UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

WATER RESOURCES IN THE BIG LOST RIVER BASIN, SOUTH-CENTRAL IDAHO

By

E. G. Crosthwaite, C. A. Thomas, and K. L. Dyer

Prepared in cooperation with the
Idaho Department of Reclamation

70-[redacted] 93
OPEN-FILE REPORT

Boise, Idaho
1970

CONTENTS

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS

TABLES

WATER RESOURCES IN THE BIG LOST RIVER BASIN,

SOUTH-CENTRAL, IDAHO

By E. G. Crosthwaite, C. A. Thomas, and K. L. Dyer

ABSTRACT

The Big Lost River basin occupies about 1,400 square miles in south-central Idaho and drains to the Snake River Plain. The economy in the area is based on irrigation agriculture and stockraising. The basin is underlain by a diverse assemblage of rocks which range in age from Precambrian to Holocene. The assemblage is divided into five groups on the basis of their hydrologic characteristics: Carbonate rocks, noncarbonate rocks, cemented alluvial deposits, unconsolidated alluvial deposits, and basalt. The principal aquifer is unconsolidated alluvial fill that is several thousand feet thick in the main valley. The carbonate rocks are the major bedrock aquifer. They absorb a significant amount of precipitation and, in places, are very permeable as evidenced by large springs discharging from or near exposures of carbonate rocks. Only the alluvium, carbonate rock and locally the basalt yield significant amounts of water.

A total of about 67,000 acres is irrigated with water diverted from the Big Lost River. The annual flow of the river is highly variable and water-supply deficiencies are common. About 1 out of every 2 years is considered a drought year. In the period 1955-68, about 175 irrigation wells were drilled to provide a supplemental water supply to land irrigated from the canal system and to irrigate an additional 8,500 acres of new land.

Average annual precipitation ranged from 8 inches on the valley floor to about 50 inches at some higher elevations during the base period 1944-68. The estimated water yield of the Big Lost River basin averaged 650 cfs (cubic feet per second) for the base period. Of this amount, 150 cfs was transpired by crops, 75 cfs left the basin as streamflow, and 425 cfs left as ground-water flow. A map of precipitation and estimated values of evapotranspiration were used to construct a water-yield map.

A distinctive feature of the Big Lost River basin is the large interchange of water from surface streams into the ground and from the ground into the surface streams. Large quantities of water disappear in the Chilly, Darlington, and other sinks and reappear above Mackay Narrows, above Moore Canal heading, and in other reaches. A cumulative summary of water yield upstream from selected points in the basin is as follows:

	Water yield (cfs)	Surface water (cfs)	Ground water (cfs)	Crop evapotranspiration (cfs)
Above Howell Ranch	345	310	35	-
Above Mackay Narrows	450	325	75	50
Above Arco	650	75	425	150

Ground-water pumping affects streamflow in reaches where the stream and water table are continuous, but the effects of pumping were not measured except locally. Pumping depletes the total water supply by the amount of the pumped water that is evapotranspired by crops. The part of the pumped water that is not consumed percolates into the ground or runs off over the land surface to the stream. The estimated 425 cfs that leaves the basin as ground-water flow is more than adequate for present and foreseeable needs. However because much of the outflow occurs at considerable depth, the quantity that is salvageable is unknown.

Both the surface and ground waters are of good quality and are suitable for most uses. Although these waters are low in total dissolved solids, they tend to be hard or very hard.

INTRODUCTION

The Big Lost River basin occupies about a 1,400 square mile area along the northwest side of the Snake River Plain in south-central Idaho (fig. 1). It is one of several basins along the northwest side of the Plain that has no surface drainage tributary to the Snake River. The mouth of the basin at Arco is about 65 miles west of Idaho Falls. That part of the Big Lost River drainage that lies below Arco is considered to be part of the Snake River Plain and is not included in this report.

Water shortages occur frequently in the basin because of wide fluctuations in annual precipitation and because the single reservoir in the basin can store only about 20 percent of the average annual flow of the Big Lost River. Thus, during wet years, much of the surface flow leaves the basin before it is used. Some of this water could be retained for use in dry years and to control floods if reservoir space were available. Despite the water shortages and lack of storage, about 67,000 acres is irrigated with surface water. During the period 1955-68, many farmers drilled irrigation wells to provide a supplemental water supply for use in dry years and also to put more land into crop production.

The Big Lost River loses and gains large volumes of water in some of its reaches resulting in a complex interchange of surface and ground water in the basin. Most of the water used for irrigation is diverted from gaining reaches of the river. Beginning about 1955, significant quantities of ground water have been pumped for irrigation, particularly during dry years.

A detailed description of the hydrology of the basin is a prerequisite to the efficient use of its water resources and the administration of State water laws. The purpose of this report, therefore, is to (1) describe the distribution of the water resources in the basin, and (2) estimate the total quantity of water available to the basin.

GAGING STATION- AND WELL-NUMBERING SYSTEM

The gaging stations in this report are numbered in downstream order in accordance with the permanent numbering system used by the Geological Survey except that the prefix (13-), which indicates that the station is in the Snake River basin, is deleted. Text and table references show a network name and number, for example, as: Big Lost River at Howell Ranch, near Chilly, Idaho (1205). To avoid repetition, the entire name and number are not always repeated when the reference to the station is clear. Points from which only miscellaneous measurements are available are not numbered in this report.

The well-numbering system used by the Geological Survey indicates the locations of wells within the official rectangular land subdivision, 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 three letters and a numeral, which indicate the quarter section, the 40-acre tract, the 10-acre tract, and the serial number of the well within the tract, respectively. 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 and 10-acre tracts are lettered in the same manner. Well 9N-21E-14bbc1 is in the SW¼NW¼NW¼ sec. 14, T. 9 N., R. 21 E. and is the first well visited in that tract.

DATA AVAILABLE

No detailed appraisal of the water resources of the Big Lost River basin has previously been made. Most of the previous investigators of the basin's water resources were concerned only with gains and losses in streamflow, with leakage from Mackay Reservoir, and with other aspects of this resource.

Stearns, Crandall, and Steward (1938, p. 245), as a part of their study of the Snake River Plain, estimated that the annual outflow of both surface and ground water from the basin averaged 226,000 acre-feet for the years 1921-27 inclusive. Mundorff, Crosthwaite, and Kilburn (1964, p. 122),

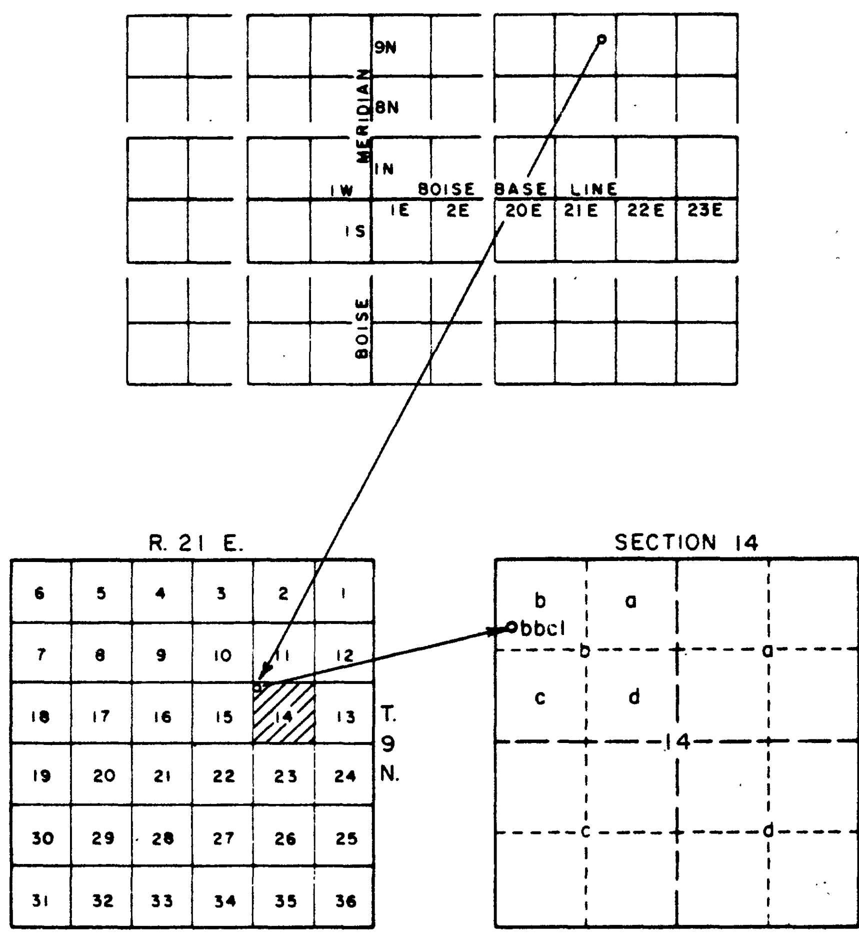


FIGURE 2.-- Diagram of the well-numbering system. (Using well 9N-21E-14bbcl).

as a part of a study of the Snake River Plain, estimated the average annual outflow from the basin to be 330,000 acre-feet.

The first measurement of streamflow was made by the U.S. Geological Survey in December 1903 at the gage site below Mackay Reservoir, near Mackay (1270). Since that time the Survey has operated gaging stations at 25 other sites in the basin for various lengths of time. In addition, a large number of miscellaneous measurements of discharge are in the files of the Survey, and the Lost River Irrigation District has measured many streams and canals during the course of the District's distribution of irrigation water. The U.S. Weather Bureau has collected temperature and rainfall data for significantly long periods at several sites since the first record began at Arco in 1894. The U.S. Soil Conservation Service has collected data on snow depth and water content of snow at a number of locations, the longest record dating back to 1936.

Much geologic mapping has been done in part of the Lost River Range (Ross, 1947) and in the mining areas in Copper Basin and the White Knob Mountains (Nelson and Ross, 1968, and Nelson, in press). General geologic mapping has been done west of the longitude of Leslie (Ross, 1963) and reconnaissance mapping has been done in the eastern part of the basin (Ross, 1963, and Mapel, written commun., 1969).

DATA COLLECTED

Although a large body of hydrologic and geologic data were available at the start of this study, many additional data were required to fulfill the purposes of this report. Beginning in the summer of 1966, continuous-record gages were operated on Lower Cedar Creek above diversions, near Mackay (1289); Alder Creek below South Fork, near Mackay (1298); and Antelope Creek above Willow Creek, near Darlington (1309). Additional miscellaneous measurements were made on tributaries and the main stem of Big Lost River in water years 1966-68. Ground-water levels were measured periodically in 30 wells. Additional water-level measurements were made in about 200 wells, and other well data were collected. Six wells were drilled to collect geologic and hydrologic data, and seismic, gravity, and resistivity surveys were made at key sites in the basin by the Regional Geophysics Section, U.S. Geological Survey. Eight precipitation-storage gages were operated in mountainous parts of the basin in cooperation with the U.S. Weather Bureau.

Unless noted otherwise, the average figures for water yield, much of the streamflow and precipitation data and other hydrologic data given in this report have been adjusted to the 25-year base period 1944-68.

CULTURE

Agriculture, dependent on irrigation, is the principal economic resource of the basin. Most of the nonirrigated area, including the mountainous terrain, is used primarily for production of beef cattle and sheep. Principal crops grown are seed potatoes, hay, and grain. Enterprises related to outdoor recreation provide considerable income to residents of the basin. Mining and logging are of minor importance.

Arco and Mackay are the principal towns with populations of 1,562 and 652, respectively, according to the 1960 census (U.S. Bureau of Census, 1961). The total population of the basin was about 4,360 in 1960.

WATER USE

The dominant use of water in the basin is for irrigation. Most irrigation water is supplied from surface sources. Table 1 shows the acreage of land irrigated by surface water and by ground water in segments of the basin. There are four irrigation wells above Mackay Reservoir and 175 wells below the reservoir. When surface-water supplies are short, ground water is pumped to supplement needs for part of the land, principally downstream from Mackay Reservoir, supplied by the canal system.

All municipal and practically all domestic water supplies are provided by wells and springs. Streams are the primary source of supply for livestock on the grazing lands.

Table 1. Irrigated and nonirrigated crop lands in Big Lost River basin.[a]

Location	Acres irrigated Surface water	Acres irrigated Ground water	Non-irrigated[b] crop land
Along Big Lost River basin above Mackay Reservoir, including Warm Springs Creek	10,840	200	1,000
Along tributaries above reservoir	1,840		
Thousand Springs Valley			9,150
Along Big Lost River below reservoir	29,340	8,300	8,155
Antelope Creek	6,200		
Alder Creek	1,000		
Totals (rounded)	49,000	8,500	18,000

a Data from Soil Conservation Service and Big Lost River Irrigation District.

b Locally called subirrigated land because the water table is near the land surface.

The large inflows of ground water to the surface streams are ideal for fish propagation. Large numbers of tourists fish for trout in the streams and in Mackay Reservoir during the summer months and enjoy the rugged alpine-type scenery of the basin.

ACKNOWLEDGMENT

Many well owners supplied useful data and permitted measurement of their wells. Well drillers furnished well logs and information concerning hydrologic and drilling conditions in the area. The Big Lost River Irrigation District and the Lost River Electric Cooperative, Inc., supplied records of their operations which helped greatly in this study. The individual members of the Cooperative and the service clubs of Arco also contributed materially to the study. The U.S. Forest Service, U.S. Soil Conservation Service, and U.S. Weather Bureau provided manpower assistance in making measurements of precipitation. The enthusiastic cooperation of all the above is gratefully acknowledged.

Special thanks are given to Mr. DeVon Jensen, watermaster of Water District 27, whose generous efforts and cooperation expedited the progress of this study.

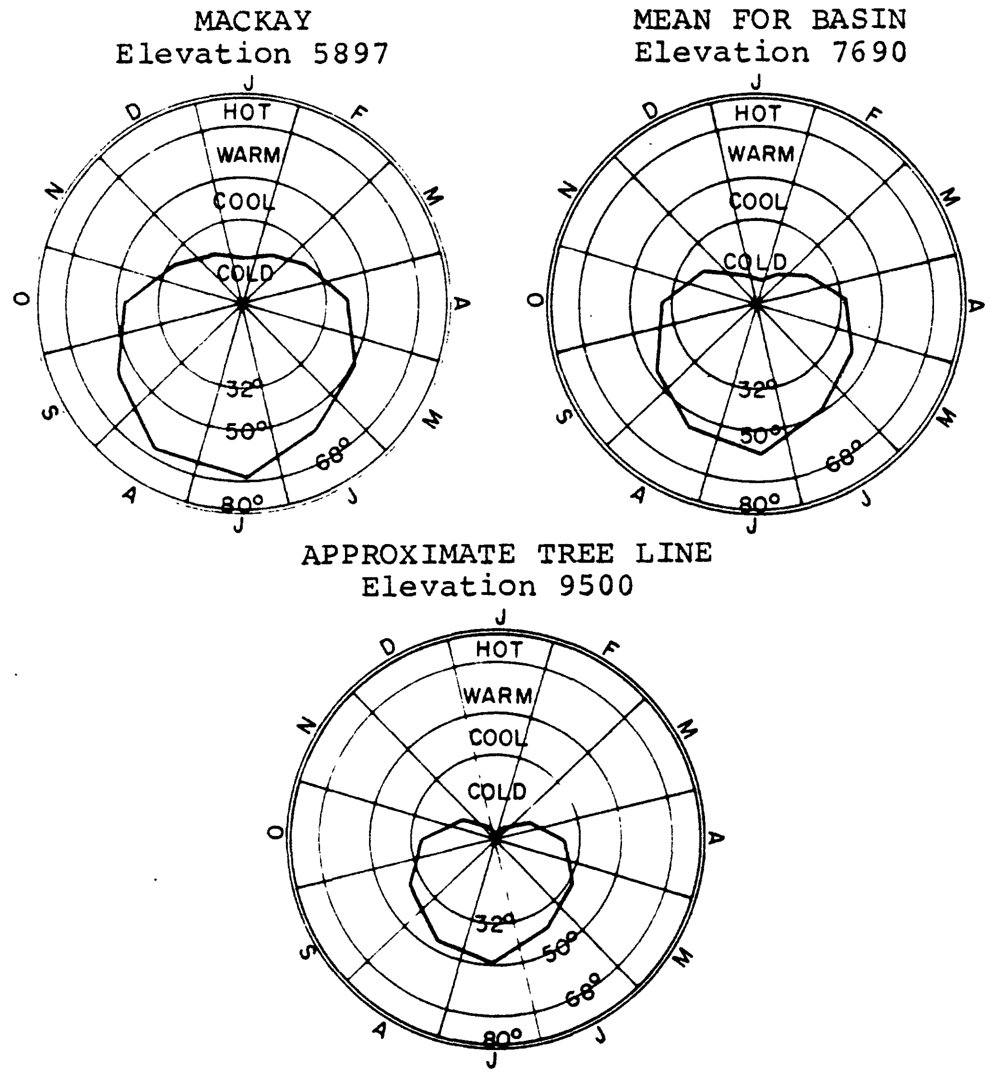
PHYSIOGRAPHY

The Big Lost River basin is at the southern edge of the Northern Rocky Mountain Province of the Rocky Mountain System in central Idaho. The basin is roughly rectangular, averaging about 45 miles long and 30 miles wide, with the long axis oriented in a northwesterly direction. The basin is bounded on the east and northeast by the Lost River Range, on the northwest by the northeast extension of the Boulder Mountains, on the southwest by the Pioneer Mountains, and on the southeast by the Snake River Plain (fig. 3). The White Knob Mountains lie almost in the center of the basin. Altitudes in the basin range from about 5,300 feet above sea level at Arco to 12,662 feet at the top of Borah Peak in the Lost River Range. Most of the divides between the basin and adjacent basins exceed 9,000 feet. About 85 percent of the basin is steep mountainous terrain. The Lost River Range is the highest and most precipitous; the Pioneer Mountains are rugged and high; the other ranges are somewhat less rugged and less high but their highest peaks exceed 10,000 feet. Approximately 10 percent of the basin is above the tree line which is at about 9,500 feet, and an equal amount is below 6,000 feet. Roughly 230 square miles, or about 16 percent, is gently sloping valley lands. These lands are confined to the main valley of the basin for about 50 miles upstream from Arco, to Copper Basin, to Antelope Creek Valley near Grouse, and to narrow bottom lands along streams and tributaries.

The Big Lost River is formed about 60 miles upstream from the mouth of the basin by the confluence of East Fork Big Lost River and North Fork Big Lost River. Star Hope and Wild Horse Creeks are important tributaries of the East Fork which rises in Copper Basin. North Fork rises in the western part of the basin and Summit Creek is its largest tributary. Thousand Springs Creek, the next important tributary, joins the river 25 miles downstream from the confluence of the East Fork and the North Fork of Big Lost River. Eight miles farther downstream at the upstream end of Mackay Reservoir, Warm Springs Creek enters the river, next below the reservoir are Alder, Antelope, and Pass Creeks. Below Arco, the Big Lost River flows on the Snake River Plain, and its channel ends about 25 miles east northeast of Arco at the so-called Lost River Sinks.

CLIMATE

The Big Lost River basin has a continental type climate characterized by a large range in seasonal and daily temperatures, in wind directions and velocities, and by the large local variations in precipitation that result from the high degree of relief in the basin. Of most significance to this hydrologic study was the appraisal of temperature, precipitation, and wind as these three parameters are critical to assessment of the evapotranspiration rates used in this report. Average monthly temperatures and precipitation at sites in and near the basin are shown in figures 4 and 5.



TEMPERATURE, IN DEGREES FAHRENHEIT, AND
ELEVATION, IN FEET ABOVE MEAN SEA LEVEL

FIGURE 4.-- Monthly mean temperatures at selected elevations in Big Lost River basin.

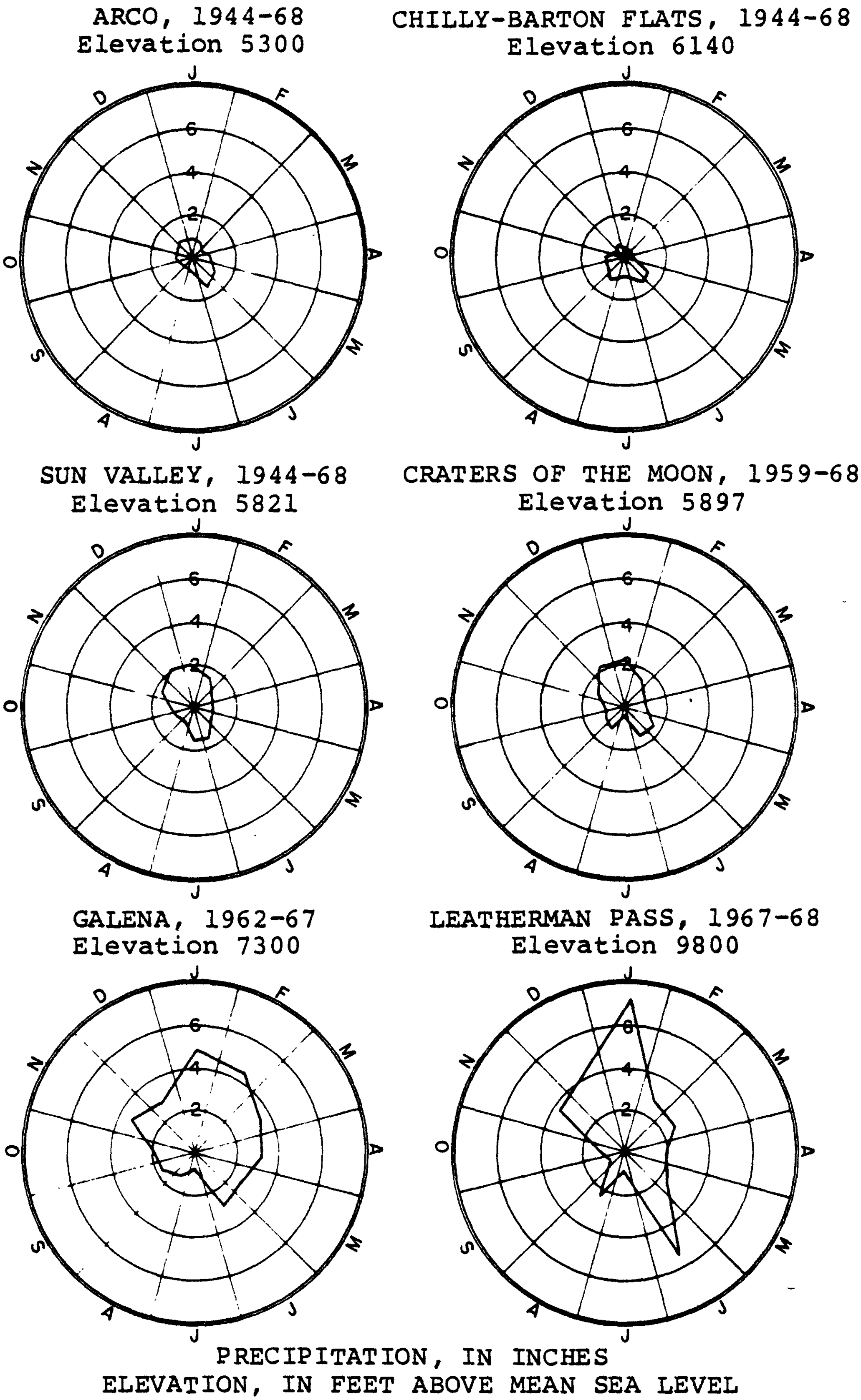


FIGURE 5.-- Monthly distribution of precipitation at selected sites in and near the Big Lost River basin. (Average for years as shown).

Temperature

Figure 4 shows the mean monthly temperatures at Mackay, at 7,690 feet, the mean elevation for the basin, and at 9,500 feet elevation, the approximate tree line. Temperatures at Mackay were from records of the U.S. Weather Bureau. The recorded minimum, maximum, and annual mean at Mackay was -29°, 104°, and 42° F, respectively. Temperatures at 7,690 feet and at 9,500 feet elevation were computed from lapse rates (see p. 20).

Precipitation

Precipitation data were available at the start of this study at Arco, Chilly-Barton Flats, Grouse, Mackay ranger station, and at a point 4 miles northwest of Mackay (fig. 3). All these stations are below 6,200 feet in elevation, and all showed a low level of precipitation, with more than 50 percent of the annual total occurring in the spring and summer. However, streamflow records, snow-course data, and daily weather records for nearby high-elevation stations at Craters of the Moon, at Sun Valley, and at Galena indicated three important trends: (1) Precipitation increases rapidly with elevation, (2) precipitation is highest on the windward (southwest) side of the Big Lost River basin, and (3) the relative proportion of cold-season precipitation increases rapidly with elevation.

Because topography has such an important effect on the distribution of precipitation, records from the daily stations (all at relatively low elevation) are poor indices of basin-wide precipitation. Prior to 1967, insufficient data were available to define elevation-precipitation relations within the basin. The then available data indicated that any given elevation-precipitation relation defined would, at least during the colder months, apply only to a relatively small part of the basin. Therefore, a considerable quantity of supplemental precipitation data was needed to define the amount and distribution of precipitation in the Big Lost River basin.

To supplement existing data, precipitation-storage gages were measured one to four times annually during the period August 1966 to September 1968 at nine high-elevation sites in or near the basin. In addition, in late March 1967 and

1968, miscellaneous measurements of snow accumulations were made at medium- and high-elevation sites in the basin. All sites from which meteorological data were obtained are shown in figure 3.

Precipitation at the storage-gage sites was proportioned by months on the basis of records at the nearby U.S. Weather Bureau stations. Efficiencies of catch at precipitation gages during winter ranged from 56 to 100 percent (average 80 percent) based on comparisons between the catch in cans and the measured water content of snow at the storage gage. Practically every comparative measurement showed that the catch in the cans was lower than the catch on the ground except at a few locations where significant melting might have occurred.

The relation between precipitation and elevation was studied in detail for the 1967 and 1968 water years. Distribution patterns of warm- and cold-season precipitation were distinctly different, so elevation-precipitation relations were developed for both seasons. The 5 months, November through March, were assigned to the cold season while the remaining 7 months were assigned to the warm season. Using these elevation-precipitation relations, detailed isohyetal maps were constructed for the 1967 and 1968 water years for use in the yield studies discussed in a later section of this report.

Warm-season elevation-precipitation relations for 1967 water year are shown in figure 6 and cold-season relations for the same period are shown in figure 7. The same relations were plotted for the 1968 water year. Only data for the 1967 and 1968 water years were available for most of the stations; therefore, the precipitation values plotted were adjusted by correlation with data from the long-term stations to make them representative of the base period 1944-68.

Figure 6 shows that a single straight line is adequate to define the warm-season elevation-precipitation relations. Although there is considerable deviation from this straight-line relation, the deviation is without pattern and can be attributed to statistical fluctuations which would tend to smooth out over a longer period of record. Also it can be seen that the deviation in the warm season is from about 6 inches to about 16 inches. Because warm-season precipitation tends to be very unevenly distributed within any given year, a very long period of record is required before a dependable average value can be established at any given station.

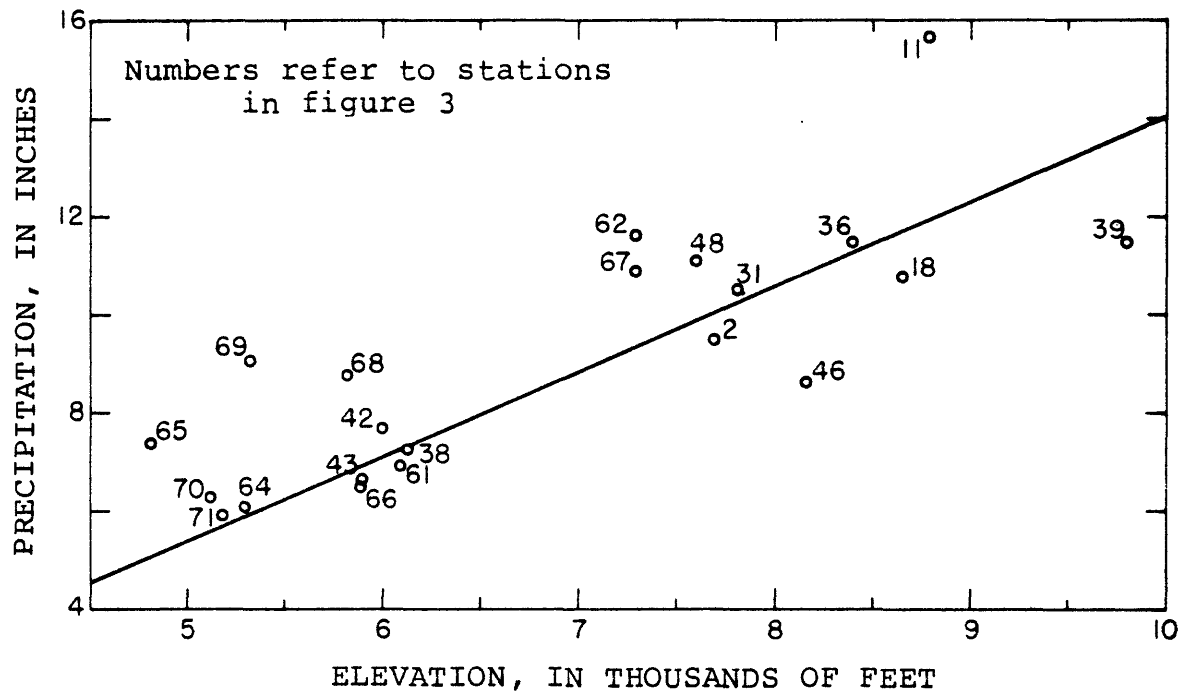


FIGURE 6.-- Precipitation-elevation relations in the Big Lost River area for the warm season of the 1967 water year.

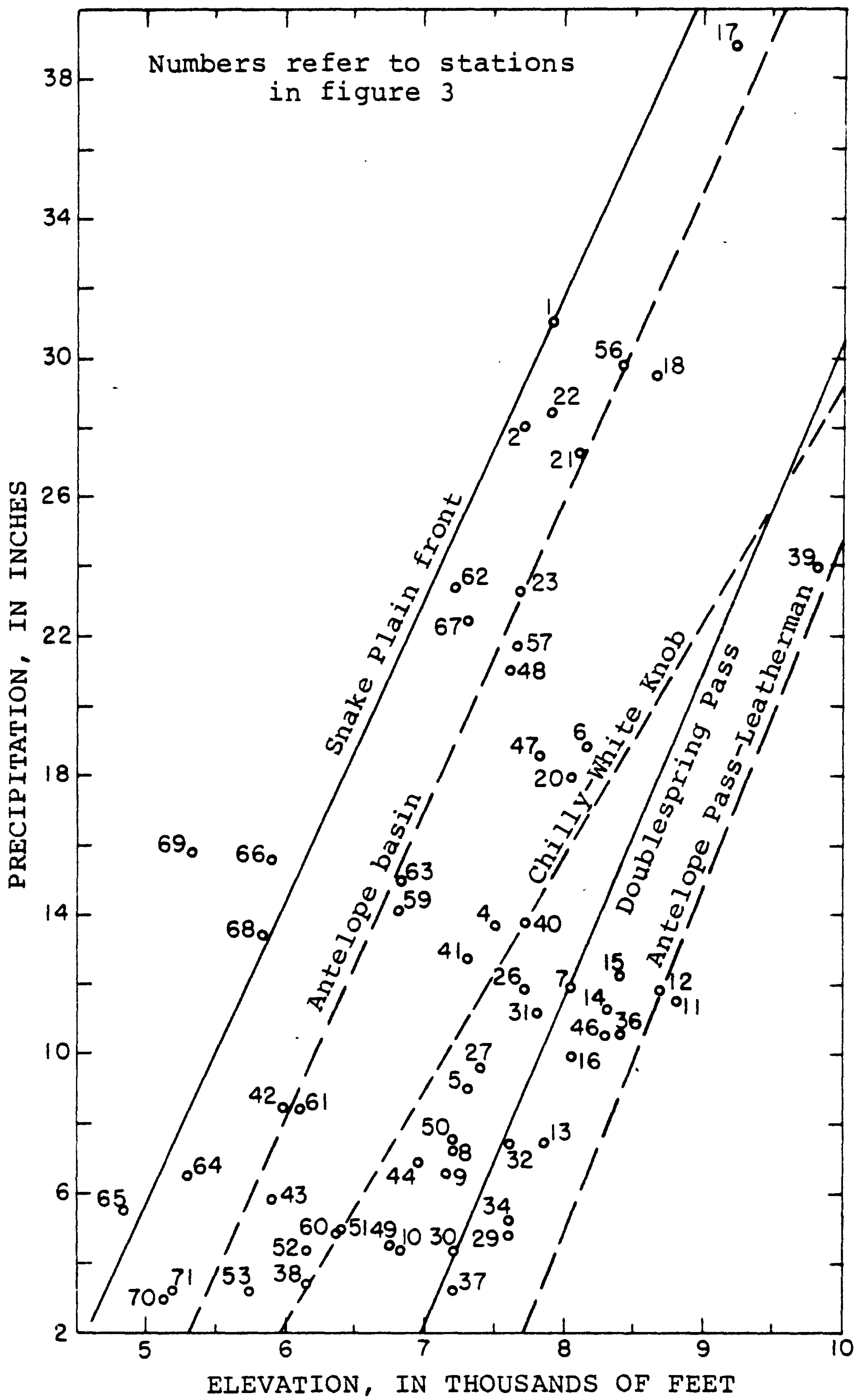


FIGURE 7.-- Precipitation-elevation relations in the Big Lost River area for the cold season of the 1967 water year.

The cold-season data shown in figure 7 are so widely scattered that a single line elevation-precipitation relation could not be established. Because a distinct linear elevation-precipitation relation was noted for each of several segments of the basin, separate straight lines were drawn to represent more nearly the elevation-precipitation relation applicable to segments of the basin. It can be seen that the deviation in the cold season is from about 3 inches to 39 inches, or nearly four times larger than during the warm season.

The information shown in figures 6 and 7 was combined with the 1968 water-year data and extended by correlation with nearby stations having a significant length of record to give an average annual (1944 to 1968) elevation-precipitation relation for each part of the basin as shown in figure 8. This relation was then used to construct the isohyetal map shown in figure 9.

Wind

Wind data collected at several atmospheric levels at the National Reactor Testing Station (Yanskey, Markee, Jr., and Richter, 1966) about 25 miles east of Arco indicate that wind movement persists most of the time at all elevations and that the prevailing direction is from the west at the general level of the higher ridges of Big Lost River basin. At lower elevations, topography exerts considerable influence on wind direction. Channeling of air flow through some of the longer valleys and over some of the ridges causes strong, persistent winds in parts of the basin.

Evapotranspiration

Evapotranspiration, as used in this study, is a term applied to the actual amount of water evaporated directly from land, water, and plant surfaces plus that transpired into the atmosphere by vegetation. In contrast, potential evapotranspiration is the water loss that could occur if at no time were there a deficiency of water in the soil for use by vegetation or for evaporation from the soil surface. In the Big Lost River basin, actual evapotranspiration is less than potential evapotranspiration because deficiencies in

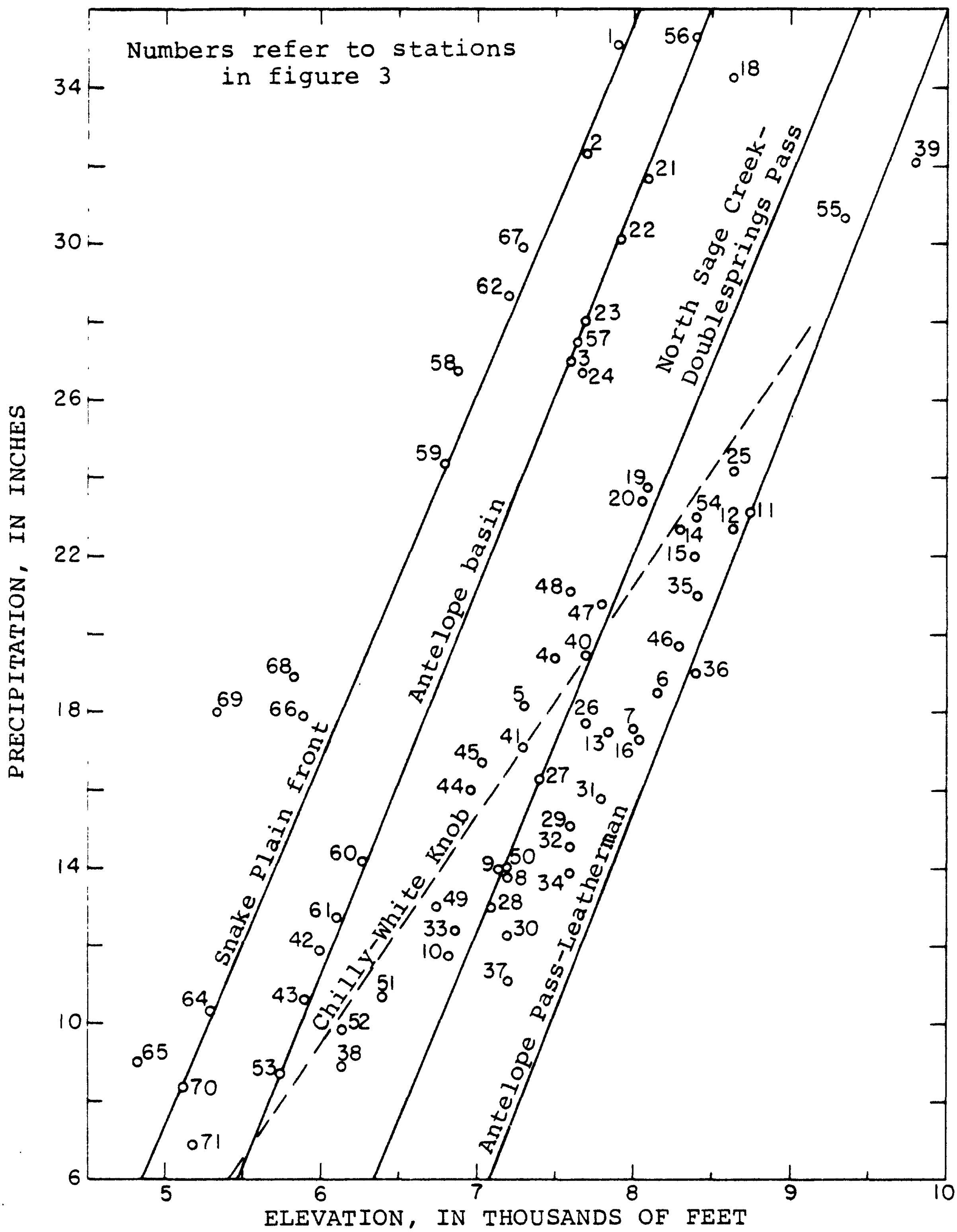


FIGURE 8.-- Precipitation-elevation relations in the Big Lost River area (25-year average).

soil moisture exist, often for extended periods of time. Actual evapotranspiration is of prime interest in this study and the techniques used to compute it are described in some detail.

Direct measurements of evapotranspiration in the Big Lost River basin were not possible within the scope of this study. Indirect estimates of monthly evapotranspiration rates were computed from potential rates using the soil-dryness correction curve published by Palmer and Havens (1958) in which the effects of available soil moisture and monthly precipitation have been empirically described. The available-water capacities of soils in the study area were estimated from soil surveys, geologic maps, vegetal cover, and limited field observations.

Potential evapotranspiration values were computed from the available data. Evaporation rates from lake surfaces and pans are generally considered to be good indices of potential evapotranspiration, and most investigators now believe that lake evaporation is nearly equivalent to potential evapotranspiration (Chow, 1964, p. 11-31; Crippen, 1965, p. E10-12). In this study, it was assumed that potential evapotranspiration in each part of the Big Lost River basin would be equivalent to the evaporation which would occur from a large lake in the same area. Using a formula developed by Rohwer (1931, p. 88), it was possible to compute a reasonable value for lake evaporation for any point within the basin. Rohwer's equation is:

$$E = 0.771\ (1.465-0.0186\ B)\ (0.44+0.118\ V)\ (P_w-P_a)$$

where

E = Lake evaporation, in inches per day

B = Mean barometric pressure, in inches of mercury at 32° F

V = Monthly mean wind velocity, in miles per hour at 6 inches above the ground

P_w = Mean vapor pressure, in inches of mercury, of saturated air at the mean temperature of the water surface

P_a = Average vapor pressure in the air, in inches of mercury

0.771 = Pan coefficient to adjust from evaporation in pans to evaporation in lakes

The climatological data needed for the formula were taken from weather-station records in and near the basin.

In this study, in lieu of actual measurements, it was assumed that the temperature of the water surface would be the same as the air temperature. This assumption should not introduce serious error into the evapotranspiration calculations because most of the evaporation rates computed in this study are applied not to evaporation from lakes but to evapotranspiration from plant and land surfaces that do have a mean temperature very close to that of the air. Monthly temperatures for points in the basin were estimated from data at Mackay adjusted for elevation on the basis of a calculated temperature-elevation lapse rate. The lapse rate was based on the relation between elevation and temperature at nearby weather stations, with elevations ranging from 3,800 feet at Buhl, Idaho, to 7,762 feet at Lake Yellowstone, Wyo. Different lapse rates were found to prevail during different months as follows: November to March, 4.6° F per 1,000 feet; June to August, 5.1° F per 1,000 feet; and April, May, September, and October, 4.5° F per 1,000 feet.

Wind movement within the basin has been measured only during the summer months and then only at Mackay beginning in 1965. Monthly estimates of wind movement at Mackay were obtained by correlation of the available data from Mackay with the 1944-1968 record for Pocatello. It was assumed that the wind velocities observed and estimated at Mackay prevailed over the entire basin, and that errors in computation of lake evaporation should largely be compensating within any large segment of the basin.

Few data on relative humidity are available in Idaho except at Boise and Pocatello. In general, the relative humidity in Idaho does not appear to increase rapidly with elevation so data taken from the Pocatello station were used without major adjustment for computations of lake evaporation in the Big Lost River basin.

Barometric pressures for points in the study area were obtained by adjusting Pocatello data for differences in elevation. The barometric estimates thus obtained should be sufficiently reliable to introduce no significant error into computations of lake evaporation.

Consumptive-irrigation requirement (net consumptive use) by crops and the associated land and water surfaces was estimated from values determined by Jensen and Criddle (1952, p. 12) and Simons (1953, p. 67). Jensen and Criddle assign values ranging from 1.07 to 1.25 acre-feet per acre depending on the type of crop grown. Simons uses 1.3 acre-feet per acre as an average value for all crops. On the basis of the consumptive-irrigation requirement determined by Jensen and Criddle (1952) and Simons (1953), it was estimated that the consumptive irrigation requirement for the irrigated lands in the valley between Arco and Mackay Reservoir was about 1.2 feet. Evapotranspiration in the irrigated areas is equal to the consumptive-irrigation requirement plus precipitation, because nearly all the precipitation falling on irrigated land in the Big Lost River valley is lost by evapotranspiration. Total evapotranspiration (including 0.8 foot of precipitation) would thus be about 2.0 feet on these irrigated lands.

HYDROGEOLOGIC FRAMEWORK

Geologic factors affect the amount of water that flows over the surface, that becomes soil moisture, or that moves underground. Alluvium and colluvium in the valley areas accept recharge and transmit large volumes of water. Also, much of the basin is underlain by limestone that absorbs and transmits large quantities of water. A characteristic of large parts of the basin is that even quick snowmelt rarely reaches the river by overland flow but rather flows underground. For example, the mountains on the northeast border of the basin nearly all exceed an altitude of 10,000 feet and nowhere is the divide more than 10 miles from the Big Lost River channel. The distances to the river from the snowfields are short and the gradients are steep (10 percent or more). Under these conditions, considerable runoff would normally be expected to occur, especially during snowmelt, but practically no surface flow reaches the Big Lost River channel. In the eastern part of the basin, stream channels are poorly developed in many of the steep canyons indicating that surface flows occur rarely. Soils are relatively thin over large parts of the basin, and many of the soils contain highly permeable gravels.

A large variety of rock types make up the geologic framework of the basin. Consolidated sedimentary strata consisting mostly of limestone, dolomite, quartzite, sandstone, shale, and argillite, ranging in age from Precambrian to Permian, occupy the mountainous areas. The strata have been folded and faulted, and are highly jointed. At some places, these rocks have been intruded by granitic rocks of Cretaceous and early Tertiary age. The Challis Volcanics, consisting principally of latite-andesite flows, breccia, and tuffs with some conglomerate at the base of the formation, blanket a large part of the older consolidated sedimentary strata at altitudes ranging from 5,500 to 9,500 feet. Glacial and stream deposits occupy the valleys in the mountainous areas. Cemented older alluvium, alluvial fans, and river alluvium comprise the fill material in the main valley, and much of the valley floor is covered with loam and gravelly loam soils. Basalt of the Snake River Group is present at the mouth of the basin.

The unconsolidated alluvial deposits transmit large amounts of water and yield large amounts of water to wells. The carbonate rocks absorb significant amounts of precipitation in the mountains and transmit water to the lowlands and probably to the Snake River Plain. Locally, the basalt transmits significant amounts of water out of the basin and yields moderately large amounts to wells.

ROCK UNITS

To describe the relation between the hydrology and the lithology of the basin, the rocks have been divided into five lithologic groups or units (fig. 10): (1) carbonate rocks, (2) noncarbonate rocks, (3) older cemented alluvial deposits, (4) unconsolidated alluvial deposits, and (5) basalt. Although the loam and gravelly loam soils in the valley are important in transmitting water from the surface to the underlying alluvial deposits and from the alluvial deposits to the atmosphere, they are not considered as aquifers and are not shown as a separate unit on the hydrogeologic map.

Carbonate Rocks

Carbonate rocks include the consolidated sedimentary strata that are predominantly limestone and dolomite. Some of the carbonate rocks are highly jointed and weathered by solution. Most of the large springs issue from or near exposures of these rocks. In many areas underlain by carbonate rocks, streamflow is lower than would be expected from established altitude-precipitation relations. For example, Elbow and Ramshorn Canyons in the southern part of the Lost River Range have only ephemeral streams because most of the water draining them flows underground through joints and solution cavities in the underlying carbonate rocks. Conversely, Lower Cedar Creek is perennial and receives about 12 cfs from a spring which issues about 50 feet above the base of a limestone cliff (p. 58). Thus, the carbonate rocks absorb and transmit significant quantities of the precipitation that falls on the basin. However, discharge measurements of streams flowing over these rocks at some places indicate that they are not all permeable.

Noncarbonate Rocks

This group includes all rather impermeable rocks: Granitic intrusive rocks, the Challis Volcanics, and sandstone, quartzite, argillite, and shale (fig. 10). These rocks, like the carbonates, also are jointed and fractured, but streams flowing over them usually are perennial, losing little, if any, flow. Springs are small and the precipitation percolating into the jointed and weathered upper part of the rocks moves laterally and eventually discharges into the streams as base flow.

The noncarbonate rocks are not uniformly less permeable, however, than the rocks in the other groups. A test well drilled near the gaging station at Howell Ranch, for example, showed that some of the shaley sandstone penetrated in the well is as permeable as the fine-grained alluvial deposits. Thus, the groupings are based on gross lithology, and exceptions to the implied permeability of the rocks must be expected.

Cemented Alluvial Deposits

These deposits compose the old alluvial fans and consist principally of calcite-cemented angular fragments of limestone, sandstone, and quartzite. They are exposed along the northeast side of the main valley from north of Leslie to beyond the upstream end of Mackay Reservoir. Seismic studies and test drilling show that the cemented alluvium extends completely across the main valley at the narrows just below Mackay Dam, but its subsurface extent is not known elsewhere. Although tightly cemented, it has some permeability and transmits some water.

Unconsolidated Alluvial Deposits

The unconsolidated alluvial deposits include river alluvium, glacial deposits, and young alluvial fans that form the main part of the valley fill and extend upstream to the heads of the tributary streams. The continuity of the alluvial deposits in the main valley is interrupted by the carbonate rocks at The Narrows above Mackay. The alluvial deposits consist of clay, silt, sand, gravel, and boulders. Most of these deposits are permeable and saturated, and they are the most important aquifer in the basin.

Drillers' logs of wells show that the alluvial deposits are highly variable in particle size and in degree of sorting. The fan deposits consist of materials ranging in size from clay to boulders. Where the side streams discharged into the main valley, their sedimentary loads were deposited within short distances, leaving little opportunity for sorting and stratification. Thus wells drilled on the alluvial fans normally encounter poorly sorted material. Subsequently, the Big Lost River eroded the toes of the fans and reworked the deposits together with younger alluvium. This resulted in the formation of good aquifers composed largely of well-sorted and stratified sand and gravel. Most wells drilled on the flood plain of the river are finished in these aquifers.

Geophysical Studies

Geophysical studies consisting of seismic profiles, gravity observations, and resistivity soundings were made in 1967 and 1968 to determine the nature and the thickness of the alluvial deposits. The work was accomplished by R. E. Mattick, D. R. Mabey, A. A. R. Zohdy, and D. L. Peterson of the Geological Survey (written commun., 1969), and R. G. Charboneau, of the Idaho Department of Highways (written commun., 1967). The following is a summary of results.

Gravity survey.--The results of approximately 215 gravity observations made by D. L. Peterson and D. R. Mabey in the main valley are shown in figure 11. The prominent features are gravity anomalies that presumedly are produced by a contrast between the less dense unconsolidated sediments and the more dense consolidated rocks.

An interpretation of the gravity data indicates that the thickness of the valley fill is on the order of 2,000-3,000 feet in the Thousand Springs and Barton Flats areas. The north-northeast plunging gravity nose in the vicinity of Chilly Buttes seems to be a buried bedrock high and the valley fill in this area and to the southwest is probably relatively thin. Another gravity high extends completely across the main valley at Mackay Narrows where the valley fill is interrupted by the carbonate rocks. Gravity data imply that northeastward from The Narrows to the Lost River Range, the fill is 200-400 feet thick. The large gravity anomaly east of Mackay indicates an alluvial fill that exceeds 5,000 feet in thickness. From Leslie southward, the gravity data suggest that the valley fill becomes progressively thinner and may be about 2,500 feet thick near the mouth of the valley. However, as explained later, other geophysical data indicate that some basalt may extend up the valley several miles north of Arco. This basalt would influence interpretation of the gravity data to the extent that the depth to bedrock probably is greater than indicated.

Seismic survey.--Six seismic profiles were made by R. E. Mattick of the Geological Survey and one by R. G. Charboneau of the Idaho Department of Highways. An interpretation of the seismic profiles in terms of the geologic conditions is shown in figures 12, 13, 14, 15, and 16 and the locations of the profiles are shown in figure 10. The profile just upstream from Howell Ranch shows that the maximum thickness of the valley fill is 75 feet (fig. 12). A test hole drilled to determine the character of the fill verified this thickness. A second seismic profile at Chilly Narrows shows that the fill is about 150 feet thick (fig. 13). The results of three seismic profiles at and near Mackay Narrows were combined to construct figure 14. Seismic data and test drilling show that the alluvial deposits are about 115 feet thick in the Mackay Narrows. The seismic data also indicate that the cemented alluvial deposits underlying the unconsolidated alluvial deposits at this place extend to a minimum depth of 1,000 feet below the surface and a maximum depth of at least 1,300 feet. Northeast of Mackay Narrows much of the surficial material is unconsolidated alluvium, but cemented alluvium also crops out along the line of the seismic profile. The seismic data indicates that the combined thickness of these deposits range from about 300-425 feet. This is in good agreement with gravity data which indicates a combined thickness ranging from 200-400 feet. Interpretation of the surficial geology and geophysical

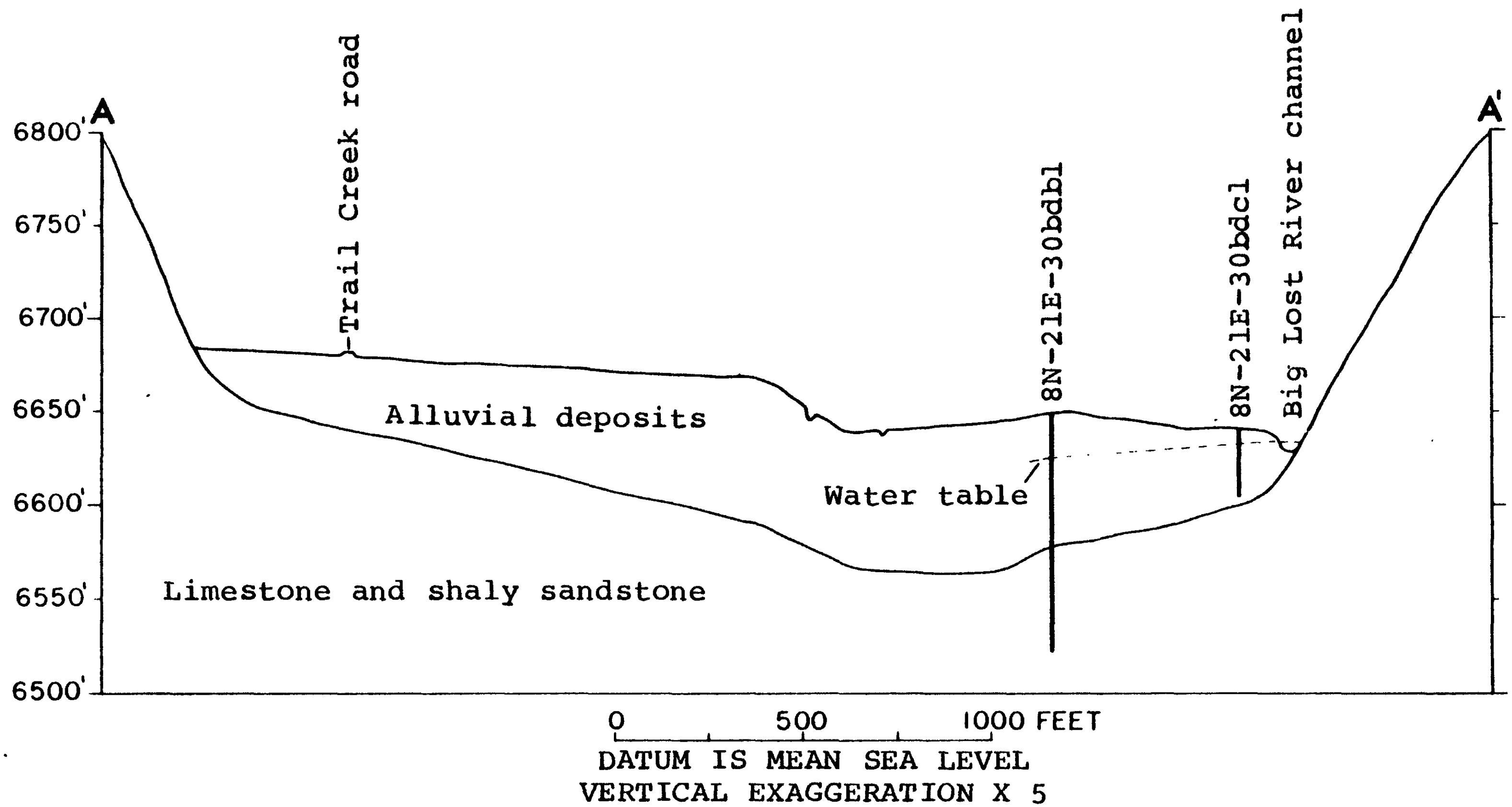


FIGURE 12.-- Geologic section A-A' near Howell Ranch compiled from well logs and seismic data. (See fig. 10 for location of section

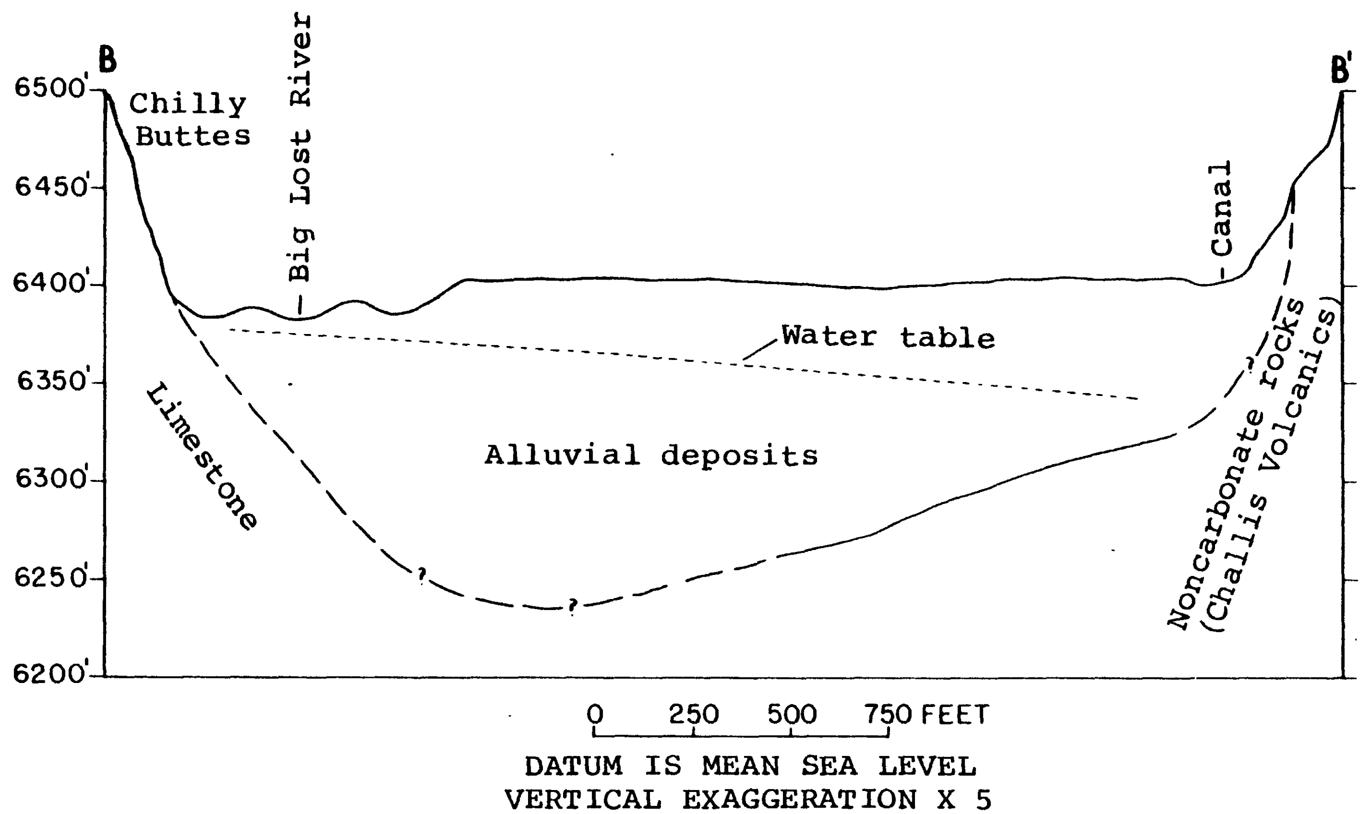


FIGURE 13,-- Geologic section B-B' across Big Lost River valley at Chilly Buttes based on seismic data. (See fig. 10 for location of section).

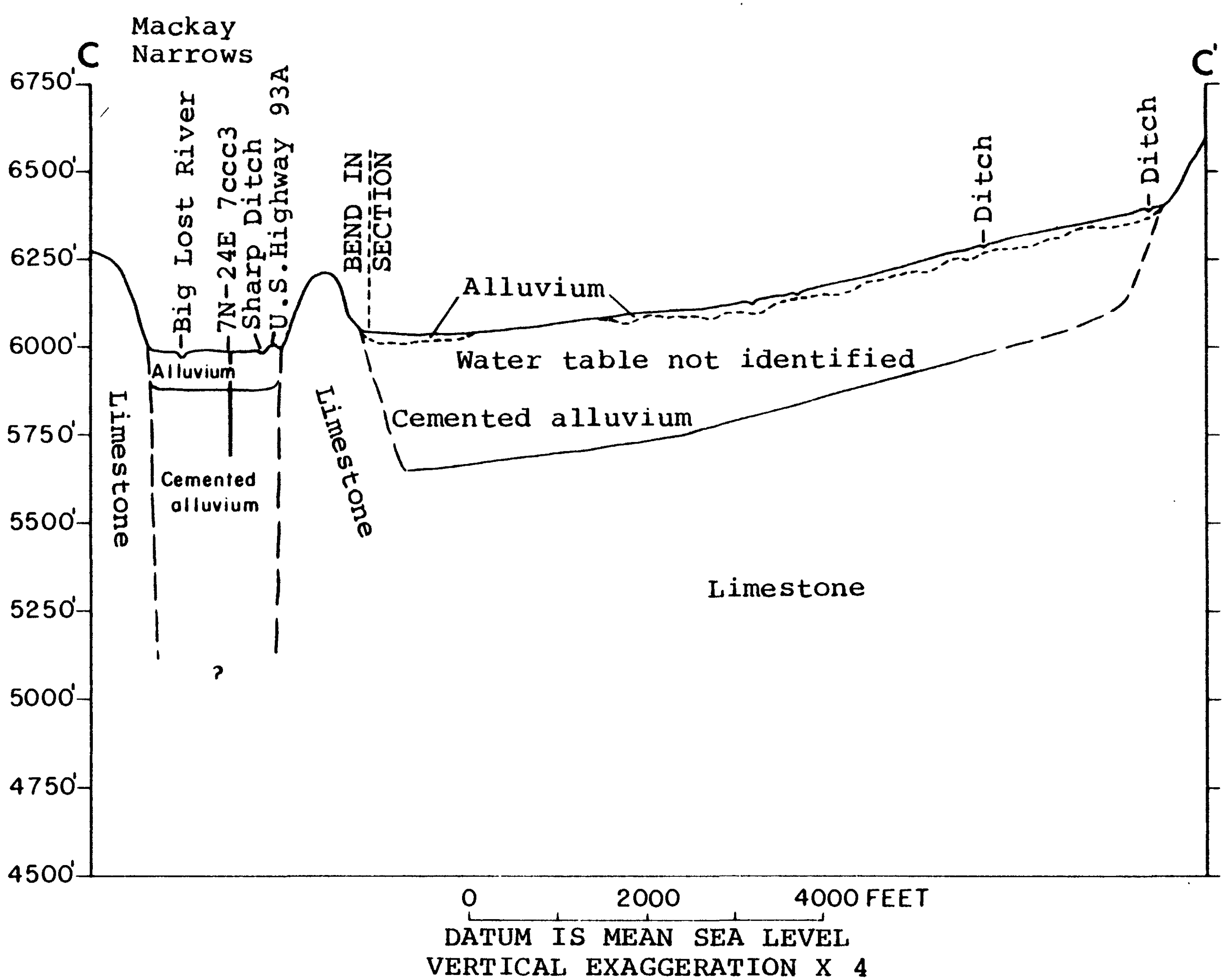


FIGURE 14.-- Geologic section C-C' across Big Lost River at Mackay Narrows, compiled from well logs, seismic data, and surficial geology. (See fig. 10 for location of section).

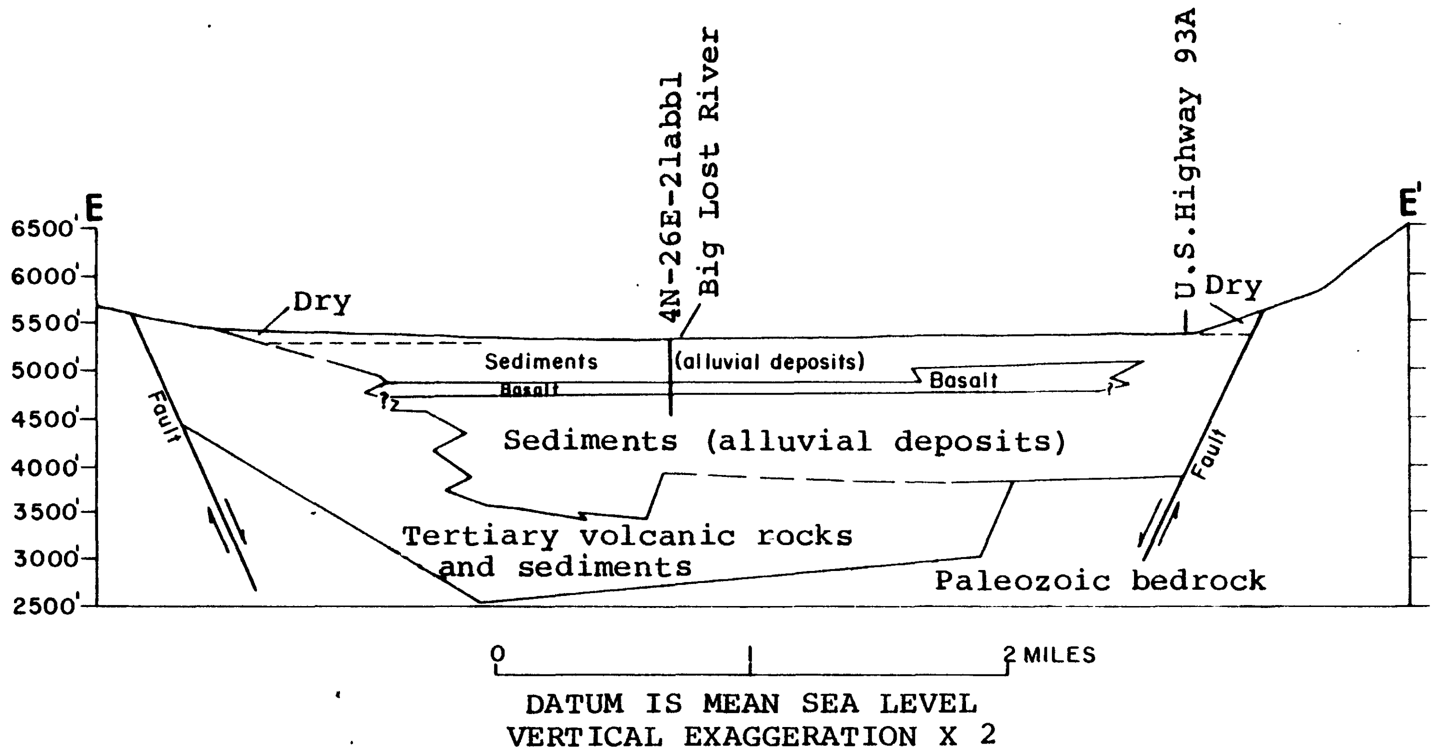


FIGURE 15.-- Generalized geologic section E-E' north of Arco compiled from gravity, seismic-refraction, and resistivity surveys. By Mabey, Zohdy, Peterson, and Mattick, 1969 personal communication. (See fig. 10 for location of section).

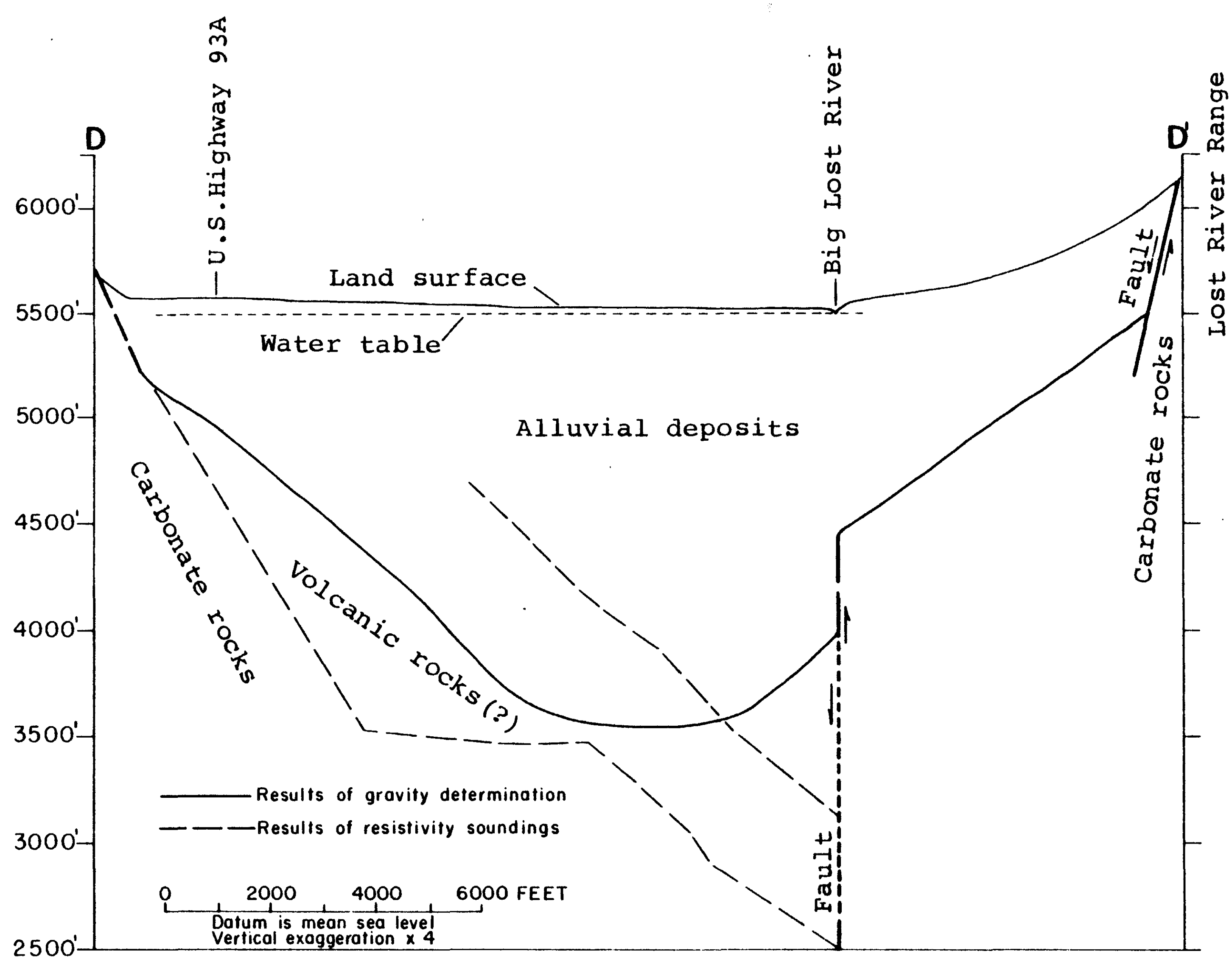


FIGURE 16.-- Geologic section D-D' north of Moore showing results of gravity and resistivity surveys. (After Mabey and Zohdy, 1968). (See fig. 10 for location of section).

data suggest that the unconsolidated alluvium is only a few feet thick whereas the cemented alluvium is on the order of 200-400 feet thick and that, although not shown in figure 14, there may be considerable relief on the underlying limestone.

The profile just north of Arco (fig. 15) was compiled from gravity, seismic, and resistivity studies together with data from a test hole 760 feet deep. The profile shows that faults bound both sides of the valley and that the total thickness of the alluvial deposits and basalt is on the order of 2,500 feet.

Resistivity soundings.--A geologic cross section of the valley 2.3 miles north of Moore is shown in figure 16. This profile is based on resistivity data collected by A. A. R. Zohdy and gravity data collected by D. R. Mabey. The data suggest that the valley fill is about 2,000 feet thick and that there is a fault about 1¼ miles west of the exposed base of the Lost River Range. The resistivity data also suggest that volcanic rocks lie between the valley fill and the older consolidated rocks. The volcanic rocks may be either Challis Volcanics, basalt of the Snake River Group, or both. The data are not adequate to determine the rock type. Aeromagnetic surveys also imply that volcanic rocks are present in this area, but the data are insufficient to interpret the depth to the volcanic rocks, their nature, or their thickness (D. R. Mabey, written commun., 1969).

Basalt

A flow of basalt of the Snake River Group crops out over 15 square miles west of Arco (fig. 10) and basalt buried by and interbedded with alluvial deposits extends from a few miles north of Arco to the Snake River Plain. The main body of basalt of the Snake River Group crops out about 5 miles south of Arco. In general, the basalt is very permeable and yields large volumes of water to wells, but interbedded sedimentary deposits, particulary west and south of Arco, tend to fill the joints in the basalt and restrict the movement of water. The significance of the basalt and interbedded sediments and the uncertainties of the hydrology of the basalt are discussed on pages 72-78.

STRUCTURE

The main valley of the Big Lost River basin was formed by block faulting of large magnitude. Baldwin (1951, fig. 1) shows the Lost River fault extending along the southwest side of the Lost River Range from beyond the northwest corner of the main valley to Pass Creek (fig. 10). Mapel (written commun., 1969) and Baldwin (1951, fig. 1) showed another fault just east of Pass Creek extending southward toward Arco along the west base of the Lost River Range. This fault is on the cross sections near Arco and Moore, figures 15 and 16, and has been exposed in an excavation in an alluvial fan 6 miles north of Arco. Relatively recent movement has occurred along this fault near Arco (Malde, H. E., oral commun., 1969). Baldwin also showed a fault, which probably does not extend very far up the main stem of the Big Lost River, along the east base of the northeast extension of the Boulder Mountains just west of the Thousand Springs area (fig. 10). Strata in the Lost River Range and the northeast extension of the Boulder Mountains have moved upward relative to the strata in the White Knob and Pioneer Mountains thus forming the main valley of the Big Lost River basin.

Many other faults displace the consolidated rocks. Hydrologically, the most important are northeast-trending faults that bound the central mass of the White Knob Mountains (Ross and Nelson, 1969). The block bounded by these faults has moved upward relative to the adjacent rocks. The uplift of the block resulted in a ridge across the main valley that now is buried by the cemented alluvium and river alluvium except where the limestone is exposed on the northeast side of Mackay Narrows (fig. 10).

Another significant fault trends north at the western edge of Barton Flats. Hamilton Springs issues from this fault, as also may Warm Springs.

All the older sedimentary deposits have been folded, some very intensely. The Challis Volcanics have been little disturbed by folding, the beds commonly having gentle undulations. The alluvial deposits are largely undisturbed other than by some gentle tilting caused by faulting.

GEOLOGIC HISTORY

The early pre-Tertiary geologic history of the area has been discussed by Ross and Forrester (1947) and by Baldwin (1951) and because it is not pertinent to the hydrology of the basin, it is not described here.

During Tertiary time, within the area of the Big Lost River basin, the Challis Volcanics were extruded on an erosion surface of low to moderate relief. After the end of volcanism, erosion again produced an area of low relief. Although some faulting occurred before and after the volcanism, the faulting that formed the main valley probably began in late Pliocene time, and continued into the Pleistocene (Baldwin, 1951, p. 901).

Glaciation during the Pleistocene Epoch has modified most of the valleys in Copper Basin and in the western part of the Big Lost River basin above an altitude of about 7,000 feet. Ross and Nelson (1969) have recognized three periods of glaciation in the White Knob and Pioneer Mountains. A glacier may have extended down the main valley of the Big Lost River as far as Chilly Buttes, but evidence of this is not conclusive. Evidence of glaciation is present on the southwest and west slopes of the Big Lost River Range, but the glacial deposits have been largely removed by subsequent erosion.

Deposition of stream-laid alluvium throughout the basin and the eruption of lava south of about the latitude of Moore have been the dominant geologic processes since the formation of the main valley. The surficial basalt at the mouth of the basin erupted from a vent about 3 miles west of Arco. The basalt interbedded with the alluvium west and southwest of Arco may be, in part, from this same vent, but it seems more likely that the flows came from the south and encroached on the alluvium contemporaneously being deposited at the mouth of the basin by the Big Lost River.

WATER RESOURCES

The source of water in the Big Lost River basin is precipitation falling on the land surface. A large part of the precipitation evaporates or is consumed by plant growth. Part of the remainder runs off from the land surface; part replenishes soil moisture; and part infiltrates to recharge the ground-water reservoir. For the purposes of this report, it is assumed that there is no interbasin movement of water.

INTERRELATIONS BETWEEN SURFACE WATER AND GROUND WATER

A distinctive feature of the Big Lost River basin is the large interchange of water from surface streams into the ground and from the ground into surface streams. At medium and low flows, all the surface flow in the main stem of Big Lost River disappears into the ground at the Chilly Sinks. Large quantities reappear in the vicinity of Mackay Reservoir, disappear again at the Darlington Sinks, reappear near Moore, and finally disappear beneath the Snake River Plain downstream from Arco.

Surface and ground water are so closely related that neither can be considered as a separate source of supply. The river alternately loses water to and gains water from the alluvial deposits in the main valley. These deposits also serve as conduits through which large amounts of water move down valley and into the Snake Plain aquifer. Glacial and stream deposits discharge water to East Fork and North Fork Big Lost River and Antelope Creek and to all tributaries. Many tributaries from the mountains bordering the main valley lose their entire flow to the alluvial deposits on entering the main valley, whereas others flow into Big Lost River only rarely when unusually large quantities of runoff occur. Surface flows are large at several places in the basin, but much of the water supply is unused and leaves the basin as ground-water underflow.

SURFACE WATER

The relatively free interchange between surface and ground water increases the difficulty of adequately describing the surface-water supply of the basin. Data from continuous-record gaging stations or miscellaneous measurements define the characteristics of the surface flow only at the gaged points, but not necessarily at other points along the stream. Not only is the surface flow affected by losses and gains, but it also is affected by diversion for irrigation.

Water from Big Lost River, and from Antelope, Alder, and Pass Creeks, and other streams is diverted for irrigation and water is stored and regulated in Mackay Reservoir. Irrigation and storage have affected profoundly some of the characteristics of surface flows in the basin. To be meaningful, the surface-water supply of the basin should be analyzed and evaluated after accounting for these effects.

Records Available

A total of about 430 station years of continuous-record streamflow data at 26 sites has been obtained by the Geological Survey at regular gaging stations in the basin. The records are summarized in table 2. Records of streamflow collected by the Geological Survey prior to 1960 are published in an annual series of water-supply papers and summarized in Water-Supply Papers 1317 and 1737. From 1961-68, streamflow data have been published in annual reports on a statewide basis. In addition, since 1922, the watermaster of the Big Lost River has collected discharge data for streams and canals in connection with the distribution of water to the water users. These data are on file with the Idaho Department of Reclamation.

To define more adequately the areal distribution of the water resources of the basin, additional measurements at miscellaneous sites were made for this study. In September 1966, the Geological Survey made measurements at 35 miscellaneous sites on tributaries in the basin. During the 1967 water year, 1 to 11 measurements were made at each of 42 miscellaneous sites, of which seven were of the flow in the main river channel; and, during the 1968 water year, 1 to 10 measurements were made at each of 41 miscellaneous sites, of which four were of the flow in the main river channel.

Characteristics of the Surface Flows

For the purposes of describing streamflow characteristics, the basin is divided into four major subareas: 1) Above Howell Ranch, 2) Howell Ranch to Mackay Narrows, 3) Mackay Narrows to Moore Canal heading, and 4) Moore Canal heading to the gaging station downstream from Arco. The streamflows, diversions from streamflow, and interchange of surface and ground water as it relates to streamflow in these subareas are described in the following sections.

Table 2. Streamflow at gaging stations in the Big Lost River basin.

Station No.	Name	Drainage area (sq mi)	Period of record	Discharge, cfs		
				Max.	Min.	Mean for period of record[a]
1200	Big Lost R. at Wild Horse, near Chilly	114	3/44 to 9/68	1,380	65	103
1205	Big Lost R. at Howell Ranch, near Chilly	450	4/04 to 11/20[b] 5/20 to 9/68	4,420	19	309
1210	Big Lost R. below Chilly Canal, nr Chilly	493	4/21 to 10/21 4/22 to 10/22	3,210	(c)	-
1215	Big Lost R. at Chilly Bridge, near Chilly	502	6/20 to 9/20	714	0	-
1220	Thousand Springs Creek near Chilly	145	12/12 to 2/13 2/14 to 9/14 4/21 to 11/21 5/22 to 9/22	85	1.0	-
1225	Big Lost R. below Chilly Sinks, nr Chilly	(c)	5/21 to 12/21	2,330	(c)	-
1235	Big Lost R. (east channel) above Mackay Res., near Mackay	(c)	5/19 to 11/59	1,360	0	72.1
1240	Big Lost R. (west channel) above Mackay Res., near Mackay	(c)	5/19 to 11/59	1,200	3.8	58.5

1245	Warm Spring Cr. (east channel) near Mackay	(c)	5/19 to 11/59	285	5.2	32.2
1250	Warm Spring Cr. (west channel) near Mackay	(c)	5/19 to 11/59	600	49	96.6
1255	Surface inflow to Mackay Res., nr Mackay	766	5/19 to 11/59	d2,760	d75	260
1260	Mackay Res. nr Mackay	788	1/19 to 9/68	45,580 ac-ft	0	(c)
1265	Sharp ditch nr Mackay	-	6/12 to 10/18	47	0	(c)
1270	Big Lost R. below Mackay Res., nr Mackay	813	3/19 to 9/68 12/03 to 8/06 5/12 to 3/15 1/19 to 9/68	2,990	18	288
1280	Cedar Creek above forks, near Mackay	4.1	11/12 to 3/13	33	.1	-
1285	Cedar Creek below forks, near Mackay	6.1	11/12 to 3/15	116	(c)	-
1289	Lower Cedar Cr. above div., near Mackay	e8.26	8/66 to 9/68	194	(c)	-

Table 2. Streamflow at gaging stations in the Big Lost River basin.

Station No.	Name	Drainage area (sq mi)	Period of record	Discharge, cfs		
				Max.	Min.	Mean for period of record[a]
1290	Clark ditch nr Mackay	-	5/20 to 9/20 4/21 to 11/21 6/22 to 9/22	26	0	-
1295	Cedar Cr. (below power-plant) near Mackay	8.4	5/20 to 9/20 4/21 to 11/21 4/22 to 9/22	297	.4	-
1298	Alder Cr. below South Fork, near Mackay	27.6	8/66 to 9/68	165	17	-
1300	Alder Cr. near Mackay	37	5/20 to 9/20 4/21 to 9/21 4/22 to 9/22	(c)	(c)	-
1305	Big Lost R. at Leslie	1,020	6/19 to 11/19 3/20 to 12/21 3/22 to 9/22	2,580	24	-
1309	Antelope Cr. above Willow Cr., near Darlington	93.4	5/66 to 9/68	829	13	-
1310	Antelope Cr. near Darlington	f210	5/13 to 9/22	833	3	-

1315	Pass Cr. near Leslie	23.6	5/20 to 9/20 4/21 to 11/21 5/22 to 9/22	(c)	(c)	-
1320	Big Lost R. near Moore	1,310	12/20 to 5/21 8/21 to 12/25 6/26 to 11/26	2,330	12	
1325	Big Lost R. near Arco	1,410	8/46 to 9/61 5/66 to 9/68	2,500	0	

a Means computed only for records having 5 years or more of continuous record.
b No winter records 1904, 1906-14, 1920-48.
c Not determined.
d Mean daily discharge.
e Records for station 1289 equivalent to combination of stations 1290 and 1295.
f No winter records except 1914-15.

Above Howell Ranch

The North Fork Big Lost River and East Fork Big Lost River supply most of the flow in the Big Lost River at the gaging station at Howell Ranch (1205). These streams in the northwestern part of the basin drain about a third of the total area, but they supply nearly half the total water yield of the basin. Runoff per unit area is higher than in most other parts of the basin. Some characteristics of the flow of Big Lost River at Howell Ranch are shown by the duration curve in figure 17. The graph shows the percent of time flow at the gage can be expected to be equalled or exceeded. For example, a discharge of 63 cfs probably will be equalled or exceeded 90 percent of the time at the Howell Ranch gage. The "departure point," about 190 cfs, at which the curve flattens noticeably, is approximately the discharge at which base flow begins or when nearly all flow comes from ground water. Most of the flow above 190 cfs comes from snowmelt. Base flow is exceeded about 30 percent of the time.

The base flow of the North Fork Big Lost River and its tributaries is sustained by ground water in the alluvium-filled valleys. Just above the gaging station North Fork Big Lost River at Wild Horse (1200), the North Fork has cut through the alluvium and flows on consolidated rock thus causing nearly all the ground water flowing through the alluvium to discharge into the stream. Table 3 shows the magnitude of inflow in this reach.

A large part of Copper Basin is underlain by glacial deposits through which flows much of the precipitation falling on headwater areas. Miscellaneous measurements of streamflow made in September 1966 show that above Wild Horse Creek the East Fork is a gaining stream in that surface outflow from Copper Basin is 17 cfs greater than total surface flow in the streams along the periphery of the basin. Similarly, as shown by column 7, table 4, measurements show an average contribution of 33 cfs of ground water to the reach of East Fork between Corral Creek and the confluence of East and North Forks.

Differences between the flows below the confluence of the North and East Forks and the flow at Howell Ranch are listed in column 11, table 4. Irregularities in the differences are caused by storage changes in the channel between the measuring sections. Selected measurements made during periods of near-steady flow indicate that an average loss to ground water of about 7 cfs occurs in the reach.

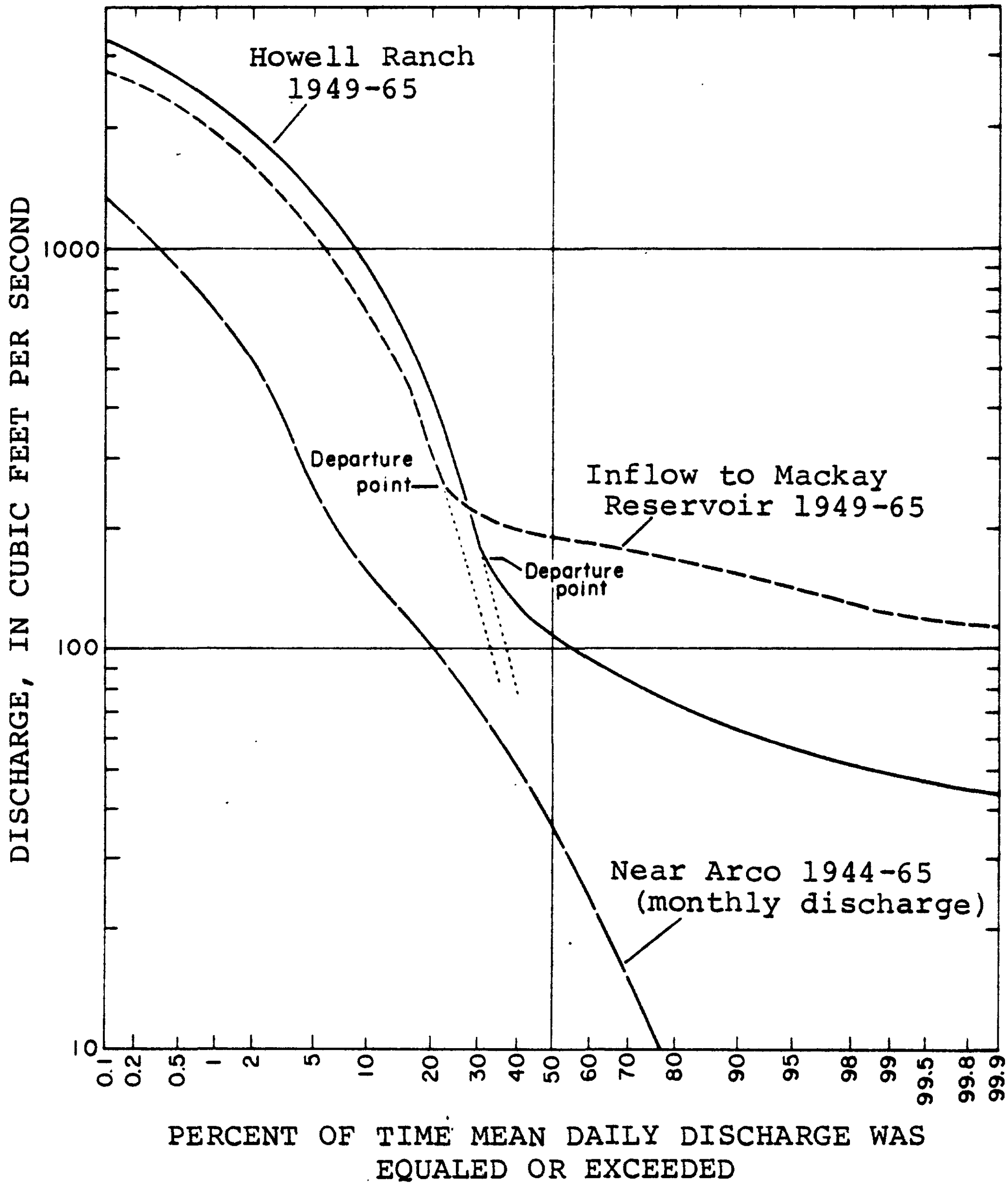


FIGURE 17.--Duration curves for flows at selected points in Big Lost River.

Table 3. Miscellaneous measurements of North Fork plus Summit Creek compared with Big Lost River at Wild Horse near Chilly (discharge, in cfs)

Date	North Fork Big Lost R. at narrows	Summit Creek	Total	Big Lost River at Wild Horse, near Chilly (1200)	Gain
Sept. 14, 1966	10.9	10.6	21.5	30	+8.5
Nov. 8, 1966	4.8	5.7	10.5	20	+9.5
July 11, 1967	1189	191	380	380	0
July 19, 1967	128	130	258	274	+16
Aug. 18, 1967	35.2	29.8	65.0	80	+15
Sept. 20, 1967	17.3	15.2	32.5	53	+20
Oct. 20, 1967	12.8	15.6	28.4	47	+19
Dec. 1, 1967	28.5	18.3	46.8	24	a-23
May 26, 1968	73.6	68.0	142	167	+25
June 20, 1968	262	280	542	549	b+7
July 31, 1968	31.2	24.8	56.0	71	+15
Aug. 29, 1968	38.7	45.8	84.5	104	+20
Average (rounded)					+11

a Affected by changing stage in the channels.

b Difference within accuracy of measurement.

Table 4. Summary of miscellaneous measurements of surface flow in East Fork Big Lost River and other tributaries above Howell Ranch, cfs.

Date	East Fork below Corral Creek (1)	Star Hope Creek at Mouth (2)	East Fork downstream from Big Rocky Canyon (3)	Wild Horse Creek (4)	Total 1,2,4 (rounded) (5)	East Fork Big Lost at mouth (6)	Difference 6-5 (7)	North Fork Big Lost at Wild Horse (8)	Howell Ranch (9)	Total 6+8 (rounded) (10)	Difference 9-10 (11)
9-15-66	18.9			28.1		89.9		33	116	123	-7
11- 7-66						61.5		21	77	82	-5
11- 8-66	a8.6	18.6		11.9	39	59.0	+20	20	75	79	-4
11-10-66	9.12							21	72		
12-10-66				8.86		44.3		17	66	61	+5
1- 5-67						47.1		18	70	65	+5
2-22-67						43.3		17	96	60	+36
3-17-67						49.0		17	78	66	+12
4-23-67						55.2		21	74	76	-2
5-27-67				476				808	2,560		
6-17-67		863		505				847			
6-22-67								b1,040	b3,620		
7-10-67	108	515	672	329	950			396	1,490		
7-11-67								b380	b1,450		
7-18-67		247		267				291	1,100		

Table 4. Summary of miscellaneous measurements of surface flow in East Fork Big Lost River and other tributaries above Howell Ranch, cfs--Continued.

Date	East Fork below Corral Creek (1)	Star Hope Creek at Mouth (2)	East Fork downstream from Big Rocky Canyon (3)	Wild Horse Creek (4)	Total 1,2,4 (rounded) (5)	East Fork Big Lost at mouth (6)	Difference 6-5 (7)	North Fork Big Lost at Wild Horse (8)	Howell Ranch (9)	Total 6+8 (rounded) (10)	Difference 9-10 (11)
7-19-67	72.1								1,000		
8-18-67	31.2	51.5		72.3	155	a226	+71	80	277	306	-29
8-19-67						224		79	274	303	-29
9-20-67	29.2	42.0		27.3	98			53	169		
9-21-67					a95			53	163		
10-27-67	21.7	36.9		29.5	88	117	+29	42	158	159	-1
12- 1-67				17.4		117		24	90	141	-51
1- 6-68				18.5		69.3		24	80	93	-13
2-10-68						63.5		24	76	87	-11
3-16-68						69.2		26	84	95	-11
4-20-68				19.5		81.8		b42	b136	124	+12
5-26-68	27.4	154		78.3	260			b167	b522		
6-19-68	103	524	705	464	1,090			511	1,790		
7-31-68	23.2	58.0		79.2	160	175	+15	71	237	246	-9
8-29-68	28.1	96.8		107	232	264	+32	104	345	368	-23

a Estimated on basis of measurements on preceding or following day.

b Surface flow in tributaries from left bank between gaging stations at Wild Horse and at Howell Ranch was measured at 59.8 cfs on June 22, 1967, 20.5 cfs on July 11, 1967, 3.5 cfs on April 20, 1968, and 5.4 cfs on May 27, 1968. Yield determination show an average of 16 cfs from drainage between Big Lost River at mouth of East Fork and gaging station at Howell Ranch.

Howell Ranch to Mackay Narrows

Although flow in the main stem of Big Lost River is perennial from its headwaters to a few miles below the gaging station at Howell Ranch (1205), large volumes of water percolate from the river channel into the ground in the reach between Howell Ranch to near the upstream end of Mackay Reservoir. A large part of this loss occurs near Chilly. Table 5 shows that measured losses in the river channel between Howell Ranch and Bartlett Point averaged about 45 cfs. However, during higher stages when the river was gaged at Chilly Store, 2 miles farther downstream, measured losses averaged about 120 cfs.

The main channel of the river is frequently dry in most of the reach between Chilly Sinks and Mackay Reservoir, containing water only during periods of highest flows, or for about 4 months during normal years. Thousand Springs Creek contributes flow to the reach, but much of this flow is diverted for irrigation, and water loss by percolation from the Big Lost River channel continues for several miles below its confluence with Thousand Springs Creek.

In 1934, the lowest year of record at Howell Ranch, when the water table adjacent to the river channel was low, the river lost its entire yearly discharge, or about 85,000 acre-feet, into the Chilly Sinks. The hydrograph in figure 18 shows that no rise occurred in the inflow to Mackay Reservoir during the period of snowmelt runoff that year. The only flow into Mackay Reservoir was base flow from the alluvial deposits downstream from the Sinks. At times, when the channel near Chilly was dry for extended periods, as in 1935 and 1959, more than 1,000 cfs was lost to underground storage along the channel (fig. 18). As shown by the hydrographs, the channel absorbed much less water after it had been wetted for a few weeks. Following high-water seasons and after water had been flowing across the Chilly Sinks for relatively long periods, flow across the Chilly Sinks did not stop until the river flow receded to less than about 300 cfs at the Howell gage.

The estimated quantity of surface water that has entered the ground in the Chilly Sinks during the period of record is shown in the last column of table 6. The contribution to ground water is assumed equal to the flow at Howell Ranch less the flow in the river channel crossing the Sinks (column 4). The figures in column 4 were computed by subtracting the base flow (column 3) from the measured inflow to Mackay

Table 5. Measurements showing losses in the river and canals between Howell Ranch and points near Chilly. (Quantities, in cfs)

Date	Howell Ranch	Discharge at Bartlett Point (River channel plus diversions)	Loss	Discharge at the bridge at the Chilly Store	Loss
(1)	(2)	(3)	(4)	(5)	(6)
11- 6-66	77	39	38		
5-29-67	2,750			2,600	150
8-22-67	255	208	47		
9-20-67	169	147	22		
10-28-67	188	140	48	--	--
4-20-68	136	89	47		
5-27-68	494			306	188
6-23-68	1,380			1,360	20
8- 1-68	223			99	124
8-30-68	324	268	56		
Average (rounded)			45		120

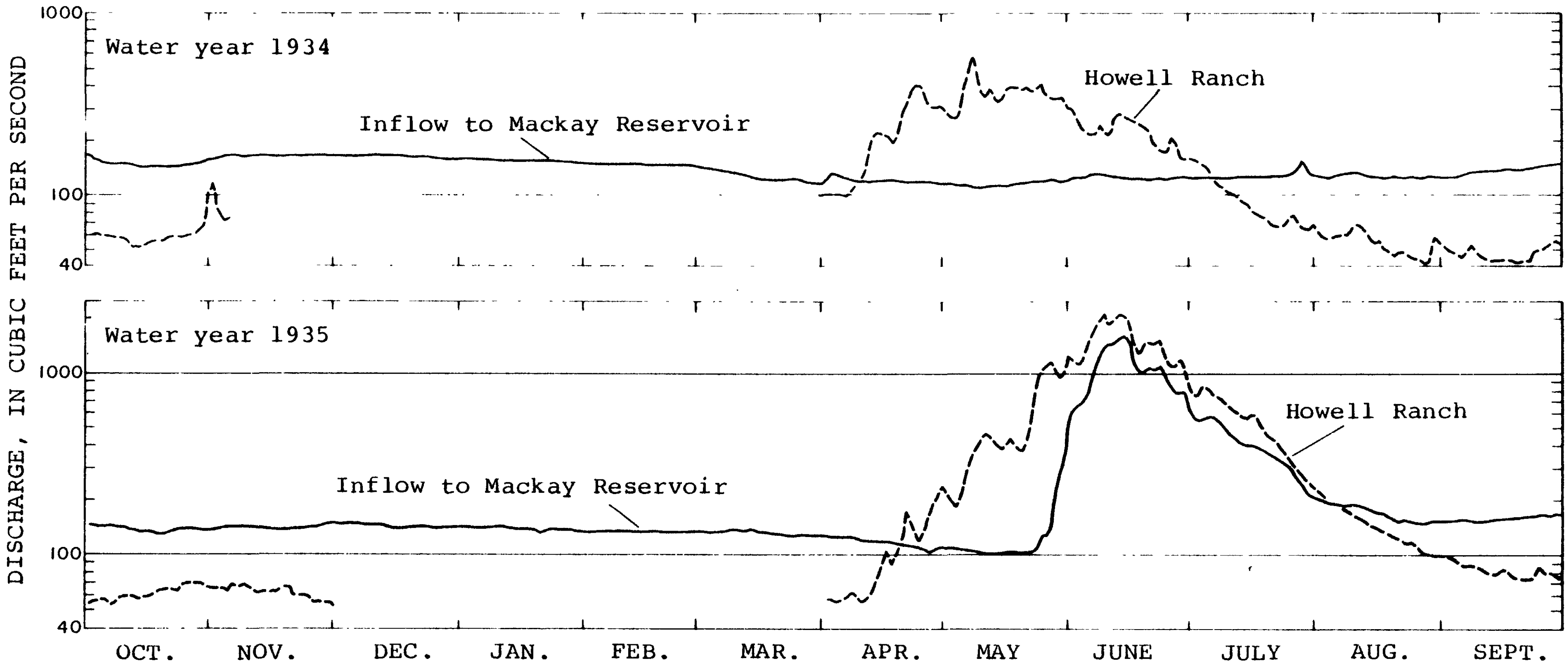


FIGURE 18.-- Hydrographs of discharge of Big Lost River at Howell Ranch and inflow to Mackay Reservoir.

Table 6. Annual flows in Big Lost River in reach between Howell Ranch and Mackay Reservoir.
(Quantities, in cfs)

Water Year	Inflow to Mackay Reservoir	Base Flow	Flow crossing Chilly Sinks	Flow at Howell Ranch	Ground-water recharge (rounded)
1920	236	164	72	263	190
1921	387	185	202	378	175
1922	385	196	189	300	110
1923	333	204	129	305	175
1924	200	181	19	150	130
1925	326	203	123	329	205
1926	195	178	17	158	140
1927	293	165	128	308	180
1928	276	180	96	261	165
1929	199	162	37	179	140
1930	235	157	78	250	170
1931	172	167	5	141	135
1932	269	146	123	284	160
1933	213	157	56	197	140
1934	137	137	0	118	120
1935	241	133	108	271	165
1936	203	157	46	204	160
1937	165	150	15	140	125
1938	405	146	259	450	190
1939	219	189	30	198	170
1940	231	167	64	237	175
1941	267	176	91	276	185
1942	330	180	150	311	160
1943	441	184	257	440	185
1944	392	200	192	354	160
1945	293	192	101	258	155
1946	311	199	112	291	180
1947	308	191	117	291	175
1948	318	173	145	307	165
1949	259	176	83	241	160

Table 6. Annual flows in Big Lost River in reach between Howell Ranch and Mackay Reservoir--Continued.
(Quantities, in cfs)

Water Year	Inflow to Mackay Reservoir	Base Flow	Flow crossing Chilly Sinks	Flow at Howell Ranch	Ground-water recharge (rounded)
1950	263	168	95	260	165
1951	367	199	168	355	185
1952	420	194	226	406	180
1953	320	173	147	307	160
1954	280	175	105	271	165
1955	237	165	72	215	145
1956	403	180	223	407	185
1957	346	179	167	354	185
1958	409	195	214	395	180
1959	227	185	42	191	150
1960	213	170	43	186	145
1961	182	153	29	170	140
1962	265	154	111	292	180
1963	333	174	159	337	180
1964	329	195	134	310	175
1965	569	214	355	538	185
1966	248	200	48	203	155
1967	488	176	312	492	180
1968	325	200	125	306	180

Reservoir. During the 8 months, on the average, when there is no flow crossing the Sinks, all inflow to Mackay Reservoir is base flow. For the remaining period of each year, base flow could be estimated with considerable accuracy to complete the annual means of column 3. The approximate annual ground-water recharge (column 6) ranged from 120 cfs (about 85,000 acre-feet) in 1934 to 205 cfs (150,000 acre-feet) in 1925. The average for the study period (1944-68) was 170 cfs (120,000 acre-feet). These quantities greatly exceed the capacity for storage in Mackay Reservoir.

Beginning at Hamilton Springs, about 4 miles southwest of the mouth of Thousand Springs Creek, and continuing to Mackay Narrows, large quantities of ground water are discharged to surface streams.

Warm Springs Creek is fed in part by Hamilton Springs and by Warm Springs which discharge near the foothills, more than 100 feet above the level of the river channel. These springs are perennial and flowed at 34.7 and 26.6 cfs, respectively, on September 23, 1968. Both springs are near outcrops of carbonate rocks and appear to discharge water from the mountains on the west rather than from the valley alluvium. The elevation of the springs, topography, and nearby geology suggest that the source or sources of water to the springs probably are upstream from Bartlett Point. Warm Springs Creek flows for several miles along the valley floor and, with Parsons Creek and other similar streams, receives additional large ground-water inflows from the valley alluvium before discharging into Mackay Reservoir.

Stations 1235, 1240, 1245, and 1250 on the four principal channels discharging into Mackay Reservoir were gaged for more than 40 years to monitor surface inflow to the reservoir (table 2). Flows at these four gaging stations are added together to give the discharges published as Surface inflow to Mackay Reservoir, near Mackay (1255).

The records of these four streams indicate that the inflow from ground water comes principally from the west side of the valley although much water undoubtedly flows underground from mountains to the east. Surface flow measured at Mackay Narrows, downstream from the reservoir, adjusted for changes in reservoir storage, averages about 30 cfs greater than that passing the above four gages, indicating additional ground-water inflow into the reservoir and at Mackay Narrows.

A duration curve of average monthly flows at Mackay Narrows is plotted in figure 17. Because all discharge is base flow for many months of each year, it is relatively uniform. The duration curve shows the change in characteristics of flow in the Big Lost River that results from losses and gains in water in the river between Howell Ranch and Mackay Narrows. The curve can also be used to estimate the part of the streamflow that comes from ground-water discharge in the gaged reaches (see Iorns, Hembree, and Oakland, 1965, p. 48-53). At Mackay Reservoir, the computed base flow averages 195 cfs, or 59 percent of the total flow. At Howell Ranch, the computed base flow averages only 100 cfs, or 30 percent of the total flow. The difference demonstrates the regulating effect of underground storage in the reach whereby the base flow was increased 95 cfs, or 68,000 acre-feet per year, 1.5 times the usable storage in Mackay Reservoir.

Annual mean flows, after adjustment for storage and releases from Mackay Reservoir, are nearly always more at Mackay Narrows than at Howell Ranch. The adjusted flows were less at Mackay Narrows only when comparatively large quantities of water went into storage in the Chilly Sinks reach (fig. 19). Records for the base period 1944-68 show that the average surface flow at Howell Ranch is 310 cfs and inflow to Mackay Reservoir is 325 cfs, an average gain of 15 cfs in the reach.

The river flow is regulated at Mackay Narrows by Mackay Dam. Mackay Reservoir (capacity 44,370 acre-feet) stores water for release on demand for irrigation of about 29,500 acres of land in the Big Lost River Irrigation District. Water leaks through the dam and its bedrock abutment. A large quantity of this leakage returns to the river channel downstream and is measured at the gaging stations below the dam. This portion of the leakage varies with the water level in the reservoir and ranges from about 40 cfs at low stages in the reservoir to 130 cfs or more at high stages.

Mackay Narrows to Moore Canal Heading

From Mackay Narrows to below Leslie the river loses slightly at high stages and gains slightly at low stages. Losses from the river channel are heavy in the Darlington Sinks, about 18 miles below Mackay Dam. Part of the water lost returns to the river just above the Moore Canal heading, a few miles below the Sinks. The watermaster's records of

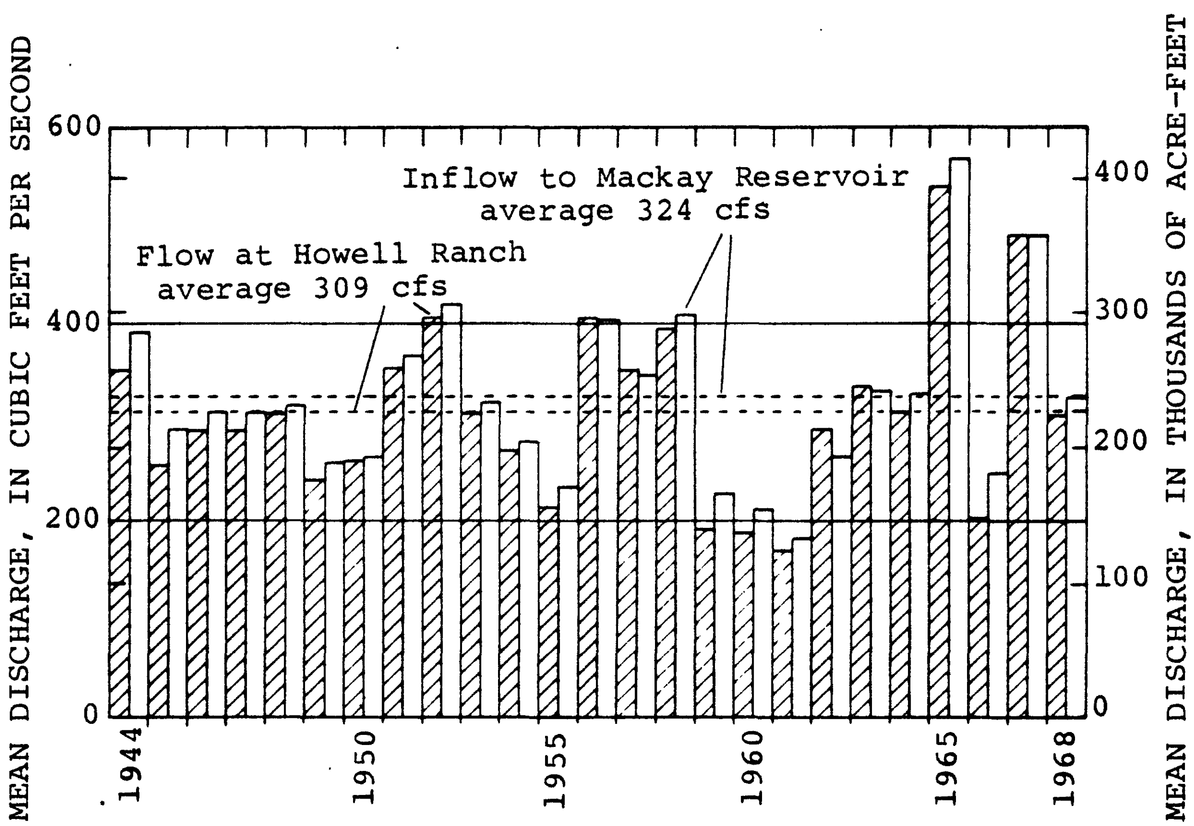


FIGURE 19.-- Annual mean discharge of Big Lost River at Howell Ranch and inflow to Mackay Reservoir, 1944-68.

surface flow at the Moore Canal heading show that the average flow for the 25-year base period was 200 cfs compared with 325 cfs at Mackay Narrows for the same period.

A correlation between annual mean flows at Mackay Narrows and at Moore Canal heading is shown in figure 20. Scatter in the plotted points reflects complex interchanges of surface and ground water in the reach. Pumping during periods of short surface-water supply, changes in inflow from the intervening tributaries, variations in diversions and percolation losses from streams, channels, and irrigated fields, and changes in ground-water storage affect the plotting of the points and cause the scatter. The points during the drought period 1930-35 tend to plot to the right because water was being diverted out of the valley through the Blaine Canal, thus bypassing the gages at the Moore Canal heading.

Moore Canal Heading to Gaging Station Downstream From Arco

Considerable water is lost by infiltration between Moore Canal heading and the gaging station on the Big Lost River near Arco (1325) although some ground-water discharges to the reach. This interchange is illustrated by measurements in the reach on November 9 and 10, 1966, when flows were steady. The total discharge in the canals and river at Moore Canal heading was 54 cfs. At Savaria road crossing, 1.3 miles downstream, the total discharge in the canal and river was 41.6 cfs. Only 3 cfs was flowing in the river and canals down the valley across the east-west road 5 miles downstream and 2.8 miles south of Moore. Surface flow increased to 16.8 cfs in the river and canals at Arco, and 11 cfs flowed at the gage near Arco, 4 miles farther downstream.

Measurements of Big Lost River made below Mackay Reservoir are listed in table 7. They further illustrate this pattern of losses and gains in surface flow. The quantities of loss and gain change with stage and with antecedent conditions. In general, the river and canals lose for several miles below the Moore Canal heading. Water reappears as surface flow a few miles above Arco in Boyles, James, and Spring Creeks, and in the river. There is a net loss between Moore Canal heading and Arco, and a further loss between Arco and the gage below Arco. Arco Canal bypasses some water around the gage near Arco, but all the flow in the canal is used consumptively or percolates into the Snake River Plain. Average loss from the Moore Canal heading to the gage below Arco was 125 cfs for the period 1944-68.

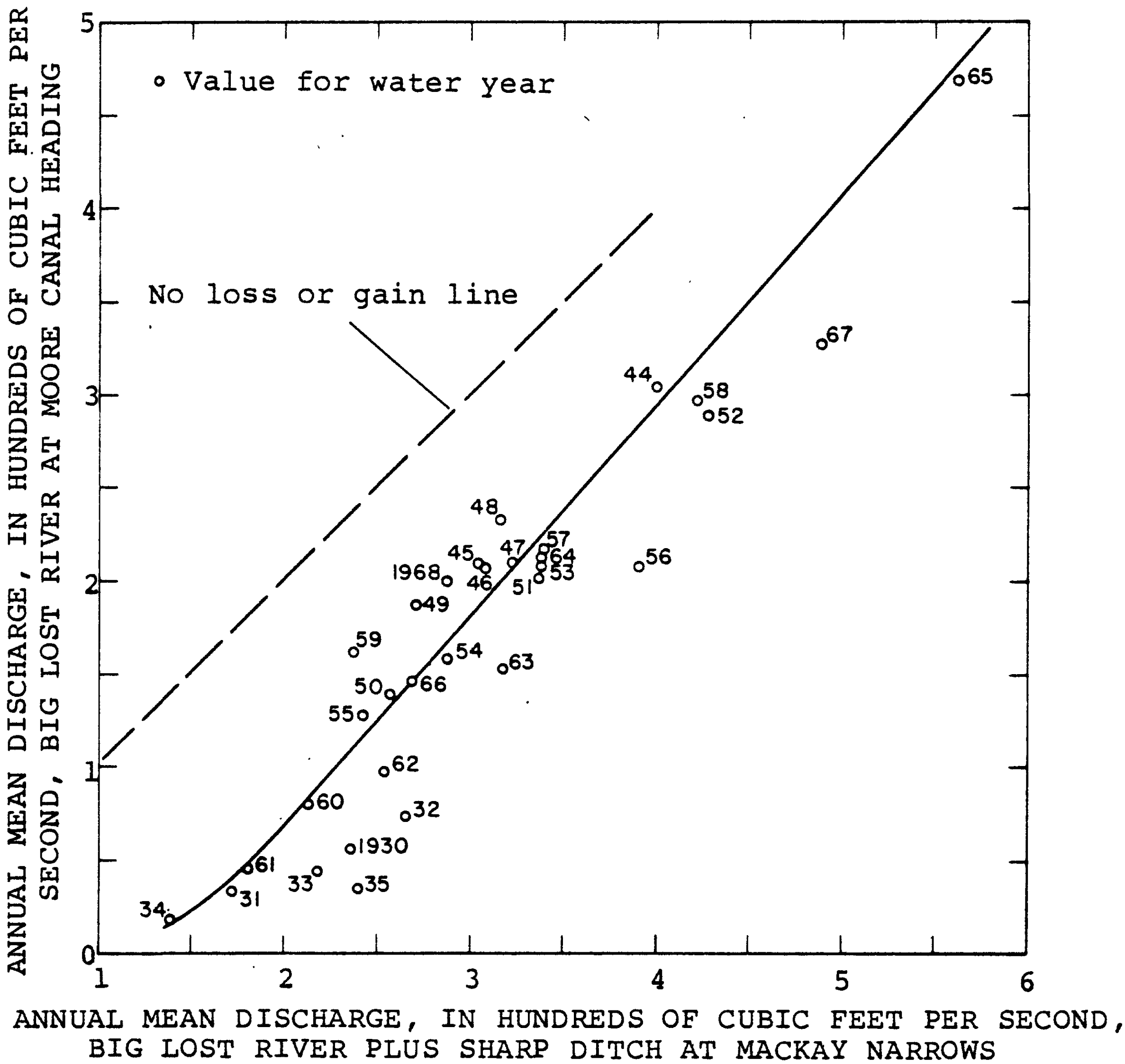


FIGURE 20.-- Correlation of annual mean discharge, Big Lost River at Mackay Narrows and at Moore Canal heading, 1930-68.

Table 7. Discharge, in cfs, in Big Lost River below Mackay Reservoir.

Date	Big Lost below Reservoir (1)	Sharp ditch (2)	Total 1+2 (rounded) (3)	Below Leslie (4)	Difference 4-3 (rounded) (5)	Darlington (6)	Difference 6-4 (rounded) (7)	Moore Canal heading (8)	Difference 8-6 (rounded) (9)	At Arco (10)	Difference 10-8 (rounded) (11)	Near Arco (12)	Difference 12-10 (rounded) (13)
11- 8-66	60	5.9	66	20.2	-46	7.95	-12					11	
11- 9-66	60	5.9	66			8.14		54	+46	16.8	-37	11	-6
12- 6-66	76	0	76							18.0		13	-5
12- 8-66	76	0	76	52.2	-24			45.3				11	
1- 3-67	92	0	92			43.2						11	
1- 6-67	93	0	93							13.1		11	-2
1- 7-67	94	0	94	39.5	-54							11	
2- 8-67	110	0	110									10	
2- 9-67	110	0				70.0		37.9	-32			12	
5-23-67	1,170	6.7	1,180							20.2		3.8	
6-20-67	1,920	22	1,940			1,130						825	
6-21-67	2,210	24	2,230							913		977	+64
6-23-67	2,370	10	2,380									1,300	
7- 8-67	1,860	25	1,880							1,730		1,680	-50
7-13-67	1,310	19	1,330	1,060	-270							1,010	
8-22-67	679	37	716	400	-316	430	+30					128	
8-23-67	649	34	683					468	a+38	220	-248	132	-88

9-19-67	498	5.1	503			405		446	+41			314	
9-28-67	416	4.0	420							273		184	-89
10-30-67	83	0.99	84					185				170	
10-31-67	65	0.92	66	77.8	+12	98.8	+21		a+86			172	
11- 2-67	39	0.89	40							161		175	+14
12- 3-67	74	0.09	74	74.7	+1			117				124	
4-21-68	118	4.2	122	71.7	-50	49	-23					80	
4-22-68	118	4.2	122			-		108		74.8	-33	76	+1
5-29-68	568	18	586	257	-329	155	-102	162	+7			13	
5-30-68	617	17	634							46.3		8.5	-38
6-17-68	972	15	987							188		119	-69
6-21-68	1,610	53	1,660			743						48	
6-22-68	1,470	49	1,520	917	-603							67	
7-29-68	542	22	564	298	-266	304	+6	325	+21	60.2	-265	16	-44
9- 8-68	225	16	241							65.9		57	-9

a Estimated based on upstream measurement on preceding or following day.

The flow-duration curve (fig. 17) for the gaging station near Arco (1325), indicates that monthly-mean flows near Arco can be expected to be less than 10 cfs 23 percent of the time, whereas the flow into Mackay Reservoir can be expected to be less than 170 cfs 21 percent of the time. As the estimated inflow to the system below Mackay Reservoir from tributary areas averages 200 cfs (an estimated 100 cfs is used consumptively), evidently large quantities of water move underground. Flows near Arco are less than those below Mackay Reservoir at all points on the duration curve in spite of the large contributions from the intervening drainage. Hydrographs of flow at Mackay Narrows, flow at Mackay Narrows plus measured contributions from the intervening drainage, and flow near Arco are compared in figure 21. The relation between the annual flows at Mackay Narrows and those at the gage near Arco is shown in figure 22. These figures also show that the flow downstream from Arco has been considerably less than that at Mackay Narrows, even though a large volume of water flows into the reach from the tributary basins. Figure 22 shows that the largest annual loss in the reach was about 300 cfs in 1967 when considerable flow probably went into storage in the aquifer. The loss averaged only 150 cfs in 1959 when a large volume of stored water drained out of the aquifer. During the drought year 1934, only 137 cfs passed the Narrows; and during this and several other years including 1961 and 1962, no surface flow passed the Arco gage.

Tributaries

Flows in tributary streams are a significant part of the total resources of the basin. Lower Cedar, Alder, Pass, and Antelope Creeks, which enter the Big Lost River valley below Mackay Reservoir, are the most important streams. Several other tributaries enter the valley between the Howell gage and Arco. The tributary basins are outlined in figure 3 and their flows are summarized in table 12.

Lower Cedar Creek.--Lower Cedar Creek (subbasin 30, fig. 3) above the gaging station near the mouth of Lower Cedar Canyon drains 8.26 square miles of steep, rocky, mountainous terrain north of Mackay where altitudes range from 6,800 to nearly 12,000 feet. The average discharge for the 1944-68 base period is estimated at 18 cfs for an apparent average yield of 30 inches per year. Such a yield is abnormally large for the watershed. Methods outlined herein show that

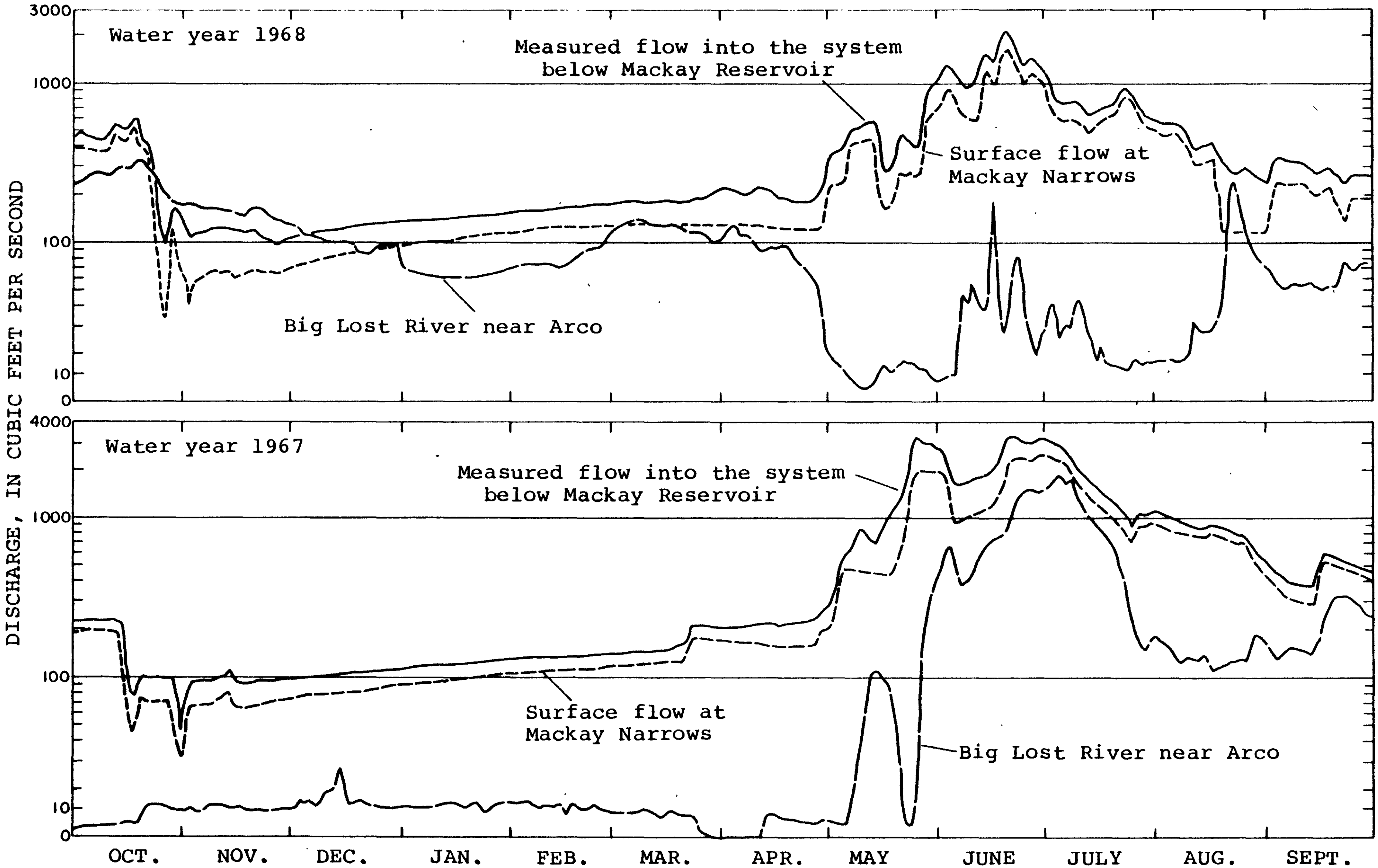


FIGURE 21.-- Hydrographs of surface flow below Mackay Narrows.

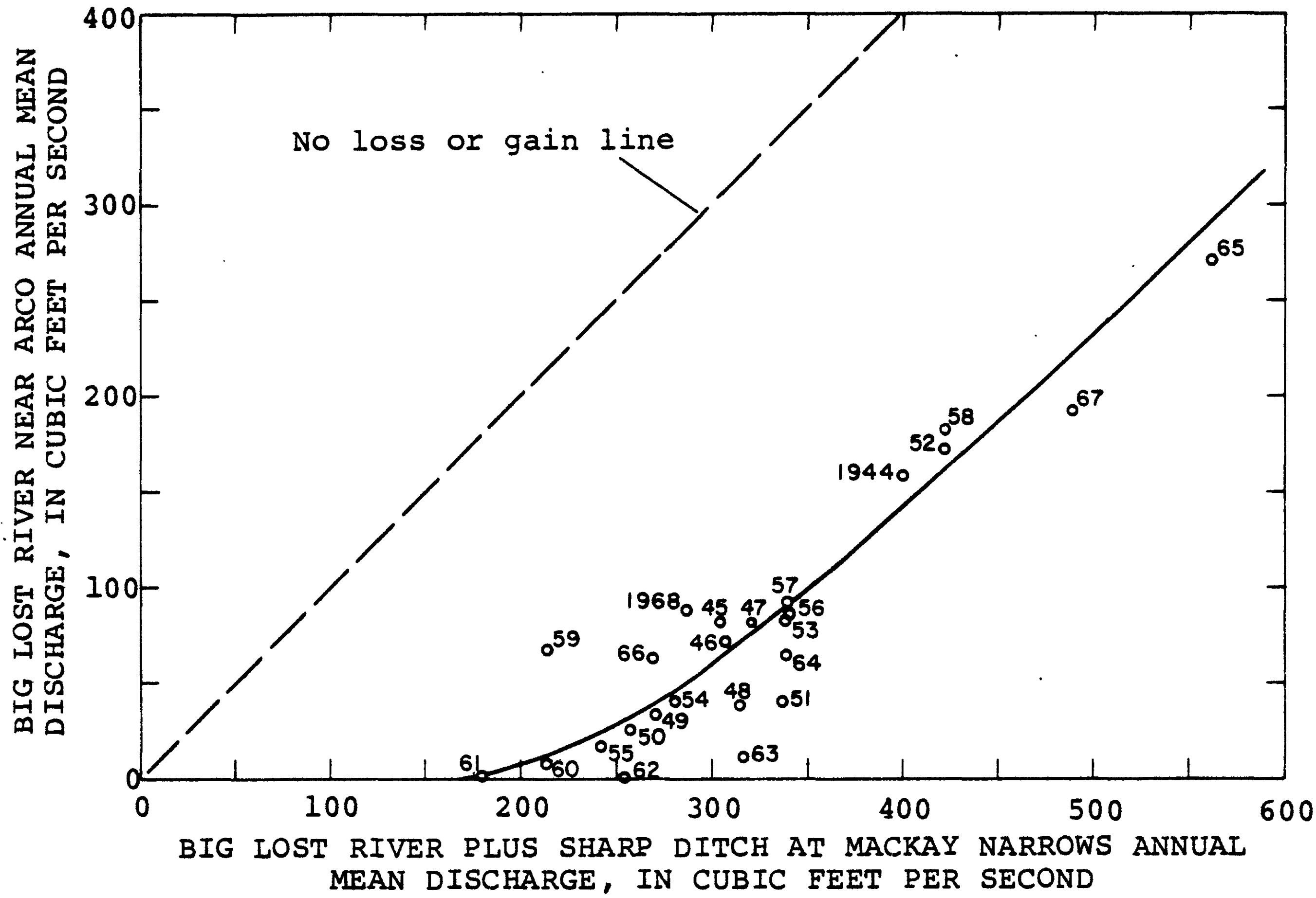


FIGURE 22.-- Relation between surface flow at Mackay Narrows and flow below Arco, 1944-68.

the estimated average yield from the subbasin is about 19 inches per year or 12 cfs (table 12, subbasin 30), indicating that an average of about 6 cfs or a third of the flow comes as underground flow from outside the subbasin. A major contributor to the high yield of this subbasin is a large spring (p. 22) that has a surface drainage area above its outlet of about 2 square miles. Records of flow indicate that the spring discharged an average 12 cfs in the 1912 water year; the spring flow was 13 cfs on September 24, 1968. This quantity would cover the 2 square miles of surface drainage area above the spring to a depth of 81 inches per year. This is far more than could be expected from the precipitation on the subbasin. Computations of water yield and the physical features indicate that the excess water may come from Pass Creek basin, but the data are inconclusive.

Water from Lower Cedar Creek is used to irrigate about 700 acres of land north and northwest of Mackay. Transmission losses from the diversion canals and percolation losses from the irrigated lands are high. Flow from the creek seldom reaches the Big Lost River channel as surface flow.

Alder Creek.--Alder Creek basin (subbasin 37) drains the southern half of the east flank of White Knob Mountains, south of Mackay. Records of its discharge from August 1966 to September 1968 have been obtained at a site just below the South Fork Alder Creek and for irrigation seasons in 1920-22 at a site about 3 miles downstream. The drainage area of the upstream site is 27.6 square miles. A small amount of flow is believed to bypass the gage underground. Downstream from the upstream gage site, considerable flow percolates into the ground and becomes a part of the ground water of the main valley. The flow is used to irrigate an estimated 1,000 acres in Big Lost River valley.

Antelope Creek.--Antelope Creek (subbasins 39-43) drains the largest basin tributary to the Big Lost River below the East Fork. It rises in the southwest corner of Big Lost River basin, northwest of Craters of the Moon, and flows northeasterly to its confluence with Big Lost River east of Darlington. The stream was gaged a few miles upstream from Grouse, above most of the diversions, since May 1966, and at a point about 6 miles downstream from Grouse for partial years 1913-16 and 1920-22. The drainage area is 93.4 square miles at the upstream gage and 218 square miles at the downstream gage site. Miscellaneous measurements of the flow of Antelope Creek and Cherry

Creek, and their combined flow during 1967 and 1968 water years are shown in table 8. Analyses and the measurements (table 8) and the data from table 12 indicate that as much as 30 cfs flows underground past the downstream gage site. More of the flow from Antelope Creek percolates into the alluvial gravels in the vicinity of Darlington Sinks.

Antelope Creek provides irrigation water for about 6,200 acres (U.S. Soil Conservation Service, written commun., 1969).

Geologic and physical data indicate that there may be some leakage into the Snake River Plain from Dry Fork Creek (subbasin 40), a southeastern tributary of Antelope Creek. An unknown amount of water was diverted from Dry Fork into Champagne Creek for many years, but the ditch has not been used recently. Data are not available to evaluate the leakage, if any, so all the water yielded in the Dry Fork Creek subbasin is assumed to follow the natural drainage channel into the Big Lost River.

Pass Creek.--Pass Creek basin (subbasin 31), with a drainage area of about 25 square miles, lies adjacent to and east of Lower Cedar Creek basin. The altitudes in the basin range from 6,200 to more than 11,000 feet above mean sea level and average about 8,130 feet. The topography is more rolling and there is more soil on the surface than in Lower Cedar Creek basin. On the basis of miscellaneous measurements in the 1967 and 1968 water years and 18 months of record in 1920-22, creek discharge for the period 1944-68 is estimated to average about 8 cfs. This discharge is considerably less than the estimated average yield from the basin, which was estimated to be 16 cfs as shown in table 12 (subbasin 31). The 8 cfs difference may move through the mountains and discharge at the large spring in the Lower Cedar Creek basin.

Water from Pass Creek is used for irrigation in the Big Lost River valley. A considerable part of this water infiltrates into stream and canal bottoms and irrigated soils, thus recharging the main valley aquifer.

Table 8. Measurements of Antelope Creek and tributary. (Discharge, in cfs)

Date	Antelope Creek at gage	Cherry Creek	Total 1+2	Antelope Cr. below Cherry Creek	Loss or Gain 4-3 (rounded)
	(1)	(2)	(3)	(4)	(5)
9-17-66	22	2.92	24.9		
11- 9-66	14	3.59	17.6		
11-11-66	17			14.1	
12- 7-66	18			14.3	
1- 4-67	17			3.0	
3- 6-67	16			17.8	
4-19-67	33			54.5	
5-31-67	514	76.2	590		
6-13-67	430	77.5	508	a501	-7
6-14-67	424			494	
7- 9-67	225	27.3	252	263	+11
7-15-67	183			186	
8-21-67	45	7.06	52	46.8	-5
9-18-67	36	6.05	42	38.9	-3
10-30-67	40	6.09	46	47.5	+2
12- 4-67	27			23.9	
3-18-68	24			35.2	
4-22-68	36	17.5	53.5	40.7	-13
5-29-68	167	22.4	189	145	-44
6-18-68	232	29.8	262	245	-17
7-30-68	32	6.03	38	38.9	+1
8-26-68	71	11.6	83	a98	+15
8-27-68	62			85.9	

a Estimate based on upstream measurement on preceding or following day.

Irrigation Diversions

Surface water is diverted from the Big Lost River and tributaries for irrigation of 12,680 acres above Mackay Reservoir and 36,540 acres below. Acreages irrigated from the principal tributaries and from the river are summarized in table 1.

Records of the diversions from Big Lost River and Warm Springs Creek for the years 1922-68 are available in annual reports prepared by the watermaster for Big Lost River and are filed with the Idaho State Reclamation Engineer. These diversions are summarized in table 9. Transmission losses are high, thus deliveries at farms are much less than the diversion figures indicate. Many acreages have been inadequately watered during the dry years. Because consumptive use of irrigation water has averaged only about 1.2 acre-feet per acre and diversions have been much more than that, a large part of the water diverted either returned to the river channel or percolated underground to recharge the aquifer.

Surface Water Quality

Chemical analyses for 13 surface-water stations in Big Lost River basin are given in table 10. All observed surface waters were calcium bicarbonate in type. Mountain streams tend to be low in salinity (less than 150 mg/l dissolved solids) while streams in the broad valleys tend to be of moderate salinity (between 150 and 300 mg/l dissolved solids).

As discussed previously, surface flow in the Big Lost River originates from two distinct sources: (1) Direct runoff and (2) ground-water discharge. Direct runoff enters stream channels promptly after rainfall or snowmelt and is characterized by less than 100 mg/l of dissolved solids. Ground water discharges into a stream as spring or seepage water at points where the water table intersects the ground surface. Ground water dissolves substances from aquifer materials during its passage underground, thus increasing its dissolved solids content. The amount of dissolved solids in the ground water depends upon the length of time of flow underground and upon the chemical characteristics of the aquifer materials. Dissolved solids concentrations in ground water discharged to Big Lost River generally range

Table 9. Diversions from Big Lost River in acre-feet (rounded).

Water Year	Above Reservoir	Below Reservoir	Flow at Mackay Narrows	Flow at gage below Arco	Apparent loss or gain Mackay Narrows to Arco
1922	112,000	200,000	279,000	a7,290	-71,700
1923	203,000	241,000	235,000		
1924	55,800	124,000	162,000		
1925	85,500	222,000	232,000		
1926	65,600	123,000	144,000		
1927	71,900	175,000	212,000		
1928	75,700	173,000	201,000		
1929	63,600	97,600	143,000		
1930	79,500	119,000	171,000		
1931	52,600	69,800	125,000	a0	-55,200
1932	68,900	140,000	192,000		
1933	53,400	82,900	156,000		
1934	61,600	35,200	94,800	a0	-59,600
1935	77,700	103,000	172,900	b2,668	-67,200
1936	81,700	69,700	145,000	a0	-75,300
1937	61,900	52,400	120,000		
1938	152,000	90,300	264,100		
1939	29,500	129,000	180,200		
1940	25,200	216,000	169,000		
1941	49,000	117,000	176,300		
1942	55,000	165,000	246,100		
1943	54,100	204,000	309,700		
1944	56,400	206,000	290,100	a119,100	+35,000
1945	57,000	203,000	220,400		
1946	65,400	212,000	222,600		
1947	63,300	208,000	232,300	60,260	+36,000
1948	73,400	219,000	228,600	26,870	+17,300
1949	55,300	189,000	195,400	23,620	+17,200
1950	46,200	175,000	185,200	18,130	+7,930
1951	59,000	224,000	243,500	28,650	+9,150
1952	67,700	240,000	310,400	124,300	+53,900
1953	84,000	242,000	244,300	58,470	+56,200
1954	66,600	218,000	208,200	28,530	+38,300
1955	40,000	148,000	175,300	12,250	-15,000
1956	63,200	239,000	282,900	61,750	+17,800

Table 9. Diversions from Big Lost River in acre-feet (rounded)--Continued.

Water Year	Above Reservoir	Below Reservoir	Flow at Mackay Narrows	Flow at gage below Arco	Apparent loss or gain Mackay Narrows to Arco
1957	61,600	220,000	245,500	66,520	+41,000
1958	57,600	275,000	304,900	131,200	+101,000
1959	32,200	140,000	170,800	47,640	+16,800
1960	36,800	106,000	154,000	5,520	-42,500
1961	29,900	65,700	130,600	0	-64,900
1962	60,700	128,000	184,300	a0	-56,300
1963	52,900	200,000	229,500	c7,960	-21,500
1964	48,100	256,000	246,400	a22,400	+32,000
1965	55,300	282,000	405,800	c195,500	+71,700
1966	40,500	177,000	194,600	c44,900	+27,300
1967	66,000	235,000	353,200	138,700	+20,500
1968	52,700	187,000	207,000	64,280	+44,300
47 year average	62,000	169,000	212,700		

a From the annual report of the watermaster.
b Flow below Arco Dam, which is probably greater than flow at gage below Arco.
c Partly estimated.

Table 10. Quality of water analysis, surface water and springs.
(Chemical constituents, in milligrams per liter)

Date of collection	Mean discharge (cfs)	Temperature (°C)	Silica (SiO_2)	Total iron (FE)	Calcium (Ca)	Magnesium (Ma)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Orthophosphate (as PO_4)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180° C	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25° C)	pH	Color
13-1205. Big Lost River at Howell Ranch, near Chilly																										
9-22-05	124																	a112								
7-20-57		13	11	0.16	20	3.4	2.4	1.0	69	0	9.4	2	0.2	0.3	0.05		84	81				7		132	7.6	0
13-1210. Big Lost River below Chilly Canal at Bartlett Point, near Chilly																										
9-20-67		9	11		27	5.5	3.8	0.8	101	0	12	2.0	0.2	0.1		0	112	116	0.16	90	7	9	0.2	190	7.9	5
13-1219. Anderson Springs near Chilly																										
9-23-68	8.13	12	14		35	10	4.4	1.0	144	0	17	3.0	0.4	0.9		0.02	157	156	0.21	128	10	7	0.2	265	8.0	0
13-1219.5 Whisky Springs near Chilly																										
8-11-67	b0.22	7	6.3		34	18	5.3	0.6	157	5	27	3.5	0.2	2.4		0	179	170	0.23	159	22	7	0.2	304	8.5	0
13-1220. Thousand Springs Creek near Chilly																										
8- 9-67		19	13		58	20	5.8	1.3	266	0	15	1.0	0.6	0.6		0	246	250	0.34	227	9	5	0.2	424	7.9	20
13-1240.3 Hamilton Springs near Chilly																										
8-24-67		9	11		33	8.5	4.7	1.0	133	0	14	2.5	0.4	0.4		0.04	191	152	0.21	118	8	8	0.2	229	8.1	0
13-1241.5 Warr Springs near Chilly																										
8-24-67		13	11		33	11	5.4	1.1	110	0	18	20	0.5	0.3		0.04	154	150	0.20	128	38	8	0.2	260	7.1	0
13-1270. Big Lost River near Mackay																										
5-15-05	124																	a218								
6-10-05	987																	a172								
7-12-05	629																	a254								
9-21-05	156																	a188								
10- 1-65	588	9	13	0.05	37	9.4	5.1	1.4	151	0	14	3.0	0.3	0.4	0.06	0.00	158	151	0.21	132	8	8	0.2	267	8.2	5
6- 9-66	663		9.4	.06	35	8.8	4.9	1.2	138	0	15	2.8	.2	.3	.01	.05	146	139	.19	124	10	8	0.2	252	7.7	0
8-26-66	235		12	.05	41	11	5.8	1.3	166	0	17	4.0	.4	.3	.05	.06	175	175	.24	148	12	8	0.2	287	7.4	5
11- 4-66			11	.04	42	11	6.1	.9	168	0	18	3.0	.3	.5	.05	.04	176	174	.24	150	12	8	0.2	303	7.9	0
5-30-67		11	9.8	1.2	26	6.3	3.9	1.7	100	0	12	3.0	.3	.5	.07	.04	112	118	.16	91	9	8	0.2	194	7.3	15
7-17-67	1,100		9.9	.11	28	7.2	3.7	1.2	114	0	11	3.0	.3	.2	.07	.04	121	121	.16	100	6	7	0.2	212	7.8	5
9-21-67	513	15	12		39	10	5.2	1.3	160	0	16	4.0	.2	.5		.08	167	163	.22	138	8	8	0.2	283	8.0	0
5-28-68		10	13		38	9.8	5.4	.9	154	0	17	2.0	.3	.2		.03	163	164	.22	136	10	8	0.2	280	8.1	0
8- 1-68		17	11		34	9.0	4.6	1.1	141	0	13	2.5	.3	.4			145	133	.18	122	6	7	0.2	252	7.9	5
10-11-68		9	12		39	9.5	5.6	1.4	162	0	15	2.5	.3	.0			165	163		136	4		0.2	286	7.9	5

Table 10. Quality of water analysis, surface water and springs--Continued.

Date of collection	Mean discharge (cfs)	Temperature (°C)	Silica (SiO2)	Total iron (FE)	Calcium (Ca)	Magnesium (Ma)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Orthophosphate (as PO_4)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180° C	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25° C)	pH	Color
13-1310. Antelope Creek near Darlington																										
9-18-67		13	15		32	7.1	5.3	1.2	123	0	17	2.0	0.3	0.2		0.06	141	144	0.20	109	8	9	0.2	233	8.2	10
13-1315. Pass Creek near Leslie																										
9-22-67		6	12		50	6.2	5.6	0.6	180	0	9.2	3.0	0.2	0.4		0.04	176	173	0.24	150	3	7	0.2	294	8.1	0
13-1324. Big Lost River at Arco																										
8-21-49		13	19				--7.6--		274	0	26	8	0.2	1.5						248	19	6	0.2	476		
10- 9-51					64	12	9.0		244	0	21	5					231			209	9	9	0.3	461		
5-24-58			14	0.03	40	13	5.9	2.9	135	0	47	4.4	0.3	0.5			195	212		152	22	8	0.2	327	7.0	
13-1325. Big Lost River near Arco																										
10- 1-65			15	0.48	51	13	7.8	1.7	209	0	17	4.8	0.3	0.7	0.04	0.00	214	202	0.27	180	8	8.6	0.3	358	8.0	5
12- 1-65			14	.62	62	14	9.3	1.7	247	0	20	5.5	.3	2.4	.04	.04	251	247	.34	212	10	9	.3	434	8.0	5
1-10-66			13	.41	58	13	8.2	1.3	227	0	20	4.0	.3	1.7	.04	.00	232	225	.31	198	12	8	.3	402	7.9	5
2-15-66			13	.31	56	15	8.1	1.2	230	0	20	4.5	.4	1.7	.03	.01	233	230	.31	202	13	8	.2	403	8.0	0
3-28-66			11	.43	55	13	7.8	1.8	219	0	20	5.2	.3	1.3	.03	.00	223	225	.31	192	12	8	.2	384	8.2	5
5- 4-66			11	1.0	59	13	9.1	1.5	234	0	22	6.8	.3	2.0	.02	.03	240	245	.33	202	10	9	.3	405	8.1	10
6- 9-66	23		12	.08	51	17	11	2.0	223	0	26	8.5	.3	.4	.01	.00	238	255	.35	197	14	11	.3	449	7.9	0
7- 8-66	9.3	24	16	.85	56	17	13	2.8	240	0	28	8.8	.4	.1	.07	.02	260	265	.36	210	13	12	.4	442	7.1	5
8-25-66	3.4		16	.05	69	19	14	2.6	291	0	28	10	.4	.2	.02	.07	302	284	.39	250	12	11	.4	508	7.9	5
9-30-66	1.8		16	.00	58	18	14	2.8	256	0	27	10	.4	.0	.01	.07	272	252	.34	218	8	12	.4	461	7.9	0
11- 1-66	8.4	4	14	.05	62	19	12	1.5	270	0	25	7.0	.3	.1	.01	.00	274	276	.38	231	11	10	.3	471	7.7	0
12- 5-66	13		13	.10	59	16	11	1.5	251	0	24	6.0	.3	.8	.02	.03	255	249	.34	213	8	10	.3	440	7.7	0
1- 4-67	11		14	.07	70	16	11	1.6	285	0	24	5.5	.3	1.5	.02	.06	284	270	.37	240	7	9	.3	481	7.9	0
2- 6-67	12	1	15	.12	64	16	11	1.5	268	0	24	6.0	.3	1.2	.02	.06	271	264	.36	226	6	10	.3	447	8.0	5
3-15-67	6.4	1	13	.11	70	17	10	1.8	282	0	22	6.5	.3	.8	.01	.06	281	285	.39	244	14	8	.3	488	8.1	5
4-17-67	7.0		14	.07	68	17	11	1.9	277	0	28	8.5	.3	.6	.02	.04	285	286	.39	240	12	9	.3	485	8.1	0
5-25-67	37	18	13	.12	52	14	8.9	1.9	214	0	23	5.5	.3	.5	.06	.02	224	229	.31	187	12	9	.3	393	8.1	5
6-14-67	706		14	1.1	44	10	6.7	2.3	180	0	18	3.0	.3	.8	.09	.16	188	192	.26	151	4	9	.2	323	7.9	5
7- 7-67	1,610		13	.43	40	10	6.2	2.2	172	0	9.6	3.0	.3	.6	.13	.06	170	182	.25	141	0	9	.2	304	8.0	10
8-24-67	134	16	16		64	15	9.5	2.1	255	0	19	6.0	.4	1.1		.03	258	259	.35	221	12	8	.3	420	8.1	5
9-26-67	280	16	14		55	15	8.6	1.5	230	0	19	6.0	.3	.8		.06	233	239	.33	198	10	8	.3	393	8.2	5
12- 8-67		0	16		63	14	8.6	1.5	248	0	21	4.5	.3	2.6		.01	254	245	.33	214	12	8	.3	433	8.1	0
1- 9-67			15		65	14	8.6	1.5	253	0	21	4.0	.3	2.5		.03	256	249	.34	220	12	8	.2	440	8.1	0
2-12-68			14		65	15	8.5	1.4	252	0	21	6.0	.3	2.2		.03	257	252	.34	224	17	8	.2	442	8.1	0
3-18-68		4	15		60	15	8.2	1.3	240	0	20	6.0	.3	1.9		.06	246	242	.33	211	14	8	.2	422	8.0	0
4-23-68		9	13		35	14	9.6	1.4	168	0	21	6.0	.3	1.2		.04	185	202	.27	145	8	12	.3	304	8.1	0
5-28-68		21	14		58	16	10	1.6	249	0	23	6.5	.3	.2		.08	253	242	.33	210	6	9	.3	443	7.9	0

13-1308. Big Lost River below Blaine Canal, near Leslie

9-19-67	14	13	43	10	5.6	1.5	172	0	16	4.0	0.3	0.9	0,06	179	181	0.25	148	8	7	0.2	302	8.0	0
6-19-68	18	13	60	16	9.7	1.8	253	0	23	6.0	.2	.8	.02	255	256	.36	216	8	9	0.3	435	8.1	5
8- 5-68		19	55	17	11	2.0	235	0	23	6.5	.3	.9		251	248	.34	207	11	10	0.3	416	8.0	5
9- 6-68	17	15	54	16	9.8	1.6	232	0	22	5.5	.3	.8		239	241	.30	200	10	10	0.3	413	7.9	5
10-11-68	7	15	66	14	9.7	1.9	257	0	22	5.0	.3	1.8		262	263	.36	222	12	9	0.3	449	7.9	0
11-16-68	1	14	57	14	8.3	1.5	233	0	20	6.0	.3	1.3		237	219	.30	200	8	8	0.3	406	8.0	0

a Erroneously published as tons per acre-foot in U.S. Geological Survey Water-Supply Paper 274.
b Estimated.

between 125 and 300 mg/l. During periods of high streamflow, direct runoff predominates; while during periods of low flow, ground-water discharge predominates.

Chemical concentrations of the surface waters listed in table 10 were compared with concentration limits recommended by the U.S. Public Health Service (1962) for drinking-water supplies. At no place did the concentration of a measured chemical constituent exceed those limits. The total iron reported in table 10 includes iron in sediment and other suspended matter, so in general it is much higher than the dissolved-iron content. Even though the total iron reported sometimes exceeds the limit of 0.3 mg/l recommended by the U.S. Public Health Service for dissolved iron, there is still no reason to expect that dissolved iron alone will exceed 0.3 mg/l in surface waters in the Big Lost River basin.

Most surface water in populated areas of Big Lost River basin is classified as either hard (120 to 180 mg/l hardness as $CaCO_3$) or very hard (above 180 mg/l hardness as $CaCO_3$) because of its high calcium plus magnesium content. Water in the smaller mountain streams at high elevations may be classified as soft or moderately soft, but this changes abruptly at the lower elevations where ground-water becomes a part of the total flow.

The surface waters were rated for irrigation suitability according to the standards set forth by the U.S. Salinity Laboratory Staff (1954). In no case was the sodium-adsorption ratio sufficiently high to indicate a potential sodium hazard. With the exception of Thousand Springs Creek and several of the springs, surface water above Mackay Reservoir tends to have a low salinity hazard. Water in Warm Springs Creek, Thousand Springs Creek, and Big Lost River below Mackay Reservoir is classed as having a moderate salinity hazard; however, this should not be a problem in the coarse-textured, well-drained soils which predominate in these valleys. Concentrations of dissolved solids in Antelope Creek appear to be on the borderline between a low and a medium salinity hazard, but here again coarse textured, well drained soils predominate so salt damage to crops should not be a significant problem in this area.

The water from Warm Springs is warmer and has a higher dissolved-solids concentration than water from Hamilton Springs. This indicates that the flow path of water from Warm Springs is probably deeper and longer than that for water discharging from Hamilton Springs.

GROUND WATER

Occurrence

During periods of rainfall and snowmelt, water enters the fractured rocks, talus, slope wash, and the alluvial deposits. Generally, much of this water soon discharges to the streams and sustains their flow during dry weather. Some of the precipitation falling on the mountain slopes moves downward through the consolidated rocks and reaches the alluvial fill in the main valley without appearing as streamflow. Precipitation on the valley floor also contributes a small amount of recharge to the alluvial deposits during periods of intense rainfall and snowmelt.

Principal areas of natural recharge to the aquifers are where reaches of Big Lost River are above the water table and lose water by seepage and where streams tributary to the main valley emerge from the mountains and disappear into the alluvial fans. Recharge also occurs by infiltration of the water applied on irrigated lands. Ground water discharges naturally from the alluvial deposits as (1) flow into the gaining reaches of Big Lost River, (2) underground flow through the mouth of the valley at Arco, (3) spring discharge, and (4) evapotranspiration where the water table is at or near the land surface.

Ground water occurs mostly under water-table conditions in the main valley but locally artesian conditions exist. There is a flowing artesian well in Thousand Springs Valley and there may be weak artesian pressures in the wells drilled for irrigation west of Chilly Buttes. Because of the variability of the alluvial deposits, weak artesian pressures may be present in other parts of the basin, but they have not yet been observed. At some places, ground water is perched above the main water table. Southwest of Moore, near the west edge of the cultivated area, water is perched on fine-grained sediments a few feet above the main water table. In the vicinity of Arco there are at least five water-bearing zones where water is moving downward and southward to the regional water table underlying the Snake River Plain.

Figure 23 shows that the principal component of slope of the water table follows the general gradient on the main valley. Because there were few wells to use for control near the edge of the lowland, the contours were arbitrarily curved slightly to indicate ground-water movement from the bordering mountain ranges toward the axis of the valley.

The nonuniformity of the water-table gradient in the valley is caused by variation in the cross-sectional area through which the water moves, the permeability of the alluvial fill beneath the valley floor, and the quantity of water in transit. The above factors cause the water-table gradient to range from 10 to 100 feet per mile at different places in the valley. Figure 24 shows the profile of Big Lost River and the position of the water table along the river.

Water-table contours were not drawn at the mouth of the basin because south and southwest of Arco ground water is found in at least three separate zones. Also, from Arco north for an unknown distance, the contours are shown on the surface of the upper water-bearing zone. The altitude of the water level in wells in the uppermost zone in the vicinity of Arco ranges from 5,375 to 5,300 feet; in the next zone, from 5,272 to 5,125 feet; and in the third zone, from 5,075 to 4,875 feet. A test well (4N-26E-21abb1) located 4 miles northwest of Arco found water levels at about 5,380, 5,135, 5,065, 4,965, and 4,815 feet altitude (fig. 25). The altitude of the well head is about 5,390 feet above sea level. It is not known how far upvalley the separation of the different water-bearing zones extends. Sparse data indicate that the upper zones become thinner in a southerly direction from the mouth of the valley, are not continuous, especially at some distance southwest of Arco, and finally disappear as the water percolates downward to the regional water table underlying the Snake River Plain.

Data from wells at the mouth of the basin indicate that several basalt flows are interbedded with the alluvial deposits. Most of these flows probably encroached into the mouth of the basin from the Snake River Plain, but at least one flow was erupted from the vent 3 miles west of Arco and some basalt may have been extruded from the faults which bound the valley on the eastern and western sides. Regardless of the source of the basalt flows, they have intermittently dammed the drainage from the valley resulting in a complex interbedded sequence of basalt, clay, sand, and gravel. What is assumed to be the main water table at Moore is at an elevation of 5,460 feet above sea level whereas in the Snake River Plain 12 miles south of Arco the water table is at an elevation of about 4,385 feet, a difference of a little more than 1,000 feet. The less permeable parts of the sedimentary

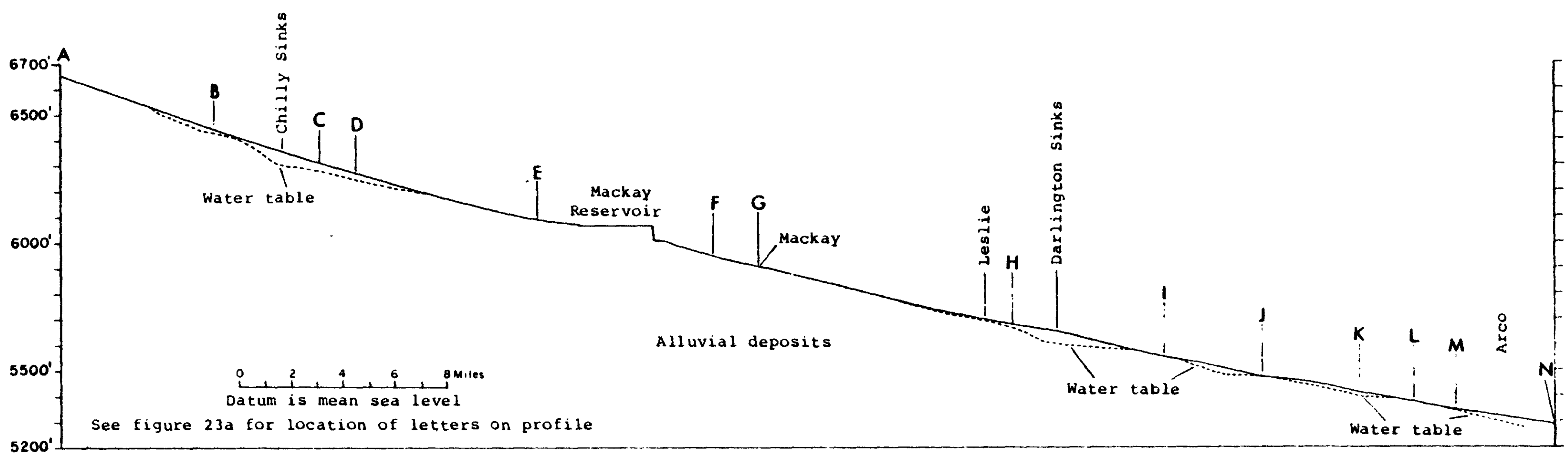


FIGURE 24.-- Profile of Big Lost River showing the position of the water table.

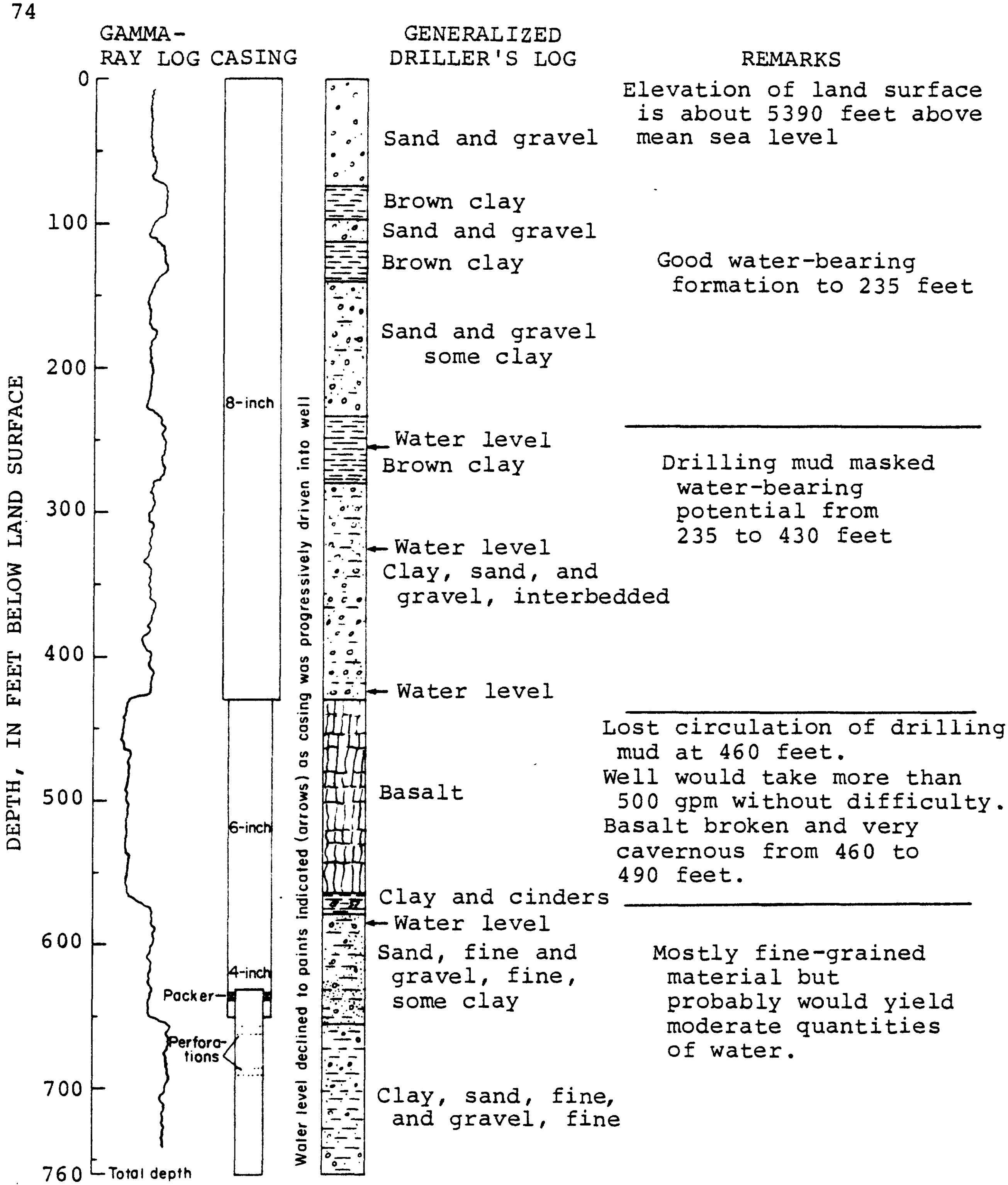


FIGURE 25.-- Logs and water levels in well 4N-26E-21abbl.

and basalt sequence have a sufficiently large areal extent to strongly influence the lateral movement of ground water out of the basin and thus cause water levels to be at several different elevations. It would require a very large number of deep test wells to define the stratigraphic details and the water-yielding potential of this part of the basin.

Throughout much of the valley the water table is less than 50 feet below land surface and near the river it is commonly less than 10 feet below the surface. Figure 23b shows the depth to water in early October 1968, a year when the water table was at a relatively high level. In a series of dry years, the water table would be 10 to 60 feet lower in the parts of the valley where the river loses water, but only a few feet lower near gaining reaches of the river. On the flanks of the valley, high on the alluvial fans, the depth to water exceeds 200 feet. At the south end of the valley, some of the water-bearing zones are more than 500 feet below land surface.

Changes in recharge to and discharge from the alluvial deposits were monitored by measuring water levels each month in 30 observation wells in the basin and operating water-level recording gages on four wells. The hydrographs from eight selected observation wells (fig. 26) show the seasonal fluctuations in water levels during the period July 1966 to September 1968. As shown in the figure, water levels are usually lowest in late winter and early spring when streamflow is at a minimum and canals are empty. Water levels are highest from midsummer to early autumn when river flow is larger and canals are in use. The hydrographs show annual water-level fluctuations ranging from 3 to 42 feet for the period of record. In contrast, the water level in well 5N-25E-11cdc1 (hydrograph not shown in fig. 26) at the apex of the Antelope Creek fan fluctuated at least 114 feet in 1968. This anomalous fluctuation may represent water levels in an aquifer underlying the alluvial deposits. Variations in the magnitude of fluctuations from year to year are due to climatic conditions, which in turn govern irrigation practices, which together affect ground-water levels.

Water levels in three wells were measured for several years prior to this study and the hydrograph from one of these wells and the discharge of Big Lost River at the Howell Ranch and Arco gages are shown in figure 27. The hydrographs indicate that water levels in the well respond to the volumes of water available for recharge, and that trends of streamflow and fluctuations of the water table are similar. For example,

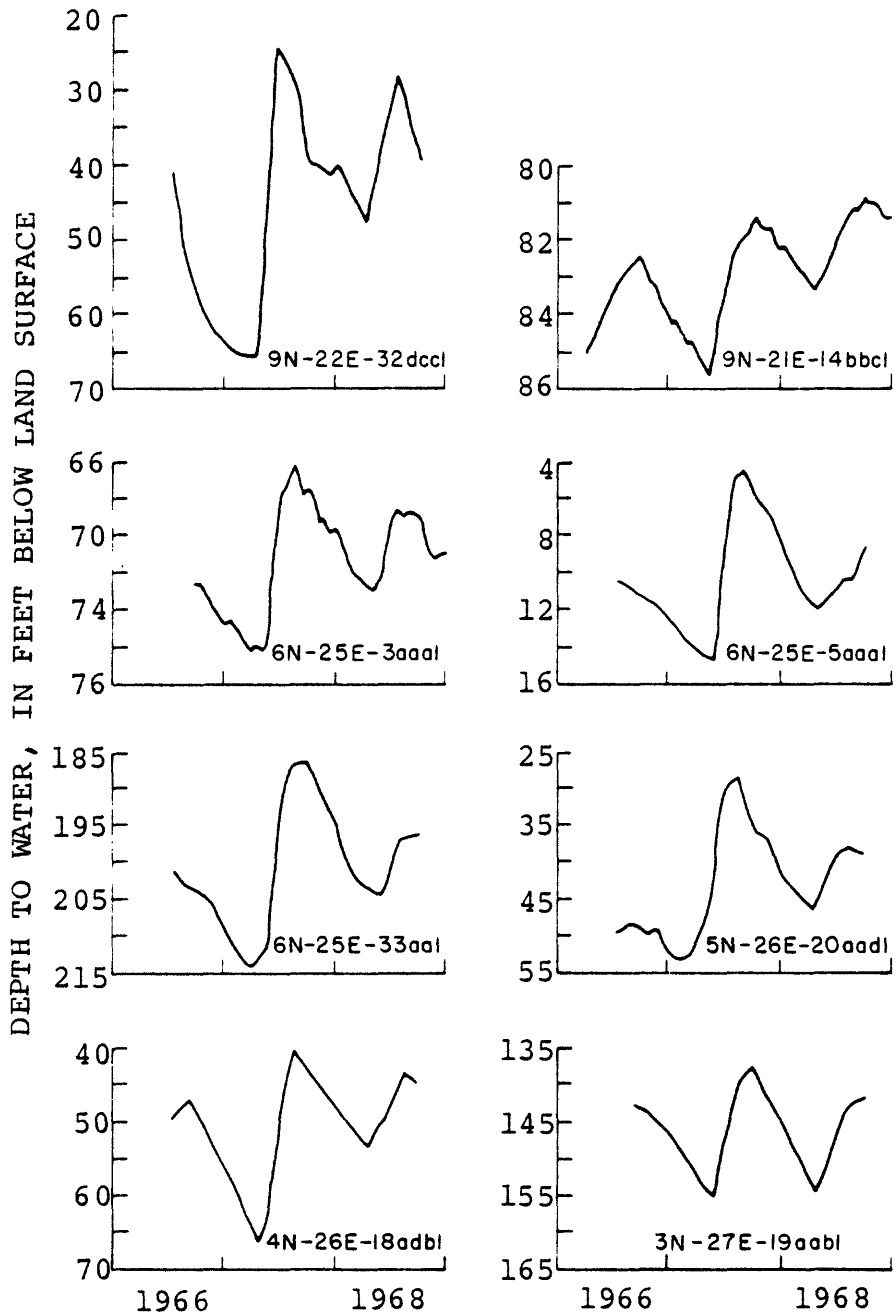


FIGURE 26.-- Hydrographs of selected wells.

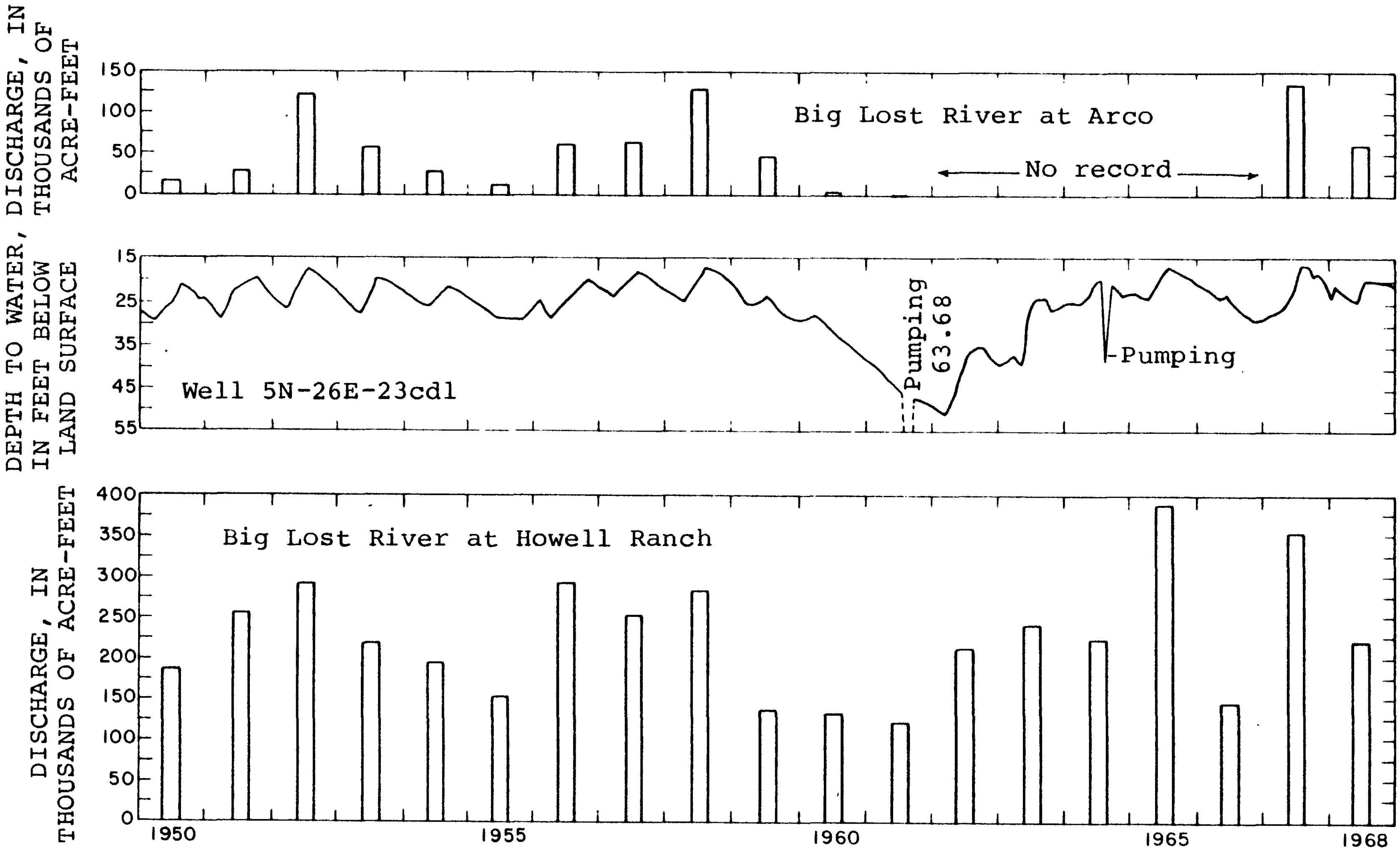


FIGURE 27.-- Hydrograph of well 5N-26E-23cdl and discharge of Big Lost River at Howell Ranch and at Arco.

precipitation, and thus streamflow, were deficient in 1959, 1960, and 1961, so water levels declined. If it is assumed that the streamflow at the Howell gage is an approximate index of the relative amount of annual precipitation on the basin, the hydrograph shows that water levels correlate fairly well with the amount of precipitation that falls in the basin each year and, also, that the water table responds rapidly to recharge and discharge. This correlation again exemplifies the intimate cause and effect relationship between the surface- and ground-water resources of the basin.

In addition to periodic water-level measurements in the observation wells, measurements were made in about 200 other wells in the autumn of 1967, and the spring and autumn of 1968. The change in water levels from the autumn of 1967 to the autumn of 1968 are shown in figure 23c. The figure shows the natural decline in the water table in an average year of water supply following an abnormally wet year. A contour map of the water table in autumn 1968 is shown in figure 23a. Stearns and others (1939, pl. 19) show the position of the water table in 1928 or 1929. Stearns also constructed a water-table contour map for the autumn of 1920 (unpublished data in files of Lost River Irrigation District). The years 1919, 1920, 1928, and 1929, were below-average water years. The year 1966 was one of the driest of record, 1967 was one of the wettest, and 1968 was about average. Direct comparison of the water-level measurements of Stearns with the 1967-68 measurements cannot be made because different wells were measured in the two periods. However, by comparison of the water-table contours on the 1968 and 1920 maps, the generalized water-level change map shown in figure 23d was constructed. This map shows that following the dry years of 1919 and 1920, the water table was as much as 20 feet lower locally than it was during the present study, and that in the reaches where the river gains water, the water table was only slightly lower.

Effects of Pumping

As indicated previously, the surface- and ground-water resources of the basin are so closely related that the use of one affects the other with but few exceptions. Where the water table is continuous with the river, the pumping of ground water will cause a decrease in streamflow because lowering of the water level at a well changes the slope of the water table and either decreases the quantity of water entering the river or increases the loss of water from the river. Where the river is dry or where its bed is above the water table, pumping does not affect river flow directly. Methods are available for computing the rate and volume of streamflow depletion by individual wells (Jenkins, 1968, p. 37-46, and Theis, 1953), and these methods might be used locally; but the amount of depletion of the water resource caused by pumping is so small when compared to the total water supply that it is impractical to compute streamflow depletion. For this reason, an estimate of the reduction of the total water supply caused by pumping is made on the basis of ground water that is consumptively used by evapotranspiration.

The quantity of supplemental water required to supply the presently irrigated acreage varies widely from year to year as shown in figure 28. In most years, about 200,000 acre-feet of surface water must flow past the gaging stations on Big Lost River near Mackay (1260) and Sharp ditch (1265) to provide an adequate supply for lands irrigated with surface water below the reservoir. In years with hot dry summers (1966, for example) usually more than 200,000 acre-feet is required; in years with moist summers less water is required. Generally, when the annual supply is less than 200,000 acre-feet, much of the difference is made up by pumping ground water. In this discussion it is assumed that the distribution of irrigation wells is such that all land needing supplemental water receives an adequate supply even though shortages do occur locally in extremely dry years. During the period 1961-68, an average of 23,400 acre-feet (rounded to 25,000) or 0.8 acre-feet per acre of ground water was pumped annually to supplement the surface-water supply. The average supplemental requirement is then about 12.5 percent (25,000 ÷ 200,000) of the total requirement, but it has ranged from less than 1 percent in 1964, 1965, and 1967 to as much as 39 percent in 1966.

For the period 1944-68, the average annual diversion was 6.8 acre-feet for each acre irrigated under the present canal system. Irrigation efficiency based on the consumptive irrigation requirement of crops (p. 21) is about 18 percent (1.2 x 100 ÷ 6.8). However, as is generally known, the irrigation efficiency using ground water is higher than the irrigation efficiency using surface water because the ground water is withdrawn near its area of use and ordinarily sustains fewer transit losses. Thus, irrigation efficiency probably exceeds 25 percent but no data are available to confirm this. If a 25 percent efficiency is assumed, then net depletion of water pumped for supplemental irrigation in an average year would be about 6,000 acre-feet. The maximum ground-water use

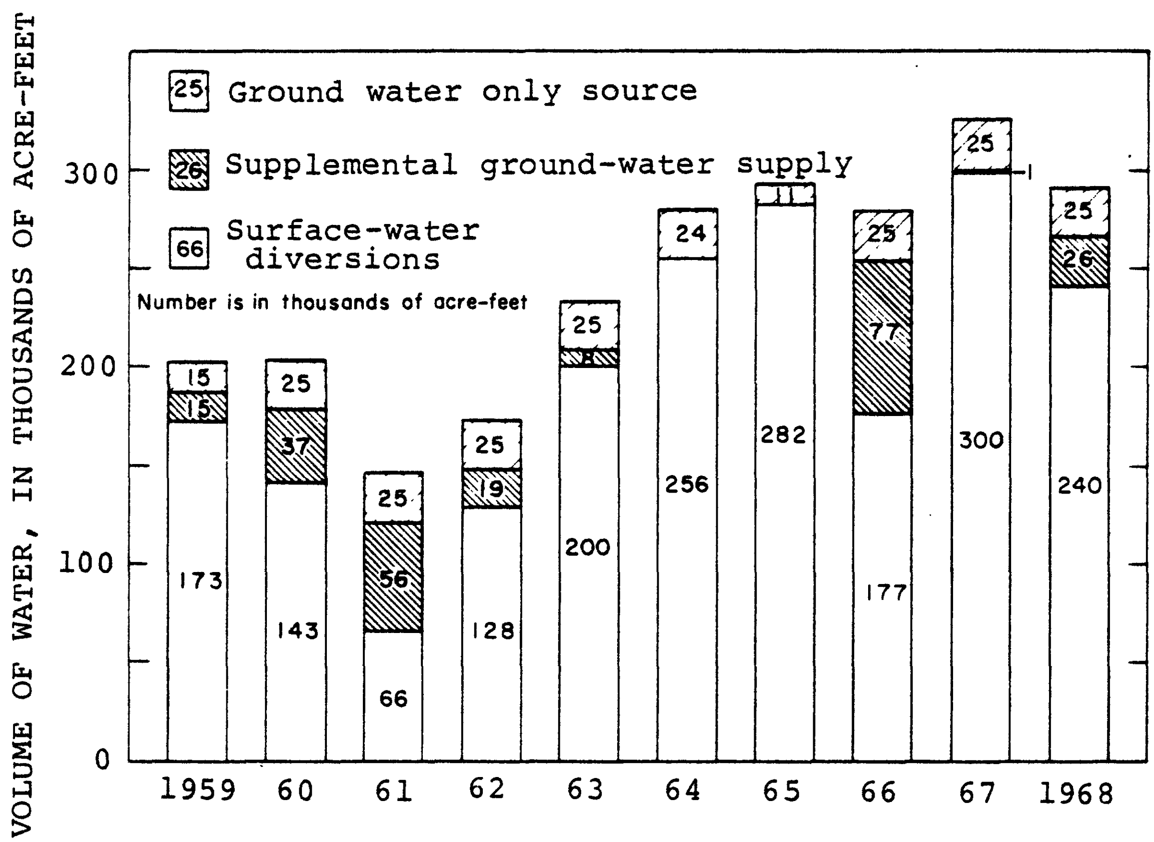


FIGURE 28.-- Sources and amounts of water used for irrigation in the Big Lost River basin, 1959-68.

for supplemental irrigation was in 1966 when an estimated 77,000 acre-feet was pumped; therefore, evapotranspiration or net depletion probably approached 20,000 acre-feet that year. Practically all the ground-water depletion from supplemental pumping occurred downstream from the reservoir.

Approximately 8,300 acres below the reservoir and about 200 above is irrigated solely with ground water. On the basis of a consumptive irrigation requirement of 1.2 acre-feet per acre, the total ground-water depletion from this acreage is about 10,000 acre-feet. Therefore, total net depletion or evapotranspiration of pumped ground water from the entire basin is estimated to average 16,000 acre-feet per year for the present acreage in crop production.

As stated previously, the hypothetical effects caused by individual wells on streamflow can be computed by adaptation of the Theis nonequilibrium formula (Theis, 1953) or by a method devised by Jenkins (1968, p. 37-46). For example, assume a storage coefficient of 0.20 and an estimated transmissivity (coefficient of transmissibility) of 400,000 gpd per foot (estimated from specific-capacity data on 20 wells), and two hypothetical wells A and B, each pumping 2,000 gpm and located 0.5 and 1 mile respectively from the river. After 100 days of pumping well A, 72 percent of 2,000 gpm or about 6.5 acre-feet per day (3.2 cfs) would be from streamflow and total depletion would be about 480 acre-feet. After 100 days of pumping well B, streamflow depletion would be about 4 acre-feet per day (2 cfs) and total about 240 acre-feet. The stream would continue to lose water after the pumping ceased, but at the beginning of the next irrigation season the residual effects of pumping would be negligible for the well 0.5 mile from the river and about 60 gpm or about 0.027 acre-foot per day for the well 1 mile from the river.

The above analysis is based on several assumptions (Jenkins, 1968, p. 38). Although the hydraulic conditions in the Big Lost River valley do not entirely fulfill all the assumptions used in the above analysis, the conditions fit the assumptions closely enough to illustrate the effect of pumping on streamflow. The actual effect on streamflow is usually quite different. Much of the surface water lost by seepage from canals and from irrigated fields is intercepted by wells before the water returns to the river or is discharged underground past Arco. Also, some of the ground water pumped seeps back into the ground or runs off overland into the river. The net depletion of streamflow and ground-water flow is equivalent to the water evapotranspired by crops plus that evaporated from ditches. Thus the effect of ground-water pumpage is to recycle water and generally delay the discharge of ground water to the streams or out of the basin.

The demand on ground water during the recurrence of an extended dry period such as in 1929-37 (fig. 29) would have a significant effect on streamflow. On the basis of pumping 1 acre-foot of ground water for each acre-foot of surface-water deficiency, ground-water depletion would have averaged about 12,000 acre-feet during this period and would have approached a total depletion of 40,000 acre-feet in 1934, the driest year.

Yields of Wells

Yields of irrigation wells range from 500 to 3,500 gpm, but most yields are 2,000 to 3,000 gpm (about 200 to 300 miners inches or 4.5 to 6.5 cfs). Commonly, water-level drawdowns in wells pumped at the above rates range between 10 and 20 feet, but drawdowns in a few wells are 50 to 100 feet. The greatest drawdowns are in wells southwest of Arco. Drawdown in a few of the wells on the Alder Creek and Antelope Creek fans exceeds 50 feet, but in most wells is less than 50 feet.

The yield to wells per foot of drawdown is influenced by two major factors: permeability of the water-bearing material, and well construction and development. In general, drawdowns are less in wells near the axis of the valley, as defined by the course of the river, than in wells on the flanks of the valley. This implies that the alluvial deposits penetrated by the wells along the axis of the valley are highly permeable and contain mostly well-sorted sand and gravel. Wells drilled closer to the bordering mountains penetrate more fine-grained, less permeable material and thus have larger drawdowns.

In some wells, perforations made in the casing are so large that the materials in the formation immediately surrounding the casing enter the well, thus causing the pump to discharge sand in quantities that locally has caused the ground to collapse around the casing. On the other hand, the holes opposite some sand and gravel deposits are so small that they become plugged and restrict the flow of water into the casing.

The size of the perforations in the casing should, ideally, be such that they allow about 50 to 70 percent of the material immediately surrounding the casing to pass through the perforations and into the well. Then during the initial pumping, or

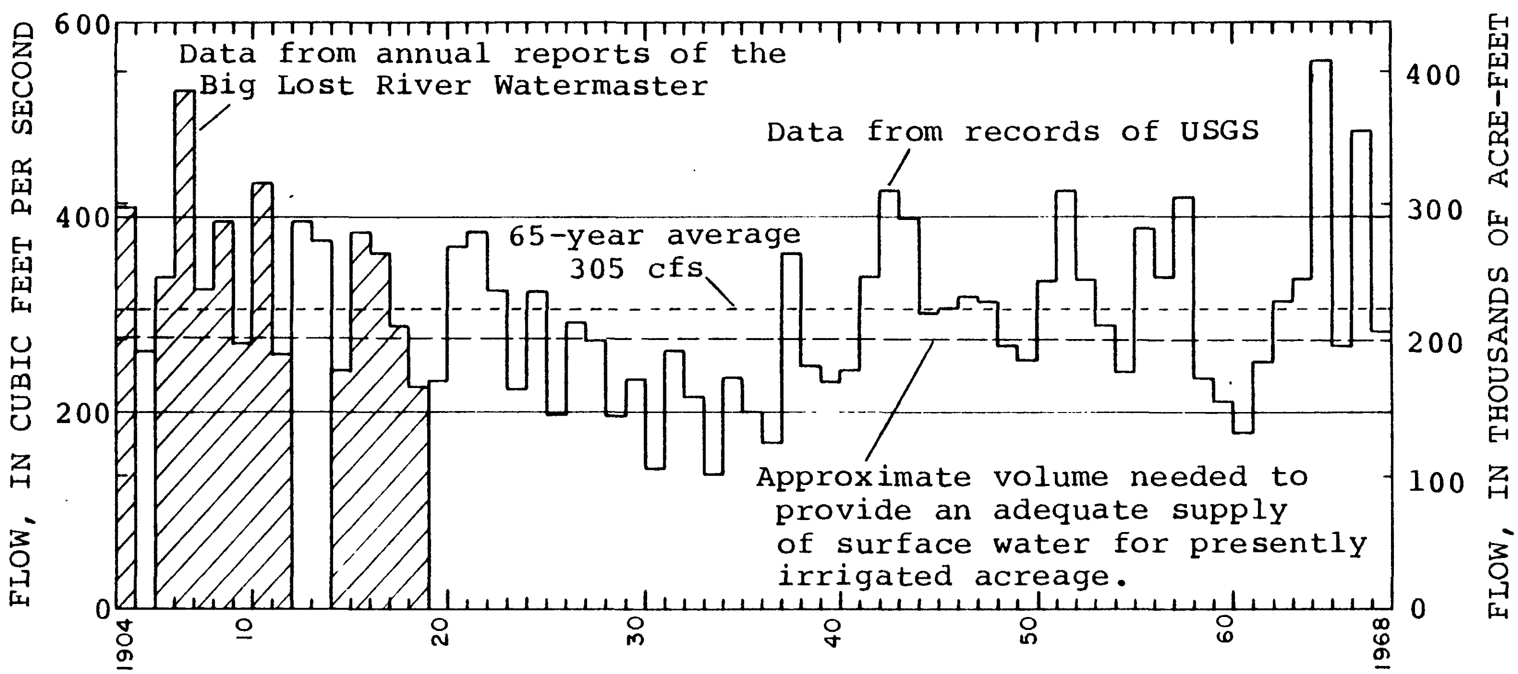


FIGURE 29.-- Flow of Big Lost River at Mackay Narrows. (Big Lost River near Mackay and Sharp Ditch near Mackay).

development, of the well, the finer material that passes into the well is removed, thus leaving a gravel envelope around the perforations which allows the least resistance to the flow of water into the well.

Water in Storage

A large amount of ground water is in storage in the alluvial deposits. Most irrigation wells are at least 75 feet deep and several exceed 200 feet, but none of the wells fully penetrates the saturated thickness of the alluvial deposits. Geophysical data (p. 25) indicate that the alluvial deposits exceed several hundred feet in thickness and may be as much as 5,000 feet thick at some places. Estimates can be made of the amount of water in storage in the upper 100 or 200 feet of the saturated alluvial deposits by computing the volume of the deposits to a specified depth between the valley walls and assuming a specific yield (see Glossary).

Johnson (1967, p. 1) listed the average specific yield of 10 different materials (total of 154 samples) ranging from clay to coarse gravel as 18.6 percent. Using this as a guide and considering the composition of the alluvial deposits in the basin, an assumed specific yield of 20 percent is used in this report. The saturated alluvial deposits in the Big Lost River basin from Mackay Narrows to near Arco occupy about 100 square miles, or 64,000 acres. On the basis of 64,000 acres and a specific yield of 20 percent, the upper 100 feet of saturated alluvium contains about 1.3 million acre-feet of water in storage, and the upper 200 feet contains twice as much. This is enough water to irrigate the presently developed land in the basin for about 10 years. As a practical matter, it is economically infeasible and probably physically impossible to withdraw only that water in the upper 100 feet of saturated alluvial deposits, but this illustrates the large volume of ground water in storage.

In general, the annual ground-water supply recoverable on a continual basis in the valley is not directly related to the amount in storage but is equal to the average annual discharge from the system. In fact, pumping increases recharge to the ground-water system by depleting streamflow at some places and the amount of ground water in storage cannot be depleted until discharge to streamflow and evaporation ceases. Furthermore, discharge from the system will not change until storage is depleted enough to change the water-table gradient at the mouth of the basin.

Ground-Water Quality

Chemical analyses of water samples from 12 wells and 4 springs are given in table 11. All samples were determined to be predominantly calcium bicarbonate in type as was true of the surface waters (p. 64).

Ground water tends to have more dissolved solids than does surface runoff because of the opportunity it has had to dissolve solids from aquifer materials. In areas of shallow ground water, the loss of water by evapotranspiration tends to concentrate the dissolved minerals. Ground water in the basin normally contains between 100 and 300 mg/l dissolved solids. The less mineralized ground waters are found in the coarse-textured alluvium upstream from Mackay Reservoir.

Chemical concentrations in sampled water were compared to the tolerances recommended by the U.S. Public Health Service (1962) for drinking water. Except for dissolved iron, there were no instances where the measured concentration of a chemical constituent exceeded the recommended limits.

The dissolved-iron content in water from three wells exceeded the 0.3 mg/l limit specified in the standards; but there is reason to believe that this high level of iron is not representative of ground water in most of the basin. The maximum iron concentrations observed would not be hazardous to the health of consumers but could affect the taste of the water and leave an undesirable deposit on pipes and containers.

Almost all the ground water in the basin can be classified as either hard (120 to 180 mg/l hardness as $CaCO_3$) or very hard (above 180 mg/l hardness as $CaCO_3$). The water from one well (8N-21E-30bdb1) in the alluvium above Bartlett Point contained only 84 mg/l hardness on September 18, 1968, so it is classed as moderately hard. However, when the same well was sampled a year earlier on August 8, 1967, the hardness was 123 mg/l placing the water in the hard class. This shows that the quality of the ground water does change with time.

The chemical characteristics of water can frequently be used to indicate the origin or route of travel of the water. In this basin, water which has spent much time

Table 11. Quality of water analysis, ground water.
(Chemical constituents, in milligrams per liter)

Well	Date of collection	Depth (ft)	Temperature (°C)	Silica (SiO_2)	Iron (FE)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180° C	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25° C)	pH	Color
3N-26E- 2bb1	10-18-49	10?	7					--3.7--		300	0	16	8							266	20	3		543		
3N-26E- 8dd1	10-18-49	600						--3.2--		188	0	17	11							180	26	4		360		
3N-26E- 8dd1	2- 4-50	582	11	14	0.11	50	13	7.6	4.0	204	0	24	11	0.3	0.0		0.00	225	215	178	11	8		377	7.4	
4N-26E- 4b	10- 2-68	160	10	18	.35	66	15	13	1.5	271	0	20	5.5	.2	11			284	276	226	4	11		478	7.6	0
4N-26E-19ad1	10-19-68	90	8	23						422	0		16	.4			.04							738		
4N-26E-26dcd1	10-18-69							--13--		198	0	15	8							160	0	15		368		
4N-26E-36aa1	1-16-49	190	10	22	.02	67	21	11	2.4	288	0	29	8.0	.2	2.6		.01		305	254	18	9		506	7.1	
4N-26E-36aa1	8-30-57	190	13	24	.06	67	18	9.0	1.8	274	0	24	7.5	.3	1.7	0.05		288	289	241	16	7		489	7.6	
4N-26E-36aa2	10-19-49	29	9					--3.7--		312	0	20	8							280	24			530		
5N-25E-1d	9-26-67	210	9	17		45	8.5	6.0	1.0	164	0	17	4.5	.2	5.1		.04	185	189	148	13	8	0.2	306	7.8	
6N-26E-32 c	10- 2-68	100	8	19	.73	53	10	6.9	1.4	200	0	16	3.0	.2	4.6			213	211	173	9	8		359	7.4	5
7N-24E- 7 c	9-28-67	298	7	12		38	10	5.2	1.0	160	0	13	2.5	.3	.6		.00	162	164	136	5	8	.2	279	8.0	15
7N-24E- 7 c	9-13-68	298	8	13	.18	38	11	4.9	1.4	158	0	17	4.0	.3	.7			168	165	140	10	7		276	7.8	0
8N-21E-30bdb1	8- 8-67	127	7	12		36	8.0	5.4	1.6	136	0	15	7.5	.2	.8		.00	154	164	123	12	8	.2	259	7.3	0
8N-21E-30bdb1	9-18-68	127	7	11	.44	25	5.3	3.5	.9	98	0	11	.5	.3	.1			110	106	84	4	8		183	7.4	0
8N-22E-26 c	9- 7-67	86	11	15		39	8.6	5.8	1.0	156	0	14	22.0	.3	1.0		.04	164	167	133	5	9	.2	277	8.0	0

underground is likely to become saturated with calcium carbonate and other less soluble constituents. Water which has spent a brief time underground in coarse alluvium or consolidated rocks may not have had sufficient time to become saturated with any constituent. This appears to be the factor in water from well 8N-21E-30db1, which, as mentioned above, changes in quality with time. There, the water occurs in a relatively narrow part of the alluvial aquifer which is situated near the base of a major snowmelt-recharge area. Apparently, because of the location and high permeability of the aquifer, water moves relatively rapidly through this section of the aquifers and its quality is affected by annual fluctuations in the quality and volume of the recharge water.

The ground waters were rated for irrigation suitability according to standards set forth by the U.S. Salinity Laboratory Staff (1954). At no place was the sodium-adsorption ratio high enough to indicate a potential sodium hazard. The electrical conductivity of the water in all but one well ranged between 250 and 750 micromhos per centimeter at 25° C (table 11), thus most of the water is in the medium salinity-hazard category. Because of the coarse-textured, well-drained soils prevalent in the Big Lost River valley, none of these waters is likely to cause salinity problems.

ANALYSIS OF WATER YIELD

Water yield is defined in this report as the total average annual input (precipitation) minus the average annual quantity evaporated at the surface and transpired by native vegetation (natural evapotranspiration) prior to the water becoming streamflow or a part of the ground-water body for the period 1944-68. In order to avoid negative values of water yield, water transpired by native vegetation after it has become a part of streamflow or the ground-water body is considered to be water consumptively used and, therefore, is a charge against water yield. The amount of ground water in storage in the basin aquifers is not a part of water yield. While all the water yield may not be feasibly used in the Big Lost River basin, it is the maximum amount perennially available for development on a continuing basis and can be changed only by changing natural water losses.

Mean annual precipitation in the basin for the period 1944-68 is shown by the isohyetal map in figure 9. Precipitation at any point, or the volume of precipitation for all or any part of the basin, can be estimated from this map.

Average annual precipitation in the basin, as derived from this map, is 20.2 inches or 1,520,000 acre-feet. Annual evapotranspiration losses were calculated for a number of representative locations in the basin using methods described previously (see p. 17-20).

Accordingly, a water yield at scattered points over the basin was obtained by subtracting annual evapotranspiration losses from mean annual precipitation and, for those areas with yields so low that in some years no water yield is produced, by using a technique described by Walker, Dutcher, Decker, and Dyer (written commun., 1969). Using the yields thus obtained, lines of equal water yield were drawn on a map of the basin (fig. 30). Water yields for each subarea were determined from this map by planimetering areas between lines of equal yield and by estimating the distribution of yield between the lines. Water yields for the 25-year period 1944-68 for each of the subbasin units shown in fig. 30 are listed in table 12. Table 12 also shows the estimated maximum and minimum annual streamflow for representative basins.

The distribution of the water crop in the basin can be determined from the detailed data in table 12. A water budget for the four principal reaches of the basin is described and the surface- and ground-water supplies summarized in the following sections.

ABOVE HOWELL RANCH

Analyses of available data for the basin above the gage at Wild Horse (1200) for the period 1944-68 and the water years 1967-68 indicate that all the water yield obtained passes this gage as streamflow even though changes in ground-water and soil-moisture storage may temporarily reduce or increase streamflow.

However, analyses of yield data for the basin above the gaging station at Howell Ranch (1205) indicate some of the yield infiltrates into the ground and bypasses this gage. Miscellaneous streamflow measurements made during the study period likewise indicate that all the yield was not at the surface at the Howell Ranch gage.

Geologic and hydrologic data indicate that about 5 to 10 cfs of flow bypasses the gage at Howell Ranch through the alluvial deposits in the valley. Also, well data and aquifer

Table 12. Hydrologic data for subareas in Big Lost River basin for the period 1944-68.

No. of subbasin (see fig. 3)	Area (square miles)	Mean elevation (feet)	Mean precip-itation (inches)	Natural evapo-transpir-ation (inches)	Estimated water yield		Consumptive use by phreatophytes and crops (cfs)	Annual surface flow (cfs)			Estimated underground flow (cfs)
									Estimated		
					inches	cfs		Average	Min. (1961 w.y.)	Max. (1965 w.y.)	
1	53	8,850	26.2	13.4	12.8	50		41	21	80	9
2	42	8,740	31.2	14.9	16.3	50		38	21	72	12
3	19	8,010	18.4	14.3	4.1	6		-	-	-	-
Total above gage at Wild Horse	114	8,650	26.9	14.3	12.6	105	0	103	59	184	2
4	67	8,750	22.7	17.9	4.8	24		34	19	54	10
5	76	8,960	32.5	16.0	16.5	92		77	41	156	15
6	58	9,300	31.7	13.8	17.9	76		66	38	125	10
7	78	8,230	20.8	15.5	5.3	30		-	-	-	-
Total East Fork at mouth	279	8,780	26.7	15.9	10.8	225		225	110	360	-
8	54	7,980	17.7	13.9	3.8	15		-	-	-	-
Total above gage at Howell Ranch	450	8,650	25.7	15.4	10.3	345	0	310	170	538	35
9	50	7,380	14.1	12.1	2.0	7		-	.7	3.4	-
10	13	8,050	18.4	13.1	5.3	5		2	-	-	3
11	40	7,790	15.8	13.4	2.4	8		-	-	-	-
12	18	7,220	13.8	12.1	1.7	2		-	-	-	-
13	1.0	9,330	25.4	10.6	14.8	1		1	0.6	1.6	0
14	13	8,580	22.7	14.0	8.7	8		0	.2	.6	8
15	6.2	9,580	27.9	11.5	16.4	7		3	2.8	4.0	4
16	4.8	9,470	28.2	11.4	16.8	5		4	3.8	5.0	1
17	3.7	8,360	20.5	13.1	7.4	2		0	-	-	2
18	67	6,590	9.2	9.2	.3	.1		-	-	-	-

Table 12. Hydrologic data for subareas in Big Lost River basin for the period 1944-68--Continued.

No. of subbasin (see fig. 3)	Area (square miles)	Mean elevation (feet)	Mean precip-itation (inches)	Natural evapo-transpir-ation (inches)	Estimated water yield		Consumptive use by phreatophytes and crops (cfs)	Annual surface flow (cfs)			Estimated underground flow (cfs)
									Estimated		
					inches	cfs		Average	Min. (1961 w.y.)	Max. (1965 w.y.)	
Total Thousand Sprs. Cr. basin	149	7,490	14.7	11.4	3.3	a36		25	18	29	-
19	2.6	9,860	30.7	12.0	18.7	4		1	.2	.8	3
20	8.8	8,430	21.8	14.0	7.8	5		0	-	-	5
21	4.4	9,230	29.4	11.9	17.5	6		2	1.7	2.7	4
22	9.9	9,520	31.2	11.7	19.5	14		9	7	11	5
23	14	9,060	27.1	13.3	13.8	17		0	-	-	17
24	9.6	7,950	17.6	13.0	4.6	3		1	.7	1.7	2
25	12	7,000	11.9	11.3	.6	.5		0	-	-	.5
26	14	8,250	20.4	14.8	5.6	6		3	.9	3.2	3
27	8.8	7,010	14.3	12.6	1.7	1		0	-	-	1
28	29	6,590	10.8	10.5	.3	.6		-	-	-	-
29	33	6,200	9.2	9.2	.02	.1		-	-	-	-
Total above Mackay Narrows	813	8,110	21.1	13.6	7.5	a450	50	325	180	561	75
30	8.26	9,470	31.4	12.4	19.0	12		18	15	23	b0
31	25	8,130	23.2	14.7	8.5	16		8	4	14	b8
32	59	7,850	22.6	16.2	6.4	28		0	-	-	28
33	16	8,410	22.9	15.0	7.9	7		0	-	-	7
34	46	6,170	10.8	10.7	.06	.2		-	-	-	-
35	107	5,680	10.3	10.3	.03	.3		-	-	-	-
36	3.6	8,840	25.4	16.6	8.8	2		1	.7	1.7	1
37	27.6	8,230	21.9	15.3	6.6	13		11	6	19	2
38	45	7,000	16.0	14.4	1.6	5		0	-	-	5

39	93.4	7,960	27.5	17.1	10.4	70		c58	32	105	12
40	19	7,580	30.4	18.8	11.6	16		1	.6	2.3	15
41	33	7,850	20.8	15.5	5.3	13		9	5	16	4
42	73	6,860	17.7	15.1	2.6	14		0	-	-	14
43	22	6,900	17.0	15.1	1.9	3		0	-	-	3
Total above Moore Canal heading	d1,310	-	-	-	-	d640	115	200	45	467	325
44	18	6,510	15.4	14.2	1.2	1		0	-	-	1
Total above gage near Arco	1,410	7,700	20.2	13.9	6.3	a650	150	75	0	270	425

a Not reduced for consumptive use on irrigated acreage.
b Underflow believed to occur from Pass Creek basin to Lower Cedar Creek basin.
c Some of flow in surface diversion past the gage.
d Does not include 9 cfs from subbasins 32, 34, and 35 which enters below Moore Canal heading.

tests show that the bedrock underlying the alluvial deposits can transmit some water. While the miscellaneous measurement and yield data are inconclusive, probably as much as 25 cfs of the average yield above Howell Ranch enters the bedrock, returning to Big Lost River in Hamilton Springs or in Warm Springs above Mackay Reservoir. Also, some of the lost water may move directly through the bedrock and discharge into the alluvial deposits above Mackay Reservoir.

HOWELL RANCH TO MACKAY NARROWS

The estimated total water yield from the area between Howell Ranch and Mackay Narrows, an area of 363 square miles, is 105 cfs (table 12). Whereas the 150 square miles of valley floor yields little water, the mountains which range from 7,000 to 12,662 feet in elevation yield considerable quantities.

Thousand Springs Creek drains nearly 150 square miles of the total area tributary to the reach. Sage, Rock, Birch, and Cedar Creeks, and an unnamed tributary of Arentson Gulch are perennial streams as they leave the mountains but disappear underground when they reach the alluvial fans. The basins of these creeks and other basins that have little or no surface flow supply an estimated 35 cfs of flow to the many springs and seeps that feed the large swamp area in Thousand Springs Creek valley. Diversion through the Chilly Canal into the Thousand Springs area averages 15 cfs. Also, an undetermined amount of water moves underground from Big Lost River upstream from the Chilly Buttes to the Thousand Springs Creek valley.

The total estimated surface flow from Thousands Springs Creek averages 25 cfs and the average consumptive use in the marshland on the valley floor is 25 cfs, giving a total of 50 cfs which equals the computed yield plus flow in the canal. Below Howell Ranch, ground-water contours show underground flow from Big Lost River into Thousand Springs basin. Water also leaves the Thousand Springs basin underground, but it is not necessary to quantify the inflow or outflow when considering the total yield between Howell Ranch and the Mackay Narrows.

An approximate water budget can be made for the reach above Mackay Narrows by using estimated and measured data. The data are summarized in table 12. The input is the total of the yields from the subbasins above Mackay Narrows and is 450 cfs. Much of the water output from the reach is evapotranspiration. For example, the water table is perennially near the surface in 9,150 acres of swampy grassland along Thousand Springs Creek; a total of 12,680 acres of cropland is irrigated from the river and tributaries above the reservoir; about 1,000 acres of willows, cottonwood trees, and pasture use water along the river channels; and the 1,300-acre surface of Mackay Reservoir loses a considerable amount of water by direct evaporation. Total consumptive use from the above sources is estimated at 50 cfs. Subtracting the consumptive use and the surface outflow from the total yield above Mackay Narrows leaves 75 cfs bypassing the gages at Mackay Narrows, as shown in table 12.

Pump-test data and the hydraulic gradient of the water table indicate that an estimated 15 cfs flows underground through the alluvium in the valley at the narrows. The remainder, 60 cfs, could pass either underneath or through the cemented alluvium between the White Knob Mountains and the Lost River Range or pass through the carbonate rocks around the west abutment of Mackay Dam, or both.

The carbonate rocks in and near the west abutment of the dam have been shattered by faulting and drill holes showed leakage from the reservoir at this place. An attempt was made to grout the abutment in order to stop or reduce the leakage, but whether or not the attempt was a success cannot be evaluated. The grout may have reduced the leakage in the vicinity of the abutment, but it is unlikely that it spread very far from the dam. Thus, a large part of the unaccounted flow may escape from the reach through the carbonate rocks and lose its identity in the reach below the Mackay Narrows.

Figure 14 shows a considerable section of cemented alluvium northeast of the Mackay Narrows. There is no evidence to indicate the position of the water table nor the permeability of the material northeast of The Narrows; but if the upper 200 feet of the cemented alluvium in Mackay Narrows is reasonably permeable and continues to the northeast, a few cubic feet per second could bypass The Narrows. Also, the geologic and geophysical evidence indicates that carbonate rocks underlie the cemented alluvium, and some water may move through them. None of the evidence is conclusive, but it does suggest that a downstream movement of

60 cfs through material other than the alluvium in the Mackay Narrows is not unreasonable. Furthermore, the unknown effect the fault (fig. 10) bounding the northeast side of the valley might have on movement of ground water from the southwest slopes of the Lost River Range could possibly account for some of the 60 cfs.

MACKAY NARROWS TO MOORE CANAL HEADING

The inflow between Mackay Narrows and the Moore Canal is the surface and subsurface flow at Mackay Narrows plus the total yield from the intervening drainage, an area of nearly 500 square miles. Subbasins 30 to 43, except portions of 32, 34, and 35, contribute to the reach. The total input is estimated at 590 cfs. This input is also the total yield to the Moore Canal heading (640 cfs) less the consumptive use above Mackay Narrows (50 cfs).

In determining the disposition of the water entering the reach, the consumptive use was estimated as follows:

Irrigated from Antelope Creek	6,200 acres
Irrigated from Alder Creek	1,000 acres
Irrigated from Big Lost River	17,000 acres
Irrigated by pumping from ground water	6,000 acres
Total irrigated	30,200 acres
Marsh and riparian vegetation lands	5,000 acres

Assuming net consumptive use of 1.2 acre-feet per acre on the irrigated land and 2.0 acre-feet per acre on the other lands assumed subirrigated by natural means, the net consumptive use in the reach averages 65 cfs (47,000 acre-feet per year). Subtracting the consumptive use (65 cfs) and surface outflow (200 cfs) from the total input (590 cfs) leaves 325 cfs (235,000 acre-feet per year) as underflow past the Moore Canal heading (table 12).

An attempt was made to approximate the flow through the alluvium at Moore Canal heading using the following formula (Ferris and others, 1962, p. 73):

$$Q = 1.55 \times 10^{-6}\ TIL$$

where

Q = discharge, in cubic feet per second,

T = transmissivity, in gpd (gallons per day per foot),

I = hydraulic gradient, in feet per mile,

L = width, in miles, of cross section through which discharge occurs, and

where

1.55×10^{-6} is a conversion constant changing gallons per day to cubic feet per second.

The water table gradient just downstream from the Moore Canal heading was about 17 feet per mile in 1968. The water-table map of Stearns (p. 95) shows the gradient was about 20 feet per mile. Because the gradient in 1920 resulted from rather dry conditions and the 1968 gradient resulted from rather wet conditions, it seems reasonable to assume that the long-term gradient would be about 18 feet per mile. The width of the saturated alluvial deposits is about 3½ miles. Assuming a transmissivity of 1 million, the largest value that would be reasonable in this section of aquifer, and using the above equation, then about 100 cfs could be presumed to move through the alluvial deposits. This, subtracted from the 325 cfs of computed ground-water flow leaves 225 cfs more than the presumed flow through the alluvium.

Geophysical evidence at cross section E-E' (fig. 15), 2 miles north of Moore, indicates a maximum thickness of alluvial deposits of about 2,000 feet and an average thickness of about 1,000 feet. The assumed transmissivity divided by the thickness of the water-bearing formation gives a coefficient of permeability of 1,000 gpd per square foot which is a reasonable value for these deposits. However, Wenzel (1942, p. 13) gave coefficients of permeability for similar materials that range upward to 4,400 gpd per square foot. If, in fact, the average coefficient of permeability of the alluvial deposits is 2,000 gpd per square foot, then the transmissivity would be 2 million and 185 cfs could flow underground past the Moore Canal heading. However, it seems unlikely that the average coefficient of permeability is this large because repeated eruption of basalt flows near and south of Arco have encroached northward into the mouth of the valley, thus reducing the thickness and/or permeability of the alluvium. It is probable that these basalt flows dammed the ancient Big Lost River and formed lakes in which less permeable fine-grained sediments were deposited.

Geophysical evidence (p. 31) also indicates that some volcanic rock does extend northward for a distance of several miles north of Moore. If this is basalt of the Snake River Group which has the comparable transmissivity values of several million gallons per day per foot that occur beneath the Snake River Plain (Mundorff, Crosthwaite, and Kilburn, 1964, p. 147, 153), then a transmissivity of 5.5 million in the basalt and of 1 million in the alluvial deposits would be required to transmit the 325 cfs of ground-water flow at a gradient of 18 feet per mile.

As previously mentioned, the carbonate rocks can transmit water, but their permeability is inferred indirectly from observations of spring discharge and the lack of perennial streams in several tributaries of Big Lost River. Carbonate rocks form the sides of the basin at Moore and geophysical evidence indicates that they underlie the alluvial deposits and volcanic rocks. It is not unlikely that a large quantity of water moves southward through the carbonate rocks to the Snake River Plain. Feth (1964) described "hidden recharge" of alluvial deposits occurring along the Wasatch Mountain front in Utah and estimated that about 1,000 acre-feet of water per year per linear mile of mountain front percolates directly from the rocks in the mountains to the alluvial deposits in the valley, without appearing as streamflow. The Wasatch Mountain front consists of gneiss and schist which normally have low permeability. The carbonate rocks of the Lost River range have a higher permeability. Thus, hidden recharge may be a more effective process in the Big Lost River basin than in the Wasatch front.

The water yield estimated for the valley reach from Mackay Narrows to Moore Canal heading may be too large. However, even if there were no water yield in the reach, an obviously erroneous assumption, there still would have to be 135 cfs moving underground at Moore Canal heading (400 cfs inflow at Mackay Narrows minus 65 cfs consumptive use minus 200 cfs surface outflow at Moore Canal heading). This would leave 35 cfs of unaccounted underflow (135 minus 100). Thus, the available data are not adequate to resolve the problem of transmitting the estimated volume of underflow to the next downstream reach of the basin, even with a significant downward adjustment of the volume of water yield. Therefore, it is probable that the basalt and carbonate rocks transmit a significant part of the ground water to the next downstream reach.

MOORE CANAL HEADING TO GAGING STATION DOWNSTREAM FROM ARCO

A rather small yield from tributary basins enters the system below the Moore Canal heading. No water flows in tributaries in the reach except for rare occasions when snow melts on frozen ground or when the rate of rainfall exceeds soil-infiltration rates. Total water yield in the reach from tributary areas is estimated to be 10 cfs, which comes from subbasin 44 and part of subbasin 32, 34, and 35 (see fig. 3 and table 12). The subbasins tributary to Big Lost River below Arco are assumed not to be contributing to the system above the gage Big Lost River near Arco (1335). Consumptive use on cropland in the reach was computed for an estimated 12,340 acres irrigated from the Big Lost River, 2,300 acres irrigated by ground water, and 3,155 acres assumed subirrigated by natural means. Assuming net consumptive use per acre to be the same as in other parts of the basin, an average net use of 35 cfs (25,000 acre-feet per year) was calculated.

ESTIMATE OF VOLUME OF WATER LEAVING BASIN BELOW ARCO

Records of discharge show that streamflow losses between Moore Canal heading and the gage near Arco averaged 125 cfs for the period 1944-68. As stated above, consumptive use accounted for about 35 cfs of these losses leaving an estimated 90 cfs of surface flow that percolates to the water table. The underground flow entering the reach at the Moore Canal heading is estimated to be 325 cfs. Thus average underground flow past the Arco gage is the total of the underground flow into the reach plus the surface flow lost to the water table or 415 cfs (300,000 acre-feet per year) (table 12).

The underground flow plus much of the surface flow past the gage near Arco eventually recharges the Snake Plain aquifer. The average annual estimated total water discharge from the Big Lost River basin for the period 1944-68 is 425 cfs underground plus 75 cfs surface flow or 500 cfs (363,000 acre-feet per year). The underground flow is nearly constant each year, because the factors in the ground-water flow equation would be relatively constant from year to year. The annual mean surface flow has ranged from zero to an estimated 270 cfs (195,000 acre-feet per year).

The formula given on pages 94-95 cannot be used to estimate the underflow leaving the basin at Arco because gradients of the several water-bearing zones found in the test well northwest of Arco cannot be determined from the existing data. It would require at least one well and probably more, upvalley from the present test well, to determine gradients. Also, because of the heterogeneity of the underlying material, no reasonable estimate can be made of its transmissivity. As mentioned previously, basalt flows have encroached into the mouth of the basin and there are at least five water-bearing zones in interbedded alluvial deposits and basalt flows in the Arco area. The relatively high permeability of the basalt in this area is indicated by the fact that during construction of test well 4N-26E-21abb1, about 200-400 gpm of water plus mud, cottonseed hulls, and visqueen plastic under a head of about 425 feet flowed into the basalt during an attempt to seal it off. However, sufficient hydrologic data are not available to determine the volumes of ground water passing through each zone. Because the carbonate rocks as discussed on page 96 and the basalt apparently transmit large quantities of water within the basin, it is reasonable to assume that similar conditions prevail at the mouth of the basin and that large quantities of water leave the basin through these rocks.

In summary, the estimated water yield of the Big Lost River basin averaged 650 cfs during the period 1944-68. Of this amount, 150 cfs was evapotranspired and 500 cfs (363,000 acre-feet per year) was contributed to the Snake River Plain--75 cfs (54,000 acre-feet per year) as surface flow and 425 cfs (308,000 acre-feet per year) as ground-water flow. Figure 31 depicts the total water yield from the headwaters of the main stem of Big Lost River to Arco and shows the estimated average water yield at any section of the valley. Also included on the figure is the water yield of Antelope Creek, the largest tributary below the East Fork.

CREDIBILITY OF RESULTS

Relief in the Big Lost River basin is large and greatly affects the quantity and distribution of precipitation and, hence, the water yield. Therefore, a good definition of the variability of precipitation was paramount in this study.

The considerable number of precipitation indices (weather stations, storage gages, snow courses, and miscellaneous snow measurements) distributed over the basin defined the major variations in precipitation. The determinations of natural water losses are based on the best climatological data available for the basin. Wind velocities for use in Rohwer's equation (p. 19) were not known for specific points in the basin, but wind values based on records at Mackay are believed to be reasonably valid. Likewise, estimates of soil-moisture storage used in determining potential evapotranspiration were not precise, but gave credible results in areas where checks on yields could be made.

The estimated water resource of the basin can be compared with results of two other investigations by the U.S. Geological Survey. Stearns, Crandall, and Steward (1938, p. 245) estimated the annual total contribution to the Snake River Plain to average 312 cfs (226,000 acre-feet per year) during the period 1920-27. Surface flow at Mackay Narrows averaged 291 cfs during 1920-27 compared with 324 cfs during the period 1944-68. The ratio obtained by dividing the average surface flow at Mackay Narrows for 1944-68 by the average flow for 1920-27 is 1.11. Assuming that values representing the contribution to the Plain for the two periods would have the same ratios as the average flows at Mackay Narrows, the method of Stearns and others would have provided a contribution of 346 cfs (250,000 acre-feet per year) to the Plain during 1944-68. The estimate of the contribution in the present study (500 cfs) is, thus, 145 percent of that estimated by Stearns and others. Their study assumed no water yield except the measured surface flows in Cedar, Alder, Pass, and Antelope Creeks plus the surface flow at Mackay Narrows. Their estimate appears to be too low because they disregarded yields in the reach from Mackay Narrows to Arco.

Mundorff, Crosthwaite, and Kilburn (1964, p. 121) estimated that the annual contribution to the Snake River Plain from surface- and ground-water sources averaged 470 cfs (340,000 acre-feet per year) for the period 1921-50. The method used by Mundorff and others was a reconnaissance-type determination using minimal data and was for a different period. Even though their estimate and our estimate are in reasonably good agreement a comparison does not prove or disprove the validity of either estimate.

A comparison of the yields and surface flows given in table 12 provides a general check on the credibility of yield estimates made. For example, the yield estimated is within

3 percent of the total measured surface flow above the gage at Wild Horse (table 12). The underground flow probably is small there, because bedrock is at the surface in the vicinity of the gage.

A comparison of estimated and measured yields above the Howell Ranch gage also indicates reasonable agreement. Estimated yield for the area above the gage at Howell Ranch is 35 cfs more than the 310 cfs measured as surface flow. Five to 10 cfs of this yield is inferred to bypass the gage underground in the valley alluvium and about 1.5 cfs is diverted around the gage. Evidence has been presented earlier that underground flow discharging from this reach feeds Hamilton and Warm Springs or flows into the alluvial aquifer downstream.

In subbasin 10 (Sage Creek), only one of three forks contains a perennial stream. The flow in this stream equals the estimated yield of its drainage area. All the yield in the two other forks is assumed to go underground because their channels are usually dry. In the Arentson Gulch tributary, where water flows over bedrock at the measuring point, the estimated yield and the surface flow check closely.

Estimated yields from subbasins 37 and 39 (Alder and Antelope Creeks) are a few percent higher than measured surface flows. Some underground flow past both gages is probable and an unmeasured surface diversion bypasses the gage on Antelope Creek.

The comparison of flows in Lower Cedar and Pass Creeks (subbasins 30 and 31) with the estimated yields has been discussed elsewhere in the report.

The above examples of calculated yields and comparison with measured yields in significant parts of the basin imply that the method of estimation and results are credible.

SUMMARY OF RESULTS

The ground and surface water of the Big Lost River basin are so closely interrelated that they should be considered as a single resource. The data developed in this report indicate that on the average about 500 cfs (362,000 acre-feet per year) leaves the Big Lost River basin. About 75 cfs leaves as surface outflow and 425 cfs as ground-water flow, almost all to the aquifer underlying the Snake River Plain. For the period 1944-68, surface outflow ranged from 0 to 2,500 cfs, but the rate of ground-water outflow presumably has remained almost constant. The average annual distribution of flow for the period 1944-68 was as follows:

	Surface Water (cfs)	Ground Water (cfs)	Total (cfs)
Above Howell Ranch	310	35	345
Above Mackay Narrows	325	75	400
Above Moore Canal	200	325	525
Above gage near Arco	75	425	500

The above flow estimates have been adjusted for loss by crop and phreatophyte evapotranspiration, an amount estimated to be 150 cfs for the entire irrigated area.

A large quantity of surface water is available for upstream storage in some years, but suitable reservoir sites and costs of construction have not been studied in detail. Also, water could be stored in the alluvial deposits by artificial recharge, particularly in the Chilly-Barton Flats area and on the alluvial fans on the east side of the valley from the vicinity of Mackay to Arco. About 45,000 acre-feet additional could be recharged in a given year in the Chilly-Barton Flats area, and the recharged water presumably would discharge into the river 3 to 18 months later.

Ground-water pumping affects streamflow where the river is continuous with the water table. In the present state of development, average annual depletion of the total water supply by pumping is estimated to be 16,000 acre-feet. The total amount of water pumped is so small compared to the total water supply that the overall effects of pumping cannot be detected, except locally.

The water resources of the basin, both surface and ground water, are of good quality. Total dissolved solids and the percentage of dissolved sodium are low, but the waters which have been in contact with carbonate rocks or soils tend to be hard or very hard.

SELECTED REFERENCES

Baldwin, E. T., 1951, Faulting in the Lost River Range area of Idaho: Am. Jour. Sci., v. 249, no. 12, p. 884-902.

Chow, Ven Te, 1964, Handbook of hydrology: McGraw-Hill Book Co., p. 11-31.

Crippen, J. R., 1965, Natural water loss and recoverable water in mountain basins of Southern California: U.S. Geol. Survey Prof. Paper 417-E, 24 p.

Dover, J. H., 1969, Bedrock geology of the Pioneer Mountains, Blaine and Custer Counties, Central Idaho: Idaho Bureau of Mines and Geology Pamph. 142, 66 p. 33 figs.

Ferris, J. G., Knowles, D. B., Brown, R. H., and Stallman, R. W., 1962, Theory of aquifer tests: U.S. Geol. Survey Water-Supply Paper 1536-E, 105 p.

Feth, J. H., 1964, Hidden recharge: Ground Water, v. 2, no. 4, p. 14-17; Jour. of Tech. Div., National Water Well Assoc.

Foster, E. G., 1948, Rainfall and runoff: New York, The MacMillan Co., 487 p.

Iorns, W. V., Hembree, C. H., and Oakland, G. L., 1965, Water resources of the Upper Colorado River basin--technical rept.: U.S. Geol. Survey Prof. Paper 441, p. 48-53.

Jenkins, C. T., 1968, Techniques for computing rate and volume of stream depletion by wells: Ground Water, v. 6, no. 2, p. 37-46; Jour. of Tech. Div., National Water Well Assoc.

Jensen, M. C., and Criddle, W. D., 1952, Estimated irrigation water requirements for Idaho: Idaho Agr. Expt. Sta. Bull. 291, 23 p. 2 figs.

Johnson, A. I., 1967, Specific yield--compilation of specific yields for various materials: U.S. Geol. Survey Water-Supply Paper 1662-D, 74 p. 19 figs.

Mundorff, M. J., Crosthwaite, E. G., and Kilburn, Chabot, 1964, Ground water for irrigation in the Snake River basin in Idaho: U.S. Geol. Survey Water-Supply Paper 1654, 224 p., 54 figs.

Nelson, M. W., and Wilson, J. A., 1965, Summary of snow survey measurements for Idaho: U.S. Dept. Agriculture, Soil Conserv. Service, and Idaho Dept. Reclamation.

Nelson, W. N., in press, Geologic map. Mackay Quadrangle, south-central Idaho: U.S. Geol. Survey Misc. Geol. Inv. Map I-580.

Nelson, W. N., and Ross, C. P., 1968, Geology of part of the Alder Creek Mining District, Custer County, Idaho: U.S. Geol. Survey Bull. 1252-A, 30 p., 2 figs.

Palmer, W. C., and Havens, A. V., 1958, A graphic technique for determining evapotranspiration by Thornthwaite Method: Monthly Weather Review, v. 86, p. 123-128.

Rohwer, Carl, 1931, Evaporation from free water surface: U.S. Dept. Agriculture Tech. Bull. no. 271, 96 p.

Ross, C. P., 1947, Geology of the Borah Peak quadrangle, Idaho: Geol. Soc. America Bull., v. 58, no. 12, p. 1087-1160.

_____1963, Geology along U.S. Highway 93 in Idaho: Idaho Bur. Mines and Geology Pamph. 130, 98 p.

Ross, C. P., and Forrester, J. D., 1947, Geologic map of Idaho: U.S. Geol. Survey and Idaho Bur. Mines and Geology.

_____1958, Outline of the geology of Idaho: Idaho Bur. Mines and Geology Bull. 15, 74 p., 10 figs.

Simons, W. D., 1953, Irrigation and streamflow depletion in Columbia River Basin above The Dalles, Oreg.: U.S. Geol. Survey Water-Supply Paper 1220, 126 p., 1 fig.

Stearns, H. T., Crandall, Lynn, and Steward, W. G., 1938, Geology and ground-water resources of the Snake River Plain in southeastern Idaho: U.S. Geol. Survey Water-Supply Paper 774, 268 p., 16 figs.

Theis, C. V., 1953, The effect of a well on the flow of a nearby stream: U.S. Geol. Survey Ground Water Note 14, 9 p.

U.S. Bureau of Census, U.S. Census Population, 1960, Number of inhabitants, Idaho: Final rept. PCC 13-14A. U.S. Govt. Printing Office, Washington, D.C., 1961.

U.S. Bureau of Reclamation and U.S. Corps of Engineers, 1961, Upper Snake River basin, v. IV, pt. I, 323 p.

U.S. Department of Health, Education, and Welfare, 1962, Drinking water standards, 1962: U.S. Public Health Service 956, 61 p.

U.S. Geological Survey, 1956, Compilation of records of surface water of the United States through September 1950, part 13, Snake River basin: U.S. Geol. Survey Water-Supply Paper 1317, 566 p.

_____1963, Compilation of records of surface waters of the United States, October 1950 to September 1960, part 13, Snake River basin: U.S. Geol. Survey Water-Supply Paper 1737, 282 p.

_____Surface water records of Idaho, 1961-64, annual repts.

_____Water resources data for Idaho, 1965-68, annual repts.

U.S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkaline soils: U.S. Dept. Agriculture Handb. 60, 160 p., 33 figs.

U.S. Weather Bureau, Climatological Data, Annual summaries for the years 1902-64.

Wing, Herbert, 1915, biennial report of the State Engineer of Idaho: Boise, Idaho, p. 138-145.

Wenzel, L. K., 1942, Methods for determining the permeability of water-bearing materials, with special reference to discharging-well methods, with a section on direct laboratory methods and a bibliography on permeability and laminar flow, by V. C. Fishel: U.S. Geol. Survey Water-Supply Paper 887, 192 p., 17 figs.

Yanskey, G. R., Markee, E. H., and Richter, A. P., 1966, Climatography of the National Reactor Testing Station: Environmental Science Services Administration for U.S. Atomic Energy Commission, mimeo. rept. IDO-12048.

GLOSSARY

Anomaly. Departure from a standard regional relation. For example: A certain elevation-precipitation relation may be prevalent in a given region, but not in those areas where deviations (anomalies) from the general relation occur.

Available water capacity. The quantity of water (measured in inches), retained against gravity by a soil which can be extracted and used by the vegetation growing on the soil. The available water capacity of a given soil as defined in this study is dependent upon the type of vegetation and the depth and extent of its root system.

Base flow. See Base runoff.

Base runoff. Sustained or fair weather runoff. In most streams, base runoff is composed largely of ground-water discharge.

°C. Degrees Celsius (formerly degrees Centigrade). To correct to degrees Fahrenheit (°F) multiply °C by 9/5 and add 32.

Cation. A positively charged ion species such as Ca^{++} (calcium), Na^{+} (sodium), etc.

Coefficient of permeability. The coefficient of permeability of an aquifer is the rate of flow of water in gallons per day through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot at a temperature of 60° F.

Coefficient of storage. The coefficient of storage of an aquifer is defined as the volume of water the aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

Consumptive use. The quantity of water transpired and evaporated from a cropped area or the normal loss of water from the soil by evaporation and plant transpiration.

Consumptive use, net; or consumptive irrigation requirement. The consumptive use decreased by the estimated contribution by rainfall toward the production of irrigated crops.

Direct runoff. The runoff entering stream channels promptly after rainfall or snowmelt.

Discharge. Outflow from a stream or aquifer. In this report the term discharge refers to the observed flow in streams and the flow of water out of a canal, ditch, reservoir, aquifer or well.

Effective precipitation. That part of the precipitation falling on an irrigated area that helps to meet consumptive use requirements.

Evaporation. The process by which water is changed from the liquid or the solid state into the vapor state.

Evapotranspiration. Water consumed by evaporation from water surfaces and moist soil and by plant transpiration.

Flow-duration curve. A cumulative frequency curve that shows the percentage of time that specified discharges are equal or exceeded.

Ground-water outflow. That part of the discharge from a drainage basin that moves through the ground water system.

Ground-water runoff. That part of the runoff which has passed into the ground, has become ground water, and has been discharged into a stream channel as spring or seepage water. See also Base runoff and Direct runoff.

Ground-water underflow. Subsurface movement of ground water, generally through alluvial deposits or other water-bearing formations underlying a stream course or valley. See Underflow.

Hardness. A measure of the multivalent cations in water that affect the sudsing action of soap. It is expressed on terms of the number of milligrams per liter of chemically equivalent calcium carbonate.

Hydrologic budget. An accounting of the inflow to (input), outflow from (output), and storage in, a hydrologic unit, such as drainage basin, aquifer, soil zone, lake, reservoir, or irrigation project.

Infiltration. The flow of a fluid into a substance through pores or small openings. It connotes flow into a substance in contradistinction to the word percolation, which connotes flow through a porous substance.

Isohyetal line (isohyet). A line drawn on a map or chart joining points that receive the same amount of precipitation.

Lake evaporation. The evaporation which would be expected to occur on a large lake. In this report it is assumed to be essentially equivalent to the potential evapotranspiration on a unit of land of similar size and location.

Lapse rate. The rate of temperature decrease per unit increase in elevation.

Low-flow frequency curve. A graph showing the magnitude and frequency of minimum flows for a period of given length. Frequency is usually expressed as the average interval, in years, between recurrences of an annual minimum flow equal to or less than that shown by the magnitude scale.

Milligrams per liter. Milligrams of constituent per liter of liquid. At concentrations prevailing in Big Lost River basin, milligrams per liter is equivalent to parts per million.

Pan evaporation. The evaporation (usually measured in inches) in an evaporation pan. The U.S. Weather Bureau Class A pan (the most common evaporation pan) is 4 feet in diameter by 10 inches deep and is set on a timber grillage so that the top rim is about 16 inches from the ground. A coefficient, usually near 0.70, is used to convert evaporation from Class A pans to the equivalent lake evaporation.

Percolation. The movement, under hydrostatic pressure, of water through the interstices of a rock or soil, except the movement through large openings such as caves.

Permeability. The rate at which a rock will transmit water through a given cross section under a given difference of pressure per unit of distance. See coefficient of permeability.

Potential evapotranspiration. Water loss that will occur if at no time there is a deficiency of water in the soil for use of vegetation. In this study it is measured in inches of depth per unit of time.

Return flow. That part of irrigation water that is not consumed by evapotranspiration and that returns to its source or another body of water. Also called return water.

Runoff. That part of the precipitation that appears in surface streams. It is the same as streamflow unaffected by artificial diversions, storage, or other works of man in or on the stream channels.

Salinity. In this report, the term salinity refers to the soluble salt content of water or soils.

Specific yield. The ratio of the volume of water that a saturated rock or soil will yield by gravity to the total volume of the rock or soil, usually expressed is a percentage.

Storage coefficient. See coefficient of storage.

Supplemental irrigation. In this report the term supplemental irrigation is applied to well water used to supplement streamflow, the latter being the primary source of water.

Surface runoff. That part of the runoff which travels over the soil surface to the nearest stream channel. It is also defined as that part of the runoff of a drainage basin that has not passed beneath the surface since precipitation. The term is misused when applied in the sense of direct runoff.

Transmissivity. Transmissivity is expressed as the rate of flow of water, at the prevailing water temperature, in gallons per day, through a vertical strip of the aquifer 1 foot wide extending the full saturated height of the aquifer under a hydraulic gradient of 1 foot per foot.

Underflow. The downstream flow of water through the permeable deposits that underlie a valley and that are more or less limited by rocks of low permeability.

Water-holding capacity. The capacity of a given depth of soil to hold water against the forces of gravity. This is not a rigidly defined term since the quantity of water held against gravity tends to decrease somewhat with time.

Water requirement. The quantity of water, regardless of its source, required by a crop in a given period of time, for its normal growth under field conditions. It includes transpiration, surface evaporation, and other economically unavoidable wastes.

Water table. The upper surface of a zone of saturation.

Water yield. The total average annual input (precipitation) minus the average annual quantity evaporated at the surface and transpired by native vegetation (natural evapotranspiration) prior to the water becoming streamflow or a part of the ground-water body.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE STATE
OF IDAHO DEPARTMENT OF RECLAMATION

70-93

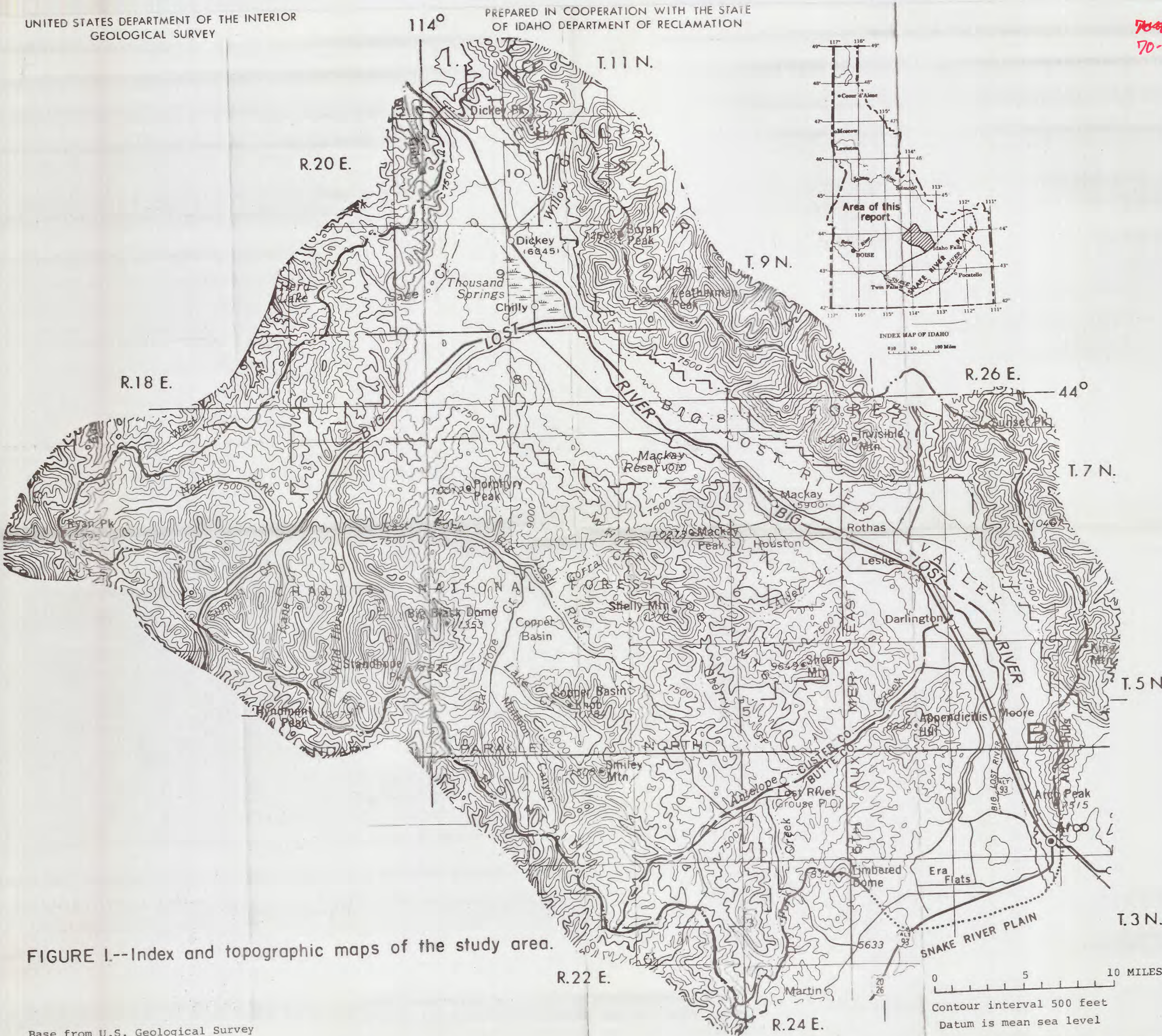


FIGURE I.--Index and topographic maps of the study area.

Base from U.S. Geological Survey
Idaho, 1968, 1:500,000

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE STATE
OF IDAHO DEPARTMENT OF RECLAMATION

70-93

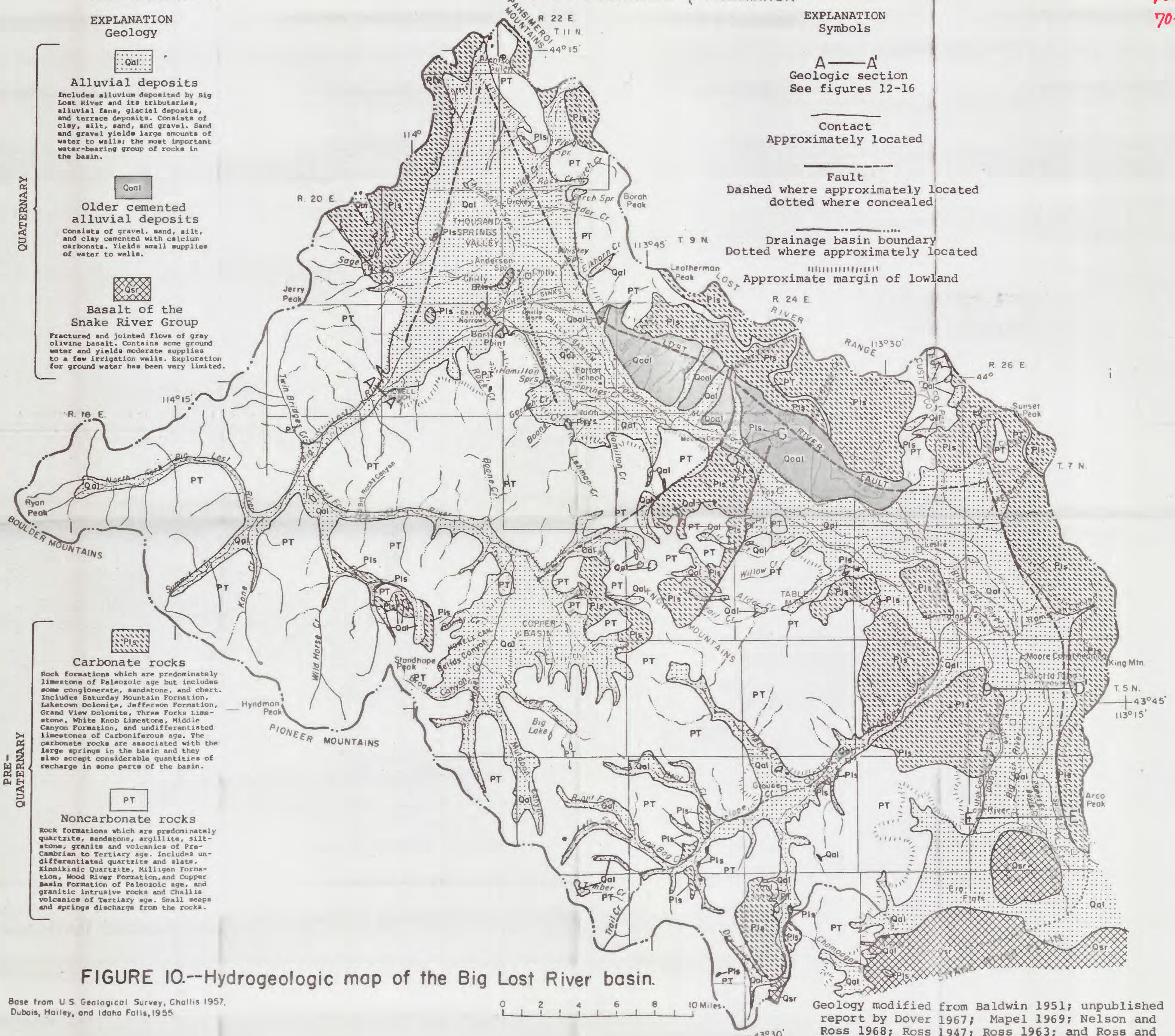


FIGURE 10.--Hydrogeologic map of the Big Lost River basin.

Base from U.S. Geological Survey, Challis 1957, Dubois, Hailey, and Idaho Falls, 1955

Geology modified from Baldwin 1951; unpublished report by Dover 1967; Mapel 1969; Nelson and Ross 1968; Ross 1947; Ross 1963; and Ross and Forrester 1947.

70-92 70-93

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE STATE
OF IDAHO DEPARTMENT OF RECLAMATION

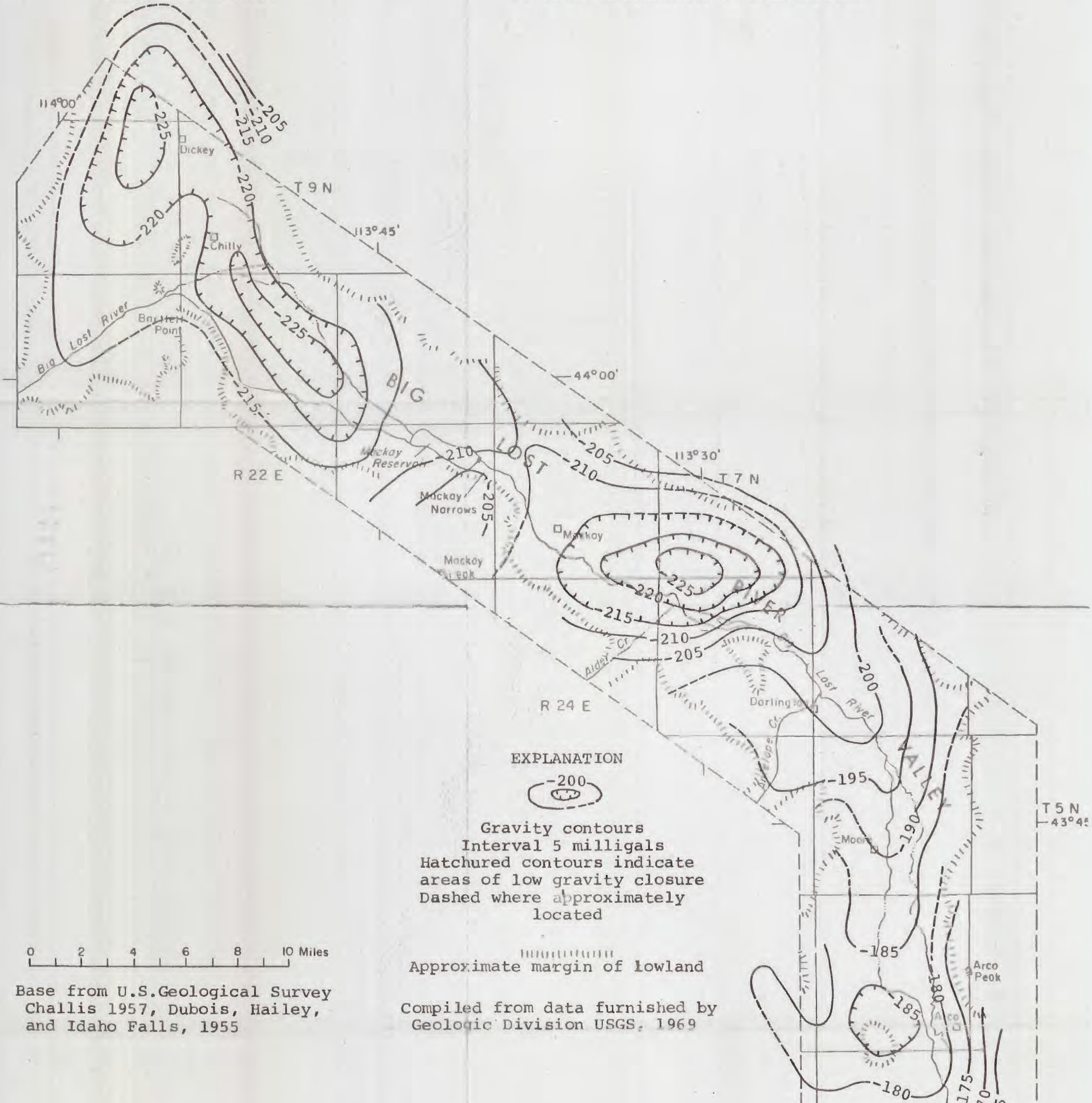


FIGURE 11.--Gravity anomalies.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE STATE
OF IDAHO DEPARTMENT OF RECLAMATION

FIGURE 23a.-- Water-level contours, fall 1968 and well locations.

FIGURE 23b.-- Depth to water, fall 1968.

FIGURE 23c.-- Water-level change, autumn 1967-68

FIGURE 23d.-- Difference in water levels between autumn 1920 and autumn 1968.

FIGURE 23.--Hydrologic maps of the Big Lost River valley.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE STATE
DEPARTMENT OF RECLAMATION

70-93

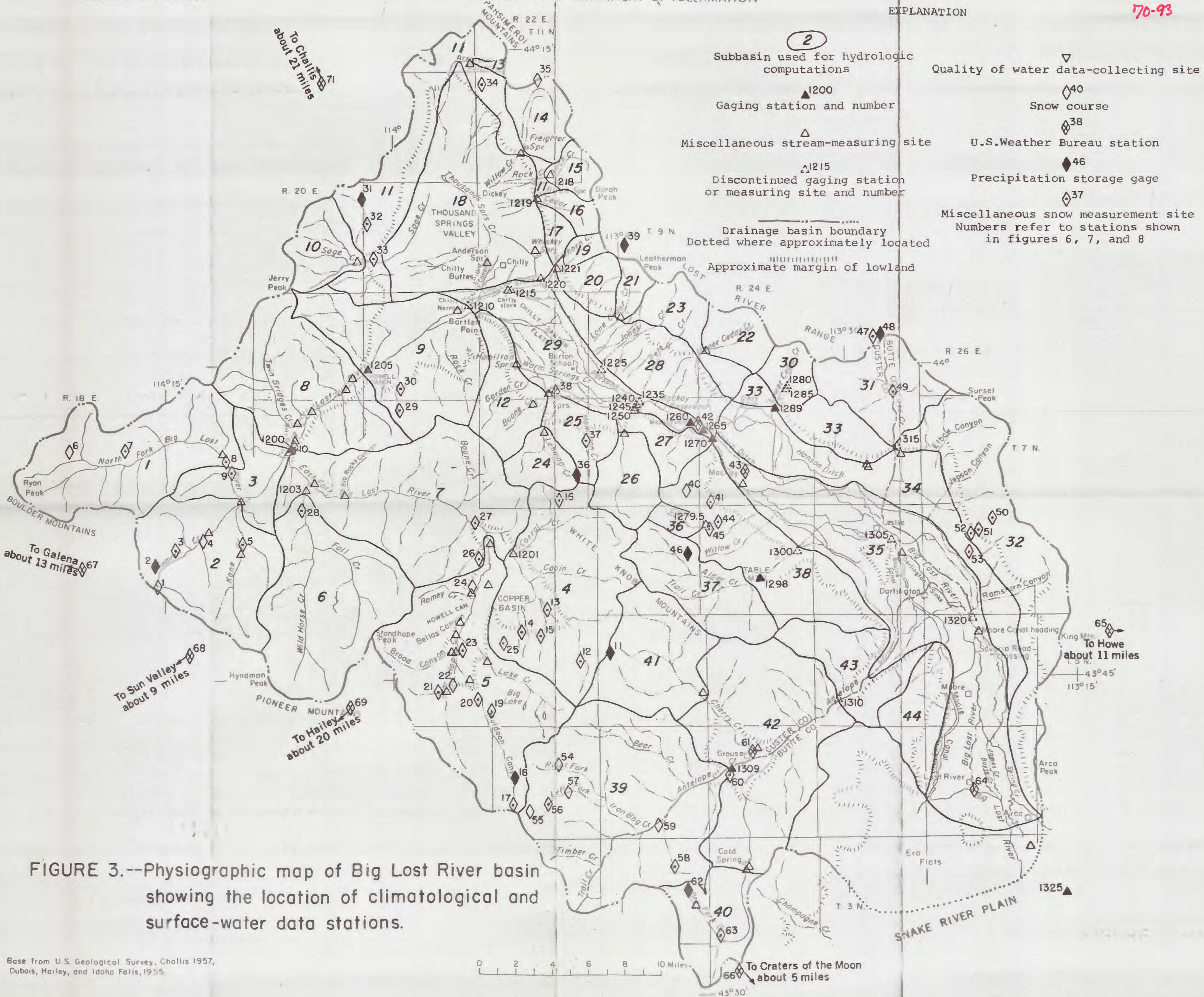


FIGURE 3.--Physiographic map of Big Lost River basin showing the location of climatological and surface-water data stations.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE STATE
OF IDAHO DEPARTMENT OF RECLAMATION

70-93

FIGURE 30.--Mean annual water yield for the period 1944-68, in Big Lost River basin.

Base from U.S. Geological Survey, Challis 1957, Dubois, Hailey, and Idaho Falls, 1955.

Hydrology by K.L.Dyer and C.A.Thomas, 1968

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE STATE
OF IDAHO DEPARTMENT OF RECLAMATION

70-93

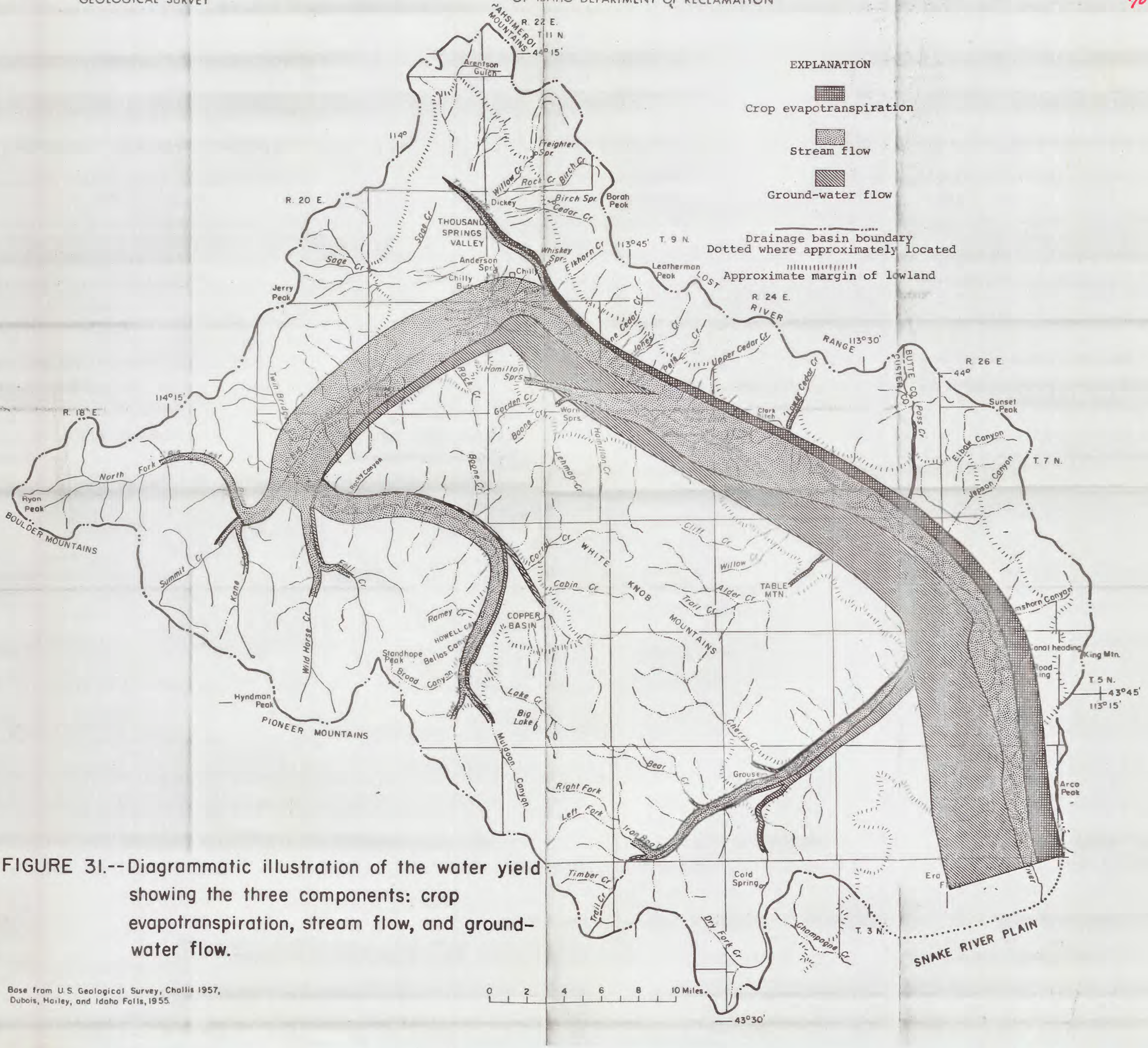


FIGURE 31.--Diagrammatic illustration of the water yield showing the three components: crop evapotranspiration, stream flow, and ground-water flow.

Base from U.S. Geological Survey, Challis 1957, Dubois, Hailey, and Idaho Falls, 1955.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE STATE
OF IDAHO DEPARTMENT OF RECLAMATION

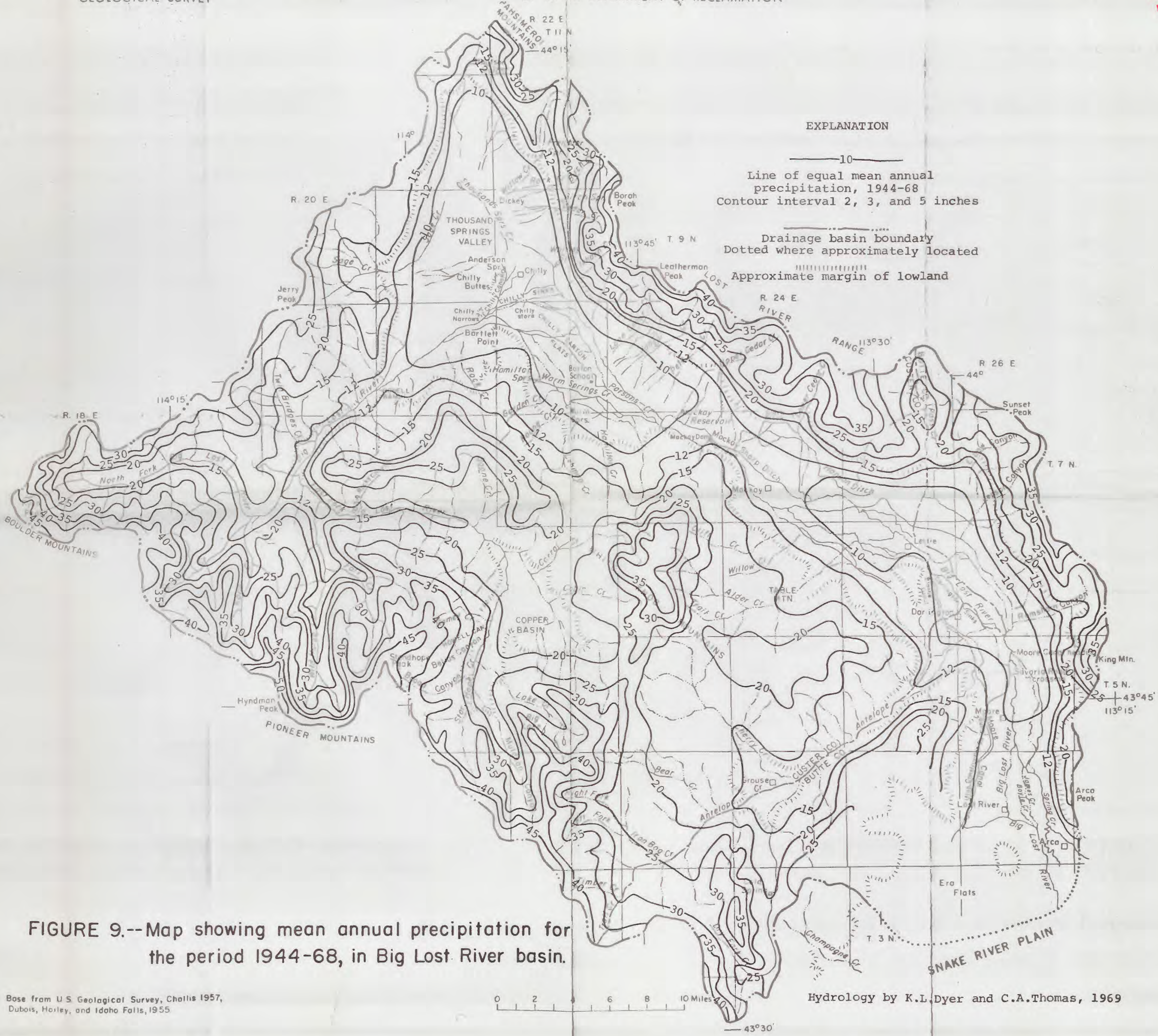


FIGURE 9.--Map showing mean annual precipitation for the period 1944-68, in Big Lost River basin.