as large as ¼ inch in diameter; looks nearly impermeable	5	30
Sandy silt with a little gravel; sample at 30 feet, sandy silt with a little gravel as large as ¼ inch in diameter; the gravel is subangular and mostly dark like the sand	5	35
Silty sand; sample at 35 feet, sand with a little silt and no gravel; sample at 36 feet, fine sandy silt containing mica flakes	2	37
Sand and gravel; sample at 37 feet, sharp coarse clean dark sand and considerable subangular ⅛-inch gravel, probably a good aquifer; sample at 39 feet, like that at 37 feet but a little less clean and contains some gravel ¼ inch in diameter; sample at 40 feet like that at 37 feet	5	42
Fine dirty sand	1	43
Sand and fine gravel; sample at 44 feet like that at 37 feet but not quite so clean	1	44
Fine sand with a little clay; sample at 45 feet fine sand containing a little clay	1	45
Sand and gravel; sample at 46 feet clean, dark gravel as large as ½ inch in diameter; should be an excellent aquifer	1	46
Clayey silt; sample at 47 feet yellow clayey silt	1	47
Gravel and sand; sample at 48 feet clean, well-rounded dark gravel like that at 46 feet; samples from 49 to 63 feet and at 68 feet clean sand and gravel as large as ½ inch in diameter	24	71
Sandy silt; sample of material that rose 10 feet in the pipe at 72 feet is sandy silt; sample at 72 feet after cleaning pipe is fine sand with many of the grains rounded	1	72

Water was first encountered in this well at a depth of 19 feet. At 25 feet the water was cased off in a silty clay. Water was again encountered at the depth of 36 feet and rose in the casing to a level 13 feet below the surface. At 40 feet, in coarse sand, the water rose at the rate of 1 foot in 15 seconds when bailed down 6 feet. At 42 feet, in fine dirty sand, the hole was bailed dry, but water was struck again at 44 feet. At 45 feet the water was cased out, but water in small quantity was again struck at 45.5 feet. The low yield at this depth is indicated by the fact that the water rose very slowly and when left over night reached only a level 36 feet below the surface. At 48 feet a more plentiful supply of water was found in a sandy gravel, and the water rose to a level 18 feet below the surface. Between 48 and 70 feet several bailing tests showed that the water rose at the rate of 1 foot in 22 seconds when bailed down 4 feet. At 61 feet the water stood 19.5 feet below the surface. At 72 feet fine sand was encountered that rose 10 feet in the casing.

The formations encountered in this hole to the depth tested are not favorable for large yields by pumping, on account of the interbedded strata of sandy clay, which evidently prevent the free movement of water through the gravel beds. In all probability these gravel beds are lens-shaped and terminate in the sandy clay.

Log of test well 2, SW¼SW¼ sec. 4, T. 5 N., R. 26 E.

[Altitude of surface 5,565.1 feet]

	Thickness (feet)	Depth (feet)
Clayey soil with a few ¼-inch pebbles; sample at 40 feet silty clay with a few pea-sized pebbles; samples at 44, 45, and 48 feet have texture like that at 40 feet; sample at 53 feet dirty ⅛-inch gravel; sample at 61 feet shot-sized gravel and silt	61	61
Sand and fine gravel; sample at 64 feet clean sand and gravel as large as ½ inch in diameter; sample at 71 feet similar to sample at 64 feet but more sand; sample at 74 feet, sand and gravel 1 inch in maximum diameter	14	75
Sand; samples at 76 feet clean, coarse sand	3	78
Sand and fine gravel; sample at 80 feet clean, coarse sand with a little ⅛- to ¼-inch gravel	2	80

Water was first struck in this well at 61 feet, at the bottom of a stratum of gravelly clay, and rose to a level 47 feet below the surface. At 70 feet the water was cased off in clay. Below 72 feet an abundant supply of water that could not be lowered by repeated bailing was encountered in gravel. Between 72 and 77 feet the water stood 50 feet below the surface. Regular measurements on another well at this point were made during 1920–22 and are tabulated on page 252.

Measurements of depth to water in well in SW¼SW¼ sec. 4, T. 5 N., R. 26 E.

[Martha Jones, owner]

	Feet		Feet		Feet
Nov. 24, 1919	39.3	Oct. 12, 1920	38.7	Oct. 21, 1921	25.7
Dec. 2, 1919	39.2	Nov. 1, 1920	37.7	Nov. 22, 1921	34.6
Feb. 19, 1920	40.2	Nov. 24, 1920	38.8	Dec. 16, 1921	36.4
Mar. 13, 1920	40.4	Dec. 30, 1920	40.7	Feb. 8, 1922	37.7
Mar. 23, 1920	40.7	Feb. 4, 1921	41.1	May 3, 1922	34.8
Mar. 29, 1920	40.2	Mar. 5, 1921	40.7	June 5, 1922	24.4
Apr. 12, 1920	40.2	Mar. 30, 1921	39.3	July 8, 1922	18.7
Apr. 28, 1920	40.5	Apr. 25, 1921	39.1	Aug. 2, 1922	23.4
May 24, 1920	38.4	May 23, 1921	28.8	Aug. 26, 1922	26.0
July 2, 1920	28.0	June 24, 1921	25.0	Oct. 2, 1922	26.7
July 22, 1920	34.1	July 26, 1921	22.1	Jan. 9, 1930	50.0
Aug. 28, 1920	38.3	Aug. 24, 1921	29.1		
Sept. 24, 1920	37.8	Sept. 26, 1921	29.7		

During the high-water year of 1932 the water table at this place rose to a level 18.7 feet below the surface. A well at this site would furnish a good yield if pumped, but the lift might be too great for economical operation.

Log of test well 3, SW¼SE¼ sec. 5, T. 5 N., R. 26 E.

[Altitude of surface 5,581.9 feet]

	Thickness (feet)	Depth (feet)
Clayey soil with a little shot-sized gravel; samples at 26, 28, 35, 40, 45, 50, 55, 60, and 65 feet, clayey soil with a little ⅛-inch gravel	65	65
Sandy silt; sample at 67 feet, sandy silt	2	67
Clay; sample at 70 feet clay	3	70
Sand and fine gravel; sample at 75 feet, clean sand and ¼-inch gravel	5	75
Silty clay; sample at 80 feet, silty clay	5	80
Sand; sample at 84 feet, fairly clean sand	4	84
Sand and fine gravel; sample at 85 feet clean sand and ¼-inch gravel; should be an excellent water bearer	1	85

Water was found in this hole at a depth of 61 feet, and it rose to a level 55 feet below the surface. At 70 feet the water was shut off in clay. At 75 feet water was again encountered but rose only to a level 63 feet below the surface. A free yield of water was obtained in this well, and it was impossible to lower the water level appreciably by bailing.

In well 4, in the NW¼NE¼ sec. 9, T. 3 N., R. 26 E., water was first found at a depth of 12 feet. Owing to the perforated casing used, water and sand came in at all depths, making it impossible to identify the water-bearing characteristics of the different formations. A plentiful supply of water was apparent, however, as the water level could not be lowered by bailing. When the hole was ended at 40 feet the water level stood 9.9 feet below the surface. This reading may have been affected by seepage inflow from an adjoining canal.

The test wells were drilled in the vicinity of the Moore diversion dam to determine the feasibility of an attempt to recover the water known to be passing through this part of the valley. Over half of the irrigated area in the valley below the Mackay Dam could be served by the canals that divert water at the Moore Dam. Hence, if the ground water could be recovered and discharged into the canals its distribution to the land would be greatly facilitated. The results of the drilling, however, were discouraging, as the main ground-water flow was found to occur west of the river, mostly at depths below the surface probably too great for economical pumping under present conditions and at a lower altitude than the river level. The portion of the ground-water flow that passes the Moore Dam adjacent to the river for a distance of half a mile or so downstream from the dam could be recovered by pumping at relatively low cost, as the depth to the ground-water level does not exceed 10 to 15 feet. The results of the drilling and the ground-water contours (see fig. 16) indicate, however, that the largest flow down the valley occurs from three-quarters of a mile to a mile west of the river channel, beneath an overburden of 50 feet of alluvial fill of the Antelope fan.

During the spring of 1929 a sump was excavated in gravel by A. W. Bell in the SW¼SE¼ sec. 4, T. 5 N., R. 26 E., 500 feet west of the river, which yielded 1.6 second-feet with a 4-foot draw-down when pumped. A test of the municipal well of the village of Arco in 1922 showed ayield of 0.24 second-foot for each foot of draw-down. Several other plants pumping 1 to 2 second-feet at different places in the valley in past years are reported to have yielded from 0.16 to 0.30 second-foot to the foot of draw-down, and it appears probable from a study of such well logs as are available that similar yields can be obtained at many places in the valley.

WELL NEAR ARCO

On May 7, 1930, through local financial aid, a test well was sunk in the vicinity of Arco. The choice of the site was determined by the presence of a canal and a power line that were already built and not by the geologic structure. The site selected was close to the edge of the alluvial fan on the east side of the valley. Probably more productive gravel would have been found if the well had been located nearer the axis of the valley.

The first 57 feet of the well was sunk by Thomas Stephenson, of Burley. When the well had reached this depth it was cased to the bottom with 10-gage butt-welded casing 20 inches in diameter. On June 14, 1930, the casing had been perforated between 45 and 54 feet with 150 slits 2 inches long and about three-fourths of an inch wide in the middle. It is estimated that these perforations have an area of about 150 square inches. By removing the sand and gravel with a vacuum-type bailer and weighting the casing the well was constructed without the use of a drill. Water was encountered at

8 feet in the upper gravel bed. It is the so-called "sub" water and fluctuates considerably with the flow of the river. This water was cased out of the hole at 27 feet, and the second water was encountered at 31 feet. It rose almost to the level of the first water. On June 8, when the casing was 46 feet below the surface, it was perforated from 34 to 42 feet, and a centrifugal pump was installed. The depth to the water on the inside of the casing from the top of the north side of the wood curb at ground surface on this date was 8.4 feet and the depth to the "sub" water outside of the casing was 0.3 foot higher. When the pump was started the water was drawn down to 14.7 feet below the top of the wood curb, or 17 feet below the center of the pump, which was essentially the suction limit. A yield of only about 90 gallons a minute (0.2 second-foot) was obtained. After pumping a short time the well filled up with about 3.5 feet of sand.

Log of test well in SW¼NW¼ sec. 25, T. 4 N., R. 26 E., to depth of 57 feet

	Thickness (feet)	Depth (feet)
Silty loam soil	2	2
Light-yellow sandy clay	3	5
Fairly clean gravel and sand; 4-inch streak of ⅛- to ¼-inch gravel and sand at 7 feet	2	7
Clean sand and gravel; pebbles fairly well rounded and some of them 4 inches in diameter	1	8
Coarse subangular gravel in silty sand; approaching hillside wash in character	1	9
Dirty gravel; hillside wash with 2-inch streak of clay at 11 feet	2	11
Dirty gravel; gravel fairly well rounded	1	12
Fine clean sand; mostly quartz and gravel as large as 3 inches in diameter; the gravel is mostly porphyry and not derived from the adjacent limestone mountain, but one large angular limestone cobble was found in it	1	13
Clean sand with pea- to apple-sized gravel; at 16.5 feet a number of subangular limestone blocks, some of them 6 inches in diameter	4	17
Fine sand, mostly quartz grains	10	27
Silty clay	4	31
Fine clean sand	5	36
Coarse dirty gravel; hillside wash	10	46
Coarse clean gravel and coarse sand; mostly ½ inch in diameter but some as large as 3 inches	11	57

As it was impossible to develop the well effectively by pumping out the sand with this equipment, the well was drilled 10 feet deeper and clean water-bearing gravel was encountered. The perforated casing was driven down into this gravel. On June 13 an 18-inch deep-well turbine pump was installed and operated with electric power. It delivered over 0.5 second-foot, and considerable coarse sand was discharged. However, after a few minutes of operation a fuse blew out, causing the motor to stop. Before the pump could be started again 5 feet of sand had settled into the well, choking the screen intake at the bottom of the suction pipe and considerably reducing the discharge. A few minutes after the pump was started again it ceased to throw out any sand. If all the sand had been pumped out it would have left a gravel wall through which water could enter the well more readily.

The pump was then pulled, the well was sunk 15 feet deeper, and the casing was perforated at all water-bearing beds. The local cooperators report that the bottom of the gravel aquifer was reached before the well had been sunk the additional 15 feet and that the well yielded about 3 second-feet of water.

CONSERVATION AND RECOVERY OF WATER

Plans to save a part of the water that will normally be lost underground from the Big Lost River Valley may be directed either toward the prevention of seepage losses in the river bed or toward the recovery of the water by pumping from wells after it has reached the water table. Practically any plan will modify to some extent the existing ground-water situation and will thus affect certain existing rights adversely. In view of the fact that at the present time the landowners in the valley have individual water rights of varying dates of priority, a consolidation of these water rights would probably have to precede any large-scale attempt at further conservation of the water supply. Several plans are discussed below.

Chilly Sinks bypass.—It is apparent from a study of the run-off records at Howell's ranch and Mackay Dam that very little if any water is lost in the section between these points, taking the year as a whole. The large losses that now occur on the Chilly Sinks during the flood period feed the ground water that supplies the inflow to the Mackay Reservoir during the late summer, fall, and winter. Hence a bypass canal would result only in a seasonal redistribution of the present annual inflow to that reservoir. This, however, might be well worth while, as the water supply for users below the reservoir in very dry years could be augmented at the expense of the reservoir inflow the following winter. Inasmuch as the reservoir, with the gates closed during the winter, is able to retain only about 50 percent of the winter inflow, this would result in a net saving of water, provided the reservoir and natural-flow interests were consolidated or could agree on some kind of a joint program.

Leslie bypass.—It has been long suggested that a canal be constructed to divert from the river below Leslie, extending to the east side of the valley and returning to the river about a mile above the Moore diversion dam. This canal would bypass the gravelly section of the river known as the "Darlington Sinks", where about 50 second-feet is now lost at normal stages, and would probably effect a conservation of about half this amount of water, besides expediting the delivery of water to the Moore Dam.

Antelope channel improvement.—Considerable quantities of water are now lost by seepage during the spring floods in the several channels of Antelope Creek on the fan where the creek enters the Big Lost River Valley. A saving of several thousand acre-feet annually could be made by cleaning and enlarging the south channel of the creek from a point in sec. 21, T. 5 N., R. 25 E., to the Big Lost River, so that it would carry the waters of that stream quickly and with minimum loss to the river.

Moore Sinks bypass.—The water supply for lands near Arco in dry years could be carried from the Moore diversion dam in a canal that could be constructed along the east side of the valley to a point 3 miles above Arco, where the water could be discharged into James Creek, a spring-fed stream that enters the river at the diversion dam a mile north of Arco.

It is suggested that in years of plentiful supply it would be best to carry the water from Leslie to Arco in the present river channel, because the large losses that occur under such conditions build the water table up beyond the height required to supply the capacity of the underground outlets from the valley, and the surplus water then appears as ground-water inflow into the river and adjacent channels and provides a substantial addition to the supply available late in the season. In dry years, however, the available supply is inadequate to build the water table to this height, and most of the water contributed to the water table in such years is a total loss to the valley.

Increased supply for Thompson Spring.—A suggested inexpensive test would be to conduct floodwaters by means of a short canal into the sinkholes at the head of the Chilly Sinks. If this water reappears in Thompson Spring and there is sufficient underground storage and a long enough time interval while the water is passing under the intervening ridge, it may offer a way to save some water for use later in the season.

Increased supply for Mackay Reservoir.—The amount of water stored behind the Mackay Dam during the winter could be substantially increased if the leakage under and around the dam could be reduced. This might be accomplished by grouting through drill holes along the axis of the dam and extending into the adjacent hillsides or by a heavy blanket of fine material on the upper face of the dam, extending for some distance upstream along each shore of the reservoir. This work, however, to be effective would involve a considerable expenditure, and the matter should be carefully considered before being undertaken.

Thousand Springs Reservoir.—There is a reservoir site at the Thousand Springs, near Chilly, but the area flooded would be large in proportion to the volume of water that would be stored, and the land that would be flooded is valuable for winter grazing on account of the luxuriant grass now produced naturally. The damage to the livestock industry of the Big Lost River Valley by the destruction of this grazing area would probably more than offset any benefits that would result from the use of the stored water.

A well near Chilly, just above this reservoir site, passed through 6 feet of mud and clay and then penetrated 50 feet of quicksand. The log of this well does not indicate that bedrock will be found close to the surface, and there might be substantial leakage from the reservoir if a dam were constructed. It is therefore doubtful whether a reservoir at this place would be feasible.

It is possible that a drainage system might be installed in the swampy area that would be flooded by this proposed reservoir. The drainage channels could be provided with checks by which the ground-water level could be maintained each year until the later part of July, when the checks could be removed, thus allowing the grass to ripen and furnishing some drainage water for use farther downstream during August and September.

Pumping ground water.—The feasibility of recovering ground water by pumping is largely a matter of cost. The original cost of drilling wells and equipping them with pumping plants would probably amount to about $1,000 a second-foot of water developed, which at the prevailing rate of delivery would be about $20 an acre for the land supplied with the pumped water. If electric power were made available at the regular irrigation pumping rates of the large companies, the cost of electric current might be as low as $1 an acre-foot of water pumped in the shallow-water areas. In years of abundant run-off, when the stream flow is adequate to fill demands until early in July, the pumps would probably not be required to furnish more than 1 or 1.5 acre-feet per acre to the lands supplied from them. In very dry years, however, they would have to pump from 3 to 4 acre-feet per acre to supply irrigation requirements and unavoidable seepage losses. To take care of the interest on the investment in wells and machinery and the cost of maintenance and power, the average annual charge for water on lands supplied from wells would probably amount to $4 an acre under the most favorable conditions. This amount is much greater than the prevailing charge for maintenance on the gravity canal systems now existing, and the conditions as to kind of soil, type of farming, and price of products would all have to be favorable to result in success from pumping operations.

Areas of specified depths to water in the valley during the period of low-water levels in the fall of 1929 are shown in plate 31. The areas where pumping would prove most feasible are those where the depth is less than 10 feet to the water table—particularly the area along the river at and just below the Moore Dam, 3½ miles north of Moore; the area along the river just southeast of Leslie; the area 4 miles northwest of Leslie; and the area in the vicinity of Arco.

A very small amount of electric current is available from a plant on Lower Cedar Creek at Mackay. Arco is supplied with electric current by a line of the Utah Power & Light Co. extending from the Mud

Lake area. This line would probably have to be rebuilt, however, to provide sufficient capacity.

CONCLUSIONS

It is probable that 15,000 to 20,000 acre-feet of water could be recovered in each irrigation season by pumping from wells in the several areas of high ground-water levels between the Mackay Dam and Arco, and a similar amount might be saved by construction of the suggested bypass canals. This additional amount of water would to some extent relieve the water shortage in the valley and could all be used on the developed lands that now have an inadequate supply. Records of stream flow indicate that these auxiliary supplies would probably have to be fully used only in years of deficient run-off, though they would be needed to some extent late in the season of each year.

The estimated annual supply of 30,000 to 40,000 acre-feet available for recovery is only about one-third of the computed annual ground-water flow past the Moore Dam (p. 248), and moreover there are large contributions to the water table downstream from the dam resulting from canal and river losses and percolation from irrigated lands. It is evident that a large part of the underflow in the great depth of the valley fill must inevitably escape beneath the Snake River Plain.

VALLEYS BETWEEN BIG LOST RIVER VALLEY AND CAREY VALLEY

Several small streams drain the area southwest of Arco, and their surplus flow during flood periods, above that required for the irrigation of a few scattered ranches, sinks in the permeable lava at the edge of the Snake River Plain. No records are available of the flow of these streams, but from occasional observations their average annual contribution to the ground water of the Snake River Plain has been estimated as follows:

Estimated average annual contributions of ground water to the Snake River Plain by small creeks between Big Lost River and Carey Valley

	Acre-feet
Nichols Ditch from Dry Fork of Antelope Creek	600
Champagne Creek, sec. 25, T. 3 N., R. 24 E.[31]	1,000
Lava Creek, Martin, sec. 11, T. 2 N., R. 24 E.	1,000
Cottonwood Creek, sec. 32, T. 2 N., R. 24 E.	1,400
Lava Lake Creek, sec. 28, T. 1 N., R. 23 E.	1,000
	5,000

BIG WOOD RIVER AND LITTLE WOOD RIVER VALLEYS

The Big Wood River rises in the high mountain range whose crest forms the boundary between Custer and Blaine Counties. It flows in

[31] This and similar notes record the points where the streams reach the Snake River Plain.

a southeasterly direction about 40 miles to the vicinity of Bellevue, where it leaves the mountains, and for about 10 miles flows along the west margin of a broad alluvial fan of its own making. The fan is very symmetrical and has the form of a triangle with the apex at Bellevue. At its base are the Picabo Hills, which extend from the Magic Reservoir to the village of Picabo. (See pl. 4.) During the growth of the fan the river at one time found an outlet around the east end of the Picabo Hills along the line of the present Oregon Short Line Railroad. Later it established its present course and found an outlet on the west side of the Picabo Hills. The alluvial fan was probably constructed largely during the Pleistocene epoch, and subsequent erosion has entrenched the stream on the west side of the fan. Only a small structure near Bellevue would, however, be required to divert the river along its previous course on the east side of the fan. At present the river loses water as it crosses the upper part of the fan. A part of the underflow reappears in a group of springs at the base of the fan near the Picabo Hills and forms Silver Creek, which escapes through the ancestral valley of the Big Wood River and joins the Little Wood River at Tikura. (See pl. 4.) The courses of the Little Wood and Big Wood Rivers from the places where they enter the plain to the Snake River were established by lava flows erupted from local cones. Prior to the extrusion of the great floods of basalt, these streams probably continued in southeasterly courses, perhaps independently, to the prebasalt channel of the Snake River.

About 12 miles below Bellevue the Big Wood River enters the backwaters of the Magic Reservoir and is joined from the west by Camas Creek. Below the Magic Reservoir it flows in a southerly direction about 18 miles to a point north of Shoshone, whence it continues westward about 35 miles to its confluence with the Snake River.

The only large tributary of the Big Wood River below Bellevue is Camas Creek. This creek drains the Camas Prairie, which is underlain by alluvial fill in a structural depression comparable with that of the fan of the Big Wood River. On the south side the Camas Prairie is bordered by the Mount Bennett Hills. The contours of the water table shown on plate 19 and the areas of different depths to water shown on plate 18 are taken from Piper's report,[32] which contains records of wells in the area.

Investigations by S. H. Chapman [33] show the following relations of the Big Wood River to the ground water. Above Hailey the ground water in the valley fill is at a higher altitude than the water surface in the river, and the river has a substantial gain from ground-water inflow. During the low-water season of 1920 the average gain was 70 second-feet between the mouth of the North Fork and Hailey, a

[32] Piper, A. M., Ground water for irrigation on Camas Prairie, Camas and Elmore Counties, Idaho: Idaho Bur. Mines and Geology Pamph. 15, 1924.

[33] Chapman, S. H. (watermaster), unpublished report on canal deliveries from Big Wood River for 1920.

distance of about 18 miles. At Hailey the average annual flow is about 340,000 acre-feet. Between Hailey and a point 6 miles south of Bellevue, a distance of about 11 miles, the water level in the river is higher than the adjacent water table in the gravel fill, and the stream loses water. During the low-water season of 1920 the average loss in this section was 70 second-feet, and during high-water periods the loss is known to be much greater than this amount. In the fall of 1920 a bypass canal was constructed around the lower portion of this section of the river, thus saving 18 second-feet of water. Downstream from this section the water table is higher than the river level, and between a point 6 miles south of Bellevue and the Magic Dam the river showed an average gain during the low-water period in 1920 of 72 second-feet, a large portion of which came from spring-fed creeks, which rise in the alluvial valley floor and flow into the river. Below the Magic Dam the river has cut a narrow gorge through the lava flows, and the water table is at a considerable distance below the river bed. Large losses are sustained in this channel, and therefore, during recent years, the water has been carried in a bypass canal with substantial reduction in losses. The Magic Reservoir has a capacity of about 190,000 acre-feet. During many years the entire flow of the river is stored in this reservoir for irrigation, and only in years of high run-off does the river reach the Snake River.

Silver Creek has an annual ground-water inflow of about 100,000 acre-feet. This large volume of water is doubtless supplied in part by losses from the Big Wood River below Hailey but largely by losses from canals and irrigated lands in the valley between Hailey and the bypass canal below Bellevue. Plans have been considered for the construction of an infiltration ditch or tunnel that would divert the ground water into the Big Wood River during the winter for storage in the Magic Reservoir, but on account of the high cost of the proposed works and the problem relating to the water rights on Silver Creek, the project has not been undertaken.

A comparison of the flow of Silver Creek and of the spring-fed tributaries of the Big Wood River with the observed losses in the river above the reservoir and the probable losses from canals and irrigated lands leads to the conclusion that practically all the ground water reappears as spring flow, either into Silver Creek, or into the Big Wood River above the Magic Reservoir, and that there is no appreciable loss underground from the upper Big Wood River Valley. The explanation for this is found in the impermeable rock that underlies the alluvial fill above the reservoir. Farther downstream the river, like the other streams that enter the Snake River Plain, has appreciable losses through leakage into the lava rock.

The estimated contributions that the Big Wood and Little Wood Rivers make to the water supply of the Snake River Plain are given in the table on page 176. The yield of the drainage basin of the Big Wood River is assumed to be represented by the flow of the river below the Magic Dam and the flow of Silver Creek near Picabo, the ground-water outflow from the upper Big Wood Valley being forced to the surface as it passes these gaging stations. The yield of the drainage basin of the Little Wood River is similarly assumed to be represented by the flow of Fish Creek at the Fish Creek Reservoir and the flow of the Little Wood River near Carey. The approximate area under irrigation during the period below these gaging stations has been taken from the watermaster's reports to be 77,000 acres. For a part of this land the water supply is rather scanty. An average consumptive use of 1.7 acre-feet per acre, exclusive of precipitation, has been assumed for lands with full water rights, but a lower consumptive use has been assumed in dry years for lands with inferior rights, in accordance with the watermaster's records of water deliveries. The average contribution to the Snake River of 424,000 acre-feet, as shown in the table, includes both surface and ground water. Incomplete records of the flow of the Big Wood River above Malad Springs indicate an average annual surface flow into the Snake River during the period of about 70,000 acre-feet, leaving an average annual ground-water contribution of about 354,000 acre-feet.

Estimated contributions, in acre-feet, to Snake River by the Big Wood and Little Wood Rivers, years ending Sept. 30, 1920–27

Year	Fish Creek at dam	Little Wood River near Carey	Silver Creek near Picabo	Big Wood River below Magic Dam	Total supply	Estimated crop consumption	Contribution to Snake River
1920	11,800	[1] 72,000	[1] 79,000	118,000	280,800	75,000	205,800
1921	24,500	164,000	108,000	460,000	756,500	130,000	626,500
1922	22,100	157,000	118,000	467,000	764,100	130,000	634,100
1923	[1] 12,000	117,000	[1] 105,000	365,000	599,600	130,000	469,600
1924	[1] 9,500	52,000	[1] 88,000	123,000	272,500	70,000	202,500
1925	[1] 11,000	[1] 99,000	[1] 100,000	384,000	594,000	130,000	464,000
1926	[1] 12,000	60,000	[1] 93,000	188,000	353,000	90,000	263,000
1927	[1] 18,000	130,000	[1] 99,000	409,000	656,000	130,000	526,000
Average							424,000

[1] Partly estimated.

The effect of silt deposits in preventing water losses in lava regions is well illustrated by records on the Big Wood River. Prior to the winter of 1919–20 the river flowed continuously throughout the winter, but in that and succeeding winters the water was stored in the Magic Reservoir, leaving the river channel entirely dry during 6 months each year for a distance of 45 miles through the lava fields between the dam and the town of Gooding. The silt deposits in the interstices of the lava dried out during the winter and apparently were partly eroded away when the water was turned back during the following irrigation season. The increased loss in this 45-mile stretch of the channel starting in 1920 was astonishing. Thus the average loss was 72 second-feet in the irrigation seasons from 1917 to 1919 and 217 second-feet in the five subsequent seasons, whereas the average flow at the upper end of this stretch was practically the same in both periods.[31]

CLOVER CREEK VALLEY

From a few measurements of the flow near King Hill (pl. 4) by comparison with available records on similar streams to the west, the average annual discharge of Clover Creek into the Snake River has been estimated at 12,000 acre-feet, all of which is surface water. This stream, throughout most of its course, flows in a channel cut in the Hagerman lake beds or intercalated basalt. However, near White Arrow Hot Spring a geologically recent lava flow covers the valley floor. Part of this lava issued from the crater occupied by the lake described on page 262. Some of the land is supplied with water from the creek. Ground water would have to be obtained from the Hagerman lake beds or the intercalated basalts, which are not promising for irrigation supplies.

[31] Unpublished reports of S. H. Chapman, watermaster for Big Wood River, Shoshone, Idaho.

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