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GROUND WATER BRANCH

FEASIBILITY OF ARTIFICIAL RECHARGE IN THE SNAKE RIVER BASIN, IDAHO

By

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Prepared in cooperation with the

U. S. Bureau of Reclamation

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Abstract

The Snake Plain aquifer is an important element in the water resources of the Snake River basin. About 800,000 acre-feet of water is available from each foot of saturated thickness of the aquifer. The coefficient of transmissibility ranges generally from 1 to 60 million gallons a day per foot.

Irrigation began on the Snake River Plain in the 1880's, with water diverted from Snake River and its tributaries. Since that time recharge from irrigation has resulted in a rise in the water table of roughly 60 to 70 feet. Coincidently with the rise in water level, total underflow in the aquifer increased from about 5,200-5,500 c.f.s. to about 9,000 c.f.s. by 1950. The aquifer discharges into the Snake River, chiefly in two reaches, the American Falls Reservoir reach and the Hagerman Valley reach.

Since 1950 far more land has been developed with ground water than with surface water, so that the trend of the water table has been reversed. Declines ranging from 1 to 12 feet between 1950 and 1960 are general over the plain.

With the increasing scarcity of favorable sites for surface storage, and the general downward trend of the water table during the past 8 or 10 years, artificial recharge has become increasingly attractive.

Surplus flood-waters are available in many years from the Snake River, Henrys Fork, and some other streams. The bare, rough, porous basalt is favorable for recharge by water spreading in many places. However, most of the central part of the plain is too high to be reached by any feasible route from the rivers. Thus, favorable areas are restricted generally to a belt of terrain between the alluvial valley of the Snake River, which is farmed, and the higher basalt surfaces to the northwest of the alluvial valley. Much of this land is public domain.

Three areas were studied in some detail. All are underlain by basalt with varying amounts of windblown sand and silt overburden.

The area between Roberts and Plano is near the eastern end of the plain. Large areas of land at a suitable altitude are available. However, the silty and sandy overburden has partially filled crevices and other openings in the basalt, thus reducing the intake capacity.

A second area is a few miles west of Idaho Falls where there are 50 to 75 square miles of bare, very rough basalt at a suitable altitude. At some places silty interbeds underlying the uppermost basalt flows

will cause perched water tables, and may spread the recharged water rather widely before it percolates downward to the main water table. In this same general area recharge might also be accomplished by diversion of water into gravel pits adjacent to the river.

A third area is along the Milner-Gooding Canal between Milner and Shoshone. Considerable areas of rough basalt with little overburden are adjacent to the canal where they could be reached by diversion from the canal. There apparently are no extensive interbeds in this area, although lenses of silt might cause local perching.

The effectiveness of recharge is demonstrated by more than 60 years of recharge from irrigation, amounting to roughly $3\frac{1}{2}$ million acre-feet a year, several times the amount of water available for artificial recharge. Artificial recharge will not reverse the downward trend in the water table, because not enough water is available to offset the increasing demands for irrigation from ground water. However, recharge of a million acre-feet will permit pumpage of 2 million acre-feet additional water (assuming 50 percent consumptive use) without any additional decline in the water table.

Introduction

The Snake River basin, upstream from Bliss, Idaho (fig. 1) includes an area of nearly 36,000 square miles of which about 29,000 square miles is in southeastern Idaho. The population of the area within Idaho is about 275,000, which is about 41 percent of the population of the State. Nearly 2 million acres or about two-thirds of the total irrigated acreage in the State is in the area; also, most industry is based on agriculture, and as a result the economy of the area is closely related to irrigation.

Most of the more easily developed sources of surface water are fully utilized, and development of additional supplies are possible only by means of expensive storage facilities. As surface-water supplies have become more difficult to obtain, use of ground water has increased greatly. The acreage irrigated with ground water has increased from less than 100,000 acres in 1945 to more than 600,000 acres in 1960.

The two largest components of outflow from the basin are ground-water discharge from the Snake Plain aquifer between Twin Falls and Bliss, averaging about 4,700,000 acre-feet per year, and flood flows in the Snake River averaging perhaps 750,000 acre-feet per year. With rapidly increasing development of ground water and the consequent decline in the water table, and with surface-storage sites becoming more costly, underground storage by means of artificial recharge becomes increasingly attractive.

Artificial recharge may be defined as a planned addition of water to an aquifer to increase the supply of ground water in storage so that, (1) more water can be withdrawn at some future date than otherwise would have been available or (2) 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 less advantageous. Although recharge incidental to irrigation with surface water diverted to an area may be very beneficial to the ground-water supply, such recharge generally is not regarded as artificial recharge because the primary objective is to raise crops, rather than to build up the water table. This type of incidental recharge has increased the ground-water supply of the Snake River basin very greatly during the past 80 years.

Purpose and scope of investigation

The investigation was undertaken by the U. S. Geological Survey at the request of the U. S. Bureau of Reclamation and is a part of their continuing study and appraisal of the water resources and potential for irrigation in the Snake River basin. The investigation by the Geological Survey included study of geology and ground-water hydrology as related to possibilities for artificial recharge in the Snake River basin east of Bliss, and especially to possible artificial recharge of the Snake Plain aquifer. This study is an offshoot of an earlier investigation, by the Geological Survey, in cooperation with the Bureau of Reclamation, which culminated in a report on ground water in the Snake River basin (Mundorff and others, 1960).

The specific objectives of this investigation were to identify areas and aquifers that might effectively be recharged, to describe the geologic and hydrologic features that would control recharge in the Snake River basin in general, and at the potential recharge sites in particular, and to evaluate the effects of artificial recharging on the hydrologic regimen of the basin.

The author was assisted in the field by Chabot Kilburn, R. C. Luscombe, and Sheldon Cordes. Field work began in July 1959, and was completed in July 1961. Field work included collection of pertinent data on wells, collection of sand and silt samples for laboratory analysis, and geologic mapping. Four test holes were drilled to provide stratigraphic and ground-water data. Recharge experiments were conducted at three locations by the Bureau of Reclamation during the period April-July 1961. Technical assistance was given by the Geological Survey, and the results of the experiments are evaluated in this report.

A large amount of data collected in previous investigations was used in the study, and records of irrigation districts and canal companies were also utilized.

Previous investigations

Although many persons have commented on the possibilities of artificial recharge in the Snake River basin, no specific study had previously been made. However, a number of ground-water reports on the area provided information which was utilized in preparation of this report.

The most important previous studies in the area were those by Stearns, Crandall, and Steward (1938); Stearns, Bryan, and Crandall (1939); Nace, Stewart, and Walton (1959); and Mundorff, Crosthwaite, and Kilburn (1960). The last cited report contains a complete list of investigations and reports on ground water in the Snake River basin through 1959.

Acknowledgments

Well owners, drillers, and pump companies gave information on wells and water levels. Data were obtained from the files of the U.S. Bureau of Reclamation, the Idaho Department of Reclamation, and irrigation districts and canal companies. Their cooperation is gratefully acknowledged.

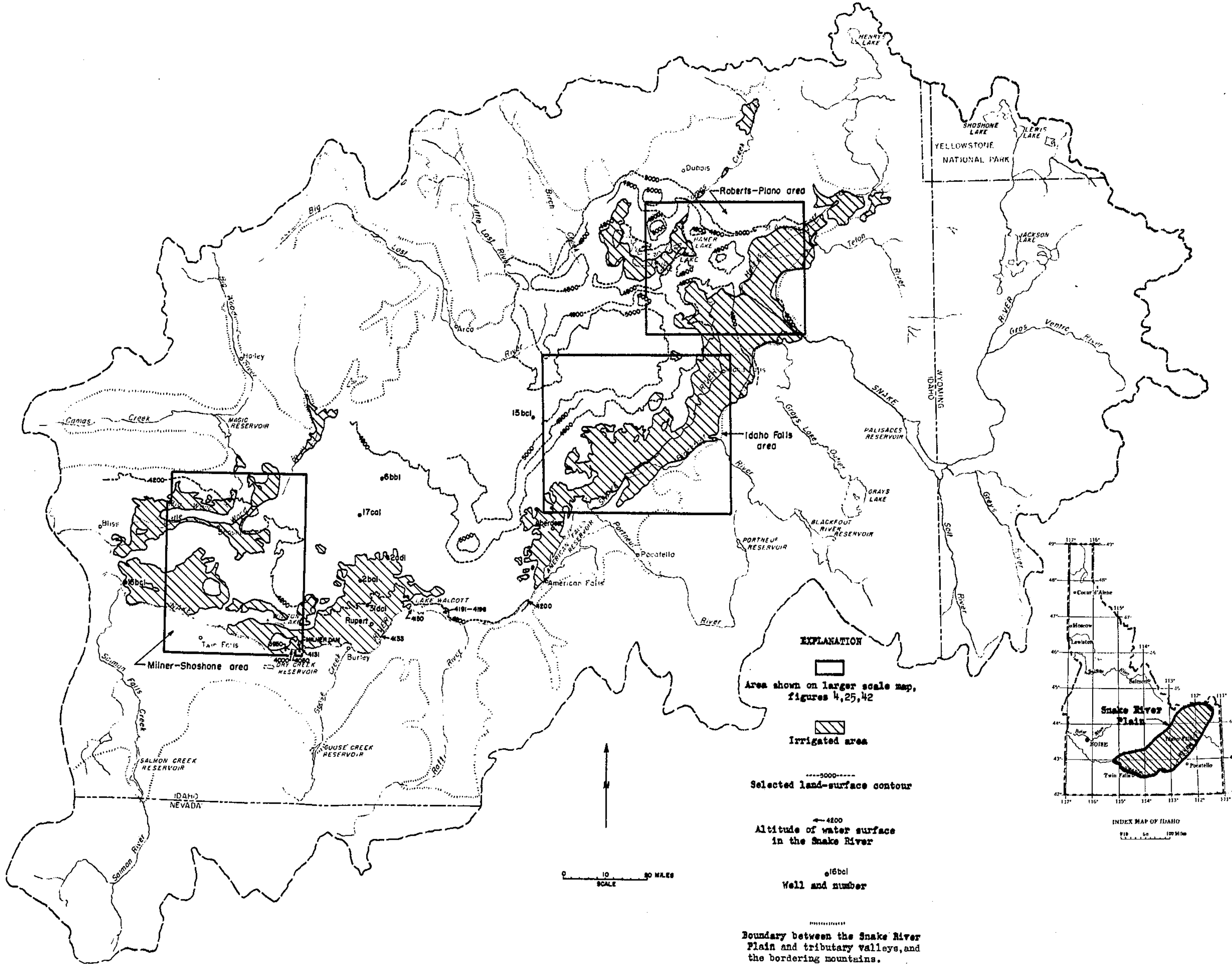

Figure 1.—Index map and map of Snake River basin showing irrigated areas and selected land-surface contours.

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. The third segment gives the section number, followed by two letters and a numeral, which indicate the quarter section, the 40-acre tract, and 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. 2). Within the quarter sections 40-acre tracts are lettered in the same manner. Well 8S-16E-12bc1 is in the SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 12, T. 8 S., R. 16 E. and is the well first visited in that tract.

Physical setting

The Snake River basin upstream from Bliss (hereafter referred to as the Snake River basin) consists of the broad central Snake River Plain, and the flanking mountain ranges (figs. 1 and 3).

The Snake River Plain averages nearly 60 miles in width and extends from Bliss northeastward approximately to Ashton, a distance of about 200 miles. The surface of the plain slopes southwestward, from an altitude of more than 6,000 feet north of Ashton, to about 3,200 feet near Bliss. The plain is underlain by a thick sequence of basaltic lava flows and sedimentary interbeds. The surface of the lava flows appears monotonously flat from a distant view but closer observation reveals a variety of land forms and a diversity of geologic features. Broad swells and domes mark some centers of volcanism; craters and cinders, at places alined along great rift zones mark others. Some of the earlier lava flows are covered with a mantle of windblown sand and silt, and in some depressions sedimentary deposits accumulated in playas. The more recent flows are virtually bare and the ropy pahoehoe lava forms flat table- and ramp-like surfaces extending for hundreds of yards. At other places the rough blocky aa forms an exceedingly jumbled and jagged mass. Large lava caves and tubes are found at a few places, and pressure ridges and collapsed lava tubes are common features. One striking feature of the surface of some lava flows are the millions of small round pits commonly 5 to 10 feet in diameter that dot the surface in some areas, and appear from a distance like the surface of a fine textured synthetic sponge. The pressure ridges, collapsed tubes, and pits are all greatly fractured, especially around their peripheries, and many of the fractures gape widely.

Bordering the Snake River Plain on its northwestern and southeastern flanks are a series of subparallel mountain ranges and intervening valleys. The mountain ranges on the northwest flank of the plain rise to altitudes of 11,000 to 12,000 feet; those on the southeast to altitudes of 7,000 to 10,000 feet. The rocks in the mountains are chiefly older consolidated rocks including granite, quartzite, limestone, shale, sandstone, and silicic and basaltic rocks. In general these have been folded and faulted into a series of northwestward trending ranges with intervening structural valleys. The surficial expression of these structures terminates abruptly at the margin of the Snake River Plain which crosses them at approximately a right angle. The older rocks were faulted and warped downward to form a basin in which the basalt flows and associated sedimentary beds of the Snake River Plain accumulated. The thickness of the fill in this broad basin beneath the Snake River Plain is not known; geophysical evidence suggests that the basin is more than 5,000 feet deep. No wells more than a mile or two from the margin of the plain have penetrated deeply enough to reach the underlying bedrock. The deepest well which is in Idaho Falls, is 1910 feet deep.

The structural valleys between the mountain ranges flanking the plain are broad, alluvial filled basins which merge with the Snake River Plain at its margin. Many of these basins are as broad at their heads as at the mouth, and the streams draining them obviously have had little or no role in shaping the valleys. The fill in these valleys consists of alluvial-fan deposits, stream alluvium, basalt, and lake beds.

Climate and agricultural development

Precipitation on the plain and in the bordering valleys is generally less than 10 inches annually, thus irrigation is required for crops. Limited forage is available for sheep and cattle on the non-farmed lowlands but this generally lasts only for a short time in the spring. Some bench lands receive 10 to 15 inches of precipitation annually, sufficient for raising wheat, or moderately good pasture. Mountain areas receive up to an average of 50 inches of precipitation, and are used for grazing in the summer months. Much of the precipitation in the mountains occurs as snow.

The length of growing season varies with altitude and other factors, and ranges from less than 60 days in high valleys to more than 120 days at the western end of the plain.

The economy of the entire area is based largely upon irrigation agriculture. Not only do irrigated crops make up the major part of the crops raised, but also stock raising depends to a considerable extent upon hay and grain raised on irrigated farms, and the irrigated fields are used for winter pasture.

A great deal of the industry also is based on irrigation agriculture. Important industries include sugar manufacturing, potato and vegetable processing, meat packing, processing of dairy products and milling of grain. Thus, an adequate water supply for irrigation is of primary importance to the economy of the area.

The basin has far more arable land than can be irrigated even if the entire potential supply could be completely utilized.

Hydrology of the basin

There are marked contrasts in the water supply of different parts of the basin. The mountain ranges and high uplands have an excess of

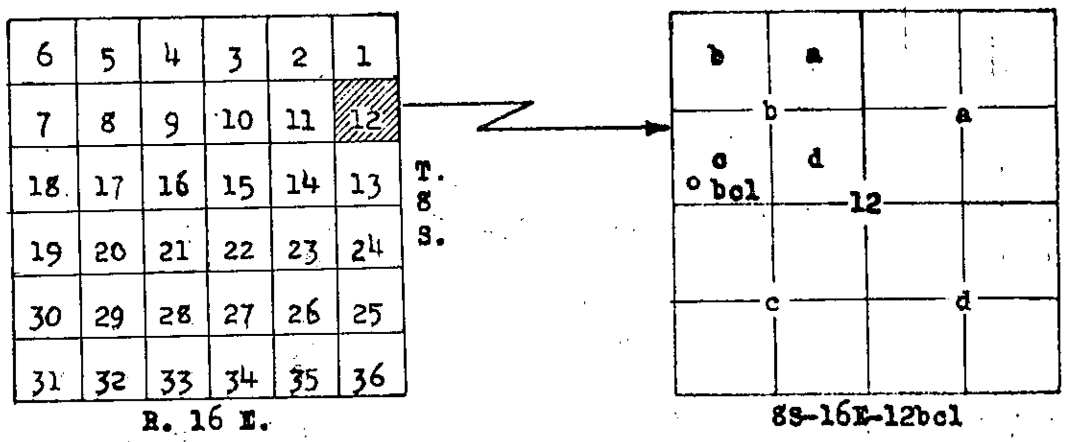

Figure 2.—Sketch of well-numbering system.

water. Precipitation, largely as snowfall, ranges up to 50 inches, much more than evaporates or is used by the native vegetation. The Snake River Plain and tributary valleys receive only 6 to 10 inches of precipitation annually, insufficient for most crops, and water must be supplied by irrigation, either with surface water that enters the plain and valleys from the mountains, or by ground water.

The Snake River which flows along the south margin of the plain is the trunk stream of the basin. Its flow is maintained by perennial streams, chiefly from the east and south. Most streams from the north do not reach the Snake River, their entire discharge is lost a short distance from the mouths of the valleys at the margin of the Snake River Plain.

The Snake River receives large ground-water inflows in two reaches. The first is in the reach from American Falls dam upstream to about the mouth of the Blackfoot River (American Falls Reservoir reach). Inflow in this reach totaled about 1,900,000 acre-feet in 1960. Water from American Falls reservoir, above the dam, is diverted through downstream canals for irrigation. The second reach is below Milner dam, some 60 miles southwest of American Falls dam. Ground-water inflow below Milner dam, largely between Twin Falls and Bliss (Hagerman Valley reach) averages about 4,700,000 acre-feet a year from the north side of the Snake River (discharge from the Snake Plain aquifer) and about 700,000 acre-feet a year from the south side of the river. Because the river is in a deep canyon below Milner dam, little water is diverted from Snake River below that point. From the standpoint of irrigation, the water is largely wasted.

Surface storage facilities upstream have been developed to the point that in less than one-half of the years is it necessary to spill water at Milner, except in minor amounts for fish and prior water-power rights. Development of additional storage, either surface or underground, that would permit irrigation of additional lands, would be of direct benefit to the economy of the area.

Hydrology of the Snake River Plain

The hydrology of Snake River Plain is summarized in this section to serve as a basis for evaluating recharge possibilities and effects. A more complete description of the hydrology can be found in the report by Mundorff and others (1960).

The limit of the Snake River Plain along its northwest flank is reasonably well defined (figs. 1 and 3). Except where tributary valleys enter the plain, the lava terminates abruptly against the mountain slopes formed on the older rocks. At the mouths of some of the tributary valleys, as at Big and Little Lost Rivers, and Birch Creek, the lavas extend a short distance up the valleys. The boundary of the plain along its southeast flank is less definite. Sedimentary materials were deposited in wide basins formed by damming of Snake River by lava flows, and extend for considerable distances up the tributary valleys. The sedimentary deposits are commonly interbedded with basalt. The southeast boundary of the plain probably can be defined most conveniently by extension across each valley from headland to headland at the northwest end of the intervening mountain ranges.

The part of the Snake River Plain of primary concern in this report is that part underlain by the Snake Plain aquifer. The Snake Plain aquifer is defined as the series of basalt lava flows and intercalated pyroclastic and sedimentary materials that underlie the Snake River Plain extending eastward from Bliss and Hagerman Valley approximately to Ashton and the Big Bend Ridge (fig. 3).

A basalt lava flow generally is fine-grained or glassy and dense at its base. Toward the center of a flow, where the lava cooled more slowly and remained fluid longer, the basalt is coarser grained. Because the top of a 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 lava flows is highly irregular, rough, and broken. At places fluid lava drained from the chilled and solidified walls and top leaving lava tubes, many of which collapsed in a jumbled mass. At other places renewed or increased pressure from the fluid lava beneath caused the crust to bulge up and break into pressure ridges leaving gaping cracks at their tops or sides.

Lava poured out over the irregular surface of an earlier flow only partly filled the irregularities, leaving voids between the earlier and later flows. The zones of voids between the top and bottom surfaces of successive flows, commonly termed interflow zones, are the important water-bearing and water-yielding horizons of the Snake Plain aquifer. Pyroclastic volcanic material such as volcanic bombs, clinkers, cinders, and ash frequently were ejected between flows. Where this material is coarse-grained and porous, it adds to the permeability and porosity of the interflow zones.

Lava flows generally have shrinkage joints, developed while cooling, more or less at right angles to the flow surface. These joints are important avenues for movement of water from one flow to another at some places, but are relatively 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 materials. If these materials are coarse sand and gravel, or cinders, the unit 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 Snake Plain aquifer comprises a tremendous hydraulic system serving both as a vast storage reservoir and as a ground-water conduit. The storage capacity of the aquifer is very large. The specific yield probably is on the order of 10 percent and the total porosity may be 15 to 20 percent. Assuming a specific yield of 10 percent, each foot of saturated thickness of the entire 12,000 to 13,000 square miles of the aquifer would yield about 800,000 acre-feet of water. Conversely, each rise of one foot over the entire area of the aquifer would represent a gain in storage of about 800,000 acre-feet.

The ability of the aquifer to transmit water is great. The coefficient of transmissibility generally ranges from 1 to 60 million g.p.d. (gallons per day) per foot, and probably averages 10 million g.p.d. per foot.

Sources of recharge to the aquifer, in order of importance, are: (1) percolation from irrigation diversions, (2) seepage from streams entering or crossing the plain, (3) underflow from tributary basins, and (4) precipitation on the plain. The report by Mundorff and others (1960) included a quantitative analysis of the hydraulic system comprised by the Snake Plain aquifer. Recharge was summarized in that report (p. 177) and is presented in a modified version of their table as follows:

Source, or segment of Snake River Plain where recharge occurs	Annual recharge (acre-feet)	Average flow (c.f.s.)
Precipitation on the plain	500,000	700
Tributary basins along north flank	1,000,000	1,400
Upper Snake River valley, above Firth	2,500,000	3,400
Snake River valley, Firth to Blackfoot	600,000	800
Snake River valley, Blackfoot to Neeley	360,000	500
Snake River valley, Neeley to Milner	400,000	600
Snake River valley, Milner to Bliss	1,200,000	1,700
Average annual recharge (rounded)	6,500,000	9,000

Discharge from the aquifer is into the Snake River and is chiefly in two areas; in the American Falls Reservoir reach, between the mouth of the Blackfoot River and American Falls (between the Blackfoot and Neeley gaging station), and in the Hagerman Valley reach between Twin Falls and Bliss. In the first reach the average discharge from the aquifer is about 2,600 c.f.s., of which about 500 c.f.s. is recharged within the section, making the net loss from the aquifer in the reach about 2,100 c.f.s. Inflow in the reach is stored in American Falls Reservoir and diverted downstream for irrigation.

Discharge in the second area is chiefly between Twin Falls and Bliss, although there are a few small springs between Milner Dam and Twin Falls, where the aquifer terminates at the canyon of the Snake River. Discharge from the aquifer (north side of river) averages about 6,500 c.f.s. Ground-water inflow in this same reach from the south side of the river averages about 1,000 c.f.s. for a total ground-water inflow in the reach of about 7,500 c.f.s. Surface inflow, about equally divided between streamflow, chiefly the Big Wood (Malad) River, and surface waste from irrigation averages about 700 c.f.s. additional so that the total gain in the reach, as measured by gaging stations below Milner Dam and at King Hill, averages nearly 8,200 c.f.s. The combined discharge from the aquifer in the Blackfoot-American Falls and the Twin Falls-Bliss reach is about 9,000 c.f.s. (rounded).

The quantitative analysis was used by Mundorff and others (1960, fig. 22) to construct a quantitative flow net, which is reproduced as figure 3 in this report. Areas and amounts of recharge and discharge and direction and amount of underflow are shown by flow lines representing underflow of 200 c.f.s. each. Because of lateral and vertical variations in permeability the flow lines do not everywhere cross the contour lines at right angles, as they theoretically would if the aquifer were completely isotropic.

The flow net was used to construct a map showing the transmissibility of the aquifer (Mundorff and others, fig. 55). Both these maps are essential to evaluation of the effects of recharge operations.

The flow net (fig. 3) represents the status of the aquifer approximately as it was in 1959. However, although the aquifer responds rather slowly, it is not static but is continually changing in response to changes of recharge and discharge. Between 1900 and about 1950, diversions for irrigation greatly increased recharge and the underflow, and raised the water table more than 100 feet in some places. The effects of recharge from irrigation diversions are described in detail in another section of the report.

Ground-water use and effects of withdrawals

Ground-water withdrawals for irrigation began to be quantitatively important after World War II, in 1945 or 1946; and sometime between 1950 and 1955 the amount of acreage added each year through irrigation with ground water began to exceed the acreage added through irrigation with surface water. The increase in ground-water withdrawals is shown graphically in figure 4. Estimated ground-water use in the Snake River basin in 1960 is shown in table 1.

A considerable part of the water pumped percolates back into the ground and returns to the aquifer. The proportions of the water that are consumed or are returned to the aquifer depend upon the method of irrigation, character of the soil, type of crop, and other factors. The amounts shown in the table are estimates only, but are believed to be approximately correct. According to the table, about one-half of all the water pumped is consumed by crops or is evaporated and one-half returns to the aquifer. Thus aquifer depletion is approximately one-half of the amount of ground-water withdrawn.

Changes in ground-water levels are caused by changes in recharge or discharge. Average amounts of recharge were shown in the table on page 7. The amount of recharge depends to a considerable extent upon diversions to irrigated lands. Because of large storage reservoirs, more water is used in the basin in some dry years than in some wet years.

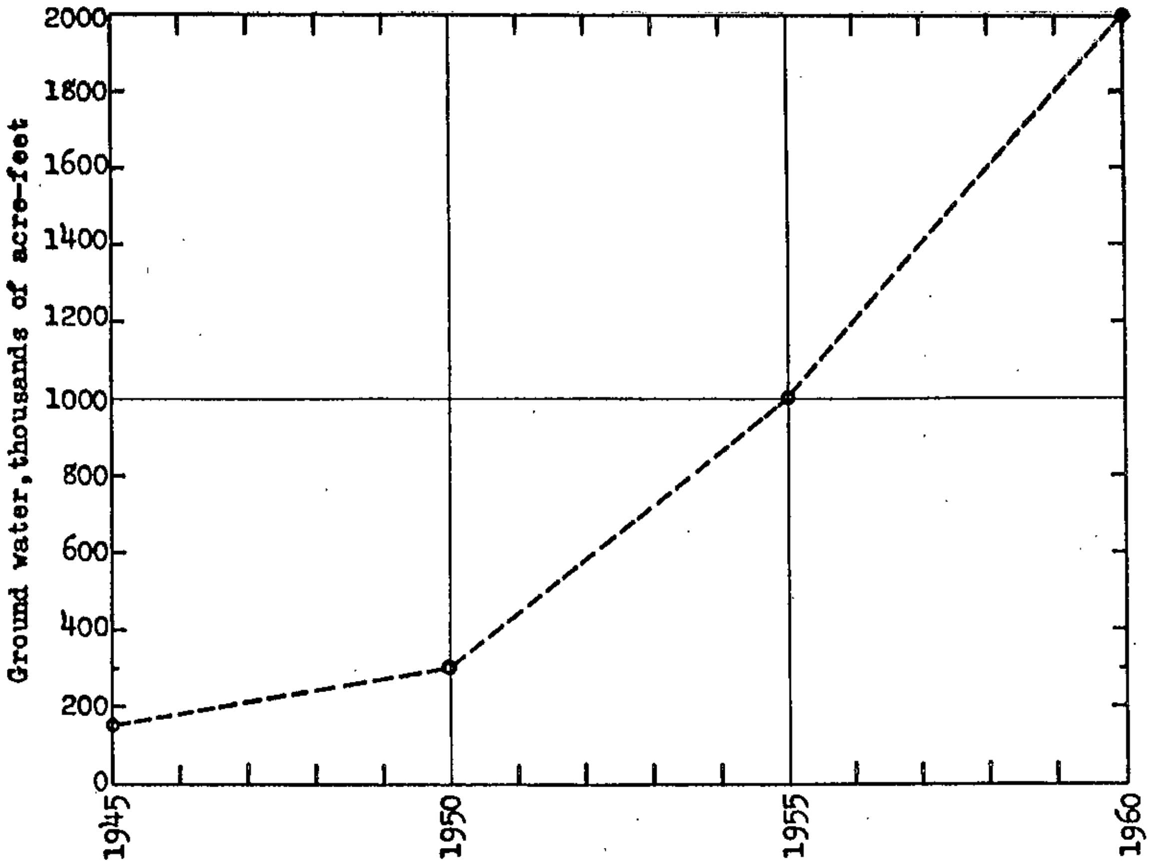

Figure 4.--Estimated ground-water withdrawals in the Snake River basin, 1945-60.

Table 1.--Ground-water use in eastern Snake River basin, Idaho

Area or Basin	1960 Acreage	1960 Amount of water (acre-foot) Pumped	1960 Amount of water (acre-foot) Consumed	1961 Acreage
Northern tributary basins:				
Big Wood-Silver Creek	10,000	35,000	16,000	12,000
Big Lost River Valley	12,000	50,000	20,000	15,000
Little Lost River Valley	9,000	40,000	15,000	9,000
	31,000	125,000	51,000	36,000
Southeastern tributary basins and areas:				
Goose Creek-Dry Creek	90,000	250,000	150,000	118,000
Raft River	38,000	127,000	65,000	40,000
Twin Falls-Salmon Falls	11,000	35,000	18,000	17,000
	139,000	412,000	233,000	175,000
Snake River Plain:				
St. Anthony-Rexburg-Ririe	15,000	50,000	22,000	20,000
Mud Lake Basin	86,000	300,000	140,000	90,000
Roberts-Idaho Falls area	40,000	130,000	65,000	50,000
Blackfoot-Aberdeen	110,000	330,000	170,000	120,000
Pocatello area	7,500	25,000	12,000	8,500
American Falls area	21,000	65,000	35,000	26,000
Michaud Project (USBR)	3,500	7,500	5,000	3,500
Minidoka Project (USBR)	61,000	205,000	100,000	62,000
Minidoka-Hazelton area	80,000	240,000	125,000	90,000
Jerome-Wendell area	21,000	65,000	35,000	30,000
Shoshone-Gooding area	5,000	15,000	8,000	8,000
	450,000	1,432,500	717,000	508,000
Total	622,000	1,969,500	1,001,000	719,000
(rounded)	620,000	2,000,000	1,000,000	720,000

Thus, the index to recharge is not precipitation on the basin, but the quantity of water retained in the basin. For the period 1941-60 the amount of inflow from every major source east of Bliss was totaled for each year, and the surface outflow at the gage below Milner Dam was subtracted. A correction was made for changes in storage in American Falls reservoir. The resulting quantity is the amount of water entering or added to the basin during the year, and is an index of ground-water recharge. The position and trend of the water table is not determined solely by the current year; recharge during previous years has some influence. In order to make allowances for earlier years in the recharge index, 1/2 the water retained in the basin during the current year, 1/3 of the previous year and 1/6 of the second preceding year were totaled for use as the index for the current year. The "recharge index" obtained in this way for the period 1950-60 is plotted in figure 5. Also shown in this figure are hydrographs of wells 2N-31E-35dcl, 8S-24E-31dcl, and 5S-15E-35dcl. Water levels in the three wells are representative of water levels measured in a large number of observation wells in the central and western parts of the Snake River Plain. The recharge index rose in 1950-53, held about steady in 1954, declined in 1955 and rose fairly steadily the remaining five years. The water levels shown by the hydrograph of well 8S-24E-31dcl (5 miles north of Rupert) rose with the recharge index through 1953, declined in 1954 and 1955, and continued declining through 1960, even though the recharge index was rising. The decline in the water table in this area since 1953 obviously is related to the great increase in ground-water pumping in the Minidoka-Hazelton area which began about 1950 and became quantitatively significant by 1952.

The fluctuations in wells 2N-31E-35dcl and 5S-15E-35dcl show about the same influences and trends, except that the wells are considerably more distant from areas of major ground-water pumpage, and pumpage in areas nearest each of these wells did not become quantitatively significant until 1957 or 1958.

Ground-water development in the Snake River Plain presumably will continue. Because of the large amount of water in storage and the very high coefficient of transmissibility the rate of decline has been, and probably will continue to be low, probably averaging less than 1 foot per year. However, the decline will continue for many years.

Factors affecting feasibility of artificial recharge in the Snake River basin

Among the many factors which affect the feasibility of artificial recharge in the Snake River basin, and limit the selection of suitable sites, a few are of primary importance. These are the availability of water suitable for recharging, a suitable topographic situation, satisfactory transportation route from source to site, and a suitable site with adequate absorptive capacity of the materials underlying the site. Large parts of the Snake River basin and the plain are eliminated from consideration because one or more of the above factors are unfavorable.

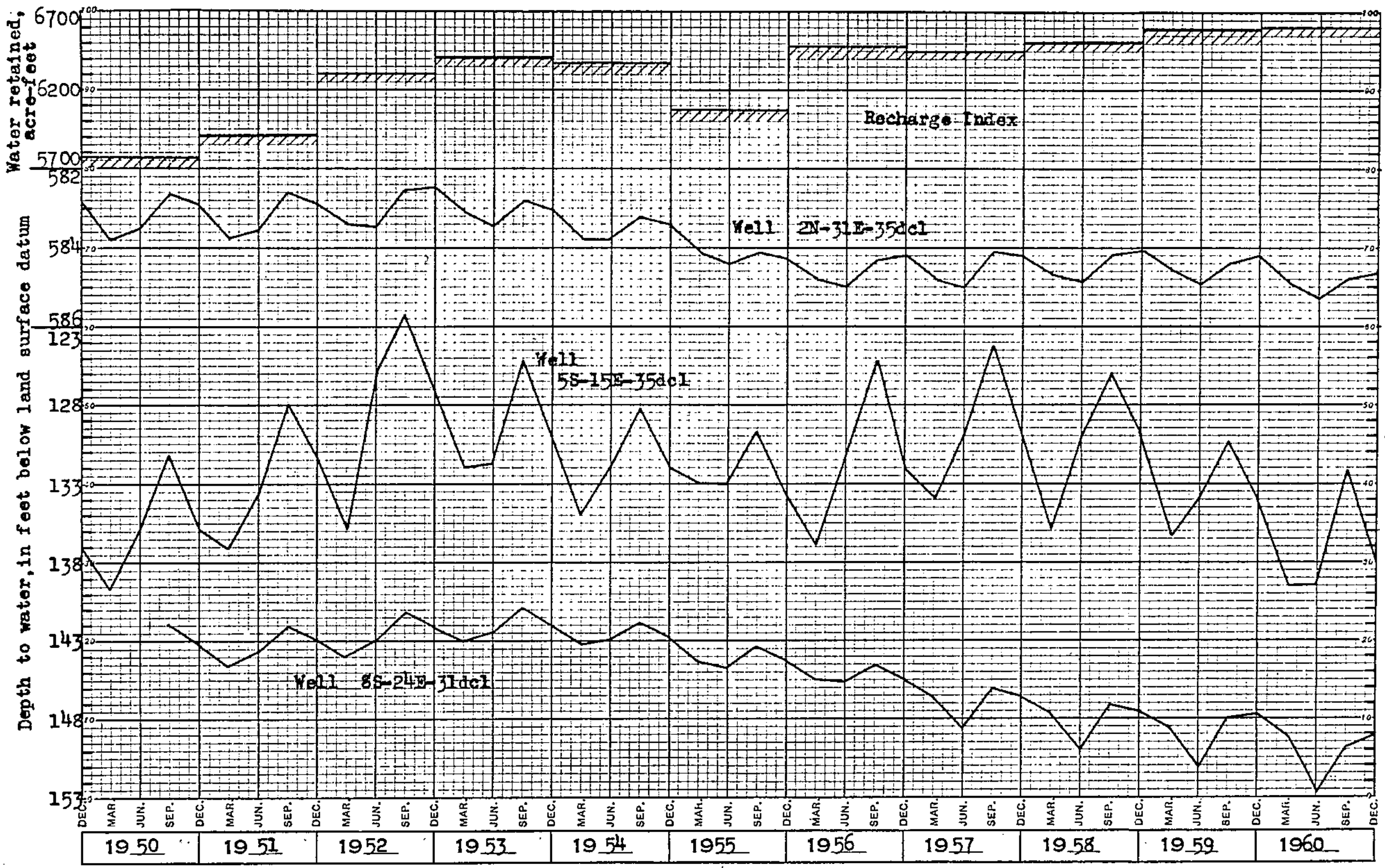

Figure 5.--Water level in three wells compared with the "recharge index", 1950-60.

Another consideration further narrows the selection of suitable sites. In the Snake Plain aquifer the ground-water mound spreads rather rapidly; at some places the water table begins rising at points as distant as 25 miles from a recharge area within a few months after recharge begins. Thus water can be stored for periods of several years only if the recharge area is remote from the points of discharge. For this reason the most desirable locations would be at the upgradient (eastern) end of the aquifer. Recharge in that part of the aquifer would raise water levels throughout the aquifer, whereas recharge near the discharge areas (i.e., near American Falls reservoir, or the Twin Falls-Bliss reach) would raise water levels only near the recharge sites, and the rise would be of relatively short duration after recharge ceased.

Availability of water

Surplus water is available in some years from the Snake River and from Henrys Fork. A study was made by the U. S. Bureau of Reclamation (written communication, 9-6-61) of historical flows past Milner Dam, the last major downstream diversion point, for the 30-year period of water years 1928-57, modified to reflect current operating conditions and storage facilities.

This study showed that in 8 of the 30 years more than 1,000,000 acre-feet of water a year would have been available for recharging, and in 14 years more than 500,000 acre-feet would have been available. In 3 other years more than 150,000 acre-feet would have been available. In 13 years little or no water would have been available.

Proceeding on the principle that the water should be recharged as far upgradient in the aquifer as is feasible, the Bureau of Reclamation concluded that water in an amount exceeding 100,000 acre-feet would have been available from the Henrys Fork at St. Anthony in 12 of the 30 years. In five other years the water available would have exceeded 20,000 acre-feet. In the other 13 years of the study period little or no water would have been available for recharging.

Assuming operation of a 2,000 c.f.s. canal diverting from the Henrys Fork for recharge of surplus water, the amount of water available from Snake River below the mouth of the Henrys Fork was estimated by the Bureau of Reclamation to exceed 250,000 acre-feet in 14 years of the 30-year period. In 2 other years the water available would have exceeded 100,000 acre-feet, and in the other 14 years little or no water would have been available for recharging. The water would have been available in the 6-month period, January through June. Although substantial quantities of water were available for recharge in more than half the years of the base period, these years are not evenly distributed. For example no water would have been available during one 8-year period, and except for about 30,000 acre-feet available in one year, this period would have extended to 12 years. On the other hand substantial flows, 150,000 acre-feet in the lowest year, would have been available each year for recharging during the last 15 years of the base period. The same pattern may not be repeated, but there probably will be periods of several years when no water is available for recharging and equally long intervals 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.

Surplus water also is available for recharging in some streams tributary to the plain. Some flood water discharges from the Blackfoot, Portneuf, and Big and Little Lost Rivers. Artificial recharge might be of local benefit within these tributary basins, but would not benefit the Snake Plain aquifer for the following reasons. Discharge from the Blackfoot and Portneuf Rivers is caught in American Falls Reservoir. Because sufficient water must be allowed to flow downstream in the Snake River to fill American Falls Reservoir, use of floodflows from the Blackfoot and Portneuf Rivers would reduce the amount of water available at upstream points from the Henrys Fork and Snake River by an equal amount. Big and Little Lost Rivers lose their entire discharge at the margin of the Snake River Plain. Diversion of floodflows for recharge in upstream reaches would reduce recharge at the margins of the plain by an approximately equivalent amount. (There might be slight differences in evaporation losses at the two recharge sites).

Surplus flood water is available in most years from the Big Wood River drainage. Discharge records at the gaging station on Big Wood River (formerly Malad River) southwest of Gooding show annual discharges ranging from 35,000 to 499,000 acre-feet during the period 1938-60. Average annual discharge for the 23 year period was about 185,000 acre-feet. In only two years was the annual discharge less than 75,000 acre-feet, and only in 6 years was it less than 99,000 acre-feet. In 9 years it exceeded 200,000 acre-feet. Surplus water could be diverted from the Big Wood River to recharge areas below Magic Reservoir; or from the tributaries, Silver Creek and Little Wood River, to areas along the margin of the plain.

Topographic situation

The Snake Plain aquifer is chiefly north of the Snake River and most of the areas suitable for recharging also are north of the river. Because of economic considerations it probably is not feasible to use pumps to raise water to a recharge site higher than the source of the water supply, or to construct long siphons or to use pumps to cross a broad depression to reach a recharge site. If the water to be used for 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 about 4,800 feet (figure 3), and the only practicable way in which to bring water from the Snake River to the plain on the north side of the river system at a higher altitude would be to divert water upstream on the Snake River through a cross canal to Henrys Fork. However, there would be sufficient flow in Henrys Fork, during periods that surplus water was available for recharging, so that a large part of the total could be taken from that river. There are feasible diversion points on Henrys Fork in the vicinity of St. Anthony at altitudes of about or slightly above 5,000 feet. Thus 5,000 feet may be taken as the upper limit of any feasible recharge site.

The central part of the Snake River Plain is higher than the flanks. In the northeastern end of the plain the terrain below 5,000 feet is chiefly adjacent to the Snake River and Henrys Fork, and in the vicinity of Mud Lake and the mouths of Birch Creek and Little Lost River.

Farmed lands generally are not suitable for recharge sites because the soil has too low a permeability for adequate percolation rates. also, it doubtless would not be economically feasible to include more than small incidental areas of arable land. The arable lands in the Snake River Plain are chiefly confined to a very irregular belt adjacent to Snake River on the southeast side of the plain, and irregular areas near the mouths of major tributaries along the north flank of the plain. Thus, areas suitable as sites for artificial recharge in general are bounded on one side by topographic contour lines beyond which it is not practicable to conduct recharge water, and on the other side by arable lands which are neither suitable for, nor available as recharge sites. The one exception are gravel pits adjacent to Snake River in reaches where the river is above the water table.

Water could be taken out of Henrys Fork at an altitude of about 5,000 feet upstream from St. Anthony and conveyed westward and northwestward into a large area north of Hamer and Mud Lake. The canal required would be 30 or 40 miles long.

A closer site which could be served by a canal of the same general alinement lies immediately west of Plano (see figure 11). However a broad sag in the topography would drop the canal about 20 or 30 feet below the 4,900 foot contour. The area above the 4,900-foot contour thus is immediately eliminated. The area below the 4,900-foot contour extends westward for many miles, passing south of Mud Lake. However a topographic depression extends northward from Roberts to Hamer (followed generally by the railroad). Topographic maps are not available for that part of the area, but elevations along the railroad indicate that a canal crossing the depression probably would do so at an altitude of not more than about 4,840 feet, further limiting the recharge area. The site is described in more detail in another section of the report.

The first feasible downstream diversion site below the junction of Henrys Fork and Snake River is south of Roberts at an altitude of about 4,750-55. Although it would be possible to divert from the Snake River near Menan Buttes and carry the water north of Roberts, the added potential recharge areas probably would not be worth the additional construction expense. Diverting at an elevation of about 4,750 south of Roberts, water could be transported to a potential recharge site southwest of Idaho Falls. Another possible recharge site is northwest of Springfield. Water could be brought to this site by constructing a canal from the Idaho Falls site, and water might reach the site at an altitude of around 4,700 feet. Because of a considerable drop in the river at Idaho Falls, and in the reach downstream to Firth, diversion canals downstream from Idaho Falls could reach only a narrow strip adjacent to the Snake River. The Shelley and Springfield sites also are described in more detail in a later section of the report.

Large unused areas underlain by basalt west of Aberdeen and north of Lake Walcott appear to be suitable for recharging. However, as can be seen by study of river- and land-surface altitudes in figure 1, canals to bring water to these areas would be impracticably long and expensive. Several existing irrigation canals divert water to the plain from the reservoir (Lake Milner) above Milner Dam. Diversions are at an elevation of about 4,130 feet. Surplus water could be diverted to areas suitable for recharge through existing canals. Diversion to this part of the plain at altitudes higher than 4,130 feet does not appear to be practicable. There is a difference in altitude of only about 60 feet between Lake Milner and Lake Walcott which is 29 miles, airline, to the northeast. Diversions from Lake Walcott would not reach any appreciably different or better recharge area. The recharge area north of Lake Milner is described in more detail in a later section of the report.

Below Milner Dam the Snake River flows in a deep canyon and diversion of water for recharge downstream from that point is impracticable.

Water quality and temperature

The chemical quality of water used to recharge an aquifer may affect the feasibility of the recharging operations. This is particularly true where the percentage of dissolved solids is large, or where the recharge water is not chemically compatible with the water in the aquifer.

Because the present recharge to the aquifer is almost entirely from the same sources as the proposed artificial recharge, chemical compatability does not appear to present any problem. Analysis of water from the Henrys Fork, Snake River, and three typical wells are given in table 2.

Differences in temperature probably will have little effect on compatibility of the water. However, water for artificial recharge will be available chiefly in late winter and spring months, and the temperature of the water will be low, at times very little above freezing. Average monthly temperatures of water in the Snake River at the Heise gaging station in water year 1957 were as follows (°F): Oct. 46, Nov. 36, Dec. 33, Jan. 32, Feb. 34, Mar. 35, Apr. 39, May 46, June 53, July 56, Aug. 59, Sept. 56. Temperature data for Henrys Fork are not available, but temperatures probably are nearly the same as for the Snake River. Thus, recharge water generally will be at temperatures between 32 and 40°.

The temperature of the ground water is considerably warmer, averaging about 54°-56°. The chief effect of the lower temperature of the recharged water will be to decrease the coefficient of transmissibility. The coefficient of transmissibility is determined at the prevailing temperature of the water in the aquifer, in this case about 55°. At a temperature of 40° the coefficient would be 79 percent, and at a temperature of 33°, the coefficient would be only 69 percent of the

Table 2.--Chemical analyses of water from 2 rivers and 3 wells.

(Analyses by U. S. Geological Survey. Chemical constituents in parts per million)

	Henrys Fork near Rexburg	Snake River near Heise 1/	Well 6N-40E-30bd1 City of Rexburg	Well 1S-32E-23cb1 near Tabor	Well 6S-17E-2ab1 City of Shoshone
Date of collection	7-14-59	-	8-27-57	9-10-54	10-30-56
Temperature (°F)	72	-	54	55	56
Silica (SiO_2)	26	10	26	36	33
Iron (Fe)	.23	-	.04	-	.00
Calcium (Ca)	19	49	53	36	48
Magnesium (Mg)	5.8	11	16	12	14
Sodium (Na)	11	10	8.3	(23	16
Potassium (K)	2.0	1.9	2.4	(	3.2
Bicarbonate (HCO_3)	97	162	235	168	220
Sulfate (SO_4)	7.4	41	10	29	19
Chloride (Cl)	5.0	10	6.5	12	8.0
Dissolved solids:					
Residue	168	219	232	229	261
Calculated	126		242	234	255
Total hardness as $CaCO_3$	71	168	198	139	177
Specific Conductance (micromhos at 25°C)	189	362	394	358	404
pH	6.9	7.0-7.9	7.8	8.4	8.0

1/ At the Heise gaging station, weighted average for water year 1957 (Water Supply Paper 1523, p. 430).

coefficient at 55°. Probably the greatest effect of water temperatures will be in percolation from the surface to the water table. Percolation may be only two-thirds as great when the water is near freezing, as it would be at a temperature of 55° to 60 °. A pond capacity nearly 50 percent larger would be required for the water at 33°F than would be needed for water at 55°F.

Recharge incidental to irrigation on the Snake River Plain

The hydrologic regimen of the Snake River Plain has been changed very markedly because of irrigation of lands on the plain. The discharge of ground water in the Twin Falls-Bliss reach increased about 2,500 c.f.s., and discharge in the Blackfoot-American Falls reach probably increased about 1,200 to 1,500 c.f.s. because of irrigation. This increase in underflow and in discharge does not represent all the water recharged to the Snake Plain aquifer by irrigation; natural recharge from Henrys Fork and Snake River has been reduced because flooding has virtually been eliminated. Thus, recharge from irrigation probably is more than half the total recharge, perhaps 4,500 to 5,000 c.f.s., about $3\frac{1}{2}$ million acre-feet a year. This is recharge to the Snake Plain aquifer; much additional water is recharged to, and discharged from perched aquifers east of Idaho Falls, and in the Burley-Rupert (Minidoka) area.

The annual recharge to the Snake Plain aquifer from irrigation operations far exceeds the amount that could be added by artificial recharge. Thus, perhaps the best clue to the effects that the proposed artificial recharge would have on the aquifer are the changes already caused in the aquifer by recharge from irrigation. The effects of irrigation on the water table in two areas are described below.

Aberdeen area

Irrigation diversions to the Snake River Plain upstream from the Aberdeen area began before 1890. According to Simons (1953, p. 60-65) the area irrigated exceeded 250,000 acres in 1900, and 355,000 acres in 1905. Not all the irrigated area listed was in the Snake River Plain, some was in headwaters areas upstream from the plain. Probably about 200,000 acres in 1900, and 300,000 acres in 1905 were in the Snake River Plain. Practically no data are available on actual diversions for irrigation, but the information that is available indicates that diversions were considered to be excessive. Assuming an average diversion of 8 acre-feet per acre, diversions would have been about 1,600,000 acre-feet in 1900 and 2,400,000 acre-feet in 1905. Undoubtedly diversions of that amount of water to lands adjacent to the Snake River had considerable effect on the water table at an early date, and even though much of the irrigated land was many miles upgradient from the Aberdeen area, the water table probably had risen considerably before irrigation of the Aberdeen tract began in about 1910.

Beginning with 1930, fairly complete records of diversions are available. Diversions in the early 1930's averaged about 3,200,000 acre-feet a year, by 1940 were averaging about 3,600,000 acre-feet, and by 1950 were exceeding 3,800,000 acre-feet a year.

In 1960 more than 4,300,000 acre-feet of water was diverted for irrigation of 432,000 acres of land in the Snake River basin above American Falls, excluding the headwaters areas (Eagle, 1960). Probably 75 to 80 percent of the amount diverted percolates into the ground and becomes ground water; however not all this water reached the Snake Plain aquifer, a substantial amount recharged perched aquifers and returned to the Snake River in upstream reaches. Of every 10 acre-feet diverted for irrigation, approximately 3.5 acre-feet is consumed or recharges perched aquifers, 2.5 acre-feet discharges into American Falls Reservoir, and 4 acre-feet continues westward in the aquifer to discharge in the Milner-Bliss reach.

Water diverted for artificial recharge upstream from American Falls will not be consumed by crops (minor amounts may evaporate) and would be recharged directly into the aquifer, or into perched aquifers which would feed into the main aquifer, not into surface streams. Therefore nearly all the water diverted would become recharge and roughly 40 percent of the water recharged by artificial means upgradient from American Falls would return in the American Falls reach, and 60 percent would return in the Milner-Bliss reach. This ratio holds only as a rough general rule. A larger proportion of water recharged in the near vicinity of the American Falls discharge area would obviously return in that reach.

Although discharge of the aquifer in the American Falls reach is related to irrigation on the entire segment of the plain to the northeast, the fluctuation of the water table in the Aberdeen-Springfield area is closely related to diversions of water for irrigation in the immediate area. Diversions to the Aberdeen Canal and hydrographs of 4 wells in the area are shown graphically in figure 7. These curves clearly show that the recharge mound produced by irrigation moves outward in the aquifer. Well 4S-33E-3cb2, within the irrigated area, responds within a few days. Water-level measurements are at too great an interval to fix the exact time required for their response, but approximate travel times can be determined. Well 2S-32E-23bb1, 8 miles from the edge of the irrigated area, responds within 40 to 80 days. Well 1S-30E-15bc1, 19 miles from the margin of the irrigated area responds after 75 to 100 days and well 2N-31E-35dc1 about 22 miles away responds after 90 to 105 days.

A total of 362,000 acre-feet of water was diverted into the Aberdeen Canal during the 1960 irrigation season of about $5\frac{1}{2}$ months. Transmission losses, mostly to ground water, were $38\frac{1}{2}$ percent, or nearly 140,000 acre-feet. Of the 222,000 acre-feet delivered to the farmer, probably about 2 acre-feet per acre, 100,000 acre-feet for 48,500 acres in the project, were consumed, another 10,000 acre-feet was surface waste, leaving about 110,000 acre-feet additional which percolated to the water table. Total recharge to the water table from irrigation thus was about 250,000 acre-feet, for an average rate of about 45,000 acre-feet per month and the maximum rate, during June and July, exceeded

50,000 acre-feet per month. This water was recharged over an area of 4 or 5 townships. The seasonal rise in water levels ranged from about 1 to 12 feet in 18 wells in the irrigated area and averaged nearly $5\frac{1}{2}$ feet.

The rise in water level caused by recharge was 2.3 feet at well 2S-32E-23bb1, 8 miles from the edge of the irrigated area; 1.3 feet 19 miles from the edge of the irrigated area; and 0.9 foot 22 miles from the edge of the irrigated area.

Minidoka Project area

Diversions of surface water to irrigate an area of about 12 by 15 miles in the Burley-Rupert area (fig. 1) (Minidoka Project) began in about 1908. Diversions exceeded 450,000 acre-feet in 1910 (calendar year), 660,000 in 1915, 730,000 in 1920 and 800,000 in 1930. Diversions for the period 1945-60 are given in the following table:

Year	Minidoka Canals North Side	Minidoka Canals South Side	Total	Year	Minidoka Canals North Side 1/	Minidoka Canals South Side	Total
1945	432,000	319,000	751,000	1953	434,000	353,000	787,000
1946	438,000	331,000	769,000	1954	456,000	370,000	826,000
1947	451,000	347,000	798,000	1955	426,000	356,000	782,000
1948	432,000	356,000	788,000	1956	460,000	380,000	840,000
1949	439,000	352,000	791,000	1957	491,000	344,000	835,000
1950	435,000	371,000	806,000	1958	528,000	365,000	893,000
1951	464,000	358,000	822,000	1959	506,000	353,000	859,000
1952	469,000	386,000	855,000	1960	525,000	386,000	911,000

1/ Includes Minidoka North Side pump canal, 1957-60.

Although diversions have varied from year to year, depending on availability of water and irrigation requirements, there has been no significant increase in diversions since the 1920-30 period. A large part of the surface water diverted percolates downward to the water table and recharges the main aquifer. Shallow aquifers are perched on clay and silt strata in the vicinity of Burley and Rupert and these perched aquifers discharge, in part, into the Snake River within the reach. In their analysis of recharge to and discharge from the Snake Plain aquifer Mundorff and others (1960, p. 174) estimated that the aquifer gained about 400,000 acre-feet a year in the reach of the river between Neeley and Milner. Part of this gain is derived from underflow from the Raft River basin, but a large part, perhaps about 300,000 acre-feet a year is derived from downward percolation of surface water diverted for irrigation. Actual percolation losses are considerably greater, probably in excess of 60 percent of the water diverted, or 450,000 to 500,000 acre-feet a year. The difference between 300,000 and 450,000 to 500,000 represents water returned to the Snake River within the Neeley-Milner reach by perched aquifers. Increased recharge because of irrigation

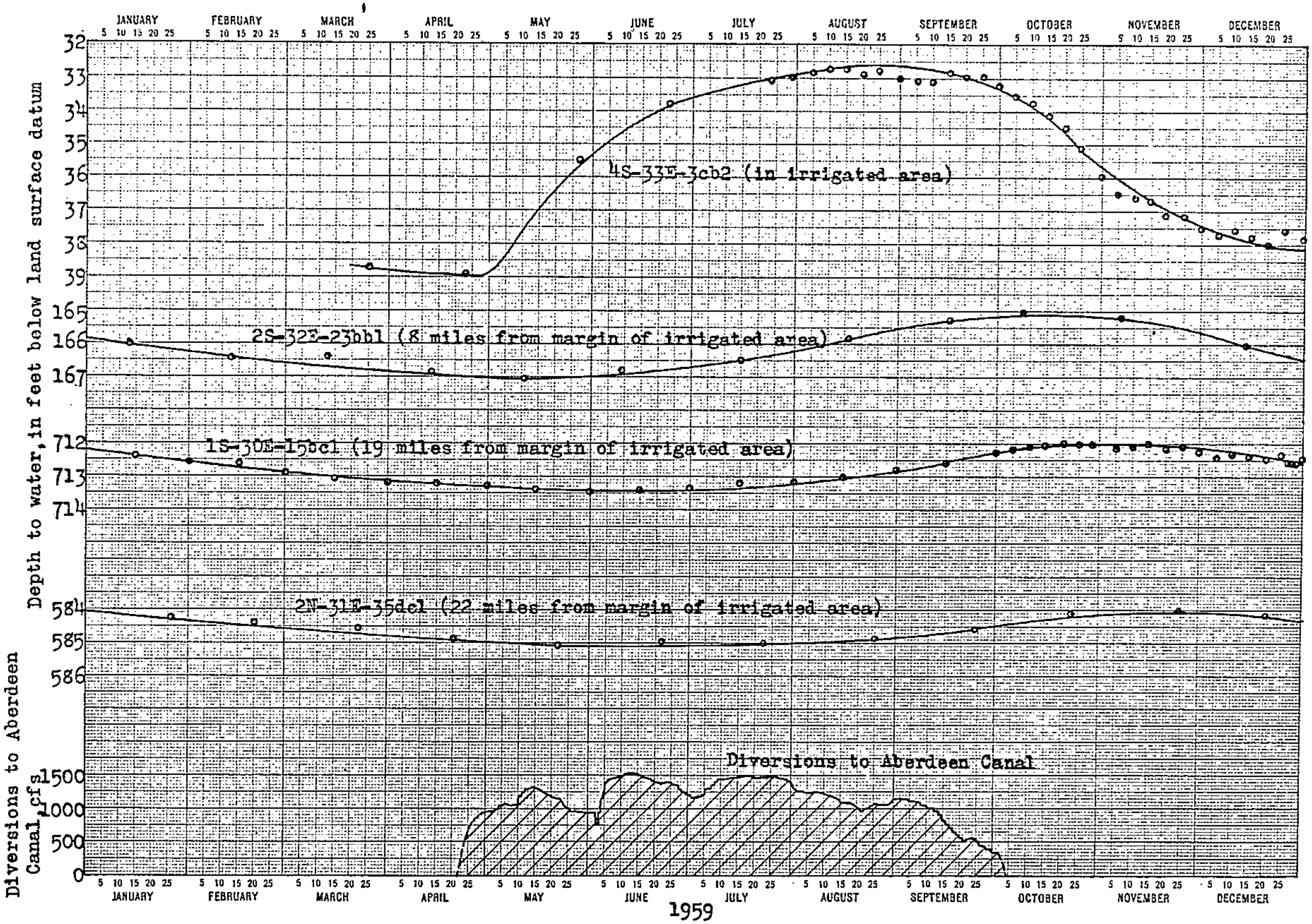

Figure 7.--Diversions to the Aberdeen Canal and hydrographs of four wells.

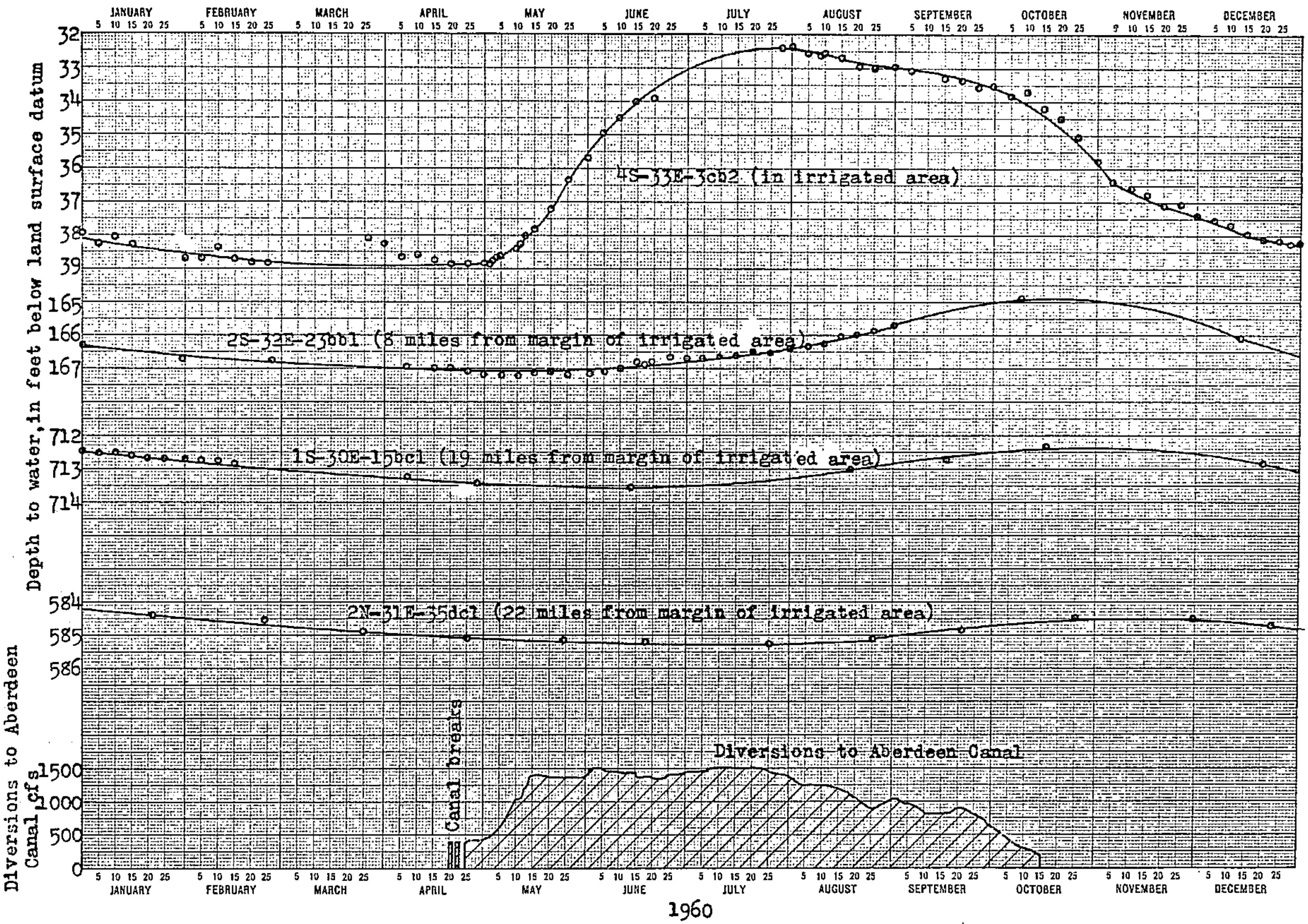

Figure 7.--Diversions to the Aberdeen Canal and hydrographs of four wells.

after 1908 raised the water table considerably. The rise in water level in the few wells for which information is available ranged from about 40 to 195 feet in the Minidoka Project area. (Mundorff and others, 1960, p. 150.) Because irrigation developments in other parts of the Snake River Plain were in progress simultaneously with the Minidoka Project, the effects of the Minidoka Project cannot be isolated. Nevertheless, it is apparent that irrigation in the Minidoka area was an important factor in raising the water table an average estimated amount of 60 to 70 feet throughout that part of the Snake River Plain. Most of the rise occurred before 1920. Occasional measurements of water level in various wells in the area indicate that the water table did not change more than a few feet from the 1920's to 1950. It thus appears that diversion of an average of 750,000 to 800,000 acre-feet of water is just sufficient to maintain the water table about its present position, or stated conversely, diversion of surface water over a period of 40 to 50 years has been sufficiently uniform to stabilize the water table within a relatively narrow range at a level estimated to be some 60 to 70 feet above the preirrigation level.

Since 1950 the greatest change in the hydrologic regimen of the area has been the drilling and use of a large number of wells for irrigation. Estimated ground-water pumpage and consumptive use on the north side of the Snake River in the Minidoka Project area is given in the following table:

Year	Ground water Pumped (acre-feet)	Ground water Consumed (acre-feet)	Year	Ground water Pumped (acre-feet)	Ground water Consumed (acre-feet)
1951	50,000	25,000	1956	200,000	100,000
1952	75,000	38,000	1957	240,000	120,000
1953	100,000	50,000	1958	300,000	150,000
1954	135,000	68,000	1959	330,000	165,000
1955	160,000	80,000	1960	365,000	183,000

Irrigation from ground water is north and northwest of the area served with surface water, and is chiefly beyond the limits of the perched aquifers so that most of the water that is not consumed returns to the Snake Plain aquifer.

The effects of recharge from surface-water diversions, as well as the effects of withdrawals of ground water, are shown very clearly by hydrographs of observation wells in the area. The hydrographs of two wells and cumulative departure from average monthly diversion of water to the North Side Minidoka Canal for the period 1951-60 are shown in figure 8. Because ground-water withdrawal was a relatively minor amount for the first few years shown on the graph (1951-53), that part of the graph shows most clearly the effects of surface-water diversions. Well 8S-24E-31dc1 is immediately adjacent to the area irrigated with surface water which lies to the south, and also to the area irrigated with ground water which lies to the north. There was little or no lag between diversion of surface water and the change from a downward to an upward trend of the water level in the well. Well 8S-23E-2ba1 is about 6 miles from the area irrigated with surface water, and there is a lag of 3 to $3\frac{1}{2}$ months between diversion of surface water and a rise in the water table. Both wells showed a net rise during the period 1951-53 which is attributed to above average diversions in 1950-52. Diversions were down slightly in 1953, but the water table continued to rise, apparently because of some lag in recharge, perhaps representing water in downward transit from perched aquifers. In 1954 the water level in both wells began a general downward trend upon which is superimposed the annual recharge-discharge cycle. The same trends are shown by more than a dozen other observation wells in the area.

Recharge from irrigation occurs chiefly during the irrigation season (allowing for some lag because of the time required for downward movement to the water table, and some lag in leakage from perched aquifers). Discharge is continuous. If there were no recharge from irrigation, the water table would continue to decline, as shown by the dotted line extending the drawdown cycle for well 8S-24E-31dc1. By drawing a perpendicular line from the highest point shown on the hydrograph (141.6 at the end of September, 1951 for example) to the extended drawdown curve, the rise in the water table caused by irrigation is found to be about 5.0 feet in 1951. Actually, the rise would have been somewhat more, but consumptive use of about 25,000 acre-feet of ground water in the adjoining area reduced the rise. Assuming that consumptive use and return to the river through perched aquifers is relatively constant from year to year on the surface-water project, the relation of these factors to the rise in the water table can be expressed by the equation $S_d - C - G_c = KR$, where S_d is surface diversion in acre-feet, C is the consumptive use, in acre-feet, on the tract irrigated with surface water, G_c is ground water consumed on the ground-water tract, K is acre-feet per foot of rise and R is the total rise in the water table. C and K are unknown but can be determined graphically. If the data from the preceding two tables and the hydrograph are used in this equation and plotted, the data roughly define a straight line passing through the points C = 500,000 at R = 0 (fig. 9). K is the slope of the line and is about 60,000 acre-feet per foot. That is, of the 750,000 to 850,000 acre-feet of surface water diverted to the Minidoka Project each year, roughly 500,000 acre-feet is consumed by crops or is returned to the river by perched aquifers, and the remainder, 250,000 to 350,000 acre-feet is recharged to the Snake Plain aquifer (recharge of 300,000 acre-feet a year was estimated by a different method on page 18).

To sum up, irrigation in the Minidoka Project of some 12 by 15 miles results in an annual recharge of 250,000 to 350,000 acre-feet. This recharge, beginning in 1908 was a major factor, along with irrigation in other parts of the Snake River Plain, in raising the water table perhaps 60 or 70 feet. The position of the water table had stabilized after 10 or 15 years of irrigation so that there was little net change in the water table from the 1920's to 1950. The annual recharge cycle is shown by a number of observation wells in the area for the period 1951-53 when withdrawal of ground water for irrigation was relatively minor. Recharge of 250,000 to 350,000 acre-feet of

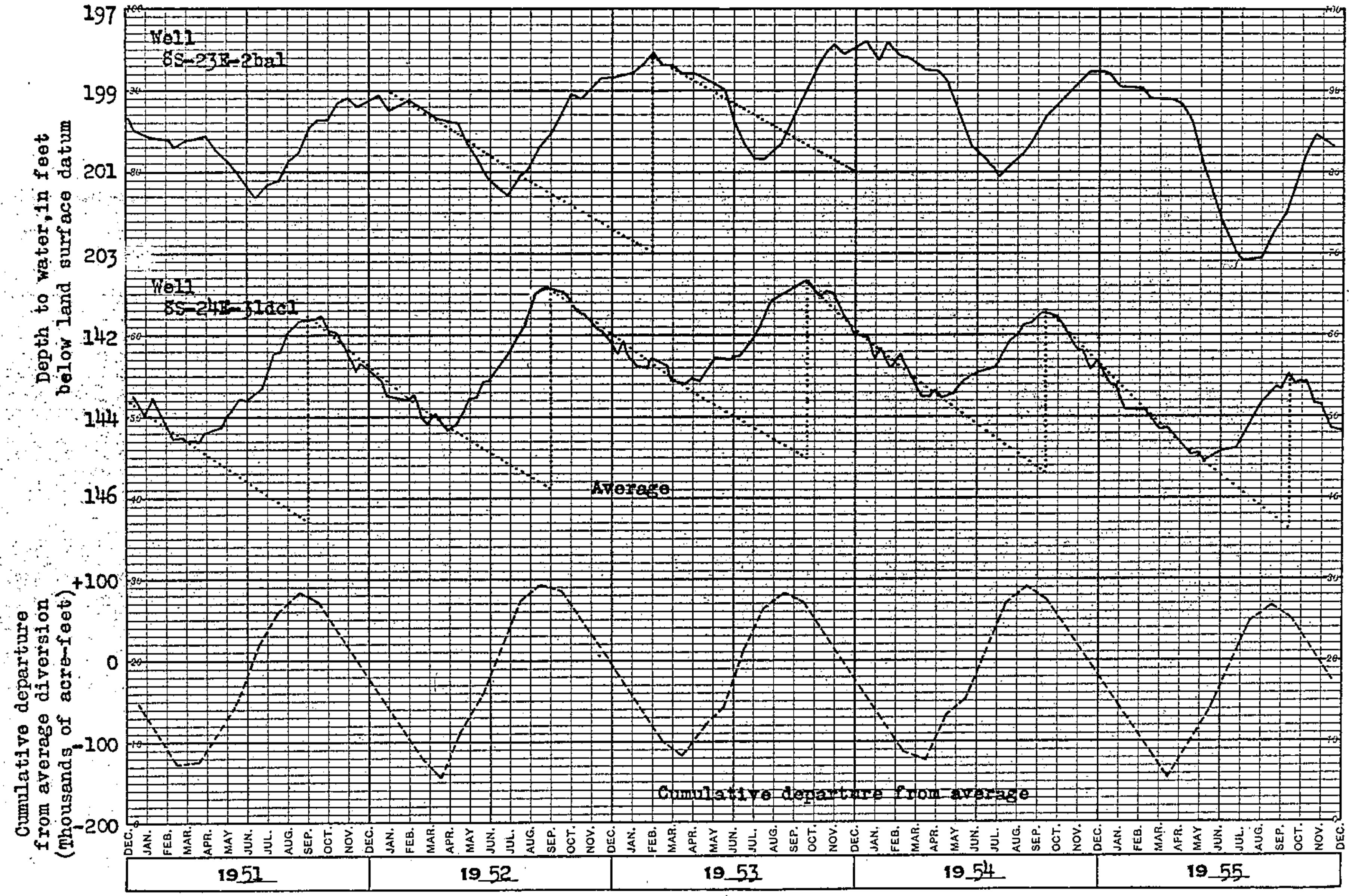

Figure 8.—Water level in two wells compared with cumulative departure from average diversion to Minidoka North Side canal.

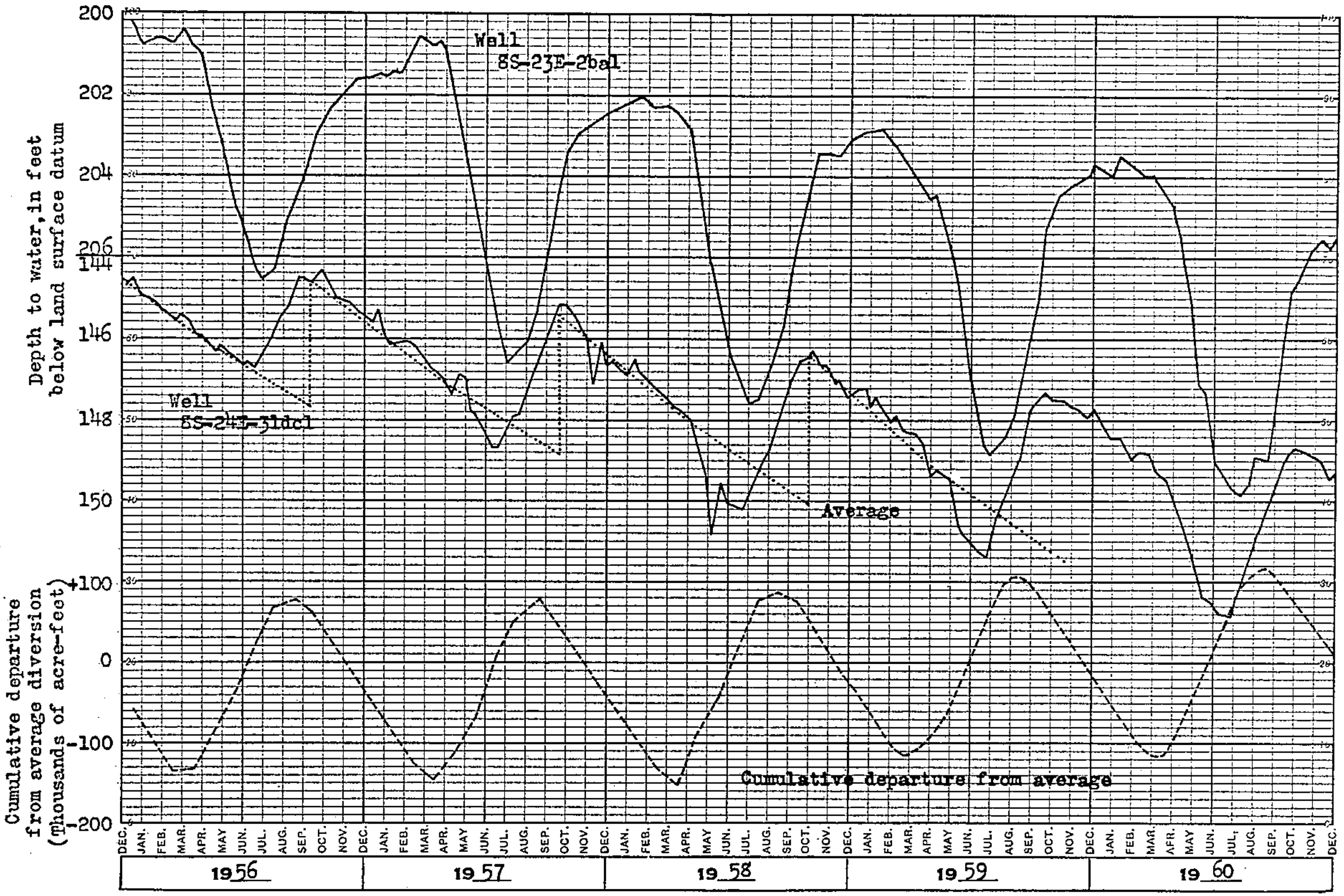

Figure 8.--Water level in two wells compared with cumulative departure from average diversion to Minidoka North Side canal.

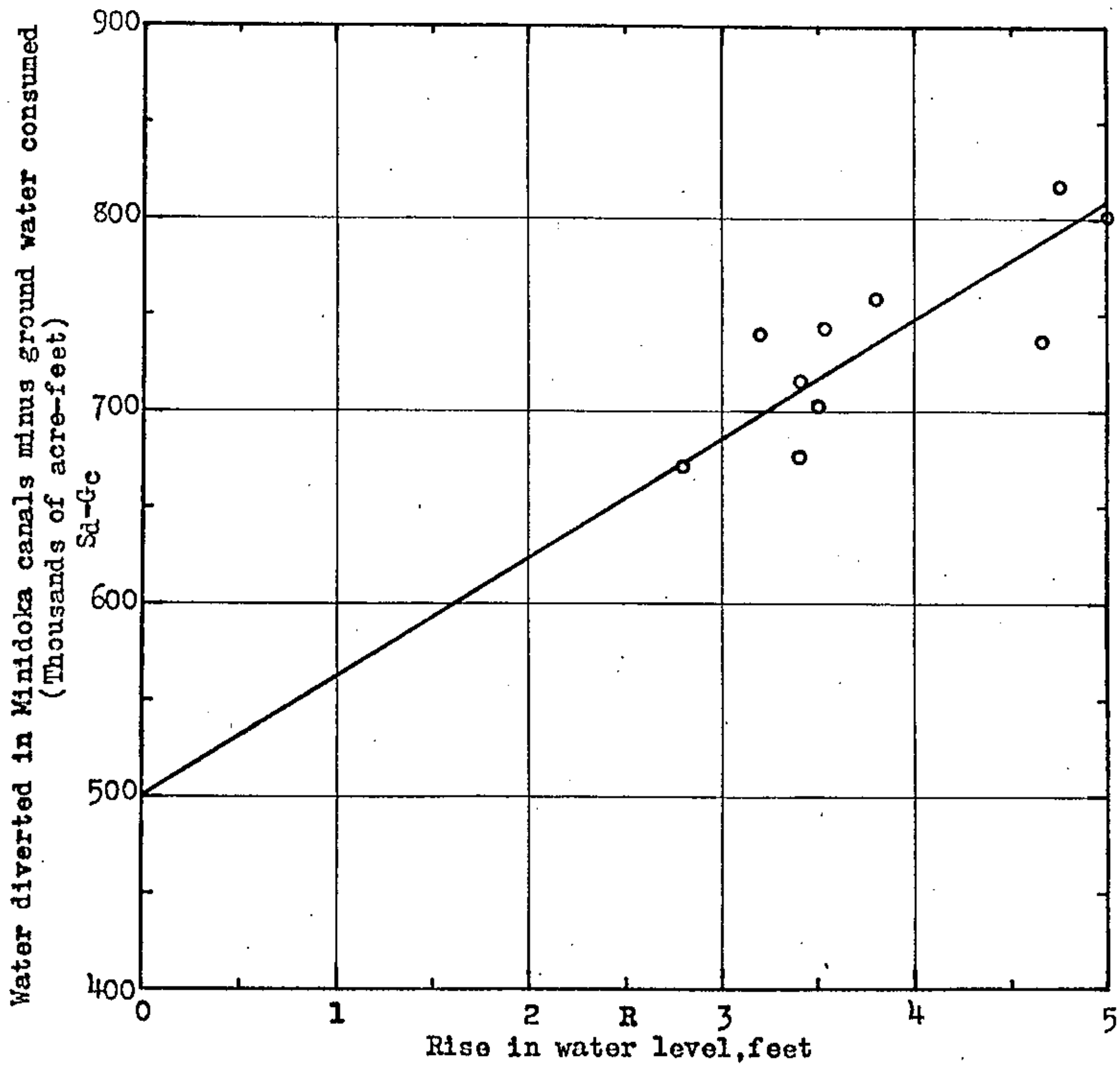

Figure 9.--Graph showing relation between surface-water diversion minus ground-water consumed, and the rise in water level in well 8S-24E-31dc1.

water results in a rise in the water level of 4.5 to 5 feet in well 8S-24E-31dc1 (fig. 9) which is immediately adjacent to the irrigated area. Well 8S-23E-2ba1 is about 6 miles north of the project irrigated with surface water, and already in 1951, the water level in this well was being affected by local ground-water withdrawals. However, it appears that the rise in the water level in this well that can be attributed to the annual recharge from surface-water irrigation is roughly $2\frac{1}{2}$ to 3 feet. The lag between diversion of surface water, and the first change in water-level trend in the well, caused by diversions, is about 3 to $3\frac{1}{2}$ months.

More distant observation wells also show the effects of annual recharge from irrigation in the Minidoka Project area. All of these observation wells are farther north, so that they are nearer the area of ground-water pumping than they are to the surface-water area. Thus the rise caused by diversion of surface water is partially offset and obscured by the decline caused by ground-water withdrawals, especially since 1954. Hydrographs of 3 of these wells are shown in figure 10. Distances from the margin of tract irrigated with surface water and the time required for the effects of surface-water diversion to reach each well, for these three wells and the two shown in figure 8, are given in the following table:

Well No.	Distance from margin of Minidoka Project area (miles)	Time required for effects of recharge from surface water (days)
8S-24E-31dc1	0	0-10
8S-23E- 2ba1	6	90-100
7S-24E- 2ad1	10	100
5S-23E-17ca1	20	150
4S-24E- 6bb1	29	160-170

Feasibility of recharge in selected areas

In a previous section of the report it was shown that large areas of the Snake River Plain were eliminated from consideration as potential recharge sites because of unfavorable topographic situation, excessive distance from a suitable water source, or nonavailability of a satisfactory surface site.

Several generally favorable areas remained and these are described in more detail in this section.

Roberts-Plano area

The Roberts-Plano area extends westward from the Egin Bench in the vicinity of Plano to the vicinity of Roberts (fig. 11).

More than half the area included on the map is eliminated from consideration for recharge by water spreading because it is occupied by farms and other developments. Much of the rest of the area is public domain used only for cattle grazing.

Geologic features

Almost all the area is underlain by basaltic lava flows of the Snake River Group. The only exception is some small areas of silicic volcanic rocks north of Egin Lakes and southeast of Rexburg. Both of these are at too high an altitude to be considered for recharging.

In the southeastern part of the area the basalt is overlain by channel, flood plain, and alluvial fan deposits from Henrys Fork, and the Teton and Snake Rivers. The deposits are chiefly coarse sand and gravel, but include some fine sand and silt.

The thickness of these alluvial deposits varies greatly. A few buttes protrude through them, including Menan Buttes and Lewisville Knolls. Elsewhere the thickness ranges from a few to more than 260 feet, according to the few available well logs.

Basalt is at the surface or is mantled by thin windblown deposits in the northwestern three-fifths of the area shown on the map. Low domes mark several centers of extrusion. The most important of these are Little Grassy Butte, about 8 miles west of Plano, and Roberts Butte, about 10 miles northwest of Roberts. According to P. R. Stevens (personal communication) who mapped the 16 townships T. 5-8 N., R. 35-38 E. in connection with another project, the lava flows from Roberts Butte, and west of Roberts are the oldest exposed in the area. The lavas from Little Grassy Butte, those north of Mud Lake, and those north of Little Grassy Butte, are the youngest. All the surficial basalts in this area are believed to be of Pleistocene age. Some of the earlier flows, not exposed, but penetrated by wells, may possibly be as old as Pliocene age.

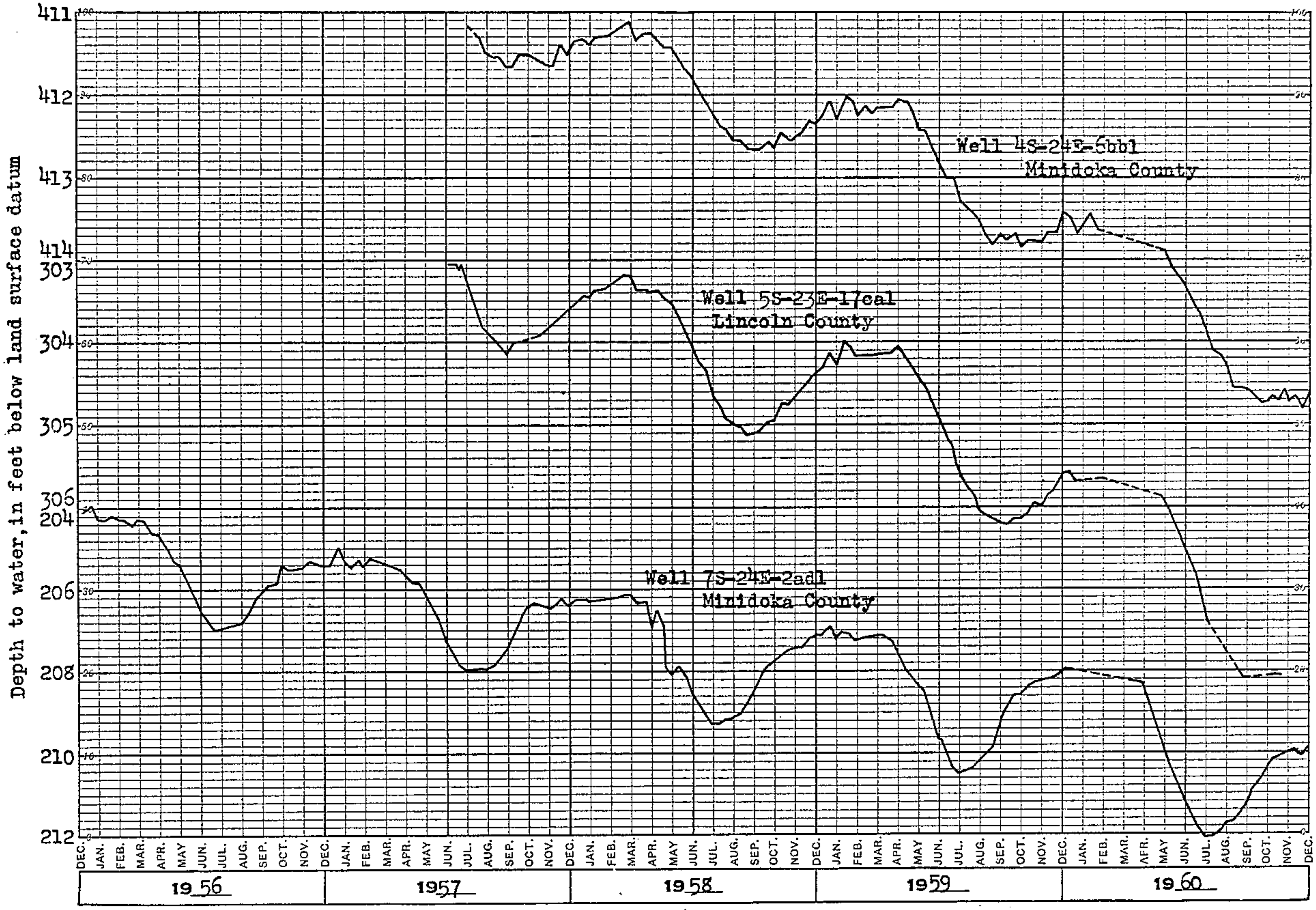

Figure 10.--Hydrographs of wells 7S-24E-2adl, 5S-23E-17cal, and 4S-24E-6bbl.

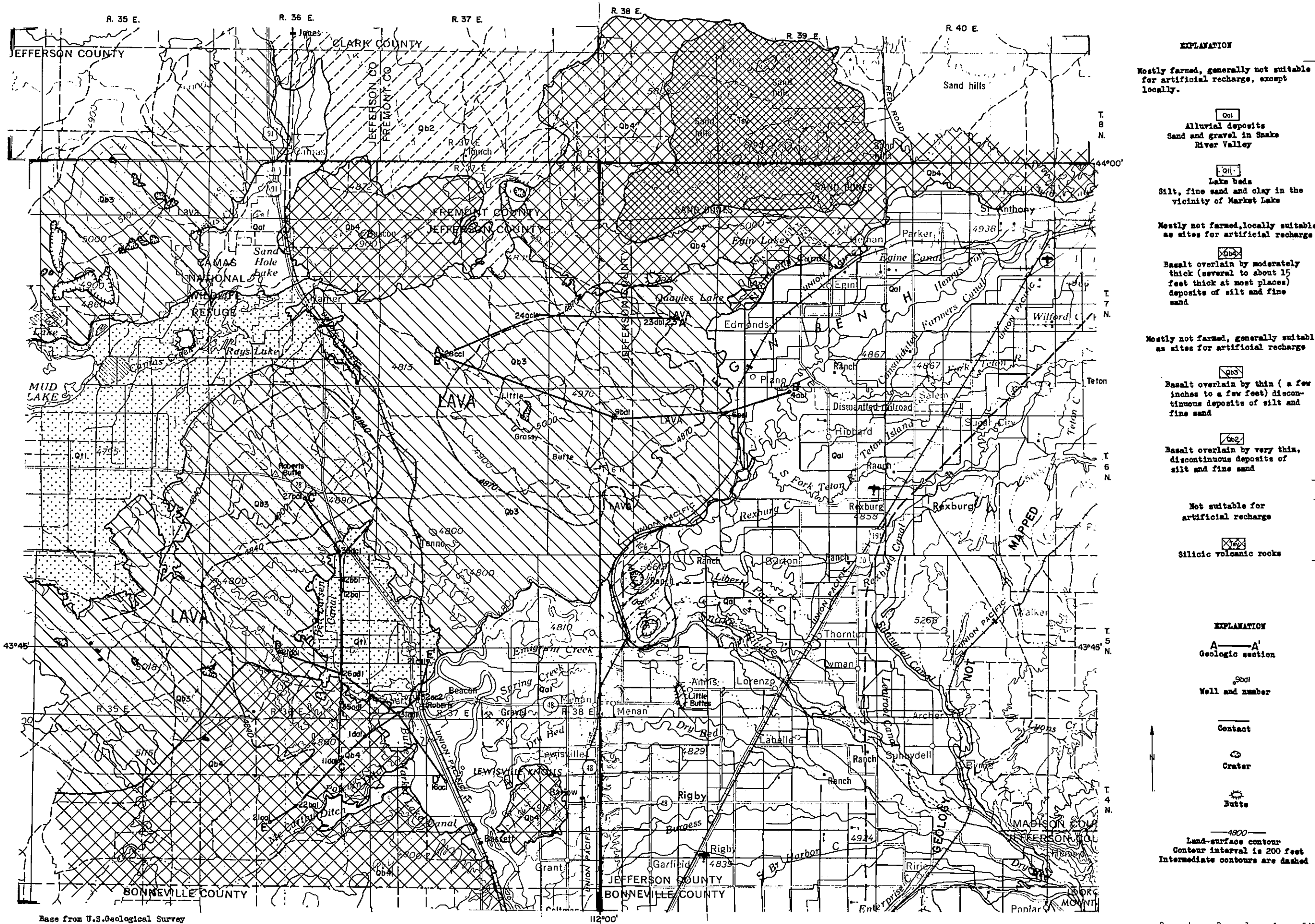

Figure 11.—Map of the Roberts-Plano area showing geologic features relating to recharge feasibility.

The lava flows are characteristically medium gray to black, olivine basalt, commonly open-textured or vesicular. The flow surfaces are very rough and irregular, with many collapse features and pressure ridges. Collapse features range from bowl-shaped depressions a few yards in diameter to very irregular interconnected depressions hundreds of yards across. The nature of the surface of the basalt is shown in the figures 12a and 12b. These photos show many but by no means all of different types of surficial features that are of significance in spreading of water for recharge.

Windblown sand and silt mantle the basalt throughout the area. A major source for these materials is to the west, in the Mud Lake area, and another source is to the southwest, in the vicinity of Roberts. Winds from the west-southwest have spread a blanket ranging in thickness from a few inches to perhaps 20 feet. The deposits are somewhat thicker on the north and northeast flanks of Little Grassy Butte than they are on the south and southwest flanks.

A stratum of sand and gravel is encountered beneath the basalt at an altitude of about 4,800 feet east of Grassy Butte. The few well logs available suggest that this stratum may continue through the area beneath Grassy Butte into the Market Lake area (fig. 13). In the vicinity of Market Lake the basalt is interbedded with lake and playa deposits (fig. 14).

Ground-water features

The main aquifer is basalt and alluvium of the Snake Plain aquifer, generally at a depth of 50 to several hundred feet below land surface. The water table ranges from a few to about 120 feet below the land surface. Perched aquifers have developed in irrigated areas along the Henrys Fork downstream from St. Anthony and the Teton River downstream from Teton.

The perched aquifers are recharged by percolation from canals and irrigated tracts.

The perched aquifers discharge in part into Henrys Fork and the Teton River, but they also lose considerable water by percolation downward to the main water table.

Recharge to the main aquifer is in part from this downward percolation from perched aquifers, and also from percolation from Henrys Fork and the Teton River. The direction of ground-water movement in the aquifer is slightly south of west, (fig. 3).

The water table (fig. 3) is quite flat from the eastern margin of the area to approximately the railroad line between Roberts and Hamer. West of this line fine-grained materials underlie considerable areas in the vicinity of Roberts and Mud Lake and these deposits, apparently form a partial barrier to westward movement of ground water. East of the barrier the main water table is above an altitude of 4,750 feet; a few miles west of the barrier it drops to less than 4,600 feet. Through the barrier zone there are a number of different water tables in basalt flows from the west that interfinger with fine-grained lake deposits to the east.

The total underflow through the area is large. On the basis of data through the period 1920-28, Stearns and others (1938, p. 203) concluded that underflow away from the Egin Bench might be about 280,000 acre-feet a year. In a later study Mundorff and others (1960, p. 169) computed recharge to the aquifer upstream from Firth to be about 2,500,000 acre-feet per year. Their flow-net map (figure 3 of this report) shows an underflow of about 1,000 c.f.s., 725,000 acre-feet per year, through the aquifer between Hamer and Roberts, a distance of about 15 miles. That amount of underflow occurs under a hydraulic gradient of about 5 feet per mile between the Egin Bench and the barrier zone.

Sourde of water and topographic factors

Surplus flood water from Henrys Fork could be diverted near St. Anthony at an altitude of about 5,000 feet. Although this is not the highest possible diversion point, diversions at higher altitudes would be somewhat less desirable because of less favorable topographic and other factors relating to diversion structures and canal alignment. Also, it appears that little advantage could be gained by diverting at higher points. Therefore, for this study, it is assumed that the maximum altitude which could be reached by recharge water is 5,000 feet. The area above 5,000 feet north of St. Anthony and Plano is shown on fig. 11. As can be seen from this map, a canal diverting at 5,000 feet near St. Anthony could convey water westward to an area west of Plano and Egin Lakes. Following approximately along the 5,000-foot contour, water theoretically could be conveyed westward and then northward to eventually reach an area west of Camas and north of Mud Lake. However, this would be a very lengthy route and ample recharge area apparently is available which is much nearer and which would be of equal benefit in recharge of the aquifer.

A few miles west of Plano an area occupied by a wide, low lava dome (Little Grassy Butte) could be used for recharge. However, this dome is entirely surrounded by a sag in the topography. Detailed topographic maps at a scale of 1:24,000 are available for the area east of longitude 112°00', but west of that longitude, and north of latitude 43°45' the only topographic map available is at a scale of 1:250,000 with a contour interval of 100 feet. Study of the available topographic map, air photos and field observation indicates that the maximum altitude by which a gravity canal could reach the lava dome is about 4,870 feet. Thus the part of the dome above that altitude is eliminated. The approximate location of the 4870-foot contour is shown on figure 11.

However, an area of roughly 100 square miles remains around the periphery of the dome to which water could be conveyed by gravity.

West of the railroad between Roberts and Hamer another large area of largely public domain appears suitable for recharge operations. However, a sag in the topography, followed by the railroad, separates this area

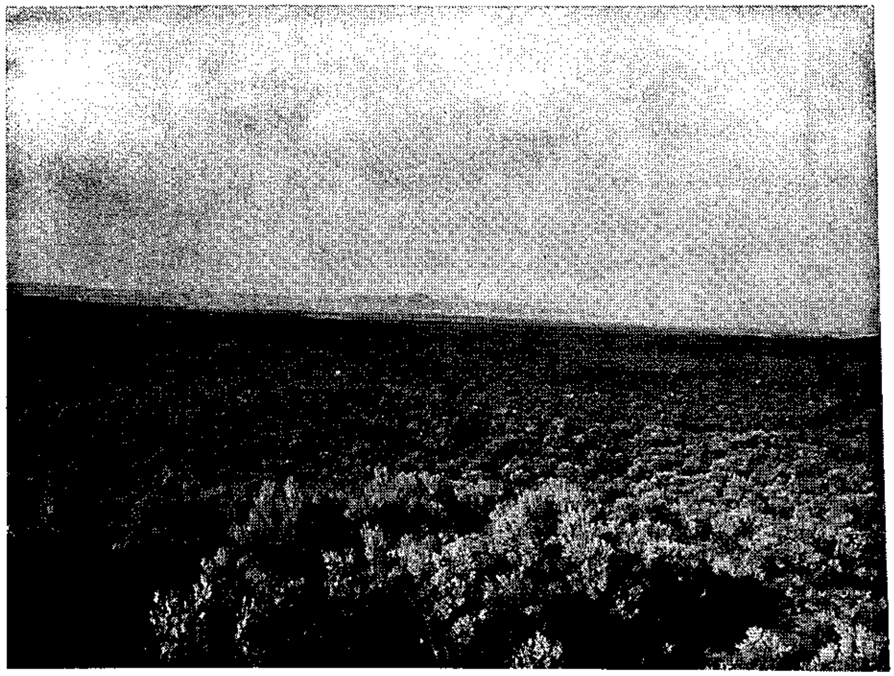

Figure 12a.--Basalt surface on north slope of Little Grassy Butte, T. 7 N., R. 38 E., section 31.

Figure 12b.--Close-up view of basalt in pressure ridge in same area as 12a. (Courtesy U. S. Bureau of Reclamation)

from the one to the east. Altitudes determined by the U. S. Coast and Geodetic Survey along the railroad indicate that a gravity canal probably could not cross this sag at an altitude above 4,830 or 4,840 feet. The approximate location of the 4,840 foot contour is shown on the map, figure 11.

Recharge experiments

Two recharge experiments were conducted in the Roberts-Plano area in 1961 by the U. S. Bureau of Reclamation and the Geological Survey.

Egin Lakes seepage study

Water is discharged into Egin Lakes from the Last Chance Canal by the Fremont-Madison Irrigation District to aid in subirrigation of the district. The lakes consist of a series of shallow ponds, in part separated by dikes and levees (fig. 15). U. S. Bureau of Reclamation personnel installed gages and other facilities for measuring pond elevations, inflow, outflow, and flow between ponds. They also bored 24 auger holes adjacent to the ponds. Surficial materials are light brown to gray, fine- to medium-grained sand; at a few places a little gravel was encountered just above the basalt. All holes except one bottomed on rock, presumed to be the surface of the uppermost basalt flow. Pertinent data on these auger holes are given in the table on the following page.

Most of the seepage loss was in the two largest ponds, labeled "A" and "B" on figure 15. The ponds are connected by a broad channel so that the water surface in both ponds is essentially the same. The area of these two ponds on April 20 and June 7 was determined with the aid of air photos. The ponded area for other times during the test was extrapolated or interpolated from those two measurements on the basis of pond elevation.

Inflow to the Egin Lakes area was measured at station M5 (fig. 15), and the discharge between small ponded areas and broadened segments of the channel was measured at stations M4 and M3. Inflow to ponds "A" and "B" was measured at M2 and outflow at M1. Seepage losses in the channel and small ponds between M5 and M2, and seepage losses from ponds "A" and "B" are summarized in table 4. Average daily seepage loss in the two larger ponds was slightly more than 0.25 acre-foot per acre.

In most auger holes the highest water levels measured were those made upon completion of the hole, or shortly thereafter. Hydrographs of some of the auger holes, and the pond level in ponds A and B are shown in figure 16. The relation of pond level and the perched water table is clearly shown. The slope of the perched water table away from the ponds is shown by the profiles in figures 17, 18 and 19.

The profiles suggest that there was some perching by silt in the pond bottom, and that below the pond a perched aquifer had developed, probably upon the basalt surface. The underlying basalt surface is irregular, and apparently channels the movement of water in preferred directions.

Table 3.--Auger holes in the Egin Lake recharge test area

Auger hole no.	Altitude of Land surface	Altitude of Water level	Date of measurement 1961	Depth of well (feet)	Reached basalt	Altitude of basalt surface	Remarks
1	4,883.21	dry	-	18.9	Yes	4,864.3	
2	4,881.77	4,871.17	4-4	16.9	yes	4,864.9	
3	4,881.11	4,875.41	4-4	14.0	yes	4,867.1	
4	4,881.30	4,879.90	4-4	6.4	yes	4,874.9	
5	4,881.87	4,879.37	4-4	5.6	yes	4,876.3	
6	4,883.48	dry	-	3.3	yes	4,880.2	
7	4,884.49	4,868.59	4-4	22.8	yes	4,861.7	
8	4,883.27	4,872.87	4-4	17.4	yes	4,865.9	
9	4,882.91	4,878.91	4-4	17.1	yes	4,865.8	
10	4,883.03	4,880.73	4-4	12.9	yes	4,867.8	
11	4,883.02	4,875.42	4-4	14.8	yes	4,868.2	
12	4,884.03	dry	-	11.8	yes	4,872.2	
13	4,881.50	dry	-	23.8	yes	4,857.7	
14	4,880.32	4,866.99	4-11	34.0	yes	4,846.3	Cased to 16.8', caved below
15	4,880.38	4,874.36	4-11	38.3	yes	4,842.1	
16	4,880.00	4,876.57	4-11	22.8	yes	4,857.2	
17	4,880.15	4,874.20	4-11	22.3	yes	4,857.9	
18	4,882.51	4,863.87	4-11	22.2	yes	4,860.3	
19	4,881.92	4,873.16	4-11	26.4	yes	4,855.5	
20	4,880.75	4,876.93	4-11	17.3	no	4,863.5	
21	4,880.01	4,876.57	4-11	49.9	yes	4,830.1	
22	4,880.35	4,874.37	4-11	31.5	yes	4,848.9	
23	4,880.35	4,874.38	4-11	30.3	yes	4,850.1	
24	4,882.47	4,872.53	3-11	23.5	yes	4,857.9	

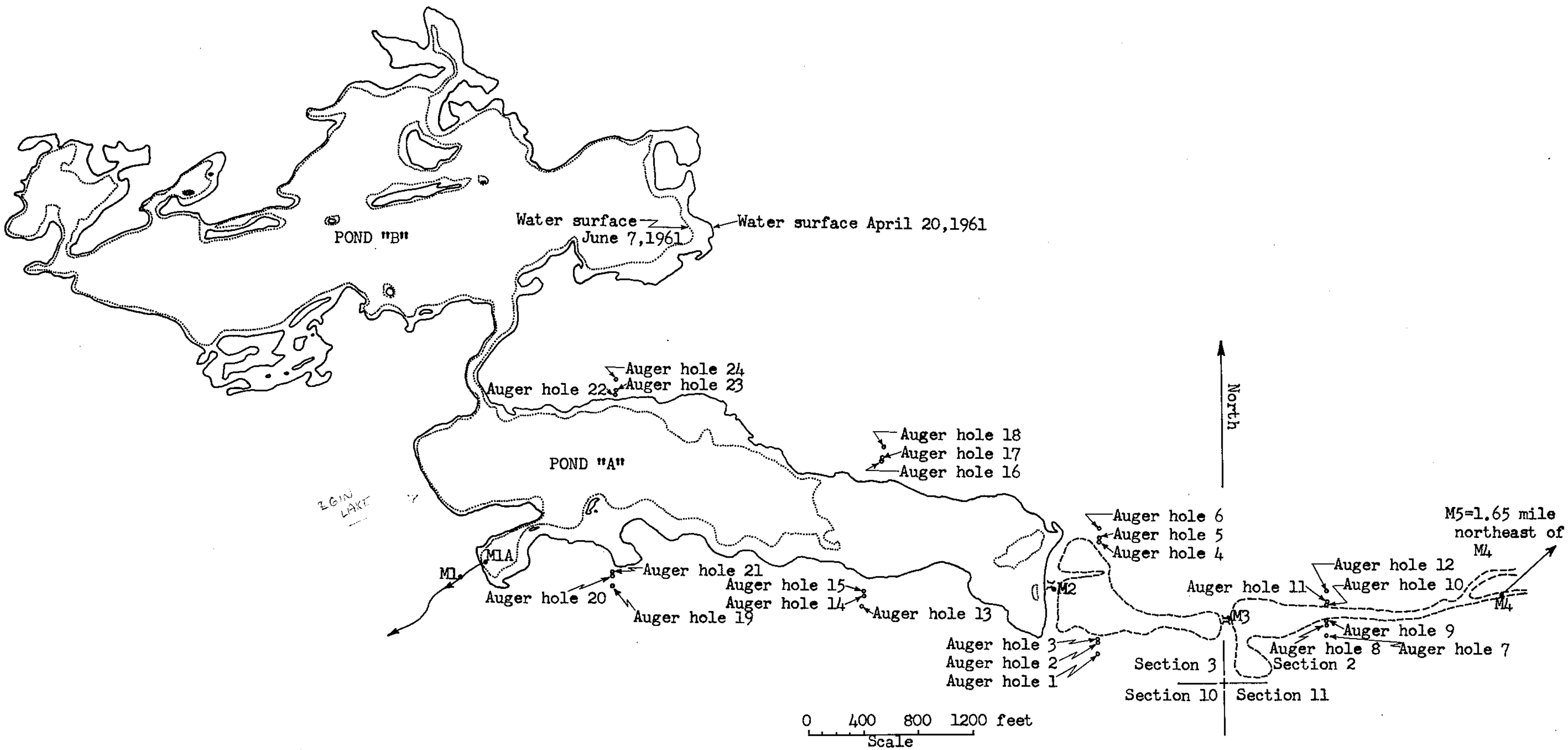

Figure 15.--Map showing Egin Lakes seepage-study area.

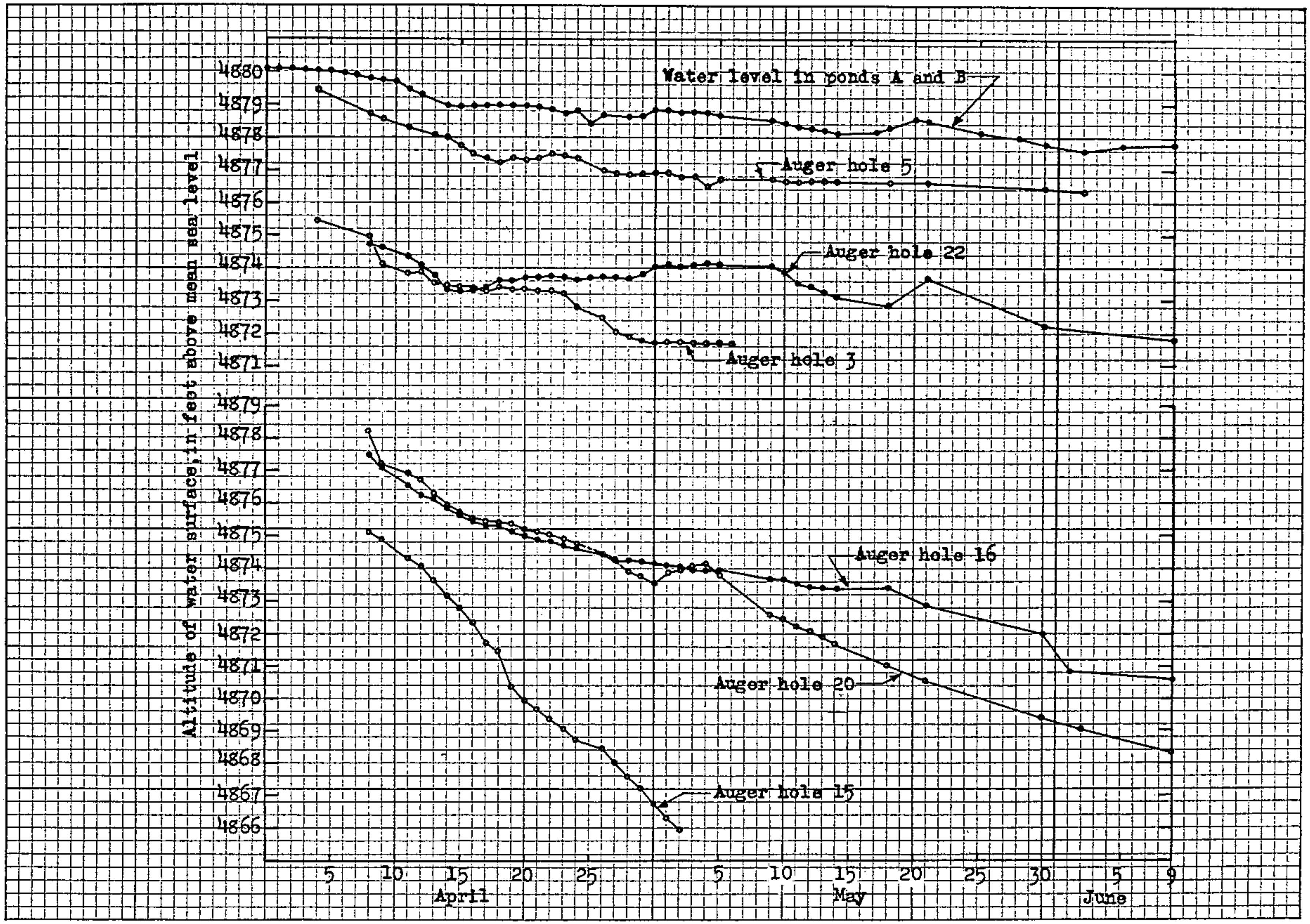

Figure 16.--Hydrographs of auger holes in the Egin Lakes area, and the water level in ponds A and B.

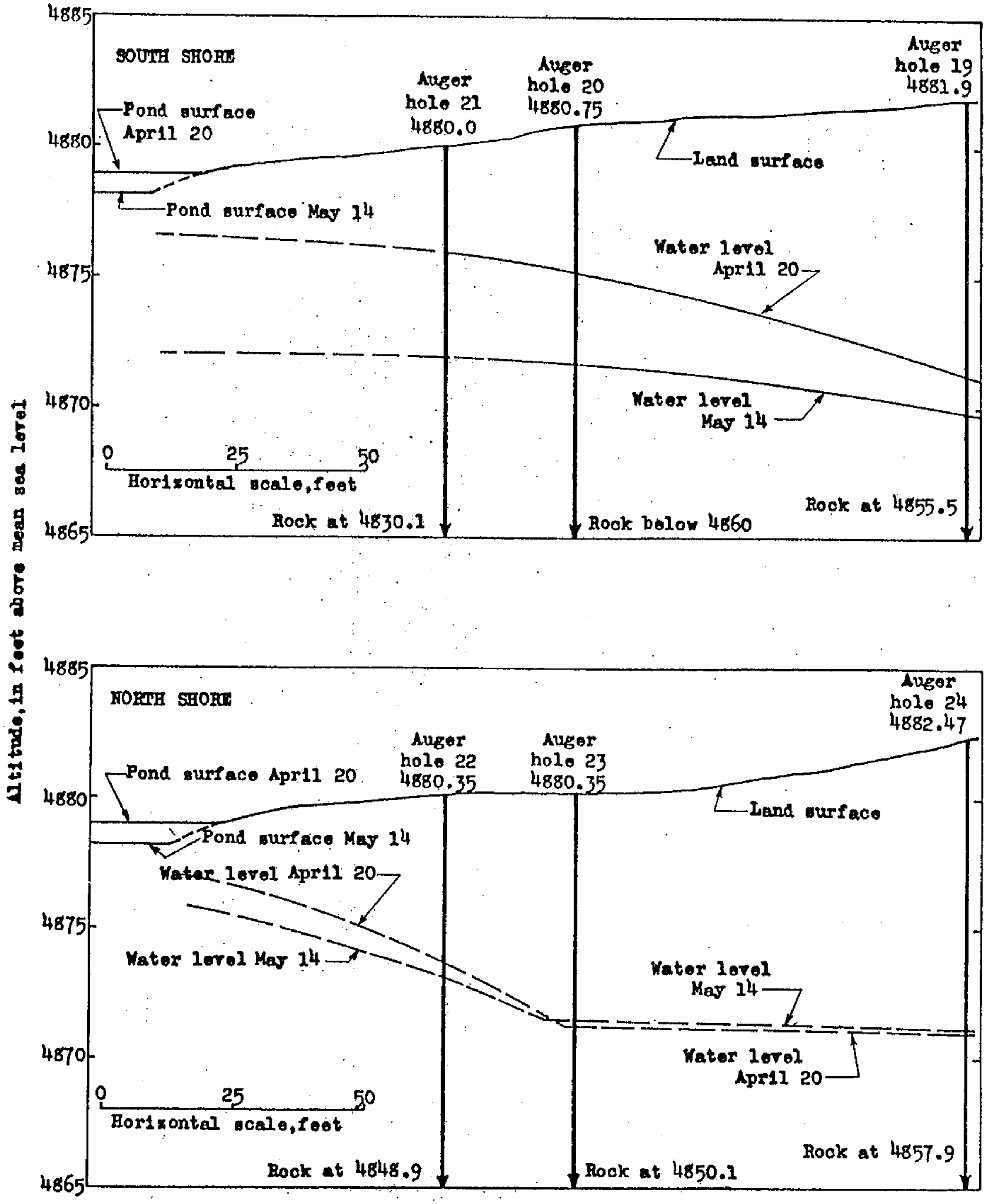

Figure 17.--Profiles from margin of Egin Lakes through auger holes 19, 20, and 21; and 22, 23, and 24.

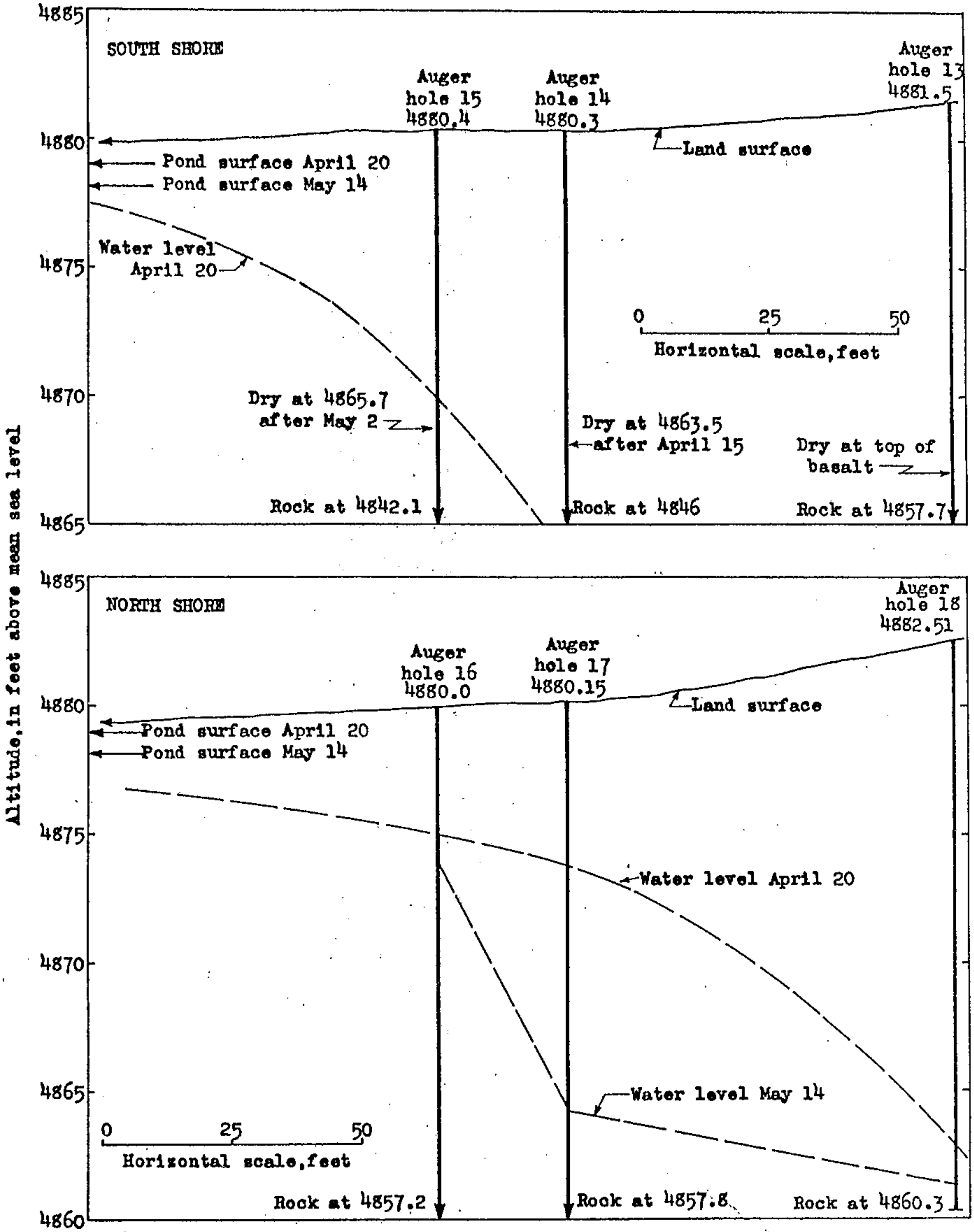

Figure 18.--Profiles from margin of Egin Lakes through auger holes 13, 14, and 15; and 16, 17, and 18.

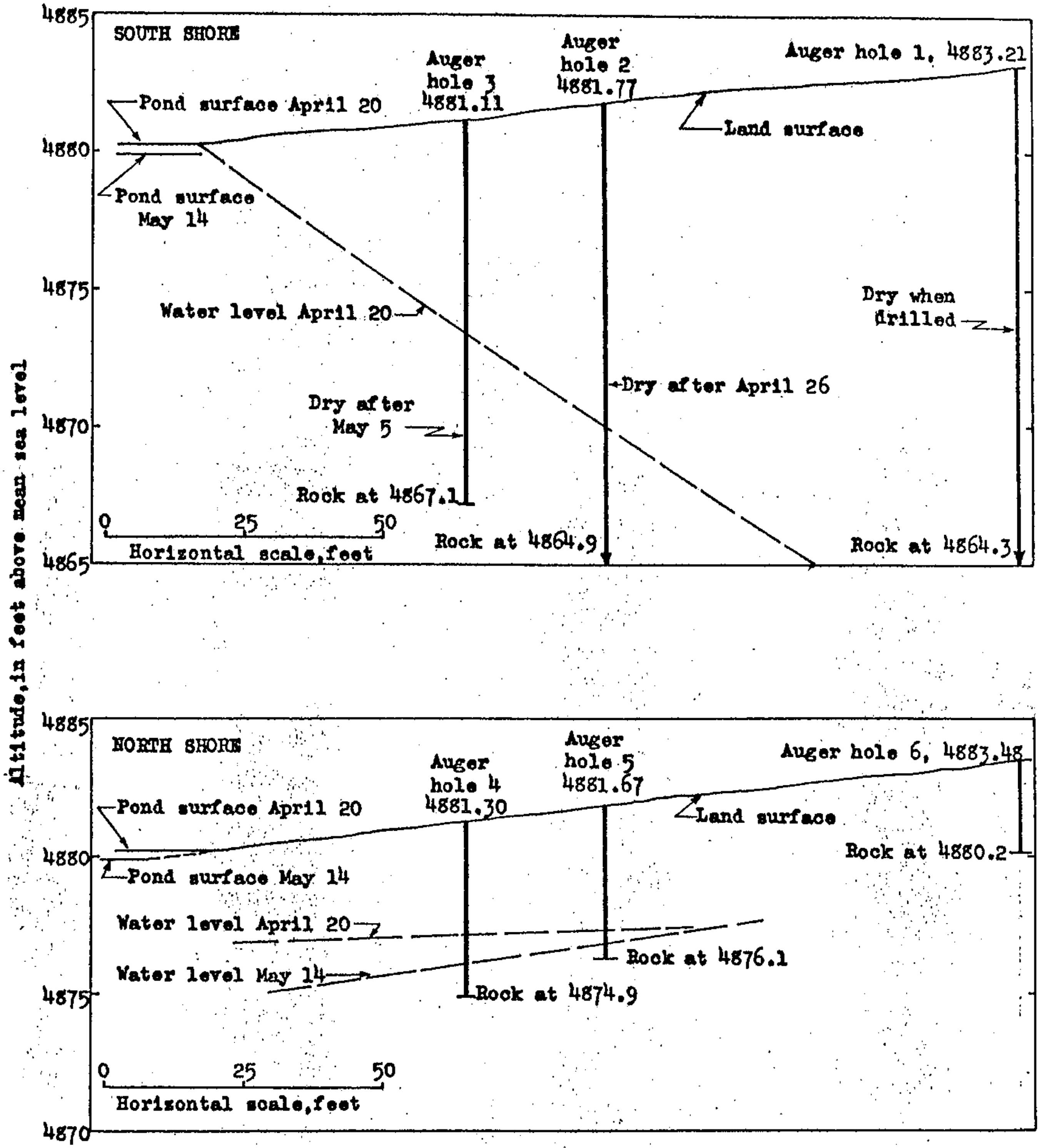

Figure 19.--Profiles from margin of Egin Lakes through auger holes 1, 2, and 3; and 4, 5, and 6.

Table 4.--Summary of seepage losses, Egin Lakes seepage study

Period (1961)	Average daily loss between M-5 & M-2 (acre-feet)	Average daily loss between M-2 & M-1 (acre-feet)	Average area of ponds A and B, (between M-2 & M-1) (acres)	Average daily change in volume of ponds A and B (acre-feet)	Average daily pond evaporation (acre-feet)	Average daily seepage loss from ponds A and B (acre-feet)	Average daily seepage loss (acre-feet per acre per day)
April 1- 5	9.6	62	270	-1.1	-2.6	58	0.224
6-10	6.8	38	256	-19	-2.0	55	.198
11-15	17	28	223	-38	-2.1	44	.160
16-20	16	35	211	+.6	-1.5	33	.156
21-25	16	29	198	-24	-1.4	48	.253
26-30	18	43	198	-19	-2.3	22	.238
May 1- 5	16	64	202	-24	-1.9	45	.235
6-10	26	28	184	-26	-3.8	50	.273
11-15	18	29	172	-12	-2.0	40	.230
16-20	13	69	176	+22	-1.8	45	.260
21-25	16	32	170	-30	-2.0	60	.366
26-30	14	36	149	-25	-2.2	58	.392
May 31 - June 9	18	41	140	-7	-2.1	23	.337
Average	15.7	41				45	.256

A composite sample was taken from each of the 24 auger holes for laboratory determination of permeability. The coefficients of permeability 1/ ranged from 2 to 240, and averaged 87. One-half the samples were between 40 and 160.

A uniform sand with a permeability of 87 would transmit about 10 acre-feet per acre per day by vertical percolation, from a ponding area if there were no perching layers below. The actual rate of seepage was only 2.5 percent of that rate, and the difference can be attributed to 3 different factors. (1) The temperature of the water was considerably below 60° F., probably about 40° to 45°, and the permeability to water of that temperature would be about 20 percent less than at 60° F. (2) Silt in the bottom of the pond apparently reduced the permeability of the top few inches of material. (3) The water was perched at the contact of the sand with the basalt. Cracks and crevices in the basalt are capable of taking large quantities of water, however, they comprise only a small percentage of the surface area of the basalt. Where sand has filled these crevices, the permeability is that of the sand filling. If, for example, the cracks and crevices comprise 5 percent of the area at the top of a flow overlain by sand, then obviously the permeability of the contact zone is only a small fraction of the permeability of either unit by itself.

TW-12 pump-recharge test

A recharge test was made in an area west of the Egin Lakes in May and June, 1961. Water was pumped from well 7N-38E-23db1 (TW-12) into a group of shallow depressions north of the well (fig. 20). A low dike was built across a sag to prevent the water from spreading too far to the north, and to keep the pond to reasonable dimensions.

The basalt in this area is covered by several feet of fine-grained compact sand. A power auger was used to bore 15 test holes to obtain information on the thickness of overburden; and 12 additional holes were bored and cased with downspout for use as observation wells as the pond filled. After the test began it was found that additional auger holes were needed so auger holes 13-21 were bored by hand. Information on the test and auger holes is summarized in table 5. A composite sample was taken from each of auger holes 1-12 (except 10) and test holes 1-3, for laboratory determination of the coefficient of permeability. Permeabilities of the 14 samples ranged from 8 to 140 and averaged 87, the same as in the Egin Lakes area. Only 2 samples had permeabilities of less than 50.

Well 7N-38E-23db1, which furnished the water for the test, is 236 feet deep and obtains water from basalt between 165 and 231 feet (see Section A-A', fig. 13). This aquifer is separated from the uppermost

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1/ The coefficient of permeability (Pm) is defined as the quantity of water, in gallons per day, that will flow through a section of aquifer 1 foot square under unit hydraulic gradient (1 foot per foot) at 60° F.

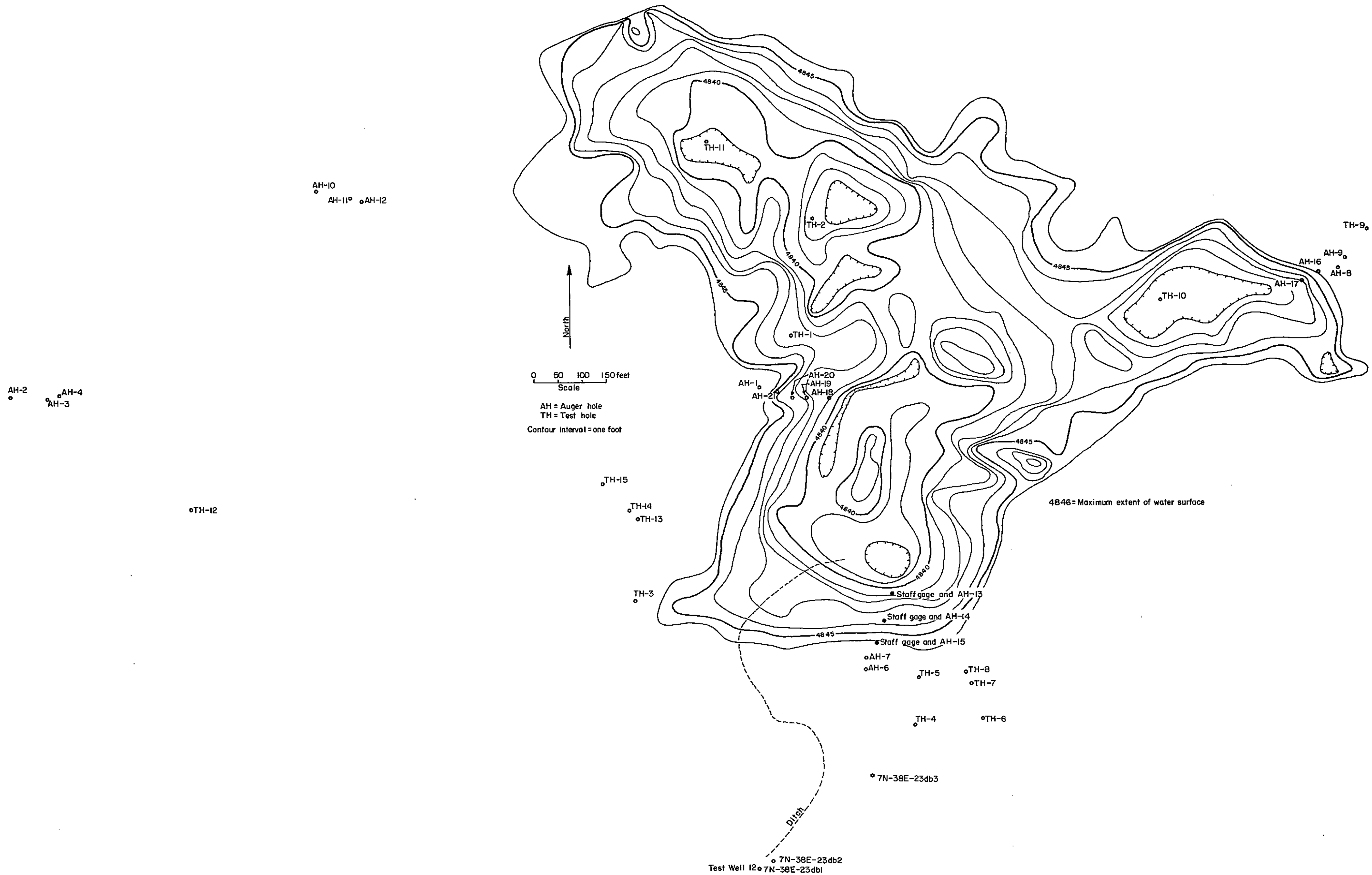


Figure 20.--Map of TW-12 pump-recharge test area.

basalt by 125 feet of silty sand and gravel. Well 7N-38E-23db2, 30 feet east, is 84 feet deep, and ends in the sand and gravel strata. Observations on the water levels in the two aquifers indicate that they are poorly interconnected, and that water in the sand and gravel is perched.

The production well, 23db1, was pumped at a rate of 2,400 to 2,600 g.p.m. Pumping began May 16, but because of engine trouble, pumping time totaled only 137 hours for the first 10 days of the test. Thereafter, pumping went somewhat better and total pumping time amounted to 673 hours between May 16 and June 21. During that period a total of 317 acre-feet of water was pumped. Data are summarized in table 6.

The average seepage loss from the pond during the test was 0.29 acre-f[redacted] acre per day. However, the [redacted] decreased during the test, and after the test ended as the [redacted] in size.

The average thickness of sand overburden in the 27 test and auger holes which reached basalt was 6.5 feet. The average thickness of overburden in the 4 holes reaching basalt within the area actually ponded was 7.5 feet. Generally, the greatest thickness of overburden is found in the bottoms of the depressions, basalt is exposed at many places at higher points, at places with gaping cracks. It is probable that as the pond filled, the seepage rate should increase, and if the water reached open cracks and crevices in the basalt, seepage losses into these might be many times greater than through sandy and silty overburden.

Water-level measurements in the auger holes, illustrated in part by the profiles in figure 21, indicate that a perched water table developed on top of the basalt. However, the perched aquifer was never very much larger than the pond, and the margins of the perched aquifer were steep.

During the recharge test, a water-level recorder was in operation on well 7N-38E-23db2, which ends in the perched aquifer in sand and gravel between the two basalt flows. The water level in this well rose (fig. 22), beginning the day that the test began, and virtually ceased to rise the day pumping ended (fig. 22). This water table was about 30 feet below the shallow perched water table that developed beneath the pond. The rise in the lower perched water table is believed not to be related to seepage from the pond, but to some other cause, perhaps loading of the pond, or to a general water-table rise caused by some other factor. There are two reasons for this belief. First, the rise ended the day pumping ceased, yet seepage from the pond continued at nearly the same rate for a week longer. Second, the aquifer supplying the water for the recharge experiment also rose during the pumping period, and by an approximately similar amount (see fig. 23). Several measurements of the static level were made in the pumped well, 7N-38E-23db1 at times when the pump was off during the test period; also, a water-level recorder was operated on well 7N-38E-23db3, which is in the same aquifer, 300 feet from the pumped well.

Summary

The seepage rates from the recharge experiments indicate that large areas would be required for recharging if only the bottoms of the depressions are utilized. For example, with a seepage rate of 0.25 acre-foot per acre per day, 4,000 acres would be required for recharging 1,000 acre-feet per day. However, as the water fills and overtops these depressions to spill from one to the other, open cracks and crevices in the basalt will furnish avenues for recharge at rates manyfold greater. Several methods of improving the intake are described in a later section of the report.

Considering the size of the area available for recharge, and the large quantities of water recharged from irrigation in nearby areas much less favorable for recharge, it is a reasonable conclusion that artificial recharge in this area would be successful.

Probable effects of large-scale artificial recharge in the area

Specifically, the question is: What will be the changes in the hydrologic regimen if a certain quantity of water is added to the aquifer in this area? The effects of recharge can be evaluated by two basically different methods. These are: (1) analysis of the effects of presently occurring recharge, from streams and irrigation; and (2) theoretical analysis based on assumed coefficients of transmissibility and storage, and boundary conditions.

In a previous section of the report it was estimated that about 725,000 acre-feet of water was recharged to the aquifer each year by percolation loss from the streams and from irrigation. Recharge from the streams is a continuous process, but recharge from irrigation is a cyclic process that accounts for perhaps 300,000 to 400,000 acre-feet of the total annual recharge in the area. The effect of this cyclic recharge is shown by the hydrograph of well 7N-38E-23db1 (TW-12) (fig. 23) which is a few miles west of the irrigated area. Annual cyclic fluctuation in this well is about 4 feet. However, if recharge had not occurred, the water table would have continued to decline, as shown by the dashed line in figure 23. That is, recharge of 300,000 to 400,000 acre-feet over an area of 3 or 4 townships (120-150 square miles) during the irrigation season results in a rise in the main water table of about 6 feet in a well a few miles from the edge of the irrigated area.

Periodic measurements made on observation wells farther to the west are insufficient to adequately define the spread of the recharge mound.

In their report on ground water for irrigation in the Snake River basin, Mundorff and others (1960, p. 189) estimated that pumping 112,500 g.p.m. from 50 wells (about 250 c.f.s.) in the Roberts-Plano area would lower the water table about 3.5 to 4.5 in individual wells at the end of one season's pumping (122 days). Drawdown at a point 2 or 3 miles from the line of wells would be on the order of 3 feet. Buildup of the water table by recharge of 250 c.f.s. for 122 days would be the same amount, about

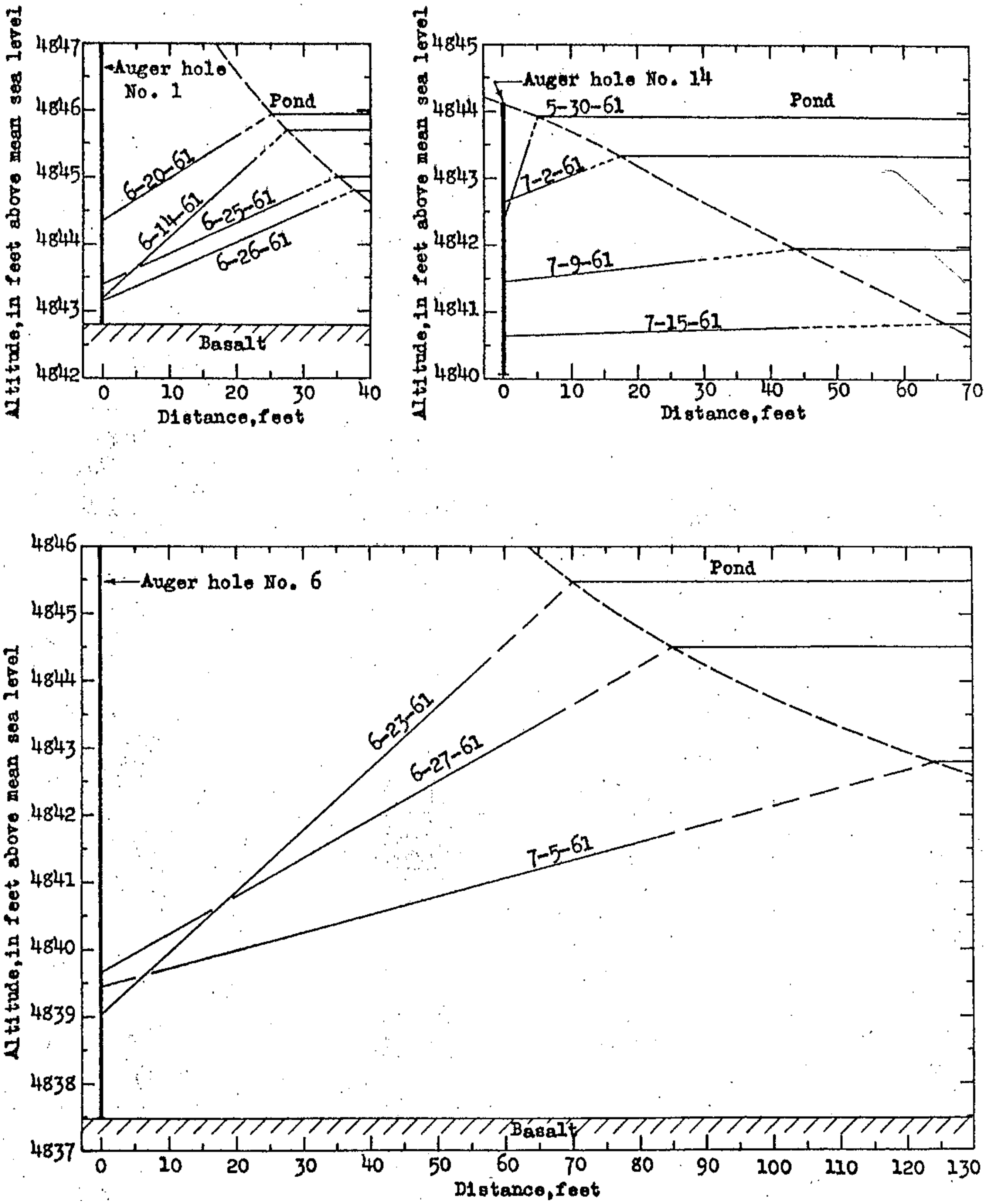


Figure 21.—Profiles of water surface between the pond and selected auger holes.

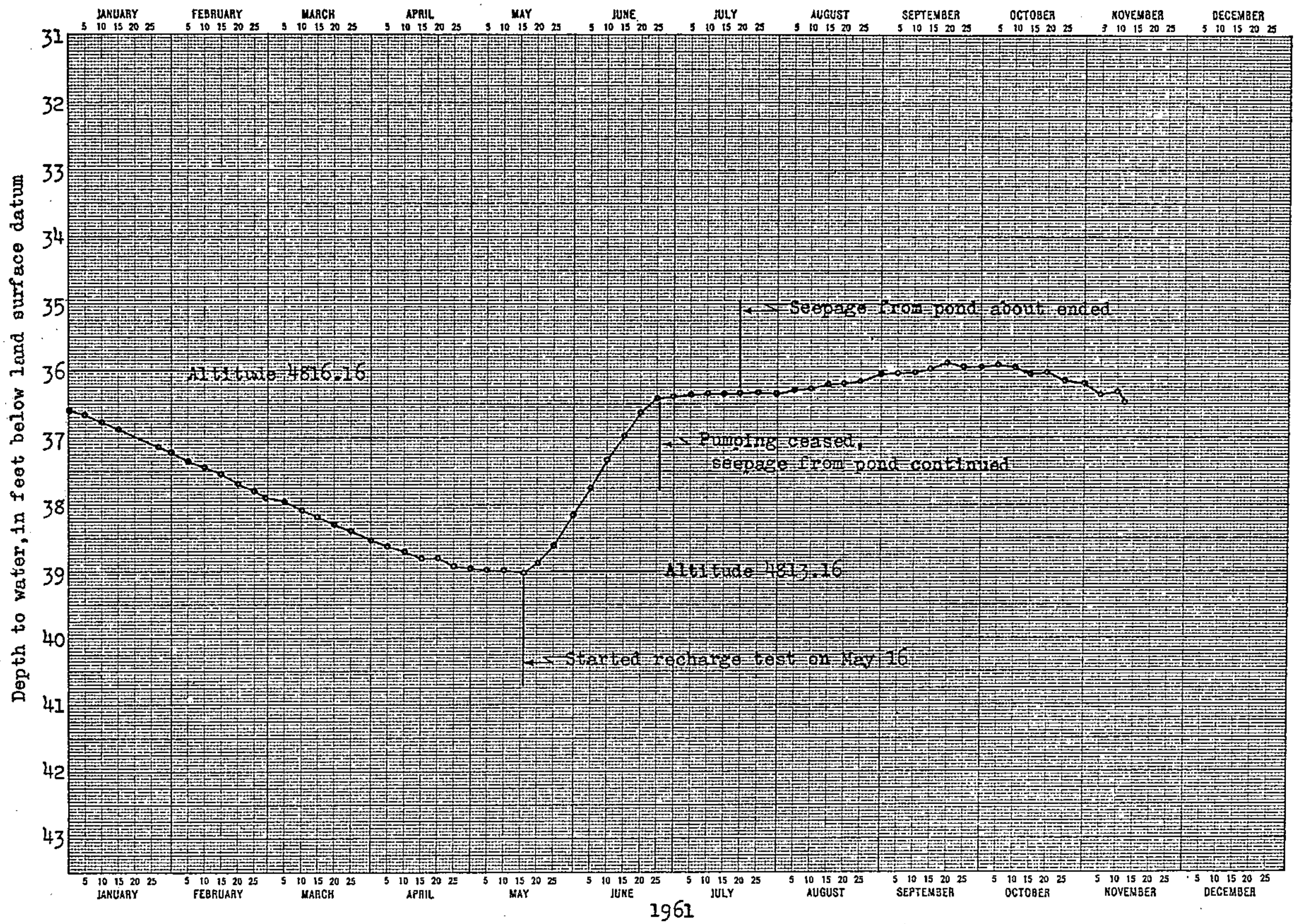


Figure 22.--Hydrograph of well 7N-38E-23db2,preceeding, during, and following TW-12 punp-recharge test.

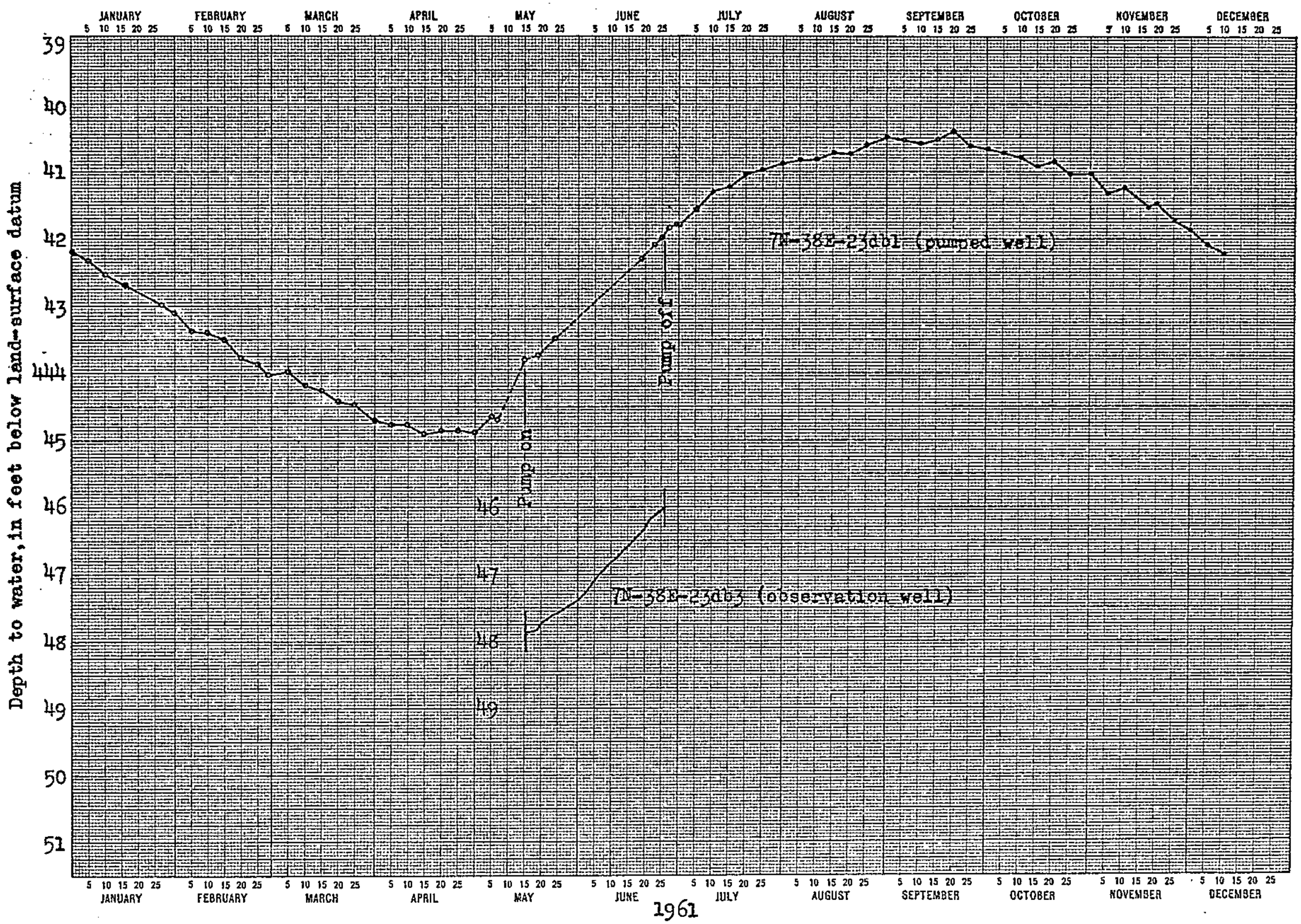


Figure 23.--Hydrographs of well 7N-38E-23db1 and 23db3.

Table 5.--Test and auger holes in the TW-12 recharge test area

Test hole no.	Depth to rock 1/	Test hole no.	Depth to rock 1/	Test hole no.	Depth to rock 1/
1	14.1	6	4.0	11	2.3
2	7.6	7	3.3	12	3.6
3	2.3	8	8.6	13	3.0
4	6.3	9	7.3	14	2.6
5	7.0	10	6.2	15	4.0

Auger hole No.	Depth to rock 1/	Altitude of Land Surface	Altitude of Basalt	Auger hole no.	Depth of Hole	Altitude of land surface
1	6.4	4,849.23		13	3.0	4,842.64
2	9.6	4,852.20		14	4.0	4,844.08
3	7.6	4,849.64		15	5.4+	4,846.62
4	5.6	4,848.44		16	4.1+	4,845.20
5	9.6	4,852.51		17	2.8	4,842.19
6	12.7	4,850.19		18	4.3+	4,840.91
7	9.5	4,849.11		19	6.5+	4,842.36
8	5.6	4,848.50		20	5.0	4,845.18
9	5.3	4,849.75		21	6.5	4,846.83
10	7.3	4,848.51				
11	7.2	4,849.37				
12	5.6	4,848.62				

1/ All test holes, and auger holes 1-12 bottomed on basalt.

Table 6.--Data from TW-12 Pump Recharge Test

Period	Number of days	Water pumped (acre-feet)	Pond elevation 1/ (feet above sea level)	Change in elevation	Volume 1/ of pond (acre-feet)	Change in storage (acre-feet)	Pond evaporation (acre-feet)	Seepage (acre-feet)	Average ponded area (acres)	Seepage (acre-feet acre day)
May 16-18	3	18.6	4,841.53		16.2	+16.2	0.10	2.2	-	-
19-20	2	11.7	4,841.49	-0.4	16	- .2	.20	11.7	8.9	0.66
21-25	5	35.6	4,842.99	+1.50	32.5	+16.5	.71	18.4	11.5	.32
26-30	5	52.6	4,843.99	+1.00	51.0	+18.5	1.38	32.7	17.3	.38
May 31-June 4	5	50.0	4,844.82	+ .83	67.5	+16.5	1.27	32.2	19.5	.33
June 5-9	5	47.0	4,845.51	+ .69	82.5	+15.0	1.60	30.4	22.0	.26
10-14	5	44.5	4,845.75	+ .24	88.3	+ 5.8	1.92	36.8	23.9	.31
15-19	5	43.1	4,845.91	+ .16	92.2	+ 3.9	2.44	36.8	24.9	.30
20-21	2	13.8	4,845.89	- .02	92.1	- .1	1.38	12.5	24.7	.25
22-25	4	0	4,844.85	- .96	68.0	-24.1	2.0	22.1	23.0	.24
26-July 1	7	0	4,843.45	-1.40	41.1	-26.9	2.9	24.0	18.0	.19
July 2-7	6	0	4,842.25	-1.20	23.3	-17.8	1.8	16.0	13.5	.20
8-13	6	0	4,841.11	-1.14	9.4	-13.9	1.3	12.6	9.5	.22
14-19	6	0	4,839.70	-1.41	1.9	7.5	.5	7.0	5.0	.23
Total - - - -		316.9								
Average - - - - - - - - - - - -										0.29

1/ At end of period listed.

3 feet, assuming the same hydraulic factors. Buildup for a recharge rate of 500 c.f.s. would be double the amount for 250 c.f.s.

The Snake Plain aquifer discharges into the American Falls Reservoir reach and the Hagerman Valley reach, as described earlier in the report. Flowlines on figure 3 indicate that, of the total underflow in the section at right angles to the flowlines between Blackfoot and Arco, about 40 percent discharges into the American Falls Reservoir reach and 60 percent into the Hagerman Valley reach. Therefore, about 40 percent of the water recharged in the Roberts-Plano area probably would be tributary to the American Falls Reservoir reach and 60 percent would be tributary to the Hagerman Valley reach.

The rate at which the recharge mound spreads, and the time-distribution of the increased discharge into the American Falls Reservoir reach is of considerable importance. A mathematical analysis can be made, by assigning average values for the coefficients of transmissibility and storage, and making some simplifying assumptions regarding boundaries. The boundaries shown on figure 3 are too complex for solution. They can be approximated by disregarding the boundary between Hamer and Idaho Falls, and shifting the remaining boundaries to form a rectangle with straight-line negative boundaries on the northwest, southeast, and northeast, and one positive boundary, representing the American Falls discharge area, to the southwest. Solution with even this simplified set of boundaries is very tedious and requires a great amount of time. Theoretically, an infinite series of image wells are required; actually with the configuration assumed, 19 image wells suffice within the time limits used. However, with the simplified boundaries, and 19 image wells, the time required for a solution was still too great, so the problem was further simplified. The negative boundaries were disregarded, and only one image well was used, reflected across an assumed straight-line positive boundary crossing the flowlines at about the upper end of American Falls Reservoir. With this assumption a graph, figure 24, was constructed showing the time-distribution in head changes in the aquifer at a point 5 miles upgradient from the positive boundary. Assuming that the changes in head are in direct ratio to changes in underflow, the area under the curve represents the total gain in underflow, at the point, caused by addition of a specific quantity of water in the Roberts-Plano area and the percentage of gain in underflow can be determined for each year. The curve was constructed by assuming continuous addition of 100,000 g.p.m. for a period of six months; however, the rate of discharge does not affect the percentage distribution of the gain in discharge.

Use of only the positive boundary, and disregarding the 3 negative boundaries, may be justified by the following line of reasoning. The magnitude of the "wave" of recharge is greatly affected by the negative boundaries, but the rate of spread of the recharge mound toward the positive boundary would not be. As a check, several points were computed using the 19-image well array. These points plotted above, but generally parallel to the curve in figure 24. The curve was used in constructing the table on the following page which can be used to determine the gain in discharge in any year, caused by recharge of a specific quantity of water.

Table 7.--Increased inflow to American Falls Reservoir reach caused by recharge in the Roberts-Plano area 1/

Years since recharging began	Years of consecutive recharging								
	1	2	Cumulative	3	Cumulative	4	Cumulative	5	Cumulative
1	0		0		0		0		0
2	12	0	12		12		12		12
3	15	12	27	0	27		27		27
4	13	15	28	12	40	0	40		40
5	11	13	24	15	39	12	51	0	51
6	9	11	20	13	33	15	48	12	60
7	7	9	16	11	27	13	40	15	55
8	6	7	13	9	21	11	32	13	45
9	5	6	11	7	18	9	27	11	38
10	4	5	9	6	15	7	22	9	31
11	4	4	8	5	13	6	19	7	26
12	3	4	7	4	11	5	16	6	22
13	3	3	6	4	10	4	14	5	19
14	2	3	5	3	8	4	12	4	16
15	2	2	4	3	7	3	10	4	14
16	1	2	3	2	5	3	8	3	11
17	1	1	2	2	4	2	6	3	9
18	1	1	2	1	3	2	5	2	7
19	0	1	1	1	2	1	3	2	5
20	0	0	0	1	1	1	2	1	3

1/ In percent of quantity of water recharged annually.

Percent of area under the curve			
Year	Percent (rounded)	Year	Percent (rounded)
1	0	11	4
2	11	12	3
3	15	13	3
4	13	14	2
5	11	15	2
6	9	16	1
7	7	17	1
8	6	18	1
9	5	19	0
10	4	20	0

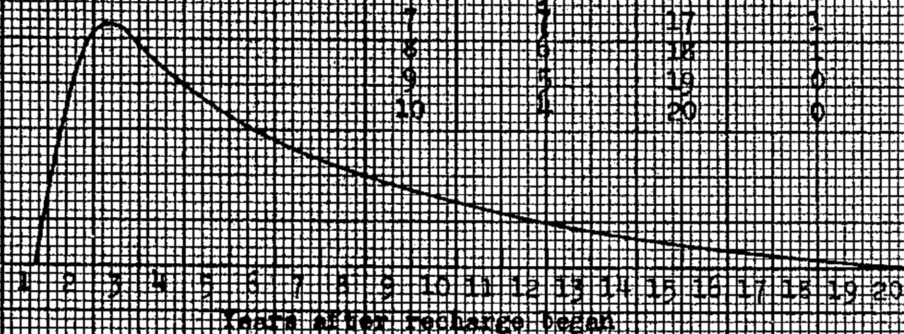


Figure 24.—Time-distribution of head changes in Snake plain aquifer.

The table shows that, if a certain amount of water were recharged to the aquifer west of Plano during a single season, the entire effects would be dissipated in about 20 years, with the rate of dissipation, in the American Falls area being 0% in the first year, 12% in the second, 15% in the third, and so on. With five successive seasons of recharge, the amount of recharge being the same each year, the rate of dissipation of the annual addition of this recharge would be 0 percent in the first year, 12 in the second, 27 in the third, 40 in the fourth, and so on.

Although, because of the simplifying assumptions made, the curve and tabular data may be in considerable error, they do give a general indication of the time-distribution of return to American Falls Reservoir.

The above discussion should not be taken to mean that the only benefit would be increase in discharge into the American Falls Reservoir and Hagerman Valley reaches of Snake River. In the process, the water table would be maintained at higher levels. For example, recharge of 1,000,000 acre-feet of water would maintain the water table at an altitude which would have resulted if pumping had been 2,000,000 acre-feet less (assuming 1,000,000 consumptive use). Or, recharge of 1,000,000 acre-feet would permit pumping of 2,000,000 acre-feet more water, without any additional drawdown. Thus, the benefits would be partly in the increased discharge into American Falls Reservoir, and partly in the maintenance of higher water levels.

Idaho Falls area

The Idaho Falls basalt recharge area extends west and southwest from Idaho Falls (fig. 25). The area which might be suitable for recharge by spreading forms an irregular, discontinuous strip a few miles wide trending southwestward beginning a few miles southwest of Idaho Falls. This strip is bounded on the southeast by fully occupied and developed lands, and on the northwest by lands too high to be reached by any feasible gravity diversion of surface water for recharge. However, within the strip remaining are many square miles that apparently are ideally suited for artificial recharge.

In addition to recharge possibilities in the basalt, gravel deposits adjacent to the Snake River could be used for recharging.

Geologic features

Except for the southeastern corner, the entire area is underlain by basalt of the Snake River Group and alluvial deposits which together comprise the Snake Plain aquifer. The southeastern corner, southeast of alluvial valley of the Snake River, is underlain by a varied assemblage of older volcanic rocks, whose only significance in this investigation is that they have a much lower permeability than that of the Snake Plain aquifer, and therefore form a negative hydraulic or barrier boundary.

Alluvial deposits about 40 to 130 feet thick overlie the basalt of the Snake River Group in a strip 5 to 10 miles wide along the Snake River. Basalt is exposed only at a few places in this strip, where the Snake River has cut through the alluvium into underlying knobs or ridges of basalt as at Idaho Falls and Woodville. Southwest of Moreland, on a terrace parallel to the Snake River, alluvial sand and gravel fill depressions in what must have been a very irregular basalt surface. Generally the sand and gravel is not more than a few tens of feet thick and is of limited extent. Basalt crops through at many places.

Basalt overlain by varying amounts of windblown silt and playa deposits occupies the northwestern half to two-thirds of the area. The exposed basalt flows were extruded during many different periods of volcanism, probably all in the Quaternary Period. In general, the oldest flows have the greatest thickness of overburden and the youngest have the least. For this study, however, age is relatively unimportant of itself, and the lavas have been separated into four groups on the basis of thickness and continuity of overburden. Basalt shown on the map with the symbol Qb_4 is overlain by moderately thick (5 to 15 feet) and continuous deposits of silt and is farmed at many places. Units shown as Qb_3, Qb_2, and Qb_1 have successively lesser amounts of overburden; Qb_1 is essentially bare (fig. 26).

Northwest of the Snake River alluvial deposits intertongue with basalt flows at depth. The alluvial deposits lens out toward the northwest and a few miles from the river the only sedimentary materials interbedded with the basalt are occasional layers of fine sand and silt which were deposited in the playas or as windblown deposits (figs. 27, 28, and 29).

Ground-water features

The basalt of the Snake River Group, and alluvial sand and gravel together comprise the Snake Plain aquifer in the Idaho Falls area. Recharge to the aquifer is by percolation from Snake River and from irrigation, as shown by the water table and flow-net map, figure 3. The importance of irrigation to recharge is shown by the pronounced rise in the water table, generally 15 to 30 feet, each spring after irrigation begins (fig. 30). Flowlines indicate that the water is moving westward beneath most of the area of recharge, but turns southwestward a few miles west of the Snake River, and much of the water discharges into the reach of the Snake River between Blackfoot and American Falls, as described in a previous section of the report.

The depth to water through the irrigated area (the recharge area) generally is 50 to 150 feet. Westward, as the land surface rises, and the water table declines, the depth to water is progressively greater. There apparently are local perched aquifers at a few places, but no extensive perched aquifer has developed as is found in the Egin Bench-Lower Teton River area.

Figure 26.--Basalt surface near the southeast corner of section 33, T. 1 N., R. 35 E.

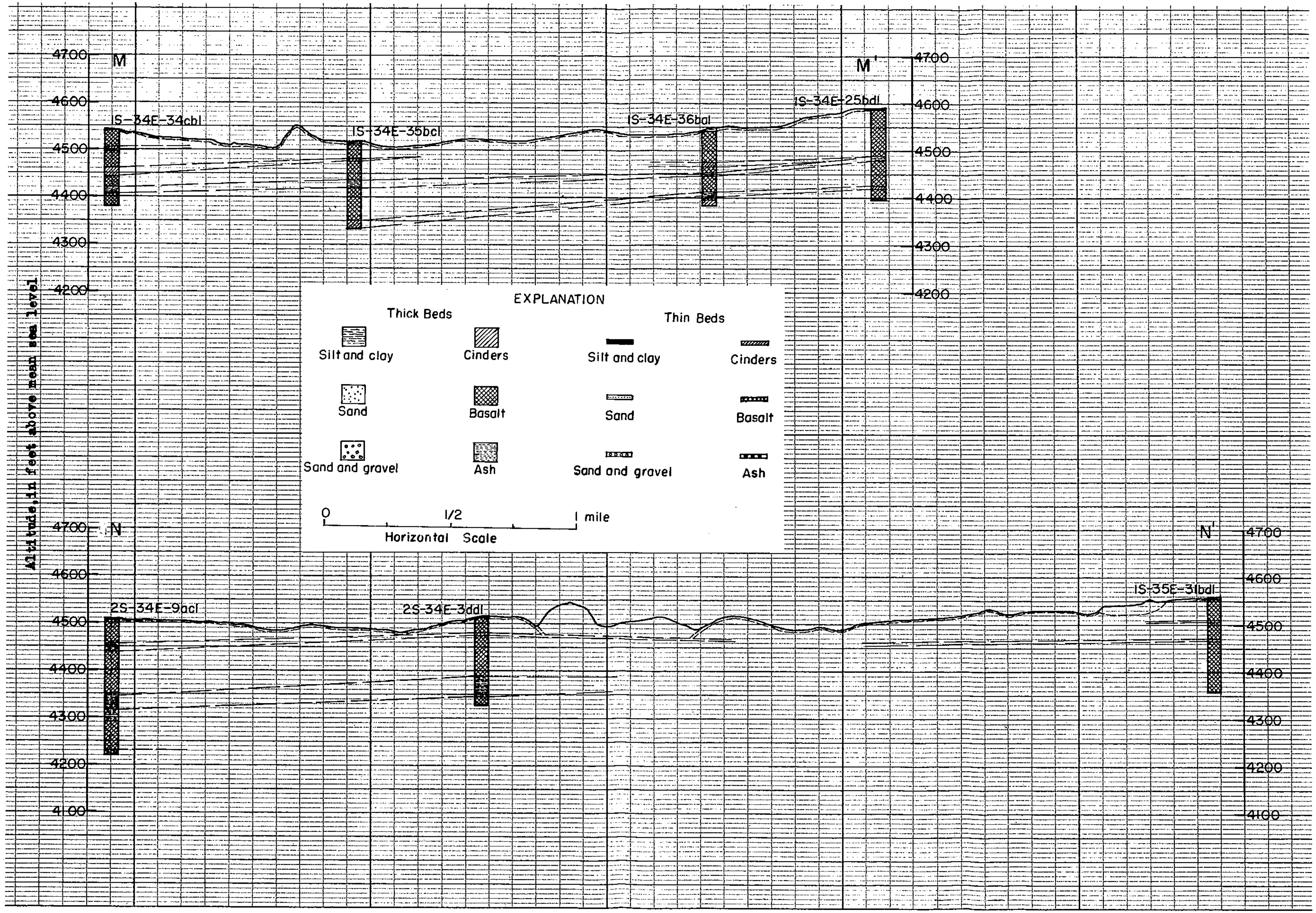


Figure 29.--Geologic sections M-M' and N-N', in area north of Moreland.

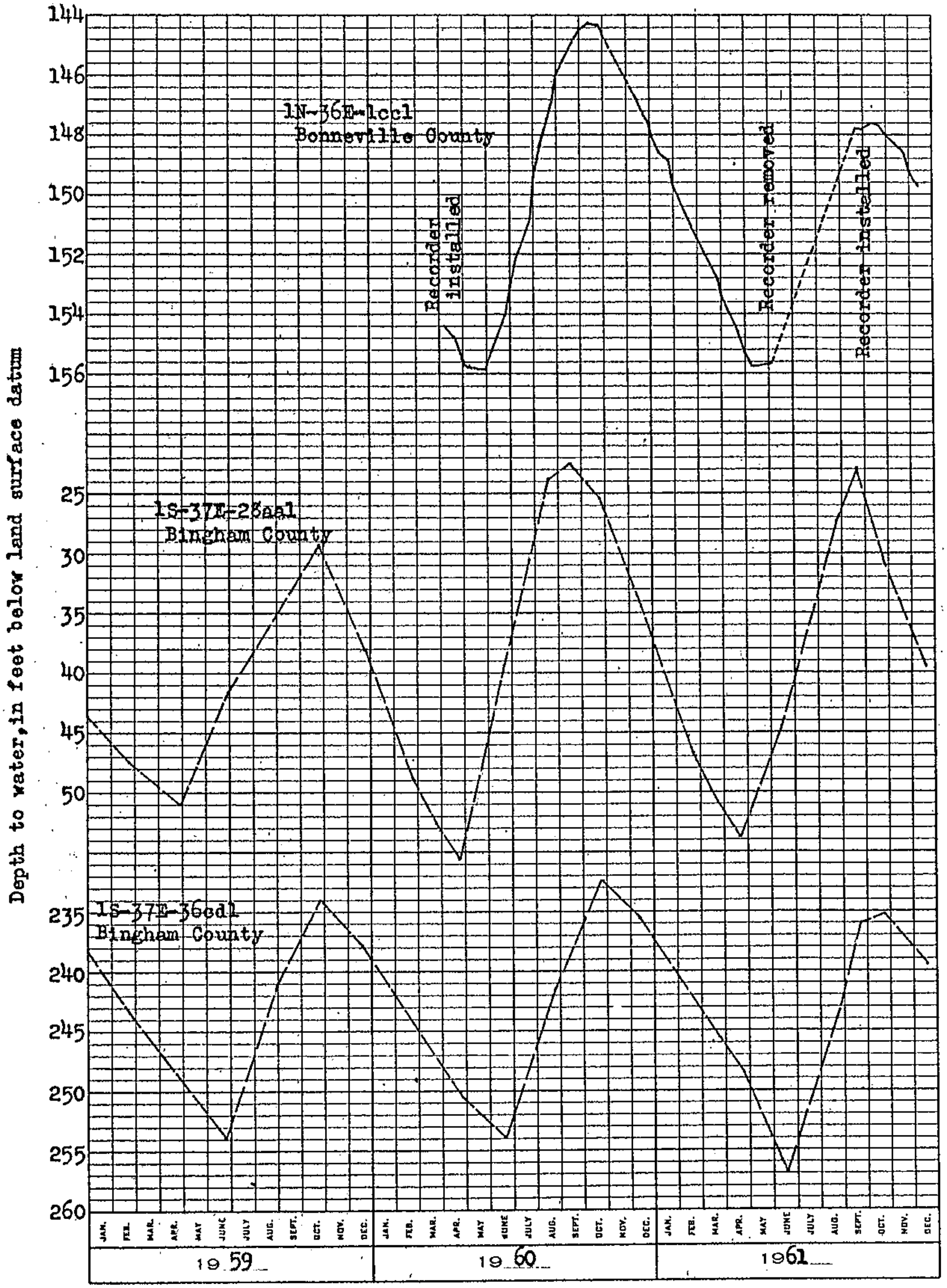


Figure 30.--Hydrographs of wells in the Idaho Falls area.

Underflow in this section of the Snake Plain aquifer is large. According to the flow net (fig. 3) underflow ranges from about 100 to 150 c.f.s. per mile of aquifer width with a hydraulic gradient 4 to 8 feet per mile.

Source of water and topographic features

The only feasible source of water for artificial recharge is the Snake River. Availability of surplus water from the Snake River was summarized on page 11. For the purposes of this study it was assumed that the maximum diversion would be 120,000 acre-feet a month.

Water could be diverted from the Snake River at some point downstream from its junction with Henrys Fork, which is at an altitude of 4,800 feet.

Studies by the U. S. Bureau of Reclamation (written communication August 1961) indicate that the most feasible diversion downstream from the junction is near or at the diversion for the Great Western Canal, about 6 miles south of Roberts. This diversion is at an altitude of 4,755 to 4,760 feet. Water could be conveyed in a canal from this point to the lava flows west of Idaho Falls. Detailed topographic maps are not available for all of the area but study of the maps that are available indicate that there is 50 to 75 square miles of bare lava surface below the 4,750 contour between Idaho Falls and Blackfoot.

TW-10 pump recharge test

A recharge test was made at a location 9 miles southwest of Idaho Falls in June and July 1961.

Well 1N-36E-1cc1 (TW-10) drilled as a test well for the U. S. Bureau of Reclamation in 1958, on public domain, was used as a source of water. There is no silt overlying the basalt at this location, and the water was discharged into a crevice in the basalt about 60 feet southeast of the well (see fig. 31).

The uppermost basalt unit is about 36 feet thick at this site. It is separated from the basalt which is the aquifer by about 34 feet of fine silt and sand (fig. 27). The water table is about 150 feet below land surface.

Five holes were drilled to the top of the second basalt primarily to serve as observation wells for the perched aquifer that was presumed would develop when recharge began. The observation well, 1N-36E-2dd1 (OW-10) which was drilled in 1958 along with TW-10, was plugged at the top of the second basalt so that it could also be used for observations on the postulated perched aquifer. Geologic sections through all the holes are shown in figure 32. Data on the wells and core drill holes are given in the table on the following page.

Well or Core-Drill Hole	Altitude of			Thickness of		Total Depth
	Land Surface1/	Top of Silt	Top of Second Basalt	Upper Basalt	Silt	
TW-10						
(1N-36E-1cc1)	4,674.05	4,638.0	4,602.0	36	36	218
OW-10						
(1N-36E-2dd1)	4,675.07	4,640.0	4,603.0	35	37	215
D.H. 1	4,674.82	4,639.5	4,603.1	35.3	36.4	71.7
D.H. 2	4,674.95	4,639.35	4,603.45	35.6	35.9	71.5
D.H. 3	4,674.09	4,638.0	4,597.1	36.1	40.9	77.0
D.H. 4	4,673.46	4,637.8	4,614.5	35.7	23.3	59.0
D.H. 5	4,675.72	4,638.9	4,610.1	36.8	28.8	66.9
Average				35.8	34.0	

1/ Land surface is top of uppermost basalt at all holes.

Pumping began at 5 P.M. on June 9 at a rate of 2,400-2,500 g.p.m. with a drawdown of 0.7-0.8 foot. Pumping was nearly continuous until June 19. Breakdown of equipment forced a complete suspension of pumping from June 20 to July 7, and pumping was intermittent from July 7-12. Pumping was nearly continuous from July 13 to August 1, when the test was terminated. A total of about 362 acre-feet was pumped during the test.

During pumping the main water table rose a total of more than 3 feet because of recharge from irrigation on nearby lands. Pumpage is shown graphically in figure 33.

The water was disposed of in a crevice in the basalt (fig. 34) and at no time was there any ponding of water at the surface. However, a perched water table did develop in and on top of the main sedimentary interbed. Hydrographs of this perched water table and its relation to the top of the silt layer are shown in figures 35-40.

The perched water table reached its maximum height in most wells near the end of the test. The maximum height of water above the top of the silt in each well was as follows:

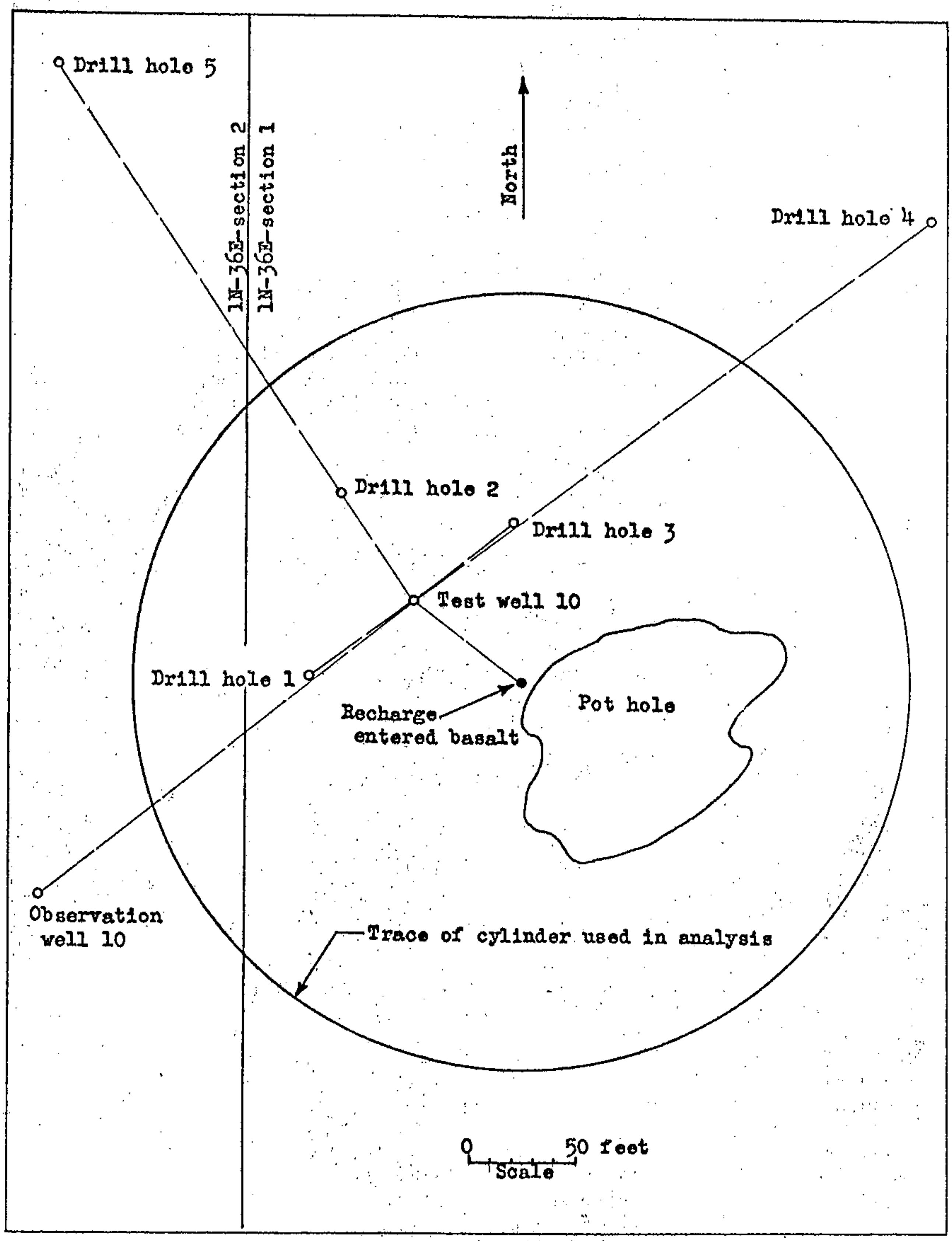


Figure 31.--Map of TW-10 pump-recharge test site

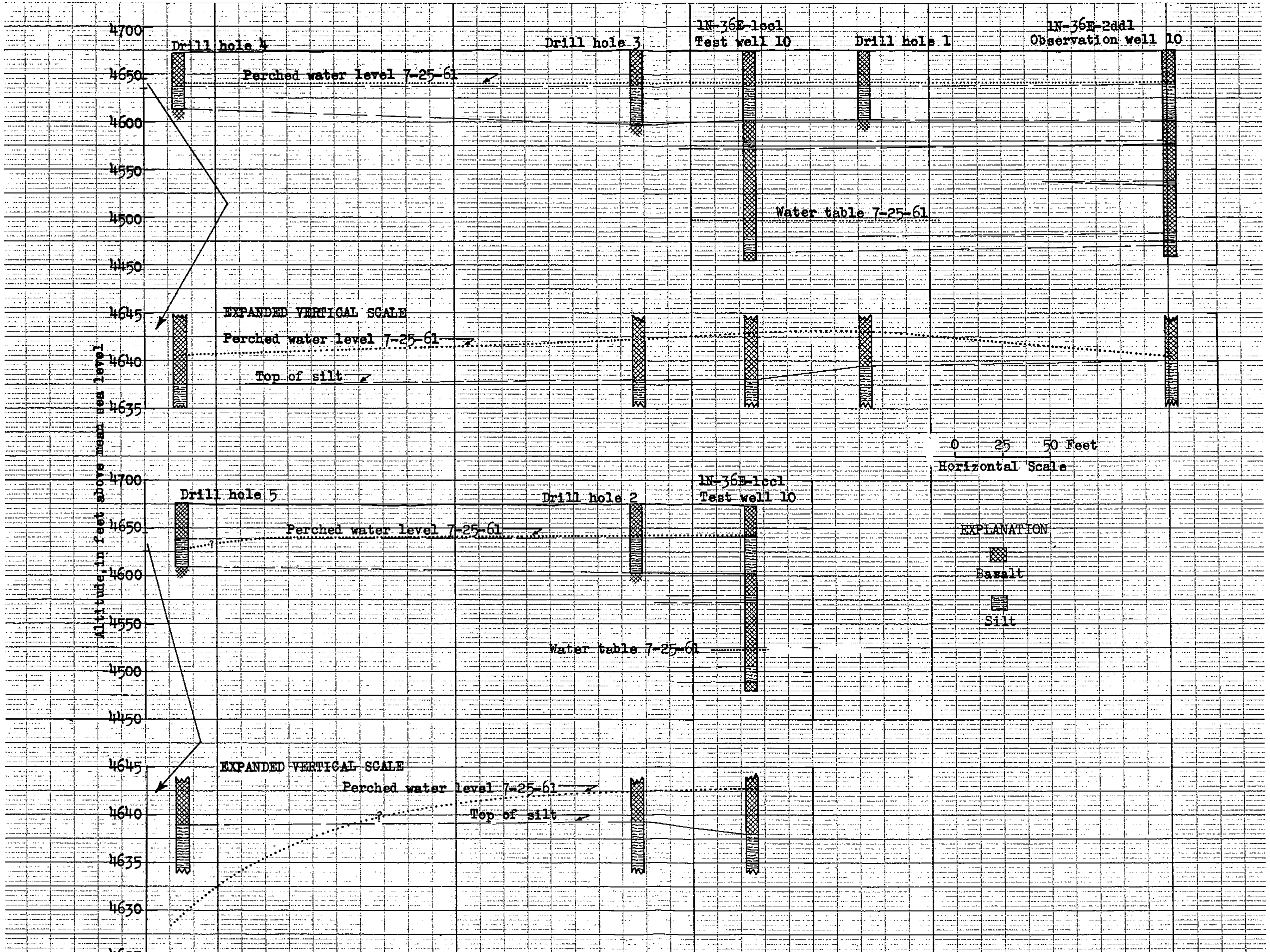


Figure 32.--Geologic sections through wells and core-drill holes in the TW-10 recharge test area.

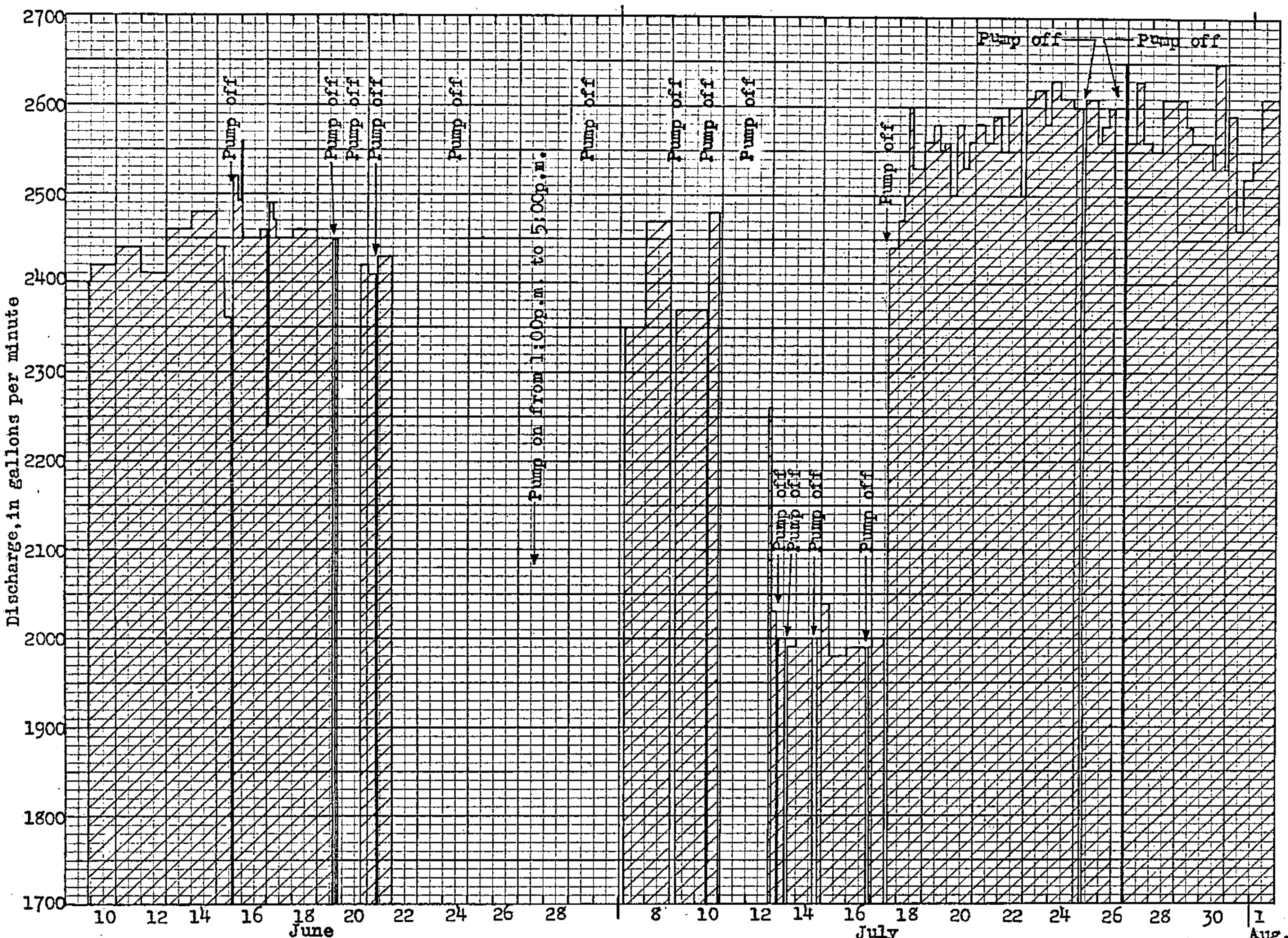


Figure 33.--Graph showing water pumped for recharge at TW-10 site.

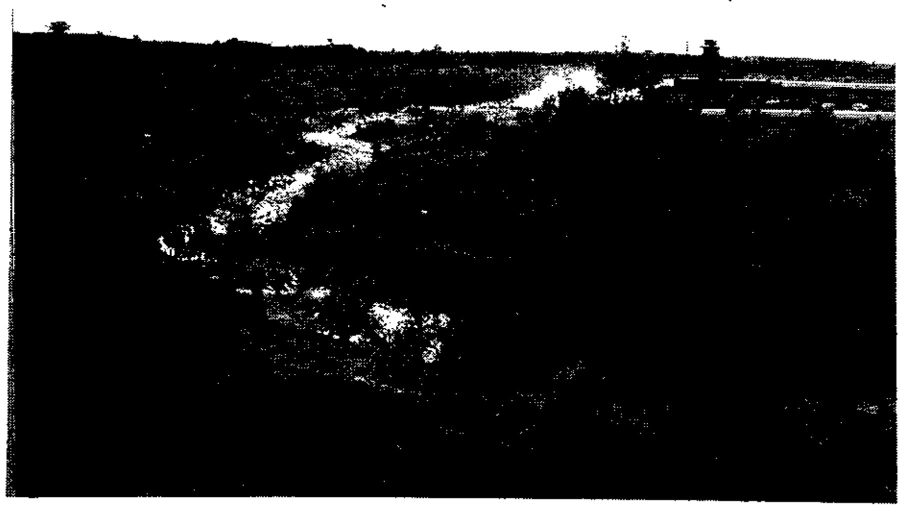


Figure 34.--View at site of TW-10 pump-recharge test.

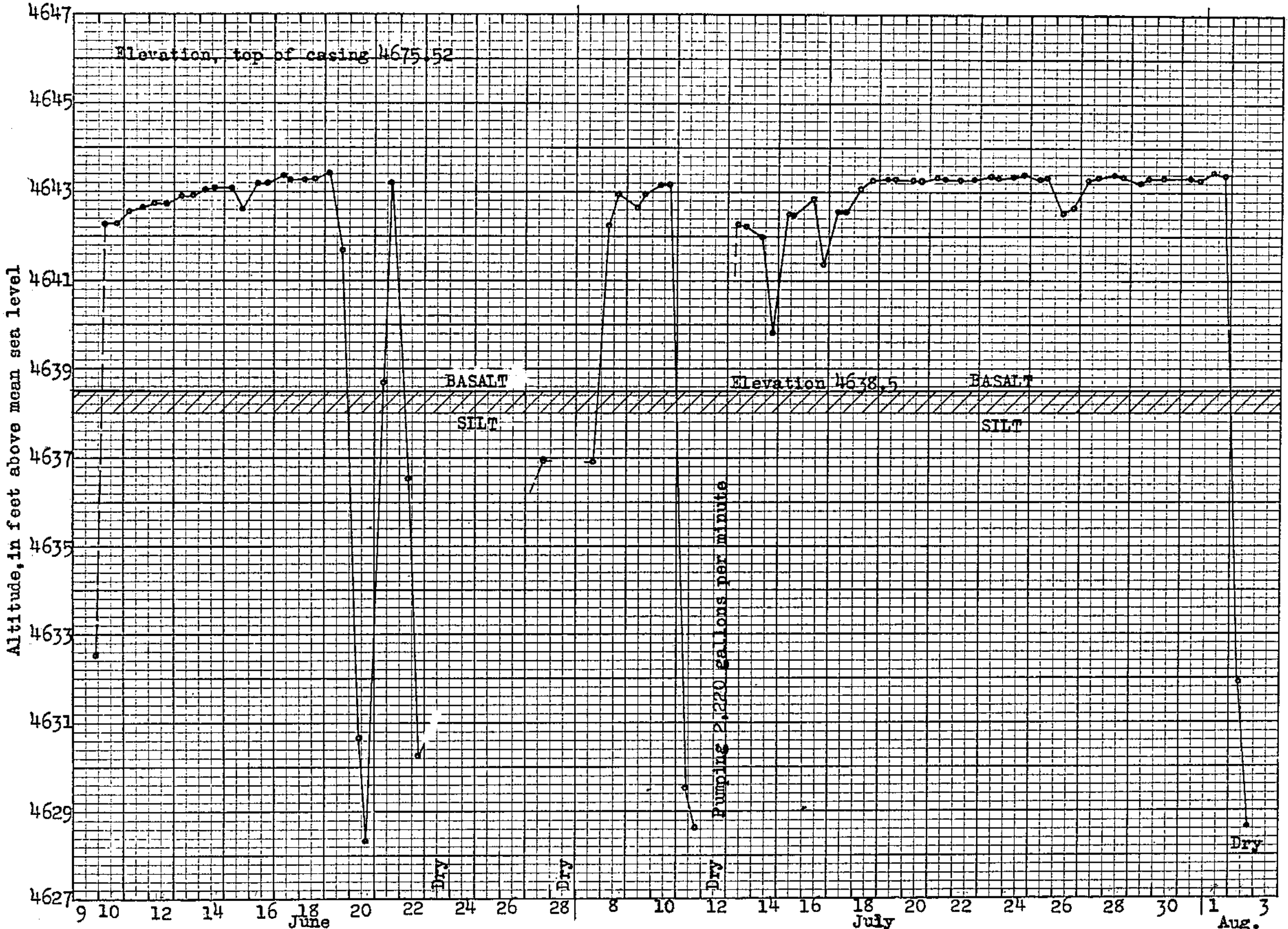


Figure 35.--Hydrograph of drill hole 1, June 9-August 2, 1961.

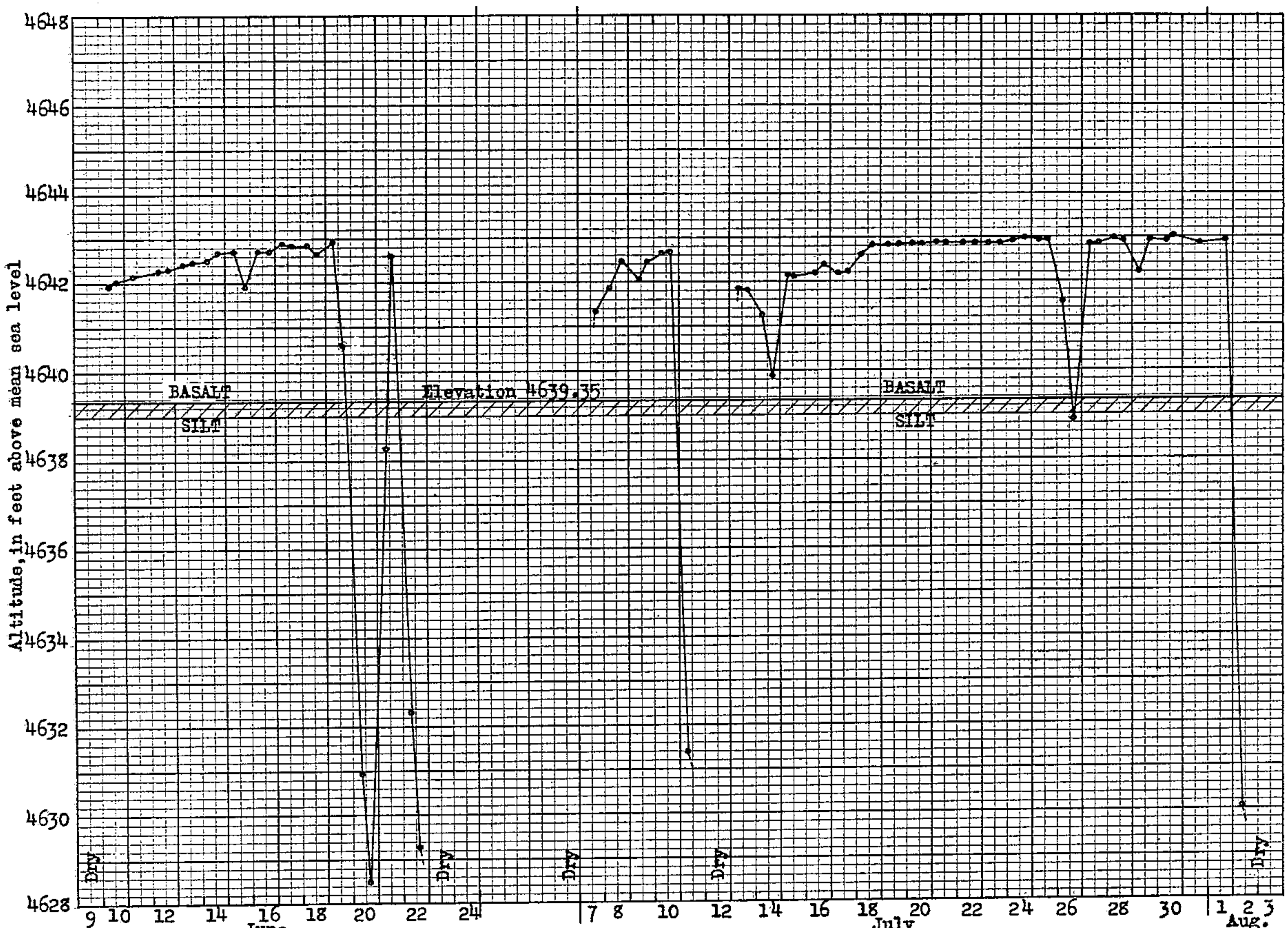


Figure 36.--Hydrograph of drill hole 2, June 9-August 2,1961.

Figure 37.--Hydrograph of drill hole 3, June 9-August 2, 1961.

Figure 38.--Hydrograph of drill hole 4, June 9-August 2, 1961.

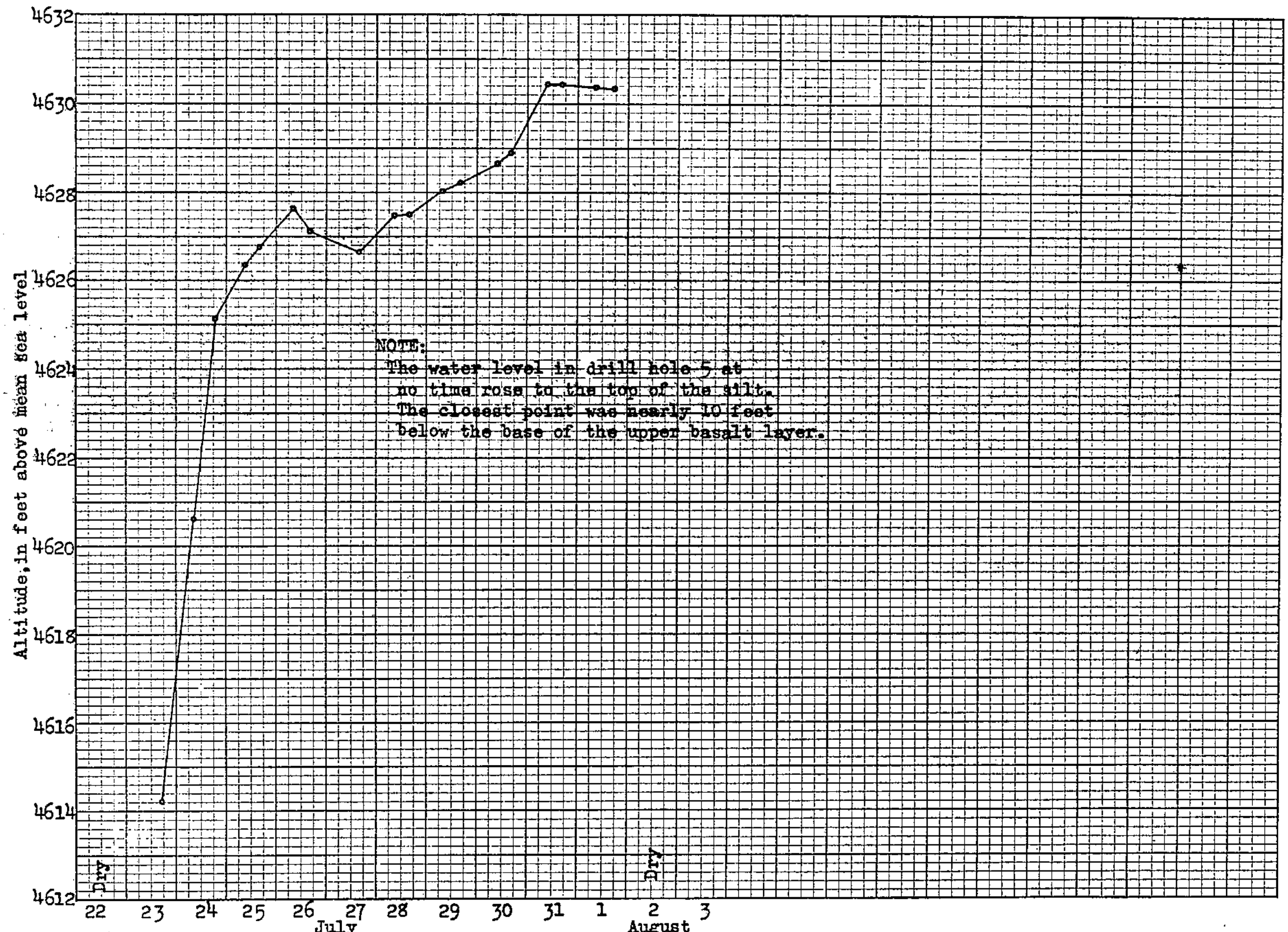


Figure 39.--Hydrograph of drill hole 5, June 9-August 2, 1961.

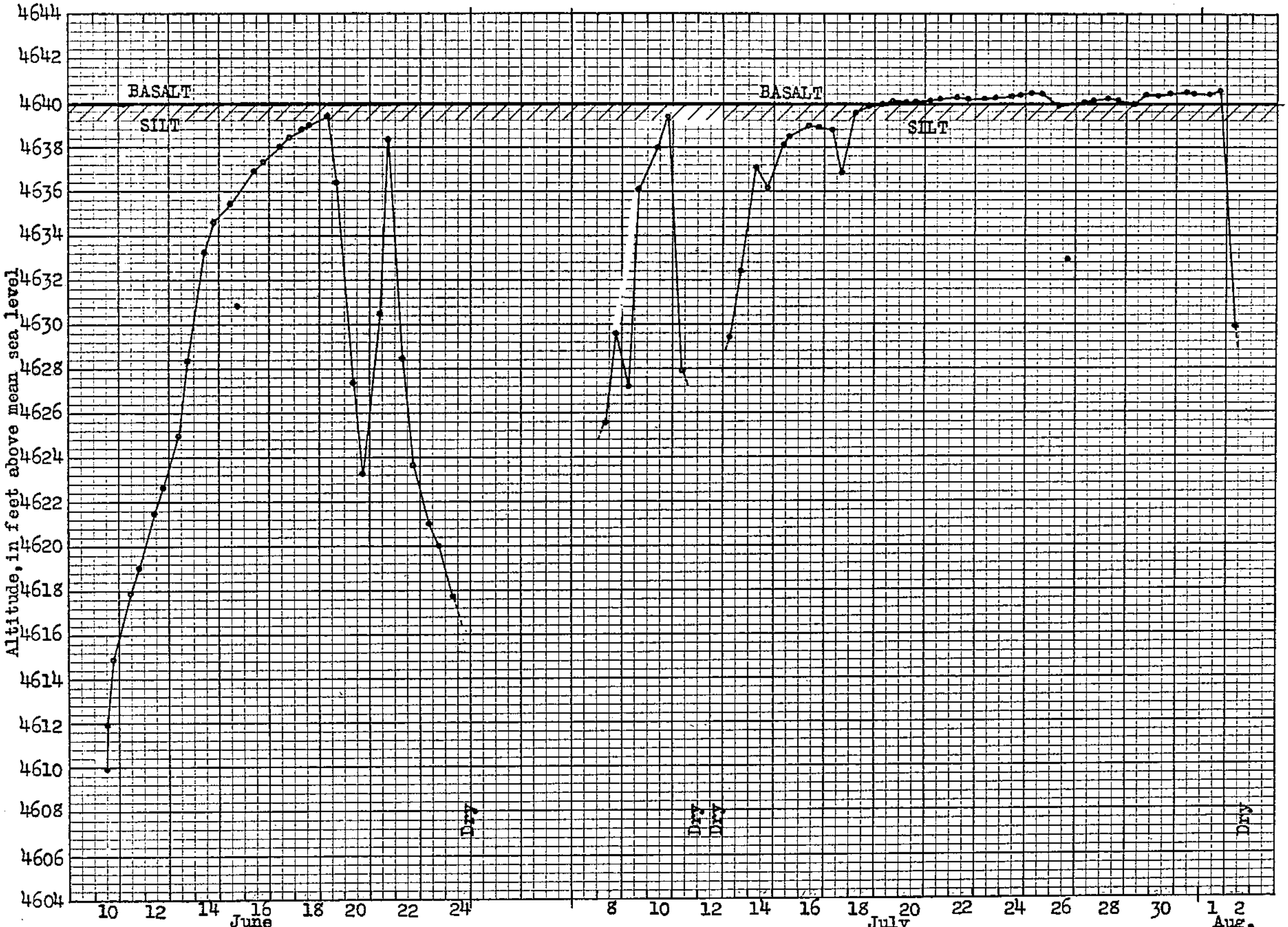


Figure 40.--Hydrograph of well OW-10 (1N-36E-2dd1), June 9-August 2, 1961.

Well	Maximum Height	Well	Maximum Height
DH 1	4.9	DH 4	3.1
DH 2	3.6	DH 5	0
DH 3	4.7	OW-10	0.5

After recharge ceased the water level in all holes dropped below the top of the silt in less than a day, and in most holes probably within a few hours.

The salient points regarding this recharge experiment may be stated as follows:

A perched water table developed in the silt layer, and this water table rose into the basalt.

The water table rose rapidly into the base of the upper basalt, and then rose gradually as pumping continued. Whenever recharge ceased, the water level dropped below the base of the basalt within a few hours. The perched water table had rather steep slopes away from the point of recharge (fig. 33).

The results shown by the test are interpreted as follows:

The pore space in the silty layer contained considerable water before recharge began, it probably was not far below saturation. There is no soil covering the basalt in this area and much of the 7 to 9 inches of annual precipitation runs into crevices and percolates down into the silt. The basalt layer below is porous and water from the fine-grained layer above will not enter the basalt until there is a positive pressure on the water, that is until the hydrostatic head exceeds one atmosphere. Thus the silt is near saturation at all times, addition of a very small amount of water at the top of the layer results in a very rapidly rising water table. In a sense, the water table actually was perched on the base of the silt.

When recharge began, the water table rose rapidly to the top of the silt; because the base of a single basalt flow overlying silt is not very permeable, the water level at first rose rather rapidly in the basalt. Thereafter it rose more slowly, reaching a level where the gradient was sufficient to move the water away from the point of recharge as rapidly as it was added. Water could be discharged by lateral outflow or by vertical percolation through the silt down to the main water table or by a combination of the two processes. The relative proportions of these two components of outflow are in question.

For the following reasons it is believed that most of the water moved down through the silt.

The mound of water in the basalt extended laterally only about 200 feet in the direction of D.H. 5, and barely reached OW-10, 250 feet away. The extent of the cone beyond D.H. 4 is not known but considering the gradient between D.H. 3 and D.H. 4, it probably was not more than about 300, for total distance of 600 feet from the crevice into which the water disappeared. The spread of the mound obtained by averaging the spread in the three directions was about 375 feet. Thus, the average diameter of the mound in the basalt probably did not exceed 750 feet. The average slope of the ground-water mound between the near and the far drill holes was 1.3 feet per 100 feet (.013 feet per foot). A circle, described around the crevice where recharge entered the basalt, with a radius of about 180 feet roughly bisects the average distance between the near and far drill holes. The average saturated thickness of basalt on July 25 at this radial distance, near the end of the test, was 2.8 feet. The equation Q = PIA, where Q is the quantity of water in gallons a day per square foot, I is the hydraulic gradient in feet per foot, and A is the cross sectional area in square feet, can be used to solve for permeability of the basalt, assuming that none of the recharged water seeps from the basalt within the area of the circle. Solving, $P = \frac{Q}{IA} = \frac{3.6 \times 10^6}{.013 \times 3,170} = 87,500$ g.p.d. per square foot. The flow across the boundary circle would be decreased by the amount of downward seepage from the basalt within the circle, and the permeability of the basalt would be correspondingly less than the figure derived.

As shown by the hydrographs of drill holes 1, 2, 3, and 4 (figs. 35, 36, 37, and 38) the water table rose rather gradually, but dropped abruptly entirely below the base of the basalt within a short time after recharge ceased. This abrupt decline is not compatible with the decay of a ground-water mound by lateral outflow but is the result to be expected of downward leakage through a semipermeable layer. If it is assumed that all the water percolated through the silty layer within an area 750 feet in diameter, the seepage rate would be about 1 foot per day.

Not much information is available regarding infiltration rates through silty sediments in the Snake River Plain. Infiltration measurements in the beds of the Big Lost River playas showed infiltration rates ranging from 0.4 to 5.4 and averaging 2.3 g.p.d. per square foot (Nace and others, 1959). These playa sediments probably are similar, but may be more permeable than the silty interbed at the TW-10 site.

Laboratory tests made on 7 samples of material from the silty layer at the TW-10 site indicate a permeability ranging from practically nil to 2 g.p.d. per square foot and averaging about 0.7 g.p.d. per square foot, equivalent to a percolation rate of slightly more than 0.1 acre-foot per acre per day. It may be that the silty layer is considerably more permeable at some places than at others; also, there may be thin spots or places where the layer is missing and the upper basalt is in contact with the lower basalt. Whatever the exact situation, most of the water recharged probably moved out of the upper basalt layer by vertical percolation.

Summary of recharge possibilities in the basalt

Conclusions as to the feasibility of recharge by spreading water on the basalt in this area cannot be based entirely upon the results of such a small-scale test as was made at the site of well TW-10. The intake capacity of the upper basalt flow apparently is almost unlimited; however, if the silty layer will transmit water to the main water table at a rate of only 1 acre-foot per acre per day, then a thousand acres would be required for recharge of a thousand acre-feet per day.

However, as shown by many well logs, and illustrated on the geologic sections I-I' and L-L' in figures 27 and 28, the sedimentary interbeds pinch out to the west and northwest, away from the Snake River. The location of the recharge test, less than one-half mile from the edge of the upper basalt flow, was not at a favorable location with respect to underlying sedimentary strata. As the water is conducted westward, from depression to depression on the basalt, conditions for vertical seepage should improve and the rates might be manyfold larger within a few miles.

Recharge of gravels adjacent to the Snake River

The Snake River loses water from its channel throughout the reach from Roberts to Blackfoot. The alluvial deposits along this reach could be used for recharge of additional water by diversions to abandoned channels, unused gravel pits and similar depressions. Through most of the reach the water table is 50 to more than 100 feet below land surface so that a large storage space is available above the water table. Basalt protrudes through the alluvial deposits at a few places; elsewhere the gravel deposits range from a few to more than 100 feet in thickness. Well logs indicate generally a fairly continuous sequence of gravelly deposits; rarely are there reports of sandy or silty intervals.

No quantitative information is available on the intake capacity of the gravel deposits, however, the gravel generally appears to be clean, coarse, and permeable.

Rates of percolation from the channel of the Big Lost River, in downstream reaches on the National Reactor Testing Station, about 60 miles west of Idaho Falls, were measured in 1951 to 1953 (Nace and others, 1959, p. 21-30). Rates ranged from about 0.3 to 2.5 and averaged 1.0 foot per day. The rates measured varied almost directly with discharge. Big Lost River is intermittent, and has a low gradient through the reach. The alluvium along the Snake River probably is considerably more permeable than along this reach of Big Lost River. Also, the depth of water would be considerably greater in gravel pits than in the shallow channel of Big Lost River, and infiltration rates would be greater because of the greater head.

At Peoria, Illinois, rates ranged from about 40 to 100 feet a day in two pits operated by the State Water Survey for three recharge seasons (Suter and Harmeson, 1960, p. 45).

Percolation rates in the gravels along the Snake River probably would be in the range of 5 to 50 feet per day. Quantitative tests would be required to derive a more precise value.

Probable effects of large-scale recharge in the area

By assuming aquifer coefficients, and making some simplifying assumptions regarding boundaries, the effect on the aquifer of adding large amounts of water by artificial recharge can be estimated.

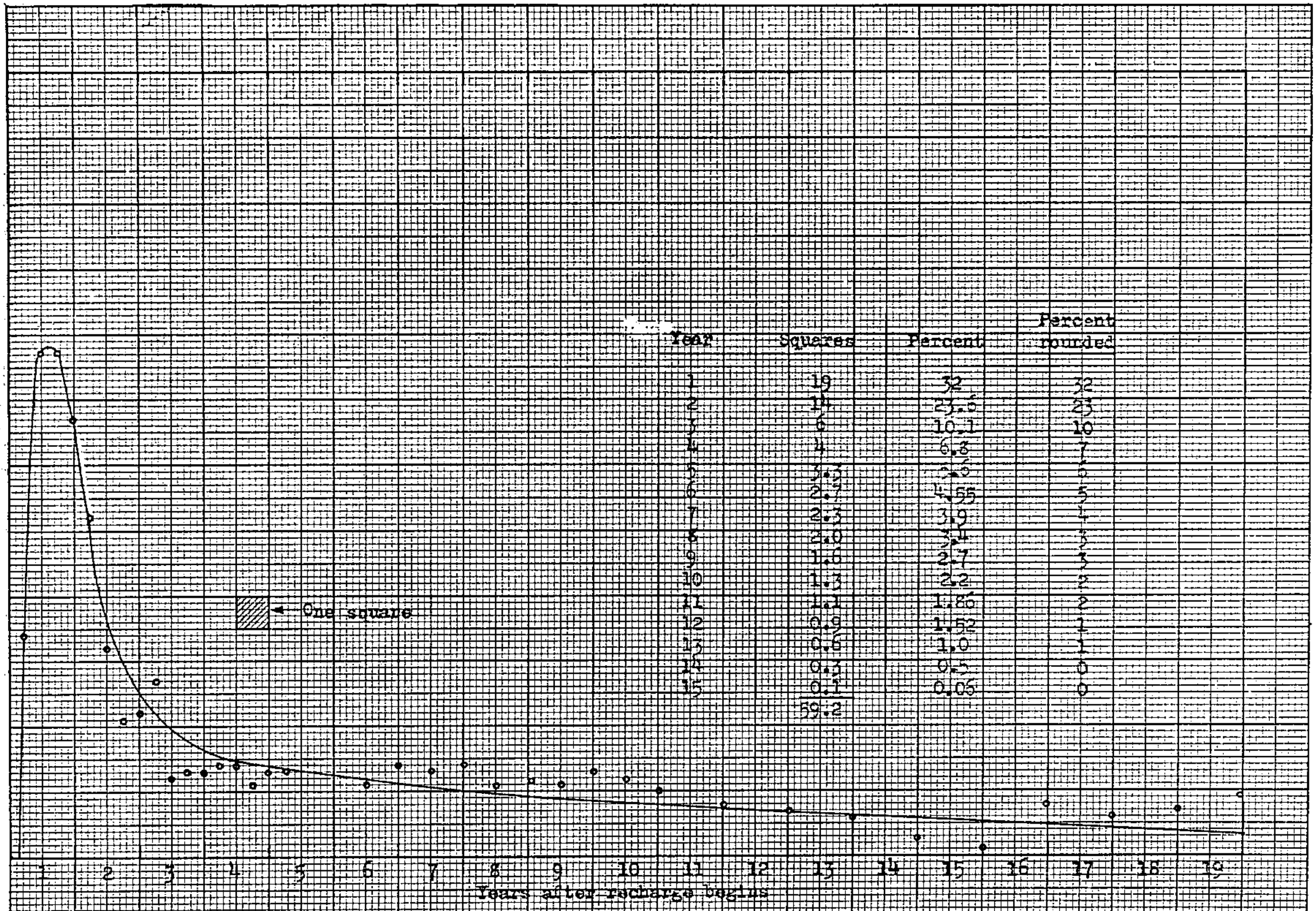
The average coefficient of transmissibility is assumed to be $2x10^7$ gallons a day per foot; the coefficient of storage is assumed to be 0.10. A positive boundary at right angles to the flowlines is idealized near the upper end of the discharge reach between the mouth of the Blackfoot River and American Falls. Point of recharge is assumed to be 27.5 miles upgradient from this positive boundary. All other boundaries were disregarded, the only other near boundary is a negative one parallel to the flowlines. Recharge is assumed to be at a constant rate for a period of 6 months.

With the above assumed coefficients and simplified boundary conditions, the head change was computed for a point 2.5 miles upgradient from the positive boundary (fig. 41). This figure indicates that under the assumed conditions, discharge into the American Falls Reservoir reach would begin to increase within a few months after artificial recharge begins and peaks within 2 months after recharge ceases.

Not all the water recharged in the area west of Idaho Falls would return to American Falls Reservoir. Flowlines (fig. 3) show that about 40 percent of the underflow through this section of the aquifer is tributary to the American Falls Reservoir reach, and 60 percent is tributary to the Hagerman Valley reach. Of that part of the water returning in the American Falls Reservoir reach, the percentage that returns each year is approximately shown by the ratio of the area under the curve for the individual year to the total area under the curve. As shown by the table on figure 41, 32 percent of the water returning in the reach discharges within the first year, 23 percent in the second year, and so on.

The above discussion does not mean to imply that the recharged water will physically move to the discharge area within a few months; actual velocity of the water probably is only a mile or two a year. However, the ground-water mound moves outward so that underflow and discharge are increased as shown.

That the calculated rate of spread of the ground-water mound is of the proper magnitude is shown by the spread of the recharge wave from irrigation in the Aberdeen-Springfield area (see page 17 and figure 7) where the ground-water mound spreads 22 miles in 90 to 105 days.



Year	Squares	Percent	Percent rounded
1	19	32	32
2	14	23.6	23
3	6	10.1	10
4	4	6.8	7
5	3.3	5.56	6
6	2.7	4.55	5
7	2.3	3.9	4
8	2.0	3.4	3
9	1.6	2.7	3
10	1.3	2.2	2
11	1.1	1.86	2
12	0.9	1.52	1
13	0.6	1.0	1
14	0.3	0.5	0
15	0.1	0.05	0
	59.2		

Figure 41.--Percent distribution of head changes in the Snake Plain aquifer caused by recharging under assumed conditions in the Idaho Falls area.

Milner-Shoshone area

The Milner-Shoshone area extends northwestward along the Milner-Gooding canal (fig. 42). The area which would be usable for artificial recharge forms an irregular strip along the canal. Diversion to the canal is at an altitude of about 4,130 feet.

The only topographic map available is the Army Map Service 1:250,000 series with 100- and 200-foot contour intervals so that altitudes are not accurately known. However, that map and air photos show that the land surface rises to the east and northeast so that the area to which water could be diverted on the east side of the canal includes only small parcels immediately adjacent to the canal.

Notch Butte, south of Shoshone, rises above the general land surface and includes perhaps a township which would be too high to be reached by surface diversions. Beginning south of this butte (about 6 miles south of Shoshone), a strip of land 4 to 6 miles wide extending for 10 to 12 miles roughly parallel to the canal, is topographically situated so that it might be reached by water diverted from the canal.

Geologic features

The entire area between the Snake and Wood Rivers is underlain by basaltic lava flows of the Snake River Group. The basalt was extruded from several centers, chiefly on the east side of the Milner-Gooding Canal. Broad lava domes mark these centers.

The basalt is overlain throughout much of the area by varying amounts of sedimentary materials which accumulated in playas or as wind deposits. Most of the land where the sedimentary deposits are a few feet or more thick and are reasonably extensive, is farmed.

Because the most important surficial characteristic for artificial recharge is the thickness, extent and continuity of overburden, the mapped area was divided into units on that basis. The subdivisions are based almost entirely on interpretation of areal photos. Of the 4 units shown, 2 generally are not suitable for artificial recharge by water spreading. The other two consist of areas too rough for farming, where basalt exposures are numerous and irregular and are separated by thin, discontinuous patches of overburden.

The basalt in this area is interbedded with sedimentary materials, as in the Roberts-Plano and Idaho Falls areas, but there apparently are no thick, extensive sedimentary deposits such as are encountered in some parts of the other two areas. The sedimentary interbeds in the Milner-Shoshone area are chiefly thin lenses of windblown silt, sand and volcanic ash and playa deposits of limited extent. Cinder deposits apparently are common, but because they generally are very permeable, they are an asset rather than a liability to recharge. Subsurface conditions are illustrated in several cross sections in figure 43.

Ground-water features

The only aquifer in the area between Milner and Shoshone is the basalt and associated pyroclastics of the Snake River Group. The water table ranges from about 150 to 250 feet below the land surface. There are no really significant perched aquifers, but local perched aquifers have been encountered beneath irrigated tracts, and near the canal. The water table slopes slightly south of west with a gradient, near the canal, of about 10 feet per mile. A few miles to the west the gradient increases to about 40 feet per mile. Flowlines (fig. 3) indicate an underflow of about 150 cubic feet per second per mile width of aquifer. The source of this underflow is chiefly at the eastern end of the plain, 100 to 150 miles eastward. However, considerable water is added to the aquifer by leakage from the Milner-Gooding canal and percolation from irrigated farms in the vicinity of Hazelton, Shoshone, and Dietrich. For that reason the water table shows an annual cyclic response to irrigation (fig. 44). These hydrographs also show a continuing downward trend. The longer term trend of the water table in the area is shown by the hydrograph of well 9S-20E-1dal (fig. 45). This curve shows a downward trend beginning in 1954, probably related to pumping in the Minidoka area to the east. The downward trend was accelerated beginning in 1958, probably because of greatly increased withdrawals of ground water in the Hazelton area.

To the west the aquifer terminates in the canyon of the Snake River (Hagerman Valley reach). The base of the aquifer, at the contact with underlying less permeable volcanic rocks generally ranges in altitude between 3,000 and 3,150 feet, 100 to 150 feet above river level. The line of discharge between Twin Falls and Bliss is 25 to 30 miles west of the Milner-Gooding Canal between Milner and Shoshone.

Summary

Large-scale topographic maps are not available to show potential recharge sites along the Milner-Gooding Canal. The Twin Falls topographic sheet of the United States series at scale of 1:250,000 indicates that areas covering many square miles are favorably situated for recharge by water spreading in the northern two-thirds of township 8S-19E. Closed depressions totaling only a few square miles are shown by the 100-foot contour interval on the map, but undoubtedly there are many more square miles of depressions than are shown. Much of this area is shown by areal photos to be rough surfaced basalt with thin discontinuous patches of silt. Several other areas further north, along the west side of the canal, also appear to be suitable for recharging.

Probable effects of artificial recharge in the area

The effects of pumping 250 c.f.s. for 122 days on the water table in the Shoshone-Dietrich area was computed in the report by Mundorff and others (1960, p. 185-186). The computations apply equally to buildup of

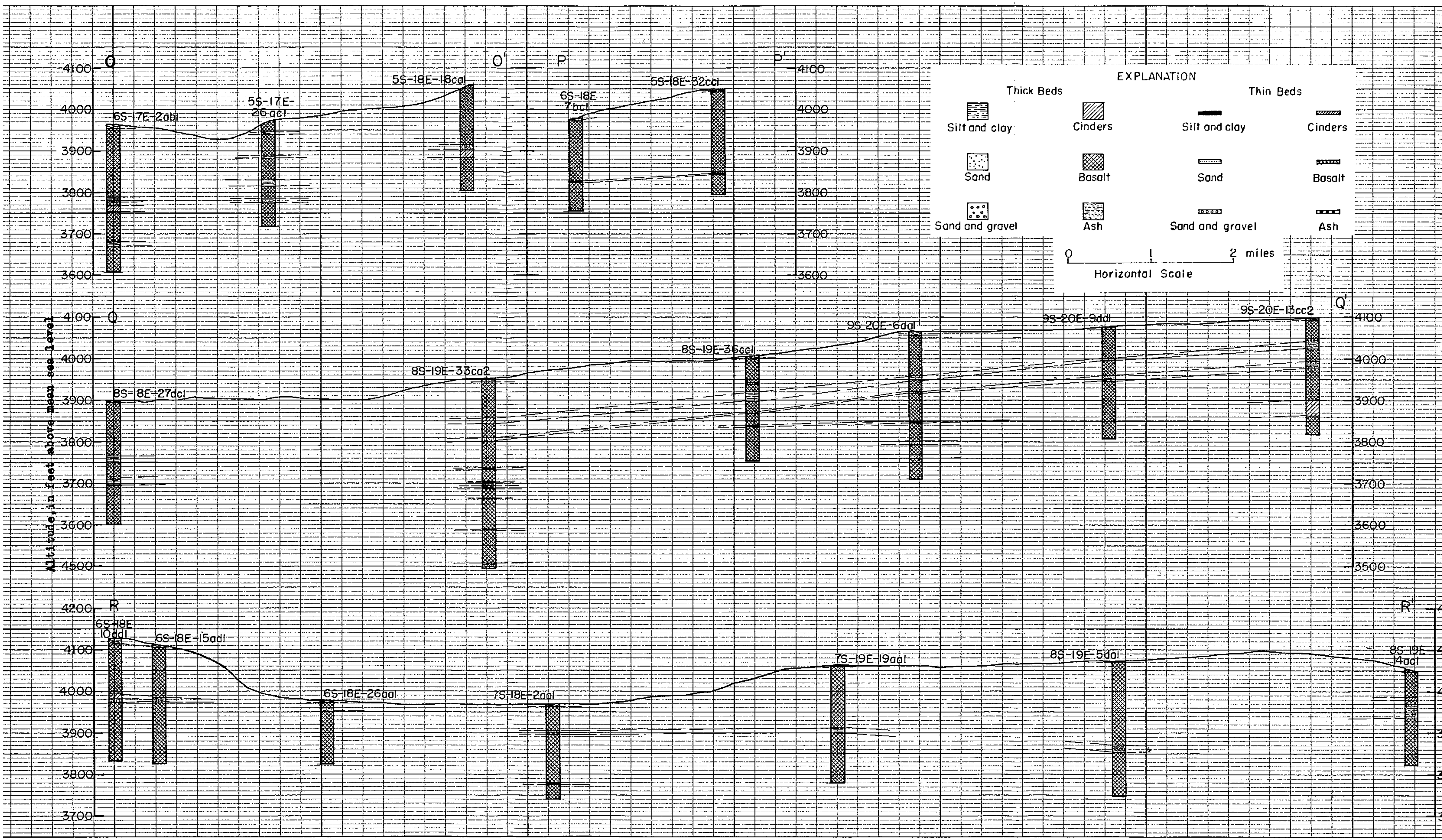


Figure 43.--Geologic sections O-O', P-P', Q-Q', and R-R', in the Milner-Shoshone area.

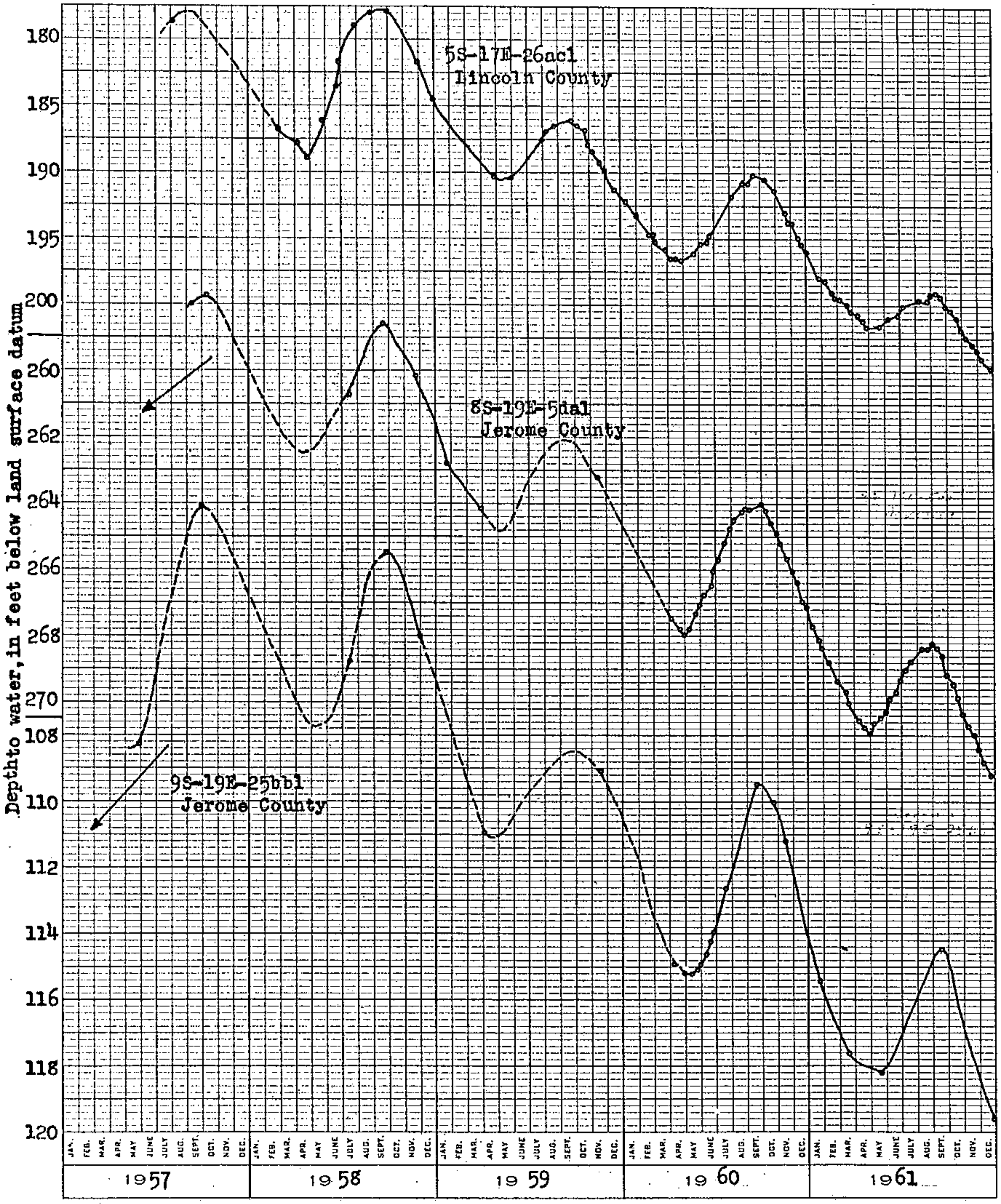


Figure 44.--Hydrographs of wells 5S-17E-26ac1, 8S-19E-5da1, and 9S-19E-25bb1.

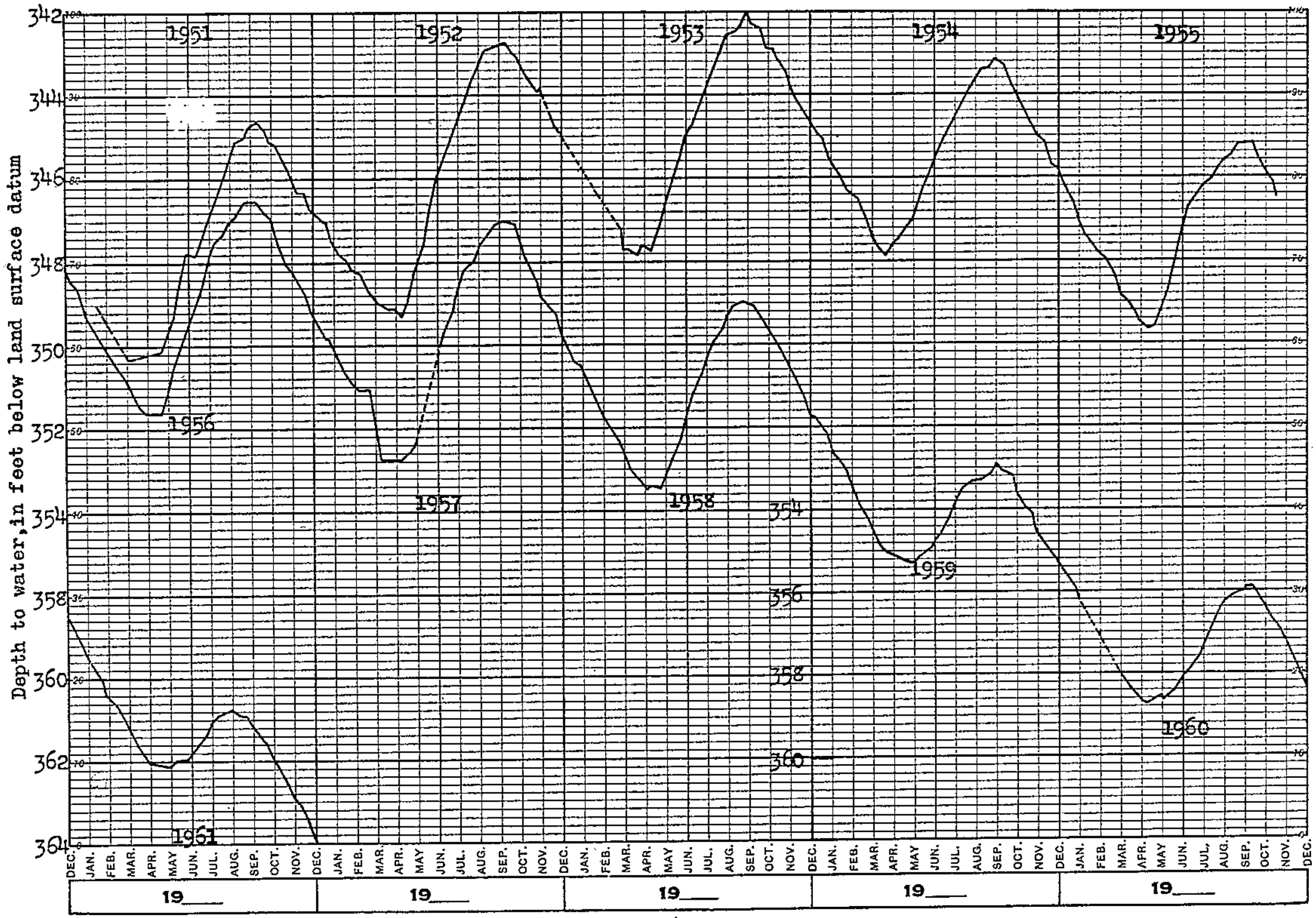


Figure 45.—Hydrograph of well 9S-20E-1dal.

the water table by recharge and therefore the values given in the cited report can be used. That is, the rise in the water table would be roughly 7 to 10 feet at the end of one recharge cycle, at a recharge rate of 250 c.f.s., and 10 to 13 feet at the end of 50 cycles. This would be the rise in the aquifer within the recharge area; the rise at distant points would be less.

The spread of a recharge mound from this area can be approximated by analogy with the spread of the cone of water-table decline caused by pumping in the Minidoka area. The water table began declining in 1954 immediately adjacent to the Minidoka Project area (hydrographs of wells 8S-24 E-31dcl, and 8S-23E-2bcl, figure 8). These wells are 55 miles east of the Hagerman Valley discharge reach. The water level in well 8S-14E-16bcl (fig. 46) which is about a mile from the discharge area did not show any decline until about 1958, and the decline was minor until 1960, but was greatly accelerated in 1960 and 1961. Thus it seems that it took 4 years for the increased pumping to affect the water table about 40 miles downgradient from the margin of the pumped area, and 6 years before the effect was appreciable. By analogy then, the spread of a recharge wave from a recharge area along the Milner-Gooding Canal some 30 miles away would require 3 to 4 years to affect the water table in the vicinity of well 8S-14E-16bcl.

Wood River basin

In a previous section of the report it was shown that annual discharge from the Big Wood River drainage exceeded 9,900 acre-feet in 17 years, and averaged 185,000 acre-feet in the 23-year period 1938-60. Not all the water could be salvaged for recharge but perhaps an average of 100,000 acre-feet could be. Part of this water would be available from Little Wood River and Silver Creek.

Originally large amounts of water were lost from the channel of Big Wood River downstream from Magic Reservoir (fig. 3) to the Snake Plain aquifer (Smith, 1960, p. 27). Since 1925 the entire natural flow has been diverted through the Lincoln Canal (Smith, 1960, pl. 2) and losses are less. The abandoned river channel crosses and skirts a basalt flow of Recent Age (Shoshone Basalt flow) which is very permeable and takes water rapidly. According to the watermaster (Smith, 1960) average losses in a 15-mile reach of the channel were about 149 c.f.s. during the irrigation seasons 1920-25. The abandoned channel and adjacent areas of the basalt could be used for recharging large amounts of water. The Hailey and Twin Falls topographic sheets of United States series at a scale of 1:250,000 show that the altitude of the basalt flow ranges from about 4,600 feet at point 8 miles south of Magic Reservoir, to about 3,600 feet near Gooding. Water could be diverted from the river onto the lava flow at almost any point along its course. However, recharge in that part of the basalt northeast of Shoshone would be more effective in raising water levels over a wider area, and being farther from the Hagerman Valley discharge area, would maintain water levels for a longer time than would recharge farther to the west.

This recharge area is about 30 miles from the Hagerman Valley, and on the basis of rate of spread of effect of large scale withdrawal in the Minidoka-Hazelton area, it probably would take several years for the effects of recharge in the basalt northeast of Shoshone to reach the Hagerman Valley.

Methods of increasing intake

It is apparent from the preceding general description and the discussion of the individual recharge areas, that one of the major problems in artificial recharge in the Snake River Plain, is to get the water through layers of low-permeability materials, down to the main water table. These materials of low permeability at some places cover the basalt surface, and at others they occur as interbeds.

The effect of these low-permeability layers is to increase the area required for water-spreading, perhaps tenfold, or more. This may not be a serious problem where large areas of public domain have little other use. However, the cost of dikes and other structures required to conduct the water from pond to pond might be substantial. Also, in some areas it may be desirable to keep the flooded areas smaller. Therefore, some method of increasing the volume of intake per unit surface area may be desirable. Several methods are described below.

Removal of surficial materials

In some areas, particularly in the Plano-Roberts area, windblown sand and silt have accumulated in depressions in the basalt. The bottom of each depression is blanketed with these deposits, and water must percolate through them. At places basalt is exposed along the flanks of the depressions, but most of the cracks and crevices in the basalt are partially choked with sand and silt. Many of these, especially the gaping crevices in pressure ridges, are capable of taking large amounts of water where they are not plugged. Some individual crevices might take tens of cubic feet per second. It might be possible to increase the intake of water by removing the sand from individual crevices by hydraulicking. Water from the recharge ponds could be used as the ponds filled. Once a crevice was clean, graded gravel could be used to fill it to prevent it from again filling with sand.

It is possible that heavy blasting at favorable spots, perhaps in crevices of the pressure ridges, would open up new channels for the downward percolation of water.

Galleries and injection wells

Where a layer of silt and sand a few feet thick overlies the basalt, wells drilled into the basalt could be used to increase the recharge rate. In order to prevent silt and debris from directly entering the basalt, the water could be filtered through gravel. A 20-inch to 24-inch casing

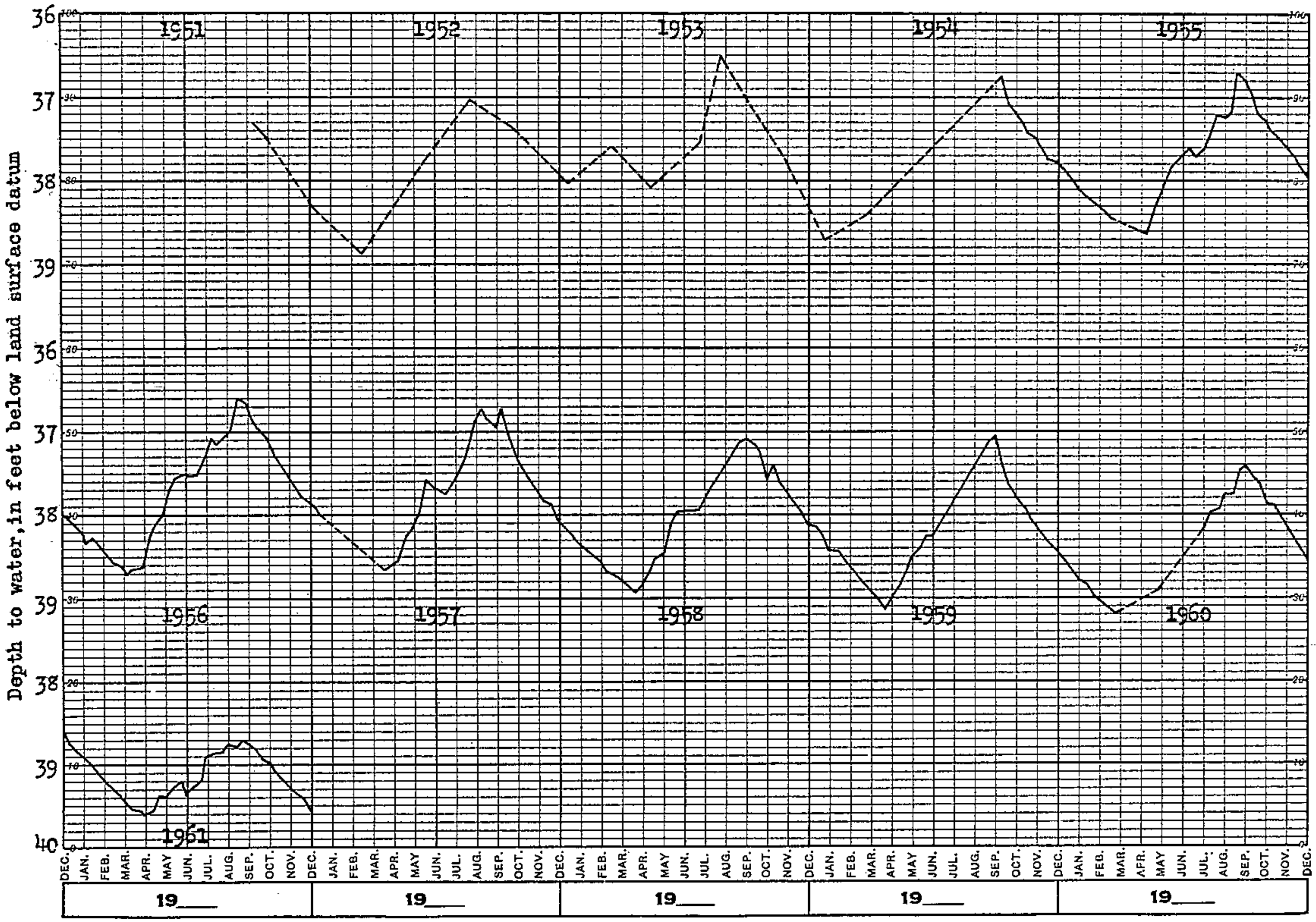


Figure 46.--Hydrograph of well 8S-14E-16bcl.

would be cemented into the top of the basalt, and the uncased hole continued on into the basalt. In one method the casing would be perforated, the sand removed from around the casing, and the annular space back-filled with gravel (fig. 47A). Alternatively, 8-inch perforated pipe or tile could be placed in a shallow trench leading into the well, and the trench back-filled with gravel (fig. 47B).

In most areas where surface water can be diverted onto basalt surface of the Snake River Plain, the basalt flows have one or more interbeds of fine-grained material at some depth, for example, the 34-foot silty-sand interbed beneath 36 feet of basalt in the vicinity of the TW-10 recharge test. These interbeds cause perched aquifers to develop. If the perched aquifers spread widely enough, all the water will seep downward to the main aquifer. However, in spreading widely they may reach farmed areas and cause waterlogging and seepage problems. Therefore, it may be desirable to increase the percolation rate. This could be done by drilling a well connecting the basalt above and below the interbed, so that water could flow from the perched aquifer into the well bore, down the bore, and out into the main aquifer. By connecting the two aquifers, instead of injecting the water directly into the well at the surface, the possibility of pollution and of silting up of the aquifer would be minimized. Construction could be similar to that shown in figure 48.

Conclusions

For more than 60 years, beginning in the 1890's and ending in the 1950's, the water table in the Snake Plain aquifer rose. This rise was caused by irrigation. The magnitude of the rise is not completely known, because records of the position of the water table prior to irrigation are not available for all parts of the plain. However, the rise probably exceeded 100 feet at some places, and the average for the entire plain may have been 60 to 70 feet.

With the great expansion in use of ground water for irrigation, beginning after World War II, and becoming quantitatively significant in 1952-53, the trend has reversed, and the water table is declining nearly everywhere beneath the plain. By 1960, ground-water withdrawals in the eastern Snake River Plain and tributary valleys reached 2 million acre-feet, and consumptive use was roughly 1 million acre-feet. The decline in water level between 1953 and 1961 generally ranged from less than a foot to about 12 feet. Ground-water withdrawals undoubtedly will continue to increase and the water table will continue to decline.

Artificial recharge will not reverse that trend, not enough water is available for that. However, recharge of a million acre-feet will permit pumpage of 2 million acre-feet additional water (assuming 50 percent consumptive use) without any additional decline in the water table.

Large areas of public domain now having only limited use for grazing, are available for recharge by spreading in shallow ponds. Surplus water can be diverted to these areas from Henrys Fork, the Snake, and Wood Rivers. Surficial conditions generally are favorable, the basalt surface contains many closed depressions, and additional depressions can be constructed by building low levees.

Small-scale recharge tests have revealed some of the problems; silty and sandy overburden greatly reduces the intake capacity of the basalt at some places, and sedimentary interbeds will result in perched water tables at other places. Where recharging is attempted under these conditions, larger areas will be required for water spreading. However, there are several different methods that can be used to increase the intake per unit area.

Present recharge from irrigation on the plain is on the order of 3.5 million acre-feet a year; in general, this recharge is accomplished in the worst possible sites for recharging operations, where the overburden and sedimentary interbeds are thickest and most extensive, and where the water table is nearest the surface.

Thus, although there will be problems connected with artificial recharge, for example, perched water tables might cause waterlogging of some nearby farm lands, there is no question but that large quantities of water can be successfully added to the ground-water supply.

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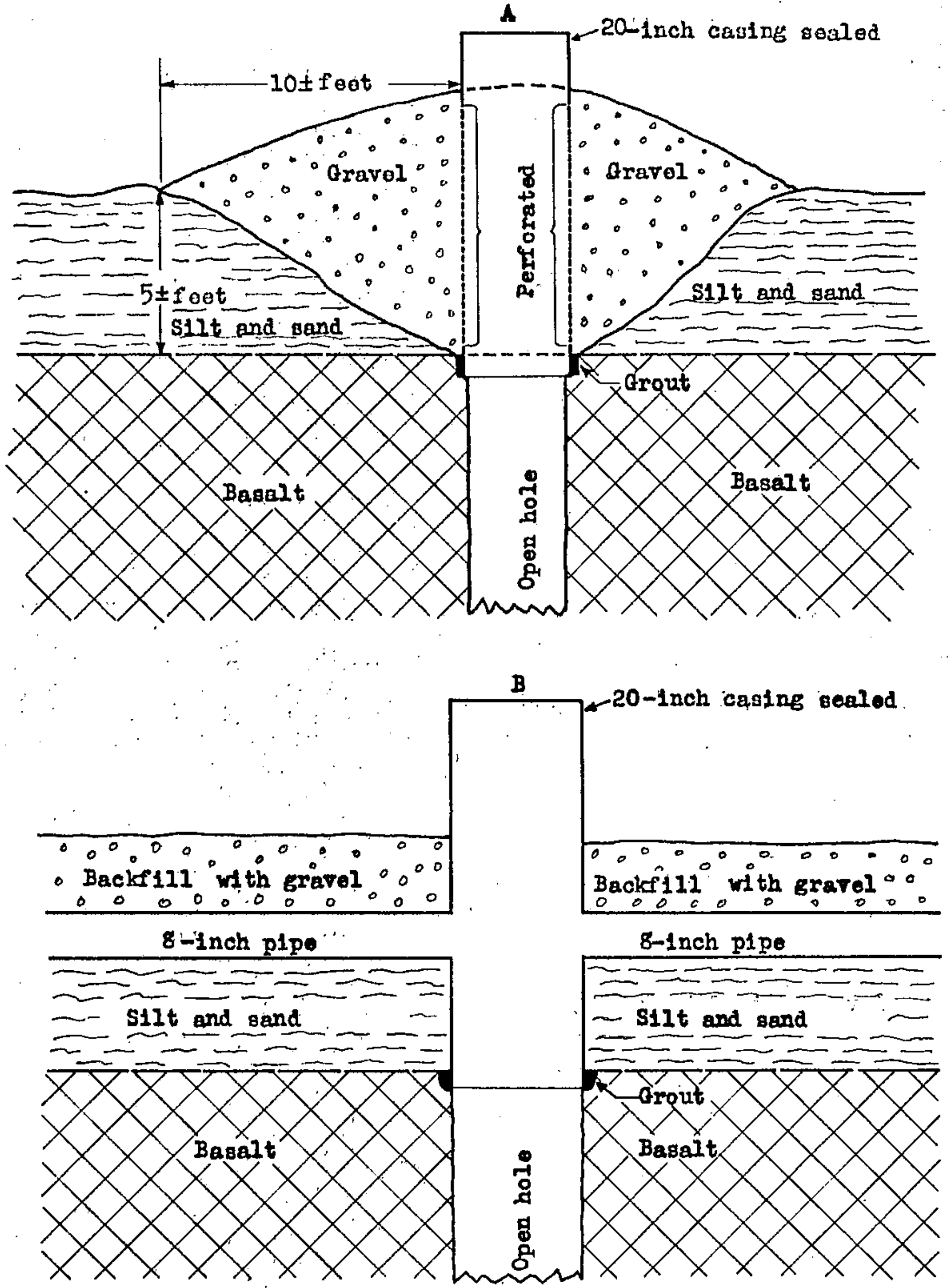

Figure 47A,B.--Methods of intake well construction to increase recharge to the basalt.

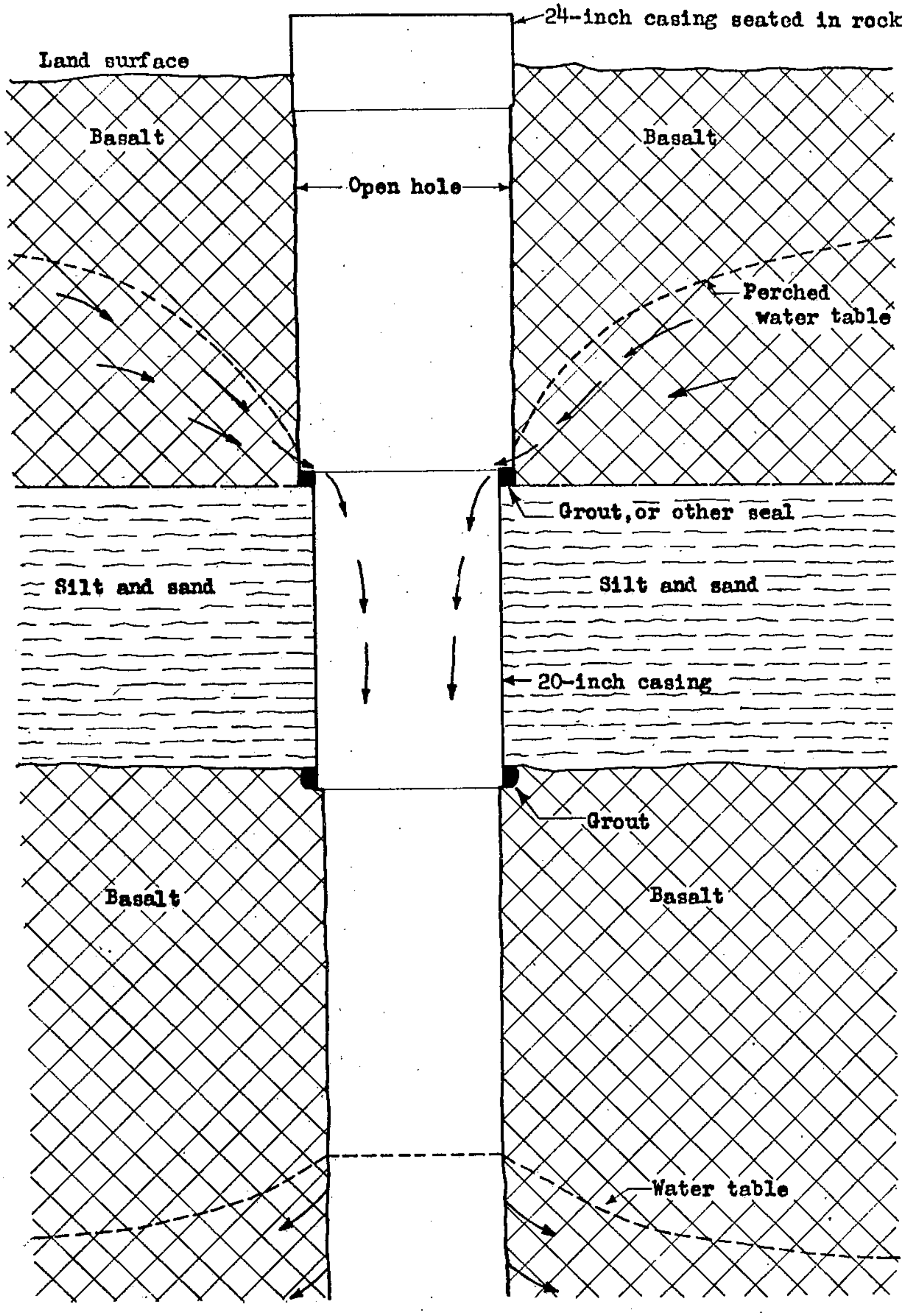

Figure 48.--Well construction to connect perched aquifer to main aquifer.

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