Ground Water for Irrigation in the Snake River Basin in Idaho

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1654

Prepared in cooperation with the U.S. Bureau of Reclamation

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By M. J. MUNDORFF, E. G. CROSTHWAITE, *and* CHABOT KILBURN

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1964

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

The U.S. Geological Survey Library has cataloged this publication as:

Mundorff, Maurice John, 1910–

Ground water for irrigation in the Snake River basin in Idaho, by M. J. Mundorff, E. G. Crosthwait, and Chabot Kilburn. Washington, U.S. Govt. Print. Off., 1964.

vii, 223 p. maps, diagrs., tables. and portfolio (maps (part col.) diagrs. (part col.)) 24 cm. (U.S. Geological Survey. Water-supply paper 1654)

Prepared in cooperation with the U.S. Bureau of Reclamation.
Bibliography: p. 213–216.

(Continued on next card)

Mundorff, Maurice John, 1910–

Ground water for irrigation in the Snake River basin in Idaho. 1964. (Card 2)

1. Water, Underground—Idaho—Snake River Basin. 2. Water-supply—Idaho—Snake River basin. 3. Irrigation—Idaho—Snake River basin. I. Crosthwaite, Emerson Gerald, 1918– joint author. II. Kilburn, Chabot, 1926– joint author. III. U.S. Bureau of Reclamation. IV. Title: Snake River basin in Idaho. (Series)

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402

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GROUND WATER FOR IRRIGATION IN THE SNAKE RIVER BASIN IN IDAHO

By M. J. Mundorff, E. G. Crosthwaite, and Chabot Kilburn

ABSTRACT

The Snake River basin, in southern Idaho, upstream from the mouth of the Powder River in Oregon, includes more than 50 percent of the land area and 65 percent of the total population of the State. More than 2.5 million acres of land is irrigated; irrigation agriculture and industry allied with agriculture are the basis of the economy of the basin.

Most of the easily developed sources of surface water are fully utilized, and few storage sites remain where water could be made available to irrigable lands under present economic conditions. Because surface-water supplies have become more difficult to obtain, use of ground water has increased greatly. At the present time (1959), about 600,000 acres of land is irrigated with ground water.

Ground-water development has been concentrated in areas where large amounts of water are available beneath or adjacent to tracts of arable land and where the depth to water is not excessive under the current economy. Under these criteria, many of the most favorable areas already have been developed; however, tremendous volumes of water are still available for development. In some places, water occurs at depths considered near or beyond the limit for economic recovery, whereas in some other places, water is reasonably close to the surface but no arable land is available in the vicinity. In other parts of the basin large tracts of arable land are without available water supply. Thus the chief tasks in development of the ground-water resources include not only locating and evaluating ground-water supplies but also the planning necessary to bring the water to the land.

Irrigation began in the 1860's; at the present time more than 10 million acre-feet of surface water, some of which is recirculated water, is diverted annually for irrigation of more than 2.5 million acres. Diversion of this large quantity of water has had a marked effect on the ground-water regimen. In some areas, the water table has risen more than 100 feet and the discharge of some springs has more than doubled. Large-scale development of ground water began after World War II, and it is estimated that in 1959 about 1,500,000 acre-feet of ground water was pumped for irrigation of the 600,000 acres irrigated wholly with ground water in addition to a substantial amount of ground water pumped to supplement surface-water supplies. Ground water is also the principal source of supply for municipal, industrial, and domestic use.

The water regimen in the Snake River basin is greatly influenced by the geology. The rocks forming the mountains are largely consolidated rocks of low permeability; however, a fairly deep and porous subsoil has formed on them by decay and disintegration of the parent rock. Broad intermontane valleys and basins are partly filled with alluvial sand and gravel. The subsoil and alluvial materials are utilized very little as a source of water supply but are important

as seasonal ground-water reservoirs because they store water during periods of high rainfall and snowmelt. Discharge from these reservoirs maintains streamflow during periods of no surface runoff. Because these aquifers are fairly thin, they drain rapidly and are considerably depleted at the end of each dry cycle.

The plain and plateau areas and tributary valleys, on the other hand, are underlain chiefly by rocks of high permeability and porosity. These rocks, mostly basaltic lava flows and alluvial materials, constitute a reservoir which fluctuates only slightly from season to season. Large amounts of water are withdrawn from them for irrigation and other uses, and discharge from the Snake Plain aquifer is an important part of the total flow of the Snake River downstream from Hagerman Valley.

The ultimate source of ground water in the basin is precipitation on the basin. In the mountainous areas, aquifers mostly are recharged directly by precipitation. On the other hand, in the plains, lowlands, and valleys which contain the principal aquifers, far more water is consumed than falls on the area and direct precipitation is a minor part of the recharge. Most recharge to these aquifers is by percolation from streams, canals, and irrigated lands.

For convenience in describing the ground water in various places, the Snake River basin was divided into ground-water subareas, 19 of which are described.

The Boise-Payette subarea includes most of the western end of the Snake River Plain in Idaho. About 350,000 acres is irrigated with water diverted from the Boise River, and 110,000 acres is irrigated with water diverted from the Payette River below Black Canyon Dam. Irrigation has raised the water table in the developed areas so that the alluvium and terrace gravels are the chief source of unconfined ground water. Other important aquifers include the Snake River basalt and sand strata in the Idaho formation. Water in the Idaho formation generally is under artesian pressure, and in some areas flows above the land surface. Wells in the alluvium and in the basalt yield as much as 3,000 gpm (gallons per minute). Some wells in the Idaho formation yield 1,000 to 2,000 gpm. In much of the area, the water table is near the land surface and many wells are less than 100 feet deep. Wells in the Idaho formation range from a few hundred to more than 1,000 feet in depth. It is estimated that about 500,000 acre-feet of ground water is potentially available for use each year and that 200,000 to 250,000 acre-feet of water could be withdrawn each year with a resultant benefit to waterlogged land.

The Mountain Home plateau includes the rolling upland surrounding Mountain Home and extends northwestward nearly to Boise. It is underlain chiefly by the Idaho formation and Snake River basalt. There is little surface-water irrigation on the plateau and ground-water use is not large. Recharge to acquifers in the basalt and the Idaho formation is from precipitation on the area and underflow from the mountains along the north flank of the plateau. In the irrigated area around Mountain Home, the water table is near the surface but elsewhere it generally is several hundred feet below the surface. About 400,000 acres of arable land on the plateau are suitable for irrigation. Although the presently available supply of ground water probably is not large, irrigation of substantial acreages of land with surface water diverted to the area would change the ground-water regimen. The water table would rise considerably, and lithologic units now dry would become saturated. Some of these would be excellent aquifers. It is estimated that 30 to 40 percent of the water diverted to the area would become ground-water recharge, some of which would be available to supplement the surface-water supplies.

The Snake River valley includes the narrow lowland area along the Snake River from Homedale to King Hill and the lower drainage basins of tributary streams within the reach. The alluvium along the principal streams contains unconfined ground water and yields small to moderate supplies to wells, especially along the Snake and Bruneau Rivers. The Idaho formation, intercalated and underlying basalt, and silicic volcanic rocks yield small to large supplies of warm artesian water to wells. Yields of wells are as much as several thousand gallons per minute; many of the larger producing wells are more than 1,000 feet deep. Recharge to the artesian aquifers is largely from precipitation on the upland area south of the valley. Natural discharge is into the Snake and Bruneau Rivers through springs and seeps. Much of the artesian water is marginal in quality for irrigation use because of high percent sodium and high sodium-adsorption-ratio. Some of the water is unsuitable for domestic use because of excessive fluoride content.

The Owyhee upland includes the Owyhee Mountains and adjacent plateau area in Owyhee County. The area is thinly populated, and the land is used chiefly for grazing. The chief aquifers probably are the silicic volcanic rocks that crop out over much of the area; however, few wells have been drilled and little is known regarding their characteristics. Recharge is from precipitation on the area. The depth to water probably is great over much of the area. At a few places the water table is shallow and some springs are utilized for watering stock.

The Sailor Creek subarea lies east of the Owyhee upland, between the Bruneau River and Salmon Falls Creek. All streams are intermittent or ephemeral. The area is thinly populated, and there are less than a dozen wells in an area of more than 1,000 square miles. Most of these yield water for stock and domestic use from sand strata in the Idaho formation. A few wells yield water from silicic volcanic rocks. The water table is from a few to more than 500 feet below the surface.

The Twin Falls South Side Project subarea includes a strip about 40 miles long and 12 miles wide adjacent to the south side of the Snake River east of Salmon Falls Creek. About 200,000 acres is irrigated in the district. Irrigation began in 1905; because the underlying basalt and interbedded sedimentary deposits were not very permeable, the water table rose rapidly. It is estimated that originally the depth to water averaged about 250 feet. Waterlogged areas appeared by 1912, and many drains, tunnels, and drainage wells were constructed to alleviate seeped conditions. Little ground water is used for irrigation, but many wells are used on farms and to supply towns and industries.

The Salmon Falls subarea lies south of the Twin Falls South Side Project area and east of Salmon Falls Creek. About 30,000 acres of land receive a generally inadequate supply from the Salmon River Canal Company system. Water is diverted from a reservoir on Salmon Falls Creek. Ground water supplements surface-water supplies to a small degree. About 80,000 acres of land is suitable for irrigation. Silicic volcanic rocks underlie the entire area and are overlain by sedimentary rocks and basalt. Each of these units is an aquifer at some places, but basalt is the most important aquifer. In general, the basalt in this area is much less permeable than the basalt north of the Snake River—and some wells yield only small to moderate quantities of water. Several wells have been drilled in ore permeable basalt and yield as much as 2,700 gpm. Recharge to the aquifers is estimated to be about 100,000 acre-feet a year.

The Dry Creek district, part of the South Side subarea between the Snake River and the Rock Creek Hills, contains about 40,000 acres of irrigable land.

The northern part is supplied with water from the Snake River. Most of the remainder of the area receives water from Dry and Rock Creeks and ground water pumped from alluvium, Snake River basalt, and silicic volcanic rocks. The silicic rocks yield small to moderate amounts of artesian water to wells in the southern part. Wells in alluvium, which blankets the silicic volcanic rocks and basalt, yield small to moderate amounts of unconfined water in the central part. The basalt yields small to large amounts of unconfined water in the northern part. The depth to water ranges from 35 to 40 feet near Murtaugh to more than 450 feet on the slopes of volcanic buttes. The artesian aquifer is recharged by underflow of precipitation on the Rock Creek Hills south of the area. The basalt and alluvial aquifers are recharged by infiltration of surface water used for irrigation, leakage from the underlying artesian aquifer, and precipitation. The artesian aquifer is extensively developed, and well interference and declining water levels are common. The unconfined water, especially in the basalt, could be more fully developed, but much of the area underlain by basalt has an adequate surface-water supply.

The lower Goose Creek valley in the South Side subarea includes a roughly triangular area south of the Snake River between the Rock Creek Hills and the Albion Range. The valley floor is underlain by silicic volcanic rocks, Snake River basalt, and alluvium. In the southern part, all three formations yield small to large quantities of water to irrigation wells. In the northern part, basalt is the principal aquifer and yields large quantities of water to wells; the silicic volcanic rocks there are far below the land surface and have been little explored. The alluvium in the extreme northern part contains abundant water at shallow depth, but it has not been extensively develop because of an adequate surface-water supply. Depth to water ranges from a few to more than 450 feet. Ground-water withdrawals for irrigation are estimated to have been from 90,000 to 100,000 acre-feet in 1958. Water from Goose Creek is stored in the Goose Creek Reservoir and used on some of the land in the southern part. In the northern part, surface water from the Snake River is used in the Burley Irrigation District. The surface-water developments help replenish the ground-water reservoir. Underflow from precipitation on the adjacent mountains and precipitation on the area are additional sources of recharge.

The Raft River basin in the central part of the South Side subarea is the largest basin tributary to the Snake River from the south side. The Raft River rises in Utah and flows northward in a broad alluvial valley to the Snake River. In Idaho, the valley is bounded by the Malta Range on the west and the Black Pine and Sublett Ranges on the east. The mountains are composed of silicic volcanic, consolidated sedimentary, and intrusive igneous rocks. The alluvium in the lowland is underlain by fine-grained sediments which probably are lake beds. Snake River basalt blankets the northern part of the valley. Nearly all the surface water is used for irrigation, and large supplies of ground water have been developed. Nevertheless, much irrigable land is used only for grazing. About 20,000 acres is irrigated with surface water, and more than 25,000 acres is supplied with ground water. The depth to water ranges from a few feet in the alluvium near the Raft River to more than 250 feet at some places in the basalt at the north end of the basin. Yields of the more than 250 irrigation wells in the valley range from 100 to 3,125 gpm, and wells having capacities as much as 900 gpm are widely distributed. Specific capacities range from 5 to 325 gpm. Water-level records indicate that ground-water withdrawals have not greatly lowered the water table.

The Rockland Valley-Michaud Flats district is in the eastern part of the South Side subarea and includes the Rockland Valley and the lowlands between

Rock Creek and the Portneuf River south of American Falls Reservoir. It lies east of the Sublett Range and north and west of the Deep Creek Mountains. The Rockland Valley has a gently to steeply sloping terrain underlain by silicic volcanic rocks and alluvium. The Michaud Flats is a gently rolling plain underlain by Snake River basalt, lake beds, and alluvium. Little is known about the hydrology of Rockland Valley, but rough estimates indicate that total annual surface- and ground-water outflow from the valley is about 50,000 acre-feet. Of this amount, about 13,000 acre-feet is discharged by Rock Creek, the master stream of the valley. In the Michaud Flats district the depth to water ranges from 10 to 200 feet and averages about 60 feet. Confined and artesian aquifers in sedimentary, pyroclastic, and volcanic rocks yield several hundred to 4,000 gpm and average about 1,000 gpm. About 6,000 acres is estimated to be irrigated with ground water.

The Eastern Highland subarea includes the foothills, mountains, and intervening valleys between Pocatello and Rexburg. The area is drained by the Portneuf, Blackfoot, and Snake Rivers and Willow Creek. The foothills and mountains are composed of consolidated sedimentary rocks with an apron of silicic volcanic rocks on the slopes facing the Snake River Plain. Snake River basalt crops out over a large area in the valleys and intermontane basins. Alluvium in the lower Portneuf River, Marsh Creek, and upper Snake River valleys yields small to large quantities of water to wells. Basalt in the upper Portneuf River valley yields large quantities of water. Small to moderate yields are obtained from the silicic volcanic rocks. The ground-water resources have not been extensively developed, although at Pocatello large quantities are withdrawn for municipal and other uses. Recharge to aquifers from precipitation on the northwest-facing slopes adjacent to the Snake River Plain is estimated to be 40,000 to 75,000 acre-feet yearly.

Camas Prairie extends westward from the northwest margin of the Snake River Plain and is the westernmost of the major drainage basins tributary to the plain along its northern margin. The drainage basin, which is about 40 miles along and 24 miles wide, is a structural depression partly filled with stream and lake deposits. Snake River basalt crops out in the eastern part of the basin. Shallow alluvial deposits contain water under water-table conditions. Deeper sand strata also contain water, and throughout a considerable area in the central part of the basin the water in these strata is confined under sufficient pressure to flow from wells. Yields of the larger production wells are as much as 1,200 gpm. The Snake River basalt yields 1,000 to 1,300 gpm to a few wells in the south-central and southeastern parts of the basin. Ground-water underflow from the prairie is estimated to be about 20,000 acre-feet per year.

Big Wood River drains an area on the south side of the mountains of central Idaho. The mountainous parts of the drainage basin are underlain by consolidated sedimentary and intrusive igeneous rocks of low permeability. Downstream, in the vicinity of Ketchum and Hailey, the river valley is about ½ to 1 mile wide and is partly filled with fluvioglacial outwash. South of Bellevue, the valley broadens into a roughly triangular alluviated basin terminated on the south by the Picabo Hills. Both surface- and ground-water outflow from the valley is through gaps on the western flank (Big Wood River valley) and the eastern flank (Silver Creek valley) of these hills. The drainage area of the basin above Magic Reservoir is about 825 square miles, and average surface-water inflow into the lowland south of Hailey is estimated to be about 380,000 acre-feet per year. Ground water is obtained chiefly from sand and gravel strata in the alluvium at depths of 10 to 70 feet. In the southern part of the basin, water under artesian pressure is obtained at depths of 125 to 150 feet. Yields of the better wells range from about 1,000 to more than 3,000 gpm. Ground-water outflow from the basin is estimated to be about 50,000 acre-feet per year. Probably 25 to 50 percent of this could be intercepted.

Little Wood River drains an area immediately east of the Big Wood River basin. Most of the basin is underlain by silicic volcanic rocks, but some of the higher ridges consist of limestone, quartzite, shale, and similar rocks. The larger valleys are partly filled with alluvium and basalt. In its lower reaches, Little Wood River is above the water table and loses water by percolation from the streambed. Ground water moves downvalley to join the main ground-water body beneath the Snake River Plain. Wells in the vicinity of Carey obtain water from sand and gravel, generally at depths less than 150 feet. A few wells east of Carey obtain water from basalt. The altitude of the water table near Carey is about 4,750 feet, but a few miles southeast of Carey it is at an altitude of 4,050 to 4,100 feet, a drop of 650 to 700 feet in a distance of a few miles. The discharge of the Little Wood River at the gaging station northwest of Carey averaged about 97,000 acre-feet per year through 1956. Total water yield of the entire basin is estimated to be about 150,000 acre-feet per year.

Fish Creek drains a small area underlain by silicic volcanic and consolidated sedimentary rocks on the south slope of the Pioneer Mountains. Water yield from the Fish Creek basin is estimated to be about 15,000 acre-feet per year, of which roughly 12,000 acre-feet is surface runoff and 3,000 acre-feet is ground-water outflow.

The Big Lost River basin is the largest basin tributary to the Snake River Plain from which surface discharge never reaches the Snake River. The Big Lost River drains an area of about 1,500 square miles underlain by granite, limestone, quartzite, shale, and silicic volcanic rocks—all are materials of low permeability. The valley of the Big Lost River is about 60 miles long and through much of its length ranges from 3 to 6 miles wide. The main valley and some of the larger tributary valleys are partly filled with alluvial sand, gravel, and clay. These materials are moderately porous and permeable. Above Mackay Reservoir on the Big Lost River, they serve as a large underground reservoir and stabilize inflow to the surface reservoir. Downstream from Mackay Dam, the water table generally is below stream level, and the alluvium serves chiefly as a conduit for transmitting water underground from the basin into the Snake Plain aquifer. Upvalley fram Arco, which is near the mouth of the valley, the water table generally is not more than a few tens of feet below the surface. Wells are as much as 250 feet deep and yield as much as 2,700 gpm from the alluvium. Larger yields could be obtained. Because of a progressively increasing amount of underflow downstream, the surface flow at the gaging station at Howell Ranch, about 60 miles upstream from Arco, equals or exceeds that at downstream stations, even though a large amount of water enters the valley below Howell Ranch. The discharge past this station averaged 218,000 acre-feet per year through 1956. The total water yield of the basin at the mouth, including both surface and underground flow, is estimated to be about 330,000 acre-feet per year.

The Little Lost River basin is similar to the basin of the Big Lost River. Much of the discharge of tributary valleys reaches the main valley as underground flow, and the alluvium in the valley serves as an underground reservoir and stabilizes the surface discharge of Little Lost River. Above a partial barrier formed by a constriction in the consolidated rock of the valley walls about 11 miles upvalley from Howe, the water table is near or at the surface along the axis of the valley. Undoubtedly the underflow in the alluvium extending through this partial barrier is considerable. Downstream, the water table is below river level, and additional water is added to the aquifer by losses from the Little Lost River and other streams. Total water yield of the basin is estimated to be about 150,000 acre-feet per year, of which perhaps 50,000 to 60,000 acre-feet might be consumptively used within the basin. About 60 wells are used for irrigation in the basin. Most are less than 150 feet deep and yield between 1,000 and 2,500 gpm with small to moderate drawdowns.

Birch Creek basin is northeast of the basins of the Big and Little Lost Rivers, and parallels those basins. The broad alluvial fill in the central valley serves both as an underground reservoir and ground-water conduit. Birch Creek is largely spring fed and the flow is remarkably uniform throughout the year and from year to year. The average measured discharge at the gaging station about midway between the head and mouth of the basin is about 80 cfs (cubic feet per second), or 58,000 acre-feet per year. The total water yield of the basin, both surface and ground water, is estimated to be about 80,000 acre-feet per year.

The southern part of the Mud Lake basin consists of a broad flat basin in the north end of the Snake River Plain: it contains several hundred square miles underlain by river alluvium and lake beds. Snake River basalt extends north and northeast to the foot of the mountains. Several streams rising in the Beaverhead and Centennial Mountains to the northwest, north, and northeast converge, spokelike, on the Mud Lake basin. None of the drainage channels reach the Snake River. The more important streams are Crooked, Warm Springs, Deep, Medicine Lodge, Indian, Beaver, and Camas Creeks. All except Camas Creek and its chief tributary, Beaver Creek, lose their entire discharge within a short distance after reaching the edge of the Snake River Plain. These two discharge some water into Mud Lake, about 32 miles south of the base of the mountains. Only three of the streams have been gaged, and, because of underflow past the stations and ungaged inflow below the stations, these records do not give the water yield of the basins. In addition to surface and underground inflow from the creeks, mass underflow probably is considerable into the Mud Lake area through moderately permeable conglomerate, sandstone, and volcanic rocks which crop out in the surrounding mountains. Snake River basalt is the chief aquifer; northeast of Mud Lake it is at or near the surface. To the south and west, it underlies lake beds and stream alluvium. A geologic barrier extending west and northwest through Mud Lake holds the water table near the surface northeast of the barrier at an altitude of about 4,800. To the southwest the water table drops several hundred feet within a few miles. Several hundred drilled wells yield as much as 10,000 gpm each for irrigation. The total available water supply in the Mud Lake area (chiefly ground water but including some surface water) is estimated to be about 500,000 acre-feet. Depletion due to irrigation is estimated to be about 90,000 acre-feet each year, and natural losses by evaporation and use by waste vegetation is estimated to be about 80,000 acre-feet a year: about 300,000 acre-feet leaves the area as underflow to the Snake River Plain.

The Teton basin trends northward in Idaho near the Wyoming State line and is tributary to the Snake River Plain at the eastern end of the plain. The valley of Teton River is about 20 miles long and 5 to 10 miles wide. It is underlain by several hundred feet of alluvial sand and gravel which constitute the chief aquifer. Recharge is from direct precipitation and from water lost by streams flowing into the valley from the surrounding mountains. The water table is several hundred feet below the surface beneath the higher alluvial slopes near the foot of the mountain ranges but is near or at the surface near the center of the valley, where a strip of land adjacent to Teton River is waterlogged. Ground water for irrigation can be obtained from wells drilled into the alluvium. Properly constructed wells probably would yield 1,500 to 2,000 gpm with small drawdowns. Pumpage of large amounts of water would reduce total basin outflow but would also lower the water table in marshy areas and might reduce the amount of water lost to waste vegetation. The amount of water leaving the basin as underflow is not known. Through 1956, the discharge of the Teton River near Tetonia averaged 280,900 acre-feet a year.

The Snake River Plain east of Bliss extends east and northeast from Bliss and the Hagerman Valley for about 200 miles approximately to Ashton. The plain is underlain chiefly by a thick sequence of numerous lava flows of the Snake River basalt, but some lakes and stream deposits are interlayered between flows. On more than half the plain, precipitation is less than 12 inches per year, although it is nearly 30 inches on the high northeastern end. Development of the approximately 1¼ million acres of land presently irrigated on the plain thus is dependent largely on water brought into the area by streams and by underground flow. More than 7 million acre-feet of surface water is diverted, and about 800,000 acre-feet of ground water is pumped for irrigation of farm lands on the plain.

The series of basalt flows and intercalated pyroclastic and sedimentary materials that underlie the Snake River Plain east of Bliss is defined as the Snake Plain aquifer. Although an individual flow may not transmit much water and some of the interbeds are not very permeable, the Snake Plain aquifer is one of the world's outstanding water-bearing formations. A large number of pumping tests and many specific-capacity data indicate that the coefficient of transmissibility of the upper part of the aquifer generally ranges from 1 to 10 mgd (million gallons per day) per foot. As most of the wells only penetrate a part of the aquifer, the coefficient of transmissibility of the entire aquifer is greater. Data from pumping tests and laboratory studies indicate that the average coefficient of storage probably is at least 5 percent and may approach 10 percent.

Recharge to the Snake Plain aquifer is from (a) precipitation directly upon the Plain, (b) percolation of irrigation water, (c) seepage from streams entering or crossing the plain, and (d) underflow from tributary basins. The water table beneath the Snake River Plain is in dynamic balance between recharge and discharge. To the present time (1959), the greatest changes in the ground-water regimen have been those caused by diversion of surface water to various irrigated tracts on the plain. These diversions have increased underflow in the aquifer by about 60 percent. This increased underflow has been accompanied by a water-table rise, estimated, on the basis of a few early reported water levels, to be about 60 or 70 feet in the western part of the plain between Minidoka and the Hagerman Valley. This rise in the water table suggests that if an amount of water equal to the increase in underflow, or about 1.8 million acre-feet per year, were withdrawn from the aquifier by wells, the water table would decline about 60 to 70 feet.

Seasonal changes in water levels are correlated with seasonal changes in recharge, either natural or man-made, and produce an annual cycle. Because several wet or dry years may occur in succession, other cycles cover periods of several to many years. Seasonal cyclic changes in water levels correlate with application of irrigation-water diversions in several areas. The fluctuations at the other places correlate with discharge of streams that terminate at the margin of the plain.

The Snake Plain aquifer discharges into the Snake River between Milner and King Hill. By determining the gain in discharge of the Snake River between gaging stations at those places and subtracting all other sources of inflow, the discharge of the Snake Plain aquifer is estimated to have been about 6,500 cfs, about 4.7 million acre-feet a year, during the past decade. Discharges of many springs in the reach have been measured occasionally or periodically since about 1902. Total measured and estimated discharge from the Snake Plain aquifer by springs was about 3,850 cfs in 1902 and 5,900 cfs in 1956. The 9 percent difference between the observed discharge of 5,900 cfs and the calculated discharge of about 6,500 cfs probably is due to discharge from seeps and springs which cannot be seen or measured. The discharge before any development or other man-made change is estimated at 4,000 cfs, or 2.9 million acre-feet a year.

Recharge from direct precipitation on the Snake River Plain was estimated to be about 500,000 acre-feet a year. About 60 percent of this amount probably is concentrated in about 15 percent of the area that is much higher than the rest and receives correspondingly greater precipitation. Recharge by underflow and by streambed percolation from basins along the north flank of the plain totals about 1 million acre-feet a year. Average annual recharge from underflow, stream losses, and irrigation in other parts of the plain was estimated as follows: Upper Snake River, above Firth, 2.4 million acre-feet; Firth to Blackfoot, 600,000 acre-feet; Blackfoot to Neeley, —1.5 million acre-feet (discharge from the aquifer into American Falls Reservoir and the Snake River in this reach); Neeley to Milner, 500,000 acre-feet; Milner to Bliss, 1.2 million acre-feet.

Hydrologic boundaries of the Snake Plain aquifier are of two types: positive (source, or recharge) and negative (barrier). The chief positive boundaries are the discharge areas in Hagerman Valley and American Falls Reservoir. The Snake River and adjacent irrigated lands upstream from Idaho Falls may form an additional positive boundary or at least a partial boundry. The chief negative boundaries are the margins of the plain.

Discharge and recharge data, the water-table map, and aquifer boundaries were used in constructing a flow net. Each flow line on this map represents an underflow of 200 cfs. The flow net and the water-table map were used to construct a map showing areal distribution of the coefficient of transmissibility of the aquifer. The coefficient ranged from less than 1 million to about 60 million gpd per foot.

The quantitative data derived in the report were used in computing probable effects of withdrawing large quantities of ground water from five places on the Snake River Plain. In the Wendell area, computed theoretical drawdowns along the line of wells would range from 6 to 10 feet at the end of the first season and from 7 to 11 feet at the end of the 50 pumping seasons. In the Shoshone-Dietrich and Eden areas, drawdowns would range from 7 to 11 feet at the end of the first season and from 10 to more than 13 feet at the end of 50 seasons. In the Idaho Falls area, drawdowns would range from 3½ to 4½ feet at the end of the first season and from 7 to 8 feet at the end of 50 seasons. In the Roberts-Plano area, the drawdowns would range from 3½ to 4½ feet at the end of the first season and from 5 to 6 feet at the end of 50 seasons.

The drawdowns given above are drawdowns in the aquifer immediately adjacent to the wells. Drawdowns in the wells would be greater by the amount of well loss, which generally averages about 1 foot.

The Snake Plain aquifer provides an excellent opportunity for artificial recharging operations. At many places the formation accepts recharge water readily; the high coefficient of transmissibility allows the recharge water to

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spread widely; a large storage space is available. However, water in storage in the aquifer is a transient resource; when the water table is raised, the gradient toward the discharge area is increased and the natural discharge eventually will be increased. Thus, some recharge water almost inevitably will escape from the area where it is stored, and the percentage lost is in part related to the length of time between recharging and withdrawal. The high coefficient of transmissibility of the Snake Plain aquifer results in a fairly short time between recharge and increase in the natural discharge and is a factor in the length of time that water can be effectively stored.

Chief sources of water for recharging the Snake Plain aquifer are the Snake River and Henrys Fork. With present utilization of surface water, 700,000 acre-feet or more of water might be available in about half the years. Little or no water would be available in most of the other years. On the basis of past records, there would be periods of 8 to 10 years when no water would be available for recharging and periods of about equal length when a large amount would be available each year.

Several areas on the plain appear to be particularly favorable for recharging. One area is between the Egin Bench and Roberts. A second is southwest of Idaho Falls, and a third is north and northwest of American Falls Reservoir. Detailed studies and analysis are needed to evaluate the hydrologic effects and possible benefits from recharging in these and other potential recharge areas.

INTRODUCTION

The Snake River basin in southern Idaho, upstream from the mouth of the Powder River in Oregon (fig. 1), includes more than 50 percent of the land area and 65 percent of the total population of the State. The economy is based almost wholly on agriculture and related industries. More than 2.5 million acres of land is irrigated.

Most of the easily developed sources of surface water are fully utilized, and few storage sites remain where water could be made available to irrigable lands under present economic standards. As surface-water supplies have become more difficult to obtain, use of ground water has increased greatly. The great expansion in ground-water use in the State is reflected in the increase in acreage included in well filings with the Idaho Department of Reclamation (fig. 2). The total acreage irrigated with ground water is not known because some of the land included in the filings has not yet been developed. On the other hand, much land is irrigated from wells for which no filings have been made because State law does not penalize failure to file. At the present time (1959), probably 600,000 acres of land is irrigated with ground water in the Snake River basin of southern Idaho.

Ground-water development has been concentrated in areas where large amounts of water are available beneath or adjacent to tracts of arable land and where the depth to water is not excessive under the current economy. Although many of the most favorable areas already have been developed, a tremendous volume of water still is

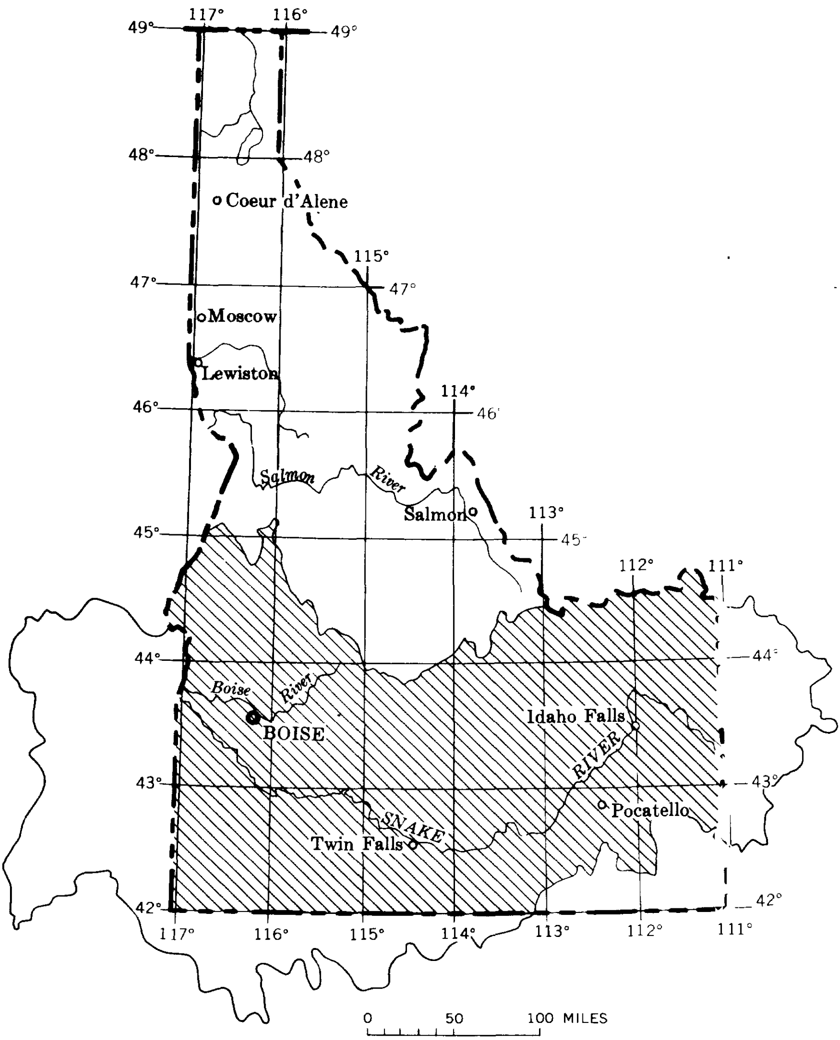

FIGURE 1.—Map of Idaho showing area described in this report.

available for development. In some areas the water occurs at depths presently considered close to or beyond the limit for economic recovery; in other places the water is reasonably close to the surface, but no arable land is available in the vicinity; in still other places large tracts of arable land are without an available water supply. Thus the chief tasks in development of the ground-water resources include not only locating and evaluating ground-water supplies but also the planning necessary to bring the water to the land.

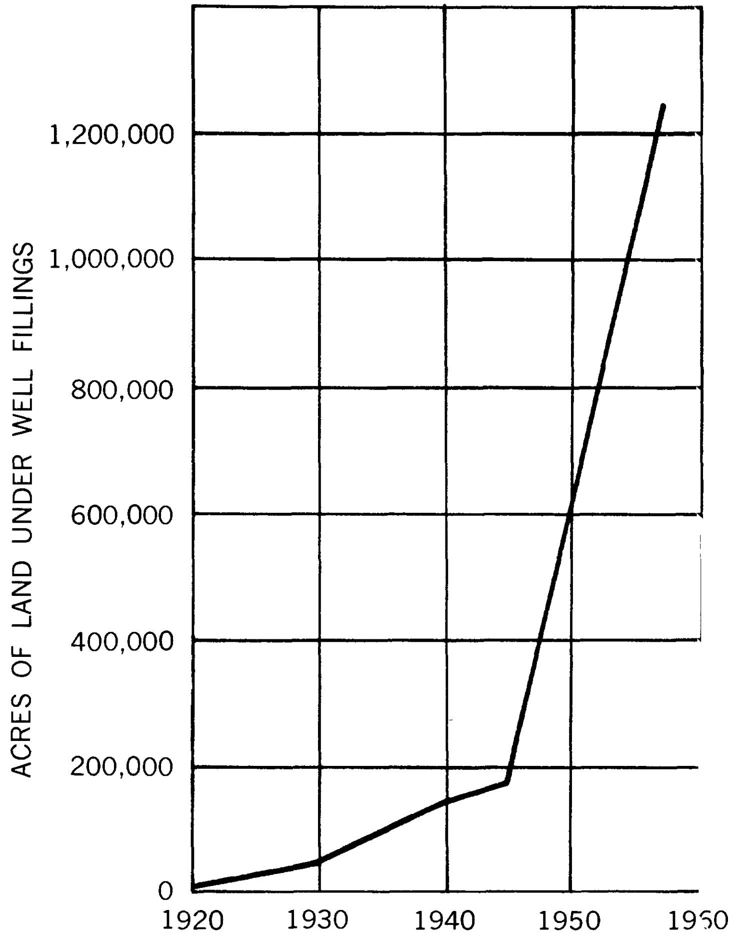

FIGURE 2.—Acreage of land under well filings with the Idaho Department of Reclamation, 1920–57. Adapted from Idaho Dept. Reclamation (1959).

PURPOSE AND SCOPE OF INVESTIGATION

The investigation was undertaken in cooperation with the U.S. Bureau of Reclamation. The Bureau, which is appraising and making plans for the development of the water resources of the entire Snake River basin, requested the Survey to supply the needed information on the ground-water resources of the Idaho part of the basin. The area includes the Snake River basin in Idaho, chiefly upstream from Weiser.

The objectives of this investigation were to estimate the quantity of ground water available in various parts of the basin, the depth to water, the quantity of water that could be withdrawn from individual wells, the quality of the water, and the effects of pumping large quantities of water.

The authors were assisted in the field by W. C. Walton, Harold Meisler, K. H. Fowler, H. G. Sisco, T. E. Parker, and R. T. Cowan of the Geological Survey. Fieldwork began in August 1956 and was virtually completed by November 1958. Because it was impracticable, in the time allowed, to make a detailed study of the entire Snake River basin in Idaho, fieldwork was concentrated in those areas where available data were inadequate and where ground-water supplies were believed to be of greatest potential importance. Data from published and open-file reports and from the files of the Geological Survey were analyzed and evaluated.

Fieldwork included collection of data on wells and springs, collection of water samples from wells and springs, measurement of well and spring discharges and of water levels in wells, and the study of geohydrologic features related to ground-water supply.

Several sites were selected where it was believed that adequate ground water would be available for irrigation at reasonable depths. The Bureau of Reclamation contracted the drilling of a well for use in making an aquifer test at each of 10 sites, and observation wells were drilled near five of these wells for use during the tests. In addition, four observation wells were drilled to obtain information on the depth to and slope of the water table and the nature of the aquifer at the sites drilled. Aquifer characteristics, geohydrologic boundaries, and well performance were determined from data from 10 aquifer tests.

Recording gages were installed on several wells in addition to the many being maintained as a part of other ground-water projects.

All the data thus obtained were used in evaluating the ground-water supply. Streamflow and climatological data also were used in evaluating basin yields, recharge, discharge, and underflow.

PREVIOUS INVESTIGATIONS

As early as 1871 the Hayden Survey made geologic observations in eastern Idaho; the results of the survey were published in the Fifth Annual Report of the U.S. Geological and Geographical Survey in 1872. Since then many geologists have studied the geology and mineral resources of the Snake River basin. The first observations on ground water (other than incidental mention of wells and springs) were made by Lindgren (1898), Russell (1902, 1903), and Lindgren and Drake (1904a, b) in southwestern and south central Idaho and southeastern Oregon. In the 1920's, Piper (1923, 1924, 1925), Mansfield (1920, 1927, 1929), Stearns and Bryan (1925), Stearns, Crandall, and Steward (1936, 1938), and Stearns, Bryan, and Crandall

(1939) studied the occurrence of ground water at several localities in eastern, southeastern, and southern Idaho. Since 1946 the Geological Survey has had a continuing ground-water program in Idaho in cooperation with the State; most of the investigations have been in the Snake River basin. During the last decade, the Geological Survey has cooperated with the Bureau of Reclamation, U.S. Atomic Energy Commission, and other government agencies in studying ground-water problems. Thirty-one reports describing the geology and ground-water resources of the Snake River basin have been published or released to the open-file. These reports, among others, are listed in the references at the end of this report.

ACKNOWLEDGMENTS

The authors acknowledge the valuable assistance provided by well owners and drillers and by power, canal, and pump companies, who supplied details about wells, acres irrigated, and power consumed, and many other data concerning water supply. The Bureau of Reclamation collaborated in the field by contracting for drilling and pumping test wells, by spirit leveling to many wells, and by making chemical analyses of water. A great deal of pertinent data was obtained from the files of the Idaho Department of Reclamation. Other public agencies, including the U.S. Bureau of Land Management, the U.S. Forest Service, and the U.S. Soil Conservation Service also furnished information.

WELL-NUMBERING SYSTEM

The well-numbering system used in Idaho by the Geological Survey indicates the locations of wells within the official rectangular subdivisions of the public lands, with reference to the Boise base line and meridian. The first two segments of a number designate the township and range, respectively. The third segment is the section number followed by two lowercased letters and a numeral. The first of the two letters indicates the quarter section and the second the 40-acre tract; the numeral is the serial number of the well within the tract. Quarter sections are lettered a, b, c, and d in counterclockwise order, from the northeast quarter of each section (fig. 3). Within the quarter sections, 40-acre tracts are lettered in the same manner. For example, well 6S–31E–14bc1 is the well first visited in the SW¼NW¼ sec. 14, T. 6 S., R. 31 E.

PHYSICAL SETTING

The physical setting of the Snake River basin determines the quantity and quality of surface and ground water available in the area. Total precipitation and seasonal distribution of precipitation affect runoff, evapotranspiration, and ground-water recharge. Topography

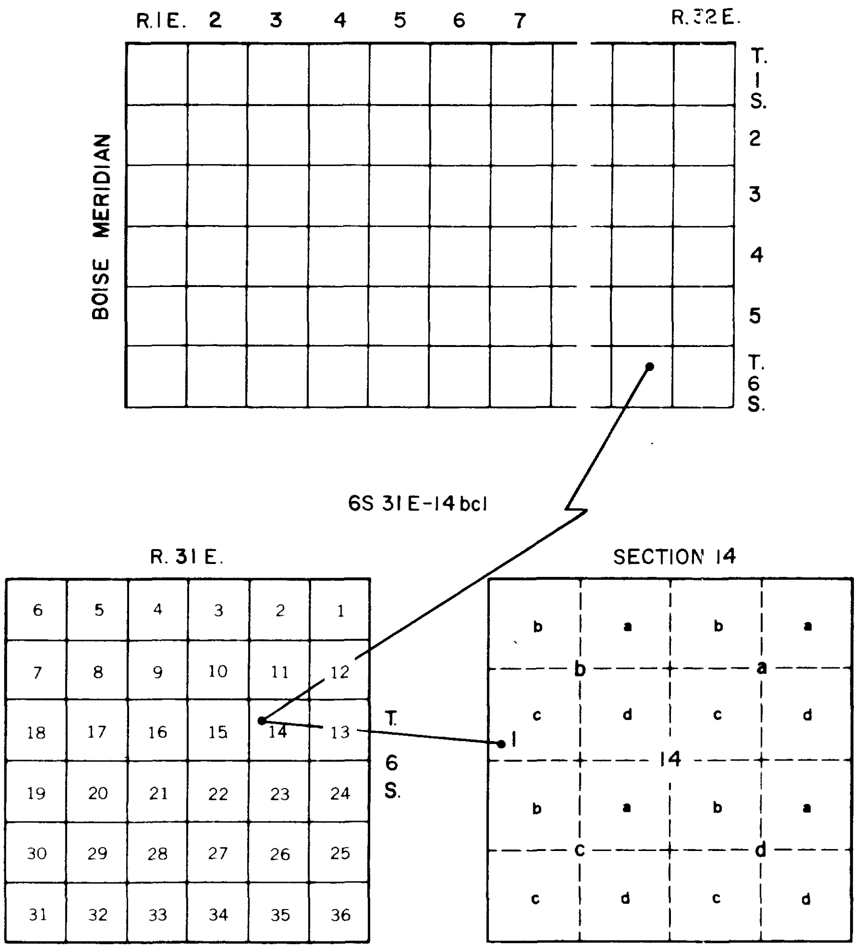

FIGURE 3.—Sketch of well-numbering system.

influences both precipitation and runoff. The amount of evapotranspiration is largely dependent upon the amount of water available, the length of the growing season, and temperatures during the growing season. Geologic factors also affect evapotranspiration and are important elements in ground-water storage and recharge.

In general, the Snake River basin may be considered as comprising three types of terrain with respect to water. The first type consists of mountains and plateaus, where average annual precipitation is as much as 50 inches. This type of terrain has an excess of water above that which is consumed within the area; the excess results in surface runoff or underground flow from the area.

The second type consists of soil-mantled terraces, benches, and plains, where the precipitation, generally less than 10 inches, is nearly all consumed by evaporation and native vegetation and where the water table is far enough below the surface that vegetation cannot reach it. In this type of terrain, relatively insignificant amounts of water are contributed to or withdrawn from the water supply of the basin.

The third type of terrain includes plains, basins, and valley floors, where the water table generally is near the surface and where consumption of water by vegetation and loss by evaporation exceed precipitation. Irrigated tracts are included in this terrain. In this type of terrain, the water supply of the basin is diminished.

Although to some extent the three types of terrain merge, the boundaries between the types are rather distinct at most places. The boundary between the first and second types is especially distinct where the mountains rise sharply from the plains and lowlands.

LANDFORMS AND DRAINAGE

The Snake River basin in southern Idaho includes parts of the Basin and Range, Rocky Mountain, and Columbia Plateaus physiographic provinces. A principal feature of the basin is the generally gently rolling Snake River Plain, which extends in a broad arc from the vicinity of Ashton southwest, west, and northwest about 350 miles across southern Idaho into Oregon (pl. 1). The width of the plain ranges from about 30 to 75 miles. Altitudes range from about 2,100 feet above sea level at Payette to about 6,000 feet in the northeastern part. Because the eastern half of the plain is somewhat different geologically and hydrologically from the western part, it is convenient to divide the plain into two parts at about 115° W. longitude, near Bliss. Numerous low, broad volcanic hills are scattered over the eastern part, and basalt is the principal rock underlying that part of the plain. Volcanic hills are present, but are not so common, in the western part, and the plain there is underlain by both sedimentary rocks and basalt.

The Snake River flows in a shallow but well-defined channel in much of the eastern part of the plain, but downstream from American Falls it flows for about 20 miles in a narrow canyon 50 to 150 feet deep. Downstream from Milner Dam, the river enters a narrow canyon as much as 400 feet deep, and from Bliss northwestward to Homedale the river is entrenched as much as 700 feet below the general elevation of the Snake River Plain in alternating canyons and broad valleys. North of Homedale, the river passes into a broad channel about 100 feet below the plain; near Payette its channel is only slightly entrenched into the broad valley. North of Weiser, the river enters a canyon several thousand feet deep. The Snake River is the drainageway for all water out of the basin, and it receives all surface- and ground-water discharge (other than evaporation and transpiration) from the Snake River Plain and tributary valleys.

About 15 major valleys are tributary to the plain. In the eastern part, most of them enter from the southeast or northwest. In the western part, the tributary valleys trend north, northeast, southwest, or west (pl. 1). Many of the valleys, such as the Big Lost and Raft River valleys, are broad and contain much irrigable land. This type of valley merges with the plain, and their downstream boundaries are arbitrary. Other valleys, such as the Blackfoot and Little Wood River valleys, are narrow and contain little agricultural land; their surface-water outflow is used on lands in the Snake River Plain.

The valleys are bordered by moderately to severely rugged mountains that range in elevation from about 7,500 feet above sea level in the Sublett Range to more than 12,000 feet in the Lost River Range. (In Wyoming, the Teton Range also rises more than 12,000 feet above sea level.) Plate 1 shows the principal mountain ranges and valleys bordering the Snake River Plain. In eastern Idaho, the mountains have northward- and northwestward-trending ridges and are fault-block mountains related to the Basin and Range physiographic province. In the extreme eastern part, the mountains merge with the Rocky Mountain province. In western Idaho, the mountains north of the Snake River Plain are part of the central Idaho mountain mass, also in the Rocky Mountain province. The mountains in southwestern Idaho are domed uplifts.

The mountains receive much heavier precipitation than the lowlands and retain a snow pack late into the summer. Snowmelt sustains streamflow so that all the master streams in the principal valleys are perennial, at least in their headward areas. Big Lost and Little Lost Rivers and Birch, Medicine Lodge, Camas, and Beaver Creeks on the northwestern side of the eastern Snake River Plain end in playa lakes at the edge of the plain or flow into Mud Lake, which has no surface outlet (pl. 1). Before irrigation development, all the other master streams discharged some water into the Snake River.

CLIMATE

In the Snake River basin, the occurrence and utilization of ground water is closely related to every phase of climate. Because there is little or no ground-water underflow into the Snake River basin, all ground-water recharge is derived from precipitation within the basin. The geographic and time distribution of precipitation and whether it occurs as rain or snow affect the amount of precipitation that becomes recharge. Recharge to ground-water reservoirs may be considered to be a residual; that is, it is the part of the precipitation that is not evaporated or transpired, is not retained by the soil as soil moisture, and does not become and remain direct surface runoff. Thus, temperature, wind direction and velocity, humidity, and time-percentage of sunshine and cloudiness indirectly control ground-water recharge by controlling the amount of evaporation and transpiration. Most of the precipitation on areas underlain by materials by low permeability becomes runoff. A large amount of precipitation in a short time may result in a high proportion of runoff and little evapotranspiration or recharge, and precipitation at a very slow rate may be chiefly evaporated and transpired with little or no runoff or recharge. On the other hand, prolonged precipitation on areas underlain by porous materials may result in a large amount of recharge. Evaporation, transpiration, and precipitation largely control the consumptive use of irrigation water by crops and thus control ground-water withdrawals.

Because of insufficient data, the climatic effects on the ground-water regimen may be only roughly evaluated, but the climatic factors must be considered and analyzed in arriving at a reasonably sound understanding of the regimen.

The climate of the Snake River Plain may be characterized as "semiarid continental." Precipitation is scanty, winters are cold, and summers are hot; however, during the summer and fall, the daily range in temperature commonly is 30° to 40°. Precipitation is much greater and temperatures are lower in the mountainous areas bordering the Snake River Plain.

PRECIPITATION

Precipitation stations in the Snake River basin are nearly all on the plain or in bordering valleys. Obviously these stations do not adequately sample the precipitation at higher elevations that produces most of the water recharging the aquifers of the Snake River basin. The locations of climatological stations are shown on plate 2, and data for selected stations are given in tables 1 to 4. Figure 3b also shows, by isohyets, the distribution of precipitation. This map is adapted from one developed by the U.S. Army, Corps of Engineers (written communication) on the basis of topography, runoff, snow-course measurements, and similar data in addition to the precipitation records.

The mountain masses bordering the plain have a pronounced effect upon the amount and distribution of precipitation. The air masses rise as they pass over the mountains and lose a large part of their moisture. As shown by the isohyetal map, precipitation at higher elevations at places exceeds 50 inches. As the air masses descend over the plain, they contain little moisture and precipitation is much less. Precipitation on the central part of the Snake River Plain generally is 6 to 10 inches; however, along the margins of the plain, depending upon local orographic effects and elevation, precipitation may be as much as 20 inches.

Precipitation is fairly well distributed throughout the year, July and August being the driest months (table 4), but it varies greatly from year to year and may range from 50 to 150 percent of average. Precipitation is chiefly snow during December, January, and February and also during November and April at higher altitudes

At higher elevations most of the precipitation is snow, and even at lower elevations a significant proportion of precipitation is snow. The greatest average annual snowfall recorded at a station is 203.1 inches at Island Park Dam (pl. 2). However, snowfall on the west slopes of some mountain ranges undoubtedly greatly exceeds that amount. Total snowfall on the Snake River Plain generally is between 2 and 3 feet. This is the average annual total and does not represent accumulated thickness which, because of melting and compaction, would be much less. The water content or water equivalent of total snowfall probably is about 10 percent, that is, the water in 50 inches of snowfall is equivalent to about 5 inches of rainfall.

Data obtained from measuring the thickness and water content of accumulated snow in mountainous areas of Idaho are collected and published by the Soil Conservation Service. These data are useful in filling gaps in the record of precipitation at higher elevation. Data for representative snow courses are given in table 1.

TABLE 1.—*Average water content at representative snow courses in the Snake River basin for the month of greatest accumulation*

[From records of U.S. Dept. Agriculture, Soil Conservation Service. Water content generally measured near end of March, occasionally at beginning of April]

Snow course	Drainage	Altitude (feet above sea level)	Water content (inches)
Lewis Lake Divide	Snake River	7,900	44.0
Moran	do	6,800	11.8
Valley View	Henrys Fork	6,500	15.5
Big Springs	do	6,500	21.8
State Line	Teton River	6,400	16.1
Somsen Ranch	Blackfoot River	7,000	11.8
Pebble Creek	Portneuf River	6,550	14.8
Sublett	Raft River	6,000	12.3
Bostetter Ranger Sta	Goose Creek	7,500	19.5
Magic Mountain	Salmon Falls Creek	6,700	20.4
Fox Creek	Bruneau River	6,800	9.0
Sawmill Canyon	Little Lost River	6,000	7.7
Stickney Mill	Big Lost River	7,500	9.2
Mascot Mine	Big Wood River	7,900	16.1
Muldoon Creek Ranch	Little Wood River	6,300	6.4
Atlanta Summit	Boise River	7,500	33.7
Moores Creek Summit (Mores creek summit)	do	6,100	32.4
South Mountain	Owyhee River	6,340	11.6
Deadwood Summit	Payette River	7,000	45.3
Crawford Ranger Station (at Crawford Guard Station).	do	4,800	6.3

TABLE 2.—*Average annual precipitation and snowfall and the mean annual temperature at selected Weather Bureau stations in the Snake River basin for period of record through 1958*

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

Station	Elevation	Precipitation (inches)	Snowfall (inches)	Temperature (°F)
Aberdeen Expt. Sta	4,400	8.79	27.4	45.1
Arco 3NW	5,300	9.43	38.2	41.8
Ashton 1S	5,220	16.21	74.7	41.4
Blackfoot Dam	6,200	15.22	76.4	
Burley	4,180	9.39	28.7	48.7
Caldwell	2,372	10.21	19.1	50.5
Council	2,936	25.78	70.0	47.9
Deadwood Dam	5,375	32.87	185.1	38.2
Driggs	6,097	16.99	79.1	38.9
Dubois Expt. Sta	5,452	11.20	53.0	42.9
Glenns Ferry	2,569	8.58	19.4	
Gooding CAA AP	3,696	9.27	38.1	47.6
Grand View	2,600	7.66	8.8	51.5
Hailey	5,322	15.33	86.4	43.5
Hollister	4,550	9.35	25.9	47.6
Howe	4,820	8.22	19.5	
Idaho City	3,965	21.48	93.9	45.4
Idaho Falls CAA AP	4,730	11.61	35.9	44.3
Idaho Falls 46W	4,933	7.69		42.3
Irwin 2SE	6,300	14.65	65.1	41.4
Island Park Dam	6,300	28.76	203.1	37.5
Mackay Ranger Sta	5,897	9.34	37.2	42.3
McCall	5,025	25.45	121.2	39.8
Moran (Wyo.)		21.17	161.2	34.4
Oakley	4,600	10.20	26.4	48.3
St. Anthony	4,968	13.53	49.5	
Spencer Ranger Sta	5,883	17.93	89.7	38.7
Twin Falls 2NNE	3,770	9.81	21.7	48.5

TEMPERATURE AND GROWING SEASON

The mean annual temperature at lowland stations in the Snake River basin ranges from 54.7° F. at Swan Falls on the Snake River in western Idaho to 41.4 and 41.5 at Ashton and Hamer, respectively, in eastern Idaho (table 3). Mean temperatures are lower in the tributary valleys and in the mountains. January is usually the coldest month and July the warmest. Recorded extreme temperatures on the plain have ranged from −45° to 120° F.

The average length of the frost-free period in the Snake River Plain and in some lower tributary valleys ranges from 95 days, as in the Henrys Fork area and the Lost River valleys, to 160 days in the Boise-Payette area. Some of the higher tributary valleys and mountain basins have shorter frost-free periods. Hardy crops, such as alfalfa, pasture, and orchard, have a much longer growing season than sugar beets, potatoes, corn, and small grains.

EVAPORATION AND TRANSPIRATION

The U.S. Weather Bureau and the University of Idaho maintain evaporation stations at a few places throughout the plain and at some of the irrigation reservoirs in the tributary valleys (table 5). Records are usually for April through October but may vary somewhat because of the length of the frost-free season or other factors.

TABLE 3.—*Mean monthly and annual temperatures, in degrees Fahrenheit, at selected Weather Bureau stations in the Snake River basin, for period of record through 1958*

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

Station	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Ashton	18.2	21.7	28.5	41.0	50.2	57.4	64.8	63.2	54.4	44.4	31.8	20.6	41.4
Boise WB AP	27.3	34.0	41.8	49.9	58.1	65.1	74.8	72.5	62.4	52.6	39.6	31.0	50.8
Burley	26.0	31.1	39.0	43.7	56.1	64.0	73.3	70.4	60.3	50.0	37.3	29.3	48.7
Caldwell	28.3	34.7	42.8	50.9	57.9	65.2	73.5	70.3	61.0	52.1	38.8	30.4	50.5
Gooding CAA AP	23.7	29.5	38.3	47.4	55.9	63.4	72.2	69.3	59.9	49.1	36.2	26.9	47.6
Hamer	12.6	18.3	29.5	42.7	52.7	59.8	67.9	64.8	55.1	55.2	30.3	19.5	41.5
Idaho Falls CAA AP	19.3	23.5	33.6	44.9	53.2	60.5	68.8	66.6	57.0	47.1	33.5	23.2	44.3
Swan Falls Powerhouse	31.4	38.0	44.7	54.0	62.1	68.7	80.1	77.4	67.3	55.9	41.0	35.6	54.7
Twin Falls 2 NNE	26.7	32.2	39.9	48.1	55.8	63.1	71.4	68.7	59.5	49.7	37.7	29.1	48.5

TABLE 4.—*Average monthly and annual precipitation, in inches, at selected Weather Bureau stations in the Snake River basin, for period of record through 1958*

[From records of U.S. Weather Bureau]

Station	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Aberdeen Expt. Sta	0.68	0.68	0.67	1.09	1.05	0.78	0.50	0.42	0.67	0.94	0.73	0.68	8.79
Blackfoot Dam [1]	1.45	1.41	1.06	1.22	1.49	1.84	.72	1.12	1.20	1.07	1.28	1.36	15.22
Burley	.94	.95	.72	1.15	.90	.79	.33	.48	.51	.82	.88	.92	9.39
Caldwell	1.26	1.14	1.04	.94	.98	.77	.33	.22	.47	.78	1.14	1.14	10.21
Deadwood Dam	4.81	4.46	3.62	1.96	1.98	1.84	.81	.66	.99	2.09	3.43	6.22	32.87
Driggs	1.67	1.27	1.10	1.18	1.96	2.03	1.21	1.32	1.43	1.23	1.18	1.41	16.99
Dubois Expt. Sta	.95	.77	.64	.93	1.32	1.61	.73	.87	.87	1.00	.61	.90	11.20
Gooding CAA AP	1.24	1.02	.75	.94	.76	.61	.30	.20	.39	.78	1.26	.99	9.27
Hailey	2.23	1.98	1.29	1.15	1.33	1.04	.53	.50	.70	1.11	1.39	2.08	15.33
Idaho Falls CAA AP	1.31	.97	1.08	.94	1.24	1.21	.62	.59	.82	.98	.79	1.06	11.61
Island Park Dam	3.08	3.24	2.48	1.81	2.37	3.56	.77	1.32	1.70	2.42	3.09	2.92	28.76
McCall	3.49	3.12	2.54	1.91	1.94	1.82	.54	.60	1.10	1.92	2.87	2.18	25.45
Moran (Wyo.)	2.24	2.18	2.05	1.69	1.89	1.86	1.02	1.33	1.32	1.43	1.80	2.40	21.21
Twin Falls 2 NNE	1.10	.88	.65	1.11	1.03	.81	.35	.22	.57	.91	1.08	.90	9.81

[1] Based on record through 1952.

TABLE 5.—*Average monthly evaporation from Class-A land pans, in inches at stations in the Snake River basin*

[From records of the U.S. Weather Bureau. No data available for January, February, March, April, November, and December]

Station	May	June	July	August	September	October	Length of record (years)
Aberdeen Expt. Sta.	6.96	7.41	8.86	8.84	5.13	3.10	23
Arrowrock Dam	6.39	7.26	10.64	9.47	5.85	2.91	42
Minidoka Dam	8.34	10.05	12.64	11.95	8.67	5 32	11
Palisades Dam	5.82	6.58	8.20	7.76	5.39	----------	10

Evaporation from Class-A land pans ranges from 36 inches at Palisades Dam to 53 inches at Minidoka Dam. Evaporation from reservoirs and ponds probably is about 70 percent of that from land pans (Follansbee, 1934).

Because of the wide range in length of growing season, the amount of water consumed by native and cultivated vegetation also has a wide range. In the main part of the Snake River Plain, precipitation ranges from 6 to 12 inches per year and native vegetation is sparse. According to the method devised by Blaney and Criddle (1949), consumptive use (evapotranspiration) by sparse native vegetation ranges from 6 to 9 inches. Net consumptive-use data (not including precipitation during the growing season) for irrigated land in Idaho are given by Simons (1953) for several irrigated areas in the Snake River basin. These range from 12 to 24 inches, to which must be added about 3 inches of precipitation during the growing season for a total evapotranspiration of 15 to 27 inches. Data are not available for forested areas, but evapotranspiration probably ranges between 10 and 20 inches.

The prevailing wind is from the northwest in the western part of the plain, west in the central part, and southwest in the eastern part. Sustained velocities of 15 to 20 miles per hour with gusts of much higher speed are common, but winds of destructive force are rare. Some wind erosion occurs on newly cleared land that is left unprotected.

ECONOMIC DEVELOPMENT

The economy of the Snake River Plain and the tributary valleys is based on irrigation agriculture and industry related to agriculture. The principal irrigated crops are alfalfa, small grains, potatoes, sugar beets, onions, beans, peas, clover, and corn. The principal dry-farmed crops are small grains, such as wheat and barley. Grains and forage crops are the principal products grown in the higher valleys, where the growing season is short. Crops are more diversified in the Snake River Plain and lower valleys, where the growing season is longer. Cattle and sheep raising and dairying are of major importance, and swine, horses, and poultry provide considerable income. Processing of sugar beets, potatoes, and dairy products and storing of potatoes and seed are major industries also.

Irrigation began in the 1860's. Simple rock and brush dams on the Snake River and tributary streams diverted water to ditches leading to nearby pasture, hay, and grain lands. At the present time (1959), more than 2 million acres is irrigated with water stored in more than 30 reservoirs and with "natural-flow" water in the river and streams. The water is distributed through several thousand miles of canals and laterals maintained by more than 150 canal companies and irrigation districts. More than 10 million acre-feet is diverted annually to irrigate crops. Diversion of this large quantity of water to various tracts in the Snake River basin has had a marked effect on the ground-water regimen. The water table in some areas has risen more than 100 feet, and the discharge of some springs has more than doubled.

Some land was irrigated with ground water as early as the 1920's, especially in the Mud Lake basin and the Snake River valley (fig. 12), but large-scale development of ground water did not begin until after World War II. In 1959, about 600,000 acres received about 1.5 million acre-feet of ground water for irrigation during the May–September irrigation season. An unknown but substantial additional acreage received ground water to supplement the original surface-water supply. The principal areas of ground-water development and estimated withdrawals are shown in the following table.

Estimated ground-water withdrawals for irrigation, in acre-feet, at some localities in the Snake River basin in Idaho in 1959

Locality	Withdrawals	Locality	Withdrawals
Mud Lake	200, 000	Upper Big Wood River [1]	10, 000
Blackfoot to Roberts	200, 000	Camas Prairie	2, 000
Little Lost River	40, 000	Dry Creek [1]	60, 000
Big Lost River	10, 000	Gooding, Lincoln, and Jerome Counties	70, 000
Aberdeen-Springfield	100, 000	Hollister-Buhl	25, 000
Portneuf, Blackfoot, and upper Snake Rivers	50, 000	Bruneau-Grand View	50, 000
Michaud Flats	10, 000	Boise and Payette subarea [1]	150, 000–175, 000
Raft River [1]	100, 000		
Southern Minidoka County	350, 000		
Lower Goose Creek [1]	100, 000	Total (rounded)	1, 500, 000

[1] Large amounts of ground water are used in these areas to supplement the surface-water supply.

Ground water is the principal source for municipal, industrial, domestic, and (except for livestock on the open range) stock supplies. Twin Falls and Pocatello are the only large cities that obtain all or part of their supply from surface sources.

GEOLOGIC FRAMEWORK

In general, the Snake River basin consists of a broad central plain and low plateaus flanked on either side by rugged mountain ranges. The geology of flanking mountains differs from that of the central plains area. Thus, the water regimen in the two areas is greatly different. Much of the abundant rainfall in the mountains is transported through streamflow and ground-water underflow to the lowlands, where a considerable part of it is used for irrigation and by native phreatophytes.

The rocks forming the mountains are largely consolidated rocks of low permeability. However, a fairly deep and porous subsoil has formed by decay and disintegration of the parent rock. At many places, this subsoil is several tens of feet thick. Broad intermontane valleys and basins are partly filled with alluvial sand and gravel.

The subsoil and alluvium in the mountains are utilized very little as a source of water supply but are important as seasonal ground-water reservoirs for storing water during periods of high rainfall and snowmelt. Discharge from these reservoirs maintains streamflow during periods of no surface runoff. Because these aquifers are fairly thin, they drain rather rapidly and are greatly depleted at the end of each dry cycle.

Much of the plain and plateau area and the tributary valleys, on the other hand, is underlain by rocks of high permeability and porosity. These rocks, chiefly basaltic lava flows and alluvium, constitute a ground-water reservoir in which the water level fluctuates only slightly from season to season. Large amounts of water are withdrawn for irrigation and other uses, and discharge from the Snake Plain aquifer is an important element of the total flow of the Snake River downstream from Hagerman Valley.

The geology of the basin obviously is an important factor in the occurrence and availability of ground water.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING CHARACTERISTICS

Geologic materials in the Snake River basin range from nearly impermeable to extremely permeable, and their capacity to accept recharge and to yield water also varies widely. Rocks of similar hydrologic characteristics have been grouped together, and their water-bearing characteristics are briefly described in table 6. Their surface distribution is shown on plate 3.

A series of limestone, sandstone, shale, quartzite, and metamorphic and granitic rocks of Preambrian(?) to Cretaceous age are grouped together for convenience and called rocks of pre-Tertiary age. They are all moderately to intensely folded and disarranged by faulting.

TABLE 6.—*Summary of the physical and hydrologic character of rock units in the Snake River basin*

Period	Epoch	Rock unit	Physical characteristics and areal distribution	Water-bearing characteristics
Quaternary	Recent to Pleistocene	Alluvium, lake beds, windblown deposits, glacial outwash, terrace gravels, and lake beds	Clay, silt, sand, gravel, and boulders; unconsolidated to well compacted; not bedded to well bedded. Alluvium floors the tributary valleys and the flood plains of the main rivers and forms fans at mouths of some valleys; lake beds formed behind basalt dams in Rupert, American Falls, Roberts, Mud Lake, and other areas; windblown deposits mantle much of the lowland areas and at some places, notably near St. Anthony, are actively migrating; terrace gravel occurs locally along streams. Glacial debris, talus, and landslide material not shown on map. Basalt flows locally intercalated with some of the lake beds. Units not differentiated on geologic map.	Sandy and gravelly alluvium yields considerable ground water to wells, especially where pumping induces recharge from streams; lake beds yield only small amounts of water to wells because of low permeability; windblown deposits usually occur above the water table; terrace gravel locally yields moderate to large quantities of water to wells, especially in the Boise River Valley; in many areas the terrace gravel is above the water table but transmit infiltrating precipitation to underlying materials.
Quaternary and Tertiary	Recent to Pliocene	Snake River basalt	Olivine basalt, light- to dark-gray dense to vesicular, aphanitic to porphyritic; irregular to columnar jointing; thickness of flows variable; includes beds of basaltic cinders, rubbly basalt, and interflow deposits. Crops out over much of the Snake River Plain and the Mountain Home Plateau; mantled at many places with alluvium, terrace gravel, and windblown deposits; locally intertongued with deposits of Pleistocene and Recent age; overlies the Idaho formation, silicic volcanic and sedimentary rocks, or the Columbia River basalt.	Permeability highly variable; formational permeability high because of jointing and rubbly contacts between flows; rock permeability low. One of the most important aquifers in the Snake River basin. Yields large amounts of unconfined ground water to wells where it lies below the water table; receives and transmits recharge readily. Interflow sediments yield little or no water to wells.
Tertiary	Pliocene to Miocene	Idaho formation	Terrestrial and lake deposits of clay, silt, sand, and some gravel, compacted to poorly consolidated, poorly to well stratified; beds somewhat lenticular and intertongued; contains beds of ash and intercalated basalt layers. Exposed in the Snake River valley downstream from Buhl to beyond the Oregon border. Also exposed in the Boise, Payette, and Weiser River valleys. The Idaho formation, of Pliocene age, overlies the silicic volcanic and sedimentary rocks, Columbia River basalt, and Payette formation; laps onto the pre-Tertiary rocks at some places; underlies the Snake River basalt, alluvium, terrace gravel, and windblown deposits in the same area. For mapping purposes, the Payette formation has been included with the Idaho formation.	Porosity and permeability highly variable; generally contains artesian water; yields to wells range from a few gallons per minute from clayey beds to several hundred gallons per minute from sand and gravel. An important aquifer in the Bruneau-Grand View-Homedale area and Boise, Payette, and Weiser River valleys. Water is warm at some places.

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TABLE 6.—*Summary of the physical and hydrologic character of rock units in the Snake River basin*—Continued

Period	Epoch	Rock unit	Physical characteristics and areal distribution	Water-bearing characteristics
Tertiary—Con.	Pliocene to Miocene—Con.	Silicic volcanic and sedimentary rocks	Rhyolitic, latitic, and andesitic rocks; massive, dense, reddish-brown, gray, and black; jointing ranges from platy to columnar; occur as thick flows and blankets of welded tuff with associated fine- to coarse-grained ash and pumice beds (commonly reworked by running water) and as clay, silt, sand, and gravel; locally folded, tilted, and faulted; include the Salt Lake(?) formation of Pliocene age in the southeastern part of the basin; crop out around the margin of the Snake River basin and presumedly occur at depth beneath the basin.	Joints and fault zones in flows and welded tuff and interstices in coarse-grained ash, sand, and gravel beds yield small to moderate and rarely large amounts of water to wells. Commonly contain warm water under artesian pressure. An important but little-developed aquifer in the Rexburg, Heise, and Bruneau-Grand View area; intensively developed near Murtaugh.
		Columbia River basalt	Flood-type basalt, light- to dark-gray, dense; rude columnar jointing at many places; folded and faulted; may include some rhyolitic and andesitic rock types; exposed on the flanks of the Snake River basin in western Idaho; not determined whether rocks occur at depth beneath the basin. The Columbia River basalt is of Miocene and Pliocene(?) age.	Locally yields small to moderate amounts of artesian water to wells from fractures and fault zones, but porosity and permeability generally low.
		Payette formation	Consolidated beds of clay, silt, sand, and volcanic ash; intercalated in the Columbia River basalt. For mapping purposes, the Payette formation, of Miocene and Pliocene(?) age, has been included with the Idaho formation.	Sandy beds yield small to moderate amounts of artesian water to wells in the westernmost part of the Snake River basin.
		Columbia River(?) basalt	Lithologically similar to Columbia River basalt.	Unknown, but probably similar to Columbia River basalt.
	Miocene(?), Oligocene, and Eocene(?)	Challis volcanics	Extrusive rocks, ranging in composition from rhyolite to basalt; include welded tuff, pyroclastic, tuffaceous and other clastic sedimentary rocks, crops out in the foothills and mountains north of basin; include some intrusive rocks of early Tertiary age.	Porosity and permeability low; yield small amounts of water where jointed. Not an important aquifer.
Pre-Tertiary		Pre-Tertiary rocks	Include well-indurated sedimentary rocks that have been folded, faulted, and intruded by granitic rocks; crop out in the hills and mountains that border the Snake River basin.	Generally very low in permeability except where jointed; important chiefly as the basement rocks of the Snake River basin.

At some places the rocks are intensely fractured. Locally these rocks are very permeable, and the subsoil on them is permeable and porous. Nevertheless, they are regarded as a relatively impermeable basement beneath the younger rocks which comprise the principal aquifers of the basin. The basement rocks crop out in the mountains surrounding the lowlands and probably transmit some ground water by underflow to the plains and valleys. These rocks and the rocky, poorly developed subsoil lying on them contribute water to the base flow of the mountain streams.

The rocks of Tertiary and Quaternary age consist of clay, silt, sand, gravel, fresh-water limestone, conglomerate, and volcanic rocks and ash ranging in composition from rhyolite and trachyte to basalt. The sedimentary units usually are not well indurated but consist of light- to well-compacted, poorly sorted clastic rocks that were deposited by streams and lakes. The rocks have been divided into seven units on the basis of lithology and water-bearing character. The division closely follows the stratigraphy (pl. 3) shown on the geologic map of Idaho (Ross and Forrester, 1947).

Locally, fractures in the volcanic rocks of rhyolitic composition yield moderate quantities of water to wells. The permeability of the basaltic rocks varies widely, but apparently the younger the basalt the more water it yields to wells. The older basalt commonly is deeply weathered, and the products of decay reduce the size of the openings in joints and the spaces between successive flows. The younger basalt is fresh, contains abundant joints and other fractures, and commonly has broken, rubbly zones between flows. These features impart a high formational permeability to the basalt, although a piece of unbroken basalt may have a very low permeability. Basalt is the most important aquifer in the Snake River basin.

Clean well-sorted coarse-grained alluvium yields large quantities of water to wells. The older, thicker stream and lake sediments yield small to moderate quantities of water because they are usually fine grained and poorly sorted.

GEOLOGIC HISTORY

Only a brief summary of the geologic history of the Snake River basin is given below. A more complete discussion is contained in a report by Ross and Forrester (1958).

In Paleozoic time, limy, sandy, and clayey sedimentary materials were deposited in ancient oceans that occupied what is now southern Idaho. With interruptions caused by uplift and erosion, deposition of sedimentary materials continued through Mesozoic time. During and after deposition, these materials were compacted and cemented by heat and pressure into limestone, sandstone, quartzite, shale, and similar rocks. Folding and faulting occurred at several intervals during Paleozoic and Mesozoic time. Some of the folding formed gentle arches in the rocks, and other disturbances produced tightly compressed folds. Faulting ranged from simple normal faults to large overthrusts. Near the end of the Mesozoic era, granitic rocks were intruded into the sedimentary rocks at some places, principally in central Idaho. These rocks now form the mountains surrounding the Snake River basin and crop out in the tributary valleys.

In earliest Cenozoic time, Idaho was mountainous owing to folding, faulting, and uplift, which began late in Mesozoic time. By the time large-scale vulcanism began in middle Cenozoic time, vigorous stream erosion had produced a surface of subdued topography cut by deep valleys. The first products of volcanic activity were lava flows of intermediate composition, and tuffaceous and clastic deposits (Challis volcanics). This period was followed by erosion; then eruptions of basaltic lava (Columbia River basalt) flooded large areas of the Pacific Northwest. The lava spread over lowlands and up valleys between the mountains. Uplift of mountainous areas, which began late in the sequence of lava flooding, accelerated dissection of higher areas. The erosion products accumulated in the lowlands as lacustrine and fluviatile deposits (Payette formation) associated with the Columbia River basalt.

Late in middle or early late Cenozoic time, silicic volcanic rocks erupted along belts of structural weakness. Viscous magma formed flows, and explosive eruptions produced volcanic ash, pumice, and welded tuff. Another sequence of deposition (Idaho formation) and of basaltic eruptions followed. Late in Cenozoic time, basaltic eruptions (Snake River basalt) predominated over deposition of sediments Sedimentation and eruption of basalt was confined principally to lowland areas, and erosion continued in the mountains. Late in the emplacement of basalt, lake deposits accumulated in basins formed by basalt dams.

The modern mountain ranges began to take form in the middle Cenozoic time, and subsidence of the arcuate area occupied by the Snake River basin began in late Cenozoic time. Uplift, tilting, and faulting of the mountains has continued to the present.

Work of glaciers during the Pleistocene epoch modified the higher mountains slightly and left some glacial debris, which occurs mostly as terraces and outwash deposits in mountain valleys.

SURFACE WATER

Stream-flow records were collected as early as 1889 in the Snake River basin, and more than 250 gaging stations have been established on the main stem and tributary streams. About 150 are now active. The length of the records vary from a few weeks or months to 52 years (through 1958). The records fairly well establish the expected maximum, minimum, and average flows for the major streams, but many streams of lesser importance have incomplete or no records.

The annual discharge of the Snake River at Oxbow, Oreg. has averaged about 12.7 million acre-feet (33 years of record) but has ranged from 7.62 million acre-feet in 1931 to 20.05 million in 1943. The gage measures the total surface outflow of the Snake River basin upstream from the mouth of the Powder River. Subsurface outflow from the basin is insignificant. The gage at Weiser measures almost all the outflow from the Idaho part of the basin plus that of the Owyhee River basin in Idaho, Nevada, and Oregon and the Malheur River basin in Oregon. The flow of the Weiser gage has averaged 12.9 million acre-feet annually (45 years of record) and has ranged from 7.39 million in 1931 to 19.4 million in 1942 (fig. 4). The average discharge of the Snake River at Weiser is slightly less than at Oxbow for the same period of record. The following table gives some of the stations, the average discharge past the station, and other data. Figure 5 illustrates the volume of flow at selected stations.

Selected stream-gaging stations in the Snake River basin, through water year 1956

Station	Length of record (water years)	Drainage area (square miles)	Average discharge	
			Cubic feet per second	Acre-feet per year (thousands)
Snake River near Heise [1]	46	5,752	6,888	4,987
At Neeley [1]	30	13,600	6,774	4,904
At Milner [1]	30	17,180	2,084	1,509
At King Hill [1]	47	35,800	10,650	7,755
At Weiser [1]	46	69,200	17,877	12,949
At Oxbow [1]	33	72,800	17,575	12,708
Henrys Fork near Rexburg [2]	47	2,920	1,910	1,383
Blackfoot River near Blackfoot [1]	25	1,295	153	110.8
Portneuf River at Pocatello [2]	43	1,000	255	184.6
Boise River near Boise [1]	19	2,680	3,038	2,199
Boise River at Notus [1]	34	3,820	1,102	796
Payette River near Payette [1]	21	3,240	3,144	2,276
Bruneau River near Hot Spring	18	2,010	404	292.5

[1] Flow affected by major reservoirs.
[2] Flow affected by small reservoirs.

The natural flow of the Snake River, all the major tributaries, and many of the minor streams have been partly controlled by storage and diversion dams for irrigation, power, municipal, and industrial uses. Simons (1953, p. 90) estimated that irrigation depletion of the streamflow at Weiser amounted to 26.8 percent of the surface-water yield of the basin in 1946. Subsequent irrigation development has undoubtedly increased the percentage of depletion. Nevertheless, because of various economic reasons, a substantial part of the total yield of the basin is not utilized for irrigation despite the availability of large tracts of land. However, discussion of possible utilization of undeveloped surface-water supplies is beyond the scope of this report.

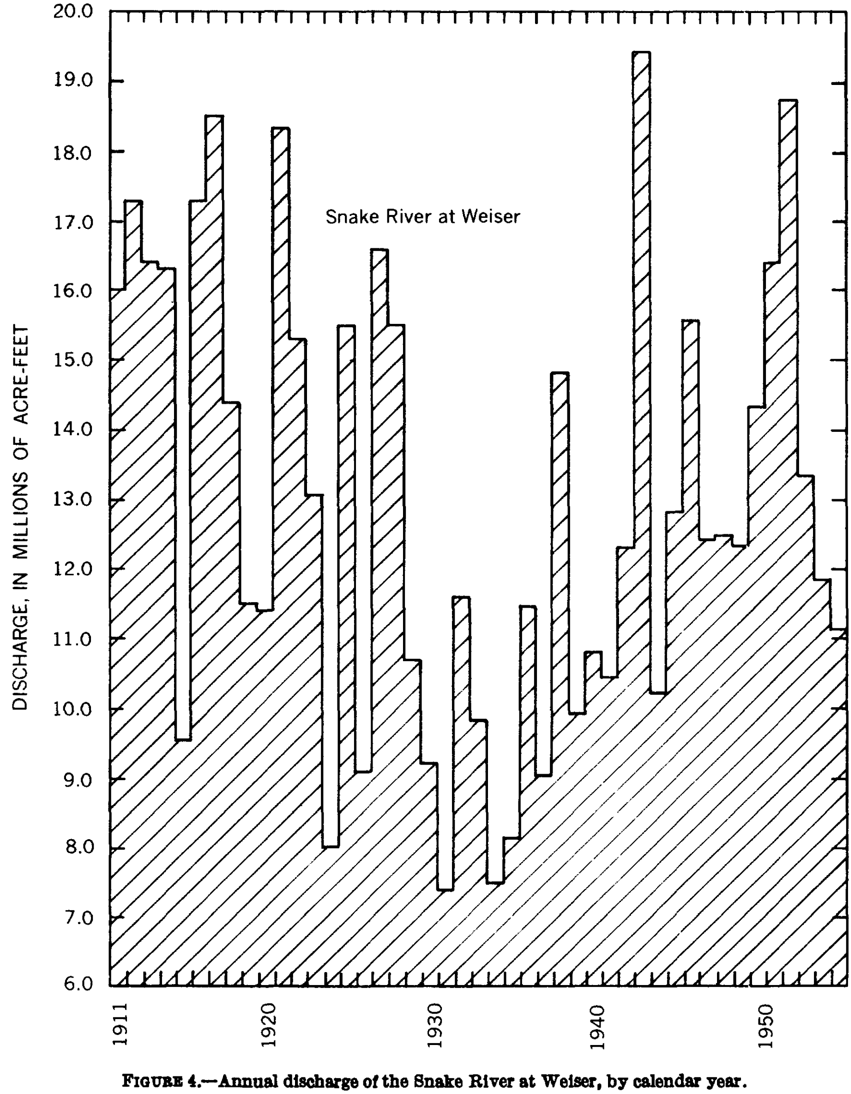

FIGURE 4.—Annual discharge of the Snake River at Weiser, by calendar year.

Streamflow varies according to the amount of precipitation on the drainage basin, control by surface reservoirs, seepage losses and gains in the stream channel, diversions for or return flow of waste irrigation water, and other factors. For example, the Big Lost River loses considerable water in part of the reach above Mackay Reservoir, but a substantial part of the loss returns to the stream channel before the river enters the reservoir. Below Arco, the river loses water by seepage and evaporation. When there is enough water to maintain flow in the channel, the river discharges into playa lakes, where percolation

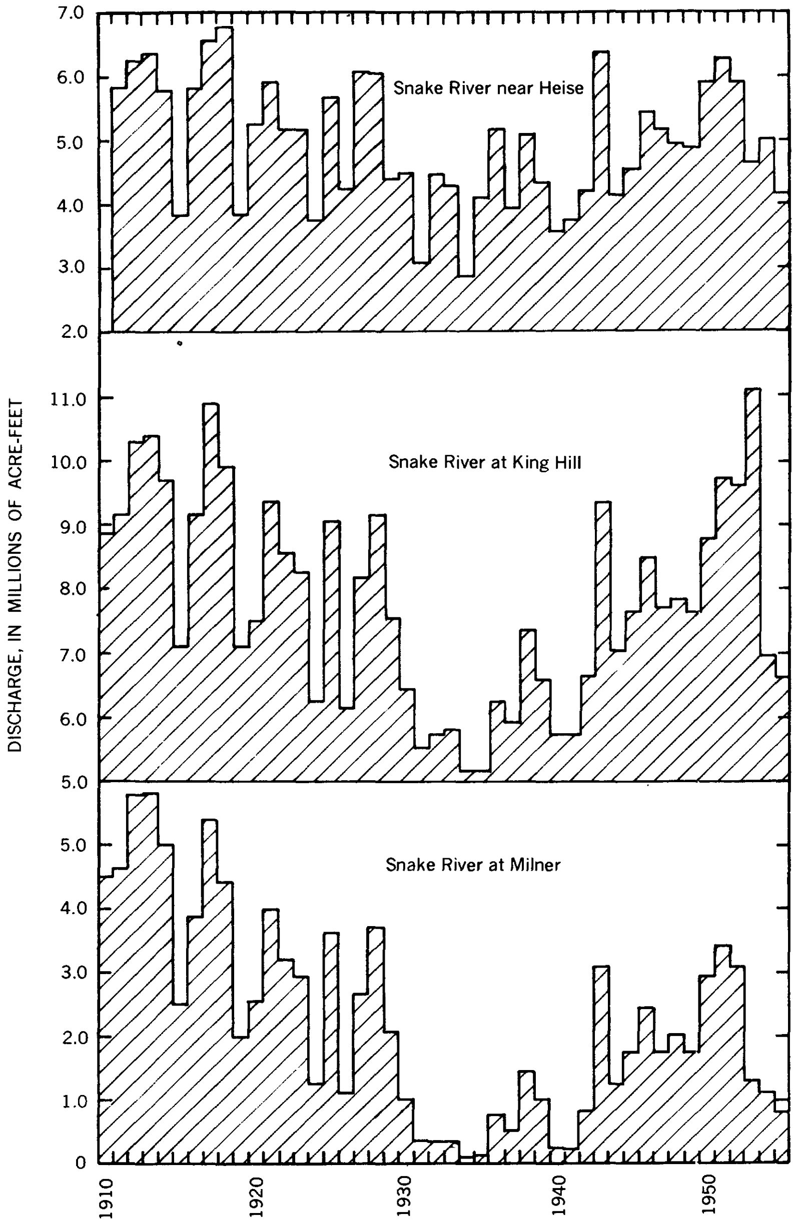

FIGURE 5.—Annual discharge of the Snake River near Heise, at King Hill, and at Milner, by calendar year.

and evaporation dissipate the water. Thus, the Big Lost River never contributes any surface flow to the Snake River, although the average flow just below all diversions for irrigation was 61 cfs (cubic feet per second) for the period 1947–56.

An outstanding example of a large gain in streamflow from ground water is illustrated by the reach of the Snake River between the Milner and King Hill gages. The major control structures on the Snake River are upstream from Milner, and during some years very little water passes the gage at Milner. Only about 400,000 acre-feet enters the river from tributaries between the two gages, yet the annual recorded flow at King Hill has never been less than 5 million acre-feet (fig. 5). Most of the gain in streamflow between the gages is ground water discharged from springs issuing from Snake River basalt.

About 2.2 million acres is irrigated with surface water in the basin in Idaho. Nine major (more than 200,000 acre-feet capacity) and several dozen minor reservoirs provide more than 7.5 million acre-feet of storage space. The following tables list the irrigation reservoirs with more than 10,000 acre-feet capacity in the basin above Oxbow, Oreg.

The surface-water aspects of the several parts of the basin are discussed in following sections of the report.

Irrigation reservoirs in the upper Snake River basin, Idaho

Reservoir	River	Active capacity (acre-feet)
American Falls [1]	Snake	1, 700, 000
Anderson Ranch [1]	South Fork, Boise	464, 200
Arrowrock	Boise	286, 600
Black Canyon	Payette	43, 900
Blackfoot-Marsh	Blackfoot	350, 000
C. J. Strike [2]	Snake	84, 000
Cascade	North Fork, Payette	654, 100
Crane Creek	Crane Creek	60, 000
Cedar Creek	Cedar Creek	26, 000
Deadwood	Deadwood	161, 900
Fish Creek	Fish Creek	14, 400
Grassy Lake	Grassy Creek (Wyo.)	15, 200
Grays Lake	Willow Creek	40, 000
Henrys Lake	Henrys Fork	79, 400
Island Park	do	127, 200
Jackson Lake	Snake (Wyo.)	847, 000
Little Payette	Lake Fork, Payette	16, 940
Lake Lowell	Boise (off stream)	169, 000
Lake Walcott [1]	Snake	95, 200
Little Camas	Little Camas Creek	22, 300
Little Wood	Little Wood	[4] 12, 200
Lucky Peak [3]	Boise	278, 200

See footnotes at end of table.

Irrigation reservoirs in the upper Snake River basin, Idaho—Continued

Reservoir	*River*	*Active capacity (acre-feet)*
Mackay	Big Lost	44, 400
Magic	Big Wood	191, 500
Mud Lake		60, 000
Oakley	Goose Creek	74, 400
Paddock Valley	Little Willow Creek	32, 000
Palisades [1]	Snake	1, 201, 600
Payette Lake	North Fork, Payette	27, 700
Portneuf-Marsh Valley	Portneuf	23, 700
Salmon Falls Creek	Salmon Falls Creek	182, 700
Twin Lakes	Camas Creek	31, 200
Wilson Lake	Snake (off stream)	18, 500
Total		7, 452, 200

[1] Also produces hydroelectric power.
[2] Primary purpose is hydroelectric power.
[3] Primary purpose is flood control.
[4] Scheduled to be enlarged to 30,000 acre-feet capacity in 1960.

Irrigation reservoirs in the Oregon and Nevada part of the upper Snake River basin

Reservoir	*River*	*Active capacity (acre-feet)*
Agency Valley	North Fork Malheur	60, 000
Antelope	Jordan Creek (off stream)	45, 400
Owyhee	Owyhee	715, 000
Thief Valley	Powder	17, 400
Unity	Burnt	25, 200
Warmsprings	Malheur	191, 000
Wild Horse	Owyhee	32, 700
Willow Creek No. 3	Willow Creek	20, 400
Total		1, 107, 100

GROUND WATER

For all practical purposes, the ultimate source of ground water in the basin is precipitation on the basin (meteoric water). Although there are many thermal springs throughout the area, the total amount of water they discharge is comparatively small. Furthermore, most of the water discharged probably is meteoric water that has descended, perhaps to only moderate depths, to where it has been heated by ascending steam or other gases. The amount of primary water brought to the surface probably is small.

The areas of high elevation are the chief precipitation-receiving areas of the basin. On the other hand, in the plains, lowlands, and valleys, which contain the principal aquifers, far more water is consumed than falls on these areas. Thus, direct precipitation on the areas of outcrop of the aquifer is a minor part of the recharge. Most recharge to these aquifers is by percolation from streams, canals, and irrigated lands.

HYDROLOGIC PRINCIPLES

Part of the precipitation on an area immediately runs off as streamflow; part is intercepted by vegetation or open-water surfaces, whence it evaporates or is transpired. The remainder enters the soil. Of the water entering the soil, part is held by molecular attraction as a film around the grains, and the remainder percolates downward to the water table. Water remaining in the soil is utilized by vegetation or, near the surface, evaporates directly from the soil. Where streams or canals cross beds of coarse gravel or bare porous rock surfaces, little water is held by molecular attraction or capillarity, and much of it percolates down to the water table.

In the Snake River basin in Idaho, a large amount of water occurs below the water table in the interstices of the rock materials. These interstices range in size from minute pores to lava tubes tens of feet in diameter. Important interstices in aquifers of the Snake River basin include (a) the pores between grains of silt, sand, gravel, and cinders in unconsolidated materials, (b) joints and other fractures in consolidated rocks, (c) solution channels and cavities in limestone and similar rocks, and (d) the irregular openings in and between lava flows. Within the zone of saturation, these interstices constitute the storage space for ground water. From this storage, water is withdrawn through wells.

The porosity of a material is the proportion of the total volume that is occupied by interstices. Rock is saturated when all interstices are filled with water, but the porosities of rock materials differ greatly. Clay may have a porosity of more than 50 percent, wheras consolidated rocks, such as a cemented sandstone or granite, may have a porosity of only a few percent. Most clean well-sorted sand and gravel has a porosity of 30 to 40 percent; silt and fine sand mixed in coarser materials reduce the porosity somewhat.

A material may have a large porosity but may yield little water, even though allowed to drain for a long time. Clay having a porosity of 50 percent or more may yield practically no water because of the smallness of the grains and interstices, the water being retained by molecular attraction; some water also may be retained in a material because the pores are isolated or poorly interconnected. The ratio of the volume of water a saturated rock will yield by gravity to the total volume of rock is the specific yield and may be stated as a decimal fraction or as a percentage. One of the most important characteristics of an aquifer is the rate with which it will transmit and yield water. This characteristic has little relation to porosity. A sand and gravel having a porosity of 30 to 40 percent may yield water at a high rate, whereas silt and clay having a porosity of 50 percent or more may yield water very slowly.

Permeability is a measure of an aquifer's ability to transmit and yield water. Clay is relatively impermeable because the pores are small. Because the pores are larger in silt and fine sand, the effect of the smallness of pores is less but still may be great enough that water can only be transmitted very slowly. An admixture of silt or fine sand in coarse sand and gravel greatly decreases both the porosity and permeability of the sand and gravel.

Ground water moves chiefly in response to the force of gravity; therefore, the discharge area of an aquifer is at a lower elevation than the intake or recharge area.

QUANTITATIVE METHODS OF APPRAISAL

In making a quantitative appraisal of the water resources of an area, several different methods may be used. In all methods certain simplifying assumptions must be made. Obviously the conclusions can be no more valid than the data used or the assumptions made. The methods used in evaluating the ground-water resources of the different parts of the Snake River basin are described briefly in the following sections.

ANALYSIS OF AQUIFER CHARACTERISTICS

The two principal hydraulic characteristics of an aquifer—its ability to transmit water (coefficient of transmissibility) and its ability to store water (coefficient of storage) can be determined by making aquifer tests. Determination of the hydraulic characteristics of an aquifer enables the hydrologist to evaluate the effects of pumping on the aquifer, to estimate the quantity of water that might be withdrawn from a well or a group of wells, and to predict future water levels under postulated conditions of pumping.

Some aquifer tests may yield information that indicates whether the geohydrologic boundary is a recharge (source) boundary or an impermeable (barrier) boundary and, if data are sufficient, may indicate the distance to and the orientation of the boundary. Aquifer tests made by pumping a well also may furnish information that is valuable in determining optimum size of casing, the size, arrangement, and number of openings in the casing, the size of the pump, and the depth of pump setting.

The coefficient of transmissibility generally can be determined by measurements of water-level drawdown and recovery in the pumped well; however, although observation wells are not essential, the information gained from them generally gives a more accurate value for the coefficient of transmissibility than does information from the pumped well only. Moreover, the coefficient of storage generally cannot be determined without data from one or more observation wells. No observation wells were available for the 5 aquifer tests made at the sites of test wells drilled for the investigation in 1957, but one or two observation wells were used in each of the five aquifer tests made on test wells drilled during 1958 in connection with this investigation.

DEFINITION OF TERMS

The coefficient of transmissibility (T) is defined by the Geological Survey as the quantity of water, in gallons per day, that will flow through a vertical strip of the aquifer 1 foot wide and extending through the saturated thickness of the aquifer, under a hydraulic gradient of 100 percent, under the prevailing temperature of the water and other conditions. The coefficient of transmissibility can be defined also as the quantity of water, in gallons per day, that will flow through a vertical strip of the aquifer 1 mile wide and extending through the saturated thickness of the aquifer, under a hydraulic gradient of 1 foot per mile, under prevailing conditions. The two definitions give identical coefficients, but the second is easier to visualize in connection with field problems. The field coefficient of permeability (P_f) is the coefficient of transmissibility divided by the thickness of the aquifer, in feet.

The coefficient of storage (S) is defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. It is expressed as a decimal fraction, and for water-table aquifers it is approximately equal to the specific yield.

In comparing yields of several wells and in evaluating the yield of an individual well, it is convenient to express the yield in terms of the specific capacity of the well, which is generally expressed in gallons per minute per foot of drawdown. Because the drawdown varies with time, that factor must be taken into consideration. The specific capacity of most wells varies also with rate of discharge because of dewatering or because of "well loss."

The drawdown in a pumped well consists of two components: the head loss due to laminar flow of water in the aquifer toward the well, and the well loss (head loss) due to turbulent flow in the aquifer in the immediate vicinity of the well, through the screen or perforated pipe, and in the casing. Well loss, in feet, may be determined approximately by use of the following equation: Well loss$=CQ^2$ (Jacob, 1947), where C is the well-loss constant and Q is the discharge. Because Q is expressed in gallons per minute in this report, the dimensions of C are

$$\frac{\text{Minutes}^2 \times \text{feet}}{\text{Gallons}^2}$$

Well loss is shown by a decrease in specific capacity when the pumping rate is increased.

FIELD PROCEDURES

The coefficients of transmissibility of the Snake River basalt and of some gravel aquifers are so great that they present certain problems in mensuration. Even with moderately large discharges, 1,000 to 2,500 gpm (gallons per minute), the drawdown in the pumped well may be only a foot or two, and in observation wells only 0.1 or 0.2 foot.

The procedures outlined below apply particularly to the aquifer tests made in test wells drilled for this investigation in 1957 and 1958 but also apply generally to other aquifer tests made in Idaho.

Water levels in most wells in southern Idaho fluctuate in response to changes in atmospheric pressure. Pressure changes producing water-level changes of 0.2 to 0.3 foot in 12 hours are common (fig. 9). During some tests, the drawdown trends caused by pumping have been reversed by barometric effects. For this reason, it is necessary to make corrections for barometric effects.

A recording barograph was maintained at each test site for 1 to several weeks prior to the test. During some tests, recording gages were operated on observation wells at a time scale, on the chart, of 3 inches per hour and a gage scale of 1:1. Measurements of water level were made with a steel tape wherever possible and with an electric tape wherever conditions prevented use of the steel tape. The electric tape was calibrated with a steel tape. The steel-tape measurements generally were accurate to 0.01 foot and the electric-tape measurements to 0.02 foot. Measurements to the nearest 0.01 foot were not satisfactory for analyzing data obtained from observation wells, and generally data from the recorder charts were interpolated to 0.001 foot. Barometric and other corrections also were made to 0.001 foot. In most tests, the equipment used was not completely adequate for such accuracy.

Deep-well turbine pumps were used for the tests, and the rate of discharge was measured at or near the end of the discharge pipe by a free-flowing or submerged orifice. The length of tests ranged from 9 to 72 hours. At some sites, preliminary tests were made to test equipment and to obtain information for planning the main test. Data from these tests also were analyzed.

METHODS OF ANALYSIS

Only a brief discussion of the methods and procedures used in analyzing the data is given; for detailed information, the papers cited should be consulted.

Analyses of aquifer tests are based on the principle that the rate of flow of water through a porous medium is directly proportional to the hydraulic gradient. This relation apparently was first observed by Darcy (1856). A simplified, general expression of Darcy's law is:

$$Q=PIA,$$

where Q is the quantity of water,
P is the constant depending upon the permeability of the material,
I is the hydraulic gradient,
and A is the cross-sectional area through which the water moves.

Data obtained during an aquifer test may be analyzed by two methods based on this principle—the equilibrium method (Thiem, 1906; Wenzel, 1942) and the nonequilibrium method (Theis, 1935). Both of these methods, as well as a modification of the second (Cooper and Jacob, 1946), were used in analyzing the test data.

In the equilibrium method, measurements of drawdown at different distances from the pumped well are used to define the profile of the cone of depression. This method requires that measurements be made in at least two wells, and only those data can be used that are obtained after that part of the cone containing the observation wells has virtually reached equilibrium form—that is, after the rate of water-level decline is the same in all the observation wells from which data are used in the analysis. The equation used for determining transmissibility is:

$$T=\frac{528Q\log_{10}\left(\frac{r_2}{r_1}\right)}{s_1-s_2}$$

where T is the coefficient of transmissibility, in gallons per day per foot;
Q is the rate of discharge, in gallons per minute;
r_1 and r_2 are the distances, in feet, from the pumped well to observation wells 1 and 2, respectively;
and s_1 and s_2 are the water-level drawdowns, in feet, in observation wells 1 and 2, respectively, at some specific time.

In practice, the equation is solved graphically. The drawdowns for all observation wells, for some specific time, are plotted on the arithmetic scale of semilogarithmic graph paper, and the respective distances of the observation wells from the pumped well are plotted on the logarithmic scale. The equation then can be readily solved by determining the slope of the line connecting the plotted points. Because the slope is the same as the change in drawdown over one log cycle (Δs), the abbreviated equation becomes:

$$T = \frac{528Q}{\Delta s}$$

The simplified equation for the coefficient of storage, using the same semi-logarithmic plot, is:

$$S = \frac{0.3Tt}{r_o^2}$$

where S is the coefficient of storage, expressed as a decimal fraction;
t is the time, in days, between the beginning of pumping and the specific moment of time that the drawdowns were measured;
and r_o is the "r" reading (distance from pumped well), in feet, at the point where the plotted line intersects the line of zero drawdown.

The nonequilibrium method is an analysis of successive measurements of the drawdown in the pumped well or in observation wells within the cone of depression caused by pumping. The relation of drawdown to time is given by the equation

$$s = \frac{114.6Q}{T} \int_u^\infty \frac{e^{-u}}{u}\, du$$

where $u = 1.87\ r^2\ \mathrm{Tt}\ \frac{S}{Tt}$
s = drawdown (or recovery), in feet, at any point of observation in the vicinity of a well discharging at a constant rate;
r = distance, in feet, from the discharging well to the point of observation;
and t = time, in days, since pumping started (or ceased).

The nonequilibrium formula is based on the following assumptions: (a) The aquifier is homogeneous and isotropic, (b) its areal extent is infinite, (c) the well penetrates the entire aquifier, (d) the coefficients of storage and transmissibility are constant, and (e) the water is released from or taken into storage instantaneously with a change in head.

The most convenient method of solving the above equation is a graphical solution devised by Theis in 1937 (Wenzel, 1942), which utilizes a type curve in which the integral of the above equation, termed $W(u)$, is plotted against u on logarithmic coordinate paper. For each observation well, the drawdown (or recovery) data are plotted against time (t) on logarithmic graph paper having the same scale as the type curve. If the assumptions listed above are valid, or reasonably so, for the area sampled during the test, a curve drawn through the plotted data will match a segment of the type curve. If, then, the data curve is superposed on the type curve so as to obtain the best possible fit, the corresponding axes of the graphs being kept parallel, the two sets of coordinates for any point common to both curves can be used in the following equations for the determination of T and S:

$$T=114.6QW(u)$$

$$\text{and } S=\frac{uTt}{1.87r^2}$$

$$\text{or } S=\frac{uTt}{2693r^2}$$

where t is in minutes.

The latter method was simplified by Cooper and Jacob (1946). Their equation for the coefficient of transmissibility, valid when a steady-state condition is reached, is

$$T=\frac{264Q\log_{10}\left(\frac{t_2}{t_1}\right)}{s_2-s_1}$$

which reduces to

$$T=\frac{264Q}{\Delta s}$$

for graphic solution. Plotted against time on semilogarithmic coordinate paper, the drawdown data should produce a straight line, and Δs is then the change in drawdown over one log cycle.

The coefficient of storage can be obtained from the equation:

$$S=\frac{0.3Tt_o}{r^2}$$

where t_o is the time intercept, in days, where the projection of the straight line intersects the zero-drawdown line.

A simplified method of analysis of the recovery of water level in a well that has been pumped was devised by Theis (1935). This method also is based on the nonequilibrium method. The coefficient of transmissibility is determined from the equation:

$$T=\frac{264Q}{s'}\log_{10}\frac{t}{t'}$$

where s' is the residual drawdown (the difference between the measured water level after pumping ceases and the static water level before pumping, corrected for prepumping trend), in feet;

t is the time since pumping began;

and t' is the time since pumping stopped.

This equation is valid when u is small, less than about 0.02, generally within a few minutes after pumping ceases. After u becomes small, s' plotted against $\frac{t}{t'}$ on semilogarithmic paper is a straight line. For graphical solution, the equation reduces to

$$T=\frac{264Q}{\Delta s'}$$

where $\Delta s'$ is the change is residual drawdown over one log cycle.

ANALYSIS OF BOUNDARY EFFECTS

One of the basic assumptions made in analyzing aquifer tests is that the aquifer is of infinite lateral extent, that is, that it has no boundaries. Actually, all aquifers have boundaries, but, during pumping tests of a few hours to a few days, boundaries several miles away have no effect upon the drawdown if the cone of depression has not reached the boundary. However, nearby boundaries will affect drawdowns during pumping tests, and even distant boundaries will affect drawdowns if pumping is continued for a sufficient length of time.

Boundaries are of two types: (a) negative, or barrier, boundaries, across which no water will flow, and (b) positive, or source, boundaries, across which no drawdown will occur. Of course, not all natural boundaries are as absolute as the two types; some barrier boundaries may leak, and not all positive boundaries are infinite sources. Nevertheless, many natural boundaries conform hydrologically to their respective types sufficiently that they can be analyzed as such.

The simplest method of analyzing the effect of a boundary is by the use of image wells (Jacob, 1950). In essence, the method is to assume, for the purposes of computation, an infinite aquifer having a recharging or discharging image well at such a distance from the pumped well that the image well has the same effect on ground-water flow as the actual physical boundary. The problem can then be analyzed as though the aquifer were infinite, the effects of the image well or wells being added to the effects of the real wells.

A single straight-line boundary at a distance a from the pumped well can be replaced by a single image well that is located along a line

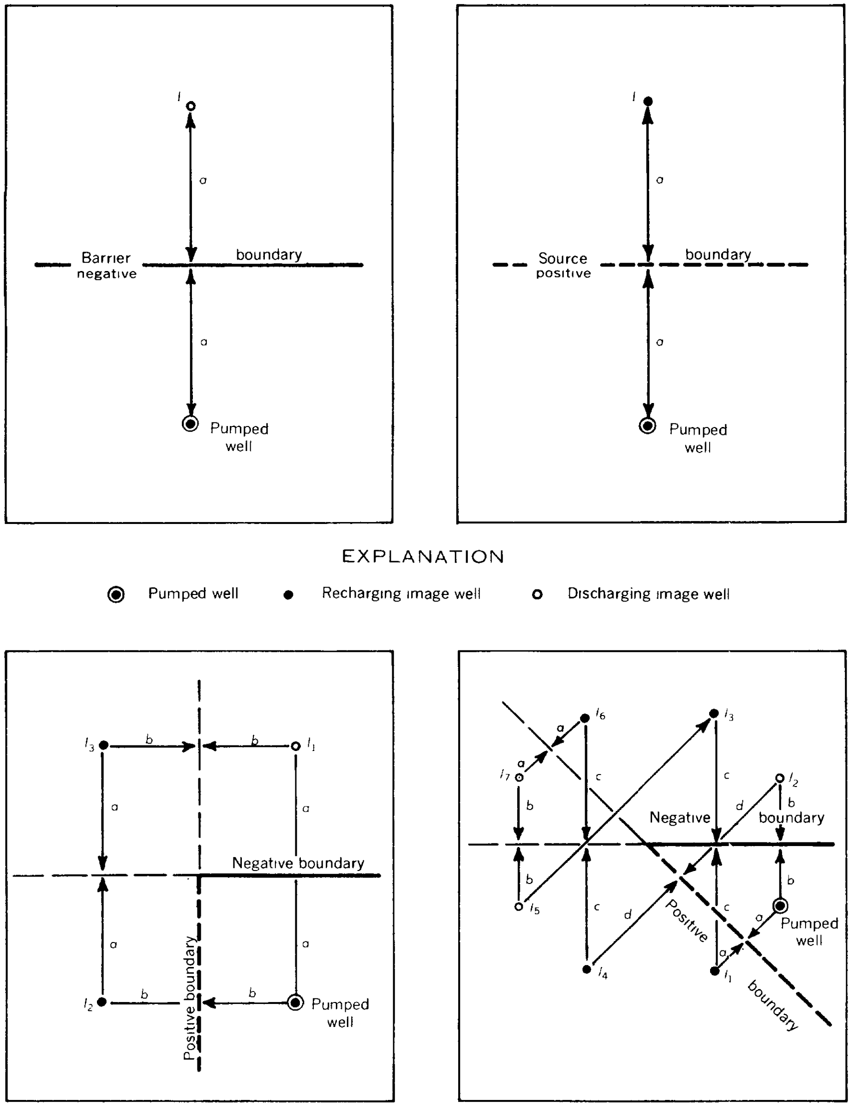

Figure 6.—Several boundary arrangements and the image-well systems required to satisfy the boundary conditions.

from the pumped well perpendicular to the boundary and at an equal distance on the opposite side of the boundary (fig. 6). If the boundary is a barrier (negative) boundary, the image well is a discharging well; if the boundary is a source (positive) boundary, the image well is a recharging well. The solution is more difficult in areas of multiple boundaries, because the pumped well must be reflected across each boundary by an image well, the resulting images also must be reflected across each boundary, and so on. If the boundaries are parallel this reflection continues, theoretically, to infinity. Where boundaries intersect at some angle, three or more image wells must be assumed. A few simple arrays of image wells are shown in figure 6.

LABORATORY METHODS

The permeability of a sample can be easily measured in the laboratory; the chief drawback to this method is the difficulty in obtaining a representative sample. This is particularly true of basalt, where the water moves chiefly through irregular, sometimes large, openings between flow layers.

A coefficient of permeability determined in the laboratory is corrected to the coefficient for a water temperature of 60° F. To apply to field conditions, the laboratory coefficient must be corrected to the viscosity indicated by the temperature of the water in the aquifier.

ANALYSIS OF WATER YIELD

"Water yield," as used in this report, includes all the water leaving a basin by surface or underground flow. It does not include the water leaving by evapotranspiration.

For those basins where geohydrologic controls are such that little or no water leaves by underground flow, water yield is equal to the outflow in streams. Stream-discharge measurements are available for all the larger streams and a few of the smaller ones.

For those basins where underground outflow is an appreciable part of the water yield, less direct methods must be utilized. In many of the basins tributary to the Snake River, ground-water outflow is an important component of the water yield and in some basins it is the chief component. For example, the average flow of Snake River at King Hill consists of about two-thirds spring discharge and one-third direct runoff.

Methods of evaluating the ground-water component of water yield can be grouped into two categories—those based on the amount of recharge to and those based on amount of discharge from the basin. Only those methods that are used in this report are described in detail, others are mentioned briefly.

METHODS BASED ON RECHARGE

The most general of these methods involves determination of total precipitation on the area, estimation of total evapotranspiration, and measurement of surface outflow. The remainder is ground-water outflow. This method probably is fairly satisfactory for humid areas if data on precipitation and evapotranspiration are reasonably adequate. However, in the Snake River basin the data generally are inadequate for even a reasonable estimate. Furthermore, the ground-water outflow commonly is such a small part of the total precipitation that a change of 10 percent in the estimate of precipitation or evapotranspiration may change the estimate of ground-water outflow from a positive to a negative amount, and it would be unusual if precipitation or evapotranspiration could be determined with less than a 10-percent error.

The main method used in this report was to relate measured water yield from selected basins to average precipitation, as shown on the isohyetal map. This method eliminates the necessity of depending on rough estimates of evapotranspiration. It also minimizes the error due to incomplete knowledge of total precipitation because all the basins used have the same general physiographic and geologic setting and geographic orientation. In general, the mountain ranges and intervening valleys lie directly across the path of the usual storm. If the isohyetal map is in error, it probably is in error for all the basins, and the error is roughly of the same magnitude for each basin. This reasoning would apply only to basins of moderate size. For very small basins, the error could be of considerable magnitude; therefore, although the figure for average precipitation may be in error, it should be in error in about the same proportion in each basin, and the map should show relative amounts of precipitation on each of the basins.

By careful selection of basins and upstream parts of basins, six stations were found where surface flow constituted nearly all the water yield. Two additional stations were used, where reasonably accurate corrections could be applied to arrive at a figure for the total water yield of the basins. The data are given in the following table.

Relation of water yield to average annual precipitation, eastern Snake River Basin

Stream and station	Average annual depth (inches)		
	Precipitation (pl. 1)	Surface discharge	Water yield
Teton River near St. Anthony	26	11.5	11.5
Willow Creek near Ririe	16	4.75	4.75
Blackfoot River near Shelley	19.1	5.2	[1] 6.4
Portneuf River at Topaz	16.3	4.7	4.7
Big Wood River at Hailey	25.6	9.2	[2] 10.1
Big Lost River at Howell Ranch	20.5	7.8	7.8
Birch Creek near Reno	14.2	3.3	3.3
Beaver Creek at Spencer	36.2	3.6	3.6

[1] Correction applied for evaporation from Blackfoot River Reservoir.
[2] Corrected for estimated underflow of 10 percent of surface discharge (Smith, 1959).

The relation of precipitation to water yield is shown graphically in figure 7. No data are available for the lower end of the curve, where average precipitation on the basin is less than 14 inches. If the curve were projected as a straight line, it would intersect the line for zero water yield at a precipitation of about 9 inches. However, because of occasional heavy storms and because of particularly favorable conditions for recharge at some places, a slight quantity of precipitation will reach the water table where precipitation is much less than 9

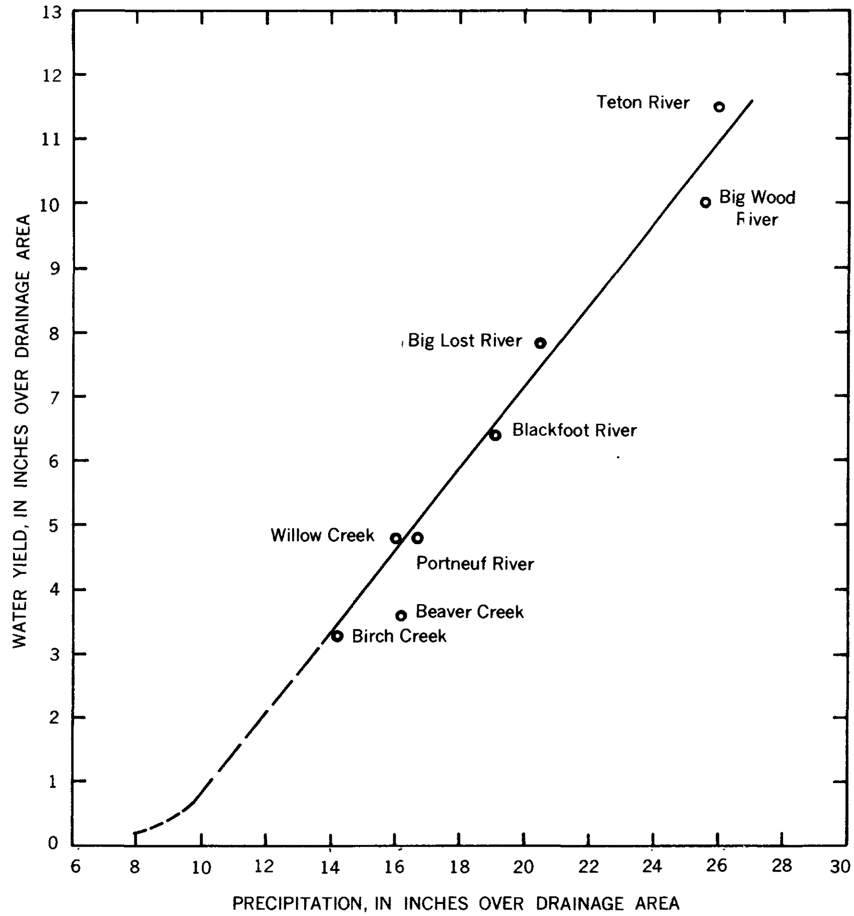

FIGURE 7.—Relation of water yield to average annual precipitation.

inches a year. The relation given by the curve should be used with great caution. Any unusual conditions relating to precipitation on the area or to unusual consumptive use within the area should be considered.

The relation given is between precipitation, as shown by the isohyetal map, and total water yield; ground-water outflow can be obtained by subtracting measured surface discharge. However, for many basins, total water yield is the important figure.

A modified version of the water-yield approach, based on stream-discharge measurements, was used for the Big Lost River basin. Because the method was used only for the Big Lost River basin, it is described with the section of the report on that basin.

METHODS BASED ON DISCHARGE

Where most of the ground-water discharge of a basin appears at the surface as springs, the yield can be measured directly. This method was used for determining underflow from the entire Snake River Plain east of Bliss, but that is the only place in the Snake River basin where the method can be used. Determination of the water yield from basins where the discharge does not appear at the surface must be by indirect methods.

Underflow in an aquifer is given by the equation

$$Q=TIW$$

where,

Q is quantity of underflow, in gallons per day,

T is the coefficient of transmissibility of the aquifer, in gallons per day per foot,

I is the hydraulic gradient, in feet per mile,

and W is the width of the aquifer, in miles.

The coefficient of transmissibility can be determined by aquifer or laboratory tests as described previously, the hydraulic gradient can be determined from measurements of water levels in several wells or, better, from a water-table map, and the width of the aquifer can be determined from surface and subsurface geologic data. Generally the most uncertain factor is the coefficient of transmissibility, and considerable caution must be observed in applying the results of one or two pumping tests to the entire aquifer. However, where adequate data are available the method is useful.

WATER-LEVEL FLUCTUATIONS

Water-level fluctuations in general indicate changes in the amount of ground water in storage. Thus, water levels rise when recharge exceeds discharge and decline when discharge exceeds recharge. Some fluctuations are caused by earthquake shocks and changes in atmospheric pressure, but such fluctuations ordinarily do not reflect changes in storage.

The Snake River basin has two significant cycles of water-level fluctuations. One is the yearly rise and fall of the water table in response to the annual change in rate of recharge and discharge of the aquifer. In water-table aquifers, the rise usually begins in the middle or late spring when the snow melts in the mountains and the irrigation season begins. The downward trend usually begins in late summer or early fall when the streamflow is at a minimum and the irrigation season is ended. Hydrographs of wells 4N–1W–35aa1 and 10S–20E–5ba1 (fig. 8) are typical of water-level fluctuations in the Snake River basin. At some places remote from sources of natural recharge or irrigated areas, the trends may not coincide with the usual yearly trends because from several to many months may be required for the recharge mound to reach these places. A comparison of precipitation on the lowlands with the hydrographs shows that the water levels often are highest during the driest part of the year.

In many irrigated areas, water levels are strongly influenced by the application of irrigation water. In well 4N–1W–35aa1 (fig. 8), water levels start to rise in April when water is turned into the irrigation canals and begin to decline in October, when the irrigation canals are dry.

The range in seasonal fluctuations varies widely. In the Boise Valley, which contains one of the most important sedimentary aquifers in the Snake River basin, the observed yearly range of fluctuations is 5 to 8 feet. In the Snake River Plain, which is underlain by the largest basalt aquifer in the basin, the yearly range is 1 to 20 feet and probably averages 5 feet. The water levels in aquifers at places in some of the tributary valleys fluctuate 40 feet or more each year.

A second trend indicates the long-term change in storage. For example, in well 10S–20E–5ba1 (fig. 8) water levels rose from the beginning of record in 1949 to 1953 and declined from 1954 to 1957. The rise probably reflects increased precipitation in the uplands during 1947 to 1951, and the decline may reflect reduced precipitation in the uplands from 1952 to 1955. Ground-water withdrawals for irrigation have substantially increased upgradient from the well during the past decade, and pumping has had some effect on the amount of water in storage in the aquifer. The amount of decline in water levels that can be attributed to pumping is not known.

In artesian aquifers, water levels respond almost instantaneously to recharge and discharge. Ordinarily, the main artesian aquifers are not affected by application of surface water for irrigation because they receive their recharge directly from upland areas by underflow, and in irrigated areas the confining beds serve to insulate the aquifers. Under these conditions, water levels usually are highest in late spring and early summer, when snowmelt runoff is at peak discharge, and lowest in winter.

Water levels in some wells fluctuate in response to changes in atmospheric pressure. The water-level fluctuations of a well in Snake

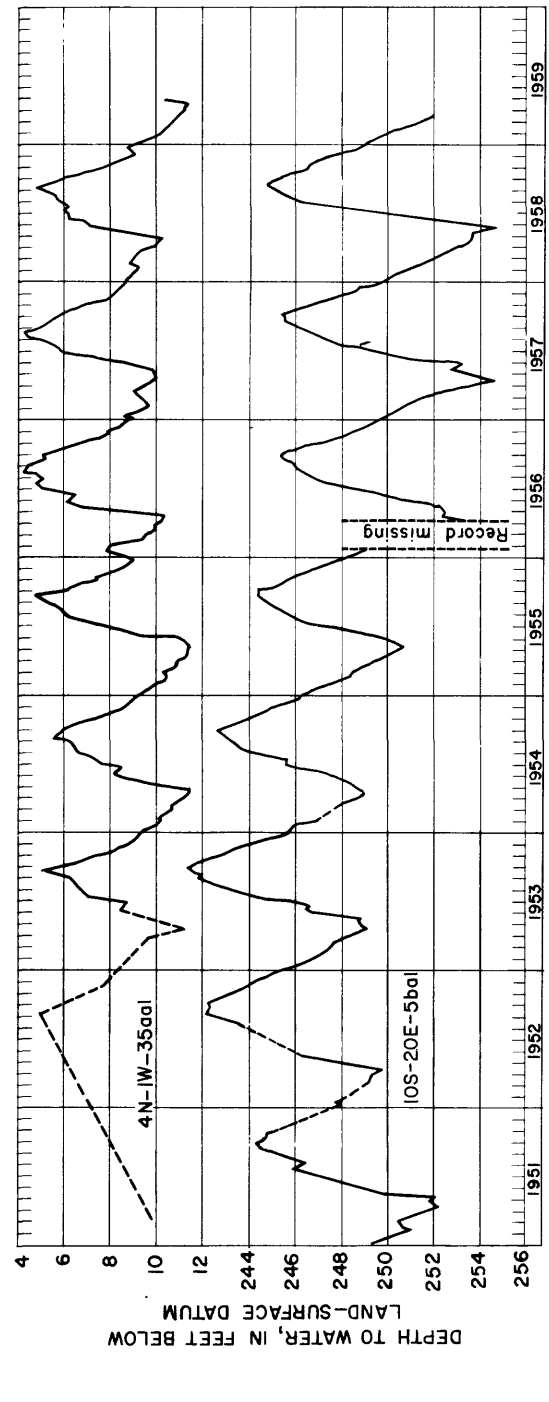

FIGURE 8.—Hydrographs of wells 4N-1W-35aa1 and 10S-20E-5ba1.

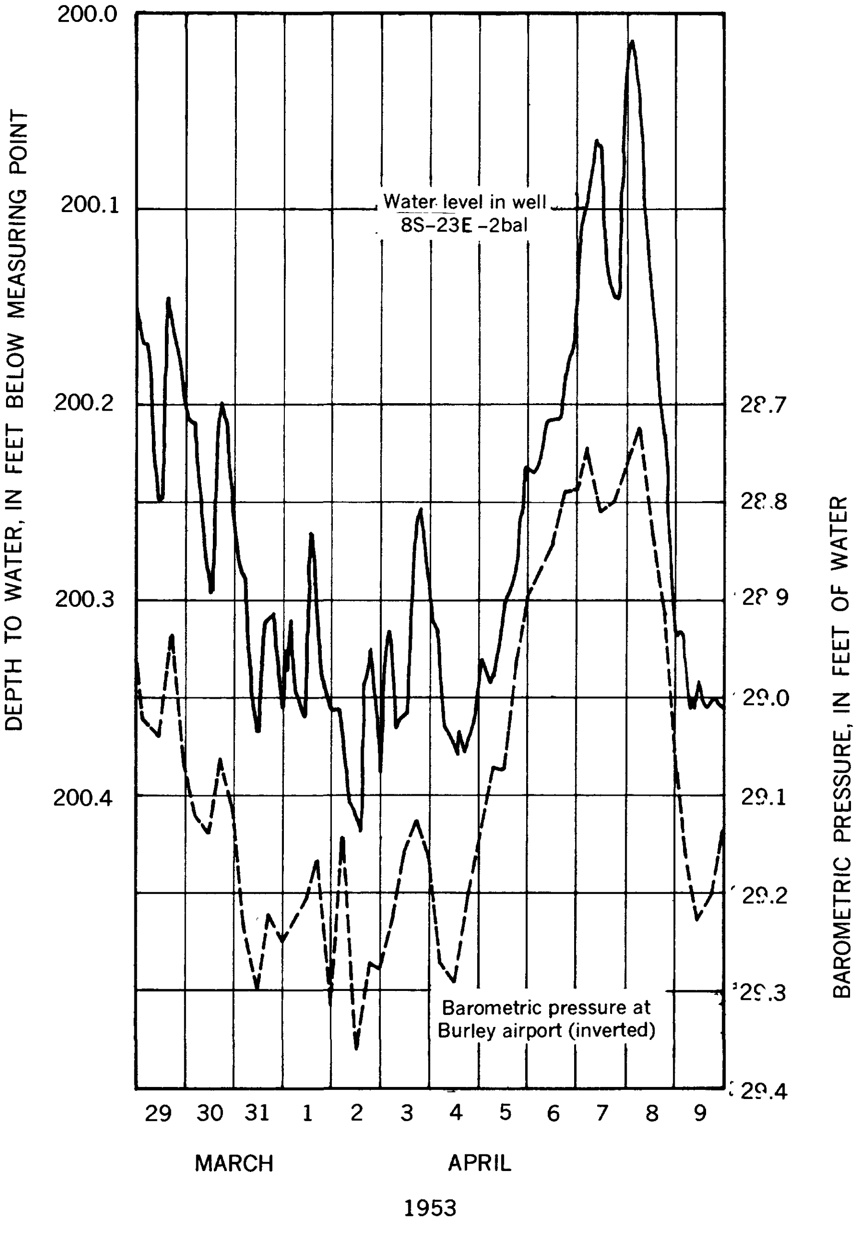

FIGURE 9.—Comparison of water-level fluctuations in well 8S-23E-2bal with barometric pressure at Burley. After Crosthwaite and Scott (1956).

River basalt are compared with barometric fluctuations at a nearby weather station in figure 9. These fluctuations must be interpreted in pumping tests before the data can be evaluated properly, especially where drawdowns due to pumping are small and barometric efficiency of the aquifer is large.

QUALITY OF WATER

The chemical and bacterial content of water determines its suitability for domestic, irrigation, stock, and industrial use. The Geological Survey does not determine the bacterial content of water. Water moving through geologic materials dissolves and retains some of the soluble products of rock weathering and decomposition. The concentration of these products in the water determines its chemical suitability for various uses. For example, calcium and magnesium cause hardness in water, and excessive hardness in water for domestic and industrial uses is objectionable. Fluoride in excess of about 1.5 ppm (parts per million) causes mottling of the tooth enamel of children (Dean, 1936).

In this report the suitability of ground water for irrigation is summarized for various parts of the Snake River basin in Idaho for which data are available. According to the U.S. Salinity Laboratory Staff (1954), "The characteristics of an irrigation water that appear to be most important in determining its quality are: (1) Total concentration of soluble salts; (2) relative proportion of sodium to other cations; (3) concentration of boron or other elements that may be toxic; and (4) under some conditions, the bicarbonate concentration as related to the concentration of calcium plus magnesium."

The concentration of soluble salts can be expressed for classification of water for irrigation by the electrical conductivity expressed as specific conductance. The four salinity-hazard classes based on specific conductance are as follows:

C1, less than 250 micromhos, low salinity hazard;
C2, 250 to 750 micromhos, medium salinity hazard;
C3, 750 to 2,250 micromhos, high salinity hazard;
C4, more than 2,250 micromhos, very high salinity hazard.

In general, water having a specific conductance less than 750 micromhos is satisfactory for irrigation as far as dissolved solids are concerned. Waters having conductances between 750 and 2,250 micromhos are satisfactory under good management and drainage conditions, but saline soil will develop if leaching and drainage are inadequate. Waters having conductances greater than 2,250 micromhos are not common in the Snake River basin in Idaho.

A large proportion of sodium causes some types of soil to become less permeable so that they do not accept water readily and, when wet, do not drain readily. An approximate measure of the sodium (alkali) hazard of a water can be obtained by dividing the sodium concentration, in milliequivalents per liter, or equivalents per million, by the total cation concentration and multiplying by 100, to obtain "percent sodium." The percent sodium can be plotted against specific conductance on a diagram (fig. 10) to define the suitability class of the water (Wilcox, 1948).

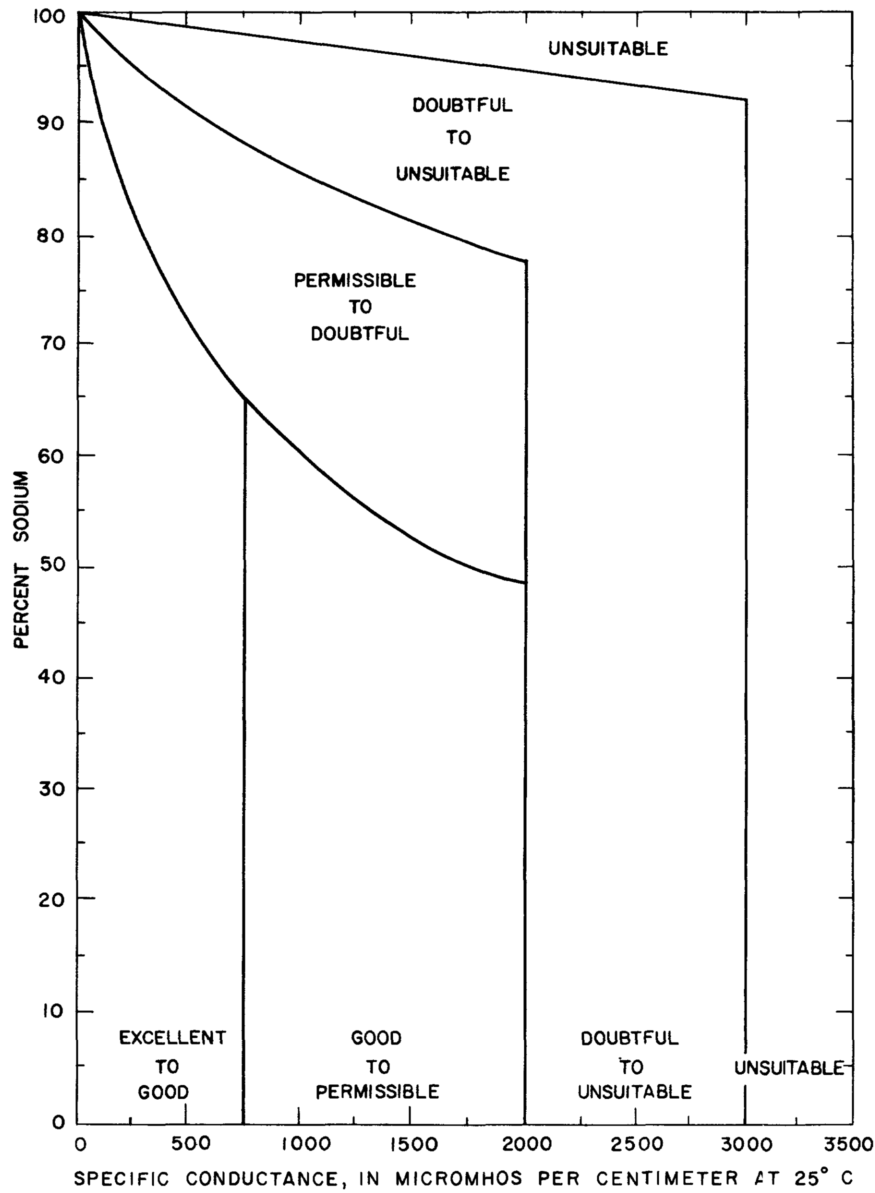

FIGURE 10.—Classification of water according to percent sodium and concentration of dissolved solids expressed as specific conductance. After Wilcox (1948).

The sodium-adsorption-ratio (SAR) is another method for expressing the sodium hazard and is defined by the equation

$$SAR=\frac{Na^{+}}{\sqrt{\frac{Ca^{+2}+Mg^{+2}}{2}}}$$

in which the concentrations are expressed in milliequivalents per liter, or equivalents per million. The sodium hazard as defined by the SAR is divided into four classes, S1 to S4, S1 indicating a water having a low sodium hazard and S4 a water having a very high sodium hazard. The divisions between the classes are delimited by empirical equations and plot as straight lines on rectangular coordinate paper. Thus, the SAR and specific conductance can be plotted on a diagram (fig. 11) to determine the sodium (alkali) hazard and the salinity hazard of a water.

Almost all natural water contains boron, and a trace of boron is essential to plant growth. However, amounts in excess of about 4 ppm are toxic even to boron-tolerant crops. The limit for boron-sensitive crops is 0.33 ppm. None of the water sampled contained boron in sufficient quantities to be toxic to crops commonly grown in the Snake River basin.

Calcium and magnesium tend to precipitate when water having a high content of bicarbonate is concentrated by evaporation. Under ordinary conditions, the reaction does not go to completion, but it can increase the relative proportion of sodium to calcium and magnesium. This reaction has led to the use of the "residual sodium carbonate" concept in classification of irrigation water. Water containing less than 1.25 milliequivalents per liter of residual sodium carbonate are probably safe, those containing 1.25 to 2.5 milliequivalents per liter are marginal, and those containing more than 2.5 milliequivalents per liter are not suitable for irrigation. Residual sodium carbonate is defined by the equation

$$RCS=(CO_3^{-2}+HCO_3^{-})-(Ca^{+2}+Mg^{+2})$$

where the concentrations of the ions are expressed in milliequivalents per liter.

GROUND WATER IN SUBAREAS OF SNAKE RIVER BASIN

The geology and hydrology of the Snake River basin differ greatly from place to place, so it is convenient to divide the basin into ground-water subareas (fig. 12). The following sections summarize the occurrence and availability of ground water in the subareas. Data from subareas not examined during this investigation were gathered from

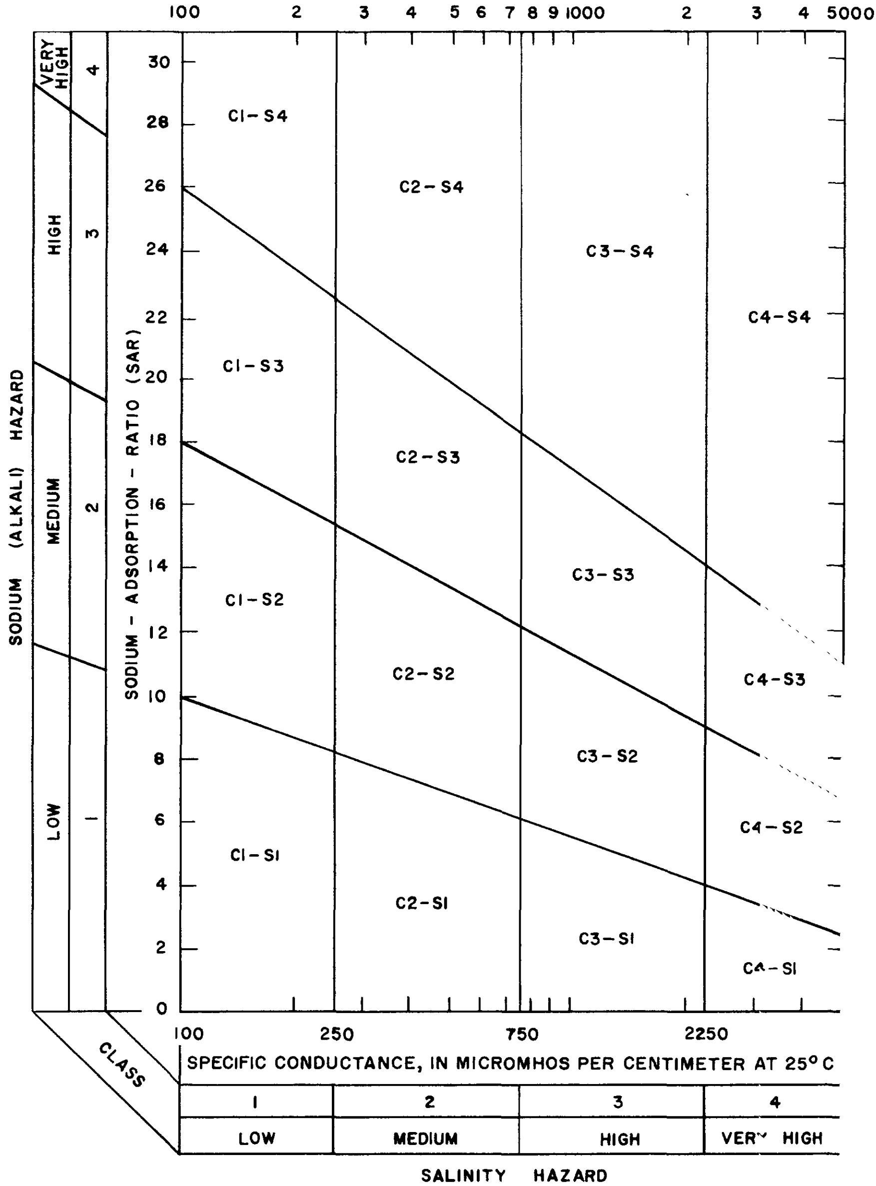

FIGURE 11.—Classification of water according to sodium-adsorption-ratio and concentration of dissolved solids expressed as specific conductance. After U.S. *Salinity Laboratory* staff (1954).

the files and published reports of the Geological Survey and other agencies.

The occurrence and availability of ground water in the mountains included in the Central Idaho Highlands, the Rock Creek Hills, and

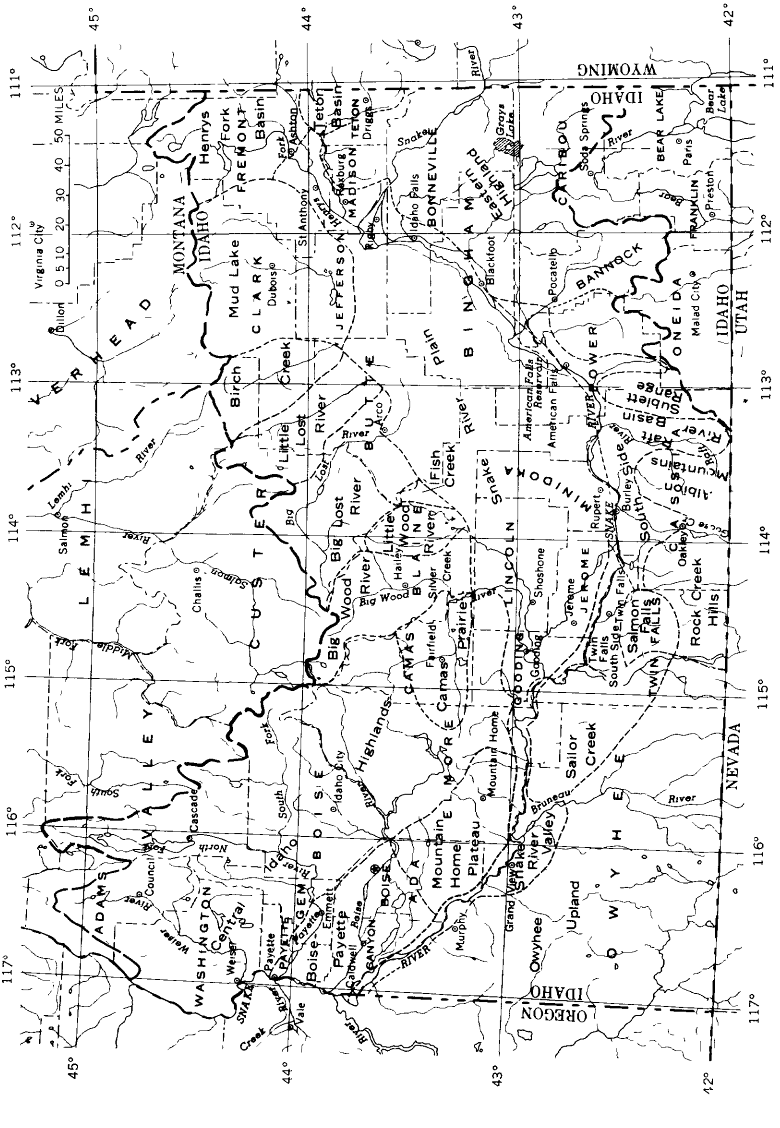

FIGURE 12.—Map showing location of ground-water subareas of the Snake River basin.

the Albion and Sublett Range subareas are not discussed. In general, only small ground-water supplies are available in the mountains because they consist mostly of dense, hard rocks probably low in permeability. Moreover, the possibility that even moderate amounts of ground water will be needed in the areas in the future is remote. However, water in the consolidated rocks and the coarse subsoil of the mountains sustains the base flow of streams and contributes some recharge to lowland aquifers by underflow. Some intermontane valleys, such as those along the Weiser and the North Fork of the Payette Rivers, are underlain by aquifers that might yield considerable quantities of ground water to wells. Practically no data are available for these areas.

The Henrys Fork subarea was not studied, and data about that part of the Snake River basin is sparse. The Henrys Fork subarea contributes to the ground-water resources of the upper Snake River basin and should receive further study.

BOISE-PAYETTE SUBAREA

The Boise-Payette subarea of the Snake River basin consists of the lower parts of the drainage basins of the Boise and Payette Rivers. It is bordered on the north and east by Boise Ridge and other highland areas and on the southwest by the Snake River; it includes parts of Ada, Canyon, Gem, and Payette Counties (fig. 12). The two basins are similar in topographic relief, aquifers, mode and relative amount of recharge and discharge of ground water, agricultural development, and climate. Only the Boise River valley had been studied previously (Nace, West, and Mower, 1957).

The valleys are broad and relief is moderately low, the most conspicuous features being a succession of stream terraces rising steplike from the alluvial plain of the rivers and occurring from less than 1 to several miles from the streams. The terrace scarps range in height from 25 to 200 feet. The altitude of the lowland ranges from 2,135 feet above sea level in the lower Payette River valley to about 2,900 feet south of Boise. A ridge ranging in height from a few hundred to 700 feet separates the valleys. About 350,000 acres is irrigated with water diverted from the Boise River east of Boise, and about 110,000 acres is irrigated with water diverted from the Payette River northeast of Emmett.

The entire subarea is a deep basin floored with relatively impermeable pre-Tertiary rocks. The basin is partly filled with a great thickness of sedimentary and igneous rocks, which include the Payette formation, the Columbia River basalt, and silicic volcanic rocks. These rocks are generally low in permeability, but commonly contain water under artesian pressure. Overlying these materials are several hundred to a few thousand feet of sedimentary materials included in the Idaho formation. These deposits consist of clay, silt, and sand; they also contain artesian water. Permeable beds of terrace and stream gravel as much as 200 feet thick lie on an old erosion surface cut on the Idaho formation. On the south side of the Boise valley, flows of Snake River basalt 5 to 40 feet thick are intercalated in and overlie the gravel. Highly permeable alluvium and windblown deposits mantle much of the region. The areal extent of the formations is shown on the geologic map (pl. 3).

Surface-water irrigation has raised the water table in the developed areas so that the alluvium and terrace gravel are the chief source of unconfined ground water. Yields from wells of 2 to 3 thousand gpm are common. The water table is generally less than 100 feet below the surface and probably averages less than 50 feet. About 25 percent of the irrigated area has a drainage problem owing to the shallow depth to water. Locally, the confining action of hardpan and fine-grained phases of the sediments cause low artesian heads.

The Snake River basalt is an important aquifer south of Nampa, where yields from wells are as much as 3,000 gpm. Elsewhere, the basalt is above the water table.

In the Boise Valley, the water table slopes generally toward the Boise River and westward toward the Snake River, and the ground water drains in those directions. At the south edge of the irrigated area, ground water drains toward the Snake River (Nace, West, and Mower, 1957, pl. 5). No water-table contour map is available for the Payette Valley, but the pattern of irrigation works is similar to that in the Boise Valley. Irrigation water, the main source of recharge, has raised the water table, so that it is near the land surface in much of the area.

The principal source of recharge is infiltrating surface water that is spread for irrigation. Nace, West, and Mower (1957, p. 47) estimated that recharge from irrigation in the Boise Valley exceeds 350,000 acre-feet but is less than 700,000 acre-feet on 350,000 acres of irrigated land. A part of the applied irrigation water may be rejected and run off before it can seep into the ground because the aquifers are full. Conditions probably are similar in the Payette Valley, and, thus, the potential annual recharge from irrigation is between 100,000 and 200,000 acre-feet in that area.

The earliest water-level records for the subarea were collected in the Boise River valley about 1912. Comparison of water-level data collected in the 1930's with the earliest records shows that the water table rose markedly in the intervening period (fig. 13). The rise correlates with the large-scale expansion of the irrigated area, which began about 1905 and was largely completed in 1915. Since the 1930's, the rate

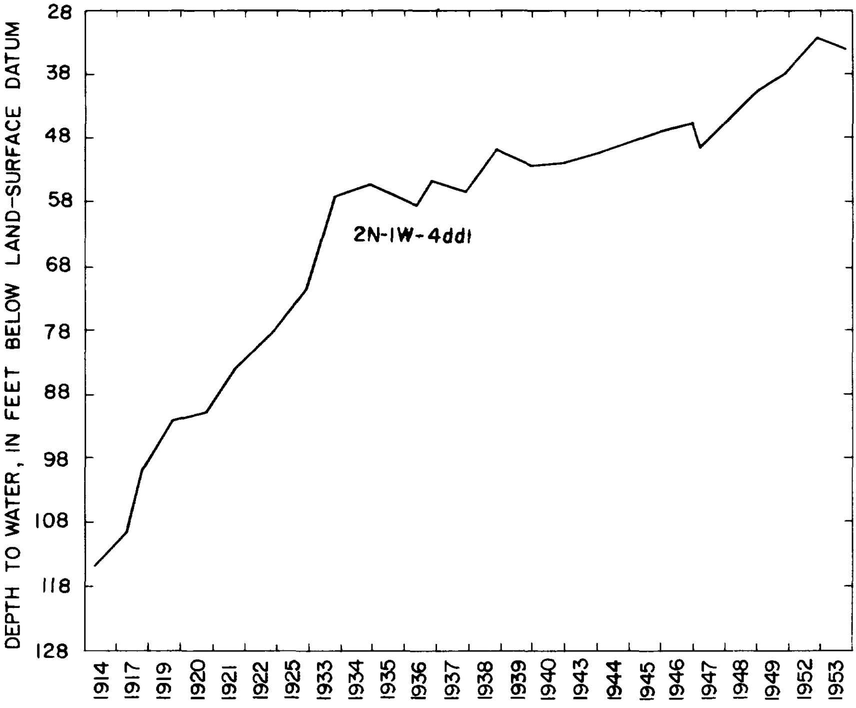

FIGURE 13.—Hydrograph of well 2N-1W-4dd1.

of rise has been less rapid, and in some localities water levels have become stabilized. Water-level records in the Payette valley are sparse. The hydrograph of well 7N-2W-35ab1 indicates that the water table not only is strongly influenced by irrigation but also is more or less stabilized (fig. 14).

Some recharge is derived from local precipitation and by underflow from the highlands on the northeastern side. Precipitation is low in the valleys (less than 12 inches yearly), and much of it restores soil moisture; probably less than half becomes ground-water recharge. An unknown but small amount runs off into the rivers. Yearly precipitation on the highlands immediately adjacent to the valley is 20 or more inches (pl. 2)—but the steep slopes promote rapid runoff. Probably only about one third becomes recharge, and part of that recharge enters artesian aquifers.

The Idaho formation and older rocks of Tertiary age yield small to large amounts of artesian water to wells. Beds of sand and gravel between confining layers of silt and clay in the Idaho formation are the best aquifers. Little is known of the hydrologic properties of the older formations, but they appear to be less permeable than the Idaho. Wells tapping the Idaho formation flow from a few to several hundred

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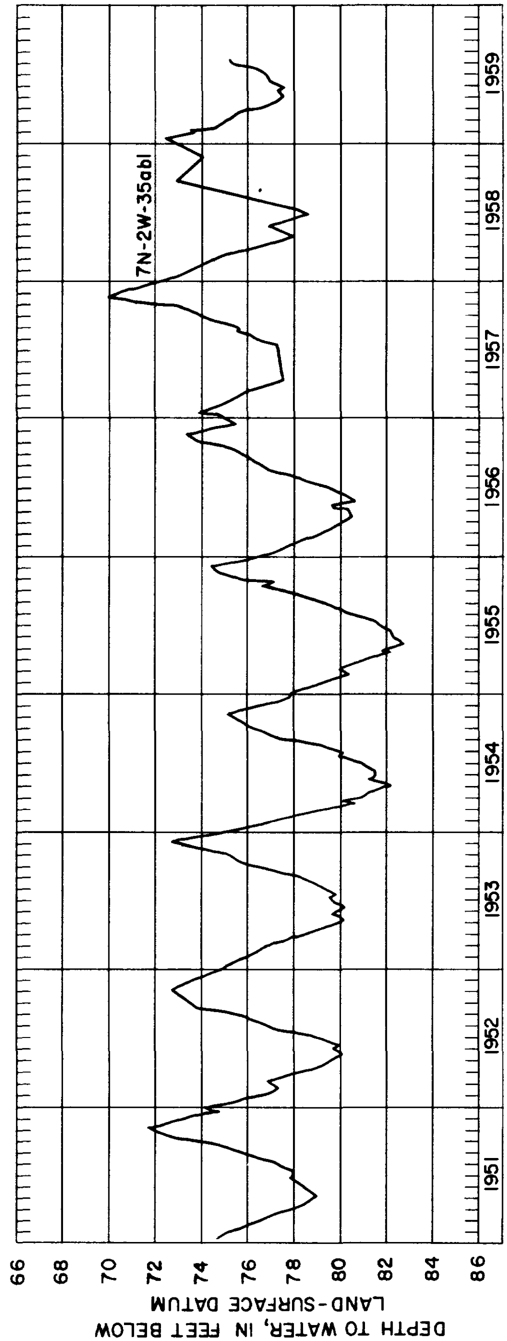

FIGURE 14.—Hydrograph of 7N-2W-35ab1.

gallons per minute, and when pumped some artesian wells yield 1,200 gpm or more. Water from aquifers buried several hundred feet below the surface yield warm water, and along the foothills northeast of Boise deep wells yield hot water. At some places south of Nampa, the Snake River basalt is an artesian aquifer, where confining layers of caliche, impermeable soil, and impermeable beds in alluvium cap the basalt. Wells in basalt flow from 200 to more than 5,000 gpm.

The artesian aquifers are recharged by precipitation on the outcrop area and by infiltrating streamflow and irrigation water in the lowlands. At shallow depth, the artesian and unconfined water are not well separated and merge into each other. Thus, at some places, the readily recharged nonartesian aquifers can transmit water to the artesian aquifers. Upward leakage of artesian water into the soil zone also causes waterlogging of agricultural land.

The trend of water levels in the Boise Valley has been upward since large-scale irrigation with surface water began. The first systematic water-level records were collected in the period 1912–16 and show that the amount of ground water in storage has been increasing for many years. Hydrographs of wells having long-term records show that from about 1915 to 1925 water levels rose 100 feet or more in some places (fig. 15). By 1930, the aquifers were nearly full and the net rise in most areas since then has been small.

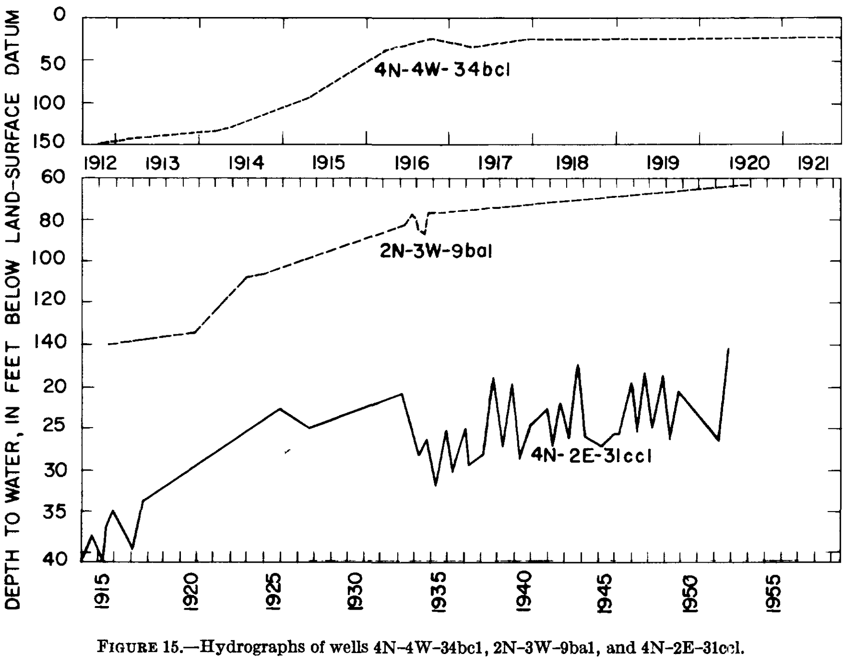

FIGURE 15.—Hydrographs of wells 4N–4W–34bc1, 2N–3W–9ba1, and 4N–2E–31cc1.

The annual range of fluctuation in observation wells in the Boise Valley is 5 to 10 feet. Because the wells are strongly influenced by irrigation, the water levels begin to rise in the spring when water is turned into the canal system. The upward trend continues until about October, when irrigation ceases. The annual water-level fluctuations in representative wells are shown in figures 8 and 16.

Pumping affects the water level for appreciable distances from the pumped well. For example, when wells 3N–2E–26aa1 and 4N–3W–25da1 are pumped, the water levels in nearby observation wells start to decline instead of continuing their normal rise to the October peak. (See fig. 17.)

Water from the Payette and Boise Rivers, which is the principal source of ground-water recharge, is of excellent quality for irrigation at the upstream diversion dams. The quality of the water that enters the Boise-Payette subarea by underflow from nearby uplands and mountains is not known, but it probably is of at least fair quality for irrigation. As surface water infiltrates into the ground, it comes into contact with the soluble minerals in the soil and underlying formations. The longer it is in contact with sediments, the more mineralized it tends to become.

The quality of the ground water in this area varies widely because of the wide variety of water-bearing materials. In general the chemical composition ranges from calcium magnesium bicarbonate waters to sodium bicarbonate and sodium bicarbonate sulfate waters. In the Boise Valley, the sodium concentration increases toward the west, or downvalley. Analyses are lacking for the downvalley part of the Payette Valley, but ground water with a high concentration of sodium is tapped by wells just west of Emmett (Bradshaw, 1954). The chemical quality of water sampled in the Boise and Payette Valleys is summarized in the following table.

Summary of chemical analyses of water in the Boise Valley

[After Nace, West, and Mower (1957). Chemical constituents in parts per million]

Constituent or property	Surface water			Ground water		
	Samples analyzed	Maximum	Minimum	Samples analyzed	Maximum	Minimum
Silica (SiO_2)	9	35	12	60	93	14
Iron (Fe)	3	----------	.00	49	1.4	0
Calcium (Ca)	26	61	7.9	89	87	7.9
Magnesium (Mg)	26	25	Tr.	89	41	.3
Sodium (Na)	16	93	3.7	50	250	7.5
Potassium (K)	16	18	Tr.	55	93	0
Sodium and potassium, calculated as sodium	10	172	3	33	134	1
Bicarbonate (HCO_3)	26	291	36	89	476	54
Sulfate (SO_4)	26	244	2.7	88	309	.8
Chloride (Cl)	26	93	.8	89	97	0
Fluoride (F)	3	.6	.2	50	7.0	0.0
Nitrate (NO_3)	13	5.9	.3	57	41	0
Boron (B)	3	.04	.02	49	.36	.02
Dissolved solids	13	788	51	66	1,040	69
Hardness:						
Total	13	251	21	66	386	24
Noncarbonate	5	31	0	40	214	0
Percent sodium	26	60	14	88	82	5
Residual sodium carbonate..milliequivalents per liter	26	.75	----------	89	4.24	0
Specific conductance..micromhos at 25° C	26	1,160	67	66	1,510	112
pH	18	8.6	6.9	87	8.8	6.6
Temperature °F	5	75	59	73	80	52

A summary of the suitability for irrigation of more than 120 samples of ground water appears in the following table.

Summary of classification of water for irrigation in the Boise-Payette subarea

[After Nace, West, and Mower (1957) and Bradshaw (1954)]

Sodium-adsorption ratio for residual sodium carbonate classification		Number of samples distributed in classes		
Salinity hazard	Sodium hazard	Safe	Marginal	Unsuitable
C1	S1	20	19	0
C2	S1	34	13	2
C2	S1	0	0	1
C3	S1	17	8	1
C3	S2	0	0	2

Samples distributed for percent sodium hazard			
Excellent	Good	Permissible	Doubtful
49	50	20	3

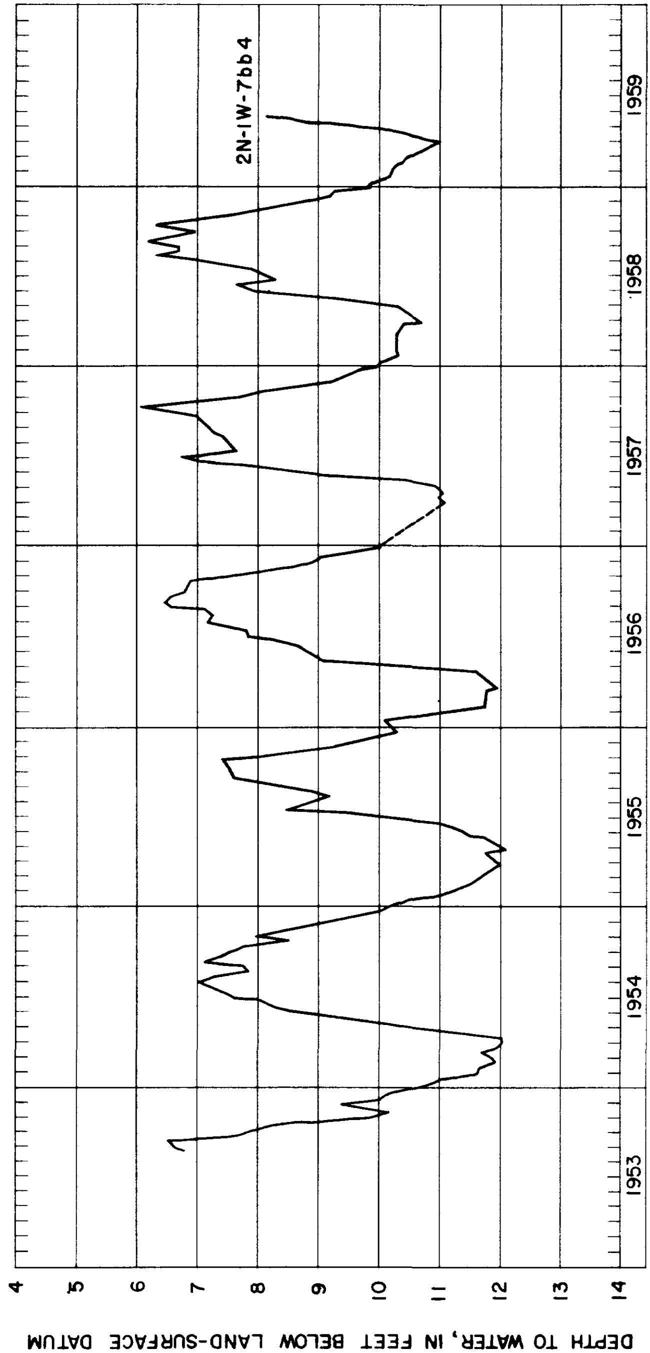

FIGURE 16.—Hydrograph of well 2N-1W-7bb4.

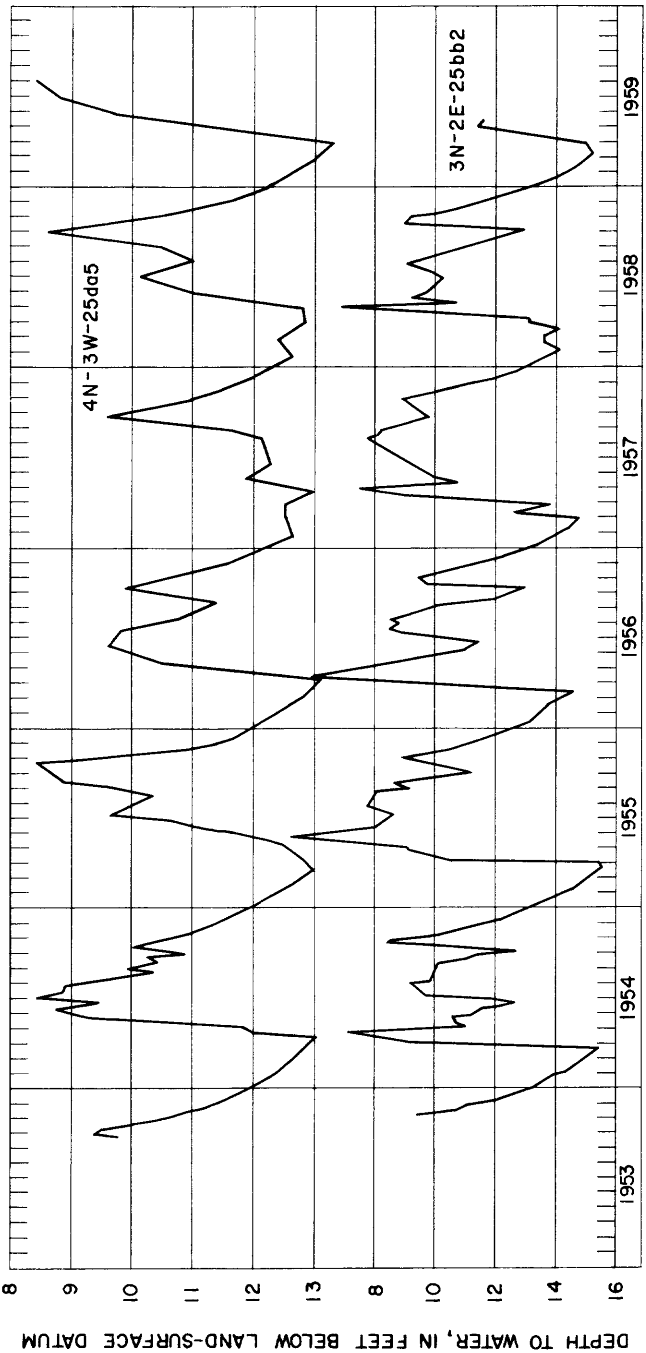

FIGURE 17.—Hydrographs of wells 4N-3W-25da5 and 3N-2E-25bb2.

From the above data, it is obvious that the ground water has a wide range in suitability for irrigation. The geographic distribution of the various types of water is poorly known and should be studied in detail before any large-scale development of ground-water supplies for irrigation is attempted. At some places, water of marginal quality probably could be diluted with surface water to achieve satisfactory quality for use on most soil types.

In general the water is satisfactory for domestic and stock use. However, two samples had excessive fluoride that could cause mottling of children's teeth during calcification, some samples were excessively hard, and three had concentrations of sulfate that are excessive by the standards of the U.S. Public Health Service (1946) for drinking-water supplies.

The principal use of ground water is for irrigation. Nace, West, and Mower (1957) estimated that 128,000 acre-feet is withdrawn annually from irrigation and drainage wells south of the Boise River, principally in the south-central part of the subarea. Much of the water from the drainage wells is used for irrigation. Probably a few thousand acre-feet is discharged from wells north of the Boise River. Stevens (1962) estimated that ground-water withdrawals in the Dry Lake area south of Nampa (not included in the report by Nace, West, and Mower (1957)) was about 9,000 acre-feet in 1957. Since 1957, in the Dry Lake area pumping probably has doubled. The amount of ground water withdrawn in the Payette Valley for irrigation is unknown but probably does not exceed a few hundred acre-feet annually. The total withdrawal from irrigation wells probably is between 150,000 and 175,000 acre-feet annually in the Boise-Payette subarea. An unknown but substantial amount of ground water is discharged by the several hundred miles of open ditches and tiled drains, and much of this water is salvaged for irrigation. The total discharge of ground water into the drains far exceeds the discharge of ground water by the irrigation and drainage wells (Nace, West and Mower, 1957). Ground water is the sole supply for about 20,000 acres of land and supplements the surface-water supply for an unknown additional number of acres.

Ground water is the source of all public supplies and almost all domestic supplies in the Boise-Payette subarea. About 17,000 acre-feet is pumped yearly, of which 13,000 acre-feet is for public supplies. Ground-water withdrawals for manufacturing and other industrial purposes probably average 2,000 to 4,000 acre-feet yearly.

Nace, West, and Mower (1957) estimated that the potential ground-water recharge, that is, water available for recharge, of a part of the irrigated area in the Boise Valley is about 554,000 acre-feet annually. Of this amount, about 230,000 acre-feet is used consumptively, and the remainder is available for development. Extending this estimate to the entire Boise-Payette subarea, the potential recharge is 800,000 to 825,000 acre-feet annually, of which about 500,000 acre-feet is available for use. Data are not available to estimate the amount that is actual recharge or the amount that could be developed. Probably as much as 200,000 to 250,000 acre-feet could be put to use with a resultant benefit to waterlogged land, especially if a substantial amount of the withdrawals were from artesian aquifers. Relief of artesian pressure would increase the efficiency of the present extensive drainage system because the drains then would remove only that water percolating down from the land surface.

MOUNTAIN HOME PLATEAU

The Mountain Home plateau is a part of the Snake River Plain lying in southern Elmore and southeastern Ada Counties (fig. 12). It is a rolling upland plain dotted at some places with volcanic cones or buttes, which rise several tens to a few hundred feet above the plain.

The altitude of the plain ranges from about 2,700 feet in the southwestern part of the subarea to about 3,200 feet near Mountain Home, and the altitude of some of the volcanic cones is more than 3,800 feet. Drainage is ephemeral and intermittent to the Snake River, which flows along the southern edge of the subarea.

The semiarid climate is characterized by warm summers and cool winters. At Mountain Home, the average annual temperature is 49.1° F, and the average annual precipitation is 10.2 inches.

Geologically, the Mountain Home plateau is somewhat similar to the Boise-Payette subarea. A great thickness of silicic volcanic rocks of Pliocene(?) age crops out in the foothills along the northeastern side of the subarea and presumably underlies the subarea at depth. Sedimentary strata of the Idaho formation overlie the silicic volcanic rocks and are at the surface in about one-third of the subarea. Snake River basalt has filled irregularities in the Idaho formation and covers more than half of the plateau. Alluvium and windblown deposits mantle much of the Idaho formation and the Snake River basalt; the alluvium is especially thick in the northern part of the plateau.

Little is known about ground water beneath the plateau. Locally, as at Mountain Home and along the base of the foothills, sand and gravel aquifers contain water at shallow depths, but elsewhere on the plateau, wells must be drilled to depths of a few to several hundred feet to reach ground water in the Snake River basalt and the Idaho formation. The shallow water at Mountain Home and other places is perched above the regional water table. Although at some places the deeper ground water is under slight artesian pressure, the pumping lifts are generally high.

Percolation from intermittent streams that cross the plateau, underflow from the foothills, and seepage losses from irrigation water diverted from the streams are the principal sources of recharge. Local precipitation in excess of that needed to restore soil moisture either runs off into streams or becomes ground-water recharge. Natural discharge is through springs and seeps to the Snake River.

Several hundred acres are irrigated with surface water at Mountain Home, near Mayfield, north of Hammett, and at other scattered localities. Ground water is the source of water for many of the farm and ranch homes, the city of Mountain Home, the Mountain Home Air Force Base, and a few commercial establishments. Wells at the Air Force base reportedly yield 750 gpm from a depth of about 330 feet. Yields of other wells are not known but reportedly are small and generally are accompanied by large drawdowns.

The ground-water supply is adequate for rural and domestic use but is not sufficient for large-scale irrigation because of the low rate of recharge. Pumping lifts are high in much of the area.

More than 400,000 acres of arable land in the plateau is used mostly for grazing. Several plans have been considered for irrigating part or all of the irrigable land with surface water imported from the Boise River basin, the Salmon River basin, or some other nearby basin. No plan for construction has been approved to date. If an area of appreciable size is developed with imported surface water, the present ground-water regimen will be drastically changed. Water levels will rise, owing to seepage losses from canals and deep percolation from irrigated land, and drainage problems, such as those that now plague the Boise-Payette subarea, could develop. However, a rise in the water table would make ground water more accessible for development. Thus, any plan for surface-water development, to make full use of the water, should include provisions to supplement the surface-water supply with ground water. The amount of water that would percolate into the ground is not known, but estimates based on results in similar areas indicate that 30 to 40 percent of water diverted for irrigation would become ground-water recharge.

SNAKE RIVER VALLEY

The Snake River valley includes the narrow lowland along the Snake River from Homedale to King Hill. In the vicinity of Bruneau and Grand View, the lowland extends southward several miles to include the lower drainage basins of the Bruneau River and Little Valley, Shoo Fly, and other creeks (fig. 10). Only the Bruneau-Grand View vicinity (fig. 10) had been studied previously (Littleton and

Crosthwaite, 1957). The area lies several hundred feet below the general level of the Mountain Home plateau. At places the river flows in a narrow canyon cut in basalt and unconsolidated sediments. At other places the river valley widens out to broad valleys, locally called coves. The Bruneau-Grand View lowland south of the river is a series of tributary valleys, dry washes, low hills, gravel terraces, and gently sloping pediments.

The Snake River, the master stream, receives little surface flow from the tributary streams except the Bruneau River. Most of the streams are perennial in their headwater reaches but are intermittent in the Snake River valley except where they receive waste water from irrigated land.

The climate is arid and has cool winters and hot summers. Rainfall averages less than 10 inches annually, and the mean annual temperature ranges from 51 to 55° F.

Much of the Snake River valley is on the southern flank of a deep troughlike basin floored with rocks of pre-Tertiary age having low permeability. Silicic volcanic rocks are exposed in the south edge of the subarea and in the mountains and plateaus to the south. The subarea is underlain principally by the Idaho formation. Basalt layers are interclated in the lower part of the Idaho formation, and, at some places, basalt underlies the Idaho formation and overlies the silicic volcanic rocks. Locally, the Snake River basalt caps the Idaho formation and occurs as intracanyon flows, especially near the Snake River. At some places, pediment and terrace gravel cap the Idaho formation and Snake River basalt. Alluvium occurs along the stream channels and dry washes, and windblown deposits mantle much of the subarea.

The terrace and pediment gravel are above the water table, but they are capable of transmitting to the water table precipitation in excess of that needed to restore soil moisture. Recharge through these deposits is not large because of the generally low rate of precipitation. Locally the windblown deposits contain unconfined ground water, but the areal extent of the saturated deposits is small and they are not important aquifers. The alluvium along the principal streams contains unconfined ground water and yields small to moderate quantities of water to wells having low lifts—especially along the Snake and Bruneau Rivers, where the alluvium is readily recharged with river water.

The Idaho formation that includes intercalated basalt, the underlying basalt, and the silicic volcanic rocks yield small to large supplies of warm artesian water to wells. In the Bruneau-Grand View lowland, wells drilled on land below 2,700 feet in altitude usually flow. Permeable beds in the Idaho formation yield a few to more than 1,200 gpm by free flow. Some pumped wells yield more than 1,500 gpm. Well depths range from 20 feet in alluvium to about 2,500 feet in the other formations and average almost 1,000 feet. Beds of tuff and contact zones between basalt flows commonly are permeable, and yields of a few tens to 900 gpm have been reported. Wells penetrating joints and other fractures in the silicic volcanic rocks yield as much as 4,000 gpm by free flow. Only a few wells are known to produce from the silicic volcanic rocks, and most of them are a thousand or more feet deep.

The silicic volcanic rocks and overlying basalt are recharged by infiltration of precipitation on the plateau and mountains south of the subarea and seepage losses from streams. The ground water migrates northward into the Snake River valley, where it enters the artesian system. The Idaho formation is partly recharged by upward leakage from the underlying volcanic rocks through imperfectly confining beds. Apparently some water migrates upward through fault zones along the south side of the area downstream from the Bruneau River.

Discharge is through seeps, springs, and wells. The Idaho formation is a leaky artesian system, and water moves upward from zones of higher pressure. Dozens of wells in the Idaho formation are uncased or improperly cased, and these permit escape of the deeper water to shallower zones. The extensive areas of alkaline and saline soil in the nonirrigated lowland indicate that much of the upward migrating water evaporates at the surface.

Water levels in the artesian aquifers fluctuate 5 to 20 feet annually (fig. 18). They are highest in the winter, when the pumps are off and some of the flowing wells are shut in, and lowest in summer, when all wells are allowed to flow and the pumps are on. In the Bruneau-Grand View lowland, water levels have declined slowly but steadily for the period of record (fig. 18). Adequate data are not available to evaluate the decline, but it is reasonable to assume that development of the ground water resource probably is in part responsible. The rather sharp decline of water level in well 6S–3E–14bc1 during 1958 probably was caused by the pumping of several nearby irrigation wells. Water-level fluctuations are not available for the rest of the Snake River valley, but they probably are similar to those in the Bruneau-Grand View lowland. Long-term water-level records for wells tapping unconfined aquifers have not been collected.

Chemical analyses of the artesian water indicate that in general it is marginal in quality for irrigation use, especially on fine-grained, poorly drained soils. Chemical analyses of water from the Bruneau-Grand View lowland show moderate to high percent sodium, high sodium-adsorption-ratios, and large amounts of residual sodium car-

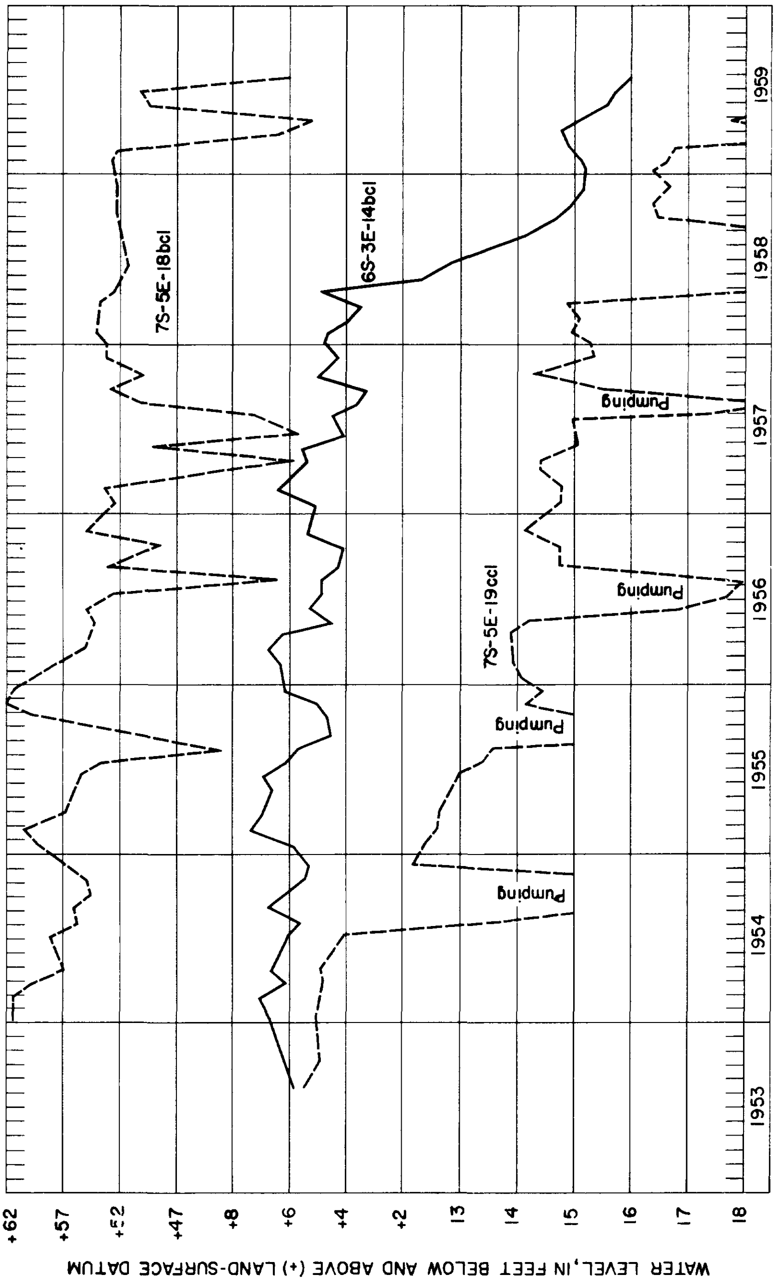

FIGURE 18.—Hydrographs of wells 7S-5E-18bc1, 6S-3E-14bc1, and 7S-5E-19cc1.

bonate. The water is soft to moderately hard, but much of it is unsuitable for domestic use because it contains excessive amounts of fluoride. The following table shows the range in chemical constituents and the irrigation suitability of 24 water samples from the Bruneau-Grand View lowland. Analyses of unconfined water are lacking, but where an aquifer is recharged by infiltration of streamflow the quality is probably better than the artesian water. Where upward leakage of artesian water recharges the unconfined water body, the quality would be similar to that of the artesian water.

Summary of chemical analyses of artesian ground water and classification for irrigation in the Bruneau-Grand View area

[After Littleton and Crosthwaite (1957). Chemical constituents in parts per million]

Constituent or property	No. of samples	Maximum	Minimum
Silica (SiO_2)	36	118	40
Iron (Fe)	20	.60	.00
Calcium (Ca)	36	56	2.4
Magnesium (Mg)	36	4.8	.2
Sodium (Na)	10	278	42
Potassium (K)	10	28	1.0
Sodium and potassium calculated as sodium	26	109	47
Bicarbonate (HCO_3)	36	710	56
Sulfate (SO_4)	36	82	1.9
Chloride (Cl)	36	17	7.0
Fluoride (F)	24	24	.9
Nitrate (NO_3)	25	4.0	.1
Boron (B)	10	.85	.01
Dissolved solids	36	825	216
Hardness: Total	36	159	8
Percent sodium	36	95	35
Residual sodium carbonate ... milliequivalents per liter	24	12.07	.34
Specific conductance ... micromhos at 25°C	24	1,260	271
pH	24	9.4	7.0
Temperature ... °F	36	126	59

Sodium-adsorption-ratio for residual sodium carbonate classification		Samples distributed in classes		
Salinity hazard	Sodium hazard	Safe	Marginal	Unsuitable
C2	S1	5	11	0
C2	S2	0	3	4
C3	S4	0	0	1

Littleton and Crosthwaite (1957) estimated that ground-water withdrawal from artesian aquifers in the Bruneau-Grand View lowland was about 22,500 acre-feet in 1954, a substantial part of which was for irrigation use. Yields ranged from 0.5 to 3,800 gpm. The average yield of 21 of the better wells was more than 1,000 gpm. Since 1954, several irrigation wells have been drilled in the Bruneau-Grand View lowland, and, reportedly, some of the wells yield moderate to large supplies of water.

A few irrigation wells on Castle and Catherine Creeks near Oreana, near Givens Hot Springs, and at a few other places in the Snake River valley tap artesian aquifers. Yields are not known but probably range from a few tens to several hundred gallons per minute.

Wells supply some villages in the valley, as at Homedale, Marsing, King Hill, and others. The water in the village well at Bruneau is not used for drinking because of the high fluoride content and unsavory taste. Many ranches and farms use ground water for stock and domestic supplies, and a few use the hot ground water for heating.

Small to moderate amounts of artesian water probably can be developed for irrigation at favorably situated places in the Snake River valley, but several factors should be considered. Much of the water is of poor to only fair quality and would not be satisfactory for long-term use on some types of soil without soil-amendment practices. Some of the water is too hot to apply directly to cropland and must be held in ponds to cool before use. Because little is known about amounts, sources, and rates of recharge, the amount of ground water that could be developed without seriously lowering the water level is not known.

OWYHEE UPLAND

The subarea here called the Owyhee upland (fig. 12) includes the Owyhee and other Mountains and the adjacent plateau region in Owyhee County. The upland is characterized by a broad, moderately rolling surface cut by deep canyons. Three broad, domelike highlands aligned northward rise several hundred to a few thousand feet above the general plateau surface in the western part of the upland. The northernmost and highest of these is the Owyhee Mountains, which reaches 8,100 feet above sea level. To the south are South Mountain and Juniper Mountain, 7,850 and 6,800 feet above sea level, respectively. The general elevation of the plateau ranges from 5,000 to 6,000 feet above sea level. The area is drained by the Owyhee and Bruneau Rivers, which flow in deep narrow canyons. Many of their tributaries are perennial, and they also have cut deep canyons at many places, especially in their lower reaches.

Annual precipitation ranges from about 8 inches at lower elevations to about 23 inches at Silver City in the Owyhee Mountains. Summers are warm and winters are cold.

The subarea is used mostly for summer grazing of cattle and sheep, and a few small ranches raise some hay by irrigating from streams and springs. Many of the ranches are not occupied during the winter, and some former ranches are now used only as cattle or sheep camps in the summer. About 9,000 acres are irrigated in the Duck Valley Indian Reservation in Idaho and Nevada with water from the Owyhee River.

The Owyhee upland is underlain by silicic volcanic rocks, small local patches of sediments, which may correlate with the Idaho formation, and basalt, which, in part, resembles Snake River basalt. Alluvium is present along some of the stream channels and in a broad area in the south-central part of the county. In the Owyhee, South Mountain, and nearby areas, granitic and sedimentary rocks of pre-Tertiary age are exposed (pl. 3). Columbia River basalt also occurs in the Owyhee and South Mountains.

At some places in the Duck Valley Indian Reservation, the alluvium contains ground water at shallow depth. West of the Indian Reservation, four wells yield water for stock, but it is not known which aquifer they tap. Well 13S–9E–35cd1 in the eastern part of the subarea obtains stock water from silicic volcanic rocks at a depth of 625 feet. Several springs, ranging in discharge from several hundred to less than 1 gpm, issue from silicic volcanic rocks. Many of the springs are used for watering stock and irrigating hay and grass.

Possibly some land could be developed for irrigation with ground water, but the generally low annual rate of precipitation, short growing season, lack of land with a suitable soil cover, long distance from markets, and unknown depth to water and yield of aquifers tend to discourage exploration for ground water.

SAILOR CREEK SUBAREA

A largely unknown region, here called the Sailor Creek subarea, lies in eastern Owyhee, southern Elmore, and western Twin Falls Counties (fig. 10). The subarea has a plateaulike aspect; it consists of a gently to roughly rolling plain and scattered volcanic domes and other hills rising several tens to a few hundred feet above the general land surface. Deep narrow canyons and gorges have been cut in the plain at a few places. Elevations range from about 3,000 feet above sea level in the northern part to about 5,000 feet in the southern part.

All streams are intermittent or ephemeral, the only perennial streams being Salmon Falls Creek and the Snake and Bruneau Rivers, which bound the subarea on the east, north, and west, respectively. The annual rate of precipitation averages 8 to 10 inches, more than half of which falls during the period November to April.

The subarea is underlain by silicic volcanic rocks, the Idaho formation which includes intercalated basalt, and Snake River basalt (pl. 3). Alluvium occurs along the main dry washes and intermittent streams, and parts of the subarea are veneered with windblown deposits.

Little is known about the occurrence of ground water in the Sailor Creek subarea because the area, more than 1,000 square miles, has less than a dozen water wells. A few scattered wells yield water for stock from the Idaho formation, and during part of the year some water is perched above the main water table in alluvium along some of the stream channels. Depth to water in the Idaho formation is estimated to range from 200 to more than 500 feet below the land surface. In the eastern part of the subarea near Castleford, at least three wells produce moderate quantities of water for irrigation from silicic volcanic rocks at depths of 250 to 350 feet.

Reportedly, the Sailor Creek subarea contains a large acreage of irrigable land. The sparse data indicate that both the permeability of the Idaho formation and recharge to it are low. The water-bearing characteristics of the volcanic rocks underlying the Idaho formation have not been explored. In other localities they yield small to large quantities of water to wells, but the great depth of wells and high pumping lifts may prohibit exploration and development of these potential aquifers.

TWIN FALLS SOUTH SIDE PROJECT SUBAREA

The Twin Falls South Side Project subarea was not studied during this investigation, and only a brief summary is presented here. The subarea is in northern Twin Falls County just south of the Snake River (fig. 12). It is elongated, about 40 miles long and 12 miles wide, and includes about 200,000 acres irrigated with water diverted from Milner Dam on the Snake River.

The climate is characterized by moderately cold winters and hot, dry summers. The average annual precipitation at Twin Falls, the largest city in the area, is less than 10 inches. The mean annual temperature is 49°F.

The subarea is underlain by Snake River basalt which has thin interflow beds of windblown sediments at many places, and is mantled by windblown deposits and alluvium. Silicic volcanic rocks and sediments and basalt of the Idaho formation are exposed in the canyons of the Snake River and Salmon Falls Creek and crop out in the extreme northwest corner of the subarea. Sedimentary and silicic volcanic rocks were penetrated at some places in a few deep wells.

Before irrigation started in 1905, the depth to water was generally 50 to 400 feet and probably averaged about 250 feet (Stearns, Crandall, and Steward, 1938). The windblown sediments between the basalt flows impeded downward percolation of irrigation water and also tended to restrict lateral movement of ground water. As a result of irrigation, water levels rose rapidly, and the first waterlogged areas appeared in 1912. Water levels in some wells rose as much as 200 feet in 8 years. By 1928, water levels apparently had begun to stabilize, the rate of water-level rise having become exceedingly slow; the depth to water averaged 40 to 60 feet. The tile drains, tunnels, and wells, which were constructed to alleviate waterlogging, discharge into creeks and drainageways, which usually were dry before irrigation began. Thus, Rock Creek, the principal stream across the subarea, now discharges an average of 200 cfs., almost all of which is waste and drainage water from the project. Many small springs and seeps have appeared in the south wall of Snake River canyon. Stearns, Crandall, and Steward, (1938, p. 129) estimated that about 6 million acre-feet of water entered ground-water storage from 1906 to 1928.

Little ground water is used for irrigation because the surface-water supply is adequate for most of the area. Many of the farms have wells for domestic use, and the smaller cities and villages use ground water for municipal supplies. Surface water from the canals is used in the Twin Falls municipal system and supplements the Buhl water supply.

In general, water from Snake River basalt is hard and contains a large amount of dissolved solids. Some water is reported to have an unsavory taste. Forty-three samples collected from representative wells contained 468 to 1,340 ppm of dissolved solids; hardness as calcium carbonate ranged from 214 to 600 ppm and averaged 424 ppm (U.S. Bureau of Reclamation, 1946).

SALMON FALLS SUBAREA

The Salmon Falls subarea is in southern Twin Falls County within Tps. 11–14 S., Rs. 15–17 E., of the Boise meridan and base line (fig. 12). It lies south of the Twin Falls Canal Co. tract between the Rock Creek Hills on the east and Salmon Falls Creek on the west. Most of the following information on the subarea was taken from the report by Fowler (1960).

The subarea is part of the Snake River Plain. It is gently rolling, and the general slope is north toward the Snake River. The surface of the plain is modified by shallow drainageways and by small volcanic hills that rise a few hundred feet above the general land surface. Elevations range from about 4,100 feet above sea level at the northern end to 5,200 feet in the southern part.

The only perennial stream, Salmon Falls Creek on the west boundary of the subarea, flows in a narrow canyon as much as 400 feet deep. A few ephemeral streams cross the subarea from the south and discharge into the Snake River.

The climate is characterized by warm summers and moderately cold winters. Average annual precipitation at Hollister near the center of the subarea is 9.35 inches, of which about 55 percent falls during the period November to April. In the mountainous watershed on the south and east, the rate of precipitation is much greater, as much as 30 inches on the highest part (pl. 2), and is estimated to average about 13 inches. Much of the precipitation in the mountains is snow.

Silicic volcanic rocks are the oldest rocks exposed. They crop out in the canyon of Salmon Falls Creek, in the hills south of Rogerson, and east of the area. They probably underlie the entire subarea at depths ranging from less than 200 to more than 1,000 feet, and many wells throughout the subarea end in silicic rocks. The rocks are generally massive, the individual units ranging in thickness from about 20 to 500 feet. The color varies from black, brown, and lavender, to light gray; the texture ranges from porphyritic to glassy. At many places, the rocks are jointed and fractured. In the hills to the south and east they are extensively faulted and tilted, and at many places they lie on rocks of pre-Teritary age. Undoubtedly faults underlie the Salmon Falls subarea, but they are concealed by the overlying formations. In the mountainous part of Idaho and Nevada that contributes water to the Salmon Falls subarea, extensive deposits of white, gray, and buff-colored fine- to coarse-grained water-laid ash are interbedded with the silicic volcanic rocks. However, in the Salmon Falls subarea, little ash has been identified in drill cuttings. The performance of wells indicates that the permeability of the formation generally is low but that joints and other fractures locally transmit moderate amounts of water.

At some places, drill holes penetrate "old lake beds" overlying the silicic rocks. The strata consist of alluvial clay, silt, sand, and gravel and are deposited on the silicic rocks. The sediments are below the water table at most places and are the main source of water in several wells, but because of their low permeability, they are not a suitable source of water for extensive irrigation development.

Most of the subarea is underlain by Snake River basalt. The basalt consists of many flow sheets; the sheets range in thickness from a few to several tens of feet. Joints and other fractures impart some permeability to the basalt, as do openings between successive flows. The surface of the flows is somewhat weathered and eroded, and many of the flows are separated by lenses of windblown or water-laid sediments. Although the basalt is much less permeable than at most places in the Snake River Plain, it is the source of most stock, domestic, and irrigation supplies of water.

Alluvium and windblown deposits of fine sand and silt mantle much of the subarea. Alluvium consisting of clay, sand, and gravel occurs along the ephemeral streams. The windblown deposits are above the water table, but in the western part of the subarea the alluvium in Deep Creek valley contains some perched water that is the source of small supplies to stock and domestic wells. The saturated thickness and areal extent of the alluvium is small, and the alluvium is not an important source of irrigation water.

GROUND WATER

At some places in the southeastern part, the silicic rocks contain water under sufficient artesian pressure to cause a few wells to flow. At other places, the depth to water is 600 feet or more, and artesian pressures apparently are low or nonexistent. The water in the basalt also may be under slight artesian pressure because some of the fine-grained interbedded sediments could imperfectly confine ground water. Spirit leveling to wells and water-level measurements revealed many irregularities in the altitude of the water surface, and drillers report water at various depths was "lost" when the wells were drilled deeper.

The generalized water-table map (pl. 4) shows that ground water moves northward and northwestward. The slope of the water table ranges from 200 feet per mile in the southeast corner of the subarea to 50 feet per mile in the northwestern part. The direction of slope has been modified by leakage from the reservoir of the Salmon River Canal Company, by leakage from artesian aquifers on the east side, and by infiltration of surface water from the Twin Falls Canal Company's tract on the north side.

Water levels range from above the land surface in a few of the artesian wells in the southeast to more than 800 feet below the surface a few miles northwest of Hollister. Water levels have not been measured systematically, so the range of water-level fluctuations and long-term trends are not known. However, the yields of many of the flowing wells in the southeastern part of the subarea have decreased, and well owners have installed pumps or dug trenches to the wells to obtain water. Drilling new wells has not increased the yield of ground water, and water levels have continued to decline. Apparently the amount of water that can be developed in the southeastern part is small.

Probably only a small amount of precipitation on the subarea becomes ground-water recharge because the rate of precipitation is low. It is estimated that 6.5 inches of the 9.35 inches of average annual precipitation is required to sustain the sparse native vegetation. Some of the remainder is retained in small ponds and reservoirs and used for irrigation, and some becomes surface runoff out of the area to the north.

Higher rates of precipitation on the hills and mountains to the east and southeast contribute recharge to artesian aquifers in their outcrop area. Because of steep slopes, the ephemeral streams quickly carry water to the lowland during the snowmelt period and recharge the alluvium at the mouths of canyons and draws by seepage losses.

An important source of recharge is seepage loss from the reservoir and distribution system of the Salmon River Canal Company. An estimated 20 percent of the gaged surface inflow plus all the ungaged inflow to the Salmon River Canal Co. reservoir is lost to the ground-water reservoir (Fowler, 1960). Seepage loss from the main canal may be 30,000 acre-feet per year (U.S. Dept. Agriculture, 1956), and seepage loss of irrigation water delivered to farms is estimated to be 20 percent. Fowler (1960) estimated that total recharge derived from Salmon Falls Creek is 25,000 acre-feet annually and that the total recharge to the ground-water reservoir from all sources is 100,000 acre-feet. The following table showing sources of recharge is from his report.

Estimated average annual increment to aquifers in the Salmon Falls subarea

[After Fowler (1960)]

Source	*Quantity (acre-feet)*
Direct precipitation	5,000
Upland to east and southeast	15,000
Reservoir losses	25,000
Seepage from canals	40,000
Deep percolation from irrigated farms	10,000
Total (rounded)	100,000

Chemical analyses of 26 samples of ground water indicate that, for irrigation, the water generally has a low sodium hazard and a low to high salinity hazard. Many of the samples had a medium to high salinity hazard and one had a very high hazard. According to the residual sodium carbonate classification, three samples were marginal to unsuitable. One sample of surface water from the reservoir of the Salmon River Canal Co. indicates that the water is satisfactory for all irrigation uses.

Four of the samples contained nitrate in excess of 50 ppm. This concentration of nitrate possibly indicates contamination from organic materials. According to standards of the U.S. Public Health Service (1962), water containing more than 45 ppm should not be used for domestic purposes. Many of the samples were hard and one was very hard. The results of the chemical analyses of water samples in the Salmon Falls subarea are summarized in the following table.

Summary of chemical analyses of ground water and suitability of water for irrigation in the Salmon Falls subarea

[After Fowler, 1960. Chemical constituents in parts per million; 24 samples analyzed]

Constituent or property	Typical (well 12S-16E-36bb1)	Maximum	Minimum
Calcium (Ca)	85	210	9
Magnesium (Mg)	31	137	3.2
Sodium (Na)	166	220	8.5
Potassium (K)	21	39	.8
Bicarbonate (HCO_3)	340	410	41
Sulfate (SO_4)	6	720	7
Chloride (Cl)	238	354	3
Nitrate (NO_3)	6.8	227	.1
Boron (B)	.3	.7	.00
Hardness—total	340	1,130	36
Residual sodium carbonate ... milliequivalents per liter	0	4.15	0
Specific conductance ... micromhos at 25° C	1,410	2,820	4.6
pH	8.2	8.5	7.2
Temperature ... °F	56	99	52

PRESENT AND POTENTIAL DEVELOPMENT OF GROUND WATER

The subarea contains more than 80,000 irrigable acres, of which 30,000 acres receives some water from the Salmon River Canal Co.'s system, the acreage varying somewhat with the amount of water available in the reservoir. Ground-water sources supply some supplemental irrigation water to lands served with surface water. About 2,000 acre-feet is pumped annually from 6 of the best irrigation wells. Nine other irrigation wells, all having generally low yields, are used only occasionally or not at all. Ground water is used for domestic, public, and stock supplies and for a swimming pool.

Two of the best wells are a few miles east of the reservoir of the Salmon River Canal Co. and reclaim water that is lost by seepage from the reservoir. The wells are between 450 and 500 feet deep, and pumping lifts range from 200 to 300 feet. One well yields 1,800 gpm and the other 2,250 gpm. Additional ground water could be developed, but the quantity available is not known.

Just south of the high-line canal of the Twin Falls Canal Co., exploration for ground water has resulted in one good irrigation well and two that yield small supplies. The depth to water ranges from 200 to 400 feet, and the drawdown ranges from 45 to 210 feet. Yields range from 650 to 1,500 gpm. Further exploration may result in development of moderate quantities of irrigation water. Recharge is by underflow through the Salmon Falls area and from seepage losses of irrigation water in the Twin Falls South Side Project.

A successful well in the east-central part of the subarea may encourage further exploration nearby. Here, the depth to water is from 125 to 150 feet, but no estimate of the potential yield of the aquifer can be made. Data on irrigation wells in the Salmon Falls subarea are shown in the following table.

Records of irrigation wells in the Salmon Falls subarea

[Depth to water below land surface: (R), reported. Yield, reported. Drawdown, reported]

Well	Owner	Altitude of land surface	Year drilled	Depth of well	Casing		Character of aquifer	Water level			Pump		Yield (gpm)	Drawdown (feet)	Remarks
					Diameter (inches)	Depth (feet)		Depth to water below land surface	Date	Altitude of water	Type	Horsepower			
11S-16E- 2dd1	O. A. Schnitiker	4,115.0	1955	500	20	------	Cinders	282.3	8-24-56	3,833	Turbine	150	1,360	45-50	
6db1	Edward Babcock	4,148.1	1957	975	20-12	860		294.6	4-16-57	3,854	do	100	680	150	
11S-17E-23ad1	Harold Nelson	4,196.1	1957	640	20-18-12	514	Sand	194.2	4-25-57	4,002	do	125	750	210	
11S-18E-32cc1	Oran Butler	4,158.4	1948	300	14	------	Gravel	48.4	4-24-57	4,110	do	75	1,350	245	Pumps "dry" after a few hours.
12S-15E-26aa1	Lee Leichliter	------	1949	625	12	415	Sand	315(R)	------	------	do	60	450	80	
12S-16E-36bb1	Roy Owens	4,480.1	1952	108	6	11	Basalt	44.5	4-16-57	4,436	do	15	225	10	
36db1	John Rayl	4,542.8	1929	------	12	------	------	20.6	9-20-56	4,520	do	5	450	100	Unused. Formerly flowed.
36db2	do	4,535.6	1929	------	12	------	------	------	------	------	------	------	------	------	Do.
12S-17E-18dd2	Glenn Nelson	------	1957	230	16	35	------	135(R)	------	------	Turbine	100	2,500	45	
13S-15E-12bc1	William Hoops	4,576.6	1957	550	20	------	Sediment and basalt.	175.8	6- 5-57	4,401	do	100	630	------	
13S-16E- 3bb2	Martin Knudson	------	1954	------	20	------	Basalt and silt	87.1	8-22-56	------	do	20	180	160	Used one season.
13S-17E- 6bc1	Ora Jones	4,677.1	1903	600	12	------	Crevice in rock	3.8	4-24-57	4,673	do	130	2,700	50	
6bc2	do	------	1903	600	12	------	do	------	------	------	do	120			
14S-15E-21db1	Ralph Schnell	4,939.9	1954	500	16	------	Gravel	170(R)	------	4,770±	do	150	2,250	20	
28ac1	do	4,972.9	1957	455	16	------	Sandstone and cinders.	190.6	9-12-57	4,782	do	150	1,800	95	

In summary, the available data indicate that small to moderate amounts of ground water can be developed for irrigation at a few places in the subarea but that the amount of water available is not sufficient to develop all the available land. It might be possible to import water from the Snake River to irrigate a substantial part of the lower or northern part of the subarea. Such development would tend to build up the water table in the newly developed locality by seepage losses from canals and by deep percolation from irrigated fields, as has occurred in the Twin Falls South Side Project subarea. Possibly the augmented supply of ground water would be sufficient to supplement the supply of imported surface water.

SOUTH SIDE SUBAREA

The Snake River Plain and valleys south of the Snake River between Rock Creek in Twin Falls County and the Portneuf River is here called the South Side subarea (fig. 12). Parts of the plain and some of the valleys have been studied by Fader (1952), Mower (1954), Nace and others (1961), Stearns, Crandall, and Steward (1938), Stewart, Nace, and Deutsch (1952), West and Fader (1953), and West (written communication, 1955). Crosthwaite (1957) summarized ground-water development in the South Side subarea. Fieldwork for the present report was confined to the lower Goose Creek valley in the vicinity of Oakley and Burley, where data were collected on several irrigation wells.

The Snake River Plain part of the subarea is gently rolling terrain locally dotted with volcanic cones rising several tens to a few hundred feet above the general surface. The principal adjoining valleys are broad north-sloping basins merging with the Snake River Plain. Prominent northward-trending mountains separate these valleys. The principal valleys or basins are Goose Creek, Raft River, and Rockland Valley.

The subarea contains a large acreage of irrigable land, part of which has been developed with water from the Snake River, Goose Creek, the Raft River, Rock Creek in Power County, Rock Creek southeast of Twin Falls, and a few of the smaller streams. Ground water is used to supplement surface water at some places and is the only supply for other land. Much irrigable land is used only for stock grazing.

The lowland part of the subarea is generally semiarid and has moderately to severely cold winters and hot dry summers. The annual precipitation ranges from less than 10 inches on the Snake River Plain in the western part of the subarea to about 24 inches in the higher mountains (pl. 2).

Rocks of pre-Tertiary age consisting of quartzite, sandstone, shale, limestone, dolomite, metamorphics, and granite are exposed in the mountains and presumably underlie the Snake River Plain and adjacent valleys. Silicic volcanic rocks and associated pyroclastic sediments crop out in some of the mountain ranges and are present at many places beneath the valleys. These rocks yield small to moderate amounts of water to irrigation wells. In most places the water is under artesian pressure. The Snake River basalt underlies much of the Snake River Plain part of the South Side subarea and yields small to large supplies of water to irrigation wells. Lake beds and fluviatile deposits are present in some of the valleys and are intercalated with Snake River basalt at some places. Most of the lake sediments are fine grained and have low permeability. Alluvium in tributary valleys and along the Snake River yields moderate to large quantities of water to wells.

DRY CREEK REGION

The Dry Creek region is north of the Rock Creek Hills and south of the Snake River in eastern Twin Falls and northwestern Cassia Counties.

Unconfined ground water occurs at depths of 25 to 100 feet below the land surface in alluvium that mantles the Snake River basalt and silicic volcanic rocks in the central part of the area. Yields range from 50 to 450 gpm. Basalt and cinder beds in the central and northern parts yield small to large amounts of water to irrigation wells. The depth to water ranges from 35 to 40 feet near Murtaugh to more than 450 feet on the slopes of the volcanic buttes.

The silicic volcanic rocks and associated sediments yield small to moderate amounts of artesian water in the south. Static water levels are usually less than 200 feet below the surface, but pumping during the irrigation season may lower the water level several hundred feet in some wells. Yields of wells in the silicic volcanic rocks are not predictable because mineral deposition and alteration has reduced the permeability of the formation at some places, and leaching has increased the permeability at other places. Faulting has tended to offset permeable beds against impermeable beds and thus has restricted the movement of ground water.

The artesian aquifers are recharged by underflow from the Rock Creek Hills. The water-table aquifers in the basalt and alluvium are recharged by infiltrating surface water used for irrigation, by precipitation, and by leakage from the underlying artesian aquifers. West (written communication, 1955) estimated that the total recharge from all sources may be about 110,000 acre-feet annually, and, of this amount, 70,000 acre-feet may be available to the unconfined aquifers.

Contour lines representing the water table (pl. 4) show that the general slope is north and northwest toward the canyon of the Snake River. In the west and central parts, ridges on the water table result from recharge from the Twin Falls South Side Canal. Contours on the piezometric surfaces of the artesian aquifers are not shown because almost all wells in that part tap more than one aquifer, each with a different hydrostatic pressure.

The hydrograph of well 10S–19E–25ba1 (fig. 19) shows typical water-level fluctuations in a well drilled into Snake River basalt in a locality not influenced by heavy pumping. The annual fluctuation is 20 to 35 feet, but the net decline during the period of record has been small. The hydrograph of well 11S–20E–10dc1 (fig. 20) shows fluctuations in an irrigation well tapping basalt. These fluctuations probably are typical of wells tapping the basalt aquifer in the region. Some wells in basalt have little drawdown due to pumping, and others have several tens of feet drawdown, the variation being caused by differences in permeability of the basalt and the interbedded alluvium. Because well 11S–20E–10dc1 is pumped almost continuously during the irrigation season, it is difficult to separate fuctuations caused by pumping and those caused by natural seasonal changes. The maximum annual fluctuation is about 30 feet, and the net decline for the period of record is about 5 feet.

Water levels in the silicic volcanic rocks fluctuate greatly and continually decline. The hydrograph of irrigation well 12S-19E–2bb1 (fig. 19) shows a seasonal fluctuation of as much as 160 feet and a net decline of about 80 feet. An observation well in a heavily pumped part of the region shows the same trend. For example, the water level in well 11S–19E–31cd2 (fig. 20) fluctuates 25 to 40 feet each year and had a net decline of about 20 feet in 7 years.

The number of irrigation wells in the Dry Creek region increased from 31 in 1946 to 213 in 1954. In 1959, about 250 irrigation wells were supplying water to 15,000 acres and were supplementing the surface-water supply to 5,000 acres served by Dry and Rock Creeks. Ground-water withdrawals increased from 6,000 acre-feet in 1946 to 53,500 acre-feet in 1954. Withdrawal in 1959 was estimated to be 60,000 acre-feet. Most of the irrigation pumpage is in the central and southern parts because the northern part is adequately supplied with surface water. It is estimated that 10,000 acres of irrigable land remain to be developed. The artesian aquifers are completely developed and locally may be overdeveloped, as indicated by the water-level fluctuations (fig. 20) and reported interference between wells. More water could be developed from the Snake River basalt because it yields moderate amounts of water to wells, recharge is rapid, and water levels have not declined significantly. However, there is

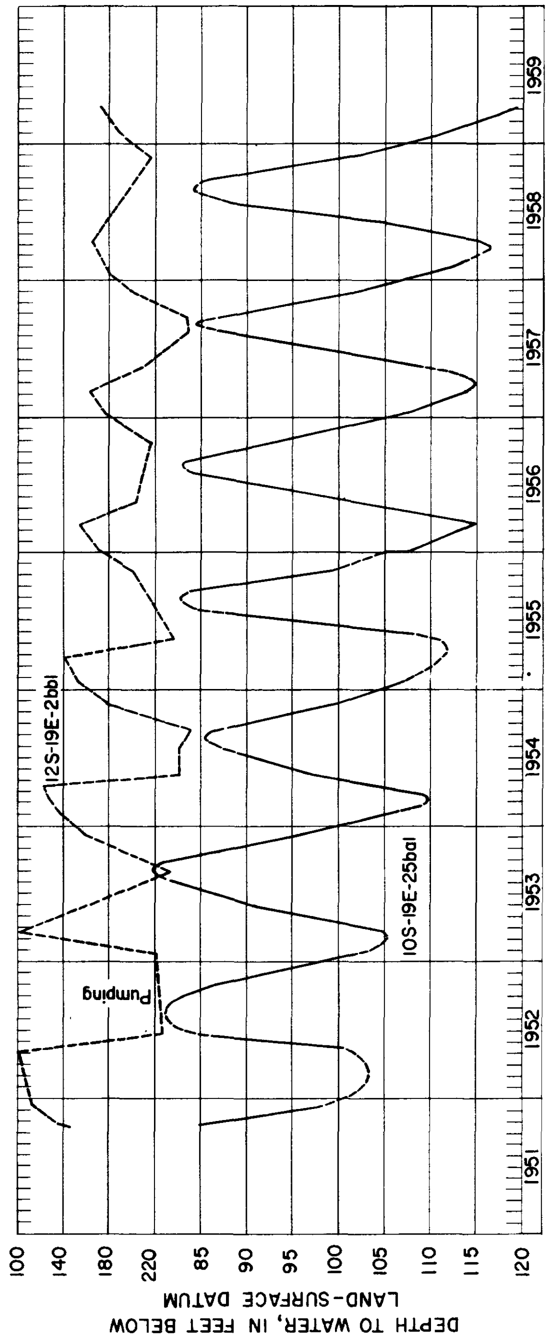

FIGURE 19.—Hydrographs of wells 12S-19E-2bb1 and 10S-19E-25ba1.

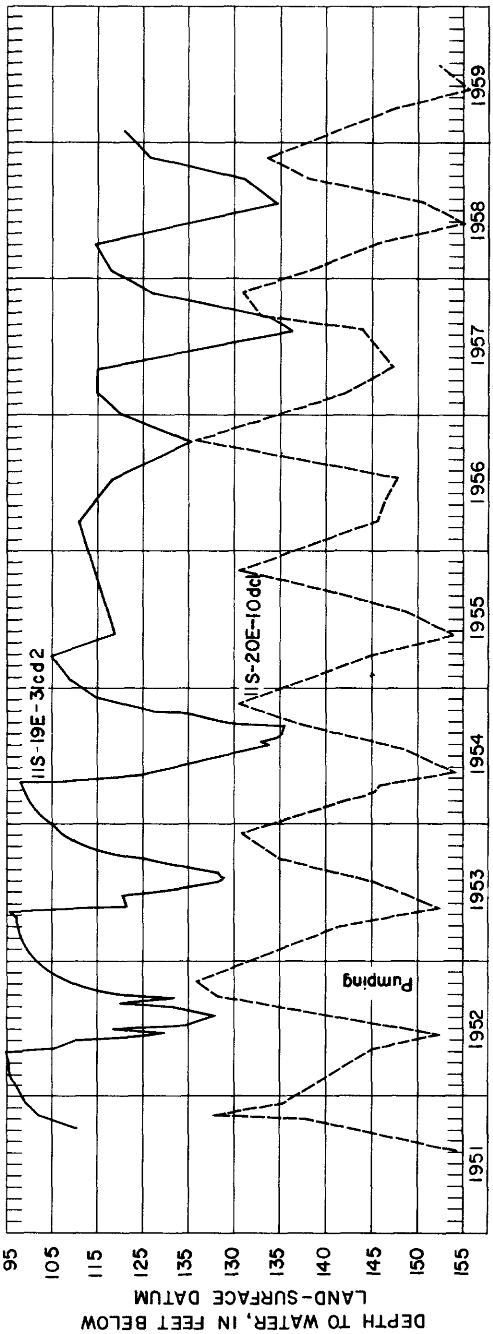

FIGURE 20.—Hydrographs of wells 11S-19E-31cd2 and 11S-20E-10dc1.

no incentive to develop ground water in the northern part, where surface water diverted from the Snake River is abundant.

Water from Rock and Dry Creeks is used to irrigate some land in the southern part of the Dry Creek area. About half the total discharge of the streams, or 18,500 acre-feet, is used for irrigation. The rest is not usable because there are no storage structures on the streams.

LOWER GOOSE CREEK VALLEY

The lower Goose Creek valley consists of the roughly triangular area south of the Snake River between the Rock Creek Hills and the Dry Creek area on the west and the Albion Range on the east. It includes the Golden Valley, Oakley, and Burley districts of Crosthwaite (1957). Except for the northeastern and northwestern parts, which are underlain by Snake River basalt, the floor of the lower Goose Creek valley is underlain by alluvium (pl. 3). About halfway between Oakley and Burley, three low mounds of silicic volcanic rocks protrude through the alluvium.

Basalt flows (probably Snake River basalt) are interbedded with alluvium and fine-grained sediments at depths of one to several hundred feet throughout most of the area. Silicic volcanic rocks underlie the basalt and sedimentary rocks in much of the area, but subsurface data are not sufficient to delineate their areal extent. Silicic volcanic rocks and rocks of pre-Tertiary age crop out in the Rock Creek Hills and the Albion Range.

The occurrence of ground water in the lower Goose Creek valley is diverse. In the southern part, alluvium, basalt, and silicic volcanic rocks yield small to large amounts of water to irrigation wells. Wells tapping the alluvium are 50 to 500 feet deep, and the depth to water ranges from 25 to 275 feet. Drawdown caused by pumping ranges from 15 to 150 feet. Wells that range in depth from 500 to 1,500 feet usually penetrate basalt interbedded with the valley-fill material. Some of the deeper wells penetrate the underlying silicic volcanic rocks. Apparently the water in the deeper rocks is under slight artesian pressure, but the water levels are lower than those in the shallow alluvial aquifers, and pumping lifts are higher. Yields range from 200 to 1,100 gpm in the alluvial aquifers and from 200 to 3,000 gpm in the basalt and silicic rock aquifers. Pumping lifts are as much as 450 feet. In general, lifts are higher and yields lower in the southwestern part of the valley.

South and west of the high-line canal of the Burley Irrigation District, irrigation wells obtain water from the Snake River basalt at depths of 275 to 450 feet. The average pumping lift is about 350 feet. The basalt yields moderate to large quantities of water to wells. The drawdown usually is small to moderate. Possibly a few of the deeper wells obtain some water from silicic volcanic rocks, but the evidence is inconclusive.

The alluvial aquifers in the southern part of the valley are recharged by underflow from the adjacent highlands and by percolation of irrigation water supplied to farms from the Goose Creek Reservoir. The underlying volcanic rocks are recharged by underflow from the highlands and possibly by leakage from the overlying alluvial aquifers.

In the northern part of the valley, the alluvium underlying the Burley Irrigation District has become saturated with irrigation water diverted from the Snake River. Because the alluvium overlies fine-grained sediments that are nearly impermeable, the water in the alluvium is perched above the main water table. The main water table is 250 to 450 feet below the surface. Recharge to the main ground-water reservoir is by underflow from the east, south, and southwest and by downward leakage from the perched zone.

Water-level fluctuations in the alluvial aquifer have been observed in well 13S–22E–9dc1 (fig. 21) about 4 miles north of Oakley. The water level rose a few feet or remained steady during the period 1948 to 1951. It declined steadily from 1952 to 1956 owing to a series of dry years in which recharge was less than in previous years. Since 1957, the water level has recovered somewhat, but, because ground-water withdrawals for irrigation have increased, the yearly water-level fluctuation is greater than it was during the earlier period of record.

Ground-water withdrawals for irrigation in the southern part of the valley in 1958 are estimated at 25,000 to 30,000 acre-feet; 60,000 to 70,000 acre-feet was pumped from basalt in the northern part. Data available are insufficient to estimate the quantity withdrawn from the unconfined aquifers, inasmuch as many wells tap both the shallow and deep water-bearing zones. The city of Burley and a few private well owners in the Burley Irrigation District pump some of the perched water from the alluvium for irrigation.

Much arable land is available for irrigation development especially in the central and western parts of the valley. However, pumping lifts are high, and at some places yields are small. Several wells in T. 12 S., Rs. 20 and 21 E., have been abandoned because of unsatisfactory yields.

All the water in Goose Creek is stored in the Goose Creek Reservoir for use on about 15,000 acres in the southern part of the valley. Ground water is pumped to augment the surface-water supply on part of the 15,000 acres. Small areas are wholly or partly irrigated with water from small tributary streams, such as Cottonwood, Birch, Basin, and Willow Creeks. About 48,000 acres is irrigated in the northern

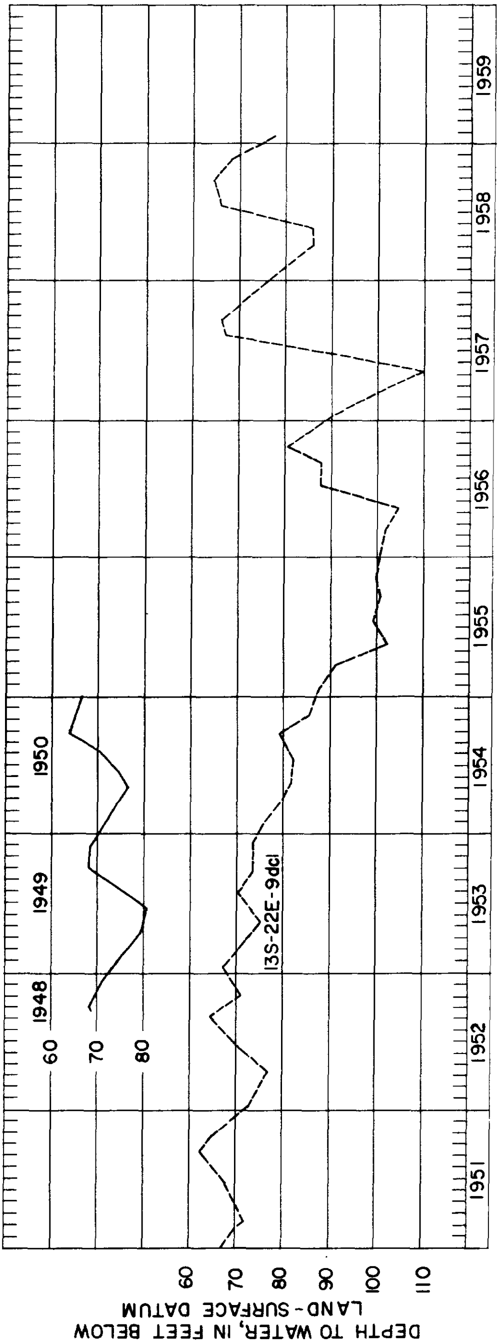

FIGURE 21.—Hydrograph of well 13S–22E–9dc1.

part of the valley with water diverted from the Snake River at Minidoka Dam.

RAFT RIVER BASIN

The Raft River rises in Utah and flows generally northward to the Snake River. In Idaho, the Raft basin is a broad alluvial valley bounded by the Malta Range on the west and the Sublett and Black Pine Ranges on the east. A basalt plain occupies the northern part of the valley, where it merges with the Snake River Plain. Lake beds and volcanic rocks underlie the alluvium. Most of the developed land lies along the axis of the basin. In 1954 about 20,000 acres was irrigated with surface water diverted from Raft River and its tributaries, and 25,000 acres was irrigated wholly or in part with about 60,000 acre-feet of ground water. Estimated withdrawal in 1955 was 87,000 acre-feet (Nace and others, 1961). More recent estimates are not available, but the withdrawal in 1959 probably exceeded 100,000 acre-feet.

Because nearly all the suitable surface water in the basin is used for irrigation and because much arable land (estimated to be about 350,000 acres) is undeveloped, development of ground water has been rapid and intensive. In response to a request of the Idaho Department of Reclamation to study the amount of ground water available for development, the Geological Survey made an investigation in the basin (Nace and others, 1961). The principal conclusions of that report follow:

1. The sources of recharge are infiltrating precipitation, seepage from streams, and infiltrating irrigation water.
2. The average annual volume of precipitation on the entire drainage basin is 1.3 million acre-feet. Of this amount, about 184,000 acre-feet runs off or infiltrates to the ground-water reservoir, and the remainder evaporates from the soil or is transpired by native vegetation. Part of the surface- and ground-water supply is used for irrigation, and some of this is transpired by crops. About 10,000 acre-feet of water is discharged by the Raft River to the Snake River annually. The net amount of unused and uncommited ground-water that leaves the basin by underflow is estimated to be 130,000 acre-feet yearly (in 1955).
3. The ground-water quality is poorly known, but records show that water from some sources is unsuitable for irrigation on some types of soil.

More than 250 irrigation wells probably are in use in the basin; most of them are near the river along the axis of the main valley. The approximate number of wells in use is difficult to estimate because of constantly changing conditions. Some wells are idle some years, others are abandoned, some are being reconditioned, and new ones are being drilled. The first wells were shallow wells dug or drilled in alluvium near the river. As development progressed, the deeper aquifers were expored, and some wells were drilled farther up the slopes from the river.

Irrigation wells yield 100 to 3,125 gpm, and wells capable of yielding as much as 900 gpm from the alluvium are widely distributed. Wells in the basalt plain at the north end of the basin yield as much as 2,500 gpm. Specific capacities range from 5 to 325 gpm. The depth to water near the river is only a few feet, and many irrigation wells are only 25 to 50 feet deep. Along the sides of the basin and in the basalt plain, the depth to water may be more than 250 feet.

Comparison of water-level fluctuations in heavily pumped localities with those remote from pumping indicate that ground-water withdrawals have not greatly lowered the water table. Hydrographs of wells 13S–26E–24aa1 and 14S–27E–33ca1 (fig. 22), which are in or near areas of heavy ground-water withdrawls, show that water levels remained more or less steady until about 1953, when a downward trend began. The records for 1957 and 1958 indicate that the downward trend may be leveling off. Well 15S–25E–6ab1, which is in a valley tributary to the Raft River and remote from pumping, has a similar trend (fig. 22). Precipitation at Strevell is plotted along with the hydrographs so that water-level fluctuations and rainfall may be easily compared. The decline in water levels follow a decline in precipitation that began in 1950 and ended in 1954. Well 9S–26E–10dd1 is in the basalt plain just south of Lake Walcott. This well has a long-term trend similar to the above wells. The well is remote from pumped areas, and ground-water recharge is from seepage losses from Lake Walcott and underflow from the northeast (pl. 4). Thus, water-level trends throughout the Raft River basin are similar, and ground-water withdrawals have not been the major cause of net water-level declines.

In 1959, the U.S. Bureau of Reclamation collected and analyzed 17 water samples from wells in the northern half of the valley mostly in Tps. 10–12 S. The residual sodium carbonate and sodium-adsorption-ratios indicated that the water represented by the samples had a low sodium hazard. Of the 17 samples, 8 had a medium, 7 a high, and 2 a very high salinity hazard.

The estimate of 350,000 acres of arable undeveloped land (p. 88) does not consider the character of the soil, topographic suitability of the land for irrigation, the chemical character of the ground water that might be used, and other factors. Nevertheless, the perennial ground-water yield of the basin obviously is inadequate for all the

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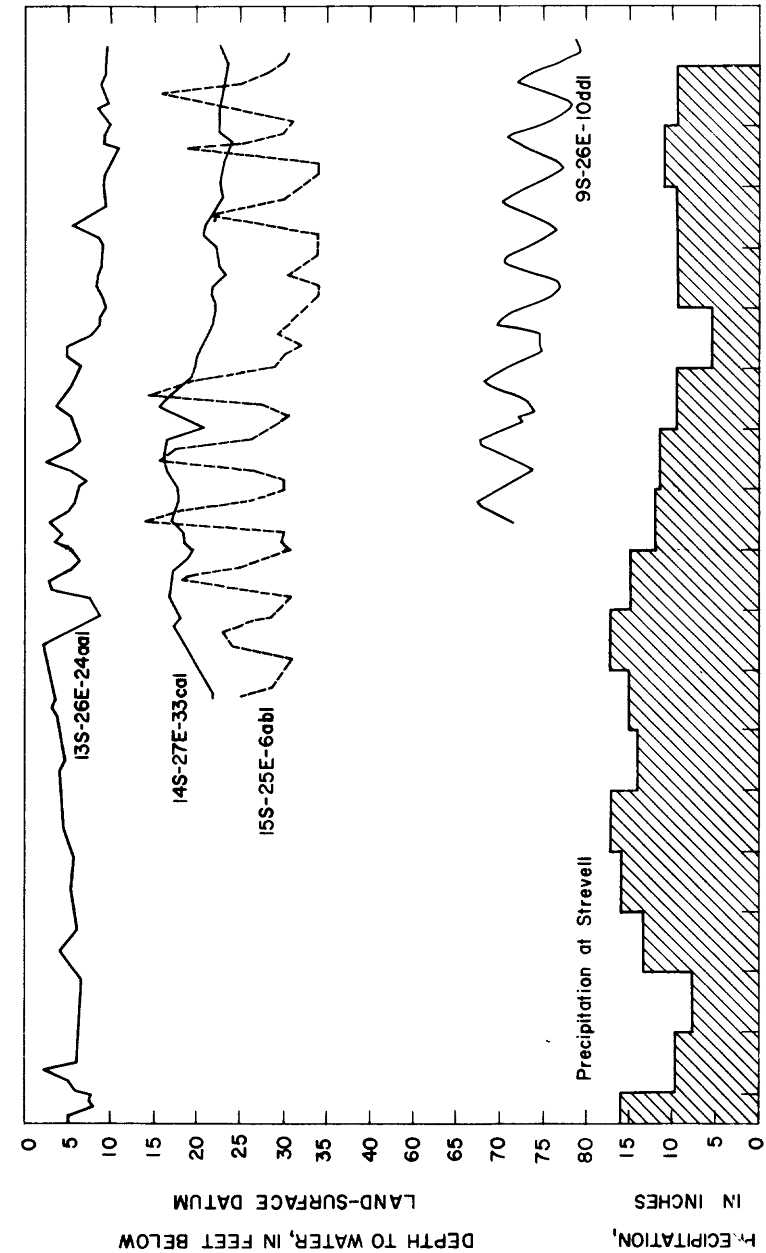


FIGURE 22.—Hydrographs of wells 13S-26E-24aa1, 14S-27E-33ca1, 15S-25E-6ab1, and 9S-26E-10dd1, and precipitation at Strevell.

irrigable land. Of the 100,000 acre-feet of water estimated to have been withdrawn in 1958 for irrigation, probably only about half was consumed by evapotranspiration. The remainder returned to the ground-water reservoir or ran off. Because the water table is near the land surface in much of the area, recharge is prompt. Net withdrawals during any single irrigation season are estimated to be 50,000 acre-feet. Probably not more than 70,000 acre-feet, or about half of the 130,000 acre-feet of the ground water which leaves the basin, could be withdrawn without seriously lowering water levels.

ROCKLAND VALLEY-MICHAUD FLATS DISTRICT

The Rockland Valley-Michaud Flats district includes the area south of the Snake River and American Falls Reservoir, east of the Sublett Range, and west and north of the Deep Creek Mountains. Rockland Valley has gently to steeply rolling terrain underlain by volcanic rocks and sediments of Tertiary age and basalt. The basalt may be correlative with Snake River basalt. Alluvium is present along the narrow floors of the creek valleys. Few geologic or hydrologic data are available for the valley.

The Michaud Flats consist of a narrow, low-lying area adjacent to the American Falls Reservoir and the Snake River. To the south is higher rolling land, which merges with the foothills and mountains. The area is underlain by silicic volcanic rocks and associated sediments, lake beds and, locally, Snake River basalt. Alluvium is present along the stream channels.

Drainage is to the north. The major streams are Rock Creek which drains Rockland Valley, and Bannock Creek, which crosses the eastern part of the Michaud Flats. Each discharges about 13,000 acre-feet per year.

The principal aquifers in the Michaud Flats are sedimentary, pyroclastic, and volcanic rocks. Ground water occurs under perched, unconfined, and artesian conditions. The perched water-bearing zones are thin and of local extent. The unconfined and artesian aquifers yield several hundred to as much as 4,000 gpm to irrigation, municipal, and industrial wells with drawndowns of 6 to 100 feet. The depth to water in the lowland area ranges from 10 to 200 feet and averages 50 to 70 feet. The average yield is estimated to be 1,000 gpm. Some wells have "sanded up" or caved, owing to poor construction practices. The best aquifers are in the eastern part of the Michaud Flats, where coarse sand and gravel beds yield large quantities of water to wells.

The water-table contour map (pl. 4) shows that the water table in the southwestern part of the Michaud Flats slopes to the northwest and west. Much of the ground water is tributary to the American Falls Reservoir. However, the southwestern part of the reservoir and the Snake River locally may be above the water table. The deeper artesian aquifers may extend beneath the reservoir and not be directly connected to it.

Ground-water recharge is chiefly from precipitation on the district and underflow from the adjacent hills and highlands. In the Michaud Flats, irrigation water recharges the perched and water-table aquifers.

Water-level measurements in observation wells show that the water table and the piezometric surface have declined about 1 foot since collection of records began (fig. 23). Wells 6S–32E–27ad1 and 7S–31E–13dc1 had a net decline of 1 to 2 feet. Both wells are in shallow water-table aquifers 1½ to 2½ miles from areas of heavy ground-water withdrawals. Well 6S–33E–20ab1 taps an artesian aquifer near an area irrigated with ground water. The net decline in water levels was about 1 foot. Well 7S–31E–1bc1 is in an area of heavy ground-water withdrawals and again the net decline has been about 1 foot. However, all wells do not show a decline; well 8S–30E–23dc1 is near an area of ground-water withdrawal but shows a net rise of about 3½ feet. The available records indicate that the slight decline in water levels may not be due entirely to ground-water withdrawals. Weather Bureau records at the Pocatello Municipal Airport show that precipitation has been below average for the past 10 years and more than 25 percent below average for 6 of the last 8 years. It seems likely that climatic factors caused part of the decline.

In 1958, 27 wells pumped 6,500 acre-feet of water for 2,800 acres in the Michaud Flats Project of the U.S. Bureau of Reclamation, near the town of American Falls. Private irrigation and industrial wells, mostly in the eastern part of the Michaud Flats, pumped about 8,000 acre-feet of the ground water and irrigated about 3,000 additional acres for a total of about 6,000 acres in the Michaud Flats. Total withdrawal in 1958 for irrigation, municipal, industrial, and domestic uses is estimated to have been 15,000 acre-feet.

When the Michaud Flats Project is complete, about 11,000 acres will be irrigated. About one-third of the project will be supplied with ground water and two-thirds with water pumped from American Falls Reservoir. The U.S. Bureau of Indian Affairs is developing 21,000 acres on the Fort Hall Indian Reservation in the eastern part of the Michaud Flats with water from Palisades Reservoir. Deep percolation and return flow of surface water in these two projects should more than offset any depletion of ground-water inflow to American Falls Reservoir caused by pumping. The sediments underlying the surficial materials are fine grained at some places, and possible waterlogging of agricultural land could result unless efficient irrigation methods are used.

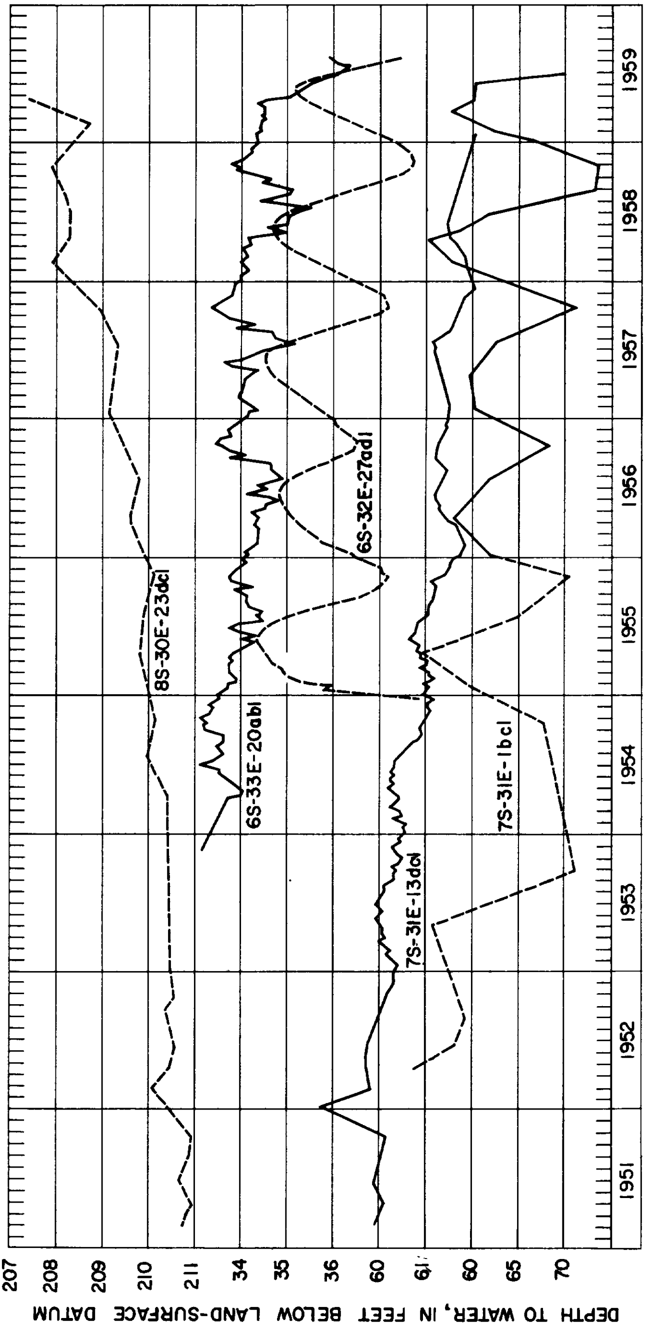


FIGURE 23.—Hydrographs of wells 8S-30E-23dc1, 6S-33E-20ab1, 6S-32E-27ad1, 7S-31E-13dc1, and 7S-31E-1bc1.

The two Federal projects will develop almost all the available area just south of American Falls Reservoir, but higher rolling lands at the south margin of the projects might be developed with ground water. Nothing is known about the aquifers or their ability to yield water to irrigation wells in the higher area.

Much of Rockland Valley is dry-farmed, and some spring and creek water is used to irrigate small areas. Apparently much land is available for irrigation, but no surface reservoirs have been built and few attempts have been made to develop ground water. Water yield of Rockland Valley has not been studied. Streamflow records are sparse and inadequate to be of much value in estimating surface runoff, and ground-water conditions have not been studied. Fifty thousand acre-feet of surface and ground water is arbitrarily estimated to be discharged annually from Rockland Valley to the Snake River Plain.

EASTERN HIGHLAND SUBAREA[1]

The high outlying land east of the Snake River Plain between Pocatello and Rexburg (fig. 10) includes many diverse landforms, drainage systems, and geologic formations. The subarea was not studied for this investigation, and only a few irrigation wells were inventoried.

The topography ranges from moderately rolling surfaces on foothill and lowland areas to steep mountains. With few exceptions, the valley floors contain but little irrigable land. The valley of Marsh Creek, a tributary of the Portneuf River, and the upper Portneuf River valley are the notable exceptions. Some upland areas are broad basins ringed by low ridges; Blackfoot Marsh Reservoir and Grays Lake are in such basins. Altitudes range from 4,400 feet above sea level near Pocatello to more than 9,000 feet on some of the highest mountains. (The Wyoming part of the Snake River basin is, at some places, more than 13,000 feet above sea level, but little of the Wyoming drainage is considered in this report.) The agricultural land is generally not above 6,500 feet.

The principal drainage basins are the Portneuf, Blackfoot, and Snake Rivers. Some of the watershed drains to the Teton River. Tributary streams of lesser importance are Marsh Creek, which empties into the Portneuf River near McCammon, and Willow Creek, a tributary of the Snake River.

[1] Much of the information on the subarea is taken from Stearns, Crandall, and Steward (1938), Mansfield (1920, 1927, and 1952), and West (1956).

Precipitation ranges from an average of 10 inches at lower altitudes near the Snake River Plain and in some of the upper drainage areas of the Portneuf River to more than 20 inches on the higher mountains (pl. 2). Some places in Wyoming receive almost 60 inches of precipitation. Temperatures are lower and growing seasons are shorter than in previously described valleys and basins.

Almost all the subarea is underlain by rocks of pre-Tertiary age, which have been folded, faulted, and deeply eroded. Theses rocks probably are generally low in permeability. Throughout extensive areas they are mantled with silicic volcanic rocks and associated sediments of clay, silt, sand, conglomerate, ash, and pumice—all of Tertiary age. Apparently, the Tertiary rocks blanketed the entire area and subsequent erosion has exposed the older rocks. At some places, such as the rolling upland south of Ririe, the volcanic rocks and coarse-grained sediments yield moderate to large quantities of water to wells. The volcanic rocks and associated sediments have been faulted and tilted so that weak artesian pressures have developed at some places.

Snake River basalt crops out extensively in the headwater areas of the Portneuf and Blackfoot Rivers and Willow Creek and at other places. The basalt was emplaced in canyons and valleys cut in the older rocks. In the valley of the upper Portneuf River near Bancroft, a few wells obtain large quantities of ground water at shallow depth from basalt. According to Stearns, Crandall, and Steward (1938, p. 227), backwater of the Blackfoot Marsh Reservoir leaks through basalt into the Bear River drainage system. Nothing is known about ground-water conditions in basalt in the remainder of the Blackfoot River drainage basin and in the Willow Creek drainage basin.

Alluvium in the lower Portneuf River, Marsh Creek, and upper Snake River valleys, which is readily recharged by infiltration from streams, contains large quantities of ground water. Municipal and industrial wells at Pocatello and irrigation wells in the Marsh Creek basin obtain substantial supplies of water from the alluvium.

The Portneuf, Blackfoot, and Snake Rivers and Willow Creek have an average annual discharge of 187,500, 256,000, 4,980,000, and 157,000 acre-feet, respectively (U.S. Geol. Survey, 1956)—equivalent to 3.5, 5.2, 16.2, and 4.75 inches of precipitation, on the respective drainage basins. The major reservoirs that control the surface runoff are Portneuf-Marsh Valley Reservoir, Blackfoot Marsh Reservoir, Grays Lake, Jackson Lake (in Wyoming), and Palisades Reservoir. The volume of precipitation on and runoff from the major drainage basins are summarized in the following table.

Water yield of basins tributary to the eastern Snake River Plain

[Average precipitation computed from isohyetal map (pl. 2). Runoff for period of record; not adjusted for reservoir storage, length of record ranges from 7 to 46 years]

Basin (above stream-gaging station)	Area (acres)	Average precipitation (inches)	Volume of precipitation (acre-feet)	Runoff		Remainder (acre-feet)
				(acre-feet)	(inches)	
Portneuf River [1] at Pocatello	838,400	15.6	1,090,000	187,500	3.5	902,500
Blackfoot River [2] near Shelly	581,800	19.1	925,000	256,000	5.2	669,000
Willow Creek [3] near Ririe	398,100	16.0	530,000	157,000	4.75	373,000
Snake River [4] near Heise	3,681,300			4,980,000	16.2	

[1] Flow partly controlled by Portneuf-Marsh Valley Reservoir (capacity 16,400 acre-feet).
[2] Flow largely controlled by Blackfoot Marsh Reservoir (capacity 413,000 acre-feet). In some years receives some water from Grays Lake.
[3] Flow partly controlled by Grays Lake.
[4] Flow controlled by Palisades Reservoir (capacity 1.2 million acre-feet) and Jackson Lake (capacity 847,000 acre-feet).

Ground-water contributions to the Snake River Plain are not known. Stearns, Crandall, and Steward (1938) estimated that the underflow from the Portneuf River, mostly through alluvium, was 50,000 acre-feet annually, but presumably most of this is discharged into American Falls Reservoir. Underflow from the other streams would be through silicic volcanic rocks and associated sediments, inasmuch as the volume of alluvium where the streams enter the Snake River Plain is small. West (1956) estimated that potential recharge on the apron of silicic volcanic rocks and associated sediments and basalt that blanket the western slopes of the foothills in the northeastern part of the Fort Hall Indian Reservation is 0.44 acre-foot per acre per year (all precipitation during the growing season plus 50 percent of the winter precipitation was assumed to be evapotranspired). In the absence of data from stations at higher elevations from which to compute the distribution of precipitation and because West's method estimates only water that might be available for recharge, it is not practical to extend this method to the mountainous areas. By applying the method to the northwest slopes of the highland areas where they dip toward the Snake River Plain and assuming that 25 to 50 percent of the water available for recharge actually becomes ground water, ground-water recharge can be estimated roughly. There are 550 square miles, or 350,000 acres, between the southeast edge of the plain and the higher part of the foothills, where they merge with the mountainous areas. Annual ground-water recharge from precipitation in this area is estimated to be between 40,000 and 75,000 acre-feet ($0.44 \times 350{,}000 \times 0.25$ and $0.44 \times 350{,}000 \times 0.5$). The ground water moves by mass underflow through the apron of silicic volcanic and sedimentary rocks to merge with the ground water in the plain.

Water in the Portneuf River and its tributaries is used to irrigate 33,000 acres upstream from Pocatello. That part not evapotranspired in the basin flows into American Falls for use downstream. Water from Blackfoot Marsh Reservoir and a small amount from Grays Lake is used on 47,000 acres on the Snake River Plain part of the Fort Hall Indian Reservation. The eastern edge of the plain between the Snake River and the foothills receives water from Willow Creek, the Snake River, and a few minor tributaries. After the streams leave the foothills, their waters are mingled in a complicated canal system. In Idaho, water from a few streams tributary to the Snake River above Heise is used to irrigate several hundred acres. Some hay and meadow land is irrigated in the upland areas of all the streams.

Ground water has not been extensively developed. The city of Pocatello obtains a substantial part of its municipal water supply from wells in alluvium, and several industrial concerns utilize the same aquifer. Reportedly, closely spaced wells in the southern part of Pocatello yield 500 to 1,500 gpm with little drawdown and little well interference. In the Marsh Creek valley of the Portneuf River, several irrigation wells obtain moderate amounts of ground water from alluvium. In the upper Portneuf River valley northwest of Bancroft, irrigation wells in basalt yield large quantities of water from depths of 20 to 100 feet. Silicic volcanic rocks and coarse-grained sand, gravel, ash, and pumice yield moderate quantities of water to irrigation wells on the rolling uplands southeast of Ririe and northeast of Rexburg. Elsewhere, the alluvium, basalt, silicic volcanic rocks, and sediments have been little explored for irrigation supplies About 100,000 acre-feet of ground water is withdrawn annually for all purposes in the eastern highland between Pocatello and Rexburg.

Ground-water irrigation probably will increase in areas of present development because of substantial acreages of undeveloped land and an adequate ground-water supply. Some land now served with surface water has an insufficient supply for full production, and ground water is available at some places to supplement surface water, but there are no large contiguous areas (several thousand to tens of thousands of acres) suitable for development. The foreseeable ground-water expansion, therefore, will be modest compared to that in many other areas in the Snake River basin.

CAMAS PRAIRIE [2]

Camas Prairie extends westward from the northwest margin of the Snake River Plain and is 25 miles north of Gooding (fig. 2). It is the westernmost of the major drainage basins tributary to the plain along

[2] Most of the information on the Camas Prairie is taken from Walton (1960).

its northern margin. Camas Creek joins the drainage of the Big Wood River basin at Magic Reservoir. The Camas Creek drainage basin is 24 miles wide and 40 miles long.

The basin is a structural depression, probably formed, at least in part, by faulting. The Soldier Mountains consist chiefly of granitic rocks and rise to an altitude of 9,000 feet; they form the north flank of the basin. The south flank is formed by low hills of silicic volcanic rocks of Tertiary age and basalt of Pliocene and Pleistocene age. The basin has been partly filled with lake deposits and alluvium of Pleistocene age. The lower (eastern) end of the basin was blocked by lava flows, which spread across the outlet ponding the water of Camas Creek to form a lake. The lake deposits, which consist of clay, silt, and fine sand, are intertongued with stream and deltaic deposits around the margin of the lake. After the basin was filled to the level of the outlet, the lake disappeared; later deposits consisted entirely of stream-laid alluvium.

Precipitation on Camas Prairie averages 15 to 16 inches annually. Winters are long and moderately cold. Summers are short and dry, and temperatures generally range from hot in the day to cool at night. The growing season is short, averaging 80 days.

The agricultural economy is based on dry-farm grains.

Camas Creek rises in high mountain meadows at the extreme western end of the basin and flows almost directly east for 45 miles to Magic Reservoir. Most of the important tributaries enter Camas Creek from the north side and drain the south slopes of the Soldier Mountains. Most of these streams are ephemeral in the lowland part of the basin and are dry during late summer. These streams probably lose water along their courses from the points at which they leave the mountains.

The discharge of Camas Creek at the gaging station 3 miles southeast of Blaine has averaged 175 cfs (127,000 acre-feet per year) for the period 1944–55 from an area of 648 square miles.

The consolidated granitic and silicic volcanic rocks yield small to moderate supplies of water from weathered zones and fracture systems to a few scattered wells, chiefly around the margins of the prairie. Yields generally are adequate for domestic and stock use, but rarely are more than 50 gpm.

Unconfined ground water occurs at shallow depths in alluvial sand underlying the prairie. Wells tapping the alluvial aquifers generally are less than 40 feet deep; the depth to water averages less than 10 feet. Yields are adequate for domestic and stock use.

The chief aquifers are two extensive lenses of sand and gravel that are separated from the shallow ground water by a thick layer of clay and silt (fig. 24). Water in both of these aquifers is under artesian

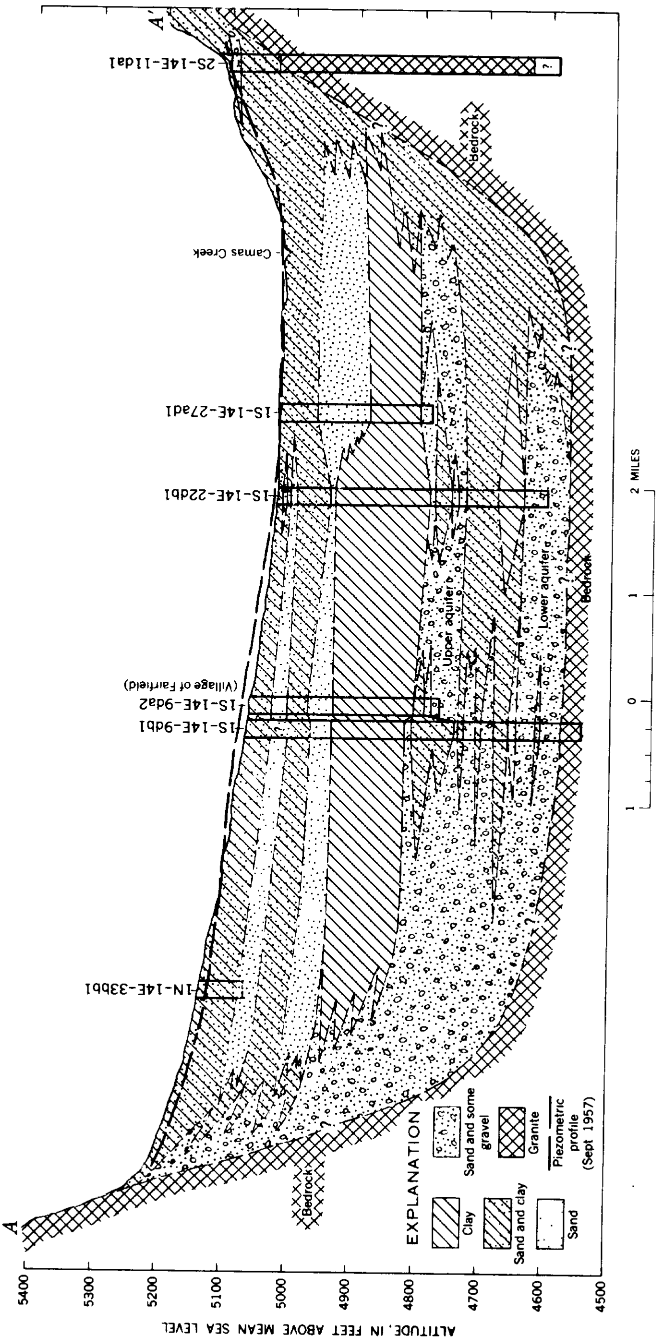


FIGURE 24.—Geologic section A–A′ (pl. 3) and profile of piezometric surface from Walton (1960).

pressure, and throughout a large part of the prairie wells tapping them will flow at the land surface. The upper of the two aquifers is 50 feet thick and is 210 feet below the surface. The lower artesian aquifer is 85 feet thick and is separated from the upper aquifer by 90 to 125 feet of relatively impermeable silt and clay that contains occasional lenses of sand and gravel. Several domestic and stock wells and a few irrigation and public-supply wells obtain water from the artesian aquifers. Yields of the larger production wells are as much as 1,300 gpm but there is considerable drawdown. Walton (1960) estimated that the average total coefficient of transmissibility of the two aquifers is 70,000 gpd per foot. Probably few if any wells tap all the permeable beds in the artesian zone; hence, the transmissibility of the materials tapped by any one well is somewhat less than 70,000 gpd per foot.

The Snake River basalt is an important aquifer at a few places on the south side of the prairie, both near the south-central part and the southeastern end. For the most part, wells in the basalt range from 90 to 250 feet in depth. Yields, commonly 1,000 to 1,300 gpm with only moderate drawdown, indicate transmissibilities several times greater than that of the sand and gravel deposits. Wells for which yield and drawdown data were reported are given in following table adapted from Walton (1960).

Well	Depth of well (feet)	Depth to water (feet)	Aquifer	Yield (gpm)	Draw-down (feet)	Specific capacity (gpm per ft)
1S-14E-9db1	535	+8.5	Sand	1,098	60	18
1S-15E-16db1	122	32.5	Basalt	1,280	35	37
21ad1	283	17	do	1,350	12	112
1S-16E- 3dc1	324	86	Basalt and sand	700	125	6
4cb1	208	85	Sand	900	40	22

The water table of the shallow aquifer and the piezometric surfaces of the artesian aquifers slope from the flanks of the valley toward Camas Creek, which is somewhat south of the center of the prairie, and then eastward along Camas Creek. Water levels in the surficial deposits generally are only a few feet below the surface. Water levels in deeper sand and gravel beneath alluvial slopes around the margins of the prairie are as deep as 85 feet below the surface, but water from these same aquifers at lower altitudes near the center of the prairie flows above the surface. Water levels in wells tapping basalt ranges generally from 15 to 50 feet below the surface.

Aquifers underlying Camas Prairie are recharged from precipitation on the prairie and by percolation from streams crossing the prairie. Streams draining the Soldier Mountains along the north flank of the prairie are particularly important sources of recharge. No information is available on the discharge of the tributary streams. The average discharge of Camas Creek, 175 cfs for the period 1944–55, is equivalent to a surface outflow of nearly 127,000 acre-feet per year, or 3.7 inches per year over the drainage area of 648 square miles above the station. This is surface outflow from the basin and does not include ground-water outflow.

Ground water in Camas Prairie generally is low in dissolved solids and is soft. Water from most wells is of satisfactory chemical quality for domestic, stock, and irrigation use.

Chemical analyses of ground water in Camas Prairie

[Walton, 1960. Chemical constituents in parts per million]

Constituent or property	Well					
	1S-13E-27cc1	1S-14E-9da4	1S-14E-12cc1	1S-14E-13bb1	1S-15E-5db1	1S-15E-21ad1
Silica (SiO_2)	78	41	54	39	26	45
Iron (Fe)	.03	.40	.50	.05	.60	.23
Calcium (Ca)	4	14	13	9.6	14	11
Magnesium (Mg)	.0	4.1	3.9	3.0	3.4	6.8
Sodium (Na)	96	14	13	13	10	25
Potassium (K)	1.4				2.0	5.0
Bicarbonate (HCO_3)	211	93	90	73	76	133
Sulfate (SO_4)	4.7	5.8	2.0	4.1	3.3	.7
Chloride (Cl)	11	1.0	1.0	3.0	1.5	3.5
Fluoride (F)	9.0	--	--	--	.3	.4
Nitrate (NO_3)	.6	--	--	--	4.6	.3
Phosphate (PO_4)	.2	--	--	--	.4	.4
Dissolved solids	309	124	128	103	125	157
Hardness: Total	10	52	48	36	49	55
Percent sodium	95	--	--	--	30	47
Specific conductance-micromhos at 25° C	415	--			142	235
pH	8.0	--	--	--	7.2	7.3
Depth of well feet	190	224	247	126	578	283
Temperature °F	95	--	--	--	63	58
Salinity hazard	Medium	--	--	--	Low	Low
Sodium hazard	Medium	--	--	--	Low	Low

Ground-water outflow is chiefly eastward, although some ground water may escape to the southeast. Walton (1960) estimated that underflow from the prairie is 20,000 acre-feet per year and stated that most of the underflow is discharged into Camas Creek and Magic Reservoir east of the prairie.

BIG WOOD RIVER-SILVER CREEK BASIN[3]

Big Wood River drains an area on the south side of the mountains of central Idaho. The basin joins the Snake River Plain along its northwest flank (fig. 12). The chief drainageway is the Big Wood River, which discharges into Magic Reservoir north of Shoshone. However, Silver Creek drains the east corner of the basin.

[3] Most of the following information on the Big Wood River basin is taken from Smith (1959).

The mountainous upstream part of the basin is underlain by indurated sedimentary rocks and intrusive igneous rocks, all of relatively low permeability. Downstream, in the vicinity of Ketchum and Hailey, the river valley is ½ to 1 mile wide and is partly filled with fluvioglacial outwash. South of Bellevue, the valley broadens into a roughly triangular alluviated basin whose southern boundary is formed by the Picabo Hills. These hills consist chiefly of Tertiary volcanic rocks of low or only moderate permeability. Outflow from the valley, including both surface and underground flow, is through gaps in the west flank (Big Wood River valley) and the east flank (Silver Creek valley) of the Picabo Hills.

The altitude of the valley ranges from 4,800 feet at both the eastern and western outlets around the foot of the Picabo Hills to 5,300 feet in the vicinity of Hailey and more than 6,200 feet at the upper end. Many of the mountain ridges and peaks rise above 10,000 feet, and a few exceed 12,000 feet. In general the mountains are extremely rugged. Annual precipitation at Hailey averages slightly more than 15 inches; downvalley the precipitation probably is considerably less. However, runoff data and snow measurements indicate that precipitation on the higher slopes and in the mountains is much greater, probably more than 40 inches on some of the highest, west-facing slopes. The winters are moderately cold, and the summers, though short, are warm. The frost-free growing season averages 110 days at Hailey.

Big Wood River and its major tributaries rise in the Sawtooth Mountains of south-central Idaho. The drainage area of the basin, above Magic Reservoir, is 825 square miles. Runoff in the headwater area is well sustained throughout the year. The average annual runoff past the gaging station 8 miles upstream from Ketchum was nearly 119,000 acre-feet for the 7-year period 1949–55. This amount, from a drainage area of 137 square miles, is equivalent to more than 16 inches over the area. Downstream areas are progressively less productive; the average annual runoff at the gaging stations on the Big Wood River and Big Wood Slough at Hailey was slightly more than 303,000 acre-feet over the 40 year period ending in 1955. This is equivalent to 9.2 inches over the drainage area of 640 square miles above this station. The contribution for the 503 square mile drainage area between stations is only 6.5 inches over the area.

In addition to the gaged inflow reaching the lowland south of Hailey, ungaged inflow from Quigley, Slaughterhouse, and Seamans Creeks and other smaller creeks is considerable. Smith (1959), using 1940–54 as a 15-year base period, gave 340,000 acre-feet per year as the gaged inflow and 38,500 acre-feet per year as the ungaged inflow.

Ground-water conditions are shown diagrammatically in the cross section (pl. 5) adapted from Smith (1959). The most important aquifer in the Big Wood River valley is the fluvioglacial deposit, which underlies the valley to depths of more than 300 feet at some places. Beds of coarse sand and gravel, interfingering with clay and silt, yield moderately large to large supplies of water to many wells. North of the Boise base line, the water is generally unconfined, and most wells are from 10 to 100 feet deep, although a few are from 100 to more than 300 feet deep. The depth to water generally ranges from a few to 40 feet below the surface, although in a few wells the water levels are 40 to 70 feet below the surface. South of the base line, the proportion of silt and clay beds increase markedly, and artesian water is obtained from sand and gravel beneath the main clay horizon. The depth to the top of the artesian zone generally is 125 to 150 feet. Artesian heads range from a few to nearly 50 feet above the land surface. Some unconfined ground water is obtained from sand and fine gravel at relatively shallow depths above the confining bed in the artesian area. The shallow unconfined ground water is fed, in part, by upward leakage through the confining bed. Many domestic and a few irrigation and stock supplies are obtained from the shallow unconfined aquifer.

The water table (pl. 4) slopes southward from an altitude of 5,300 feet at Hailey to slightly less than 4,800 feet at Picabo. Between Hailey and Bellevue, its average gradient is 40 feet per mile, and downvalley from Bellevue it is 25 feet per mile. Contour lines on the piezometric surface of water in the artesian zone are not known on plate 4, but in most places the piezometric surface is 10 to 40 feet higher than the water table.

The water table in unconfined deposits generally reaches its lowest level in late winter or early spring, then rises until June or July, after which it declines steadily until the following spring. Water levels in the artesian aquifier follow about the same cycle, but generally are somewhat more erratic, possibly because of pumping from nearby wells. The seasonal fluctuations generally range from about 2 to 14 feet.

Fluctuations of water levels are illustrated in figure 25.

Five aquifer tests were made in the valley during the investigation by Smith. The coefficient of transmissibility determined from these tests ranged from 7.25×10^5 to 2.2×10^6 gpd per foot. Because the alluvial deposits are stratified and the test wells did not completely penetrate the aquifer, the coefficient of transmissibility of the entire aquifer

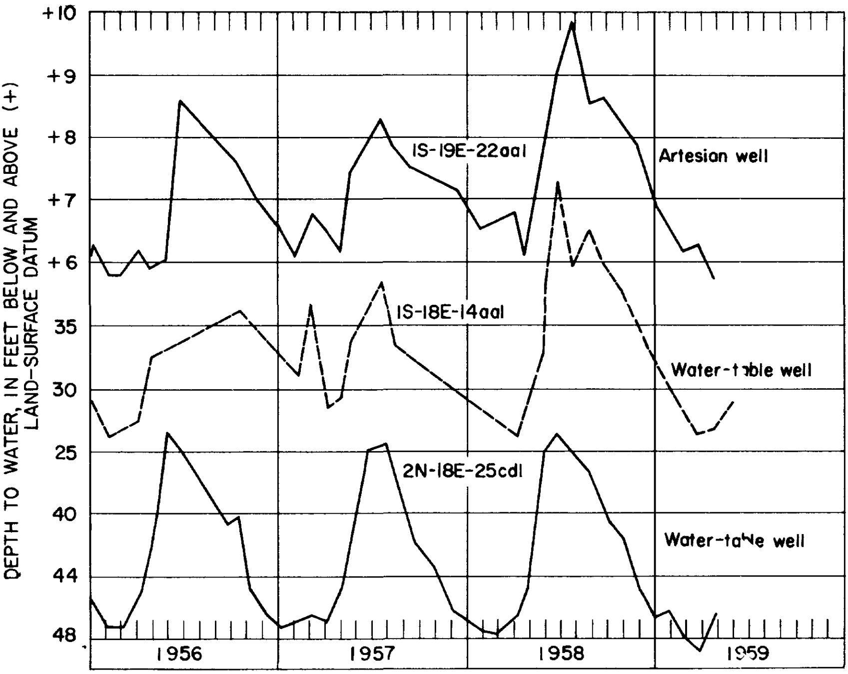


FIGURE 25.—Hydrographs of wells 1S-19E-22aa1, 1S-18E-14aa1, and 2N-18E-25cd1.

probably is greater. The following table summarizes information obtained from the 5 tests.

Well	Well depth (feet)	Pumping rate (gpm)	Duration of test (hours)	Drawdown (feet)	Specific capacity	Coefficient of transmissibility (gpd per ft)
1N-19E- 6cb1	81	1,200	67	4.3	280	9.5×10^5
31ca1	72	1,155	51	6.1	190	1.5×10^6
1S-18E-2dd1	126	1,090	30	(1)	(1)	7.25×10^5
1S-19E-3cc1	50	2,165	51	4.3	504	2.2×10^6
2S-20E-1ac2	209	780	71	7.5	104	8×10^5

[1] Not determined; discharge during test was by natural flow.

The general characteristics of representative irrigation wells are given in the following table (adapted from Smith, 1959). The unconfined-aquifer data are an average of 12 wells; wells in Recent alluvium near channel of Big Wood River are excluded. The artesian-aquifer data are an average of 16 wells; wells in southeastern part of main artesian area where yields are low are excluded.

Characteristic	Unconfined aquifer [1]			Artesian aquifer [2]		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Depth feet	81	23	59	174	118	139
Diameter inches	42	10	17	8	6	6.5
Length of casing feet	81	23	59	172	117	137
Water level, feet above (+) or below (−) land surface, August 1954 [3]	−40	−5	−18	+39	+14	+27
Penetration of saturated zone [4] feet	48	16	38			
Depth to artesian aquifer feet				172	117	137
Yield, pumping gpm	3,400	565	1,875			
free flow gpm				1,525	355	825

[1] Average of 12 wells; excludes wells in Recent alluvium near channel of Big wood River.
[2] Average of 16 wells; excludes wells in southeastern part of main artesian area where yields are low.
[3] Water levels in unconfined aquifers based on measurements on nine wells; in artesian aquifers based on measurements on 14 wells.
[4] Based on records for nine wells.

Some of the irrigation wells are completed with perforated casings, but the casing of many wells is inadequately perforated. Most of the artesian wells are completed with an open-end casing, which extends just to, or only 1 to 2 feet into, the aquifer. Well screens are used rarely, if at all. Few wells were adequately developed by surging and bailing when drilled. The yields of wells could be increased significantly if construction and development procedures were improved.

Chemical analyses have been made of water from several wells in the Big Wood River-Silver Creek basin. A summary of the analyses is given in the following table. Data from more than 30 analyses indicates that the water is uniformly of good quality for most uses, although it is moderately hard to hard. All samples analyzed were satisfactory for irrigation, according to standard criteria for percent sodium, boron, and residual sodium carbonate.

Summary of chemical analyses and suitability for irrigation of ground water in the Big Wood River—Silver Creek basin

[Smith (1959). Thirty-four wells sampled. Chemical constituents in parts per million]

Constituents or property	Maximum	Minimum	Typical (well 1N-19E-31ca1)
Silica (SiO_2)	40	16	16
Iron (Fe)	.24	0	
Calcium (Ca)	77	16	52
Magnesium (Mg)	34	2.8	9.7
Sodium (Na)	23	4	4
Potassium (K)	3.1	Tr.	1.1
Bicarbonate (HCO_3)	355	52	197
Sulfate (SO_4)	26	4	12
Chloride (Cl)	15	1	2
Flouride (F)	1	0	.1
Nitrate (NO_3)	13	.3	5.6
Boron (B)	.38	.00	.04
Dissolved solids	368	162	206
Hardness:			
Total	302	51	170
Noncarbonate	34	0	8
Percent sodium	30	4	5
Specific conductance micromhos at 25° C	605	247	345
pH	8.4	7.2	7.9
Temperature, °F	63	36	52
Sodium-adsorption-ratio	.8	.1	.1
Residual sodium carbonate	.03	0	0

An approximation of the potential supply can be made from a water inventory or budget for the subarea. Average gaged surface inflow is 340,000 acre-feet per year, and ungaged inflow is estimated to be about 38,500 acre-feet per year (Smith, 1959).

Surface-water flow past Hailey is not the entire water yield of the basin above that point. According to Smith (1960), ungaged underflow in the alluvium through this reach probably amounts to 10 percent of the total water yield. The valley widens downstream, and below Bellevue it broadens and deepens into a triangular alluvial basin that absorbs a large part of the total water yield of the upper basin, partly through percolation from the stream bed and partly by diversion for irrigation on the area. Precipitation on the alluvial basin averages 14 inches a year, and some precipitation on alluvial terraces and slopes reaches the water table.

Smith (1959, p. 24) estimated that the annual ground-water outflow from the basin is 38,000 acre-feet. However, his water inventory for the area (1959, p. 30) showed 22,000 acre-feet more inflow to the basin than can be explained. Deep percolation from the basin may be somewhat greater than he assumed; the estimate for ground-water outflow therefore is rounded to 50,000 acre-feet. Smith (1959) stated that most of the ground-water outflow passes through the southeastern (Silver Creek) outlet.

Just how much of the total ground-water outflow from the basin can be intercepted is difficult to estimate. Yields of properly constructed and developed wells would be fairly large, perhaps averaging 2,250 gpm or more. Pumping during the irrigation season by 20 to 25 such wells might withdraw one-half the estimated ground-water outflow, but water levels would be drawn down extensively, and in some places the aquifers might be dewatered more than desirable. On the other hand, the increased withdrawal might lower the water table sufficiently to decrease use of water by waste vegetation. Heavy withdrawal from the artesian aquifer undoubtedly would decrease to some extent the discharge of springs that feed Silver Creek. These factors would tend to increase the total ground-water supply available, so that pumping of an amount equal to half the present underflow would not decrease the underflow by half. In general, the proportion of the underflow that feasibly can be intercepted probably ranges between 25 and 50 percent of the total. Because aquifers are shallow and the water table is near the land surface in the Big Wood River-Silver Creek basin and because withdrawals by pumping would to some extent increase the total available ground water supply, the higher part of the range might apply in this basin. This percentage of ground-water withdrawal does not take into consideration the adverse effects heavy pumping might have on present ground-water developments and on streamflow, particularly of Silver Creek.

LITTLE WOOD RIVER BASIN

The drainage basin of the Little Wood River lies immediately to the east of the Big Wood River-Silver Creek basin (fig. 12). Little Wood River drains the rugged south slopes of a part of the Sawtooth and Pioneer Mountains. It is a tributary of the Big Wood River, but because it joins that river only after flowing for a considerable distance across the Snake River Plain, its drainage basin is here considered as a separate basin tributary to the plain.

Most of the basin is underlain by silicic volcanic rocks of Tertiary age. Consolidated sedimentary rocks, including limestone, shale, and quartzite, crop out especially on the higher ridges. The valleys of the Little Wood River and its major tributaries, Copper and Friedman Creeks, have been partly filled with basalt and alluvial deposits. Apparently, the basalt originated in the vicinity of the mouth of Copper Creek (Smith, 1960) and dammed Copper and Friedman Creeks. Extensive deposits of sand and gravel accumulated upstream from the "dam." Downstream along Little Wood River, from a point 6 miles north of Carey, the basalt is overlain by alluvial deposits, but it is not known whether the basalt underlies the alluvium for the entire distance between that point and the edge of the Snake River Plain, where basalt is again at the surface.

Most of the basin is rugged; valley floors constitute a small proportion of the total area. Altitudes on the drainage divide generally range from 8,000 to more than 11,000 feet. The altitude at the mouth of the basin, in the vicinity of Carey, is 4,800 feet.

Precipitation at the mouth of the basin at the margin of the Snake River Plain averages only 14 inches per year, but most of the basin receives considerably more. The isohyetal map (pl. 2) shows that precipitation is as much as 32 inches in the headwaters of the basin. The weighted average annual precipitation in the basin probably exceeds 22 inches.

In its lower reaches, Little Wood River is above the water table and loses water by percolation from the stream bed. Ground water moves downvalley to join the main ground-water body beneath the Snake River Plain. In test wells drilled by the Bureau of Reclamation at the damsite of the Little Wood River Reservoir, water was found in basalt. The depth to water below the land surface ranged from a few feet to 130 feet. The altitude of the water table at the site was about 5,100 feet in 1954.

In the vicinity of Carey, most wells obtain water from sand and gravel at depths generally less than 150 feet. The depth to water ranges from a few feet to 100 feet. The altitude of the water table at Carey, probably about 4,750 feet, indicates a downvalley slope of 40 feet per mile from the reservoir. East of Carey, a few wells obtain water from basalt. The depth to water is somewhat greater than in the alluvium, as much as several hundred feet below the surface.

A short distance southeast of Carey, the main water table probably is at an altitude of 4,050 to 4,100 feet, a drop of 650 to 700 feet in a distance of a few miles.

Yields of wells in the alluvium near Carey are moderately large, and several irrigation wells have been developed.

Discharge of Little Wood River has been measured since 1927, at a station 6 miles northwest of Carey. The average discharge through 1956 was 134 cfs, or 97,000 acre-feet per year. That amount is equivalent to 5.8 inches over the area of 312 square miles above the station. Underflow through aquifers at the station site was estimated by Smith (1960) to be 5 to 10 percent of the total discharge. About 6,500 acres of land is irrigated with water diverted from the streams above the station. All the land irrigated by these upstream diversions is also above the station, and there are no bypass channels. The gaged surface flow and ground-water flow past the station (estimated) constitute the water yield of the basin above the gaging station. The water yield of the basin is, according to Smith (1960), about 105,000 acre-feet per year. However, the isohyetal map (pl. 2) shows an average annual precipitation over the basin of 22.8 inches, and the relation of precipitation to water yield (fig. 7) gives a water yield of 150,000 acre-feet per year. Possibly, therefore, the ground-water outflow is considerably more than was estimated by Smith.

Inasmuch as Dry Creek and minor tributaries contribute some water below the gaging station, the total water yield may be as much as 150,000 acre-feet per year. Of the total water yield, the quantity measured at the station, averaging 97,000 acre-feet per year, leaves the basin as surface flow; the remainder leaves as underflow. Most of the water not used by vegetation reaches the Snake River Plain aquifers within a short distance of the mouth of the basin. For the purposes of estimation, 100,000 acre-feet is considered to be surface-water outflow and 50,000 acre-feet to be ground-water outflow.

FISH CREEK BASIN

Fish Creek drains a small area of about 90 square miles on the south slope of the Pioneer Mountains southeast of the Little Wood River basin (fig. 12).

The basin is underlain by silicic volcanic rocks and consolidated sedimentary rocks. All are of comparatively low permeability.

Altitudes range from 7,000 to 9,000 feet on the drainage divides around the headwaters to 4,900 feet at the mouth of the basin. Annual precipitation on the basin probably averages 20 inches.

Average discharge at a former gaging station 11 miles northeast of Carey for 7 complete years of record between 1919 and 1939 was 14.8 cfs, or 10,700 acre-feet per year. Smith (1960) estimated that underflow past the station was 10 to 15 percent of the surface flow. Total water yield of the basin above the station thus would be 12,000 acre-feet per year, or 3.6 inches over the area of 62.9 square miles above the station.

Runoff from precipitation in the basin below the gaging station probably increases the water yield substantially. Total water yield may be more than 15,000 acre-feet per year. The estimated water yield is arbitrarily divided into 3,000 acre-feet ground-water outflow to the Snake River Plain and 12,000 acre-feet surface-water outflow, much of which becomes ground-water recharge in the vicinity of Carey.

BIG LOST RIVER BASIN

Big Lost River basin is a moderately large (1,500 square miles) basin on the northwest flank of the Snake River Plain (fig. 12). Included in the drainage area are parts of the Sawtooth and Pioneer Mountains and the Lost River Range. Lost River valley extends northwestward from the margin of the Snake River Plain at Arco for about 50 miles.

Most of the drainage area is on the southwest side of the valley. Through most of its length, the valley is 3 to 6 miles wide, but the widest place, 10 miles, is at the upper end of the valley north of where Big Lost River enters the main valley from the southwest, in the Thousand Springs Valley (pl. 1).

The valley floor rises from an altitude of 5,300 feet at Arco to more than 6,500 feet north of the Thousand Springs area. The downvalley slope is only 20 feet per mile from Chilly to Mackay Dam, but averages nearly 30 feet per mile from Mackay Dam to Arco. The Lost River Range rises abruptly along the northeast flank of the valley to general crest elevations of 11,000 to 12,000 feet. The broad mountainous area on the southwest side of the valley rises to elevations of 10,000 to 11,000 feet at the northern end of the basin and 8,000 to 10,000 feet at the southern end, adjacent to the Snake River Plain.

Big Lost River heads in the northern part of the latter mountainous area, flows northeastward for 16 miles, where it makes a right-angle turn into the main valley, and flows southeastward to the Snake River Plain at Arco. After reaching the plain, it continues southeastward for a few miles but gradually veers until it flows northward along the margin of the plain to terminate in several broad playas. Surface-water discharge never reaches the Snake River. The largest tributary is Antelope Creek, which drains the southwestern part of the basin.

The valley areas are semiarid and are moderately cold in the winter and occasionally hot in the summer. Because of the fairly high altitude and proximity to the mountains, the growing season is short, averaging about 100 days. Precipitation averages 8 to 10 inches in the valley, which is in the rain shadow of the bordering mountains. There are no precipitation stations at high elevations within the basin; records of precipitation at high elevations outside the basin and snowfall records suggest that average annual precipitation at high altitudes at some places in the Big Lost River basin may exceed 40 inches. The heaviest precipitation probably is on the western side of the Lost River Range, a short distance below the crest. A large proportion of this precipitation is snow, and runoff is chiefly during the spring thaw.

The Lost River Range, on the east and northeast flank of the main valley, consists chiefly of limestone, shale, and similar rocks of Paleozoic age. The strata are cut by several faults and are greatly folded; in places they are overturned. The mountainous headwater area on the southwest flank is chiefly underlain by rocks shown on the State geologic map (Ross and Forrester, 1947) as Challis volcanics. They include a varied assemblage of silicic and mafic flows, tuffs, and breccias of Tertiary age that have been considerably altered.

The narrow stream valleys in headwater areas are floored with glacial drift and fluvioglacial outwash. In the vicinity of Chilly and farther downvalley, these deposits are much more extensive. Alluvial-fan materials from the flanking mountains interfinger with the fluvioglacial and fluvial deposits. At least three different stages in deposition of the fan deposits can be recognized; successively younger deposits are at progressively lower levels.

The geology of the alluvial deposits has not been studied in detail, but reconnaissance suggests that they probably range in age from late Tertiary to Recent and have a varied history.

Near the mouth of the valley, immediately west of Arco, basaltic lava flows interfinger with and overlie the alluvial deposits. The basalt crops out in an oval-shaped area 3½ miles wide and 4 miles long. The center from which the lavas were extruded, 2½ miles west of Arco, is marked by a zone of craters and low cones. These lavas appear to be older than the bare black basalt a few miles to the south and in the vicinity of the Craters of the Moon, and so are considered to be a part of the preceding series of flows.

The Big Lost River and most of its larger tributaries rise in the mountainous area on the west side of the main valley. According to the isohyetal map, precipitation averages 20 inches over the headwaters area, and runoff, as measured at the gaging station at Howell Ranch, averaged 218,000 acre-feet for the 9 years, 1904–05 and 1948–56. This is equivalent to more than 9 inches over the 450 square miles above the station. Although the area is less than one-third the total area of the basin, and parts of the remainder contain high water-yield areas, the discharge at the Howell Ranch station is as great or greater than the discharge at any other station along the Big Lost River. In general the discharge decreases downstream, as underflow through the permeable alluvial deposits increases. Only fragmentary records of discharge are available for tributary streams in the Big Lost River basin. Most of these were obtained during the period 1920–22 and were for spring and summer only. By plotting hydrographs and by interpolating for the missing periods, a reasonably good estimate of annual runoff for the 3 years (1920–22) was derived for Pass, Antelope, Alder, and Lower Cedar Creeks. The runoff (partly estimated) for these streams is given in the following table:

Creek	Drainage area (square miles)	Runoff (acre-feet)		
		1920	1921	1922
Pass	23.6	5,100	8,200	9,100
Antelope	210	32,000	67,000	66,000
Alder	37	6,200	11,700	10,200
Lower Cedar	8.4	11,200	17,000	15,000

The valley of the Big Lost River contains extensive deposits of permeable sand and gravel. Southwest of Howell Ranch, the valley is ½ to ¾ of a mile wide. Downstream from that point, the valley widens rapidly and is about 10 miles wide at the Thousand Springs Valley. From there downstream to Arco, a distance of 40 miles, the valley ranges in width from 3 to 6 miles.

The alluvial deposits contain and transmit large quantities of ground water. The Big Lost River is a losing stream down valley from the Howell Ranch gaging station, and all tributaries lose a large part of their flow in the alluvial fans at their mouths or in the alluvial deposits of the main valley before reaching the Big Lost River. Many smaller streams lose their entire discharge by percolation within a short distance after they enter the valley, and, except during unusual floods, their water never reaches the river.

The thickness of the alluvial deposits is not known. Several wells in the vicinity of Moore are more than 200 feet deep, and several between Moore and Arco are about 240 feet deep. As far as is known, all these penetrate only alluvial materials. South of Arco, the alluvial deposits interfinger with basaltic lava flows in the Snake River

Plain. Well 3N–27E–9ab1 at Butte City, 3 miles southeast of Arco, penetrated a section consisting of approximately equal thicknesses of basalt and sedimentary materials and bottomed in a layer of sand and gravel extending from 450 to 500 feet.

Throughout most of the valley, the water table is only a short distance below the surface. The water-table map in the report by Stearns, Crandall, and Stewart (1938) shows the water table from Chilly to a few miles south of Arco. Water-level measurements in recent years indicate that the general configuration of the water table has not changed materially. However, in the vicinity of Arco and southward into the Snake River Plain, the occurrence of ground water is complex because of multiple water tables. Irrigation and percolation from the river channel have produced a shallow perched water table at an altitude of 5,250 to 5,300 feet. Deeper wells penetrate a second water table at an altitude ranging from 5,100 to 5,150 feet. Both of these water tables slope generally southward toward the plain. The 500-foot well at Butte City penetrated a third water table at an altitude of 4,920 feet. This third water table is about 500 feet higher than the main water table of the Snake River Plain (pl. 4), which, 6 to 8 miles south of Arco, is at an altitude of 4,400 feet.

In general, the downvalley slope of the water table approximately parallels the surface slope. The average slope of the water table is 25 feet per mile, but it is somewhat steeper (30 to 40 feet per mile) in the vicinity of Leslie and Darlington and somewhat flatter (15 to 20 feet per mile) in the vicinity of Chilly and between Moore and Arco.

The water table fluctuates in response to irrigation and to runoff in the Big Lost River. In most wells, the water table begins to rise in the spring, reaches a peak in July or August, and declines the rest of the year. Comparison of the hydrograph of well 4N–2[illegible]E–26cd1 (fig. 26) to the cumulative departure from average combined discharge of the Big and Little Lost Rivers (fig. 44) suggests that the discharge of the Big Lost River influences the longer term trends shown by the well but not the annual cycles. The annual cycles probably are related to application of irrigation water.

Moderately large yields of water have been obtained from wells drilled in the alluvial deposits. Probably several dozen wells are used to furnish irrigation water in the lower part of the valley. The size of pump (20 to 100 horsepower) and the acreage irrigated indicate that most of the wells yield moderate to large amounts, though yield and drawdown data are available for only a few wells. Per-

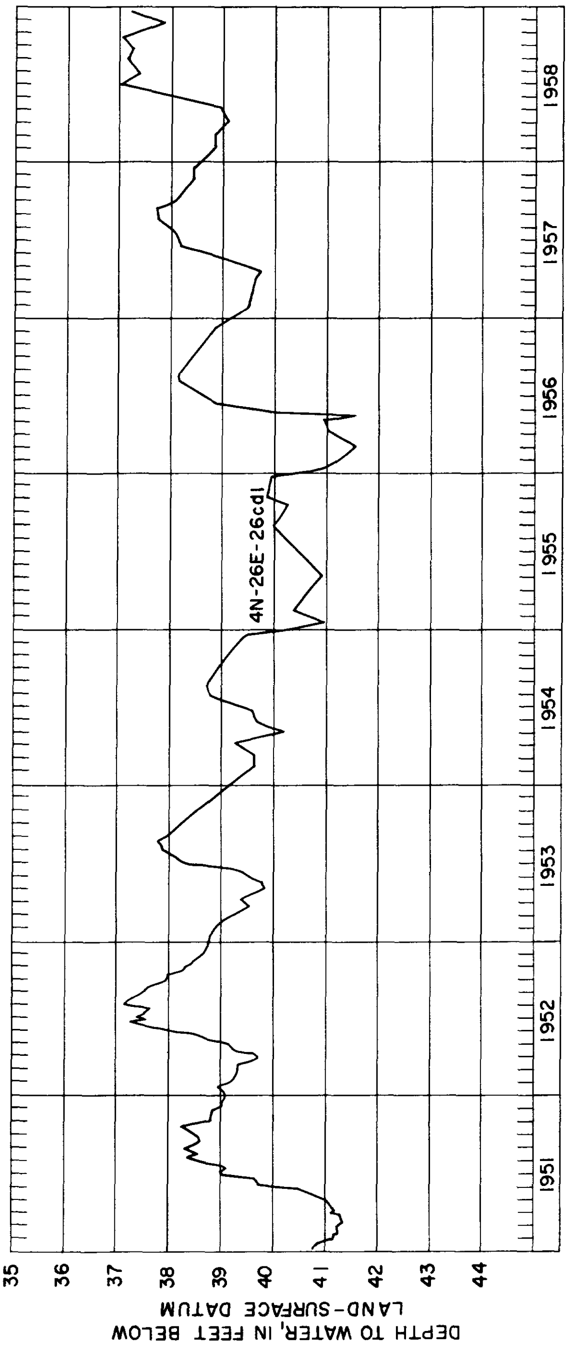


FIGURE 26.—Hydrograph of well 4N-26E-26cd1

tinent data for nine wells in the vicinity of Arco and Moore are given in the following table.

Wells in the Big Lost River Valley

[Water-level measurements to tenths of a foot were made by the Geological Survey. All other data were reported]

Well	Depth of well (feet)	Depth to water (feet)	Yield (gpm)	Drawdown (feet)	Specific capacity (gpm per ft)
5N-24E-32	240	13	1,800	45	40
5N-25E- 2dc1	210	69.4	2,250	50	45
5N-26E-21bc1	175	29.8	2,700	9	300
23cd1	198	27.2	1,200	45	27
33ad1	140	24	1,800	40	45
4N-26E-16dc1	25	12	1,200	12	100
32cb1	253	198.1	610	24.2	25
36aa1	28	12.1	450	1.2	375
36aa2	60	12.6	350	----------	----------

Of the eight wells for which specific-capacity data were available, three have specific capacities of 100 gpm per foot or more and five have specific capacities of less than that amount.

The drilled wells generally are 12 to 20 inches in diameter and are completed by perforating the casing. Undoubtedly, a large part of the drawdown is caused by entrance loss. Pumping tests of wells of similar construction indicate that well (entrance) loss generally constitutes 50 to 90 percent of total drawdown and averages perhaps 75 percent. Thus, specific capacity based only on aquifer drawdown would be generally in the range of 200 to 400 gpm per foot in the Arco area.

As a part of this investigation, one test well and one observation well were drilled in the Big Lost River valley 4 miles west of Arco. The wells penetrated perched water in alluvium at 100 feet but were completed in basalt at a depth of 250 feet. The main water table was 198 feet below the surface. An aquifer test was made by pumping the test well 18 hours at a rate of 610 gpm. The drawdown of 24.25 feet in the test well showed a specific capacity of 25 gpm per foot. The well was cased to 205 feet, and the water-bearing zone in the basalt was uncased. The coefficient of transmissibility determined from the test was 7.3×10^5 gpd per foot, and the coefficient of storage was 2.4×10^{-2}. Data and a detailed analysis of the test are given by Mundorff (1960). The specific capacity of the well is low in comparison with the coefficient of transmissibility of the aquifer. A reasonably efficient well tapping an aquifer having a coefficient of transmissibility of 7.3×10^5 gpd per foot should have a specific capacity of about 500, roughly 20 times as great as the measured specific capacity of the test well. The recovery data for the well showed that the water level recovered 21.4 feet of the total of 24.25 feet of drawdown within 1.5 minutes after the pump was shut off. Undoubtedly, a part of the "excessive" drawdown was caused by the proximity of negative boundaries, but it is also probable that an even larger part was caused by partial penetration of the aquifer and some entrance losses in the well.

Consideration of all the data suggests that moderately large to large yields (3 to 6 cfs) can be developed from properly completed and adequately developed wells 100 to 200 feet deep in the Big Lost River valley.

A few chemical analyses have been made of water from wells in the Big Lost River basin. The few available analyses, given in the following table, indicate that the water is moderately hard to hard. The samples analysed were satisfactory for irrigation, according to standard criteria for percent sodium, salinity hazard, boron, and residual sodium carbonate.

Chemical analyses of ground water in the Big Lost River basin

[Chemical constituents in parts per million]

Constituent or property	Well				
	4N-26E-19ad1	4N-26E-26cd1	4N-26E-36aa1		4N-26E-36aa2
Silica (SiO_2)	23		24	22	
Iron (Fe)			.06	.02	
Calcium (Ca)			67	67	
Magnesium (Mg)			18	21	
Sodium (Na)		13	9.0	11	3.7
Potassium (K)			1.8	2.4	
Bicarbonate (HCO_3)	422	198	274	288	312
Sulfate (SO_4)		15	24	29	20
Chloride (Cl)	16	8	7.5	8.0	8
Fluoride (F)	.4		.3	.2	
Nitrate (NO_3)			1.7	2.6	
Boron (B)	.04			.01	
Dissolved solids			289	305	
Hardness:					
Total		160	241	254	280
Noncarbonate		0	16	18	24
Specific conductance micromhos at 25°C	738	368	489	506	530
pH			7.6	7.1	
Temperature, °F	47		55	50	48
Percent sodium		15	7	9	3
Salinity hazard		C2	C2	C2	C2

Because of the large amount of unmeasured underflow through the alluvial deposits underlying the Big Lost River valley, no stream-gaging station, or combination of gaging stations, adequately measures the water yield of the basin. Not even the upstream station on the main stem measures the total yield above that station, although in general, but not invariably, the proportion of underflow to total yield decreases upstream.

The gaging station at Wild Horse on the main stem of the Big Lost River, a quarter of a mile upstream from the East Fork, probably measures nearly all the water yield above that station. Average discharge at that station for 12 years of record (1944–56) is 103 cfs, which is equivalent to a runoff of more than 12 inches over the area of 114 square miles above the station. The discharge of the Big Lost River at Howell Ranch, 7 miles downstream, is equivalent to only a little more than 9 inches over the area of 450 square miles

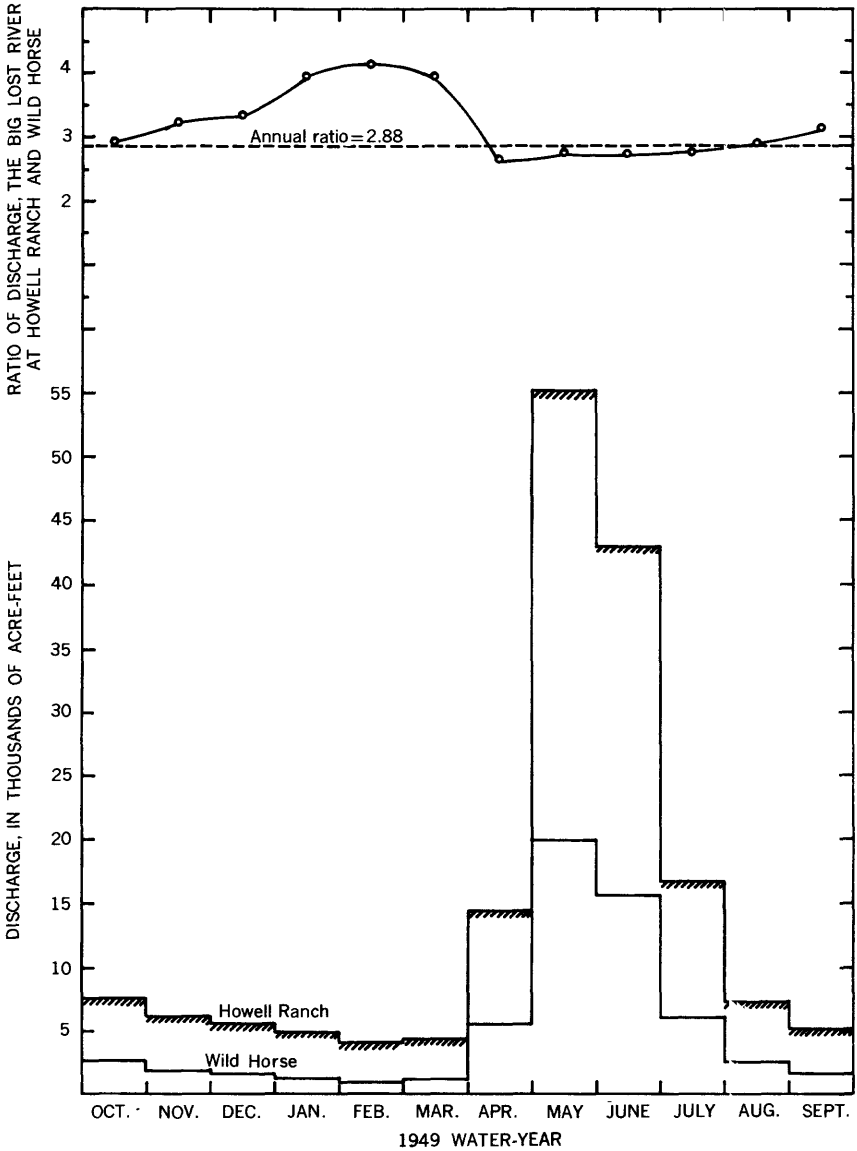


FIGURE 27.—Comparison of average monthly discharge of the Big Lost River at the Wild Horse and Howell Ranch gaging stations.

above the station. The decrease in water yield, expressed in inches over the area, at the downstream station may be caused in part by less precipitation in some parts of the basin and in part by a larger proportion of underflow past that station. The valley floor between the stations ranges in width from ½ to 1 mile and is underlain by coarse alluvium. For several miles upstream on the East Fork, the valley floor averages more than a mile in width. The alluvial deposits in these areas act as an equalizing reservoir on the discharge of the Big Lost River and greatly delay runoff, as is shown by a month-to-month comparison of discharge at the two stations (fig. 27). The ratio of the dicharge for the 1949 water year at Howell Ranch to that at Wild Horse was 2.88 to 1, but, beginning with a ratio of 2.92 in October, the ratio of the monthly discharges gradually and steadily increased as discharge declined, until, in February, the ratio was 4 to 1. During late winter and early spring, coincidental with the period of snowmelt and high runoff, the ratio dropped abruptly to 2.63, considerably below the annual ratio, and remained below that ratio during the period of high runoff. Clearly, a large part of the discharge during the period of low flow from August or September through March is derived from ground-water storage.

The following table gives the monthly discharge at the two stations, the ratio between discharge at the stations, the discharge at Howell Ranch (calculated from the annual-discharge ratios), and the losses or gains, presumed to be ground-water storage.

Discharge of the Big Lost River, in acre-feet, at Wild Horse and Howell Ranch for 1949 water year

Month	Measured discharge		Ratio (2):(1)	Calculated discharge at Howell Ranch (1)×2.87	Change in ground-water storage, loss (−) or gain (+) (4)−(2)
	At Wild Horse (1)	At Howell Ranch (2)	(3)	(4)	
October	2,590	7,570	2.92	7,445	−125
November	1,890	6,100	3.23	5,433	−667
December	1,660	5,560	3.35	4,772	−788
January	1,230	4,900	3.98	3,536	−1,364
February	990	4,080	4.12	2,846	−1,234
March	1,100	4,340	3.94	3,162	−1,178
April	5,490	14,460	2.63	15,781	+1,321
May	19,840	55,140	2.78	57,031	+1,891
June	15,650	42,930	2.74	44,986	+2,056
July	6,050	16,750	2.77	17,391	+641
August	2,530	7,340	2.90	7,273	−67
September	1,640	5,200	3.17	4,714	−486
Annual	60,660	174,370	2.88	174,370	0

Because the method used was based on exactly 1 year of record, the total loss and gain between stations should be exactly equal. The analysis does not take into account possible changes in storage during the 1-year period. According to this method of calculation, approximately 5,900 acre-feet of water was derived from storage during the period of low flow and was replaced during the period of high runoff in the spring.

A similar comparison of water yield and analysis of ground-water storage was made in the section of the valley between the gaging station at Howell Ranch and the stations measuring total inflow into Mackay Reservoir. That this section of the valley serves as a large underground-storage reservoir and modifies the inflow into Mackay Reservoir has been known for many years. The most detailed account is given by Stearns, Crandall, and Steward (1938). According to that report, a flow of 750 cfs is required before surface flow is maintained across the sinks near Chilly:

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 (gage). 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.

Average monthly flow at Howell Ranch is compared with average monthly inflow to Mackay Reservoir (period used 1949–56) in the following table and in figure 28. The data indicate that during the 8-year period an average of 34,000 acre-feet of water went into storage in spring and early summer, and a like amount came out of storage during the remainder of each year.

Discharge of the Big Lost River, in acre-feet, at Howell Ranch and into Mackay Reservoir for the period 1949–56

Month	Measured discharge		Ratio (2):(1)	Calculated inflow into Mackay Reservoir (1)×0 94	Change in ground-water storage, loss (−) or gain (+) (4)−(2)
	Howell Ranch (1)	Inflow into Mackay Reservoir (2)	(3)	(4)	
October	6,520	10,640	1.66	6,130	−4,510
November	5,390	10,300	1.90	5,070	−5,230
December	5,150	10,100	1.96	4,840	−5,260
January	4,600	9,400	2.05	4,320	−5,080
February	3,870	8,130	2.09	3,640	−4,490
March	4,340	8,850	2.04	4,080	−4,770
April	13,460	9,050	.67	12,650	+3,600
May	54,100	32,600	.61	50,900	+18,300
June	69,400	55,100	.79	65,200	+10,100
July	36,700	32,100	.87	34,500	+2,400
August	12,800	13,900	1.09	12,030	−1,870
September	6,790	9,760	1.44	6,380	−3,380
Annual	223,100	209,900	0.94	209,740	−190

The data in the table above show the ability of the alluvial sand and gravel to store and discharge large volumes of water. They cannot be used, however, as an indication of the total underflow through the alluvium. The approximately 34,000 acre-feet of water that goes into

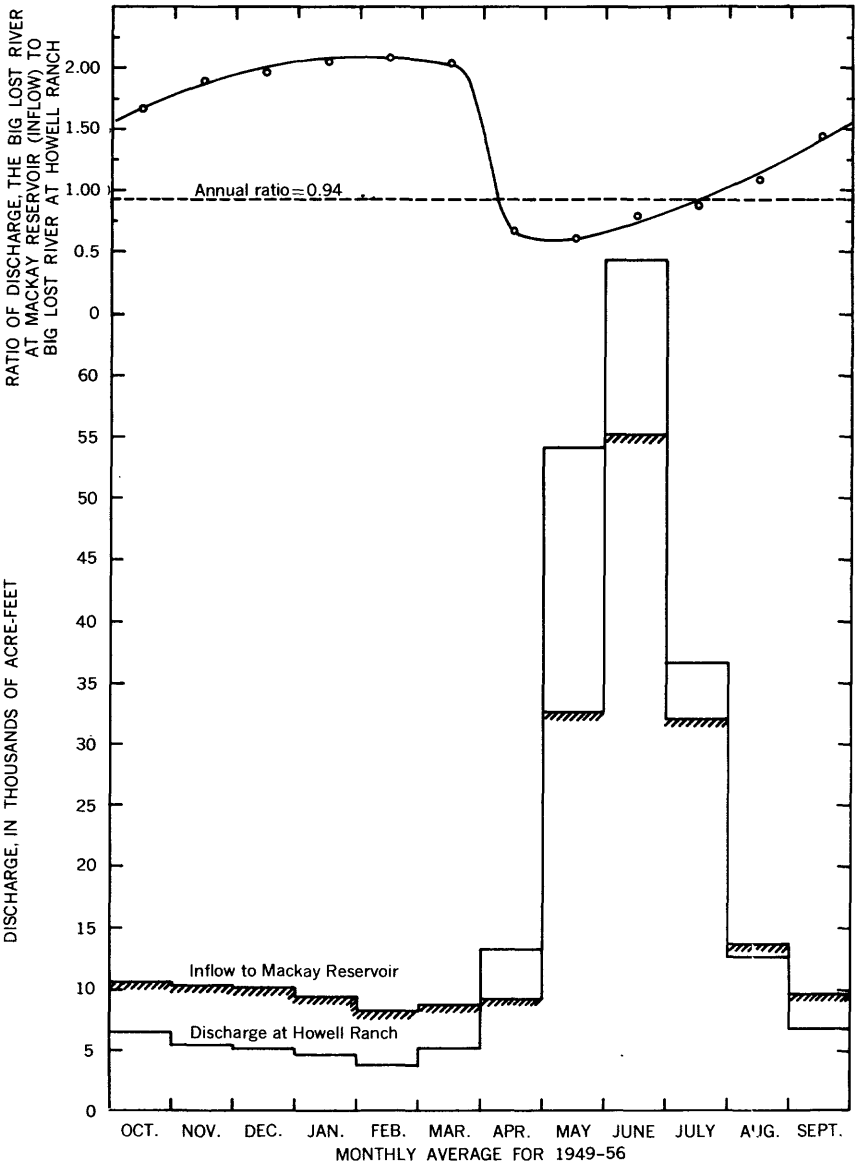


FIGURE 28.—Comparison of average monthly discharge of the Big Lost River at Howell Ranch with inflow into Mackay Reservoir.

and out of ground-water storage each year above Mackay Reservoir is a measure of the annual change in the total underflow.

The water yield of the Big Lost River basin was obtained by dividing the basin into terrain types related to their water-yielding or water-consuming properties, determining the areas included in the types, and applying a factor for water yield or water use per unit of area. Separate water budgets were developed for the areas above and below Mackay Dam.

Water-yield factors for the different terrain types were based on measured discharges at stations on various streams. Obviously, only those stations could be used where the surface discharge was all or nearly all the total water yield above the station. Records obtained where underflow was an appreciable part of the total yield could not be used. Records for some of the smaller streams are incomplete and fragmentary. These were extended by comparison with more complete discharge records of other streams in the area. The average inflow into Mackay Reservoir for the period 1921–50 was the base period used, and all other records were adjusted to that base.

The high mountain ranges and slopes leading from the valleys to the ridges are the principal water-yielding areas (terrain type A). Water-yielding areas were divided into areas of high, medium, and low yield, A_1, A_2, and A_3, respectively. Area A_1 is confined to the westward-facing high slope on the Lost River Range on the east side of the valley. The water yield of Lower Cedar Creek, based on 5 years of partial record and adjusted to the 30-year base period, was 12,000 acre-feet per year, equivalent to an annual precipitation of nearly 27 inches over the 8.4-square mile area above the station. This yield probably is slightly higher than average for the area, and a water-yield factor of 2.0 acre-feet per acre was used for area A_1.

Area A_2 includes only the drainage area of the Big Lost River above the gage at Howell Ranch, and the record at that station was adjusted to the 30-year base period, that is the measured discharge at the station was used as the water yield; underflow, which may be as much as 10 percent of the total discharge, was disregarded.

Above Mackay Reservoir, area A_3 includes the mountain slopes on the west side of the Big Lost River valley drained by streams entering the valley downstream from the Howell Ranch gage. The discharge of Alder Creek probably is representative of the area and was used as the water-yield factor, even though Alder Creek enters the Big Lost River below the reservoir.

Below Mackay Reservoir, two low water-yield areas were distinguished. The one on the west side of the valley is represented by the Antelope and Alder Creek drainages. The water-yield factor for these two drainage areas is nearly identical. The other low water-yield area is on the east side of the valley and is represented by the discharge of Pass Creek which heads on the back (east) slope of the Lost River Range. The water-yield factor for this area is somewhat larger than that for the Alder and Antelope Creek drainages and its yield was computed separately.

The alluvial slopes and terraces (terrain type B) between the mountains and the valley floor were considered to provide no water because most of the water that falls on the area was evaporated or transpired; the small amount of runoff from the area was disregarded. Water originating in other areas and crossing terrain type B as underflow is not evaporated or transpired by vegetation.

The valley floors occupied by irrigated farms and marshy lands are water-consuming areas (terrain type C) in that more water is evaporated and transpired than falls on the area. Water use was estimated to average 1.5 acre-feet per acre per year in addition to rainfall on the valley.

Mackay Reservoir is considered as terrain type D, and evaporation from the surface is assumed to be 2½ acre-feet per acre per year.

The water budget of Big Lost River basin is given in the following table.

Annual water budget of the Big Lost River basin

Terrain type	Area		Water yield (acre-feet)		Water consumed (acre-feet)	
	Square miles	Acres	Per acre	Total	Per acre	Total
	Above Mackay Reservoir					
A_1	76.5	49,000	2.0	98,000		
A_2	383	245,000	.77	190,000		
A_3	137	87,700	.32	28,000		
B	116	74,200	0	0	0	0
C	30	19,200			1.5	29,000
D	3	1,920			2.5	4,800
Total	745.5	477,000		320,000		34,000
Net water yield, surface and ground water (rounded)						280,000
	Below Mackay Reservoir					
A_1	67	43,000	2.0	86,000		
A_3[1]	36	23,000	.4	9,200		
A_3[2]	320	205,000	.32	66,000		
B	80	51,000	0	0	0	0
C	109	70,000			1.5	100,000
Total	612	392,000		160,000		100,000
Net water yield, surface and ground water						60,000
Total water runout above and below Mackay Reservoir (rounded)						340,000

[1] Pass Creek drainage.
[2] Antelope and Alder Creek drainages.

Total water yield, computed as shown in table above, is about 340,000 acre-feet per year. Part of the water leaves the basin as surface discharge, but the entire flow is lost along the margin of the Snake River Plain by infiltration into the ground, evaporation, and transpiration. Discharge at the gaging station 4 miles southeast of Acro averaged 61 cfs (44,000 acre-feet per year) for the 10-year period ending September 30, 1956.

Average annual precipitation on the 1,350 square miles of the basin above Arco is 15.7 inches, according to the isohyetal map. Annual water yield determined by the relation in figure 7 is 315,000 acre-feet. That results of the two methods check closely may be fortuitous and may be due in part to the similarity of the two methods, though it does seem significant that the method based on a general relation developed for the entire Snake River basin east of Bliss gives a closely similar result to a detailed analysis based only on data from the Big Lost River valley. The rounded figure of 330,000 acre-feet is used in later sections of this report.

LITTLE LOST RIVER BASIN

The Little Lost River basin is another in the series of southeastward-trending basins tributary to the Snake River Plain along its northwestern flank (fig. 12). The mouth of the Little Lost River valley is approximately 50 miles northwest of Idaho Falls.

The basin is more than 50 miles long and averages 20 miles wide. It is flanked by the Lost River Range on the west and the Lemhi Range on the east. The highest peaks in these two ranges rise 11,000 to 12,000 feet above sea level, and the average height of the divides is probably about 10,000 feet. The alluviated valley floor slopes from 6,500 feet at the northern end of the basin to 4,800 feet at its southeastern end, where it joins the Snake River Plain. Its average width is 7 miles, and it is as wide at the head of the valley as it is at the mouth. The area of the basin above Howe is 800 square miles.

The flanking mountain ranges are formed chiefly of folded and faulted limestone, quartzite, and shale of Paleozoic age. At some places, Tertiary volcanic rocks, chiefly andesitic or silicic in composition, constitute a major part of these mountains. The Little Lost River valley is apparently formed in a down-faulted block of these consolidated rocks, and the resulting basin has been partly filled with alluvium from the flanks.

Precipitation averages 8.22 inches annually at Howe, the only station in the valley. Records from other nearby stations suggest that precipitation everywhere on the valley floor averages less than 10 inches annually. However, as the flanking mountain ranges are 10,000 to 12,000 feet high, precipitation on some of the higher peaks probably exceeds 30 inches annually.

The Little Lost River begins at the junction of Sawmill and Summit Creeks at the upper end of the basin. Sawmill Creek rises in the Lemhi Mountains on the east side of the basin, and for the first 12 to 14 miles its channel is chiefly in rock with only minor amounts of alluvium. From the point where Sawmill Creek enters the broad alluviated part of the basin to its junction with Summit Creek, it loses water by percolation from the channel. Summit Creek rises in numerous springs and seeps at the northwest end of the basin. Its course is intermittent downstream to its junction with Sawmill Creek. Except for West and Dry Creeks, which drain areas of moderate size in the Lost River Range on the west side of the basin, the other tributaries of the Little Lost River are short and flow fairly directly off the flanking mountains. Most of the water percolates into the alluvial fans between the canyon mouths and the Little Lost River. The Little Lost River is a perennial stream fed largely by groundwater inflow; except during the winter and during floods, the entire flow is used for irrigation. During periods of excess flow, water spreads over a low area east of Howe at the edge of the Snake River Plain. Part of the flood water percolates into the aquifers of the plain and the remainder evaporates.

The average discharge of the Little Lost River, for the period 1941–55, at the gaging station 7 miles northwest of Howe was 69.1 cfs, or 50,000 acre-feet per year. Diversion into the Blaine County Investment Co. Canal below the station averaged 9,000 acre-feet during the same period.

The most important aquifer in the valley is alluvial sand and gravel, possibly originating in part as fluvioglacial outwash. The deepest well known in the valley, about 250 feet deep, bottomed in alluvium, so the maximum thickness of the valley fill is not known. Not all the fill is sand and gravel, some layers of clay and silt being intercalated with the coarser materials.

Near the mouth of Little Lost River valley, in the vicinity of Howe, basalt flows are interbedded in the alluvium. Southward, as the valley merges with the Snake River Plain, most of the strata are Snake River basalt flows.

About 60 wells have been drilled for irrigation in the valley; many are less than 100 feet deep and few are more than 150 feet deep. Approximately 40,000 acre-feet of water was pumped for irrigation in 1959.

Yield and drawdown data for six wells are given in the following table.

Wells in Little Lost River Valley

Well	Depth (feet)	Depth to water (feet)	Yield (gpm)	Drawdown (feet)	Specific capacity (gpm per foot)
10N-27E- 7	125	12	2,475	80	31
9N-27E-28ab1	110	16	1,000	47	21
7N-28E- 7cc1	87	10	1,350	18	75
6N-29E- 7b1	95	53	1,200	13	92
22cb1	82	42	800	12	67
25ab1		35	450	15	30

The average well diameter is about 16 inches, and most wells are completed with perforated casings. Specific capacities of the 6 wells ranged from 21 to 92 gpm per foot of drawdown and averaged about 53 gpm per foot. Wells completed with perforated casings generally are not very efficient; it is likely that 70 to 90 percent of the drawdown represents well loss and that only 10 to 30 percent of the drawdown is drawdown in the aquifer. If it is assumed that 25 percent of the drawdown is the average aquifer drawdown, the specific capacity would be more nearly about 200 gpm per foot. This specific capacity would represent a coefficient of transmissibility of 400,000 to 500,000 gpd per foot. Properly constructed and developed wells should yield 1,500 to 2,000 gpm with only moderate drawdowns.

Water levels throughout most of the valley are near, slightly above, or slightly below the level of the Little Lost River. Above Wet Creek for about 5 miles, the water table is near or at the surface of the marshy central part of the valley. According to Crandall and Stearns (1930), the river is perched above the water table for the next 17 miles downstream, except in the vicinity of Knollin Springs in sec. 12, T. 7 N., R 27 E. However, the reported depth to water of 16 feet in well 9N–27E–28ab1 in this reach, suggests that the water table is not far below the surface. Beginning at about the north edge of T. 8 N., and extending downstream 12 miles to a point 11 miles northwest of Howe, where the consolidated bedrock extends halfway across the valley and forms a constriction in the ground-water channel, the water table is again near or at the surface in the central part of the valley. Downstream from the constricted area, the water table slopes more steeply than the land surface and is at progressively greater depths below the surface. In the irrigated area immediately north of Howe, the water table ranges generally from 30 to 80 feet below the surface. The water table drops abruptly south and southeast of Howe, the break coinciding approximately with State Route 22. A few miles south of the highway, the water table is 250 to 300 feet below the surface.

The ground-water reservoir is recharged chiefly by percolation from stream channels. At places the Little Lost River is above the water table and loses water to the ground, especially south of the center of T. 7 N. Most of the recharge is from tributaries, which seldom if ever discharge surface water into the Little Lost River because the water is lost as the streams cross their alluvial fans. Generally a large part of the water is lost within a mile of the mouth of the canyon. Most of the tributary streams flow throughout the year; recharge, therefore, is a continuous process, as is discharge, but spring snowmelt nearly always produces an extra spurt of recharge.

Water-table fluctuations chiefly reflect changes in recharge. The wave of recharge occurring in late winter and spring is shown by the hydrograph of well 6N-29E-33dc1 (fig. 29). The water-level fluc-

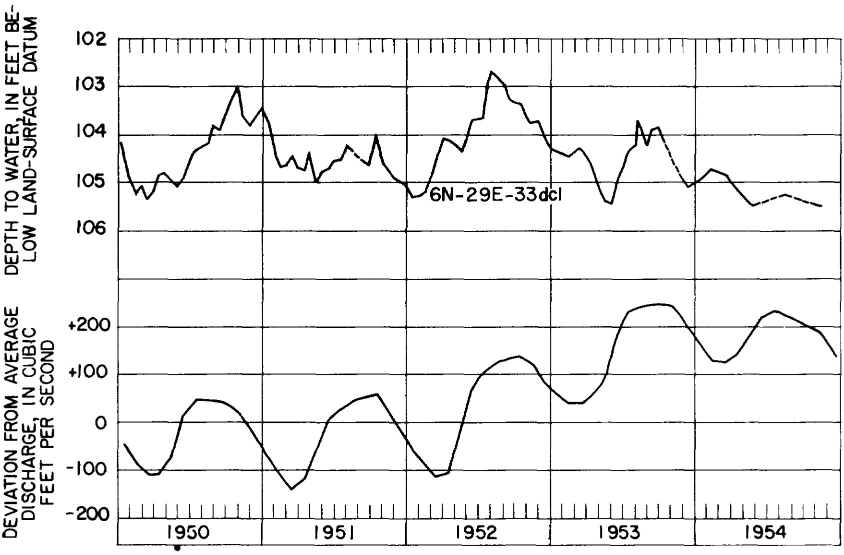


FIGURE 29.—Hydrograph of well 6N-29E-33dc1 and cumulative departure from average discharge of the Little Lost River (at station 6 miles north of Howe).

tuations in this well correlate fairly closely with the discharge of the Little Lost River at the gaging station 7 miles northwest of Howe, but other factors also affect the water level.

Chemical analyses of four water samples probably fairly representative of ground water in the valley are given in the following table. The water appears to be of excellent quality for irrigation.

Chemical analyses of ground water in the Little Lost River valley

[Chemical constituents in parts per million]

Constituent or property	Well			
	6N-29E-20dc1	6N-29E-21dd1	6N-29E-33cc1	5N-29E-4dd2
Silica (SiO_2)	17			26
Iron (Fe)	.06			
Calcium (Ca)	50			67
Magnesium (Mg)	18			28
Sodium (Na)	27	11	3.9	24
Potassium (K)	2.1			
Bicarbonate (HCO_3)	244	220	264	216
Sulfate (SO_4)	26	40	15	26
Chloride (Cl)	14	35	6	50
Fluoride (F)	.1			.6
Nitrate (NO_3)	16			72
Boron (B)	.02			.00
Dissolved solids	290			400
Hardness:				
Total	199	248	232	282
Noncarbonate	0	68	16	105
Percent sodium	22	9	4	16
Specific conductance micromhos at 25°C	457	534	462	607
pH	7.6			
Temperature °F	45			57

Discharge of the Little Lost River at the station near Howe has averaged about 50,000 acre-feet per year for the period of record. This discharge is not a measure of the water yield of the basin because none of the tributary streams are gaged and many lose a large part of their flow before reaching the main stem. Undoubtedly underflow through the valley alluvium is considerable. The quantity of underflow could be calculated if accurate data were available on the transmissibility and thickness of the deposits. Such data are not available, but a reasonable estimate can be made.

On the basis of specific-capacity data and by comparison with the Big Wood and Big Lost River valleys, the average coefficient of transmissibility of the valley fill probably is about 500,000 gpd per foot. The downvalley slope of the water table is about 40 feet per mile. The aquifer at the gaging station near Howe, is 5 miles wide. Computations indicate the underflow is more than 100,000 acre-feet per year. Probably 40,000 acre-feet of the 50,000 acre-feet passing the gage reaches the margin of the Snake River Plain by way of the river channel or by percolation into the aquifer below the gaging station. Total water leaving the basin may therefore be as much as 140,000 acre-feet per year and is in addition to the water presently being used for irrigation.

The average annual precipitation on the basin above the gaging station, according to the isohyetal map, is 14.7 inches. The water yield, in inches over the basin, was about 3.75 from the relation shown in figure 7 on an area of about 820 square miles; computation gives an annual water yield for the basin of about 160,000 acre-feet. The two independent estimates are reasonably close, and the average of 150,000 acre-feet is used in computing the flow net in a later section of the report.

Not all the underflow could be intercepted, but in view of the present shallow depth to water and the depth of wells, perhaps 50,000 to 60,000 acre-feet, 30 to 40 percent of the underflow, might be withdrawn and consumed in the area without lowering the water level beyond economic recovery limits.

Development of that quantity of water would result in a general decline of the water table, perhaps as much as 50 feet. If such an extensive development were planned, the production wells should be drilled deep enough to allow for the general decline of the water table.

These conclusions are based on scanty data, particularly with reference to the coefficient of transmissibility. One or two test wells and several aquifer tests would assist in making an evaluation of ground-water supplies in the valley.

BIRCH CREEK BASIN

The mouth of Birch Creek basin is 50 miles northwest of Idaho Falls (fig. 12). The basin extends northwestward from the Snake River Plain and is separated from the Little Lost River by the Lemhi Range. That range and the Beaverhead Mountains along the east side of the basin rise to altitudes exceeding 10,000 feet. The basin is 40 miles long and from 12 to 18 miles wide. The Birch Creek basin occupies only the southeastern half of the trough between the two mountain ranges. The other half constitutes the Lemhi basin, which drains northwestward into the Salmon River.

The rocks forming the mountain ranges are chiefly consolidated strata of Paleozoic age. These strata consist of limestone, sandstone, and shale. The mountains, which were uplifted by faulting, rise abruptly from the broad, gently sloping valley floor. The down-faulted basin has been partly filled with alluvium, but the depth of the alluvium is not known. Large alluvial fans slope toward the center from both ridges, and, as they were built, they alternately pushed Birch Creek from one side of its valley to the other. Obviously this small creek has had little or no part in forming the topographic features of the alluviated valley, which averages 7 to 8 miles wide and extends the entire length of the basin. Actually, both the drainage basin and the alluviated central valley are widest near the head of the basin.

The altitude of the saddle separating the Birch Creek basin from the Lemhi basin to the north is at an altitude of 7,200 feet, and the altitude of the valley floor of Birch Creek where it joins the Snake River Plain is 5,200 feet. A lava flow of Snake River basalt blocked the valley south of Reno and caused deposition of alluvium above the dam. The downvalley slope above the lava dam, which has been breached, is only 25 feet per mile, whereas below the dam the slope is more than 60 feet per mile.

There are no precipitation stations in the basin, but comparison with other areas indicate that annual precipitation ranges from less than 10 inches at the mouth of the basin to more than 30 inches on the high west-facing slopes.

Birch Creek, which rises as an ephemeral and intermittent stream at the head of the basin, flows in nearly a straight line to the Snake River Plain. Most of the tributaries to Birch Creek are short and direct, and enter from the flanking ranges at about right angles. Most are intermittent and ephemeral, and little water flows in their courses after they leave their canyons at the base of the mountains. Near Reno, numerous springs discharge into Birch Creek, and the flow of the creek through this reach is remarkably uniform throughout the year and from year to year.

The discharge of Birch Creek is measured at the gaging station a few miles south of Reno about midway between the head of the basin and its mouth. The drainage area above the station is 320 square miles. Generally the discharge of Birch Creek does not vary more than 15 percent during the year. For the 8-year period of record the 1956 water year, discharges, in cubic feet per second, were: maximum, 111; minimum, 61; and average 80. Downstream from the gaging station, the creek is above the water table and loses water by percolation. Generally no surface flow reaches the mouth of the valley.

Little information is available on ground-water conditions in the Birch Creek basin. Undoubtedly large yields could be obtained from properly constructed wells, as in all other basins along the northwest flank of the plain. The water table is at an altitude of 4,580 to 4,585 feet over a wide area at the mouth of Birch Creek, but its upstream gradient is not known.

About 58,000 acre-feet of water passes the gaging station on Birch Creek south of Reno each year. The gaged outflow from the 320 square-mile area above the station is equivalent to 3.3 inches of water over the area. Many short streams rise on mountain slopes on both sides of the basin downvalley from the gaging station, but discharge from these streams rarely reaches Birch Creek. An unknown but large quantity of water enters the alluvium in this reach. The area of the drainage basin below the gaging station in 245 square miles, and the area of the entire basin is 565 square miles.

Undoubtedly underflow in the valley fill is considerable, but no information is available regarding the quantity. However, by making an assumption regarding the transmissibility of the aquifer, some idea of the possible magnitude of the underflow may be gained.

The average hydraulic gradient is unlikely to be much different from the downvalley slope of the land surface; near the mouth of the basin this slope is more than 50 feet per mile. The width of the valley between bedrock walls is about 7 miles; these rocks slope into the valley, and the width at depth may be somewhat less. The coefficient of transmissibility is unknown, but the coefficients of transmissibility of a similar alluvial fill in the Big Wood River basin ranged from 7.25×10^5 to 2.2×10^6 gpd per foot. If the hydraulic gradient is assumed to be 50 feet per mile, the width of the alluvial fill to be 4 miles, and the coefficient of transmissibility to be 5×10^5 gpd per foot, the underflow is 100 mgd, or more than 70,000 acre-feet per year. The underflow could be less, or much more, though the estimate probably is conservative.

The average annual precipitation on the basin is 13 inches, and, according to the relation shown by figure 7, the water yield for the basin is about 80,000 acre-feet.

During the summer, small amounts of water are diverted from Birch Creek for irrigation along its course, and several miles below the gaging station the entire flow is diverted for irrigation of a ranch on the Snake River Plain several miles east of the mouth of the basin. Much of the unlined canal crosses coarse gravel, and transmission losses are large. The growing season is short, about 100 days, and depletion of basin outflow due to consumptive use for irrigation probably is not more than 5,000 acre-feet.

MUD LAKE SUBAREA

East of the Birch Creek basin several streams have their headwaters in the Beaverhead and Centennial Mountains, which form the Continental Divide and the boundary between Montana to the north and Idaho to the south. From west to east, these streams flow successively southeastward, southward, and southwestward, converging on the Mud Lake subarea. None of the drainage channels reach the Snake River.

The central part of the Mud Lake subarea consists of a large shallow basin. The southern part is a broad, flat plain underlain by lake beds and stream deposits. To the north and northeast, basalt forms a ramp that slopes gently upward to the base of the mountains.

The mountains surrounding the Mud Lake subarea rise generally to an altitude of 8,000 to 10,000 feet, although a few peaks rise to more than 11,000 feet. The altitude of the Snake River Plain at the base of the mountains ranges from about 5,000 feet in the vicinity of Lidy Hot Springs in the western part of the subarea to more than 6,400 feet near the Island Park area. Some of the higher peaks along the

Continental Divide and in the Beaverhead Mountains west of the Mud Lake subarea consist of sedimentary rocks, including limestone, shale, and quartzite. The larger part of the headwater drainage area is underlain by rhyolitic lava flows and associated pyroclastic rocks. Large areas also are underlain by sandstone and conglomerate. The overall permeability of these materials probably is considerably greater than that of the consolidated sedimentary rocks of the headwater drainage of Birch Creek and Big and Little Lost Rivers and may be an important factor in recharge to the aquifers in the Mud Lake subarea.

Annual precipitation at Hamer averages 7.8 inches and at Dubois 11.1 inches. Precipitation on the higher slopes ranges generally from 20 to 40 inches. Most of the basin is above an altitude of 5,000 feet, and winters are moderately cold; winter precipitation is mostly snow. Summers are short, the average length of the growing season being 100 days. Days usually are warm to hot, but nights are cool.

The courses of most of the streams have been determined by the dip of the underlying strata, and the streams flow more or less directly down the slope. From west to east, the more important streams are Crooked, Warm Springs, Deep, Medicine Lodge, Indian, Beaver, and Camas Creeks. All but two of the streams lose their entire discharge and their courses disappear within a short distance after they reach the edge of the Snake River Plain. These two, Camas Creek and its chief tributary, Beaver Creek, discharge some water into Mud Lake, which is 32 miles south of the base of the mountains.

Data pertaining to gaging stations on three of these streams are given in the following table.

Creek	Station	Drainage area (square miles)	Period of record	Discharge	
				Cubic feet per second	Acre-feet per year
Camas	At Eighteen-mile shearing corral near Kilgore.	210	1947-53	72.8	52,600
	At Camas	320	1926-55	27.4	19,800
Beaver	At Spencer	120	1940-51	[1] 32	[1] 23,000
	At Dubois	220	1921-55	17.0	12,300
	At Camas	510	1921-55	3.9	2,800
Medicine Lodge	Near Argora	160	1939-43	[1] 33.4	[1] 24,200
	At Ellis Ranch, near Argora	165	1940-55	43.0	31,100
	Near Small	270	1921-23 1941-48	61.5	44,500

[1] Estimated, in part.

The average annual discharge of Camas Creek at the gaging station at Eighteen-mile shearing corral near Kilgore for 7 full years of record from 1947 through 1953 was 72.8 cfs (52,600 acre-feet per year). A comparatively long record of the discharge of Camas Creek is available at Camas, 25 to 30 miles downstream. Comparison of the upstream with the downstream records shows large losses by percolation from the stream channel between stations. Although quantitative comparison is complicated by diversions and inflow between the stations, a qualitative appraisal is possible. During periods of high discharge, in May and June, when the monthly mean discharge at the upstream station may reach 350 cfs, the loss is 100 to 150 cfs. At lower stages, losses are less, but it appears that the minimum losses are at least 25 cfs. During the winter, the difference between discharges at the upstream and downstream stations are much less, and, on a few occasions, the downstream station has shown a greater monthly discharge than the upstream station. Percolation from the streambed may be less during the winter than in the spring and summer, but the most obvious explanation is that some runoff occurs between stations, especially in the winter.

It is not at all certain that the upstream gaging station measures the entire yield of the basin above that point. The geologic map prepared by Stearns, Bryan, and Crandall (1939) shows Snake River basalt extending several miles north of the station site. Glacial outwash underlies and borders the creek at the site, and for several miles upstream these materials could transmit large quantities of water that would not appear in the stream at the gage. The average gaged discharge at the gaging station, 52,600 acre-feet per year from 210 square miles, is equivalent to 4.7 inches of water over the area. It is probable that the total water yield of the basin at that point is considerably greater.

Discharge records for spring, summer, and fall are available for 13 years for the gaging stations near and at Spencer. Records of winter discharge are available for only 3 of these years. However, winter flows are comparatively low and fairly uniform. Interpolation and extrapolation to fill in the missing records gives reasonably good results. The average annual discharge at the Spencer stations for the period 1940 through 1951 is estimated to have been 23,000 acre-feet.

Gaging stations have been maintained on Beaver Creek for many years at Dubois, 15 miles downstream from Spencer, and at Camas, 27 miles downstream from Spencer. Like that of Camas Creek, the discharge of Beaver Creek decreases downstream, owing both to channel losses and to diversions for irrigation. The average annual discharge at Camas is less than 4 cfs, or 2,800 acre-feet per year. Some runoff is derived from the area between Spencer and Camas, so it is probable that little of the water flowing past Spencer ever reaches Camas Creek at Camas.

The discharge of 20,000 to 25,000 acre-feet per year at Spencer is equivalent to about 3.5 inches of water over the area of approximately 120 square miles. Probably a small amount of underflow moves past the station, and outflow to the Snake River Plain by percolation through the volcanic rocks underlying the basin may be considerable.

The average annual discharge of Medicine Lodge Creek at the station at Ellis Ranch was 43 cfs, or 31,100 acre-feet, for the period 1940–55. The discharge 7 or 8 miles downstream, at the station near Small, for a somewhat different period of record (1921–23 and 1941–48), was 61.5 cfs. Discharge at the Argora station is equivalent to 3.5 inches of water over the area of 165 square miles above the station, and discharge at the station near Small is equivalent to 3.1 inches of water over the drainage area of 270 square miles. The basin may yield considerably more water than is measured at these stations, but, if so, the additional water must be leaving the basin by general ground-water outflow, for the records do not indicate a great deal of percolation loss from the channel above the station near Small. Downstream from this station, however, the entire streamflow disappears within a distance of 15 or 20 miles.

The Snake River basalt and associated beds of cinders and other pyroclastic material is the chief aquifer in the Mud Lake subarea. The basalt is extremely permeable and yields large quantities of water to wells. North of Mud Lake, the basalt is at or near the surface, and the land generally is not suitable for agriculture. The water table is near the surface, and about 15 well fields discharge water into canals, which carry the water to irrigated lands to the west and southwest. Most of the well fields have 10 or 12 wells. The wells range in depth from 80 to 160 feet and in diameter from 18 to 30 inches; their yields range generally from 2,000 to 9,000 gpm with a drawdown of only 1 or 2 feet. In addition to the well fields, many irrigation wells are scattered through other parts of the area.

The water table is nearly flat and is between the altitudes of 4,790 and 4,800 feet over an area of several townships north of the lake. Water levels just before the irrigation season begins range from 5 to 140 feet below the surface, depending largely upon topography. Although the drawdown caused by single wells is small, the combined drawdown caused by pumping more than 100 wells within an area of a few townships is as much as 40 feet at some places. The water table recovers rapidly after the end of each irrigation season, and even during recent years of greatly accelerated development the residual drawdown at the start of the following irrigation season is small. The fluctuation of the water table caused by pumping is shown by the hydrographs of wells 7N–34E–4cd1, and 7N–35E–20cb1 (fig. 30).

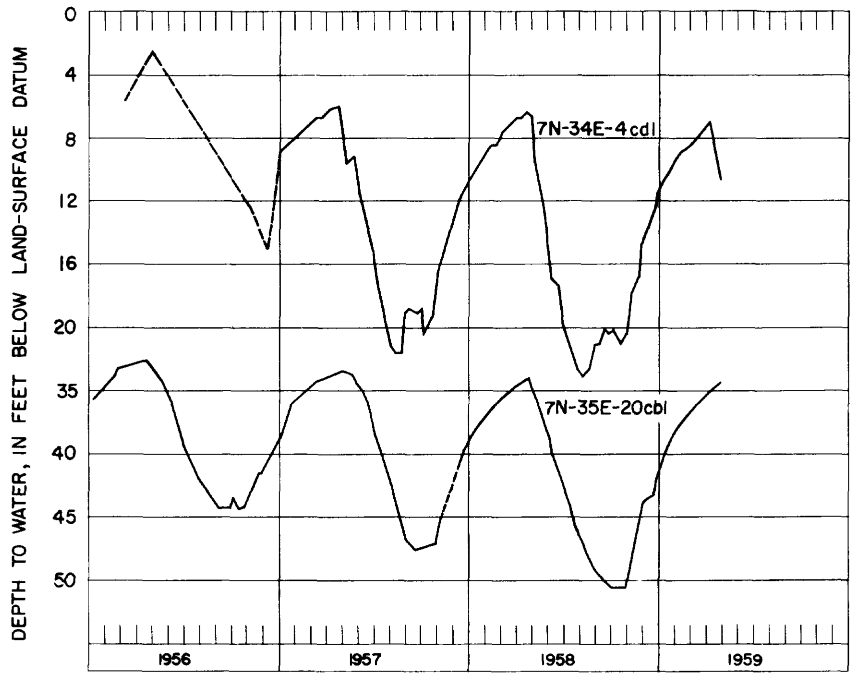


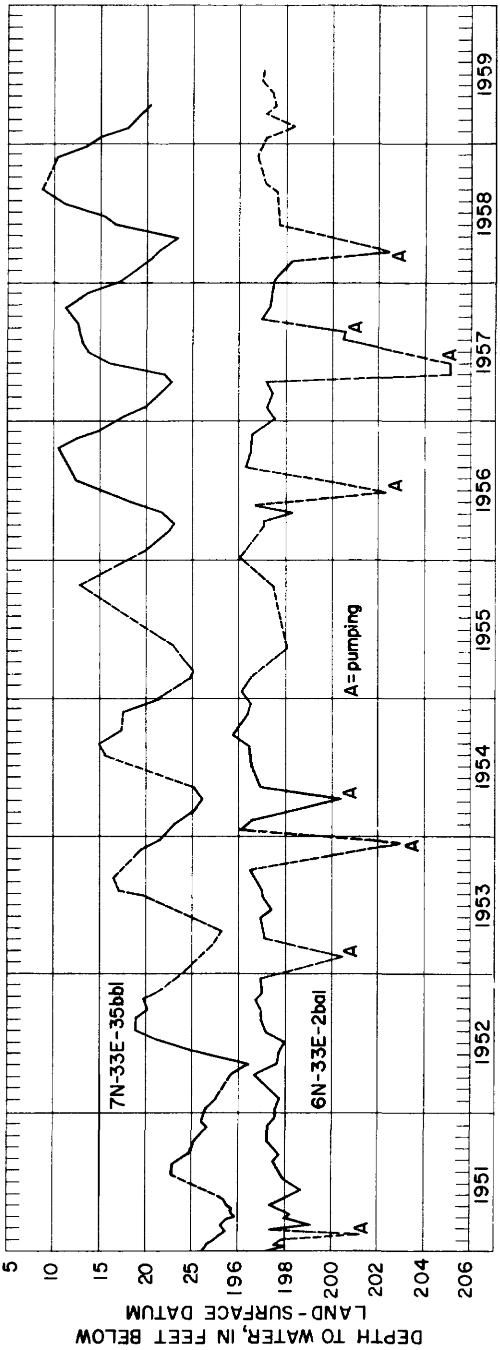
FIGURE 30.—Hydrographs of wells 7N-34E-4cd1, and 7N-35E-20cb1.

The effect of applying this ground water on the irrigated area west of the pumped area is shown in figure 31. The hydrograph of well 7N–33E–35bb1, in the shallow perched water table, shows immediate response to application of water which begins in April or May. Well 6N–33E–2ba1 taps a much deeper aquifer that is fed in part by leakage from the perched aquifer, and the response is much slower.

West and south of Mud Lake, the water table declines from an altitude of about 4,790 to 4,580, in a distance of 2 miles.

Apparently the water table in the Mud Lake subarea is held at the higher level by a barrier. The exact nature of this barrier is not known, but it is presumed to be in part formed by sedimentary lake beds of low permeability. Aerial photographs reveal fault traces parallel to the barrier, and probably the barrier is related to these faults. North of the barrier, the gradient of the water table generally is less than 2 feet per mile; immediately south of the barrier, the gradient ranges generally from 5 to 10 feet per mile. The gradient between these areas, through the barrier, averages nearly 100 feet per mile; this steep decline has been aptly termed a "ground-water cascade."

Many domestic wells have been drilled in the barrier area. At some places, water levels are progressively lower as successively deeper aquifers are penetrated and indicate that at least some of the aquifers are



DEPTH TO WATER, IN FEET BELOW
LAND-SURFACE DATUM
5
10
15
20
25
196
198
200
202
204
206
1951
1952
1953
1954
1955
1956
1957
1958
1959
7N-33E-35bb1
6N-33E-2ba1
A=pumping
A

perched on materials of low permeability, presumably lake-bed sediments. Apparently, where these perching beds pinch out to the south and east, the individual aquifers drain to lower levels.

Wells south and east of Mud Lake and Monteview are as deep as 400 feet. Water levels are as deep as 250 feet below the surface.

Chemical characteristics of ground water in the Mud Lake subarea are shown by the analyses in the following table.

Summary of chemical analyses of ground water in the Mud Lake subarea

[Chemical constituents in parts per million. Twenty-one wells sampled]

Constituent or property	Maximum	Minimum	Typical (well 6S–35E–26ba1)
Silica (SiO_2)	44	26	39
Iron (Fe)	.33	.00	.02
Calcium (Ca)	144	.8	37
Magnesium (Mg)	41	.1	9.7
Sodium (Na)	86	4.9	16
Potassium (K)	6.4	1.8	2.6
Bicarbonate (HCO_3)	345	47	160
Sulfate (SO_4)	133	.8	14
Chloride (Cl)	206	3.5	17
Fluoride (F)	.9	.1	.5
Nitrate (NO_3)	17	.0	1.1
Boron (B)	.1	.01	.1
Dissolved solids	932	92	218
Hardness:			
Total	528	2	132
Noncarbonate	356	0	1
Percent sodium	96	10	20
Specific conductance micromhos at 25°C	1,250	88	330
pH	9.1	7.7	7.9
Temperature °F	60	45	54

Most of the water is satisfactory for all uses. The water of poorer quality, that with higher mineral concentration, generally is from areas where percolation from irrigated tracts is the principal source of recharge.

Available discharge records of streams flowing into the area were summarized on pages 150–132. Records are available for three of the larger creeks, but little or no information is available for other streams.

Discharge records for the three measured streams do not give the water yield of even those stream basins because some water bypasses the gaging stations by underflow. The measured discharge of Camas, Beaver, and Medicine Lodge Creeks at upstream stations was equivalent to 4.7, 3.5, and 3.5 inches of water over the area, respectively. The stations are at altitudes of 6,260, 5,850, and 5,708 feet. According to the isohyetal map (pl. 2), the average annual precipitation on the drainage area above 5,800 feet (1,170 square miles) is 19.7 inches. Water yield on the basis of the relation shown in figure 7 is 430,000 acre-feet.

Probably little precipitation reaches the water table in the vicinity of Mud Lake and Monteview, where fine-grained sedimentary materials are at and below the surface. Large areas north, northwest, and northeast of Mud Lake and Monteview are underlain by porous materials—sand, gravel, cinders, and basalt—having little or no soil mantle. In that part of the area, precipitation averages 11.1 inches a year, and recharge in the winter and spring probably is considerable. On the basis of the relation shown in figure 7, water yield from that part of the area is 70,000 acre-feet per year. Thus the total amount of water available in the Mud Lake area would be 500,000 acre-feet per year.

Ground water moves from the Mud Lake subarea by lateral percolation to the south and southwest into the main part of the Snake River Plain. The amount of underflow that escapes the Mud Lake subarea is the difference between the total water yield of the basin and the sum of the amounts consumed by irrigation and evapotranspiration.

The total irrigated area in the Mud Lake subarea is estimated to be 70,000 acres, and consumptive use, in addition to direct precipitation on the cropland, is estimated to be 1.3 acre-feet per acre per year, for a total depletion due to irrigation of 90,000 acre-feet. There is considerable loss from lake surfaces and by waste vegetation. In their investigation of the Mud Lake subarea, Stearns, Bryan, and Crandall (1939) made a detailed study of evapotranspiration. Their data and current observations indicate that these losses are approximately 80,000 acre-feet per year at the present time (1959). Depletion of the water supply by consumptive use within the basin thus is estimated to be 170,000 acre-feet per year. This amount subtracted from the available water supply in the area (estimated to be 500,000 acre-feet) is 330,000 acre-feet, which leaves the area as underflow.

TETON BASIN

The Teton basin is mostly in Idaho along the Idaho-Wyoming State line (fig. 12). The northward-trending valley is 20 miles long and ranges in width from 5 miles at its upper (south) end to 10 miles at its lower (north) end. It occupies the central part of the Teton basin, which is a mountainous drainage basin covering 470 square miles and within which are the major valley of the Teton River and the valleys of several minor tributaries.

The axis of the valley is nearly parallel to the axis of the Teton Mountains to the east. It is a structural depression formed in part by normal and thrust faulting along its southern and western sides. From the igneous core of the Teton Mountains, uplifted sedimentary rocks of pre-Tertiary age form a westward-dipping monocline and pass under the valley. These are exposed also in the Big Hole Mountains, which form the west side of the basin, and in the Snake River Range, which is at the southern terminus of the basin.

Silicic volcanic rocks of Tertiary age crop out continuously along the western side of the Teton Mountains north of Darby Creek and along the Big Hole Mountains north of Mahogany Creek, where they are locally intercalated with thin beds of water-laid sand. Remnants of similar volcanic rocks crop out discontinuously along the Snake River Range at the southern end of the valley between the Teton River and Little Pine Creeks. Similar rocks probably underlie most of the alluvial valley fill north of Driggs but may underlie only parts of the valley south of Driggs. Within the Teton Basin, their aggregate thickness probably does not exceed 1,000 ft.

Several basaltic lava flows of Tertiary or Quaternary age that crop out northwest and west of Tetonia blocked the northern end of the basin and ponded the waters of the Teton River in a lake in which silt, sand, and gravel were deposited. The river later cut a canyon through the basalt into the underlying silicic volcanic rocks. The southern end of the canyon is now called "The Narrows."

The Teton basin has been partly filled with alluvium of Pleistocene and Recent age, and some of the material at the base of the Teton Mountains may contain glacial till of Pleistocene age. The thickness of the valley fill has not been determined.

Precipitation in the valley averages between 16 and 17 inches annually but is much higher in the mountains. Winters are long and cold. Summers are short and moderately dry. Temperatures range from −50° F to 97° F, with a mean of 39° F. The average annual frost-free growing season is 82 days (U.S. Dept. Agriculture, 1942).

The Teton River rises at the southern end of the basin and flows northward out of the basin through a canyon cut through the basaltic lava flows and into the underlying silicic volcanic rocks. Most of the larger tributaries originate in the Teton and Big Hole Mountains. A large part of the flow of these tributaries is lost where they leave the mountains and flow across their alluvial fans. During the spring and summer, the flow of some streams is largely diverted for irrigation, and little or no water reaches the Teton River. The discharge of the Teton River is measured at a gaging station 4½ miles northwest of Tetonia at the mouth of the gorge. The discharge has averaged 388 cfs (280,900 acre-feet per year) for the periods 1929–32 and 1941–56. The maximum discharge observed was 1,900 cfs on June 28, 1945, and the minimum observed was 62 cfs on January 16 and 17, 1943.

The silicic volcanic rocks yield small to moderate amounts of water to wells along the edges of the valley. Yields generally are less than 50 gpm but are adequate for domestic and stock use.

The chief aquifer in the valley is sand and gravel, which were deposited by streams discharging from the surrounding mountains. The

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depth to water ranges from less than 1 foot in the waterlogged area along the Teton River to more than 200 feet near the east and west margins of the basin. The depth to water is governed in part by the topography and in part by local recharge and discharge to the aquifer. During the spring and fall, water levels may fluctuate as much as 100 feet along the east side of the basin. The water table is lowest during early spring and rises rapidly during May, June, and July, as the snow in the surrounding mountains melts. During the latter part of the summer, the water table declines rapidly as the water is discharged into the Teton River from the waterlogged lower parts of the valley. Thus, the porous rocks beneath the valley serve as a storage reservoir, which is recharged largely during the late spring and early summer and which discharges continuously through the year.

An unknown amount of water leaves the valley by underflow toward the north. Some of the underflow enters the Teton River through springs that discharge several miles below the gaging station.

The alluvium is recharged by precipitation on its surface, by springs discharging from the pre-Tertiary sedimentary rocks along the margins of the basin, and by seepage from streams and canals which cross its surface. The water table slopes toward the central or lower parts of the valley on the west, south, and east sides; it forms a trough whose axis parallels the Teton River and which slopes downward toward the north. The water table intersects the land surface in the lower parts of the valley. Springs mark this line of intersection and produce an extensive waterlogged area. Discharge from these springs is greatest during late spring and early summer.

The alluvium yields adequate supplies of water for domestic and stock use and is capable of yielding amounts sufficient for irrigation to properly constructed and developed wells. A test well, drilled in the NE¼ sec. 13, T. 4 N., R. 45 E., 3.5 miles southeast of Driggs, was pumped for nearly 16 hours at 1,330 gpm. The drawdown at the end of the test was slightly more than 17 feet. Because the test well penetrated only part of the aquifer and also was somewhat inefficient, the drawdown was considerably greater than it would otherwise have been. Properly constructed and developed wells probably would yield as much as 2,000 gpm with small drawdown.

Withdrawal of large quantities of water from the aquifers would reduce the total outflow from the basin, and, because ground water discharging from the alluvium helps to maintain the flow of the Teton River during dry weather, the dry-weather flow would be reduced to some extent. However, the water yield from the basin would be reduced only by that amount of water consumed in excess of the amount now consumed. If large quantities of ground water were to be pumped for irrigation, the water table in the marshy areas would be lowered, and evapotranspiration would be reduced. Thus, pumping of ground water for irrigation in the Teton Valley probably would not decrease the water yield of the basin by more than 1 acre-foot per year per acre of land irrigated.

Ground water in the Teton Valley is generally low in dissolved solids and is moderately hard. The water is of satisfactory chemical quality for most uses. The water issuing from springs along the base of the Snake River Range and the Big Hole Mountains may contain appreciably greater amounts of sulfate but is similar in other respects.

SNAKE RIVER PLAIN EAST OF BLISS[4]

In general usage in Idaho, the term "Snake River Plain" refers both to the entire plain extending from Wyoming to Oregon, as described at the beginning of this report, and to that part of the plain east of Bliss. In the following section the terms "the Snake River Plain" or "the plain" will be used for "the Snake River Plain east of Bliss" (fig. 12) except where ambiguity is possible.

The Snake River Plain east of Bliss is the broad plain extending eastward and northeastward from Bliss and the Hagerman Valley for 200 miles, approximately to Ashton. It is underlain chiefly by basaltic lava flows, which, from a distant view, form an undulating surface extending to the horizon. Closer observation discloses a great variety of landforms and a diversity of geologic features. Broad swells and domes mark some centers of volcanism; craters and cinder cones, at places alined along great rift zones, mark other such centers. Lava caves and tubes are found at numerous places. Some of the earlier lava flows are covered with a mantle of windblown sand and silt, and at places sedimentary materials accumulated in playas. More recent flows are virtually bare, and the ropy pahoehoe lava forms ramplike surfaces extending for hundreds of yards. At other places, blocky lava forms a jumbled and exceedingly rough and jagged mass.

A few islands of older rocks protrude through the sea of lava. These include Big Southern and Twin Buttes west of Idaho Falls and Juniper Buttes northwest of St. Anthony.

Bordering the plain on its northwestern and southeastern flanks are older consolidated rocks including granite, limestone, quartzite, shale, and silicic and basaltic volcanic rocks. In general, these older rocks have been folded and faulted into northwestward-trending mountain ranges with intervening structural valleys. All these structures terminate abruptly at the margins of the Snake River Plain, which crosses them at approximately right angles. These older rocks

[4] A comprehensive description of the geology and physiography of the Snake River Plain east of Bliss is given by Stearns, Crandall, and Steward (1938).

were faulted or warped downward to form a basin in which the basalt lava flows and associated sedimentary rocks accumulated. No wells more than a mile or two from the margin of the plain have penetrated deeply enough to reach the underlying basement rock.

The limit of the Snake River Plain along its northwest flank is reasonably well defined (pl. 4). Except where tributary valleys enter the plain, the lava flows terminate abruptly against the mountain slopes formed on the older rocks. At the mouths of some of the tributaries, as at the Big Lost and Little Lost Rivers and Birch Creek, the lavas extend a short distance up the valleys. The boundary along the southeast flank is less definite. Sedimentary materials, deposited in basins formed largely by damming of the drainage by the lava flows during the period of volcanism that produced the Snake River basalt, are much more extensive than along the north flank and extend for considerable distances up the tributary valleys. For this report, the boundary between the plain and the tributary valleys along the southeast flank is arbitrarily assumed to be a line connecting the north ends of the mountain ranges separating these valleys.

CLIMATE

The climate of the Snake River Plain is influenced by its altitude and latitude but is dominated by the effects of the surrounding mountain masses. The prevailing westerly winds are channeled by the bordering mountains into a dominantly southwestward flow of air. As the air masses are lifted over the bordering high mountain ranges, they are dried so that precipitation on the plain is much less than that on the surrounding areas. As shown on the isohyetal map (pl. 2), average annual precipitation ranges from less than 6 inches in the central part to nearly 30 inches at the high northeastern end on the slopes of the Centennial Mountains. Average annual precipitation on more than half of the Snake River Plain is less than 12 inches. Average annual precipitation at several stations on the plain is given in table 2, and seasonal distribution at two representative stations is shown in figure 32.

Summers are moderately warm to hot and winters are fairly cold. However, the generally low humidity results in less discomfort than that in more humid areas at equivalent temperatures. Maximum summer temperatures commonly are in the 90° to 100° range, and winter minimums often are below zero. Mean monthly and annual temperatures at several stations are given in table 3.

Evaporation measurements in Class-A land pans are made at two stations in the Snake River Plain, at Minidoka Dam and the Aberdeen Experiment station, for part of the year. Average evaporation

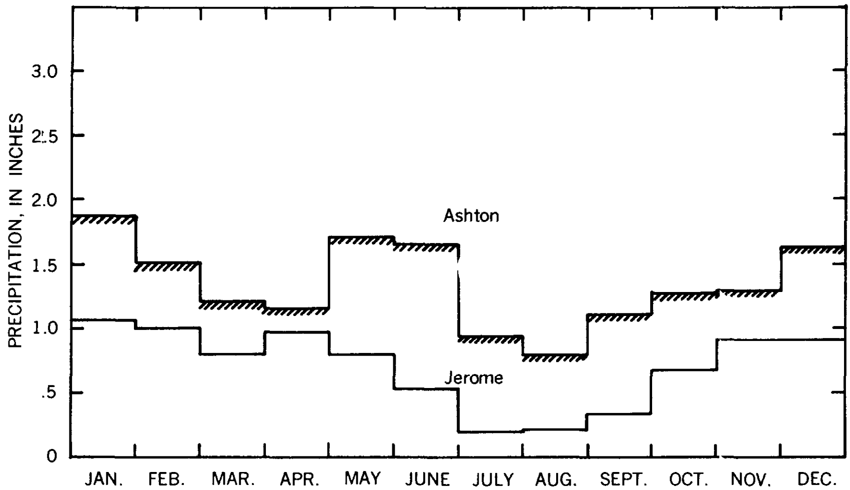

FIGURE 32.—Precipitation at two representative stations on the Snake River Plain of eastern Idaho.

for the period May to October at these stations is 57 and 40 inches respectively (table 5).

DEVELOPMENT OF WATER RESOURCES

The Snake River Plain contains some of the most highly developed agricultural lands in the State. As in most of the other subareas, irrigation began on a modest scale before 1890 with simple brush and rock dams in the Snake River to divert water to farms. At the present time (1959), more than 90 canals divert 7 million acre-feet of water from the river to more than a million acres of land. Surface-water irrigation is confined to narrow strips, rarely more than 15 miles wide, along both sides of the river from Ashton to Bliss. The one exception is in the Shoshone-Gooding area, where a large canal (Gooding Canal) carries water to lands extending 25 to 30 miles from the river.

As the surface-water resources became more fully utilized, exploration for and development of ground water was intensified. Since World War II, development of ground water has expanded rapidly, and, in 1959, more than 200,000 acres of land was irrigated wholly with ground water, and probably more than 25,000 acres was receiving a supplemental supply. Ground-water development has been mostly north and west of the Snake River, either in areas adjacent to the tracts irrigated with surface water or in higher areas within the surface-water tracts.

The principal areas of ground-water development are north of Rupert and between Aberdeen and Roberts. Smaller scale development includes that in areas south of Wendell, north of Jerome, south of Hazelton, and north of Menan. One of the largest integrated developments was constructed by the Bureau of Reclamation a few miles north and west of Rupert. In 1958 this project pumped 168,800 acre-feet of ground water from 158 wells for 54,700 acres. Withdrawals averaged 3.1 acre-feet per acre, and the average amount of water withdrawn per well was 1,070 acre-feet. Adjacent to the Federal project, private developers irrigated an equal amount of land from approximately the same number of wells and probably pumped an equal amount of ground water.

The principal irrigated crops in the Snake River Plain are hay, grain, pasture, potatoes, sugar beets, and seed crops, which include clover, alfalfa, and beans.

Almost all municipal and domestic water supplies are obtained from wells, and several stock wells have been drilled by the Bureau of Land Management at strategic locations on the Federal grazing lands.

SNAKE PLAIN AQUIFER

The Snake Plain aquifer is herein defined as the series of basalt flows and intercalated pyroclastic and sedimentary materials that underlie the Snake River Plain east of Bliss. The Snake Plain aquifer extends from Bliss and the Hagerman Valley on the west to Ashton and the Big Bend Ridge on the northeast. Its lateral boundaries are formed at the contacts of the aquifer with less permeable rocks near the margins of the plain.

Although one lava flow may not be a good aquifer, a series of flows may include several excellent water-bearing zones. If the sequence of lava flows beneath the Snake River Plain east of Bliss is considered to constitute a single aquifer, it is one of the world's most productive.

A basalt flow generally is fine-grained or glassy and dense at its base. Toward the center of the flow, where the lava cooled more slowly and remained fluid longer, the basalt is coarser grained. Because the top of the flow generally crusted over rather quickly and was subject to pressure from the still-fluid lava beneath, it broke into blocks. Thus, the surface of many of the lava flows is irregular. At some places, fluid lava drained from the chilled and solidified walls and top and left lava tubes.

Lava pouring out over the irregular surface of an earlier flow only partly filled the irregularities; it left voids at the top of the earlier flow. The zones of voids at the top of each of the successive flows, commonly termed interflow zones, are the major water-bearers of the Snake River Plain. Much of the lava contained a great deal of gas, and the escaping gas left behind vesicles and other cavities. These openings are largest and most numerous near the tops of the flows; they add to the porosity and permeability of the lava, especially where the lava is fractured. During the period of volcanism, considerable amounts of volcanic material were violently ejected in the form of bombs, clinkers, cinders, and ash. Where this material is coarse grained and porous, it adds to the porosity and permeability of the interflow zones.

As the lava flows cooled, they contracted, and shrinkage joints developed, generally at right angles to the flow surfaces. Although at some places these joints are important avenues for movement of water from one flow to another, they probably are unimportant in the lateral transmission of water. The inability of water to move freely between superimposed water-bearing zones is demonstrated by the commonly observed, slight but significant, differences in water levels in successive zones.

A single flow overlain by a sedimentary deposit rarely is a good aquifer because most of the openings and interstices at and near its top are filled with sedimentary material. If this material is coarse sand and gravel, it will transmit water freely, but filled openings transmit far less water than ones that are not filled. If the capping and filling material is silt or clay, little or no water will be transmitted.

The thickness of individual flows generally ranges from 10 to 50 feet, and the average thickness may be 20 to 25 feet. Thus, a well that penetrates 100 feet of saturated basalt probably penetrates four or five interflow zones. Differences in the transmissibility of these zones are great, and some zones may yield extremely large quantities of water, whereas others may yield only small amounts.

AQUIFER PROPERTIES

Hand specimens and cuttings and cores from drill holes indicate that the Snake River basalt, compared to the extensive sandstone aquifers of the mid-continent or sand beds of the coastal plains, is an extremely heterogeneous aquifer. However, in an area of several square miles, the wide local differences are largely averaged out and the Snake River basalt is reasonably homogeneous. For these reasons, aquifer tests give much more diagnostic data than laboratory tests, though laboratory tests have aided in evaluating aquifer properties of the Snake River basalt.

AQUIFER TESTS

Ten aquifer tests were made in connection with this investigation. All the test wells were drilled under contract with the Bureau of Reclamation. Detailed analyses of the results of these tests were given in reports by Walton (1959) and Mundorff (1960). The results of the tests are summarized below.

During 1957, six test wells were drilled between Hazelton and a point about 2 miles north of Shoshone. Five of the wells were completed, and aquifer tests were made at their sites. One well was abandoned before reaching water. Two observation wells were drilled in remote parts of the plain to locate the water table, but no observation wells were drilled in connection with the test wells. In 1958, three test wells were drilled in various parts of the Snake River Plain and one test well was drilled in the Teton basin. Two observation wells were drilled to obtain geologic data and depths to water in the Teton basin near Tetonia. Seven observation wells were drilled near the test wells for observation of water levels during the aquifer tests. Data for these wells are given in table 7.

TABLE 7.—*Records of test and observation wells*

Well No.		Date completed	Depth (feet)	Casing		Static water level	
USGS	USBR			Diameter (inches)	Length [1] (feet)	Feet below land surface	Date
5S-17E-26ac1	TW-1	8- 2-57	253.5	21-16	200.7	179.44	11- 5-57
6S-18E- 7bc1	TW-2	6-24-57	223.8	21	8.4	156.66	11- 1-57
7S-19E-19aa1	TW-4	6-27-57	279.9	21-16	208.4	226.17	10-23-57
8S-19E- 5da1	TW-5	8-27-57	329.1	21-16	197-277	257.7[illegible]	10- 7-57
9S-19E-25bb1	TW-6	5-27-57	207.6	21-16	134	101.06	10- 1-57
6S-19E-14bc1	TW-7	----------	191	21-18	106	(2)	----------
4S-24E- 6bb1	OW-1	8- 1-57	445.1	21-6	444.4	411.17	8- 1-57
5S-23E-17ca1	OW-2	7- 1-57	332.7	21-6	332.7	303.04	7- 2-57
5S-17E-26ac2	OW-3	6-21-58	252.7	10	1.7	180.37	7- 8-58
26ac3	OW-4	8- 2-58	251.4	6	213.9	179.36	8- 1-58
4N-26E-32cb1	TW-9	9-13-58	253.0	16	205.5	198.14	9-23-58
32cb2	OW-9A	8-30-58	252.7	8-6	183.4	198.32	9-23-58
1N-36E- 1cc1	TW-10	10-17-58	218.0	16	184.5	145.18	10-20-58
2dd1	OW-10A	10- 3-58	214.5	8	3.8	145.96	10-14-58
7N-38E- 23db1	TW-12	10- 8-58	236.0	20-16	175.8	39.99	10- 9-58
23db2	OW-12A	8-23-58	152.0	8	153.3	35.90	9- 8-58
23db3	OW-12B	8-26-58	202	8	177.8	43.45	9- 8-58
6N-44E- 2dd1	OW-5	7-17-58	257.5	8	242.5	196.49	7-18-58
22dd1	OW-6	8- 1-58	300.0	8-6	144.6	153.93	8- 6-58
4N-45E-13ad1	TW-13	11- 1-58	304.0	10	298.8	193.40	11-17-58
13aa1	OW-13A	9- 5-58	325.0	8-6	229.0	191.62	11-17-58

[1] Length of casing given is depth below land surface. Total installed length generally includes 1 to 3 feet which extends above surface.
[2] Well abandoned before reaching water.

Aquifer tests were made at the sites of five of the test wells in 1957, and the coefficients of transmissibility of the aquifer were calculated from the data obtained during the test (Walton, 1959). Because no observation wells were available, it was not possible to determine the coefficient of storage at any of the sites. The modified nonequilibrium formula was used in computing transmissibility, and, because such factors as changes in pumping rates, incomplete development of wells prior to the test, and pump failures produced erratic time-drawdown data, only recovery data were used for the determinations.

One or two observation wells were drilled near each of the four test wells drilled in 1958, and two observation wells were drilled near test well 5S-17E-26ac1 (TW-1), which was drilled in 1957. In 1958, aquifer tests were made at these five sites. Because observation wells had been drilled at each site, the coefficients of both transmissibility and storage could be computed. The equilibrium method, nonequilibrium method, modified nonequilibrium method, and the Theis recovery method were all utilized in analyzing the data obtained in 1958 (Mundorff, written communication, 1959).

Pertinent data regarding each of the aquifer tests are given in table 8.

Representative graphic solutions for the coefficient of transmissibility (T) and the coefficient of storage (S), selected from those given by Walton (1959) and Mundorff (1960), are given in figures 33–41.

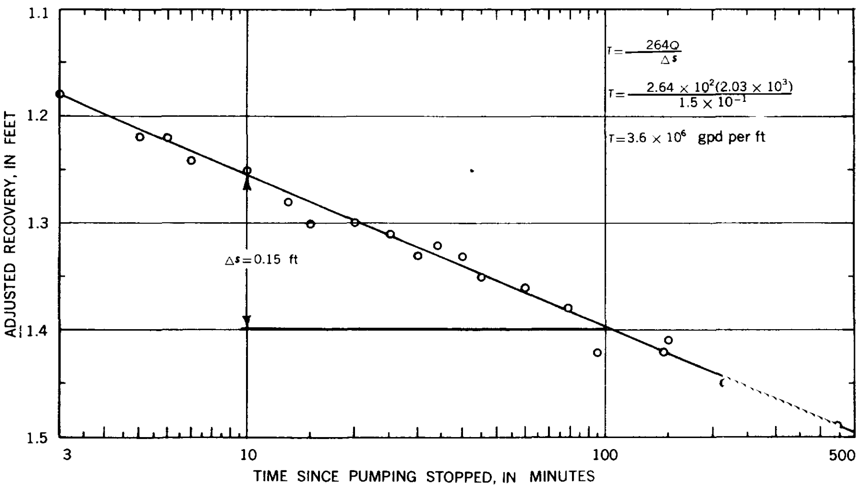

FIGURE 33.—Semilog time-recovery graph for well 5S–17E–26ac1 (TW–1).

The values shown by these graphs are not necessarily exactly the same as the values selected as most probable. A large amount of data was collected during and subsequent to pumping, and, because of deviations from ideal conditions, the data from different wells and different rates and durations of pumping did not always give identical results. Detailed analyses of results of these tests are given in the reports by Walton (1959) and Mundorff (1960). Results of the tests are summarized in table 9.

Many aquifer tests were made by the Geological Survey in connection with investigations in the National Reactor Testing Station west of Idaho Falls. These investigations were made in cooperation with the Atomic Energy Commission, and results of the aquifer tests have been released for administrative use in various manuscripts (Walton, written communication, 1958; Nace, Stewart, and Walton,

TABLE 8.—*Aquifer-test and specific-capacity data*

Test well No.		Test data					Specific-capacity data			Observation well	
USGS	USBR	Started: Date	Started: Hour	Stopped: Date	Stopped: Hour	Duration (hours)	Pumping rate (gpm)	Drawdown (feet)	Gpm per foot of drawdown	No.	Distance from test well (feet)
5S-17E-26ac1	TW-1	11- 5-57	1:25p	11- 6-57	1:25p	24	1,030	0.64	1,610		
							1,650	1.12	1,470		
							2,030	1.49	1,360		
6S-18E- 7bc1	TW-2	11- 1-57	12:06p	11- 1-57	8:06p	8	1,460	2.88	510		
							1,820	3.98	457		
7S-19E-19aa1	TW-4	10-23-57	10:26a	10-23-57	6:30p	8.07	1,630	.76	2,150		
8S-19E- 5da1	TW-5	10- 8-57	1:15p	10- 8-57	8:55p	7.67	1,330	15.09	88		
9S-19E-25bb1	TW-6	10- 2-57	8:46a	10- 2-57	4:46p	8	2,230	1.51	1,470		
5S-17E-26ac1	TW-1	8- 6-58	12:40p	8- 6-58	4:40p	4	1,570	---	---	OW-3	28
			4:40p	8- 9-58	12:40p	68	1,300	1.02	1,339	OW-4	306
4N-26E-32bc1	TW-9	9-24-58	9:51a	9-25-58	3:55a	18.07	610	24.25	25	OW-9A	194
1N-36E- 1cc1	TW-10	10-31-58	10:00a	10-31-58	2:36p	4.60	1,600	.35	4,570	OW-10A	222
			2:36a	10-31-58	3:29p	.88	1,760	---	---		
		11- 1-58	8:35a	11- 1-58	10:38a	2.05	1,600	.28	5,700		
			10:38a	11- 1-58	5:35p	6.95	2,480	.53	4,670		
7N-38E-23db1	TW-12	10-10-58	10:55a	10-10-58	11:05a	.17	680	.60	1,130	OW-12B	300
			11:05a	10-10-58	3:00p	3.92	1,080	1.69	640		
			3:00p	10-10-58	7:33p	4.55	1,210	2.06	590		
			7:33p	10-11-58	7:59a	12.43	1,320	2.40	550		
		10-11-58	7:59a	10-11-58	11:00a	3.02	1,820	4.20	434		
4N-45E-13ad1	TW-13	11-14-58	3:59a	11-14-58	4:10p	.18	420	1.93	218	OW-13A	300
			4:10p	11-14-58	4:20p	.17	700	3.92	197		
			4:20p	11-14-58	4:35p	.25	910	5.93	154		
			4:35p	11-14-58	5:15p	.67	1,330	13.23	100		
		11-17-58	1:18p	11-17-58	4:21p	3.05	610	3.82	157		
			4:21p	11-18-58	8:00a	15.65	1,330	17.12	78		

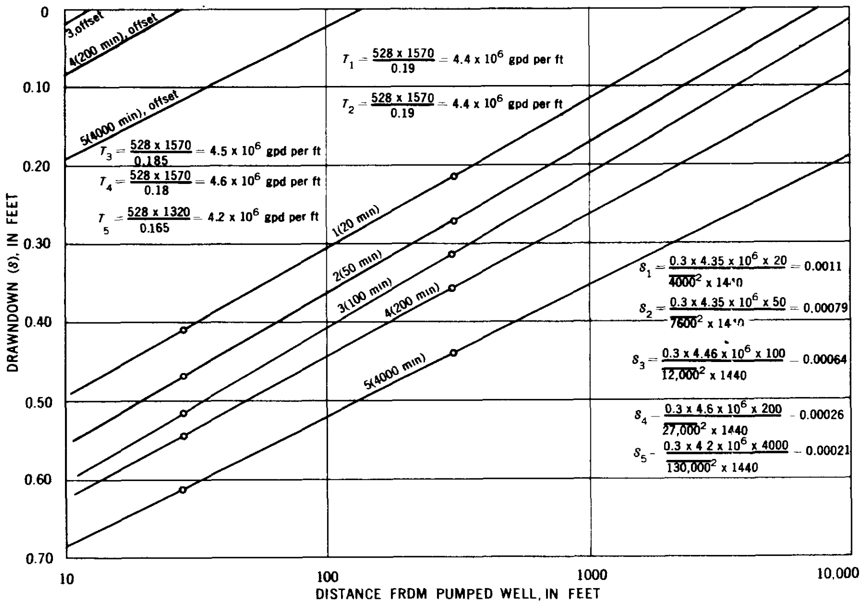

FIGURE 34.—Distance-drawdown, 5S-17E-26ac2 and 5S-17E-26ac3 (OW-3 and OW-4), Aug. 6-9, 1958.

TABLE 9.—*Coefficients of transmissibility and storage, and well-loss constants*

Well Nos.		Coefficient of trans-missibility (gpd per ft)	Coefficient of storage (S)	Well-loss constant $\left(\frac{min^2\ ft}{gal^2}\right)$
USGS	USBR			
5S-17E-26ac1	TW-1	3.6×10^6		5×10^{-8}
6S-18E- 7bc1	TW-2	3.4×10^6		7×10^{-7}
7S-19E-19aa1	TW-4	8.6×10^6		
8S-19E- 5da1	TW-5	5.0×10^6		1×10^{-6}
9S-19E-25bb1	TW-6	2.8×10^6		
5S-17E-26ac1	TW-1	4.3×10^6	2×10^{-4}	5×10^{-8}
4N-26E-32cb1	TW-9	7.3×10^5	2.4×10^{-2}	
1N-36E- 1cc1	TW-10	1.5×10^7	7.5×10^{-2}	4×10^{-8}
7N-38E-23db1	TW-12	1.2×10^7	1.7×10^{-5}	1×10^{-6}
4N-45E-13ad1	TW-13	5.5×10^5	3×10^{-2}	3.3×10^{-6}

written communication, 1959; Walker, written communication, 1960). Because most of the tests were made without observation wells, the coefficient of storage could not be determined. In a few tests, one observation well was available; in one test two observation wells were used and coefficients of storage were determined. In all but a few tests, the analysis was based on time-drawndown data.

Table 10 summarizes the data obtained from the aquifer tests in the vicinity of the National Reactor Testing Station.

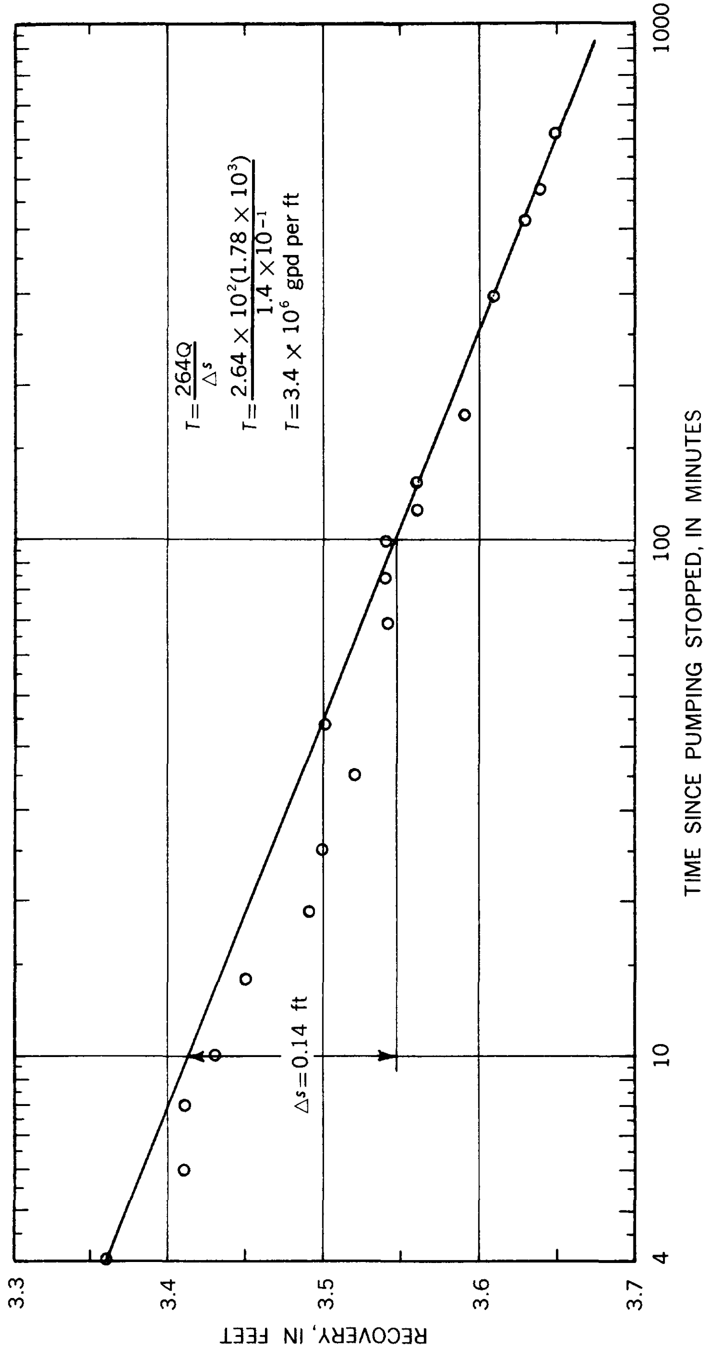

FIGURE 35.—Semilog time-recovery graph for well 6S-18E-7bc1 (TW-2).

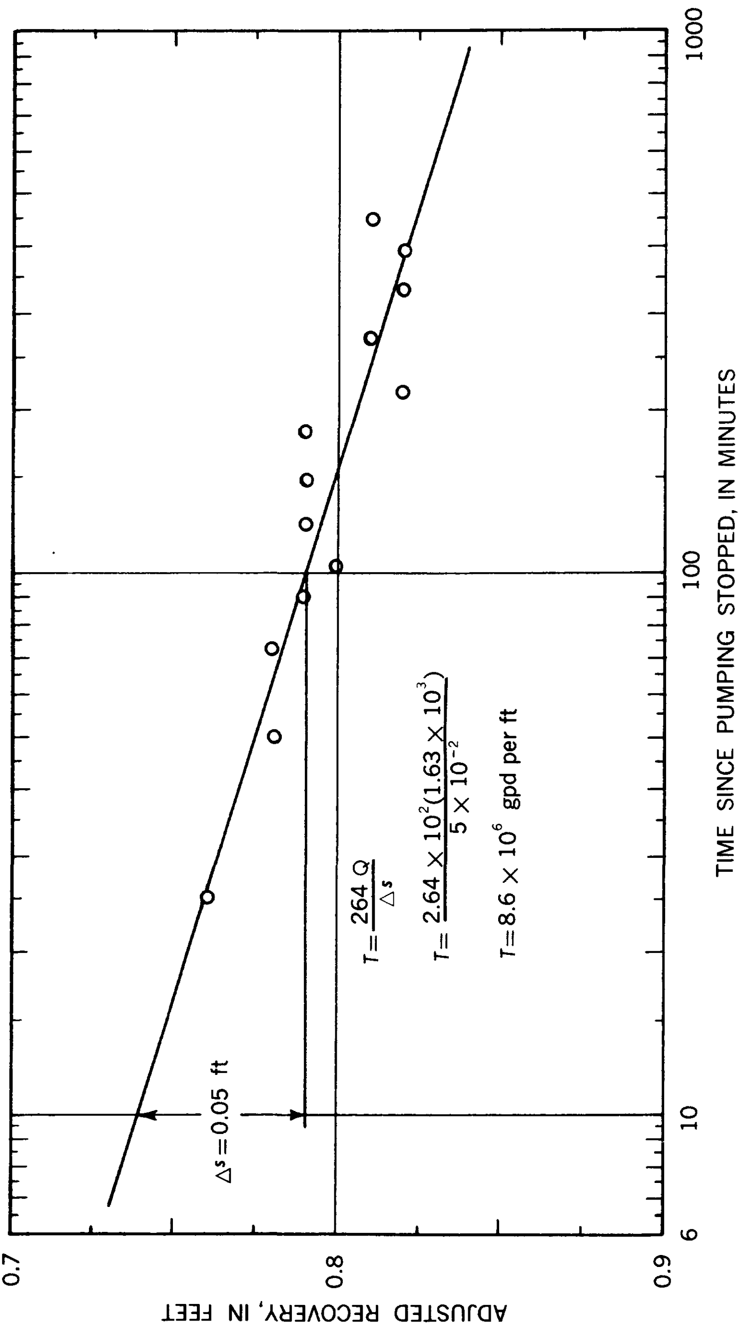

FIGURE 36.—Semilog time-recovery graph for well 7S-19E-19aa1 (TW-4).

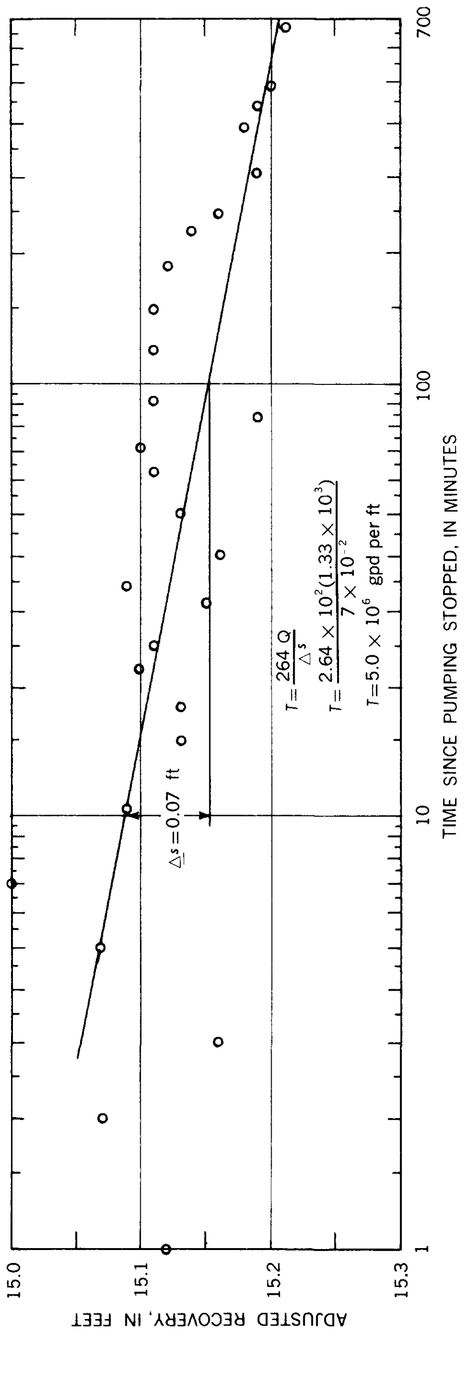

FIGURE 37.—Semilog time-recovery graph for well 8S-19E-5da1 (TW-5).

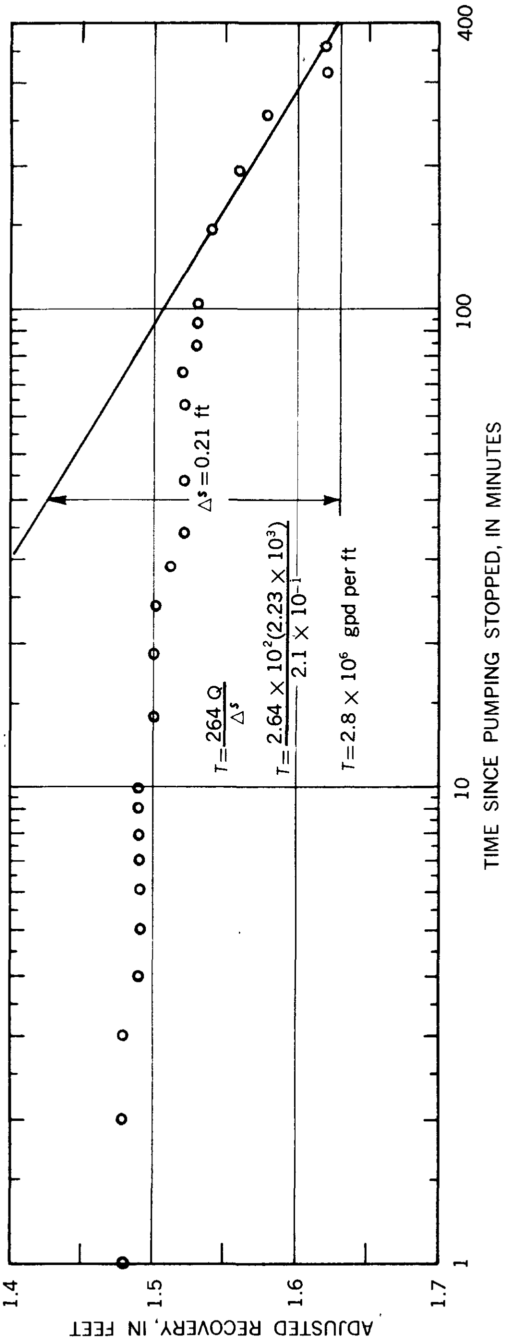

FIGURE 38.—Semilog time-recovery graph for well 9S-19E-25bb1 (TW-6).

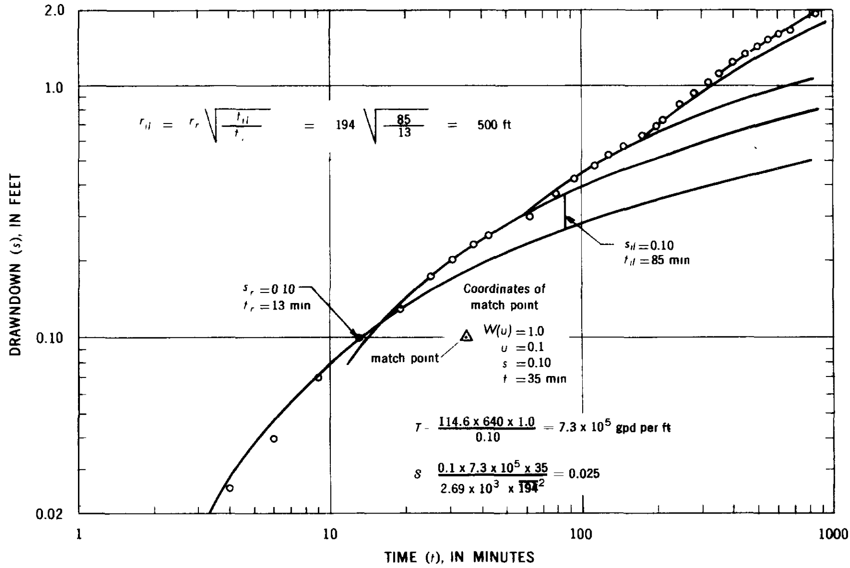

FIGURE 39.—Time-drawdown, well 4N-26E-32cb2 (OW-9A), Sept. 25-26, 1958.

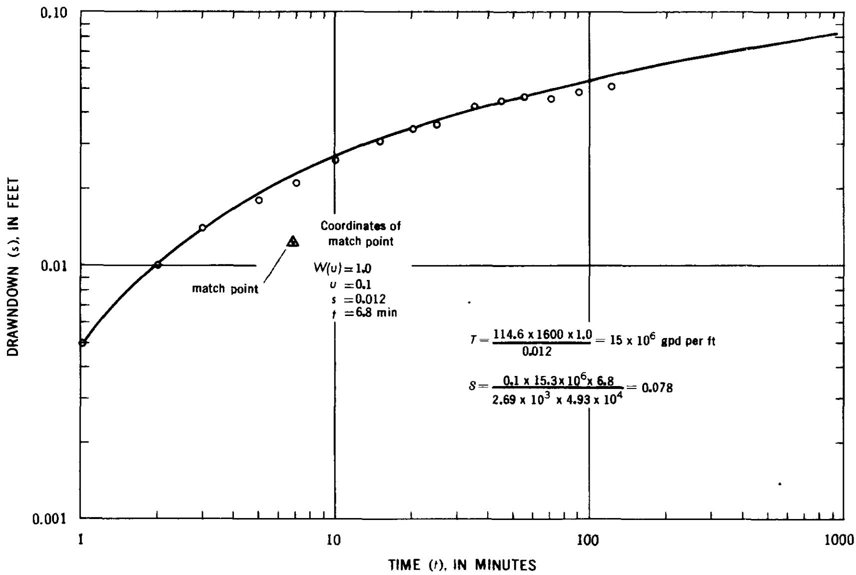

FIGURE 40.—Time-drawdown (first step), well 1N-36E-2dd1 (OW-10A), Nov. 1, 195?

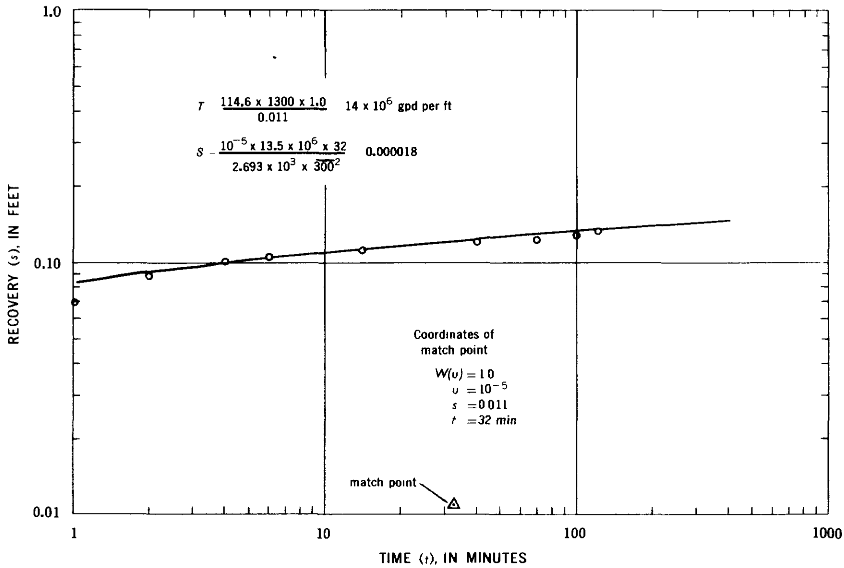

FIGURE 41.—Time-recovery, well 7N-38E-23db3 (OW-12B), Oct. 11, 1958.

TABLE 10.—*Coefficients of transmissibility and storage of the Snake Plain aquifer from tests in the vicinity of the National Reactor Testing Station*

Well Nos.		Penetration of well below water table (feet)	Date of test	Coefficient of transmissibility (gpd per ft)	Coefficient of storage
USGS	AEC				
2N-29E-1db1	CFA-2	209	2-27-51	1.6×10^5	---
3N-29E-14ac1	MTR-1	144	7-22 to 24-57	1.4×10^7	0.02
14ad1		134			
14ac1	MTR-1	144			
14ad1	MTR-test	134	6-7 to 11-57	1.8×10^7	.06
14ad2	ETR-1	141			
3N-30E-34ba1	SPERT	196	1-11 to 13-56	1.2×10^5	---
3N-29E-24ad1	CPP-2	153			
3N-30E-19bc1	CPP-1	136	11-11 to 13-51	3.3×10^6	.06
19cb1	CPP-3	147			
4N-30E-7ad1		367	8-29 to 30-50	1.7×10^6	---
30aa1	NRF-1	172	11-17 to 18-50	1.5×10^6	---
30ad1	NRF-2	163	8-3 to 5-50	3.7×10^6	---
			2-19 to 21-57	4.3×10^6	---
30aa2	NRF-3	180	8-24 to 26-56	1.1×10^6	---
			3-25 to 27-57	4.8×10^5	---
5N-31E-10cd1		177	7-10 to 11-53	5.7×10^5	---
6N-31E-13ac1	ANP-1	157	4-16 to 17-53	7.0×10^5	.01
			4-30-53	9.5×10^5	
6N-31E-13ac1	ANP-1	112	7-20 to 23-53	6.4×10^5	.01
13db1		109			
13ac2	ANP-2	133			
13ac1	ANP-1	157	11-12 to 15-53	7.9×10^5	.03
13ca1	ANP-3 Disposal	111			
6N-32E-22cc1	LPTF Disposal	109	6-20 to 21-57	3.0×10^4	---

A few miscellaneous aquifer tests have been made at various places in the Snake River Plain in connection with other projects. Coefficients of transmissibility and storage and other data are summarized in the following table.

Well	Location	Depth (feet)	Pumping rate (gpm)	Duration of test (hours)	Drawdown at end of test (feet)	Specific capacity (gpm per ft)	Coefficient of transmissibility	Coefficient of storage
8S-15E-33cc1	Near Wendell	107	1,490	4			1.0×10^7	0.045
8S-24E-8ad2	Near Rupert	258	3,400	4.5	4.9	695	8.7×10^6	.014
10S-21E-34dd1	Near Burley	473	1,510	25.3	1.75	860	6.3×10^6	.22

Three aquifer tests were made in the Mud Lake subarea in 1958, as a part of an investigation of ground-water resources by the Geological Survey in cooperation with the Idaho Department of Reclamation. P. R. Stevens made the tests on irrigation wells and analyzed the data. Data for the test and observation wells and test results are summarized in the table on the following page.

All three wells obtain most of their water from basalt, although sedimentary materials penetrated in one well probaby yield some water.

These three aquifer tests were the most complete and detailed ever made in the Snake Plain aquifer. An analysis of the data yields some interesting and enlightening information regarding the aquifer properties.

In all three tests, the coefficients of transmissibility determined from time-drawdown data on individual wells are larger than the coefficients determined from distance-drawdown data (on the basis of data from several or all of the wells). On the other hand, coefficients of storage obtained from time-drawdown data generally are smaller than those obtained from distance-drawdown data, and also the coefficients of storage obtained from the distance-drawdown data are progressively larger at increasing intervals of time after pumping began.

The different coefficients of storage obtained from the distance-drawdown data were plotted against time since the beginning of pumping, and for all three pumping tests they plotted as reasonably smooth curves rising rapidly at the beginning. The curves for two of the tests leveled off at a coefficient between 0.15 and 0.20 after 1 to 2 days' pumping. However, the curve for the third test shows, in the part of the curve that rises rather steeply, the effects of one or more boundaries. The last usable data gave a figure of 0.073 for the coefficient of storage, but during the latter part of the test the coefficient probably reached at least 0.15.

Pumped well	Depth (feet)	Pumping rate (gpm)	Duration of test (hours)	Drawdown at end of test [1] (feet)	Specific capacity (gpm per ft)	Coefficient of transmissibility	Coefficient of storage	Remarks
7N-34E-24aa1	106	7,160	73.6	2.87	2,500	4.2×10^6 to 4.9×10^6.	0.017 to 0.19	Distance-drawdown data; 14 observation wells used, 35 to 3,100 feet from pumped well.
8N-34E-11dc1	116	5,450	74	2.91	2,060	8.0×10^6	0.036 to 0.073	Distance-drawdown data; 6 observation wells used, 750 to 1,720 feet from pumped well.
8N-34E-11dc1	116	5,450	74	2.91	2,060	1.1×10^7 to 1.9×10^7.	0.013 to 0.076	Time-drawdown data.
6N-35E-26cc1	300	2,560	80.2	------	------	3.6×10^6 to 5.3×10^6.	0.0008 to 0.068	Distance-drawdown data; 3 observation wells used, 305 to 3,450 feet from pumped well.

[1] Corrected for barometric change.

The coefficients of storage determined from the time-drawdown data were generally much less than those from the distance-drawdown data. They were in the higher part of the artesian range or the lower part of the water-table range (0.001 to 0.02), as were the determinations based on time-drawdown data from most other aquifer tests in the Snake Plain aquifer. The implication is that if distance-drawdown data had been obtained for all the other tests, higher storage coefficients would have been obtained in those tests where pumping continued for several days.

The reason for the increasing storage coefficient with continued pumping probably is the result of slow draining of moderately porous but only slightly permeable materials in the aquifer. Evidence supporting this conclusion was obtained from laboratory determinations and is given on pages 158–159.

The Snake River Plain includes an area of about 12,000 square miles, excluding tributary basins. Aquifer properties based on data from 33 tests are given in this report. If the average aquifer test sampled an area of 12 square miles, 400 square miles of the aquifer have been tested, or only about 3 percent of the total area of the plain. Perhaps if these tests were distributed uniformly throughout the plain, they would represent a reasonably adequate sample. However, the tests were concentrated in certain parts of the plain, and wide areas exist in which no tests have been made. None of the wells tap the full thickness of the basalt, so the transmissibility of the total saturated section has not been determined in any of the tests.

SPECIFIC-CAPACITY DATA

Specific capacities (yield, in gallons per minute, per foot of drawdown) have been measured or reported for many irrigation wells distributed widely over the plain. The specific capacity is related to the coefficients of transmissibility and storage of the aquifer and thus gives a measure of those coefficients, but it is related also to the efficiency and effective diameter of the well. Most wells have entrance losses, and drawdowns are considerably greater than they would be in a well having an efficiency of 100 percent. Actual drawdown also is increased over theoretical drawdown by incomplete penetration of the aquifer. Although it is not possible to relate exactly the specific capacity to the coefficients of transmissibility and storage, useful approximations can be made by making certain assumptions.

Well losses determined during six of the aquifer tests averaged nearly 50 percent of the total drawdown. By assuming that this percentage applies to other wells in the plain, and by assuming a coefficient of storage of 0.05, the specific capacities can be related to the coefficient of transmissibility. Specific capacities of wells and the possible coefficients of transmissibility indicated are given in table 11.

TABLE 11.—*Specific capacities of wells in the Snake River Plain and possible transmissibilities represented*

Location	Wells	Average depth (feet)	Average penetration below water table (feet)	Average diameter of casing (inches)	Average length of test (hours)	Average pumping rate (gpm)	Average specific capacity (gpm per ft)	Coefficient of transmissibility—	
								At 100 percent efficiency [1]	At 50 percent efficiency [1]
Jefferson County	5	200	72	16	16	2,400	3,200	7×10^6	1.4×10^7
Minidoka project, Northside Pumping Division:									
Group 1	15	266	83	21	--------	2,900	2,300	4.5×10^6	9×10^6
2	21	264	94	24	2½	2,500	4,500	9×10^6	1.8×10^7
3	29	282	91	21	3	2,200	1,700	3.2×10^6	6.4×10^6
4	31	276	88	21	3	1,800	1,800	3.4×10^6	6.8×10^6
5	22	308	83	21	4½	1,700	1,800	3.4×10^6	6.8×10^6
6	18	402	112	21	2½	1,500	800	1.5×10^6	3×10^6
7	30	271	71	21	3½	1,800	3,900	7.8×10^6	1.5×10^7
Bingham County	15	252	71	18	8	1,900	1,800	3.5×10^6	7×10^6
National Reactor Testing Station, Butte County	14	590	200	16	24	900	900	1.8×10^6	3.6×10^6
Gooding County	9	120	60	12	2	1,000	900	1.7×10^6	3.4×10^6
Jerome County	6	362	77	16	3	1,700	900	1.6×10^6	3.2×10^6
Bonneville County	6	207	88	18	4	1,800	500	8×10^5	1.6×10^6
Blaine County	2	226	179	16	2	1,400	70	1×10^5	2×10^5
Camas County	3	210	77	16	6	1,200	60	9×10^4	1.8×10^5

[1] Efficiency of well is the ratio of actual to theoretical drawdown expressed as a percentage.

If the assumed coefficient of storage is decreased from 5 to 1 percent, the coefficient of transmissibility increases about 10 percent, and if it is increased from 5 to 20 percent, the coefficient of transmissibility decreases about 10 percent.

Few wells are 100 percent efficient, so the figures for transmissibility based on 100 percent efficiency probably are too low. However, the better wells listed in table 11, such as the well in Jefferson County and the wells in groups 2 and 7 of the Minidoka project, may be considerably more than 50 percent efficient.

The average coefficient of storage, based on 18 tests, is about 0.04, and the average coefficient of transmissibility, based on 33 tests, is about 5×10^6 gpd. The coefficients of transmissibility indicated by the specific capacities are in the same range and indicate that coefficients assumed on the basis of specific capacities are generally of the proper magnitude.

LABORATORY TESTS

Most of the water in the Snake Plain aquifer is transmitted through interflow zones. Obviously, a fragment or core of basalt does not represent the aquifer, but laboratory tests have been made on more than 100 fragments and cores, and the results are enlightening.

Tests on 25 samples of basalt collected from the discharge area of the springs in Hagerman Valley were made by J. W. Stewart (Nace and others, 1959). The porosity and water content of each was determined. Porosities ranged from 3.8 to 24.8 and averaged 10.7 percent and water content ranged from 1.4 to 11.6 and averaged 4.4 percent. According to the report cited, "The basalt is permeable to air and 'breathes' freely. Dried samples exposed to the atmosphere change weight in response to changes in relative humidity."

The porosity of 83 core samples and the coefficient of permeability of 24 core samples were determined in the Hydrologic Laboratory of the U.S. Geological Survey at Denver, Colo. The depth of eight of the samples is not known, but the other samples were taken at regular 5-foot intervals from holes 50 to 100 feet deep to get representative samples of the basalt between interflow zones. The porosities ranged from 3.8 to 37.4 and averaged 17.6 percent. Permeabilities ranged from 0.0004 to 0.9, and averaged 0.14 gpd per square foot. The porosities determined in the laboratory were total porosities, that is, some of the pores may be unconnected with the other pores. The effective porosity probably is considerably less—possibly within the magnitude of the porosity determined by Stewart, which was determined by difference in saturated and dry weight and represented only interconnected pore space. Until additional data are available, the effective porosity is considered to be approximately 10 percent. The average permeability (0.14 gpd per square foot) shown by the laboratory tests is exceedingly low in comparison with aquifer permeabilities, which are in the range of 10^3 to 10^5 and perhaps average 2×10^4 gpd per square foot, an average permeability about 100,000 times greater than that of the small samples. Nevertheless, an average permeability of even 0.1 gpd per square foot for the basalt between the interflow zones is sufficient to permit draining of the water from storage in the 90 to 95 percent of the aquifer between interflow zones.

AQUIFER BEHAVIOR DURING PUMPING

The average coefficient of transmissibility of the Snake Plain aquifer, determined in 33 pumping tests, was about 5×10^6 gpd per foot. The average of 18 determinations of the coefficient of storage was about 0.04. The coefficient of storage ranges widely and, at least in some places, increases with continued pumping. In some tests, the coefficients of transmissibility determined from time-drawdown data are higher than those determined from distance-drawdown data. This apparent discrepancy probably is the result of slow drainage from the porous but only slightly permeable zones that are interlayered with the highly permeable water-yielding zones. Laboratory tests substantiate the water-yielding capacity of the slightly permeable zones. The reaction of the Snake Plain aquifer to pumping can be postulated by assuming the following aquifer characteristics: (a) a coefficient of transmissibility of 5×10^6 gpd per foot, and a coefficient of storage of 1×10^{-4} for the most productive water-yielding zone in the aquifer; (b) an overlying zone of porous but only slightly permeable basalt; (c) a coefficient of storage in the overlying zone of 5×10^{-2}, and a coefficient of permeability of 1.5×10^{-1} gpd per square foot; (d) a water table 10 feet above the most productive water-yielding zone.

When pumping starts, the aquifer acts as an artesian aquifer; the cone around the well expands rapidly. Coefficients determined from data obtained during the early part of the test apply to only the most productive water-yielding zone in the aquifer. Within a few minutes, the head on the water-yielding zone declines sufficiently over a large enough area that downward leakage from the overlying basalt supplies a measureable part of the water pumped. At the end of 1 day's pumping, leakage supplies a significant part of the pumpage; after several days' pumping, practically all the water is obtained by downward leakage from the overlying basalt. The aquifer then acts as a water-table aquifer, and the coefficient of storage is the average coefficient of the material dewatered. Because of the continually increasing coefficient of storage during the early part of the pumping, the rate of change in water level will be less than it would have been had the coefficient of storage remained constant. For this reason, the early drawdown data in the computations give coefficients of transmissibility that are too high.

That material having a coefficient of transmissibility of 1.5×10^{-1} gpd per square foot and a coefficient of storage of 5×10^{-2} will drain as rapidly as the water table declines, after the first day or two of pumping, can be shown by a simple computation. Each cubic foot of the overlying basalt is assumed to contain 0.05 cubic foot, or about 0.37 gallon, of water that will drain by gravity. This basalt transmits water to the productive water-yielding zone according to the equation

$$Q_d = P_1 I,$$

where

Q_d is the discharge, in gallons per day, through 1 square foot of area, P_1 is the vertical permeability of the overlying basalt, and I is the hydraulic gradient of the water in the overlying basalt. Drainage of the overlying basalt will keep pace with the lowering of the piezometric surface of the productive water-yielding zone when the difference in head on the two zones causes a steepening of the hydraulic gradient from the upper zone sufficient to transmit water from it to the lower, more permeable zone at a rate equal to the rate of withdrawal. Computations using the above equation and the Theis nonequilibrium formula show that, after the first day or two, drainage of the upper zone will keep pace with the lowering of the piezometric surface in all parts of the cone, where the piezometric surface has declined half a foot or more. Thus, within a few days after pumping begins, most of the water is supplied by the upper zone, and the coefficient of storage for the aquifer as a unit approaches that of the upper zone, whereas the coefficient of transmissibility approaches that of the lower zone.

SOURCES OF GROUND WATER

All recharge to aquifers of the Snake River Plain comes from precipitation within the Snake River drainage basin. The sources of recharge can be separated conveniently into four categories (a) precipitation directly upon the plain, (b) percolation of irrigation water, (c) seepage from streams entering or crossing the plain, and (d) underflow from tributary basins.

THE WATER TABLE

The water table beneath the Snake River Plain is in dynamic balance between recharge and discharge. Changes in natural recharge are dependent directly upon changes in precipitation; changes in induced recharge are governed largely by the amounts of surface water diverted to the irrigated areas. Changes in total recharge affect the position of the water table, which in turn controls the quantity of natural discharge. The position of the water table is affected also by artificial withdrawals (pumping), which eventually decrease natural discharge and, under certain circumstances, may induce additional recharge.

Through 1959, the greatest changes in the ground-water regimen of the plain have been those caused by diversion of surface water to various irrigated tracts on the plain. As is shown in a later section of this report, these diversions have increased underflow in the Snake Plain aquifer by about 60 percent. It is unfortunate that so few early water-level measurements are available to indicate the position of the water table prior to irrigation, for it may be assumed that withdrawal and consumptive use of an amount of ground water equivalent to the increased underflow caused by irrigation would return the water table to approximately the position it had before development of the area. There would be local differences, caused by differences in location of recharge from irrigation and withdrawal through wells, but the general situation would be roughly as before. Thus, the most important single hydrologic fact concerning the Snake Plain aquifer would be approximately known, that is, how much the water table would decline if a specified, very large amount of water was withdrawn annually by pumping. Although data on the position of the water table prior to irrigation are scanty, the information available does permit some general conclusions.

Large parts of the Snake River valley north of Idaho Falls were developed for irrigation in the period 1880 to 1900. No records of the depth to water prior to irrigation are available for that area. Areas downstream from American Falls Reservoir were developed after 1900, much of the development occurring during the period 1905–15. Only a few measurements of the depth to water before irrigation are available. Although not all the original records could be found and the exact locations of many of the wells are not known, these records do give an indication of the position of the water table before diversion of irrigation water to the lower reaches of the plain changed its position. These early reported depths to water and the present depths to water, at what are believed by the authors to be the same locations, are given in the following table.

Well		Depth to water		Depth to water		Change (feet)
No.	Location	Date	Feet	Date	Feet[1]	
6S-13E-6dd	Bliss railroad station	Before 1901[2]	430	1959	350	+80
8S-15E-28ba		1909	94	1959	62	+32
7S-15E-sec. 33	Wendell	1907	190	1959	150	+40
7S-15E-sec. 8	Railroad	1907	215	1959	190	+25
5S-15E-sec. 31 or 32	Gooding	1907	145	1959	[3] 110	+35
6S-17E-2ab(?)	Shoshone	1890	Dry at 280	1952	210	+70
8S-17E-19bb1	Jerome	1907	342	1954	298	+44
8S-18E-15cc		1907	318	1959	200	+118
4S-19E-26da1	Richfield, railroad	1913	330	1957	311	+19
9S-19E-15ac		1907	252	1959	160	+92
9S-19E-26	Eden railroad station	1912	189	1959	127	+62
6S-20E-15da	Owinza railroad station	Before 1901[2]	341	1959	200	+141
7S-23E-5	Kimama railroad station	do	265	1959	210	+55
8S-25E-1cb1	Minidoka railroad station	do	375	1959	185	+190
9S-24E-29aa1	Rupert	1905	101	1951	[3] 59	+42

[1] Estimated from water-table map or from measurement made in well having the same or nearly the same depth and location as original well.
[2] Data from Russell (1902).
[3] Water level in well of equivalent depth. Deeper aquifers have somewhat lower water level, but the original position is not known.

Some of the data in the preceding table are inconsistent. The rise in water level at the Kimama railroad station well is only 55 feet, whereas the rises at Owinza and Minidoka, which are on opposite sides of Kimama, were 141 and 190 feet, respectively. Possibly an error of 100 feet is involved in these data; that is, the depth to water at Owinza and Minidoka may have been 100 feet less than reported, or the depth to water at Kimama may have been 100 feet greater.

The railroad well at Eden was completed in October 1912, at which time the reported depth to water was 189 feet. The reported depth to water in January 1913 was 170 feet, a rise in water level of 19 feet in 3 months. Irrigation on the Twin Falls North Side tract began in 1908, and the water level probably rose considerably between 1908 and 1912. A rise of 19 feet between 1913 and 1959 is indicated at Richfield, though there also most of the rise probably occurred before 1913.

Data in the table suggest that the water table generally rose 25 to 100 feet and that the average rise may have been 60 to 70 feet. Irrigation developments have increased discharge from the Snake Plain aquifer by about 2,500 cfs, or more than 1.8 million acre-feet per year (see pp. 171–181). It may be assumed that pumpage of 1.8 million acre-feet of water each year from the Snake Plain aquifer from wells distributed fairly widely over the plain would cause a general decline of the water table downstream from American Falls Reservoir of roughly, 60 to 70 feet.

The general slope and position of the water table at two locations in the plain is shown on figures 42 and 43, and the approximate altitude of the water table is shown on plate 4. The gradient of the water table ranges from 2 to 25 feet per mile and probably averages about 5 feet per mile.

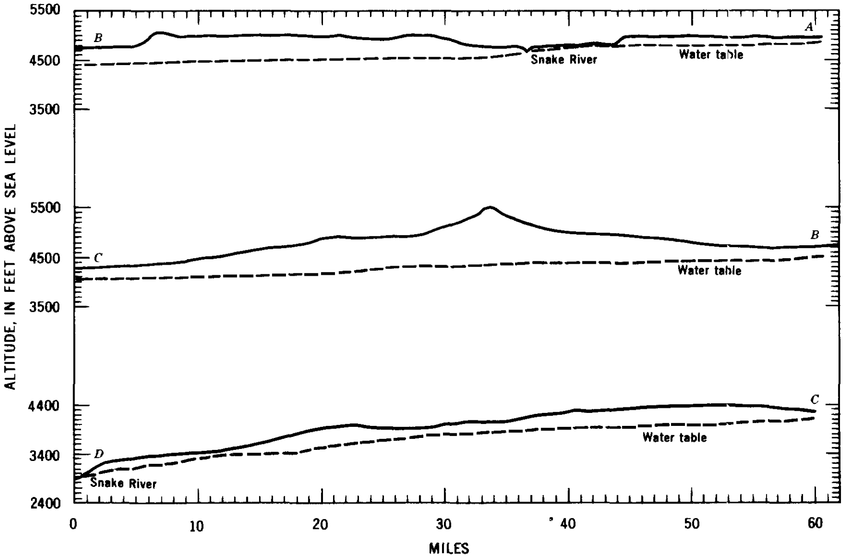

FIGURE 42.—Postulated hydrologic section, *ABCD* (pl. 1).

FLUCTUATIONS OF THE WATER TABLE

The water table beneath the Snake River Plain fluctuates chiefly in response to changes in recharge to the system and only in small part to discharge. Short-term changes in water level in wells also are caused by temporary changes in load on the aquifer, for example, those produced by wind, seismic shocks, and change in atmospheric pressure. The fluctuations caused by wind and earthquakes are relatively minor. Atmospheric-pressure changes at many places cause water-level changes of a few tenths to more than a foot for periods of a few hours to more than a week. Recognition and correction of barometric changes are necessary in analysis and interpretation of aquifer-test data. These changes also at times mask the true seasonal cycle in wells measured periodically. The barometric efficiency of some wells in the plain is nearly 100 percent, so that a change in atmospheric pressure of 1 inch would cause a change in water level of about 1 foot. Some apparently anomalous water-level measurements no doubt are caused by changes in atmospheric pressure between measurements.

Seasonal changes in water level are correlated with seasonal changes in recharge, either natural or man-made, and produce an annual cycle. Because several dry (or wet) years may occur in succession, some cycles may include periods of many years.

In the west-central part of the National Reactor Testing Station, water-level fluctuations in several wells are related to runoff in the

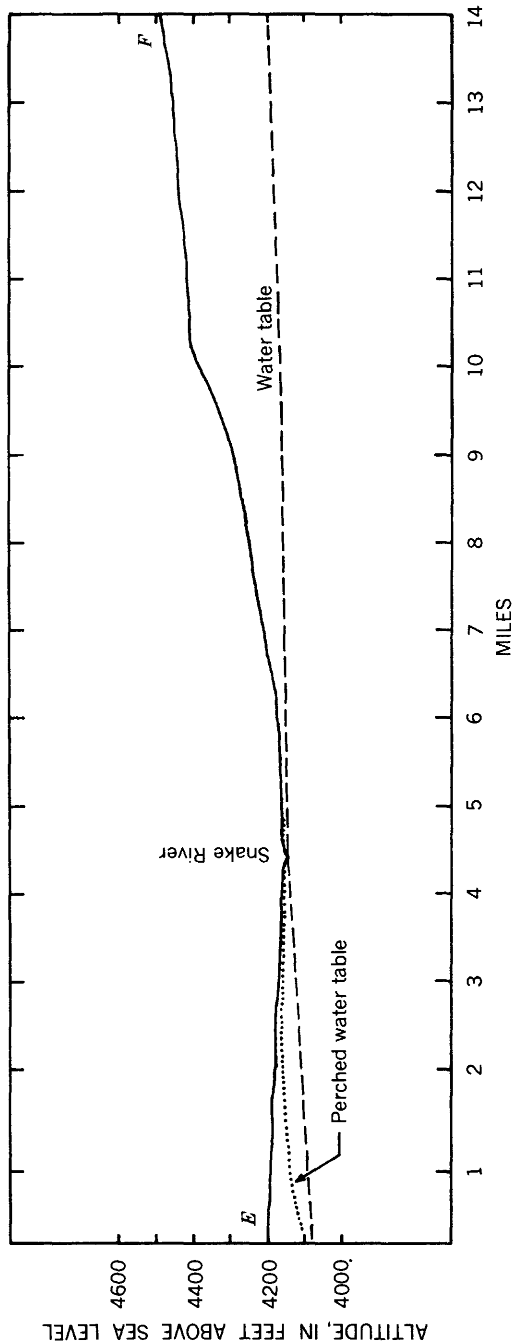

FIGURE 43.—Postulated hydrologic section, *EF* (pl. 1).

Big and Little Lost Rivers, which supply considerable recharge to the Snake Plain aquifer. Hydrographs for wells in the area show a direct correlation between the position of the water table and the cumulative departure from the average combined discharge of the Big and Little Lost Rivers (fig. 44). Those segments of the hydrographs made from the charts of recording gages show clearly the fluctuations caused by changes in atmospheric pressure. Changes in water level of 0.4 to 0.5 foot are common. Because similar pressure changes affected the water levels during the periods when only tape measurements were made, the seemingly sharp decline and subsequent apparent water-level rise in well 5N–31E–14bc1, as indicated by water-level measurements made in November 1954 and May 1955, probably were caused by variations in atmospheric pressure. The average slope shown by the dashed line probably more nearly represents the change in water table minus short-term barometric changes. Several apparently anomalous water-level measurements shown on the other hydrographs may have been caused in the same way.

It is not implied that the only source of water to this part of the plain is from the Big and Little Lost Rivers; underflow is also derived from Birch Creek basin and basins in the Mud Lake area. Obviously, however, the fluctuations of the water table in the area are closely related to the discharge of the Big and Little Lost Rivers.

Water-level records are available for several wells in the area between the National Reactor Testing Station and American Falls Reservoir. Hydrographs for five of these wells are shown in figure 45. All show the same general pattern of annual fluctuations and the same longer term trend.

Wells 4S–32E–12dd1 and 3S–33E–14bb1 are in the Aberdeen-Springfield-Moreland irrigated area, and the seasonal cycles shown by their hydrographs are obviously related to recharge from irrigation water. Water from the Snake River is diverted to the area through the Aberdeen-Springfield and Peoples canals. In recent years, diversions for 80,000 acres have averaged about 460,000 acre-feet, of which probably more than 250,000 acre-feet becomes ground-water recharge. Recharge of 50,000 to 60,000 acre-feet a month causes the water table to rise rapidly, generally beginning near the end of April. The water table reaches a high point in August when diversions are about maximum, begins to decline in September when diversions are reduced, and declines sharply in late September or October when diversions cease. The average amplitudes of the seasonal cycle in wells 4S–32E–12dd1 and 3S–33E–14bb1 are, respectively, 5.5 and 4 feet.

Well 2S–32E–23bb1 is 8 miles and wells 1S–30E–15bc1 and 2N–31E–35dc1 are 20 miles from the edge of the tract irrigated with surface water. In general, the farther outside the irrigated tract a

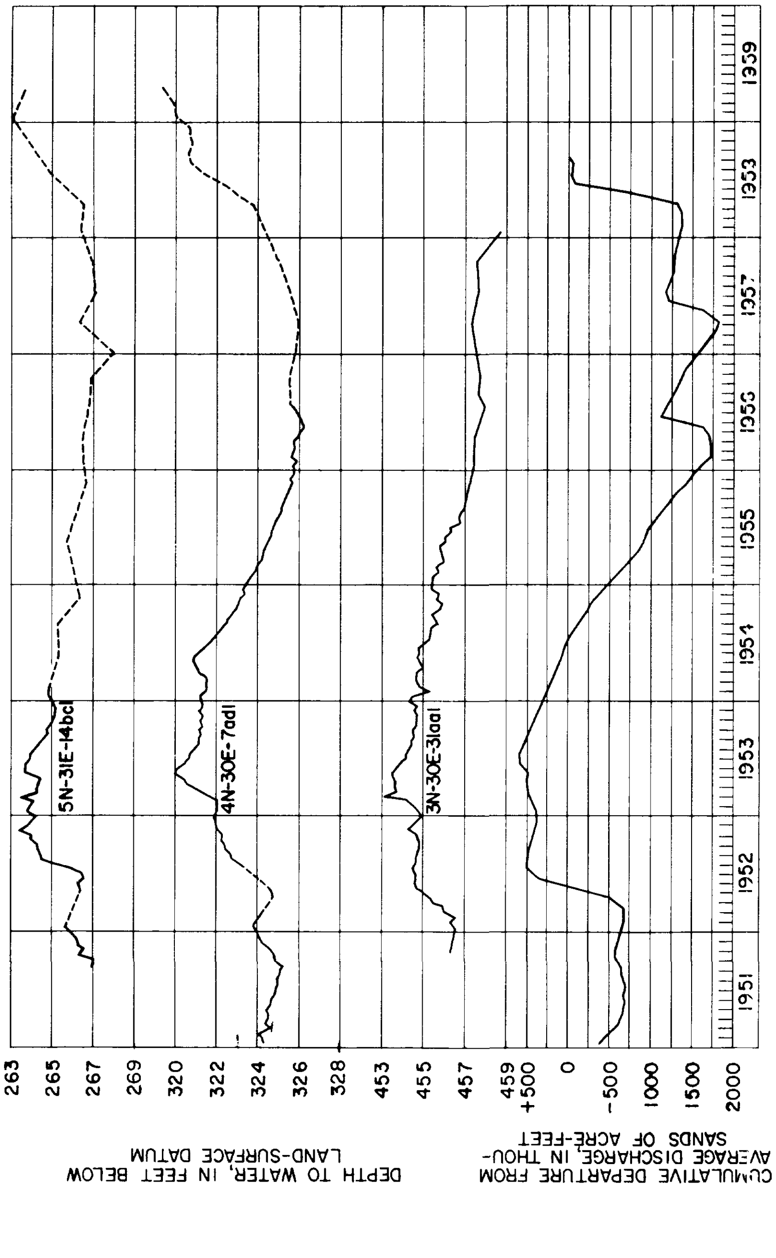

FIGURE 44.—Hydrographs of three wells at the National Reactor Testing Station and the cumulative departure from the average combined discharge of the Big and Little Lost Rivers.

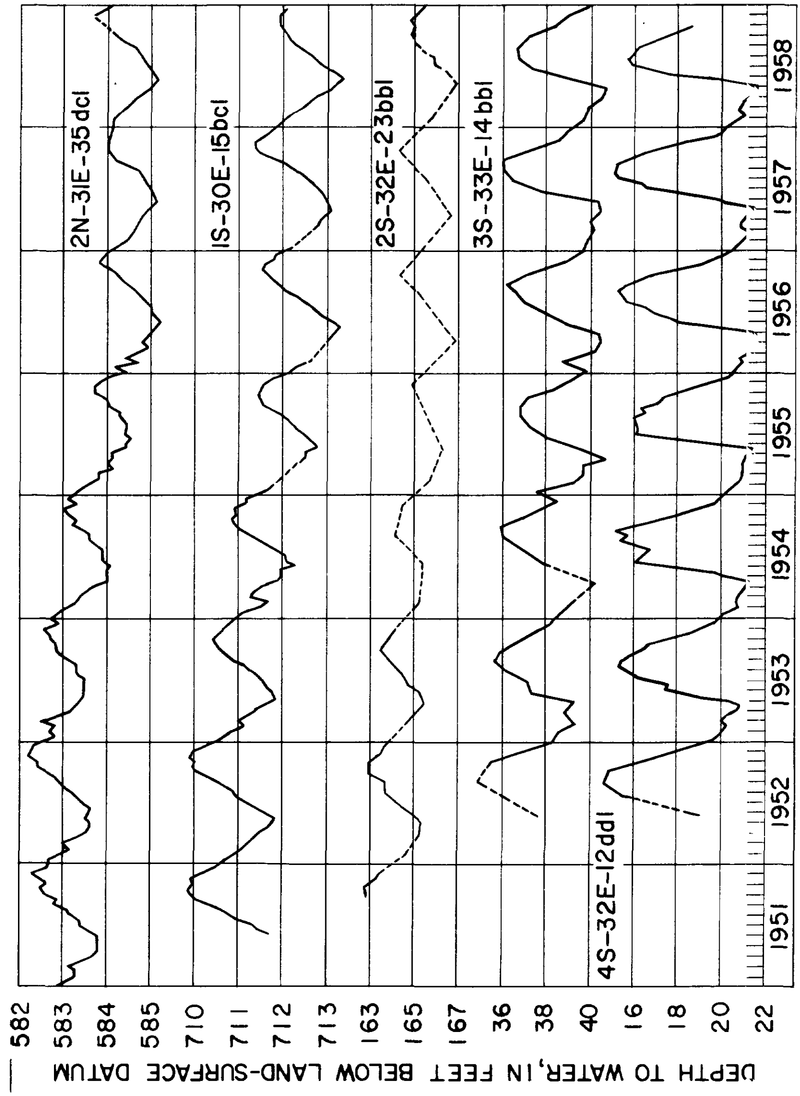

FIGURE 45.—Hydrographs of five wells between American Falls Reservoir and the National Reactor Testing Station.

well is, the longer the delay in the water-level rise that results from irrigation recharge.

The amplitude of the water-level rise caused by recharge from irrigation appears to decrease with increasing distance from the Aberdeen-Springfield-Moreland area; the amplitude of the seasonal cycle in well 2N–31E–35dc1, the most distant well, averages 1.25 feet.

The apparent correlation of water-level fluctuations in these distant wells, as much as 20 miles from the Aberdeen-Springfield tract, does not prove that they are caused by application of surface water in the Aberdeen-Springfield area. Irrigation on other parts of the upper Snake River Plain begins at about the same time, though the Aberdeen-Springfield-Moreland area is considerably closer to these wells than any other large unit irrigated with surface water. Furthermore, admitting even if the fluctuations are caused by application of water in the Aberdeen-Springfield-Moreland area it does not necessarily follow that the water from that area is the source of underflow through the area to the north. The water-table and flow-net map (pl. 4) show that ground water is flowing southwestward, whereas the wells showing the rise are north and northwest of the Aberdeen-Springfield-Moreland area. The correlation does show that application of irrigation water in the Aberdeen-Springfield area and other parts of the upper Snake River Plain strongly influences the position of the water table beneath a considerable part of the adjacent plain.

Well 2N–31E–35dc1 near Atomic City is the most remote observation well whose water levels have been correlated with application of irrigation water in the area. It is 25 to 30 miles from the center of irrigation (more than 20 miles from the margin of the tract), and the seasonal rise in water level averages 1.25 feet. Because of fluctuation produced by barometric changes and other factors, the time-lag between the application of irrigation water and the beginning of the seasonal rise in the water level of this well is obscured somewhat; however, comparison of its hydrograph with that of well 4S–32E–12dd1 suggests that the rise in well 2N–31E–35dc1 lags from 30 to 45 days.

The change in water level in well 2N–31E–35dc1 caused by recharge of about 60,000 acre-feet of water per month can be used with the Theis nonequilibrium formula as a rough check on the hydraulic characteristics of the aquifer in the area. Data for the year 1955, uncorrected for barometric changes were used for the computation. The coefficients of transmissibility and of storage were computed to be 2.7×10^7 gpd per foot and 0.000053 respectively, which are reasonably close to the coefficients shown by the map showing coefficient of transmissibility (pl. 6) and aquifer-test data.

Longer trends are shown by the hydrographs. A slight downward trend beginning in 1953 and continuing through 1955 is shown. Diversions to the area during the period were about 6 percent less than those in the previous 2 years and probably account for some of the decline. Diversions in the following period 1956–58, were the greatest of record, but they succeeded only in halting the decline, not in raising the water level. The decline in the deep wells northwest of the Aberdeen-Springfield-Moreland area was greater even than that in the wells within the irrigated area. The water-levels in several wells within the National Reactor Testing Station declined during the period 1953–55, apparently in response to decreased recharge from the Big and Little Lost Rivers, but all these wells recovered in 1957 and 1958 and in 1959 were near or at record high levels. At least part of the decline in the area between the southern boundary of the National Reactor Testing Station and the Aberdeen-Springfield-Moreland area may be caused by withdrawals from recently drilled irrigation wells in the area.

The relation of the downward trend in water levels to the increased ground-water withdrawal is even clearer in the Minidoka area. Water-level fluctuations in two typical wells are shown in figure 46 together with cumulative departure from average diversions in the Minidoka North Side Canal. Seasonal correlation is obvious. Diversions to the area were above average (on the basis of the period 1950–58) in 1951 and 1952, and the general trend in water level was upward. Diversions in 1953 were slightly below average, but the trend was still upward, probably as a holdover from the above-average diversions in 1951 and 1952. Beginning in 1954 and continuing to the present time (1959), the trend has been downward at an average rate of 1 foot a year. This downward trend coincides with greatly increased withdrawal of ground water in the Minidoka area. Estimated pumpage in the Mindoka area is shown in the following table.

Year	*Pumpage (acre-feet)*	*Year*	*Pumpage (acre-feet)*
1947	<3,000	1953	[1] 79,000
1948	<6,000	1954	?
1949	?	1955	160,000
1950	[1] 28,000	1956	?
1951	[1] 68,000	1957	220,000
1952	[1] 72,000	1958	275,000

[1] From Crosthwaite and Scott (1956).

Not all the decline can be attributed to pumping. Water levels declined at other places in the plain in 1954 and 1955 because of decreased recharge, but part of the decline clearly was caused by the increase in withdrawal.

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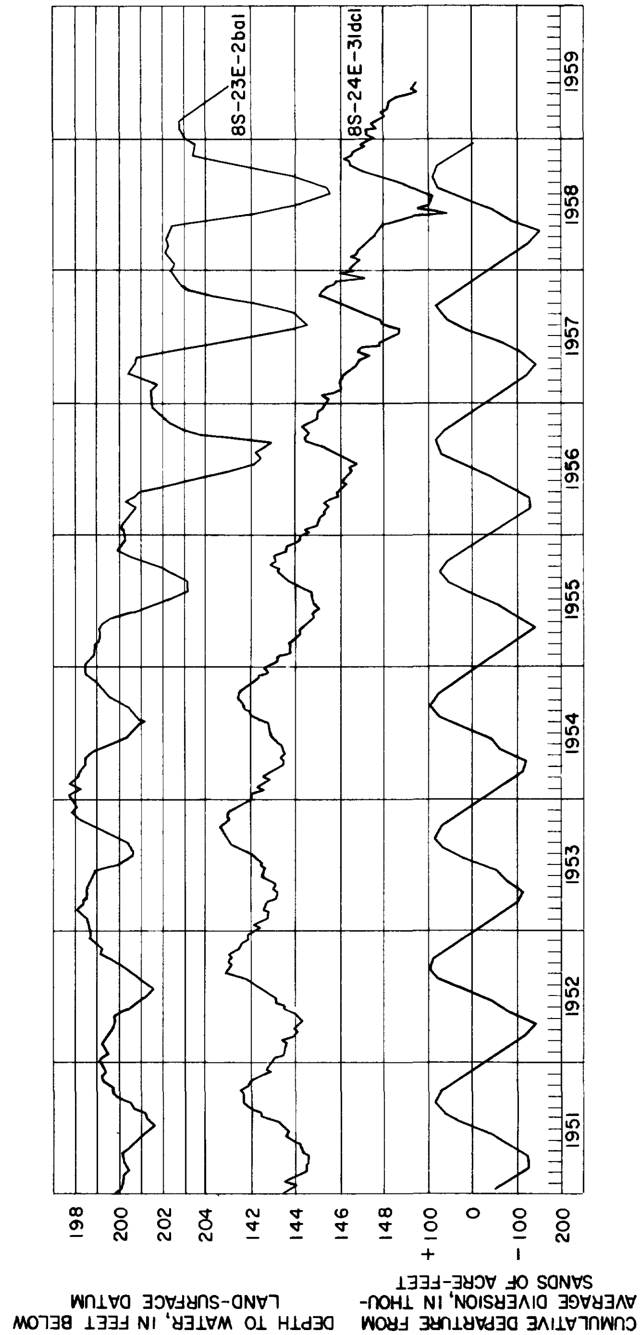

FIGURE 43.—Water levels in two wells and cumulative departure from average diversions to Minidoka North Side Canal.

ANALYSIS OF THE SNAKE PLAIN AQUIFER AS A HYDRAULIC SYSTEM

The total ground-water supply of the Snake River Plain is great, and large quantities of water are being used at some places. At many other places, some of which are favorable for irrigation, the aquifer is virtually untapped. At still other places, the great depth to water or unsatisfactory hydraulic characteristics make development of large supplies less favorable.

In making an analysis of the Snake Plain aquifer as a hydraulic system, all factors influencing the system must be determined and evaluated quantitatively. These include the quantity of recharge from the various sources, the areas of recharge, the direction of movement, the slope of the water table or piezometric surface, the amount and places of discharge, the regional aquifer properties, and the location and nature of hydraulic discontinuities or barriers. Although data are not sufficient for precise determination of all these factors, that data probably are adequate for a preliminary quantitative analysis of the system.

The analysis of a hydraulic system usually begins with recharge and ends with discharge. However, in the Snake River Plain, the location and amount of discharge is the most accurately known hydrologic factor. The average discharge of the Snake Plain aquifer probably is known to within 5 percent, and the limits of error may be less. Because the recharge data are less accurate, the components of recharge have been adjusted so that total recharge approximately equals the average total discharge. The sources and amounts of recharge to the Snake Plain aquifer have not altered greatly since the 1930's; therefore, the flow pattern probably has reached, at least approximately, a state of equilibrium with respect to recharge. On the other hand, pumping of ground water from the aquifer has been accelerated greatly since 1950, though the effects of pumping at most places probably have not yet reached the boundaries of the system and have not materially altered recharge to or discharge from the hydraulic system except locally. Most of the water pumped in the past few years probably has been taken from storage. Because it is extremely difficult to analyze a hydraulic system while it is in a state of change, the effects of the greatly accelerated pumping have been disregarded in this section.

DISCHARGE FROM THE WEST END OF THE AQUIFER

Between Twin Falls and Bliss, the Snake River has cut through the Snake Plain aquifer. The canyon generally has been cut 50 to 100 feet below the base of the aquifer, and the less permeable underlying rocks are exposed. Many springs emerge from the canyon wall on the northeast side of the river in this reach. A few small springs discharge into the Snake River canyon upstream from that reach, between Milner Dam and Twin Falls. Because the permanent gaging stations are at Milner and at King Hill (15 miles downstream from Bliss) and because surface inflow to the Snake River between Bliss and King Hill is small, the gains in discharge between the two stations can be used in computing the discharge from the aquifer.

Discharges of some of the springs have been measured from time to time since the early 1900's, and gaging stations have been established on a few of the larger springs within the past few years. Attempts have been made to measure all the water contributed by springs along selected reaches of the river. Discharge records of springs in the Snake River valley for the period 1899–1947 were compiled by Nace, McQueen, and Van't Hul (1958). During the period April 15–28, 1902, J. D. Stannard measured or estimated the discharge of all known springs between Milner Dam and a point 3 miles below the mouth of the Malad River; he computed their total discharge to be 3,834 cfs (Ross, 1903). The discharge of the Malad River (all from springs) was included in the total.

Between 1902 and 1947, discharge measurements were made at irregular intervals on some of the springs, and since 1947 annual discharge measurements have been made on about 20 springs. Changes in discharge of some of these springs are shown graphically in figures 47 and 48. The general increase in discharge of the springs is due to the increase in recharge from irrigation.

Irrigation of the Twin Falls North Side tract began in 1908. By 1911, the discharge of Blue Lake Springs had increased moderately and by 1913 had more than doubled. The discharges of the other springs adjacent to the North Side project (Niagara, Clear Lakes, and Crystal Springs) show similar sharp increases during the same period. The total discharge of these four springs increased from 680 cfs in 1902 to about 1,400 cfs by 1917.

The discharges of several springs downstream from Clear Lakes Springs are shown in figure 48. The increase in the discharge of these springs was much less than that of Clear Lakes Springs and the other upstream springs.

In a report on the ground-water resources of the Snake River Plain, Stearns, Crandall, and Steward (1938) made a detailed study of the springs and their yields. Their report showed that the discharge of the springs in the reach between Milner and Bliss increased about 1,200 cfs between 1902 and 1917. Their data for 1902 and 1917 together with comparable data for 1931 (Nace, McQueen, and Van't Hul, 1958) and 1956 (U.S. Geol. Survey, 1958) are given in table 12. According to these data, the total discharge of the springs has in-

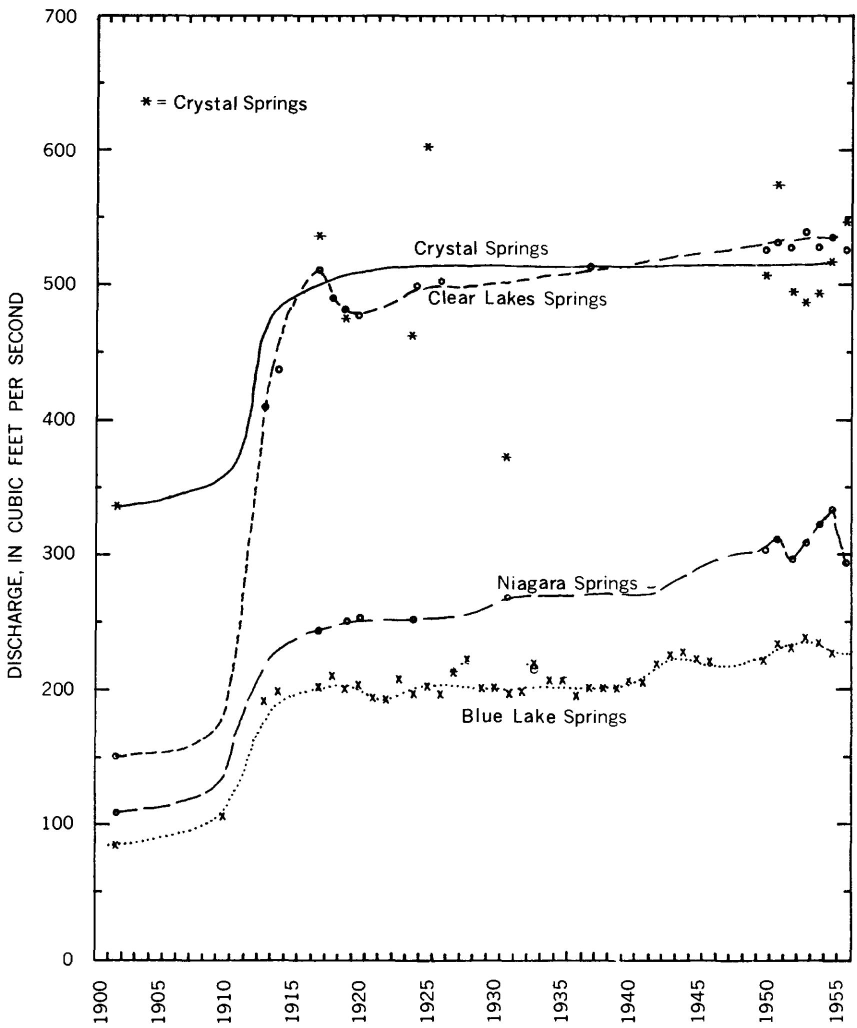

FIGURE 47.—Discharge of Clear Lakes, Niagara, Crystal, and Blue Lake Springs

creased from 3,847 to 5,915 cfs between 1902 and 1956, an increase of 54 percent.

In discussing the earlier discharge records, Nace, McQueen, and Van't Hul (1958) stated that discharge measurements "were made carefully and were as accurate as channel conditions and other factors allowed. Channel conditions were so poor in many of the measured sections, however, that high accuracy was difficult or impossible to attain." They also stated, "Conditions at several of the springs make accurate measurement of the total flow impossible. Part or all of the water from many springs is discharged through talus,

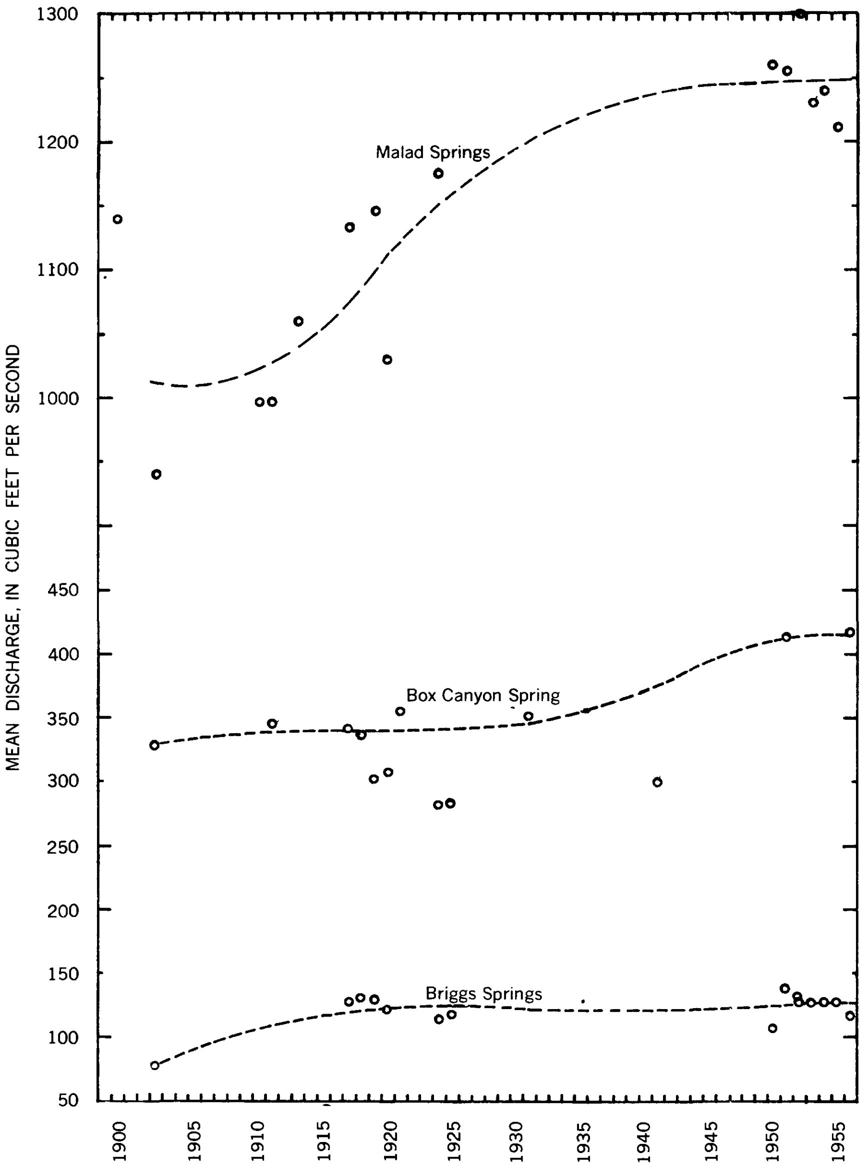

FIGURE 48.—Discharge of Malad, Box Canyon, and Briggs Springs.

where it cannot be measured. In some spring coves there is substantial unmeasurable underflow through loose basalt. A few springs emerge below the water level in the channel of the Snake River."

Obviously the total measured spring discharge is not the total discharge of the aquifers in that reach but represents some unknown

TABLE 12.—*Discharge of springs, in cubic feet per second, Milner to Bliss*

Spring	1902 [1]	1917 [1]	1931 [2]	1956 [3]
Springs between Milner and Blue Lakes	90	[4] 110	[4] 100	83
Blue Lakes outlet	80	192	197	226
Springs between Blue Lakes and Crystal Springs	25	33	[4] 20	18
Crystal Springs	336	536	374	548
Niagara Springs	107	242	269	294
Subtotal	638	1,113	960	1,169
Clear Lakes Springs	150	504	[4] 510	527
Briggs Spring	77	128	149	111
Banbury Springs	66	124	[4] 125	[5] 123
Blind Canyon Springs	2	12	[4] 12	13
Box Canyon Springs	[4] 450	[4] 461	[4] 474	852
Springs at river level below Box Canyon	[4] 94	[4] 90	[4] 100	100
Blue and Riverside Springs	63	75	[4] 75	[4] 80
Sand Springs	51	80	78	----------
Thousand Springs group (includes Bickel Spring)	797	982	1,009	[6] 1,250
Springs between Thousand Springs group and Malad Canyon	344	[4] 350	[4] 350	[4] 400
Malad Springs	1,090	1,133	[4] 1,200	[7] 1,250
Malad Springs to Bliss	25	33	35	40
Total	3,847	5,085	5,077	5,915

[1] From Stearns, Crandall, and Steward (1938, p. 143).
[2] From Nace, McQueen, and Van't Hul (1958, p. 26–55).
[3] From U.S. Geol. Survey (1958).
[4] Wholly or partly estimated.
[5] Includes 5 cfs from unnamed spring near Banbury Springs.
[6] Includes Sand Springs; computed by measuring flow of river above and below reach where springs enter.
[7] Estimated average annual discharge based on occasional measurements.

fraction of the total discharge. The geology and hydrology of the Snake Plain aquifer are such that practically all discharge is into the Snake River upstream from Bliss. The nearest permanent gaging station is 16 miles downstream at King Hill. Perhaps a more accurate method of determining ground-water discharge from the Snake River Plain is to subtract measured or estimated inflows other than underflow contributed by the Snake Plain aquifer from streamflow at the lower end of the reach. Sources that must be subtracted are:

1. Surface inflow:
   a. Snake River (flow past Milner).
   b. Northside streams (chiefly the Malad River).
   c. Southside streams (Cedar, Salmon Falls, Deep, Cottonwood, McMullen, Rock and Dry creeks).
   d. Surface waste from irrigation.
2. Subsurface inflow, from the south side of the Snake River.

The flow of the Snake River at the upper end of the reach is measured at the gaging station below Milner Dam. Gains in the reach can be obtained readily by subtracting discharges at Milner from discharges at King Hill. Average annual gains for the period 1910–55 are shown in figure 49. The data are fairly consistent. Total gains for the reach have increased from about 6,000 cfs in 1910 to a little more than 8,000 cfs during 1950–55. The discharge data shown include surface inflow from both sides of the river and subsurface inflow from

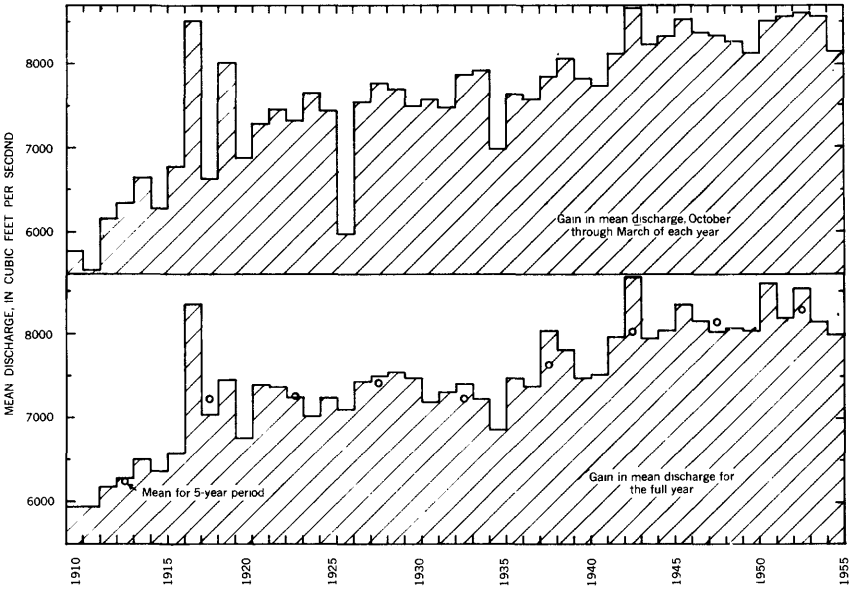

FIGURE 49.—Annual gain in mean discharge of the Snake River between Milner and King Hill.

the south side of the river, both of which must be subtracted to obtain subsurface discharge from the Snake River Plain.

Tributary streams entering the Snake River from the south side between Milner and King Hill contribute a small amount to the flow of the river. However, during much of the year most of the water in upstream reaches is used for irrigation. Most of the water that reaches the Snake River through these tributaries is waste water and return flow from the Twin Falls South Side tract and enters the tributaries only a few miles above their mouths.

Discharge data for the first half of each water year (October through March) were tabulated for the period 1910–55, and the mean discharges at Milner were subtracted from those at King Hill. The differences were plotted on the upper graph in figure 49. More of these points plot on or near a smooth curve than those based on the entire year (lower graph), which included the period of flood runoff and surface runoff of irrigation waste. Although a few of the points deviate rather widely from the others, these deviations probably result from unusual circumstances, such as local floods, unusual amounts of surface waste from canals, and failure to correct for delay in travel time of water between stations and for channel storage. Most of the points form a well-defined curve, which probably approximates closely the average gain to the river in this reach. Although the graph for the 6-month period probably shows the change in discharge of the aquifer better than the graph of annual gain (fig. 49), the average annual gains were used in table 13. Because of considerable variation from year to year, the average gain for the last several years was used. The data indicate that spring discharge did not change materially during the decade 1945–55.

Surface waste from the north side of the river is measured periodically by the North Side Canal Co. The surface waste in the measured drains was slightly more than 70,000 acre-feet, or 100 cfs, for the period April 1957 through March 1958, and that figure was considered to be the total surface waste entering the Snake River from the north side between Milner and Bliss. The figure does not include surface inflow from the Malad River.

Stream inflow from the north side of the Snake River is from the Malad River and Clover Creek. Although discharges vary widely from year to year, the average of about 250 cfs was used for the period of record because no trend is indicated by the data.

The King Hill canal annually diverts about 100,000 acre-feet of water from the Malad River. The diversion is from the river within the area of spring discharge and consists chiefly of ground water. The part of this water that is consumed by crops or does not return to the river above King Hill represents a depletion between Milner and King Hill. Consumptive use and evapotranspiration loss is estimated to be 20,000 acre-feet, and, of the 80,000 acre-feet remaining that returns to the river, 50,000 acre-feet is estimated to return below the King Hill gaging station. Total depletion thus would be about 70,000 acre-feet per year, or nearly 100 cfs. This is a negative entry in table 13 because it represents a loss instead of a gain.

Tributary streams on the south side of the Snake River include Salmon Falls, and Deep Creeks, Cedar Draw, and McMullan, Dry, and Rock Creeks. Total natural discharge from these streams never was large but flow is considerable in the lower reaches of some of these streams because of irrigation waste and return flow from the Twin Falls South Side Project area, and most of the available water is utilized for irrigation. Return flow from these irrigated areas has augmented natural ground-water discharge from the south side of the river, but the total contribution of these drainage basins to the river has been reduced approximately to the extent that consumptive use on irrigated areas exceeds natural consumptive use on the same areas before irrigation.

The entire surface flow of Salmon Falls Creek is stored for irrigation, although a small amount leaks past the dam and runs off in the stream. Fowler (1960) estimated that the annual recharge to aquifers in the Salmon Falls area is about 100,000 acre-feet. The estimate includes contributions from the Deep Creek drainage. Inflow to the

Snake River from the Salmon Falls area is, therefore, about 140 cfs. An additional 10 to 15 cfs probably is contributed from underflow and irrigation return flow on the west side of Salmon Falls Creek, making a total of 150 cfs. Because consumptive use by crops in the Salmon Falls tract is about 30,000 acre-feet and because the natural water loss probably has decreased slightly, the total annual outflow from the Salmon Falls Creek drainage is estimated to have decreased 25,000 acre-feet since irrigation began. The increment to the Snake River before irrigation probably was 175 cfs.

Other tributary streams on the south side between Milner and King Hill discharge very little water into the Snake River because most of their flow is utilized for irrigation. However, a large amount of water is diverted from the Snake River for irrigation of land on the south side of the river, and return flow from this irrigation augments the flow of the river. For convenience, the area is divided into three units: Milner low-lift tract, Dry Creek district, and Twin Falls South Side Project.

Irrigation of the Milner low-lift tract began about 1920. Within 10 years, 8,000 acres had been developed for irrigation and about 35,000 acre-feet of water per year was being applied. During the period 1950–55, diversions averaged 57,000 acre-feet annually and the area irrigated was 10,500 acres. If consumptive use is assumed to have been 1.5 acre-foot per acre per year and if evaporation and nonbeneficial evapotranspiration are assumed to have totalled 1.0 acre-foot per irrigated acre per year, return flow to the Snake River was 15,000 acre-feet (21 cfs) in 1930 and 30,000 acre-feet (41 cfs) in 1955.

According to S. W. West (written communication, 1955), the average annual runoff of Rock Creek was about 27,000 acre-feet during the period 1944–53. About half of the runoff was diverted for irrigation, and depletion by irrigation is estimated to have been 7,000 acre-feet. The annual runoff of Dry Creek during the same period averaged 7,300 acre-feet, but, according to West, consumptive irrigation use decreased this to less than 6,000 acre-feet. Recharge from precipitation and by seepage from ungaged streams, estimated by West to be 77,000 acre-feet annually, supplies additional underflow from the area. Prior to any irrigation, discharge to the Snake River would have been about 110,000 acre-feet (150 cfs) annually. At the present time (1959), the depletion of the ground-water supply by pumping for irrigation is estimated to be 30,000 acre-feet each year, and the surface-water supply is depleted about 20,000 acre-feet each year by diversion for irrigation. Thus, the water yield of the south side of the Dry Creek district is about 100 cfs at present. Most of the depletion caused by pumping from wells has occured since 1930.

The one remaining inflow to be subtracted is return flow from irrigation on the Twin Falls South Side Project area, which is irrigated with water diverted from the Snake River at Milner Dam. Return flow from the project is a new increment to flow of the Snake River caused by irrigation. Approximately 203,000 acres was irrigated in 1958, and about 1.3 million acre-feet of water was diverted to the area. Diversions began in 1905, and in 1910 the diversion was 1.16 million acre-feet. Diversions and acreage irrigated have not changed appreciably since about 1915. Because the water table was low prior to irrigation, for the first few years of irrigation much of the unconsumed water went into ground-water storage. However, by 1930 the water table was largely stabilized. Return of surface waste to the river in 1910 is estimated roughly to have been 25 percent of the diversion, or 290,000 acre-feet (400 cfs). Return flow to the river during the period 1930–55 is based on an estimate of consumptive use, evaporation, and transpiration waste. Consumptive use is estimated to be 1.5 acre-feet per irrigated acre per year, and an additional 0.8 acre-foot per irrigated acre per year is deducted for evaporation loss from free water surfaces and for transpiration by waste vegetation. The total of 2.3 acre-feet per irrigated acre per year is equivalent to 465,000 acre-feet per year for 203,000 acres. Thus, 835,000 acre-feet (1,150 cfs) was returned annually to the river from 1930 through 1955.

According to the above analyses, the total inflow to the Snake River from the south side below Milner, including surface and underground inflow, is about 1,400 cfs. In 1958, an inflow study was made by the Surface Water Branch of the Geological Survey. Measurements, beginning September 15, 1958, show a total inflow of 1,188 cfs from Milner Dam to and including Salmon Falls Creeks. A second set of measurements, made in March 1959 prior to the start of the irrigation season, showed a total of 778 cfs. In this reach of approximately 50 miles, inflow which cannot be measured because it never appears at the surface before entering the Snake River probably is considerable. Thus, the estimate of 1,400 cfs for surface and underground inflow probably is not too large.

The sources of gain between Milner and King Hill are shown in table 13. The discharge from the Snake Plain aquifer was obtained by subtracting all other sources from the total gain.

For an analysis of the Snake Plain hydraulic system, it is convenient to divide inflow to the Snake River into two parts—that in the reach between the gaging station at Milner and the gaging station near Buhl in the NW¼ sec. 9, T. 9 S., R. 15 E. (between Niagara and Clear Lakes Springs) and that between the gaging station near Buhl and Bliss.

TABLE 13.—*Sources of gain, in cubic feet per second, in flow of the Snake River between Milner and King Hill*

	1910	1930	1955
1. Total gain, Milner to King Hill	6,000	7,400	8,150
2. All gains (or losses) other than discharge from Snake Plain aquifer:			
Malad River and Clover Creek	250	250	250
Surface waste, north side	100	100	100
Depletion, King Hill irrigation		−100	−100
Water yield, Salmon Falls Creek basin	175	150	150
Return flow, Milner low-lift	0	20	40
Water yield, Dry Creek area (includes Dry Creek and Rock Creek)	140	140	100
Return flow and surface waste, Twin Falls South Side tract	400	1,150	1,150
Total (rounded)	1,000	1,700	1,700
3. Ground-water discharge from Snake Plain aquifer (difference 1–2, rounded)	5,000	5,700	6,500

The average gain between the gaging stations at Milner and near Buhl was 2,170 cfs for the 6-year period 1951–56. From this amount must be deducted the proportionate amount of inflow from the south side that enters in this reach. The inflow study indicated that 55 percent of the inflow from the south side entered the Snake River between Milner Dam and the Buhl station. If this percentage is applied to the 1,400 cfs estimated for total inflow from the south side, the inflow from the south side above the Buhl station is 770 cfs; if this rate is subtracted from the total gain of 2,170 cfs, the discharge from the Snake Plain aquifer in this reach is 1,400 cfs. The difference between this figure and the 1,170 cfs measured or estimated spring discharge from the north side in 1956 in the same reach represents unmeasured discharge from the Snake River Plain in that reach.

The remainder of the discharge from the Snake River Plain (6,500−1,400=5,100 cfs) is discharged from the Snake River Plain between the gaging station near Buhl and Bliss.

No discharge measurements were made at King Hill or Milner prior to 1909, so data on gains in the reach prior to irrigation of the Twin Falls North Side and South Side projects are not available. However, the total measured spring inflow in 1902 and 1956 can be used to obtain a reasonably accurate figure. The visible measured or estimated spring discharge in the reach was about 5,900 cfs in 1956, or 90 percent of the total calculated outflow from the Snake Plain aquifer within the reach. If it is assumed that the measured or estimated spring discharge in 1902 was 90 percent of the total, the discharge from the aquifer in 1902 would have been 3,800÷0.90=about 4,200 cfs.

Irrigation of the lower end of the plain did not begin on any significant scale until after 1902 (about 1908–09). Irrigation in the Big Wood River drainage basin earlier was considerable, but it is unlikely that this irrigation materially affected the amount of recharge to the Snake Plain aquifer. Irrigation in the Henrys Fork-Idaho Falls area began prior to 1900, but considering the distance from the discharge area (150 miles) the effect of this irrigation probably did not cause much increase in spring discharge until years later. Thus, the increase in discharge prior to 1902 probably was not more than a few hundred cubic feet per second, and 4,000 cfs appears to be a reasonably accurate estimate of discharge from the Snake Plain aquifer prior to any significant hydrologic changes produced by man. The annual discharge near the end of the nineteenth century (4,000 cfs) increased to 6,500 cfs during 1950–60—an increase of 60 percent.

RECHARGE TO THE SYSTEM

Sources of recharge to the aquifer system of the Snake River Plain in order of increasing quantity are (a) precipitation on the plain, (b) underflow from tributary basins, (c) seepage from streams entering or crossing the plain, (d) percolation from irrigation.

The first item, precipitation, is evaluated as such, but the last three items, which constitute more than 90 percent of the total, cannot conveniently be evaluated separately. Inasmuch as all recharge to the plain except for precipitation originates outside the plain, the recharge was analyzed at the place and from the tributary basin where it occurred. This method, modified to take advantage of information on losses and gains of the Snake River, was used in the following analysis.

The objective in analyzing recharge to the aquifers of the Snake River Plain was not merely to determine the total amount of recharge; the total was reasonably well known from determination of the discharge, which must equal the recharge plus any change of ground water in storage. It has been shown that storage has not changed significantly during the past 10 years (p. 171). Therefore, the principal objective was to isolate, inasfar as possible, the several sources of recharge and indicate the amount of recharge in these areas. This information is essential to an understanding of the hydraulic system of the plain. The sources and (or) areas of recharge used are:

Precipitation on the plain.
Tributary basins along the north flank of the Snake River Plain.
Upper Snake River and Henrys Fork to Firth (gaging station at Shelley).
Snake River and plain, Firth to Blackfoot.
Snake River and plain, Blackfoot to Neeley (gaging station below American Falls Reservoir).
Snake River and plain, Neeley to Milner Dam.
Snake River Plain, Milner Dam to Bliss.

The division of the plain into the segments listed above for computing recharge was influenced by locations of gaging stations. Where alternative locations were available for streams tributary to the plain, stations were selected where ungaged underflow probably was small. Along the main stem of the Snake River, stations were selected where canal bypass was least. It also was essential to use the same period of record for computing average discharge for all stations along the main stem of the Snake River, and the period 1931–56 was used. Periods of record for tributary streams differ greatly; some of the stations were abandoned and others were installed during this period. Generally, all available records were utilized.

The general method of determining recharge to the Snake Plain aquifer from each segment was to total all known and estimated inflows to the segment and to subtract from this total the measured outflow and estimated consumptive use within the segment. Where the difference is positive, it represents recharge to the Snake Plain aquifer. Where the difference is negative, it represents loss in excess of recharge from the segment into the Snake River, and this loss is supplied from the Snake Plain aquifer.

Figures for irrigated acreage were obtained chiefly from annual Geological Survey Water-Supply Papers giving streamflow data and from annual reports of Water District 36.

The biggest unknown item in the water budget (except for the item sought, ground-water recharge) was consumptive use by crops and waste vegetation. Estimates of consumptive use by crops in irrigated areas of Idaho are given in a report by Criddle (1947). Consumptive use on the Snake River Plain ranges from 11 inches for potatoes and 14 inches for alfalfa in the Henrys Fork-Snake River area to 15 inches for potatoes and 21 inches for alfalfa in the Twin Falls area. These figures do not include growing-season precipitation. On the basis of these data, the annual consumptive use was estimated to range from slightly more than 1 acre-foot per irrigated acre in the northeastern end of the plain to 1.5 acre-feet in the western end. To this, an amount was added for evaporation from water surfaces and evapotranspiration on nonirrigated lands adjacent to the irrigated areas and bordering the canals and streams within the plain. Areas where evapotranspiration is large are much more extensive in the eastern end of the plain than in the western end and tend to offset the greater consumptive-use factor at the western end of the plain. A single consumptive-use factor based on reported irrigated acreage for the entire plain was used. The consumptive-use factor included evapotranspiration waste of irrigation water in nonirrigated areas and depletion of streamflow by evapotranspiration of waste vegetation. As a first approximation, 2.5 acre-feet per irrigated acre per year was tried, but apparently it was too great because the resulting figure for total recharge to the Snake River Plain was considerably less than the discharge from the plain. Because a consumptive-use factor of 2.3 acre-feet per irrigated acre per year gives a recharge approximately equal to the calculated discharge of the aquifer, this factor is used throughout the report. It may be noted that the biggest unknown element in determining aquifer discharge was consumptive use on the Twin Falls South Side Project (p. 179). The same consumptive-use factor was used for that project as for the remainder of the plain. A reduction in the consumptive-use factor decreased the calculated discharge of the aquifer by increasing the deduction for consumptive use on the Twin Falls South Side Project; at the same time it increased the calculated recharge from other parts of the plain. Any further decrease in the consumptive-use factor would result in recharge exceeding discharge, whereas an increase in this factor would result in discharge exceeding recharge. Of course, this approximation does not prove that the consumptive-use factor selected was correct, but does lend support to its selection.

PRECIPITATION

As shown by the isohyetal map (pl. 2), more than half the Snake River Plain receives less than 10 inches of precipitation annually. Marginal parts of the plain, notably the Craters of the Moon area and the extreme northeast end of the plain, receive as much as 20 inches annually. Throughout much of the plain, the soil absorbs all the precipitation during the growing season and most of the precipitation during the nongrowing season, and all or nearly all of the water evaporates or is used by vegetation. Even in areas having a soil cover, however, occasional heavy showers or melting snow produce runoff, which reaches watercourses underlain by permeable materials through which the water can percolate to the water table. In 10 to 20 percent of the plain, the soil cover is thin or absent, and rough broken basalt or coarse sand and gravel lie at the surface. A large proportion of the precipitation on these areas may reach the water table.

Many estimates have been made of the quantity of precipitation that becomes ground-water recharge on the Snake River Plain, but these estimates are based on few, if any, actual data. Most of the estimates indicate less than an inch over the area. In this report, the ratio between precipitation and water yield (fig. 7) was used. Because of the considerable range in precipitation over the plain, the plain was divided into four areas and the water yield for each area was determined separately. Because most of the plain has no surface runoff, the entire water yield is assumed to be recharge to the water table. The estimates are summarized below.

Recharge to Snake Plain aquifer

Area	Area (square miles)	Average annual		
		Precipitation (inches)	Recharge (inches)	Recharge (acre-feet)
Central part of plain (precipitation generally less than 10 inches)	6,100	9	0.3	100,000
Craters of the Moon	900	13	3.5	170,000
Big Bend Ridge area	400	18	6.0	130,000
South Side of plain (Lake Walcott-American Falls area and northeast along southeast side of the Snake River)	1,000	12	2.0	100,000
Total	8,400			500,000

The above estimates are only approximations. In general, however, the surficial materials in the Snake River Plain are more receptive to recharge than those in the basins in which the relation of precipitation to water yield was derived. Therefore, if the water-yield relation (fig. 7) is reasonable, the above estimates may be too low.

The above table shows clearly the importance of the small areas of greater precipitation as sources of recharge to the Snake River Plain.

TRIBUTARY BASINS

Only that recharge from basins along the north flank of the plain is included in this category. Recharge from basins along the south flank of the plain is included with the segment of the plain in which it occurs and is given in later sections of the report.

Water yields from tributary basins were calculated in previous sections of the report. For some of the basins, separation into ground-water outflow and surface flow onto the margin of the plain seemed unnecessary because the total water yield was the quantity sought. However, water from the Big Wood River and Camas Creek is stored in Magic Reservoir and distributed for irrigation in the Richfield-Shoshone-Gooding area. Recharge from this source is evaluated with the segment of the plain from Milner to Bliss. Only actual underflow from the Big Wood River basin, through the Silver Creek outlet, is included here. Water from Silver Creek, the Little Wood River, and Fish Creek also is used for irrigation on the plain; recharge by percolation from canals, stream channels, and irrigated areas is evaluated with the Milner to Bliss section.

For the Big Lost and Little Lost Rivers, Birch Creek, and the Mud Lake basin, total water yield (contribution to the Snake River Plain) was the quantity derived. Recharge from tributary basins on the north flank of the Snake River Plain is summarized as follows:

Recharge to Snake Plain aquifer

Source	*Average annual recharge*	
	Acre-feet	*Cubic feet per second*
Big Wood River basin (Silver Creek outlet)	50, 000	70
Little Wood River basin	50, 000	70
Fish Creek basin	3, 000	4
Big Lost River basin	330, 000	456
Little Lost River basin	150, 000	205
Birch Creek basin	80, 000	110
Mud Lake basin	330, 000	456
Total (rounded)	1, 000, 000	1, 400

SNAKE RIVER PLAIN ABOVE FIRTH

Included in this segment are all sources of recharge from the northeast, east, and south downvalley to Firth. Recharge is from percolation from stream channels and from irrigation with water diverted from the streams. The segment is terminated a short distance downstream from Shelley, approximately on a north-south line through Firth, because canal bypass at this point is small and the gaging station near Shelley (at Woodville) gives the surface outflow.

Henrys Fork, Snake River, and other streams are above the main water table through much of this reach. Hundreds of canals divert water for irrigation, and recharge to ground-water bodies is from percolation from stream beds, canals, and irrigated tracts. The canal system is complexly interwoven, and it was impracticable to determine separately the amounts of recharge derived from individual streams. Instead, the difference between the total inflow to the segment and the surface outflow from the segment plus consumptive use within the segment were assumed to be ground-water recharge.

The discharge of Henrys Fork is measured at a gaging station near Ashton. Geologic and hydrologic evidence suggest that there is little underflow at this site. Downstream from Ashton, the river is above the main water table and loses water by percolation through its channel. Many canals divert water for irrigation on both sides of the river in this reach. In the vicinity of St. Anthony and Parker, the main water table is about 100 feet below the surface, and a perched water table has developed in the area because of the large diversions, particularly on the north side of the river on the Egin bench. The perched and main water tables converge toward the west and merge a few miles west of the Egin bench.

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The discharge of the Fall River is measured at the gaging station near Squirrel. To this discharge must be added canal bypass and discharge from downstream tributaries, chiefly that from Conant and Squirrel Creeks. Canal bypass is based on measured bypass for 5 months of the year (May through September) from 1941 through 1956 and on the measured bypass for 1 entire year (1943). Inflow from Conant and Squirrel Creeks is estimated in part on partial records of gains in discharge of Fall River between the gaging stations near Squirrel and near Chester (corrected for canal diversions) and in part on the size of drainage area. The partial record at Chester cannot be used alone because percolation losses upstream from that station are large. The record of discharge of the Teton River at the station near St. Anthony is used for water yield of the Teton River drainage. Underflow past the station probably is small. The discharge of Moody Creek and other small drainage basins was estimated on the basis of size and altitude of the drainage area.

The discharge of the Snake River at the gaging station near Heise was considered to be the total inflow from the upper Snake River drainage because underflow at this station probably is small. Inasmuch as the discharge differs considerably from year to year, losses and gains along the Snake River were computed from records collected during the same years at all stations. The gaging station near Shelley has been in continuous operation since 1931 only, so the period 1931–56 was used in computing average discharge at all stations on the Snake River.

The discharge of Birch Creek and other small creeks was estimated. The discharge of Willow Creek was based on the 7-year record at the former gaging station near Ririe. Ground-water inflow from the drainage basins of Henrys Fork, the Teton River, and the Snake River above Heise was estimated.

The surface outflow from the upper Snake River Plain segment is measured at the gaging station near Shelley (at Woodville). Canals divert water to about 380,000 acres of land between that station and the stations upstream where inflow to the area was measured or estimated. The amount of water carried beyond the arbitrary limits of this segment by a few of the canals is only a small part of the total surface outflow. Any error in the recharge computed for this segment would be cancelled in the computation for the next segment because outflow from the one segment is inflow to the next segment.

Inflow, outflow, and consumptive use are summarized in the following table. The difference between inflow and outflow plus consumptive use is assumed to be ground-water recharge.

Recharge to Snake Plain aquifer, Snake River Plain above Firth

	Average annual quantity of water (acre-feet)
Inflow:	
Henrys Fork near Ashton	978, 100
Fall River near Squirrel	545, 900
Canal bypass (bypasses station near Squirrel)	[1] 40, 000
Conant and Squirrel Creeks	[1] 75, 000
Teton River near St. Anthony	[2] 542, 000
Moody Creek and other small creeks	[3] 20, 000
Snake River at Heise	[4] 4, 692, 000
Riley ditch bypass (bypasses station at Heise)	5, 000
Birch Creek and other small creeks	[3] 5, 000
Willow Creek	157, 000
Ground-water inflow	[3] 50, 000
Total	7, 110, 000
Outflow and consumptive use:	
Snake River near Shelley	[4] 3, 817, 000
Consumptive use (380,000 acres at 2.3 acre-feet per acre)	875, 000
Total	4, 692, 000
Ground-water recharge (inflow minus outflow, rounded)	2, 400, 000

[1] Partly estimated.
[2] Figure includes about 4,000 acre-feet per year diverted to river above station from Henrys Fork cross-cut canal.
[3] Entirely estimated.
[4] Average, 1931–56.

The quantities of inflow that are entirely estimated in the above table constitute only about 1 percent of the total inflow. Partly and entirely estimated inflows combined constitute less than 3 percent of the total.

SNAKE RIVER PLAIN, FIRTH TO BLACKFOOT

From the Snake River Plain near Firth to the mouth of the Blackfoot River, 9 miles southwest of Blackfoot, the water table is below river level, and the Snake River loses water by percolation. Additional sources of inflow to this segment are the drainage basins on the southeast side of the Snake River.

Inflow from the Snake River is measured at the gaging station near Shelley (outflow from the previous segment).

The discharge of the Blackfoot River basin probably is given most nearly correctly by the records of the gaging station 10 miles southeast of Shelley. Records of total annual discharge are available only for the period 1909–26, and the average discharge for that period was used. Discharge of the Blackfoot also is measured at a station near Blackfoot, but the flow is so depleted by canal diversions and channel losses that it is not representative of basin yield.

Some ground-water inflow is derived from the Blackfoot River basin. Several smaller streams leave the foothills to the south in this part of the Snake River Plain and lose much or all their water in volcanic rocks and alluvial deposits before their channels reach the Snake River valley. In this reach of 20 miles, about 150 square miles of hill land on the south contribute unmeasured inflow. The average precipitation is 13.5 inches and, on the basis of the relation shown in figure 7, the water yield is estimated to be about 25,000 acre-feet.

Several canals divert water from the Snake River below the gaging station at Shelley. However, except for the Fort Hall canals and the Aberdeen canal, all the water diverted is consumed by crops or percolates into the ground within the section. On the basis of incomplete records, the average annual bypass through the Fort Hall canals is estimated to be 200,000 acre-feet.

The water budget for this reach is estimated as follows:

Recharge to Snake Plain aquifer, Firth to Blackfoot

	Average annual quantity of water (acre-feet)
Inflow:	
Snake River near Shelley	[1] 3, 817, 000
Blackfoot River near Shelley	[2] 256, 000
Ground-water inflow	[3] 25, 000
Total	4, 098, 000
Outflow and consumptive use:	
Snake River near Blackfoot	[1] 2, 847, 000
Aberdeen-Springfield Canal	[4] 315, 000
Fort Hall canals	[4] 200, 000
Consumptive use (70,000 acres at 2.3 acre-feet per acre)	160, 000
Total	3, 522, 000
Ground-water recharge (inflow minus outflow, rounded)	600, 000

[1] Average discharge, 1931–56.
[2] Average for available period of record.
[3] Estimated (see above).
[4] Estimated on basis of partial record. Average diversion of Fort Hall canals estimated at 250,000 acre-feet, of which 50,000 acre-feet is estimated to be used or to enter the aquifer within the section.

SNAKE RIVER PLAIN, BLACKFOOT TO NEELEY

The sources of inflow in this segment of the plain are the Snake River (measured at Blackfoot) and the drainage basins on the southeast side of the river, of which the Portneuf is the most important.

The discharge of the Portneuf River is measured at Pocatello. The average discharge for the entire period of record through 1956 was used.

A small amount of inflow to the Snake River is obtained from miscellaneous streams, such as Bannock Creek. Considerable inflow also is derived from ground-water underflow past the gaging station on the Portneuf River and as mass underflow along the southeast flank of the plain.

The water yield of the Bannock Creek basin is estimated to be 45,000 to 50,000 acre-feet (fig. 7). The average annual discharge of Bannock Creek near Pocatello was 16,000 acre-feet for the 3-year period 1956–58. The difference, roughly 30,000 acre-feet, is assumed to be underground inflow from Bannock Creek basin.

The water yield of unmeasured streams and the underground inflow for an additional area of about 150 square miles that has an average annual precipitation of 13 inches is estimated to be 20,000 acre-feet (fig. 7). Underflow from the Portneuf River basin was estimated by Stearns, Crandall, and Steward (1938) to be 50,000 acre-feet.

From the mouth of the Blackfoot River downstream to beyond American Falls Reservoir, the water table is above river level on both sides of the Snake River. Numerous springs and seeps discharge a large amount of water to the river, and outflow and consumptive use far exceed inflow into this segment of the plain. A large part of the discharge is from the Snake Plain aquifer, and underflow in the aquifer is reduced correspondingly in this segment.

Surface outflow from the segment is measured at the gaging station on the Snake River near Neeley, 0.9 mile downstream from the American Falls Dam.

There are no canal diversions within the reach, and practically all the water diverted upstream from the gaging station near Blackfoot is consumed or percolates into the ground before reaching the end of the section. No surface water bypasses the gaging station at Neeley.

Because of the large size of the American Falls Reservoir, the estimated loss by evaporation from its surface was added separately.

Estimates of inflow, outflow, and consumptive use are summarized in the following table. The difference, a negative amount, is assumed to be ground-water discharge from the Snake Plain aquifer to the Snake River in this reach.

Snake River Plain, Blackfoot to Neeley

	Average annual (acre-feet)
Inflow:	
Snake River near Blackfoot	[1] 2, 847, 000
Aberdeen Canal	315, 000
Fort Hall Canals	200, 000
Portneuf River at Pocatello	[2] 185, 000
Bannock Creek near Pocatello	[2] 16, 000
Ground-water inflow	[3] 100, 000
Total	3, 663, 000
Outflow and consumptive use:	
Snake River at Neeley	[1] 4, 826, 000
Consumptive use (90,000 acres at 2.3 acre-feet per acre)	207, 000
Reservoir evaporation	[3] 150, 000
Total	5, 183, 000
Excess of ground-water discharge over recharge (outflow minus inflow, rounded)	1, 500, 000

[1] Average, 1931–56.
[2] Average for available period of record.
[3] Estimated; average area about 47,000 acres, average annual evaporation about 38 inches (Kohler, Nordenson, and Baker, 1959, pl. 2).

SNAKE RIVER PLAIN, NEELEY TO MILNER

From Neeley to a point about 5 miles downstream from the mouth of the Raft River, the water table is above river level, and some ground water discharges into the Snake River. This water may be perched and the main water table may be below river level. Irrigation in this reach is negligible, and ground-water discharge to the river also probably is small. Meisler (1958) estimated that average ground-water discharge from the Lake Channel springs on the north side of the river and Lake Walcott was about 100 cfs. The amount of such discharge is immaterial; if it appears as a positive entry for inflow into the segment, it must also appear as a negative entry representing discharge from the Snake Plain aquifer and would thus cancel out.

Downstream from a point about 5 miles west of the mouth of the Raft River, the river generally is above the main water table; considerable water percolates downward from irrigated areas and the river channel to join the main ground-water body of the Snake River Plain.

Surface inflow to the area is given by the discharge record at the station near Neeley. Inflow from Rockland valley was based on the size of the drainage area and other factors, as derived in another section of this report. Inflow from the Raft River valley is based on studies by Nace and others (1961). Estimates of inflow for Marsh Creek are given by Stearns (1938).

Surface outflow from this segment consists of outflow in the Snake River below Milner Dam and canal diversions out of Lake Milner, above Milner Dam, for irrigation of tracts downstream from the segment.

Water is diverted for irrigation of 135,000 acres of land on the Minidoka tracts within the segment, and the same factor for consumptive use was used as for other segments.

Estimates of inflow, outflow, consumptive use, and recharge within the segment are summarized in the following table.

Recharge to Snake Plain aquifer, Neeley to Milner

	Average annual (acre-feet)
Inflow:	
Snake River at Neeley	[1] 4, 904, 000
Rockland Valley	[2] 50, 000
Raft River Valley	[3] 140, 000
Marsh Creek	2, 000
Total	5, 096, 000
Outflow and consumptive use:	
Snake River at Milner	[1] 1, 363, 000
P.A. Lateral north of Milner Dam	19, 000
Milner Low-Lift Canal south of Milner Dam	55, 000
Gooding Canal	714, 000
North Side Twin Falls Canal	910, 000
South Side Twin Falls Canal	1, 272, 000
Consumptive use (135,000 acres at 2.3 acre-feet per acre)	310, 000
Total	4, 643, 000
Ground-water recharge (inflow minus outflow, rounded)	500, 000

[1] Average, 1931–56.
[2] Estimated (see p. 94).
[3] Estimated (see p. 88).

SNAKE RIVER PLAIN, MILNER TO BLISS

From Milner to Bliss, the Snake River is in a deep canyon. From Milner to Murtaugh, the river is above the water table in the Snake Plain aquifer on the north side of the river and may lose some water; records are not available to indicate the extent of such loss, if any. The water table on the south side of the river is above river level to a point several miles east of Murtaugh, and some ground water probably discharges to the river within this reach.

From Murtaugh to Bliss, the water table is above river level on both sides of the river; a short distance from the canyon wall on the north side the water table generally ranges from 100 to 200 feet above river level. In this reach the entire underflow from the Snake Plain aquifer discharges into the river.

Sources of recharge to the Snake Plain aquifer in this reach are

(a) water diverted to the area from the Snake River through the P.A. Lateral, the Gooding Canal, and the North Side Twin Falls Canal and (b) water brought into the area by the Big Wood and Little Wood Rivers, Fish and Silver Creeks (tributary to the Little Wood River), and Dry and Thorn Creeks. The Malad River is formed by the confluence of the Big and Little Wood Rivers. Moderately long term records are available for all these sources except for Thorn and Dry Creeks.

Surface outflow from the area is by way of the Malad River and surface wasteways. The discharge of the Malad River is gaged near Gooding, and surface waste is measured occasionally by the North Side Canal Co.

Land in the Gooding-Shoshone area was originally irrigated with water from Big and Little Wood Rivers. However, the supply was inadequate, so additional water was brought to that area from the Snake River through the Gooding Canal. A great deal of water is lost by canal seepage between the Snake River and the Gooding area. For these reasons, it is not practicable to determine separately the amount of recharge derived from the two major sources.

The water budget for the area is given in the following table.

Recharge to Snake Plain aquifer, Milner to Bliss

	Average annual quantity of water (acre-feet)
Inflow:	
From Snake River:	
P. A. Lateral	[1] 19, 000
Gooding Canal	[1] 714, 000
North Side Twin Falls Canal	[1] 910, 000
From the north side of plain:	
Big Wood River below Magic Reservoir	[1] 309, 000
Little Wood River near Carey	[2] 100, 000
Fish Creek	[2] 12, 000
Silver Creek near Picabo	[1] 112, 000
Dry and Thorn Creeks	[3] 25, 000
Total	2, 201, 000
Outflow and consumptive use:	
Malad River near Gooding	168, 000
Northside wasteways	70, 000
Consumptive use (316,000 acres at 2.3 acre-feet per acre)	725, 000
Total	963, 000
Ground-water recharge (inflow minus outflow, rounded)	1, 200, 000

[1] Average for period of record.
[2] The average discharge of the Little Wood River near Carey is 97,000 acre-feet; 3,000 acre-feet is added for inflow below station. The average discharge of Fish Creek near Carey is 10,700 acre-feet; 1,300 acre-feet is added for inflow below station.
[3] Estimated on basis of size of drainage area and amount of precipitation on area.

SUMMARY OF RECHARGE

In previous sections of the report, all significant sources of recharge to the Snake Plain aquifer have been evaluated. Most data were not complete enough for precise determinations, and most of these evaluations are based on indirect measurements and methods. However, similar procedures and factors were used to determine quantities from the several sources, and the total of the quantities very nearly equals the total discharge; therefore, the quantities probably are fairly accurate.

Sources and estimated amounts of annual recharge to the Snake Plain aquifer are summarized in the following table:

Source or segment of Snake River Plain	*Annual recharge*	
	Acre-feet	*Average flow (cfs)*
Precipitation on plain	500, 000	700
Tributary basins along north flank	1, 000, 000	1, 400
Upper Snake River, above Firth	2, 400, 000	3, 300
Snake River, Firth to Blackfoot	600, 000	800
Blackfoot to Neeley	[1] −1, 500, 000	[1] −2, 100
Neeley to Milner	500, 000	700
Milner to Bliss	1, 200, 000	1, 700
Net annual recharge (rounded)	4, 700, 000	6, 500

[1] Ground-water discharge in excess of recharge.

The total annual recharge to the Snake Plain aquifer is approximately 6.2 million acre-feet, of which 1.5 million acre-feet discharges into the Snake River and American Falls Reservoir between Blackfoot and Neeley. The remainder, 4.7 million acre-feet, discharges into the Snake River between Milner and Bliss.

AQUIFER BOUNDARIES

The boundaries of the aquifer are important factors in analyzing the aquifer system. Several of the boundaries of the Snake Plain aquifer are not absolute; some flow will cross some barrier boundaries and some drawdown will occur across some positive boundaries. Not all boundaries of the Snake Plain aquifer can be sharply delineated; the contact of the aquifer with less permeable rocks at the margin of the plain is sloping, not vertical, and the line representing the boundary can only represent the average effective boundary. The boundaries of the Snake Plain aquifer were delineated on the basis of the best available surface and subsurface hydrogeologic data. The two types of boundaries are shown by different symbols on pl. 4.

The line of spring discharge between Twin Falls and Bliss represents a positive boundary. No drawdown can occur across this boundary, and withdrawal of water upgradient decreases the discharge, which has the same effect on the system as increasing recharge. The boundaries where the Snake Plain aquifer abuts against the impermeable rocks of bordering areas are negative boundaries; the boundary line was averaged across headlands and re-entrants, allowance being made for the slope and configuration of the basement complex beneath the Snake River Plain. In the Burley-Rupert area, recharge of the aquifer might be increased, if water levels were lowered, by increased infiltration from the perched water zone and the Snake River. The extent to which recharge would be increased is problematical, so a doubtful recharge boundary is shown (pl. 4). Between Lake Walcott and the mouth of the Blackfoot River, the aquifer discharges into the river and American Falls Reservoir. This reach of the river represents a true positive boundary and it is shown as such. Water from the Snake River and Henrys Fork and from application of irrigation water recharges both a perched aquifer and the main water table in the Rigby-St. Anthony area. No positive boundary is shown on plate 4 because it is questionable whether lowering of the water table in the main aquifer would increase recharge.

The water-table gradient in the Mud Lake-Roberts area is steep, as shown on the water-table map (pl. 4). Water flows across this zone, in places, as a sort of underground cascade. (See also p. 133.) Lowering the water table downgradient probably would not increase the flow across the barrier; therefore, in relation to the aquifer downgradient, the barrier serves as a negative boundary. On the other hand, lowering the water level upgradient from the barrier would, at some places, decrease the flow across it, and thus the barrier would, at least to some extent, act as a positive boundary.

Actual boundaries are irregular, but analysis of the system based on these irregular boundaries would be impractical. The boundaries have therefore been approximated by straight-line segments most suitable for the analysis desired.

FLOW NET AND AQUIFER ANALYSIS

The data on recharge to and discharge from the Snake Plain aquifer were used in constructing the flow net shown on plate 4. Each line on the map represents a ground-water flow of 200 cfs. The water represented by the line is flowing through the entire thickness of the aquifer in a band extending to the midpoint between the flow line in question and the adjacent flow lines on either side. Because recharge and discharge occur at an almost infinite number of points, the flow net is only an approximation.

Vertical percolation of 200 cfs of water to the water table obviously is not concentrated at one point; dashed lines were used in the recharge area to indicate that the line in that area does not necessarily represent the entire 200 cfs and that recharge is distributed throughout the dashed section.

In a completely homogeneous aquifer, flow lines cross contour lines at right angles. However, the Snake Plain aquifer is not homogeneous; it displays considerable range in transmissibility, part of which may be related to the thickness of the aquifer. Anisotropy of the aquifer over considerable areas may be in the ratio of 10 to 1, or greater, as shown in the section of the report describing aquifer characteristics (pp. 142–143), and as shown by abrupt changes in the water-table gradient. Furthermore, most places have several water-bearing zones, and water in each of these zones probably is flowing in a somewhat different direction than water in each of the other zones. For these reasons, the flow lines, which are generalized, do not necessarily cross the contour lines, also generalized, exactly at right angles.

The following table was used in constructing the flow-net map. Where fractional lines were indicated, the line was dashed until sufficient recharge was gained from the next source downgradient to fill out the 200 cfs required for the line.

Source of water	Quantity		Lines	Cumulative lines
	Acre-feet per year	Cubic feet per second		
North side:				
Mud Lake basin	330,000	455	2.3	2.3
Big Bend area, precipitation	130,000	180	.9	3.2
Birch Creek basin	80,000	110	.55	3.75
Little Lost River	150,000	205	1.03	4.78
Big Lost River	330,000	455	2.27	7.05
Craters of the Moon area, precipitation	170,000	235	1.17	8.2
Little Wood River	50,000	70	.35	8.57
Fish Creek	3,000	4	.02	8.59
Big Wood River (Silver Creek outlet)	50,000	70	.35	8.9
Eastern area and south side:				
Snake River Plain and Henrys Fork (above Firth)	2,400,000	3,300	16.5	16.5
Snake River Plain, Firth to Blackfoot	600,000	800	4.0	20.5
Snake River Plain, Blackfoot to Neeley	−1,500,000	−2,100	−10.5	10.0
Central Snake River Plain, precipitation	100,000	138	.7	10.7
South-east side Snake River Plain, precipitation	100,000	138	.7	11.4
Snake River Plain Neeley to Milner	500,000	700	3.5	14.9
Western area:				
Snake River Plain, Milner to Bliss	1,200,000	1,700	8.5	8.5
Total discharge at western end of plain (rounded)	----------	6,500	32.5	32.5

In some areas, particularly in the Blackfoot to Neeley section along American Falls Reservoir, a large amount of irrigation water recharges the aquifer on both sides of the reservoir and returns to the reservoir or the river within the section. No attempt was made to show this water quantitatively; dashed flow lines were used to show this exchange qualitatively but were neither added to nor subtracted from the quantitative net. In the reach from Neeley to Milner, the net gain to the aquifer is estimated to be 700 cfs, about 3½ flow lines. However, the aquifer discharges to the river from Neeley to about midway of Lake Walcott; from the latter point to Milner, the water table is below river level, and recharge is received from the river and from irrigation of land on both sides of the river (Minidoka irrigation tracts). One flow line is shown as ending at the river between Neeley and Lake Walcott, and an extra flow line as originating between Lake Walcott and Milner. Whether or not the loss and gain is exactly one flow line (200 cfs) is of minor importance; it does not affect the calculated net gain of 700 cfs. The fact that perched aquifers on the Minidoka tracts are recharged by irrigation and return some water to the Snake River within this section does not affect the computations of net gain of 700 cfs to the aquifer.

The flow net can be used to determine the coefficient of transmissibility of the aquifer at any place by use of the equation $T=\frac{Q}{IW}$ which is a modification of Darcy's law, as given in a previous part of the report. In this equation, Q is the discharge in gallons per day through the section of aquifer in question, I is the average hydraulic gradient in feet per mile at the section, and W is the width of the section in miles. If each quadrilateral bounded by two water-table contours and two flow lines is considered as an individual section, T can be calculated for each quadrilateral. This method was used in constructing the map showing the coefficient of transmissibility of the Snake Plain aquifer (pl. 6).

The water-table-contour interval for much of the plain is 50 feet. More detailed data were available at some places in the plain, and the auxiliary 10-foot contours were used where possible. The abrupt changes in the coefficient of transmissibility at some places are caused by seemingly abrupt changes in the hydraulic gradient due to the large contour interval. A smaller contour interval, based on more data, no doubt would show a more gradual change in the gradient, which would be reflected in more gradual lateral changes in the coefficient of transmissibility. The coefficient of transmissibility shown ranges from less than 1 to more than 20 mgd (million gallons per day) per foot. The part of the plain having the lowest transmissibility is the barrier southwest of the Mud Lake and Roberts area, where the water table drops about 200 feet in 1 or 2 miles. The area with the next lowest transmissibility is between Milner and Bliss, where many springs discharge. Undoubtedly the decrease in transmissibility is caused, at least in part, by thinning of the saturated zone as the water table declines toward the discharge area.

Three areas are shown as having a transmissibility of more than 20 mgd per foot. One is the Minidoka area, northward toward Carey, the second is the area north of American Falls Reservoir, and the third is between Egin Bench and Roberts, extending northwest to include the Mud Lake area. The area north of the American Falls Reservoir has the greatest coefficient. A large part of the area shown as "more than 20 million" has a coefficient of 40 to 60 mgd per foot.

The transmissibility of an aquifer is equal to the product of the permeability and the thickness of the aquifer:

$T = P_f m$, where P_f is the field coefficient of permeability and m is the saturated thickness of the aquifer.

Thus, with the same unit permeability, where the aquifer is half as thick, the transmissibility would be only half as large. This low permeability suggests the possibility that some of the areas of lower transmissibility may be caused by thinning of the aquifer over buried ridges or other "highs" in the underlying basement rocks.

The transmissibility map is necessarily greatly generalized. Some places undoubtedly have higher or lower transmissibilities than those shown for the areas within which they lie. The transmissibility shown by a pumping test probably rarely will be that of the entire thickness of the aquifer because of partial penetration and the low vertical permeability between water-bearing zones. However, for evaluation of regional effects of pumping a large number of wells, the entire thickness of the aquifer can be considered to be involved. Nor is the transmissibility just that of the immediately surrounding area; it is a composite of the transmissibility of the entire area affected.

THEORETICAL EFFECTS OF POSTULATED WITHDRAWALS IN SELECTED AREAS

In previous sections of the report, aquifer characteristics were derived and evaluated, the position and gradient of the water table were described, the geohydrologic boundaries were located and evaluated, and a flow net was developed. All this had one major objective: to permit analysis of the effects that changes in discharge from or recharge to the aquifer would have on the system. The changes that could be imposed on the system are almost infinite in variety: the location, spacing, and number of wells, the average discharge, and the length of pumping cycle are all possible variables. The same applies to places, quantities, and cycles of recharge. However, the effects, under specified conditions, of pumping or of recharging can be evaluated, if certain assumptions are made. The effects of pumping have been analyzed for the following areas: (a) Wendell, (b) Shoshone-Dietrich, (c) Eden, (d) Idaho Falls, (e) Roberts-Plano.

ASSUMED CONDITIONS

The assumed conditions are of two types (a) assumed aquifer coefficients and (b) assumed operating conditions. No particular effort was made to use "conservative" aquifer coefficients; that is, the coefficients indicated by the preponderance of evidence were used, in the belief that safety factors should be included in the design of an operational system, not in the calculation of theoretical effects.

The coefficient of storage of 5 percent was used for all computations. Most aquifer tests indicate storage coefficients in the water-table range, from 1 to several percent. The tests appear to indicate that the storage coefficient increases with long-term pumping. The coefficient of storage undoubtedly differs considerably from place to place, but, with any large withdrawal, storage over thousands of square miles would be affected, and an aquifer-wide average probably should be used. The average coefficient of storage may be 10 percent or more; however, there are insufficient data to support that figure. The preponderance of data do suggest that the coefficient exceeds 4 percent; therefore 5 percent was used.

Different coefficients of transmissibility were used for different locations, depending upon the results of aquifer tests and analysis of the flow net. The depth of penetration of aquifer-test wells also was taken into account. Although the Snake Plain aquifer reacts as a unit to large-scale withdrawals over any considerable period of time, local impermeable horizons between water-bearing zones limit the effect of an aquifer test lasting from a few hours to a few days almost entirely to the zones penetrated by the pumped well. In considering the regional effects of pumping for many seasons and the effects of boundaries tens of miles from the pumping, the entire aquifer must be considered, not merely the part penetrated by the production wells.

The following primary assumptions are made regarding operating conditions:

1. Fifty wells are spaced at intervals of 1,000 feet along a line about 10 miles long.
2. Each well is pumped at a rate of 2,250 gpm (about 5 cfs).
3. The wells are pumped 122 days each year at the same time every year.
4. None of the water pumped returns to the ground (aquifer) within the area affected by the pumping.

Drawdowns caused by cyclic pumping were calculated on the basis of an infinite aquifer, and the method of images was used to determine the effects of geohydrologic boundaries. The drawdowns calculated for the pumped wells are the drawdowns in the aquifer immediately adjacent to the well. Well loss must be added to this. In seven of the aquifer tests at the sites of Bureau of Reclamation test wells in the Snake Plain aquifer during 1957 and 1958, well losses ranged from 0.2 to 2.25 feet at pumping rates ranging from 1,300 to 2,600 gpm, and the average well loss was less than 1 foot. Tests at the National Reactor Testing Station near Arco and at other places also indicated that well losses generally are small. Well loss probably averages less than 1 foot; however, an occasional well may always have a large well loss because of poor construction or local differences in hydrologic properties of the aquifer.

Effects of cyclic pumping were determined by the method devised by C. V. Theis (Theis and Brown, written communication, 1954). The drawdowns at various distances at the end of the first cycle were calculated in the conventional manner; additional drawdown caused by pumping for 49 additional cycles was added to that amount. The distance-drawdown relations for an infinite aquifer at the ends of the first season and the fiftieth seasons of cyclic pumping are shown in figures 50 and 51.

These graphs can be used to determine the drawdown caused at any point in the assumed infinite aquifer by pumping any number of wells located at any distance from the point. For example: Assume that the coefficient of transmissibility in the area is 5×10^6 gpd per foot. Wells are located 1,000, 2,000, and 3,000 feet from point *A*. If each well were pumped at 2,250 gpm for 122 days a year for 50 years, the drawdown at point *A* (fig. 50) would be 0.51+0.44+0.39=1.34 feet. This figure is the drawdown in the theoretical infinite aquifer; the effects of hydrologic boundaries must be added. Most of the boundaries were far enough from the center of pumping that the cyclic wave disappears before reaching the boundary, so the average discharge for the entire period was used in calculating drawdowns of the image wells, that is: $\frac{Q}{3}$ for 50 years (18,250 days).

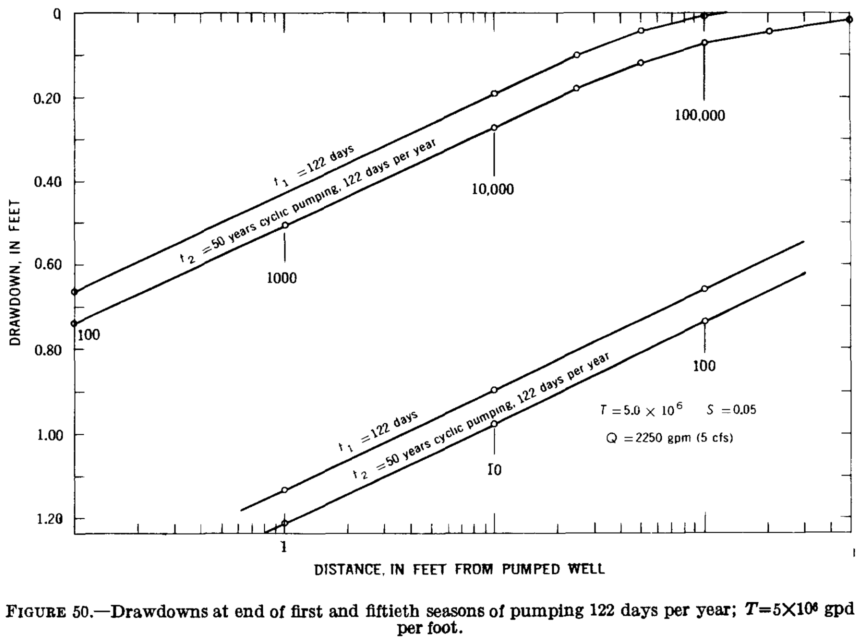

FIGURE 50.—Drawdowns at end of first and fiftieth seasons of pumping 122 days per year; $T=5\times10^6$ gpd per foot.

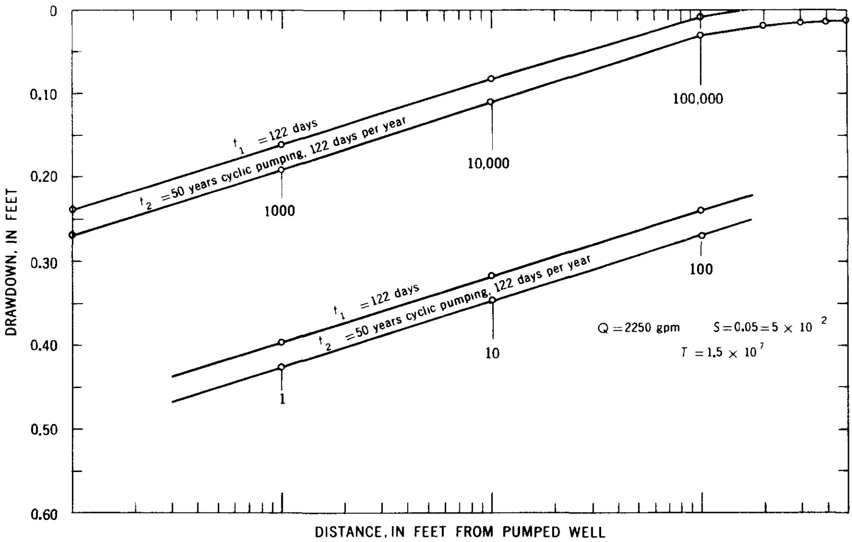

Figure 51.—Drawdowns at end of first and fiftieth seasons of pumping 122 days per year; $T=1.5\times10^7$ gpd per foot.

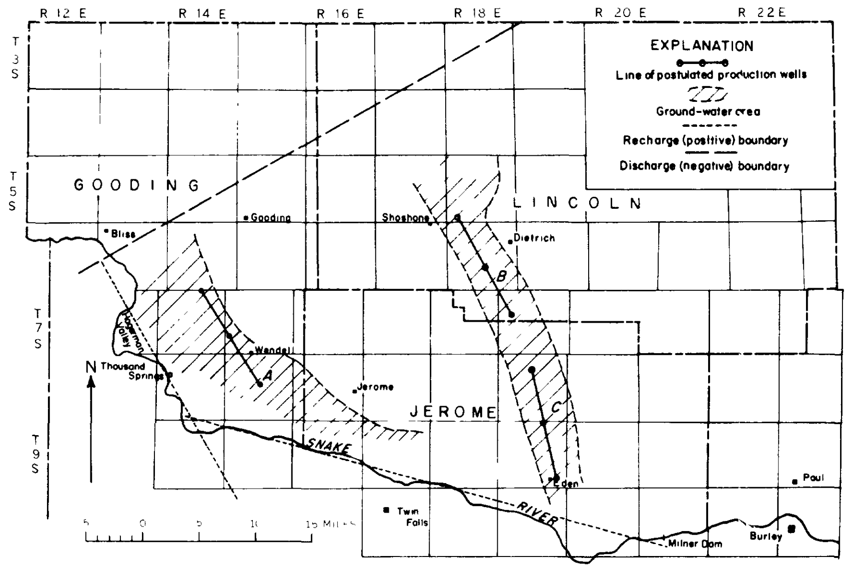

Figure 52.—Sketch map of Wendell (*A*), Shoshone-Dietrich (*B*), and Eden areas (*C*), showing geohydrologic boundaries and lines of postulated wells.

The nonequilibrium formula, as described on pages 39–41, was used in the analysis. This equation is based on the assumption that the aquifer is artesian and that no dewatering occurs. Although the Snake Plain aquifer is not artesian in the regional sense, that part of the aquifer dewatered under pumping is generally so thin compared to the total thickness of aquifer that the aquifer can be analyzed by use of the nonequilibrium formula. However, if extremely large quantities of water were withdrawn, perhaps one-third of the underflow, the analysis might give significantly wrong results.

WENDELL AREA (A)

The present depth to water in the Wendell area generally is less than 150 feet. The line of 50 wells is oriented northwestward, as shown in the sketch, figure 52.

The line of discharge of the aquifer along the Snake River forms a positive boundary, and the edge of the Snake Plain aquifer to the north forms a negative boundary. The location of the latter boundary is known only approximately. The boundaries intersect at about a right angle, as shown in figure 52, and three image wells satisfy the boundary conditions. The map, plate 6, shows that the coefficient of transmissibility ranges from about 3 to 20 mgd per foot. The average, based on analysis of the flow net between the 3,800- and 3,200-foot contour on the water table, is about 5.2 x 10^6 gpd per foot. This value was rounded to 5 x 10^6 gpd per foot and used for the coefficient in the computations.

For simplification in computing the boundary effects, the pumping is considered to be concentrated at the center of the line of wells, and this center of pumping is reflected across the boundaries as a single "giant" well. The negative boundary is about 11 miles from the center of pumping, and the positive boundary is about 6 miles. If the wells are numbered from 1 to 50, starting at the southeast end of the line (wells 25 and 26 would be equidistant from the center point), the theoretical drawdowns, under the assumed conditions, would be as follows (well loss is not included, and must be added to obtain actual drawdowns in the wells):

Theoretical effects, in feet, of pumping in the Wendell area (A)

	Wells			
	25, 26	15, 36	5, 46	1, 50
Drawdown at end of 1 cycle (after pumping 122 days):				
Caused by discharge from an infinite aquifer	10.5	10.0	8.5	7.2
Caused by discharging image wells	.1	.1	.1	.1
Caused by recharging image wells	+1.2	+1.2	+1.2	+1.2
Total	9.4	8.9	7.4	6.1
Drawdown at end of 50 cycles (50 years of pumping 122 days a year):				
Caused by discharge from an infinite aquifer	14.5	14.0	12.5	11.2
Caused by discharging image wells	3.2	3.2	3.2	3.2
Caused by recharging image wells	+7.2	+7.2	+7.2	+7.2
Total	10.5	10.0	8.5	7.2

690–440 O—64——14

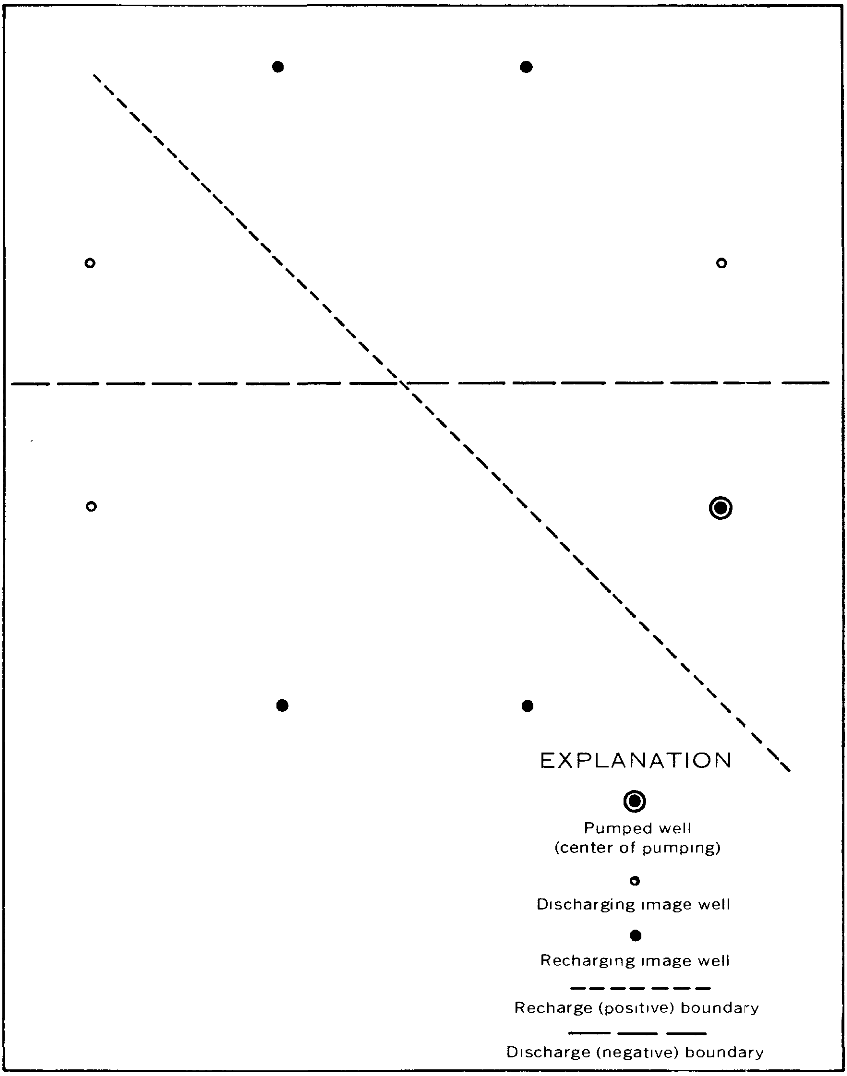

FIGURE 53.—Image-well array required to satisfy boundary conditions assumed for the Shoshone-Dietrich area.

The discharge area along the Snake River between Thousand Springs and Blue Lake Springs, shown on figure 49 as a positive boundary, would further reduce the computed drawdowns, but the effects are difficult to calculate and have been disregarded.

SHOSHONE-DIETRICH AREA (B)

The Shoshone-Dietrich area extends southeastward between Shoshone and Dietrich. The depth to water generally is less than 200 feet. As shown on the sketch map (fig. 52), the center of the line of wells is approximately 16 miles from the negative boundary and 18 miles from the positive boundary between Milner Dam and Thousand Springs. In this area, the positive boundary represented by the discharge area in the Hagerman Valley is disregarded, as is the negative boundary south of Burley (pl. 4). The two boundaries used intersect at an angle of 45 degrees, and an array of seven image wells (fig. 53) is required to satisfy the boundary conditions.

The coefficient of transmissibility in the area, and in the aquifer to the east, ranges from 5 to 10 mgd per foot. Westward it is generally less than 5 mgd per foot. Therefore, a coefficient of 5 mgd per foot was used for the computations.

Numbering the wells as before, the theoretical drawdowns, under the assumed conditions, would be:

Theoretical effects, in feet, of pumping in the Shoshone-Dietrich area (B)

	Wells			
	25, 26	15, 36	5, 46	1, 50
Drawdown at end of 1 cycle (after pumping 122 days):				
Caused by pumping from an infinite aquifer	10.5	10.0	8.5	7.2
Caused by discharging image wells	0	0	0	0
Caused by recharging image wells	0	0	0	0
Total	10.5	10.0	8.5	7.2
Drawdown at end of 50 cycles (50 years of pumping 122 days a year):				
Caused by pumping from an infinite aquifer	14.5	14.0	12.5	11.2
Caused by discharging image wells	4.5	4.5	4.5	4.5
Caused by recharging image wells	+5.7	+5.7	+5.7	+5.7
Total	13.3	12.8	11.3	10.0

EDEN AREA (*C*)

Area *C* extends northward from Eden (fig. 52). The water table ranges from 150 to 250 and probably averages about 200 feet below the land surface.

The center of pumping, as shown in figure 52, is about 7 miles from the east end of the positive boundary represented by discharge to the Snake River near Twin Falls. The west end of the discharge area is nearly 40 miles to the northwest. The negative boundary formed by the northern margin of the aquifer is about 30 miles to the north, and the negative boundary along the south margin of the aquifer is 12 to 17 miles to the south. The effects of this southern boundary may be offset by increased infiltration of perched water in the Burley-Rupert area (pl. 4).

Analysis of the hypothetical effects of the boundaries shown is exceedingly difficult. The total drawdown caused by the combined boundaries probably would be somewhat less than that computed for the Shoshone-Dietrich area. Drawdowns calculated for that area are assumed to apply in the Eden area.

IDAHO FALLS AREA (*D*)

Area *D* extends southwest from Idaho Falls along the west side of the Snake River (fig 54). The depth to water ranges from 50 to 250

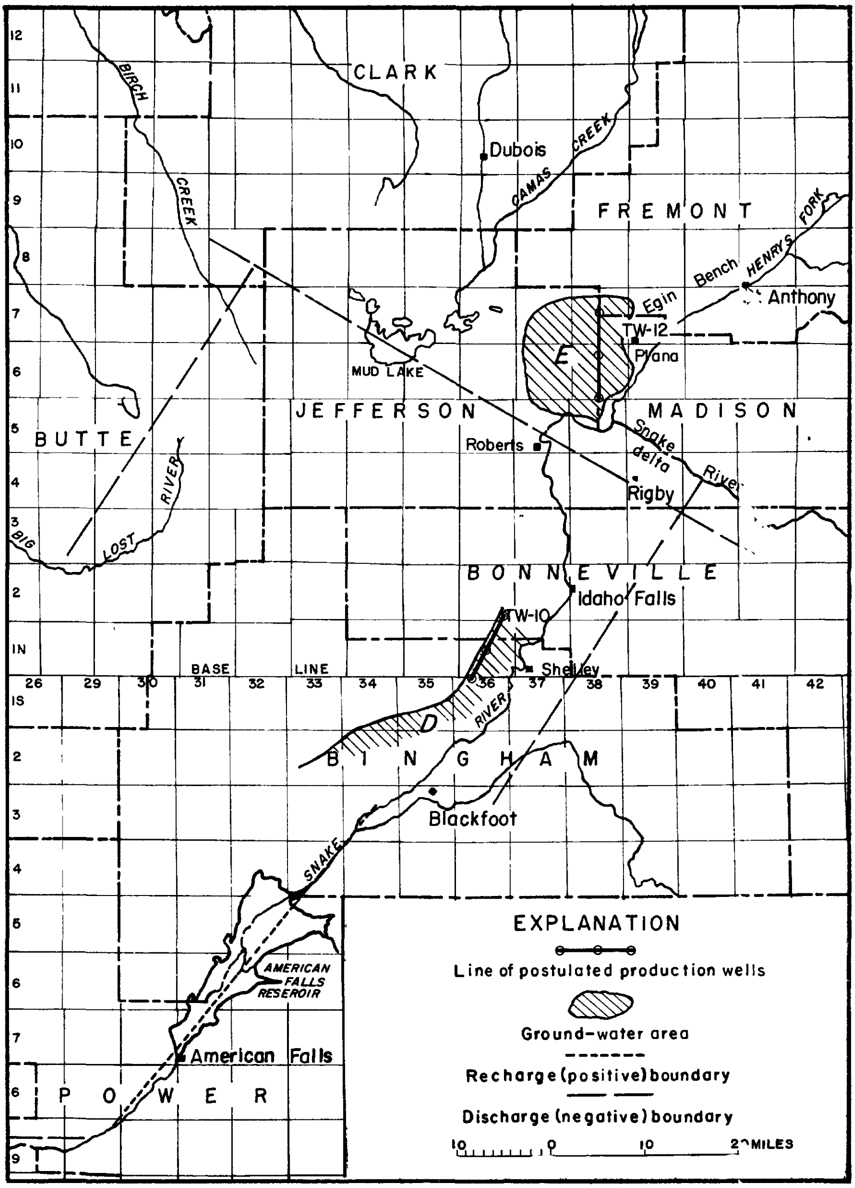

FIGURE 54.—Sketch map of the Idaho Falls (*D*) and Roberts-Plano (*E*) areas showing geohydrologic boundaries and lines of postulated wells.

feet and probably averages about 150 feet below the land surface. The negative boundary formed by the margin of the aquifer along its northwest flank is represented by a straight line, 45 miles from the center of pumping. The boundary formed by the discontinuity in water level between this area and the Mud Lake-Roberts area is represented by a straight-line boundary 22 miles to the northeast. The aquifer margin east of Shelley and Idaho Falls is a negative boundary. However, the perched water table and influent Snake River northeast of Idaho Falls may form a partial positive boundary. The Snake River and American Falls Reservoir, from Blackfoot to Lake Walcott, definitely represent a positive boundary. The effects of the actual boundaries are too complex for analysis without some simplification: it is assumed that the latter three boundaries (one negative, one positive and one partial positive) offset each other and leave the negative boundaries to the northwest and the northeast. The effects of these boundaries, which intersect at about 90°, can be computed by using three negative image wells, each discharging 112,500 gpm for 122 days a year. The distances to these image wells are 44, 90, and 100 miles. The locations of these image wells are not shown on figure 54.

The coefficient of transmissibility determined by the aquifer test at the site of Bureau of Reclamation test-well TW–10 (1N–36E–1cc1) was 1.5×10^7 gpd per foot. Plate 6 shows that the coefficient of transmissibility ranges from 10 to considerably more than 20 mgd per foot; a coefficient of 1.5×10^7 gpd per foot was used for the computations. The following table gives drawdowns computed for an infinite aquifer and the effects of the two negative boundaries.

Theoretical effects, in feet, of pumping in the Idaho Falls area (D)

	Wells			
	25, 26	15, 36	5, 46	1, 50
Drawdown at end of 1 cycle (after pumping 122 days):				
Caused by discharge from an infinite aquifer	4.4	4.25	3.75	3.35
Caused by discharging image wells	0	0	0	0
Total	4.4	4.25	3.75	3.35
Drawdown at end of 50 cycles (50 years of pumping 122 days a year):				
Caused by discharge from an infinite aquifer	5.9	5.75	5.25	4.85
Caused by discharging image wells	2.15	2.15	2.15	2.15
Total	8.05	7.9	7.4	7.0

ROBERTS-PLANO AREA (*E*)

The Roberts-Plano area lies between the Egin Bench and Roberts (fig. 54). The water table ranges generally between 40 and 150 feet below the surface. The average depth to water is probably less than 100 feet.

The coefficient of transmissibility determined from a test at the site of Bureau of Reclamation test-well TW-12 (7N-38E-23db1) ranged from 1.0×10^7 to 1.2×10^7 gpd per foot. However, because the transmissibility map (pl. 6) indicates a coefficient of more than 2×10^7 gpd per foot for most of the area, a coefficient of 1.5×10^7 gpd per foot (the same as was used for the Idaho Falls area) was used for computing theoretical drawdown.

The geohydrologic boundaries are shown on plate 4. The negative boundaries are formed by the margin of the aquifer. The discontinuity in the water table, as indicated by the steeper gradient in the vicinity of Mud Lake and Roberts may represent, in effect, a discharge area and therefore a positive boundary. In other places the steeper gradient may be caused by materials of low permeability. The perched aquifer in the Egin Bench-Snake River delta area and the Snake River, which also is perched, may represent partial positive boundaries.

The effects of the actual boundaries shown on plate 4 cannot be analyzed. The partial positive boundaries probably will offset to a considerable extent the effects of the negative boundaries. If they do, the drawdown caused by pumping in the Roberts-Plano area can be approximated by assuming an infinite aquifer for the computations. Theoretical drawdowns in selected wells in a line of 50 wells are given in the following table. Differences between the assumed and the actual effects of the geohydrologic boundaries may cause appreciable differences between computed and actual drawdowns.

Theoretical effects, in feet, of pumping in the Roberts-Plano area (E)

	Wells			
	25, 26	15, 36	5, 46	1, 50
Drawdown at end of 1 cycle (after pumping 122 days):				
Caused by discharge from an infinite aquifer	4.4	4.25	3.75	3.35
Caused by discharging and recharging image wells	0	0	0	0
Total	4.4	4.25	3.75	3.35
Drawdown at end of 50 cycles (50 years of pumping 122 days a year):				
Caused by discharge from an infinite aquifer	5.9	5.75	5.25	4.85
Caused by discharging and recharging image wells	0	0	0	0
Total	5.9	5.75	5.25	4.85

SUMMARY

The drawdown in a well is approximately inversely proportional to the coefficient of transmissibility; an error in the coefficient will result in an error in computed drawdowns. If the actual coefficient is only half as great as that used in the computations, the drawdowns will be nearly twice those computed. An error in the coefficient of storage will cause much less error in computed drawdowns. An error by a factor of 10 (that is, if S were 0.005 instead of 0.05) would increase the drawdowns by perhaps 20 to 30 percent.

Doubling the amount of water withdrawn from an area, either by doubling the discharge of each well or by spacing the wells 500 feet apart and doubling the number of wells, will approximately double the computed drawdowns. The drawdown in the aquifer at any point adjacent to the line of wells depends on the distance from the line and the location with respect to the center of the line. At any considerable distance, as for example 1 mile from the center (at right angles), the drawdown would be appreciably less; if two parallel lines of 50 wells were constructed 1 mile apart, the total drawdown in each well would be somewhat less (perhaps a foot or two less) than twice the drawdown computed for a single line. Well loss generally averaging about 1 foot must be added to the drawdowns. An occasional well may have several feet of well loss.

The effects of pumping in five areas have been considered individually, and no allowance was made for mutual interference between areas. The Roberts-Plano area is presumed to be separated from the other areas by a geohydrologic boundary; inasmuch as the other areas are downgradient, pumping from them could not affect the water levels in the Roberts-Plano area. Pumping in the Roberts-Plano area, however, would reduce underflow in the Snake Plain aquifer to some extent and thus would eventually affect water levels in areas downgradient.

The Idaho Falls area is more than 100 miles from the three areas at the western end of the Snake River Plain. Pumping 50 wells near Idaho Falls under the assumed conditions would cause a drawdown of about 0.5 foot in the western end of the aquifer after 50 years, and pumping in each of the three areas at the western end of the Plain would cause about 0.5 foot drawdown in the Idaho Falls area.

Theoretical drawdowns caused by pumping 50 wells at a rate of 2,250 gpm each for 122 days a year for 50 years in the five areas are summarized in the following table:

Area pumped	Drawdown (feet) in area—				
	A (Wendell)	*B* (Shoshone-Dietrich)	*C* (Eden)	*D* (Idaho Falls)	*E* (Roberts-Plano)
A	7.2–10.5	2.5	3.0	0.5	0
B	2.5	10.0–13.3	3.5	.5	0
C	3.0	3.5	10–13	.5	0
D	.5	.5	.5	7–8	0
E	Small	Small	Small	Small	5–6

The table can be used to compute the theoretical drawdown in any of the areas caused by pumping in any combination of areas.

QUALITY OF GROUND WATER

Many chemical analyses of ground water from the Snake Plain aquifer, made by the Geological Survey and the Bureau of Reclamation, are on file in the offices of the Geological Survey. Eight analyses that probably are representative are given in table 14. Six are from wells and two are from springs. These analyses indicate that the chemical character of water from the aquifer is rather uniform. The water is chiefly a calcium magnesium bicarbonate water with moderate amounts of sodium and sulfate. Two of the analyses, those from well 1S–36E–18dd1 and from Blue Lake Spring, have somewhat greater hardness and higher content of dissolved solids, sulfate, and chloride than the others. Probably a higher percentage of the surface water used for irrigation percolates to the aquifer near the sources from which these two samples were taken.

The water represented by the eight analyses is of good chemical quality by most standards and is entirely suitable for irrigation.

ARTIFICIAL RECHARGE

Artificial recharge is a planned addition of water to an aquifer to add to the supply of ground water in storage, so that more water than otherwise would have been available can be withdrawn at some future date, or so that the same amount of water can be withdrawn with less pumping lift. To be effective, recharge must be with water that otherwise would not have reached the aquifer or that would have reached it at some other place, where the recharge would have been ineffective or less effective. In one sense, recharge caused by irrigation with surface water diverted to an area is artificial recharge; however, as the primary objective is the raising of crops—not building up the water table—it generally is not regarded as artificial recharge.

To be effective, artificial recharge must increase the amount of water in storage by causing a rise in the water table. In most aquifers the water is moving from the areas of recharge to the areas of discharge. When the water table is raised in an area of recharge, the gradient towards the discharge area is increased, and the water moves more rapidly toward the discharge area. Thus, water placed in storage underground cannot be held indefinitely; it is a transient resource, and the sooner it is used the larger is the percentage of the stored water that can be recovered. Some of the factors affecting, and the

TABLE 14.—*Chemical analyses of ground water from the Snake Plain aquifer*

[Chemical constituents in parts per million]

Constituent or property	Well						Spring(s)	
	6N-40E-30bd1	5N-37E-8cc1	5N-33E-10cd1	1N-29E-30bb1	1S-36E-18dd1	6N-24E-35ca1	Blue Lake	Thousand
Silica (SiO^{2})	26	48	37	24	27	31	41	33
Iron (Fe) (total)	[1] .04	.38	.05	1.2	[1] .03	.25	.02	.06
Calcium (Ca)	53	45	36	38	71	33	54	36
Magnesium (Mg)	16	11	13	13	18	13	19	18
Sodium (Na)	8.3	18	14	6.9	36	17	35	25
Potassium (K)	2.4	5.8	3.3	2.6	4.2	3.2	6.5	3.5
Bicarbonate (HCO^{3})	235	191	169	162	258	152	214	182
Sulfate (SO^{4})	10	29	24	21	55	29	52	37
Chloride (Cl)	6.5	12	10	8.8	40	13	41	20
Fluoride (F)	.3	1.1	.6	.3	.7	.7	.4	.7
Nitrate (NO^{3})	3.9	.3	1.3	.8	5.1	1.5	3.7	2.7
Phosphate (PO^{4})	.15	.20	------	------	.05	------	.08	------
Boron (B)	------	------	.08	.02	------	.06	.23	.08
Dissolved solids	232	259	220	199	406	215	362	266
Hardness (total)	198	158	143	148	252	136	214	164
Percent sodium	8	19	17	9	23	21	30	24
pH	7.8	8.1	7.9	7.9	7.9	8.2	7.7	7.8
Specific conductance ... micromhos at 25°C	394	390	344	314	629	337	583	412
Date of collection	8-27-57	7-22-57	7-11-53	9-12-50	7-23-57	6-23-53	5-18-58	3-23-53
Temperature ... °F	53.5	48	60	53	50	58	60	58

[1] In solution, at time of analysis.

way in which they generally affect, the recovery of recharged water are listed below.

Factor	*More water recovered*	*Less water recovered*
Length of time stored	Short	Long
Transmissibility of aquifer	Low	High
Storage coefficient	High	Low
Hydraulic gradient	Low	High

In some respects, the Snake Plain aquifer is ideally suited for artificial-recharging operations. At many places, the irregular broken surface of the lava takes water readily, and large fractures and other openings permit rapid percolation of water to the water table. A large storage space is available; a water-level rise of 10 feet over the entire area of the aquifer would represent an increase of perhaps 5 million acre-feet of water in storage. Because of the great coefficient of transmissibility of the aquifer, the recharge mound will spread rapidly, and large amounts of water can be recharged at one place without raising the water table to excessive heights.

At places where silt and fine sand overlie the basalt, the infiltration capacity is substantially less, and larger pond areas would be required for water spreading. In such areas, however, large volumes of water could be recharged through wells during the time that surplus water is available.

No comprehensive study has been made of recharge possibilities in the Snake River basin. The following paragraphs merely present some of the possibilities and problems involved. Detailed study and analysis is a necessary prerequisite to planning a recharge system or systems.

SOURCES OF RECHARGE WATER AND QUANTITIES AVAILABLE

The chief sources of water for recharging are surplus flows in the Snake River and Henrys Fork. Other possible sources include the Malad (the Big Wood River, the Little Wood River, and Silver Creek), Portneuf, and Blackfoot Rivers.

A study of the discharge of the Snake River during the period 1927–53 was made by the Bureau of Reclamation (study U.S. 55–1, 1–8–57). Spills past Milner, the last downstream major diversion point, during that period were calculated; all presently operating reservoirs were assumed to have been in operation during the period. The study showed that in 14 of the 26 years the spill past Milner Dam would have exceeded 700,000 acre-feet and that in 11 of the 26 years the spill would have exceeded 1.5 million acre-feet. In 11 of the 26 years, substantial spills (more than 80,000 acre-feet per month) occurred in at least 6 months of each year, and, in 2 other years 80,000 acre-feet or more spilled at least 4 months of the year. If it is assumed that no great amount of additional surface storage will be constructed and that historic streamflows are representative of future flows, a recharge system or systems having a capacity of 100,000 acre-feet per month could recharge more than 500,000 acre-feet of water in about half the years. In some years, as much as 900,000 acre-feet of water could be recharged. Recharge systems of larger capacity could recharge greater amounts of water, but the number of months they could operate at capacity would be less.

Although substantial quantities of water were available for recharge in about half the years of the base period, these years are not evenly distributed through the period. During the 7-year period 1930–37, no water spilled at Milner, and during the 13-year period 1929–42, substantial spill occurred in only 1 year. On the other hand, during the 11-year interval 1942–53, the minimum spill in any year was 965,000 acre-feet. Thus, there will certainly be long periods when no water is available for recharging and other long periods when ample water is available. Design of any recharge and recovery system must take into account the erratic time-distribution of surplus streamflows that would be available for recharging.

EFFECTS OF RECHARGING ON THE HYDRAULIC SYSTEM

Even though the Snake Plain aquifer has a high transmissibility, recharge of 100,000 acre-feet of water a month distributed over an area of several townships would be required to prevent an unduly great buildup of the water table at any one point. After recharging ceased, the water table would decline rather rapidly, and, at the beginning of the next recharge season, the residual buildup of the water table would be small. The water contributing to the increase in storage would occupy a wide area. The distance any particle of recharged water would move in 1 year would be short; computations and observations on rates of movement of water in the Snake Plain aquifer indicate that the rate of movement probably ranges from a few feet to a few tens of feet per day and probably is generally less than 1 mile per year. On the other hand, computations and correlation of water levels with application of irrigation water indicate that the ground-water mound caused by recharging may spread 25 miles in a few months. Recharging in an area a few tens of square miles would result in an increase in storage in an area of several thousand square miles by the end of one recharge cycle.

Where the recharge area is within a few tens of miles of the discharge area, discharge will increase within a few months; water can be stored for several years only if the recharge areas are remote from the points of discharge. For these reasons, it is desirable that recharge areas would be located in the northeastern (upgradient) part of the Snake Plain aquifer.

AREAS SUITABLE FOR RECHARGING

The Snake Plain aquifer is almost entirely north of the Snake River, and most of the areas suitable for recharging also are north of the river. If the water to be used in recharging is to be transported by gravity, the potential recharge areas are limited to lands lower in altitude than the highest practicable diversion from Henrys Fork or the Snake River. Henrys Fork enters the Snake River at an altitude of just under 4,800 feet. Water farther upstream on the Snake could be diverted through a cross canal to Henrys Fork. There would be sufficient flow in Henrys Fork, during the periods that surplus water would be available for recharging, so that a large part of the total available recharge water could be taken from that river. The altitude of the highest feasible diversion point on Henrys Fork would limit the altitude of potential recharge sites. There are feasible diversion points on Henrys Fork upstream from St. Anthony at altitudes exceeding 5,000 feet.

In the northeastern (upgradient) end of the Snake Plain aquifer, the central part of the plain is higher than the flanks, and terrain below 5,000 feet is confined to a strip along the southeast flank adjacent to the Snake River and Henrys Fork and to an area including Mud Lake and the mouths of Birch Creek and Little Lost Rivers.

One of the more favorable areas for recharge is west of the Egin Bench and north of the Menan Buttes. The area extends westward between Roberts and Mud Lake and is almost wholly below an altitude of 5,000 feet. There are numerous closed depressions and other areas that could be closed with a small amount of construction. Basalt is at or near the land surface throughout several townships, and its upper part is greatly fractured and broken. Some of the fractures formed in pressure ridges are large. Much of the basalt is cover by windblown sand and silt that have partly clogged the openings in the basalt and greatly reduced its infiltration capacity, but this area probably is well suited for recharge operations, either by water-spreading or by a combination of injections wells and water-spreading.

A second area that appears to be very suitable for artificial-recharging operations lies southwest of Idaho Falls. Basalt is at the surface over several hundred square miles. Because of a sag in the topography between this area and the terrain to the east, it probably would not be feasible to bring water to it at an altitude of more than 4,800 feet. About 80 square miles of the area is below an altitude of 4,800 feet. The basalt surface is extremely rugged and broken, and closed or nearly closed depressions are numerous. Little windblown material overlies the basalt, and the infiltration capacity of the basalt undoubtedly is extremely high. The only disadvantage of this area is that, according to the flow net (pl. 4), ground water moves directly toward and discharges into the American Falls Reservoir. Because this possible recharge area is only 30 to 40 miles from the reservoir, some of the water recharged during several consecutive wet years might discharge into the reservoir before, in the ensuing dry period, it could be recovered by pumping from wells.

A third area that would be suitable for recharging operations lies north and northwest of the American Falls Reservoir. Basalt is at the surface at altitudes below 4,800 feet over about 150 square miles. This area is also close to a discharging area of the aquifer (American Falls Reservoir) ; if recharging were to continue for several consecutive years, discharge into the reservoir would increase and not all the recharged water would represent a gain in storage.

Other areas probably are suitable and practical for artificial recharge. Studies may show that artificial recharge at some places would be more economical than construction of surface reservoirs.

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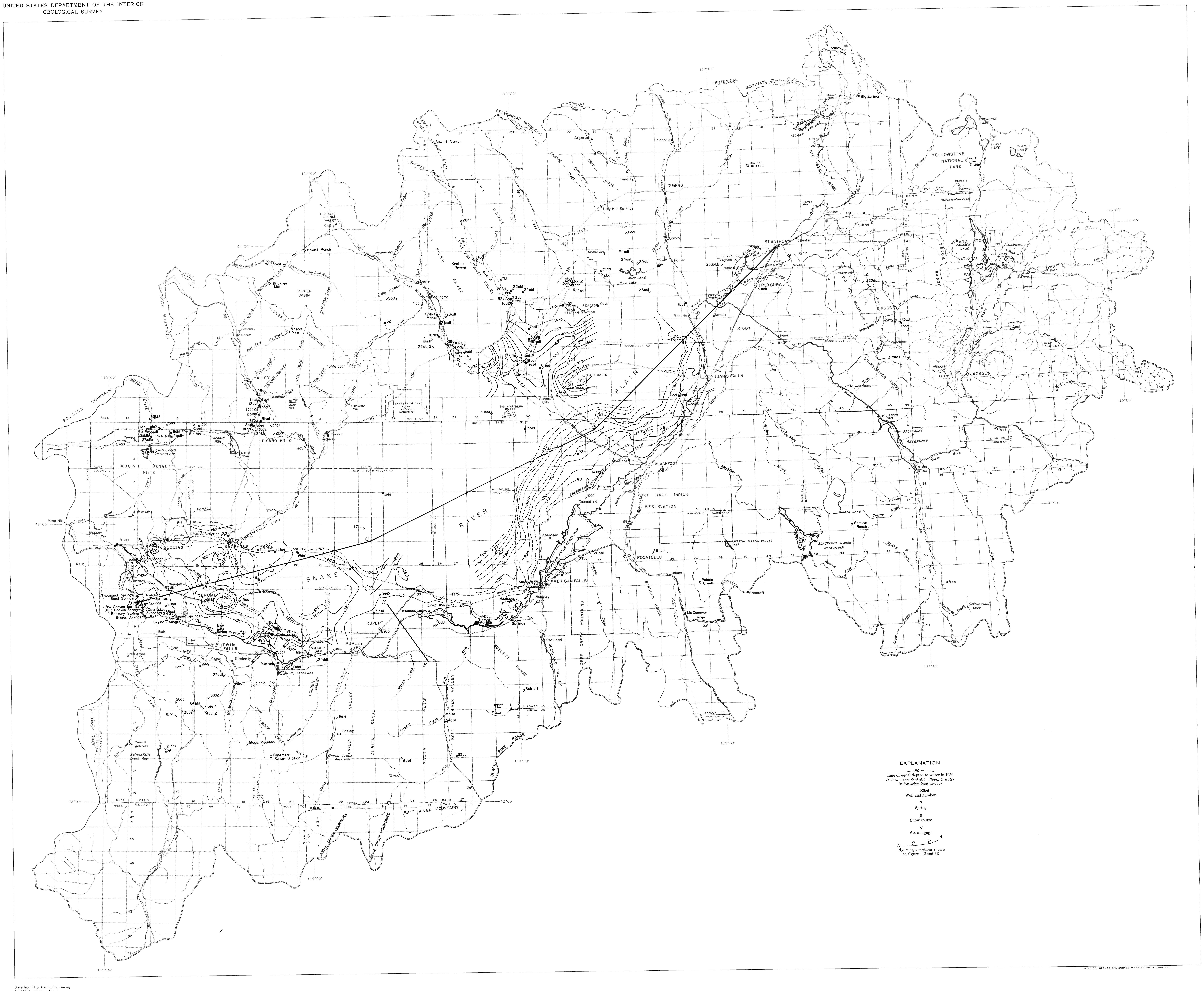
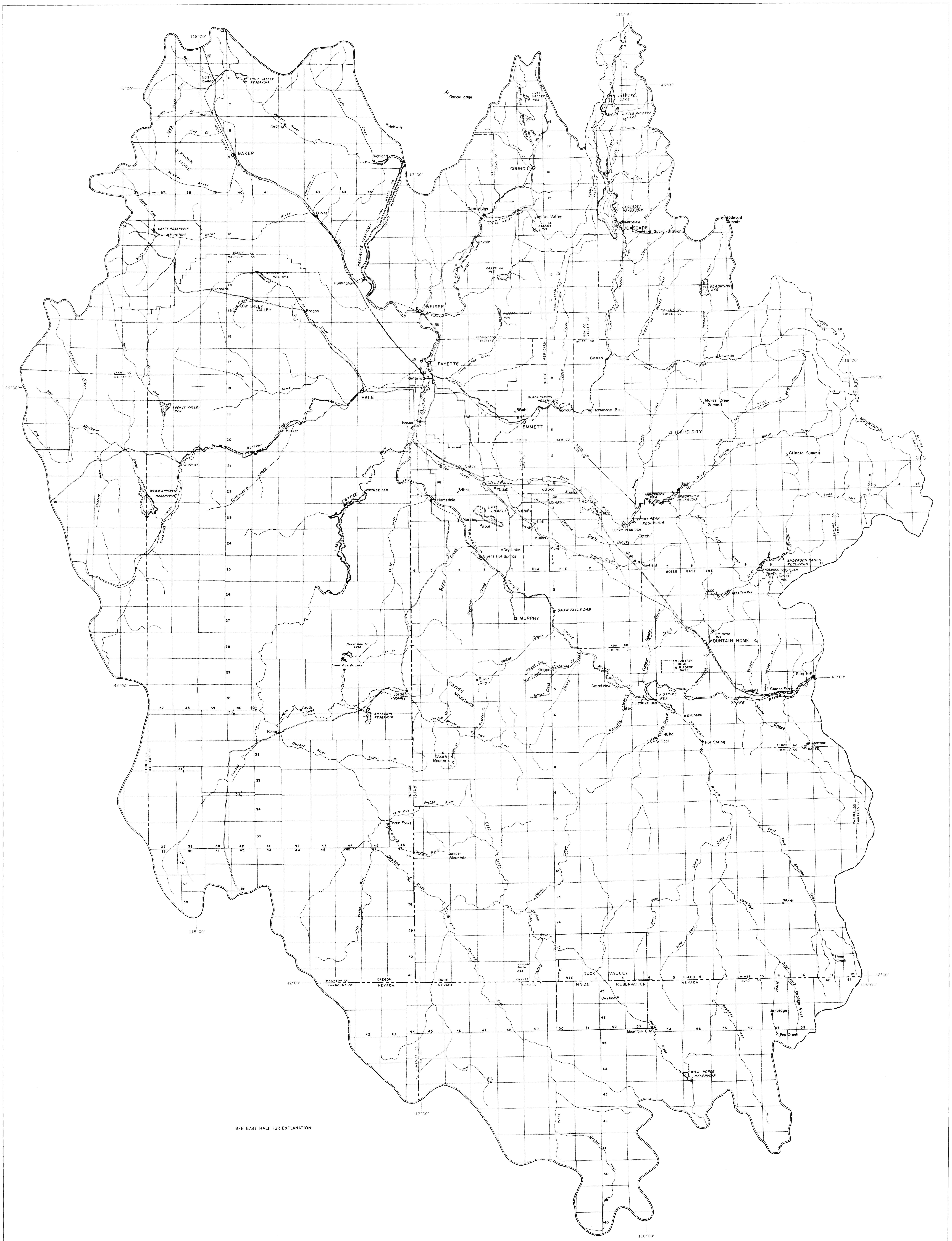


MAP OF THE SNAKE RIVER BASIN (EAST HALF) IDAHO, SHOWING HYDROLOGIC FEATURES

5 0 5 10 15 20 MILES



Base from U.S. Geological Survey
250,000 series quadrangles

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MAP OF THE SNAKE RIVER BASIN (WEST HALF) IDAHO, SHOWING HYDROLOGIC FEATURES

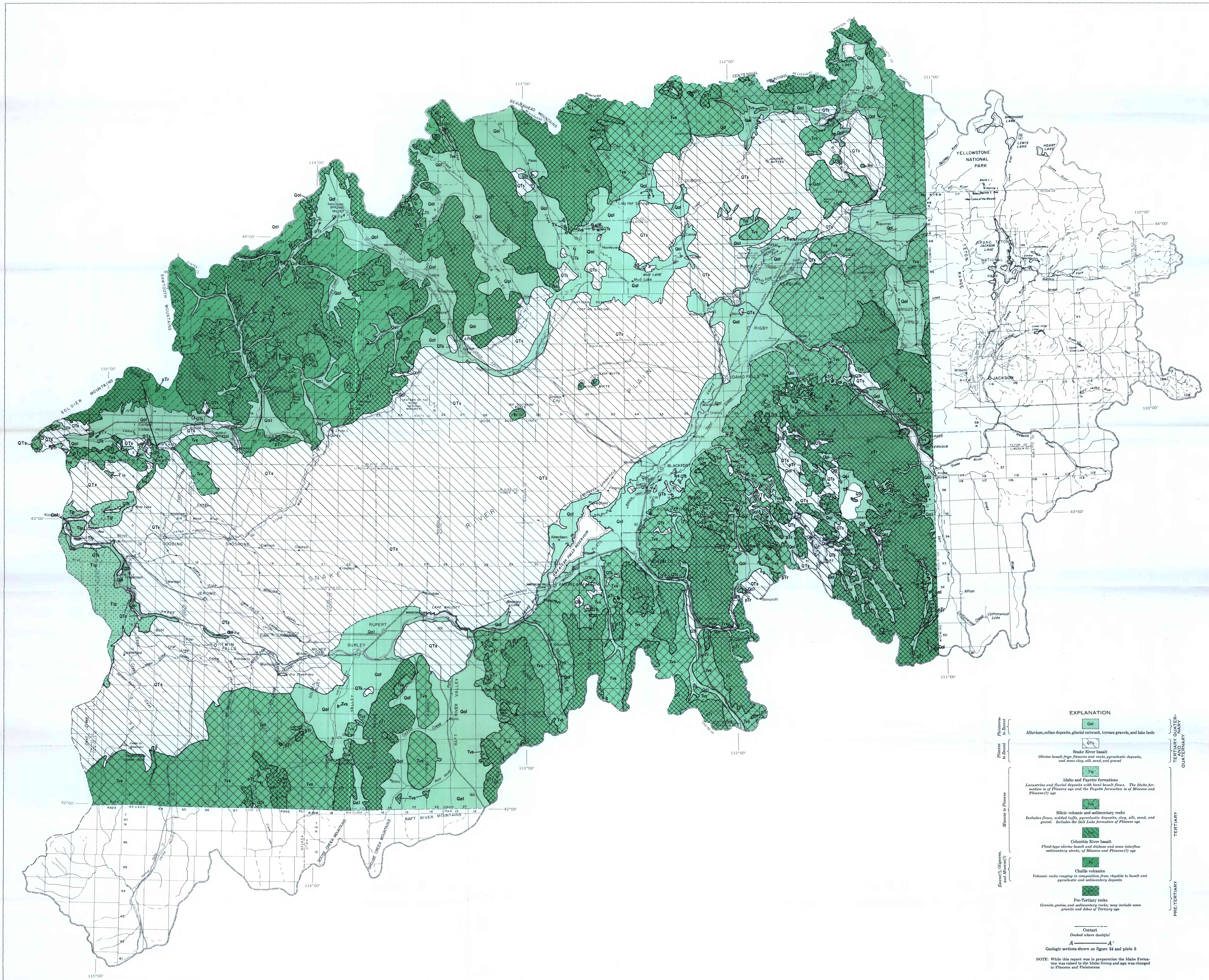
5 0 5 10 15 20 MILES

Base adapted from U.S. Corps of Engineers map

ISOHYETAL MAP OF THE SNAKE RIVER BASIN, IDAHO

10 0 10 20 30 40 MILES

690-440 O - 64



Base from U.S. Geological Survey 250,000 series quadrangles

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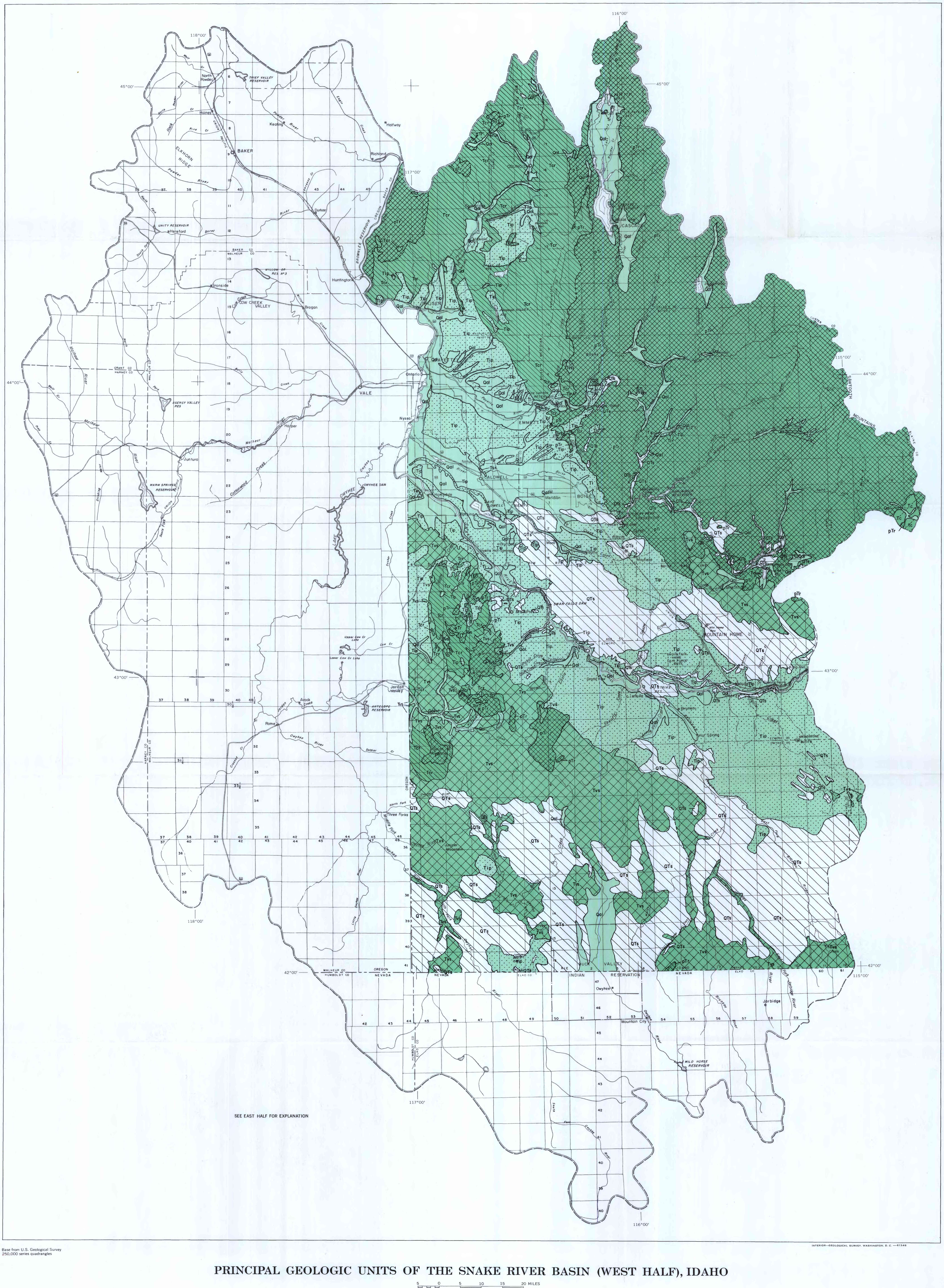
PRINCIPAL GEOLOGIC UNITS OF THE SNAKE RIVER BASIN (EAST HALF), IDAHO

5 0 5 10 15 20 MILES

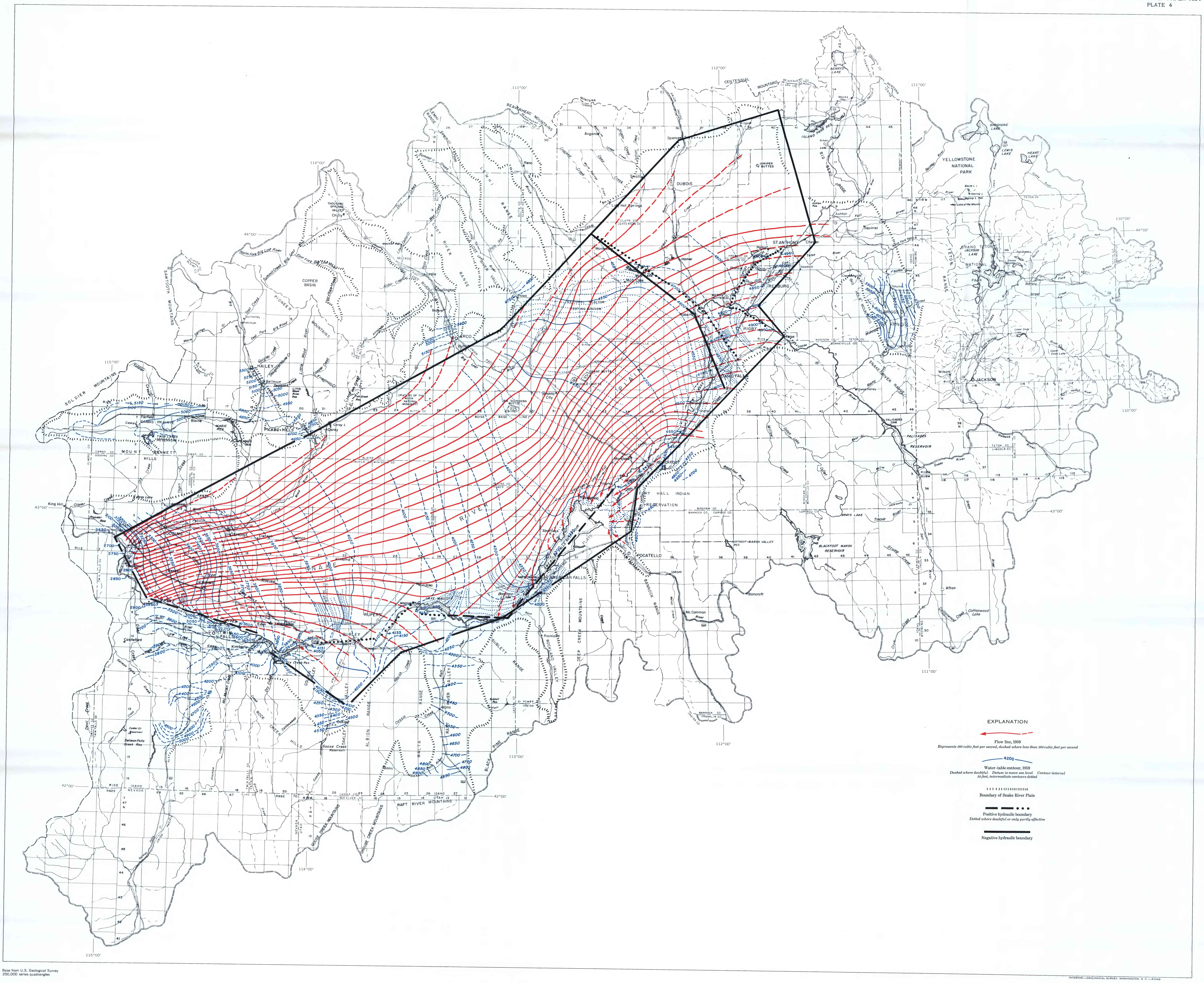


Base from U.S. Geological Survey
250,000 series quadrangles

PRINCIPAL GEOLOGIC UNITS OF THE SNAKE RIVER BASIN (WEST HALF), IDAHO

5 0 5 10 15 20 MILES

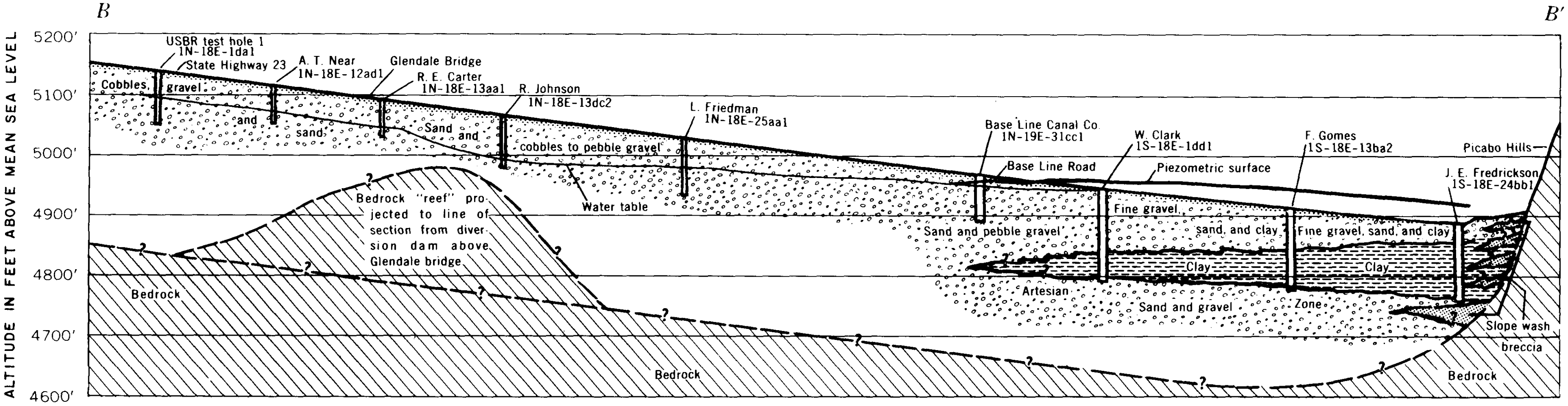
INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—67346



Base from U.S. Geological Survey 250,000 series quadrangles

CONTOURS ON THE WATER TABLE AND FLOW NET OF THE SNAKE PLAIN AQUIFER, IDAHO

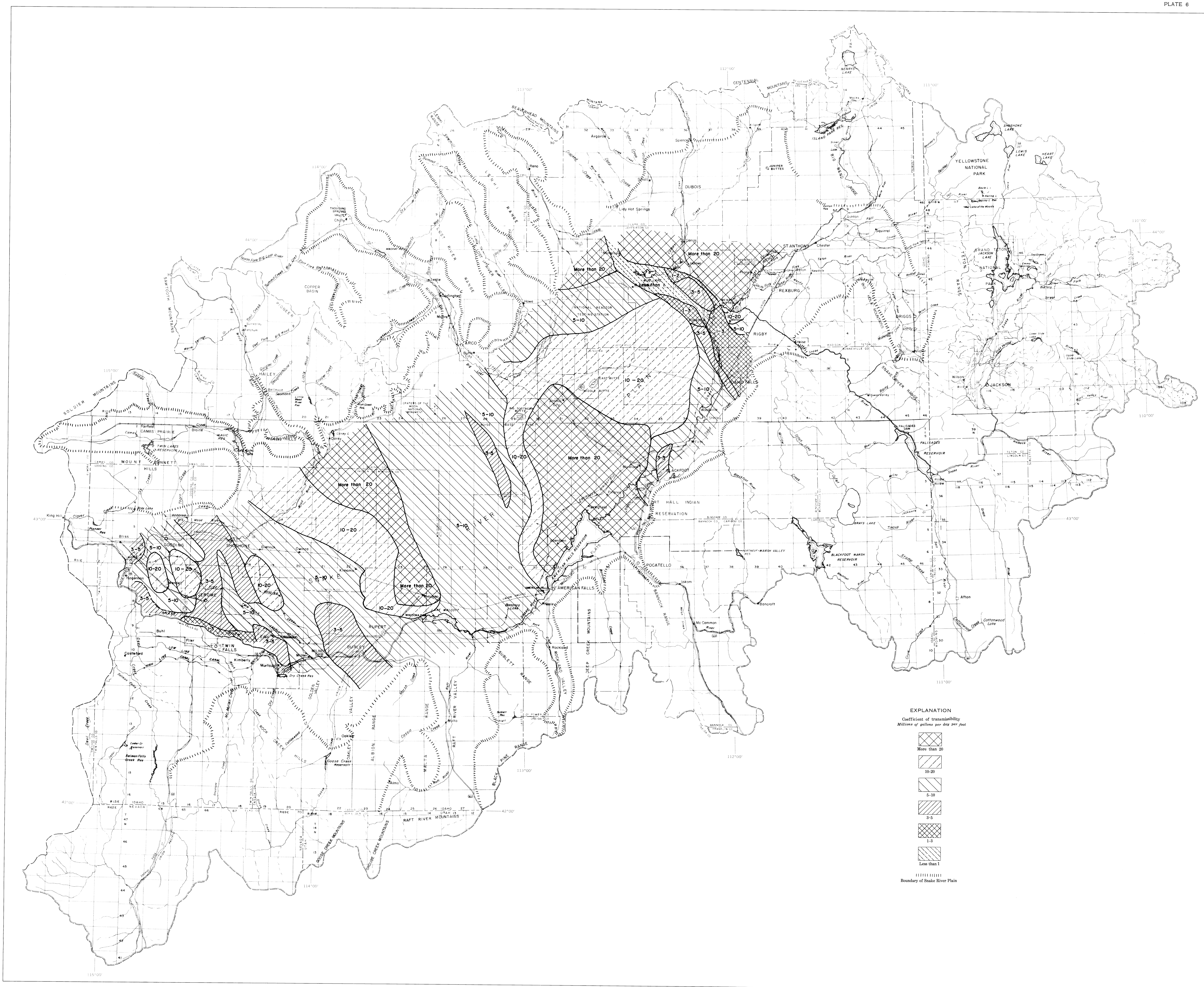
5 0 5 10 15 20 MILES



GENERALIZED GEOLOGIC SECTION B–B′ (PL. 3) SHOWING POSITION OF WATER TABLE AND PIEZOMETRIC SURFACE, AUGUST 1954 (FROM SMITH, 1959)

1 0 1 MILE

690-440 O - 64



Base from U.S. Geological Survey
250,000 series quadrangles

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—61346

MAP SHOWING COEFFICIENT OF TRANSMISSIBILITY OF THE SNAKE PLAIN AQUIFER, IDAHO

5 0 5 10 15 20 MILES