Water Resources of Bannock Creek Basin, Southeastern Idaho

By Joseph M. Spinazola and B.D. Higgs

U.S. Geological Survey

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SHOSHONE-BANNOCK TRIBES

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CONVERSION FACTORS, VERTICAL DATUM, WATER YEAR DEFINITION, AND ABBREVIATED UNITS

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per square mile per year [(acre-ft/mi^2)/yr]	476.1	cubic meter per square kilometer per year
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot per mile (ft/mi)	0.1894	meter per kilometer
foot squared per day[1] (ft^2/d)	0.09290	meter squared per day
gallon per minute (gal/min)	0.06309	liter per second
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
kilowatthour per year (kWh/yr)	3,413	British thermal units
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
ton, short (2,000 lb)	0.9072	megagram

[1]The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. For the nontechnical reader, this mathematical expression is reduced to foot squared per day (ft^2/d) in this report.

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = 5/9\ (°F - 32).$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Water year: In this report, water year is the 12-month period beginning October 1 and ending September 30. The water year is designated by the year in which it ends. For example, the year ending September 30, 1987, is called the "1987 water year."

Abbreviated water-quality units used in report:

µS/cm microsiemens per centimeter at 25 degrees Celsius
mg/L milligrams per liter

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Abstract

The potential for development of water resources in the Bannock Creek Basin is limited by water supply. Bannock Creek Basin covers 475 square miles in southeastern Idaho. Shoshone-Bannock tribal lands on the Fort Hall Indian Reservation occupy the northern part of the basin; the remainder of the basin is privately owned.

Only a small amount of information on the hydrologic and water-quality characteristics of Bannock Creek Basin is available, and two previous estimates of water yield from the basin ranged widely from 45,000 to 132,500 acre-feet per year. The Shoshone-Bannock Tribes need an accurate determination of water yield and baseline water-quality characteristics to plan and implement a sustainable level of water use in the basin.

Geologic setting, quantities of precipitation, evapotranspiration, surface-water runoff, recharge, and ground-water underflow were used to determine water yield in the basin. Water yield is the annual amount of surface and ground water available in excess of evapotranspiration by crops and native vegetation. Water yield from Bannock Creek Basin was affected by completion of irrigation projects in 1964. Average 1965–89 water yield from five subbasins in Bannock Creek Basin determined from water budgets was 60,600 acre-feet per year. Water yield from the Fort Hall Indian Reservation part of Bannock Creek Basin was estimated to be 37,700 acre-feet per year.

Water from wells, springs, and streams is a calcium bicarbonate type. Concentrations of dissolved nitrite plus nitrate as nitrogen and fluoride were less than Maximum Contaminant Levels for public drinking-water supplies established by the U.S. Environmental Protection Agency. Large concentrations of chloride and nitrogen in water from several wells, springs, and streams likely are due to waste from septic tanks or stock animals. Estimated suspended-sediment load near the mouth of Bannock Creek was 13,300 tons from December 1988 through July 1989. Suspended-sediment discharge was greatest during periods of high streamflow.

INTRODUCTION

The potential for development of water resources for agricultural and other uses on the Fort Hall Indian Reservation in the Bannock Creek Basin of southeastern Idaho (fig. 1) is limited by water supply. Although hydrologic data are sparse, water yield from the basin was estimated to range from 45,000 acre-ft/yr (Mundorff and others, 1964, p. 189) to 132,500 acre-ft/yr (Balmer and Noble, 1979, p. 13). The Shoshone-Bannock Tribes are concerned that an accurate determination of water yield is necessary to plan and implement a sustainable level of water use.

Purpose and Scope

The purpose of this report is to present a description of the water resources, water yield, chemical characteristics of water, and suspended sediment in the Bannock Creek Basin. Seven holes were drilled to help describe subsurface geology and were completed as observation wells for water-level measurements. Interpretations of data that described geologic setting, precipitation and evapotranspiration, and surface-water and ground-water conditions were used to determine

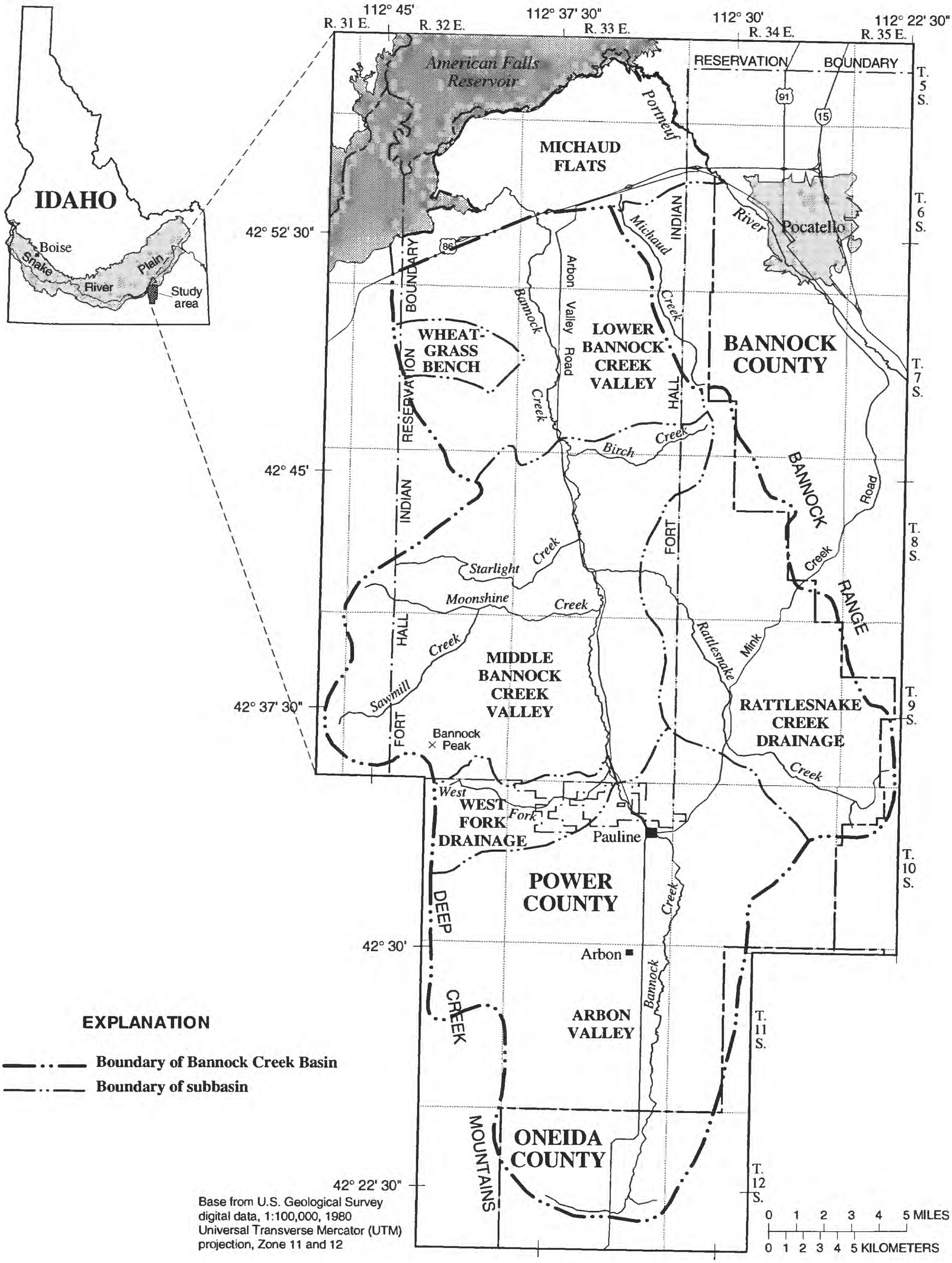


Figure 1. Location of Bannock Creek Basin, subbasins, and geographic features.

water yield. Water yield was calculated for average 1965–89 conditions. Water yield from Bannock Creek Basin and from that part of the Fort Hall Indian Reservation in the basin was described by water budgets for five of six contiguous subbasins. The quality of water in the basin was described by the chemical characteristics of surface and ground water. Suspended sediment from Bannock Creek was described for part of the 1989 water year when streamflow was greatest.

Previous Studies

The stratigraphy, structure, and geologic history of Precambrian through Quaternary rocks and deposits in the study area are described in reports by Carr and Trimble (American Falls quadrangle, 1963), Trimble (Michaud and Pocatello quadrangles, 1976), and Trimble and Carr (Rockland and Arbon quadrangles, 1976). Brief descriptions of the geology and hydrology of Bannock Creek Basin and streamflow in Bannock Creek are presented in reports by Mansfield and Heroy (1920) and Stearns and others (1938). Mundorff and others (1964, p. 189) estimated water yield from Bannock Creek Basin to be 45,000 to 50,000 acre-ft/yr. Balmer and Noble (1979) estimated water yield to be about 132,500 acre-ft/yr. The geohydrology of part of Michaud Flats east of the mouth of Bannock Creek is presented in two reports by Jacobson (1982; 1984). Other drainage basins near the study area were studied by Walker and others (Raft River, 1970), Norvitch and Larson (Portneuf River, 1970), and Williams and Young (Rockland Basin, 1982). The Portneuf River Basin is immediately east of Bannock Creek Basin; Rockland Basin is immediately west. The Raft River Basin is immediately west of Rockland Basin.

Planning reports include a proposal for a dam on Bannock Creek upstream from Rattlesnake Creek (U.S. Department of the Interior, written commun., 1964). Another report describes the expansion of agricultural development on tribal lands in the Bannock Creek area (Davis and others, 1978).

Site-Numbering System

Streamflow-gaging stations in Idaho are assigned station numbers in downstream order in accordance with the permanent numbering system used by the U.S. Geological Survey (Harenberg and others, 1987). Numbers are assigned in a downstream direction along the main stream, and stations on tributaries between main-stream stations are numbered in the order they enter the main stream. A similar order is followed for tributaries. In this report, the complete station number is divided into a two-digit basin number, a four-digit station number, and a two-or-more-digit sequence number to simplify reference. All stations in the study area are in the Snake River Basin, so the two-digit basin number "13" is omitted from the beginning of all station numbers. Sequence numbers are omitted for all station numbers ending in "00." For example, the complete station number 13076200 is represented by the number 0762 in this report.

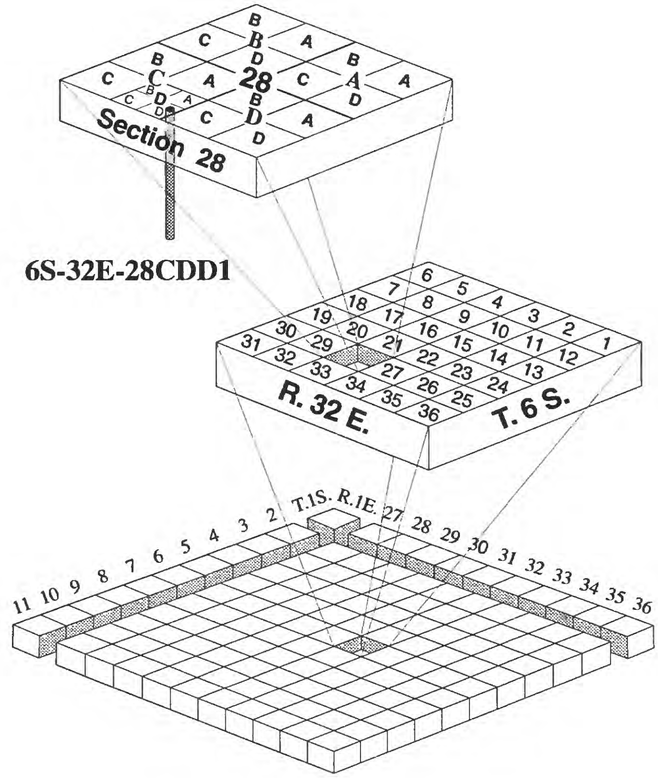


Figure 2. Well- and spring-numbering system.

The well- and spring-numbering system (fig. 2) used by the U.S. Geological Survey in Idaho indicates the location of wells or springs within the official rectangular subdivision of the public lands, with reference to the Boise base line and Meridian. For example, the first segment (6S) of site number 6S-32E-28CDD1 designates the township south (or north); the second (32E), the range east (or west); and the third (28), the section in which the site is located. Letters (CDD) following the section number indicate the site's location within the section and are assigned in counterclockwise order beginning with the northeast quarter. The first letter (C) denotes the 1/4 section (160-acre tract), the second (D) denotes the 1/4-1/4 section (40-acre tract), and the third (D) denotes the 1/4-1/4-1/4 section (10-acre tract). The last number (1) is a serial number assigned when the site was inventoried. Springs are denoted with the letter (S) in the last position.

Acknowledgments

This 3-year study and subsequent report were done by the U.S. Geological Survey in cooperation with the Shoshone-Bannock Tribes. The Shoshone-Bannock Tribal Council provided the initial impetus for the study and granted access to tribal lands. The cooperation of basin residents was essential for obtaining much of the hydrologic and chemical information from wells and springs and is gratefully acknowledged. The staff of the Bureau of Indian Affairs, Michaud Irrigation Project, were helpful in supplying necessary descriptions of irrigated areas and irrigation amounts and in providing access for drilling observation wells.

DESCRIPTION OF STUDY AREA

Bannock Creek drains an area of about 475 mi^2 upstream from where Bannock Creek discharges into American Falls Reservoir in southeastern Idaho (fig. 1). The valley floor is gently rolling to rolling; land-surface altitude ranges from about 5,300 ft above sea level near the southern margin of the basin to about 4,400 ft near the mouth of Bannock Creek. Mountain peaks and ridges rim the western and eastern perimeters of the basin. The Deep Creek Mountains separate Bannock Creek Basin from Rock Creek Basin to the west of the study area; the Bannock Range separates Bannock Creek Basin from the Portneuf River Basin to the east. Bannock Peak, at an altitude of 8,256 ft in the Deep Creek Mountains, is the highest mountain in the basin. A barely detectable topographic divide separates Bannock Creek Basin from Deep Creek Basin to the south of the study area.

Michaud Flats is the area between American Falls Reservoir on the Snake River and, for this study, a line approximated by Interstate Highway 86. Physiographically, Michaud Flats is distinctly different from the rest of the study area. Michaud Flats is a relatively flat bench and is part of the eastern Snake River Plain (Whitehead, 1986, 1 sheet). Unless noted otherwise, water resources of Bannock Creek Basin described in this report exclude Michaud Flats.

Bannock Creek is the major stream in the basin and flows northward about 45 mi before entering American Falls Reservoir. Rattlesnake Creek, which drains much of the eastern part of the basin, and West Fork, which heads at a group of springs on the western flank of the basin, are major tributaries to Bannock Creek.

Climatic conditions range from semiarid on the valley floor and adjacent foothills to subhumid at higher altitudes due to orographic effects of the mountain ranges. Summers are generally warm and dry, winters cold and snowy. Weather stations near American Falls (about 6 mi west of the study area) and at Arbon have recorded climatological data since 1917 and 1962, respectively. At American Falls, normal temperatures are 25.1°F in January and 71.0°F in July; at Arbon, average temperatures are 22.4°F in January and 67.9°F in July (U.S. Department of Commerce, annual summaries, 1964 through 1989).

Bannock Creek Basin was separated into six subbasins (fig. 1) to facilitate determination of water yield described later in the report. The six subbasins, from south to north, are: Arbon Valley, Rattlesnake Creek drainage, West Fork drainage, middle Bannock Creek Valley, lower Bannock Creek Valley, and Michaud Flats (fig. 1). Arbon Valley and most of the Rattlesnake Creek drainage are privately owned and cover about 144 and 79 mi^2, respectively. West Fork drainage (about 17 mi^2), middle Bannock Creek Valley (about 120 mi^2), lower Bannock Creek Valley (about 75 mi^2), and Michaud Flats (about 40 mi^2) are part of the Fort Hall Indian Reservation.

Agriculture is the predominant industry in the basin. Most cropland in the southern part of the basin is not irrigated. Water from a few wells is used to irrigate crops in Arbon Valley, and some water is diverted from Rattlesnake Creek for irrigation. Diversions from Bannock Creek are used to irrigate about 1,300 acres of cropland in middle Bannock Creek Valley. Diversions from the Portneuf River are pumped over the topographic divide into Bannock Creek Basin to irrigate about 13,800 acres of cropland in lower Bannock Creek Valley. Some of the water is pumped onto Wheatgrass Bench to irrigate about 2,400 acres (fig. 1). Diversions in lower Bannock Creek Valley are supplemented, at times, by water pumped locally from wells. About 7,200 acres of cropland on Michaud Flats is irrigated solely with ground water. Irrigated areas were digitized from maps (Alan Oliver, Bureau of Indian Affairs, written commun., 1986).

GEOLOGIC SETTING

Geologic processes, tectonic activity, and rock type affect the occurrence and movement of water. The hydraulic characteristics of rocks at the surface and in the subsurface affect whether water will run off into streams and become part of the surface-water system or will infiltrate to the subsurface and become part of the ground-water system.

The present structure of Bannock Creek Basin resulted from tectonic activity and volcanism. Tectonic activity produced a series of northwest-trending normal faults in the region that is now southeastern Idaho and northern Utah (Trimble, 1976, p. 69). Basin-and-range-type structures that characterize the region consist of downthrown valleys filled with alluvium, separated by uplifted mountain ranges. The northern limit of the Basin and Range physiographic province was established by faulting and extrusion of volcanic rocks that underlie the Snake River Plain. The northern part of the Bannock Creek Basin was uplifted about 10 million years ago, and flow in Bannock Creek was forced southward. Massive rhyolites and flow tuffs were extruded at the margin of the Snake River Plain and flowed southward into Bannock Creek Valley. Subsidence of the plain along a normal fault of inferred location separated the Basin and Range Province from the plain (fig. 3); uplift of the southern half of the basin, or a combination of subsidence and uplift, established the present drainage direction toward the north (David Ore, Idaho State University, Geology Department, oral commun., 1989).

The surface and subsurface geology of Bannock Creek Basin is represented by Precambrian, Paleozoic, and Cenozoic rocks (figs. 3 and 4). Precambrian rocks include quartzite, argillite, and limestone that crop out in the Bannock Range in T. 6 S., R. 34 E. and in T. 7 S., R. 34 E. Paleozoic rocks include marine limestone, dolomite, quartzite, and minor amounts of shale and sandstone that crop out on the eastern side of Bannock Creek Basin in T. 7 S., R. 34 E. Paleozoic rocks also crop out along the western margin of the basin in the Deep Creek Mountains southward from T. 8 S., R. 31 E. Cenozoic volcanic rocks and alluvial deposits are widespread in Bannock Creek Basin, mostly at low altitudes. Tertiary volcanic rocks crop out or are present in the shallow subsurface in much of the northwestern part of the basin. Quaternary alluvium fills the valleys along Bannock and Rattlesnake Creeks. Pediment gravel is present between stream channels and mountain slopes.

The hydraulic characteristics of Precambrian and Paleozoic rocks in the basin are such that these rocks typically are not considered aquifers. Precambrian and Paleozoic rocks generally have small infiltration rates and do not store or transmit significant quantities of water. Hence, most water that contacts Precambrian or Paleozoic rocks runs off into streams. Exceptions are where fractures or dissolution channels in limestone store water and provide avenues for water movement. Although such may be the case on a local scale in many parts of the basin, no evidence suggests widespread connection of a substantial number of fractures or dissolution channels in the basin.

Some Cenozoic rocks and unconsolidated deposits contain aquifers. Coarse-textured alluvial deposits generally have infiltration rates that allow water to move into the subsurface. Interconnected voids in alluvial deposits and basalt store and transmit water, and these rocks are of sufficient areal extent to serve as aquifers on a basinwide scale. Rhyolite is fine textured and, though capable of storing large quantities of water, typically transmits water too slowly to qualify as an aquifer in the study area, unless fractured.

Rhyolitic tuff and pre-Cenozoic rocks underlie much of the basin and are considered to form the base of the aquifer, or bedrock surface. In middle and lower Bannock Creek Valleys, rhyolitic tuff is present beneath alluvial deposits from T. 7 S., R. 33 E., to T. 10 S., R. 34 E. (Trimble, 1976, p. 71) and forms the low, rolling hills that flank the valley bottom. Rhyolitic tuff is present below a mantle of loess in the Moonshine, Starlight, and Birch Creek Basins (fig. 3). Drillers' reports, surface geophysics, and test drilling indicate that rhyolitic tuff constitutes the bedrock in Bannock Creek Valley from the inferred normal fault to at least the northernmost part of Arbon Valley in T. 10 S., R. 33 E. (fig. 4, section *C–C'*). Depth to rhyolite from land surface is about 110 ft in two test holes drilled in sec. 20, T. 7 S., R. 33 E. (fig. 4, section *A–A'*). Gravel, sand, silt, and clay overlie the rhyolite throughout this part of the valley. Drillers' reports describe basalt in the upper 100 ft of a few domestic wells in T. 8 S., R. 33 E.

A bedrock surface has not been defined under Michaud Flats, and the rhyolitic tuff described by Trimble (1976, p. 39–45) has not been penetrated by drilling. Drillers' reports obtained from the Idaho Depart-

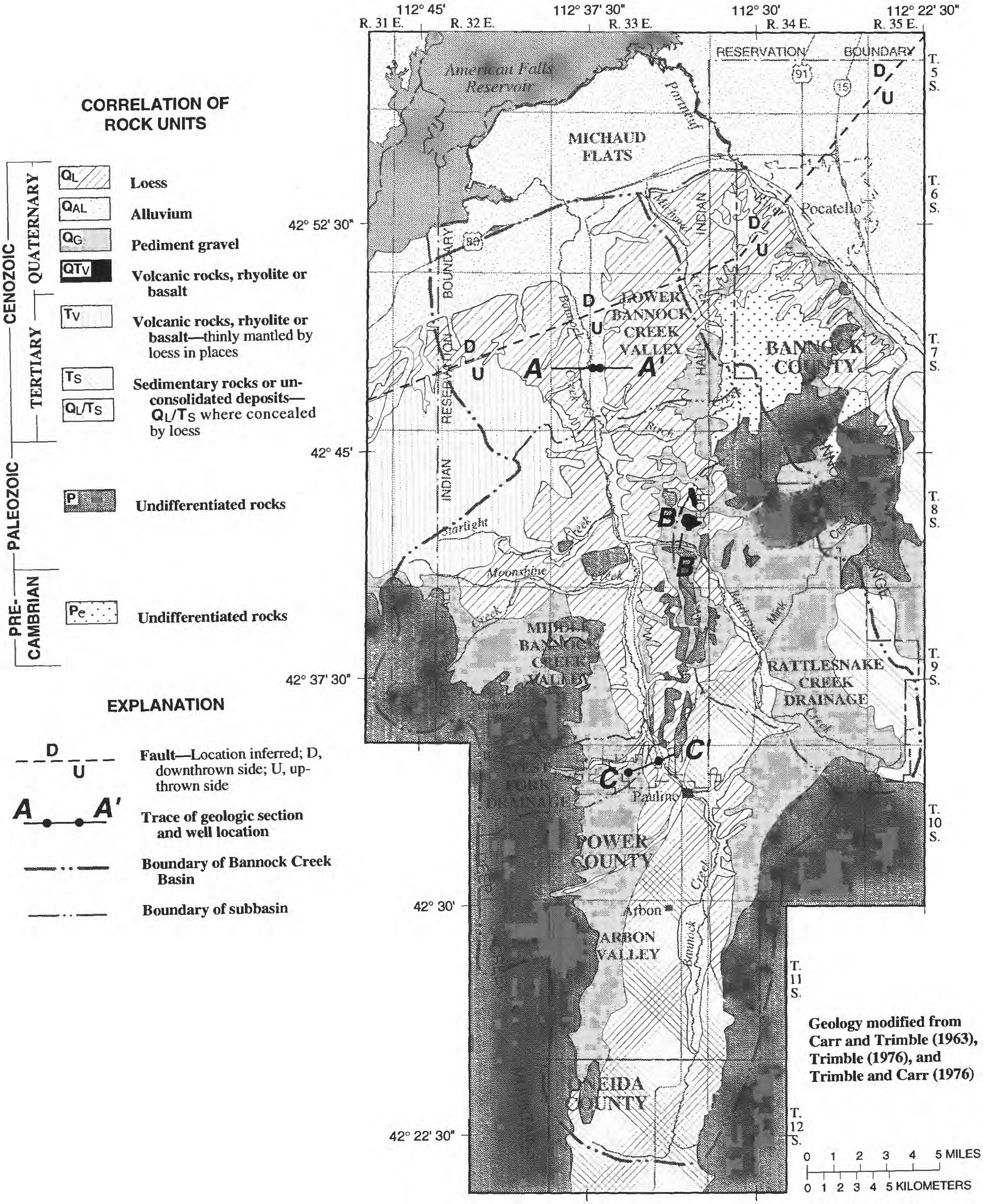
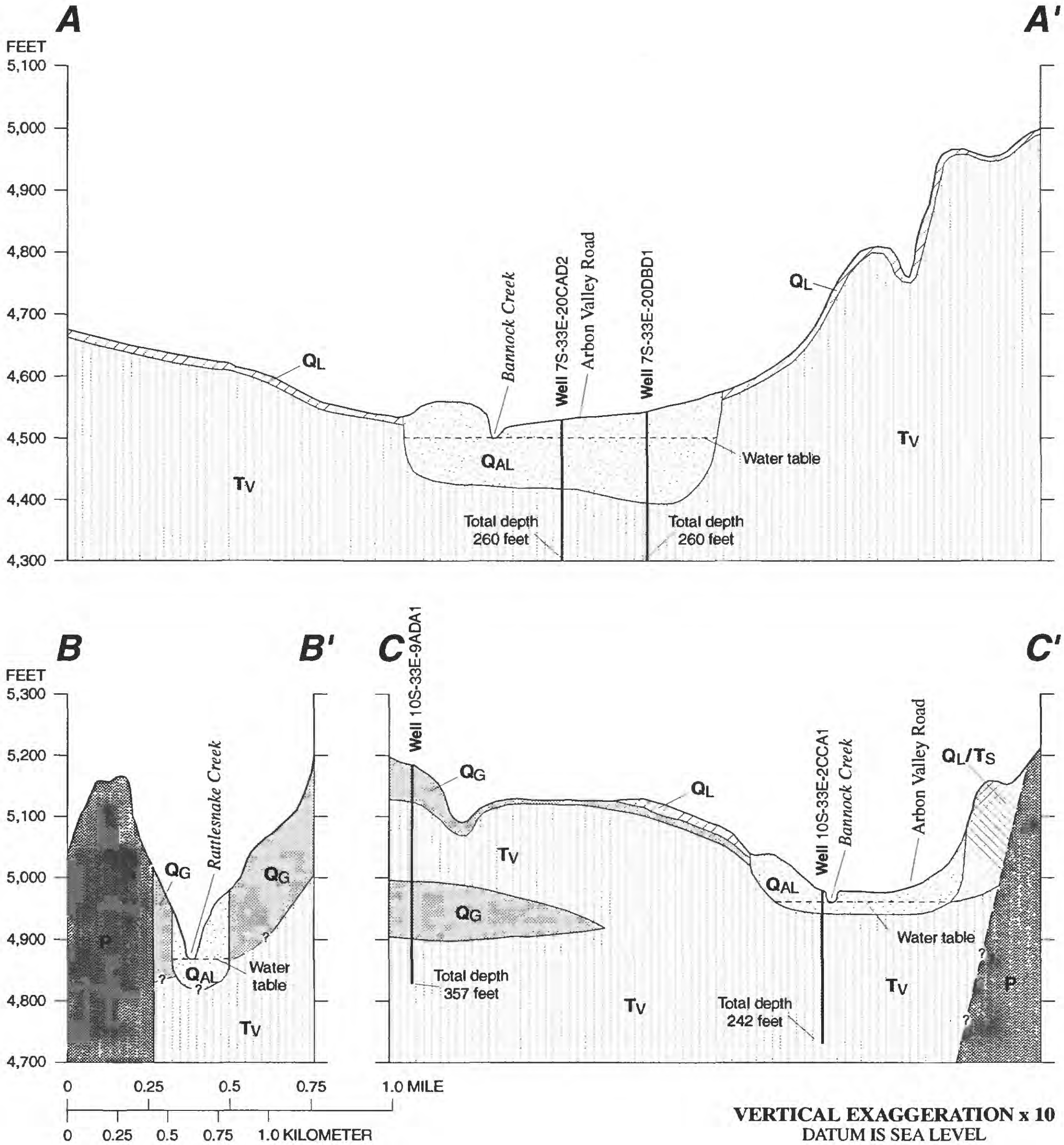


Figure 3. Surficial geology in Bannock Creek Basin. (Geologic sections shown in figure 4)



EXPLANATION

——— — — —?— **Geologic contact**—Dashed where approximately located, queried where inferred

- - - - - - - - - - **Water table, approximately located**

Figure 4. Generalized geologic sections for Bannock Creek Basin. (Correlation of rock units shown in figure 3)

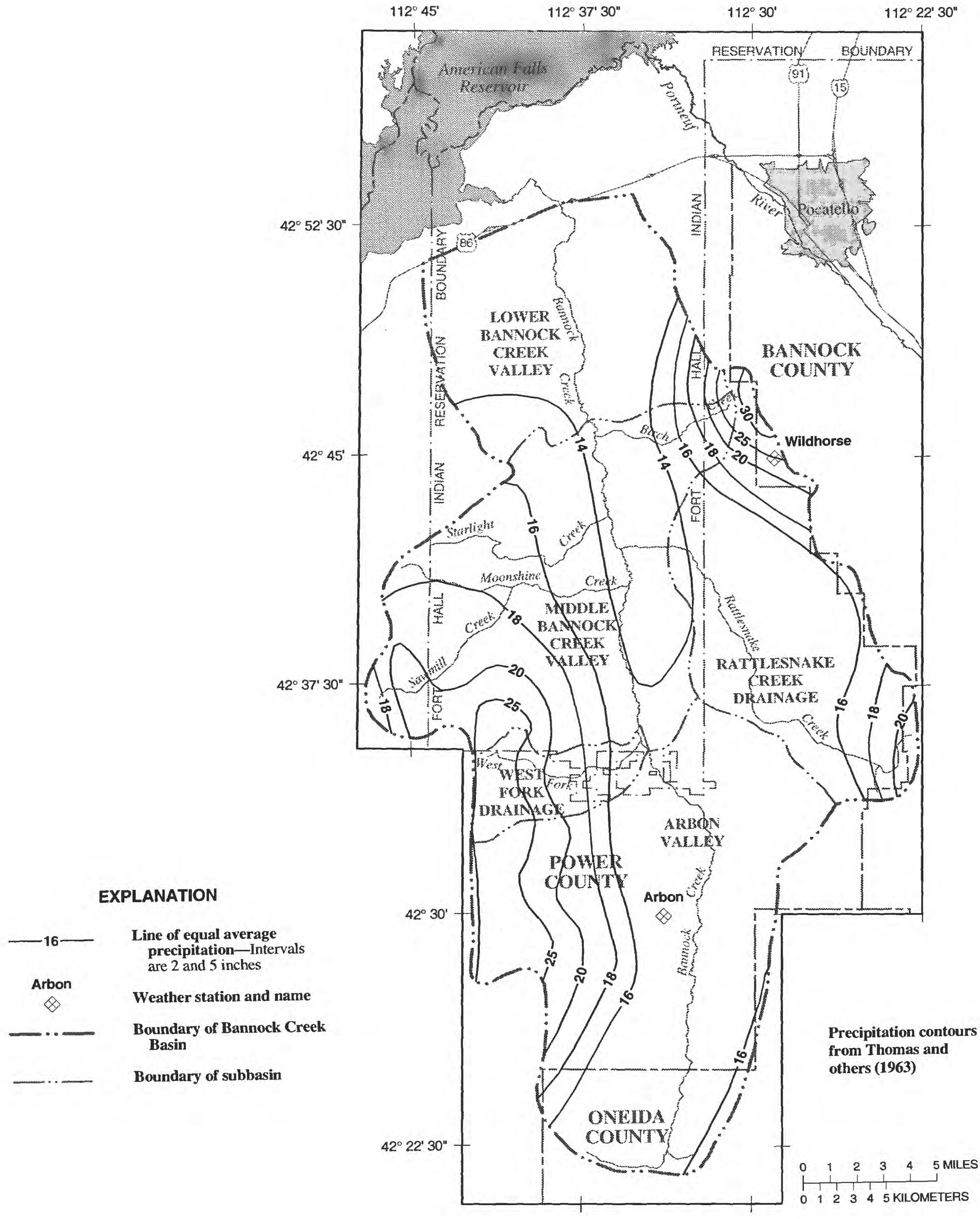


Figure 5. Average annual precipitation, 1930–57, and location of weather stations in Bannock Creek Basin.

ment of Water Resources and on file with the U.S. Geological Survey indicate that wells completed in Michaud Flats penetrate as much as 400 ft of sedimentary deposits or basalt without intercepting rhyolitic tuff. Wells in Michaud Flats typically bottom in permeable volcanic rock (basalt) or in sedimentary deposits.

The composition of the bedrock surface in Arbon Valley south of T. 9 S., R. 33 E., and in Rattlesnake Creek drainage is largely unknown. "Lime" (probably limestone) is reported at a depth of 1,070 ft below land surface on a driller's report from an oil test hole in Arbon Valley in sec. 2, T. 11 S., R. 33 E. Paleozoic limestone, dolomite, and shale likely constitute the bedrock in Arbon Valley and in the Rattlesnake Creek drainage. Unconsolidated sedimentary deposits of gravel, sand, silt, and clay overlie the bedrock.

WATER RESOURCES

Precipitation and Evapotranspiration

Normal annual precipitation at American Falls is 10.4 in., and average annual precipitation at Arbon is 16.6 in. (fig. 5). Only 17 percent of the annual precipitation falls during the summer months of July, August, and September (U.S. Department of Commerce, annual summaries, 1964 through 1989). Remaining precipitation is distributed about evenly throughout the rest of the year.

Average annual precipitation from 1965 to 1989 was calculated for five subbasins in the Bannock Creek drainage. Average precipitation was calculated from a map of average annual precipitation for 1930–57 (Thomas and others, 1963) and from precipitation records from Arbon and Wildhorse weather stations (fig. 5). The precipitation record from the Wildhorse station for 1982–89 was extended by regression with records from nearby weather stations. Average precipitation for each subbasin was calculated as the sum of the average precipitation between adjacent precipitation contours in figure 5, weighted by the ratio of map area between the contours to total surface area. Comparison of precipitation contours, which incorporated 1930–57 data, with average 1965–89 precipitation at weather stations indicated that the average annual precipitation at Arbon for 1965–89 was 110 percent of the map value, and the average annual precipitation at Wildhorse for 1965–89 was 128 percent of the map value, or an average of 119 percent for both stations. Therefore, average

Table 1. Average annual precipitation for five subbasins in the Bannock Creek drainage, 1965–89

[Total average annual precipitation was weighted by the area in each subbasin and calculated from a map by Thomas and others (1963) and precipitation records (U.S. Department of Commerce, annual summaries, 1964 through 1989)]

Subbasin	Area (square miles)	Average annual precipitation (inches)
Arbon Valley	144	20.3
Rattlesnake Creek drainage	79	20.4
West Fork drainage	17	24.1
Middle Bannock Creek Valley	120	19.0
Lower Bannock Creek Valley	75	16.2
Total	435	19.4

annual 1930–57 precipitation values calculated from the map for each subbasin were adjusted to average 1965–89 values by multiplying the weighted average precipitation by 119 percent. Estimated average annual precipitation for 1965–89 in each of the five subbasins ranged from 16.2 to 24.1 in., and the weighted average for the five subbasins was 19.4 in. (table 1).

Evapotranspiration (ET) from cropland was determined using a computer program that calculates ground-water recharge (Johnson and Brockway, 1983). The program calculates recharge as a residual from applied water minus crop ET minus changes in soil-moisture storage. The program requires data on applied water from precipitation and irrigation; crop growth and harvest characteristics; climatic data that include temperature, relative humidity, windspeed, and solar radiation; and available water-holding capacity of the top 3 ft of the soil profile. Climatic data from nearby weather stations, available soil water-holding capacity of 6 in. (Chugg and others, 1968), and crop-growth data for southern Idaho, included in the original computer code, were specified for the program. Calculated crop ET averaged 23.1 in/yr for the growing season from April through September. Crop ET was reduced by 25 percent from 23.1 to 17.3 in/yr to provide an initial approximation of ET from native vegetation.

Surface Water

STREAMFLOW

Streamflow in the basin is (1) that part of precipitation that runs off directly into Bannock Creek and its tributaries and (2) ground water that discharges to streams through the streambed or from springs (base flow). The natural streamflow regimen was altered

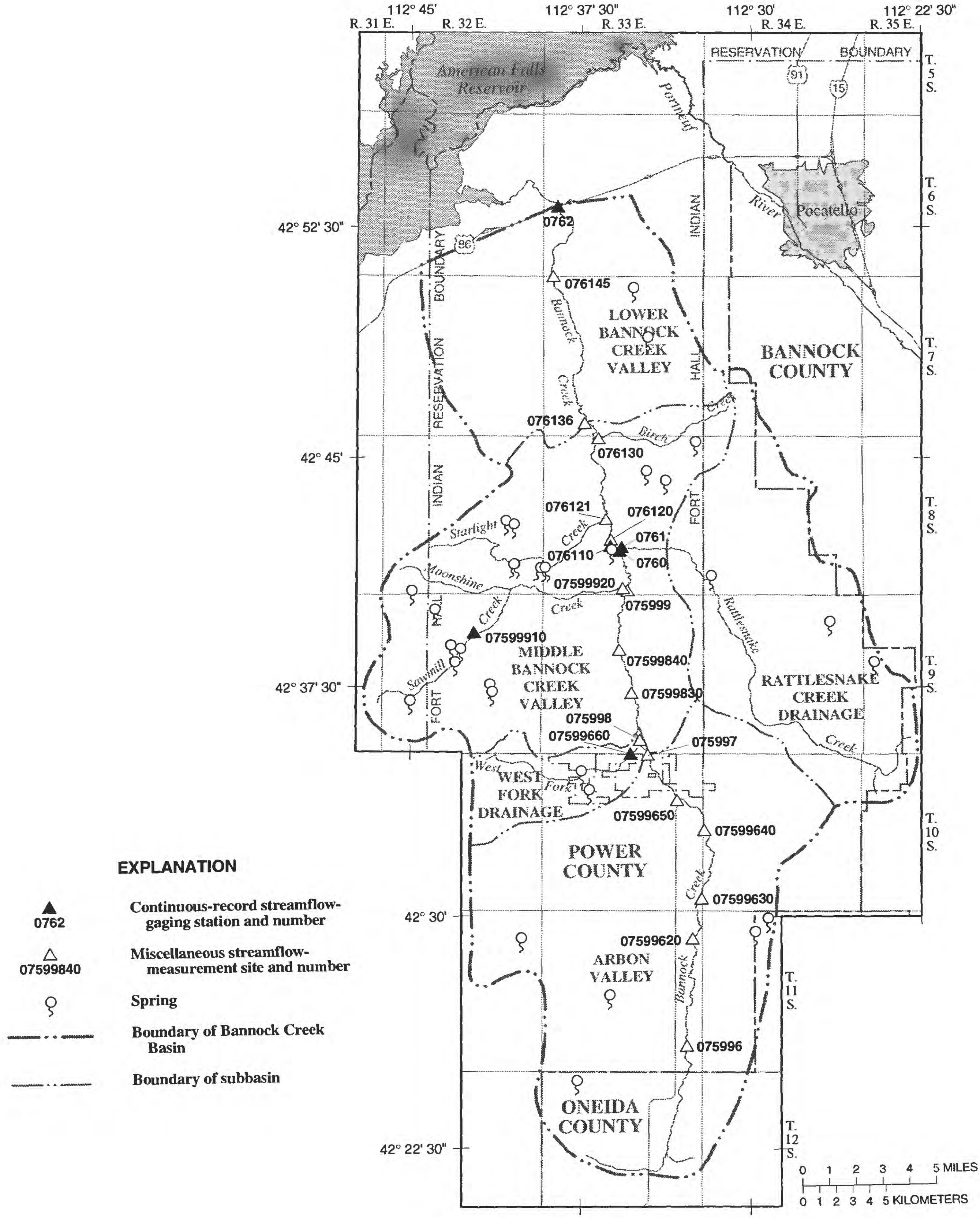


Figure 6. Location of selected sites where streamflow was measured in 1987 and location of springs measured in 1988, Bannock Creek Basin.

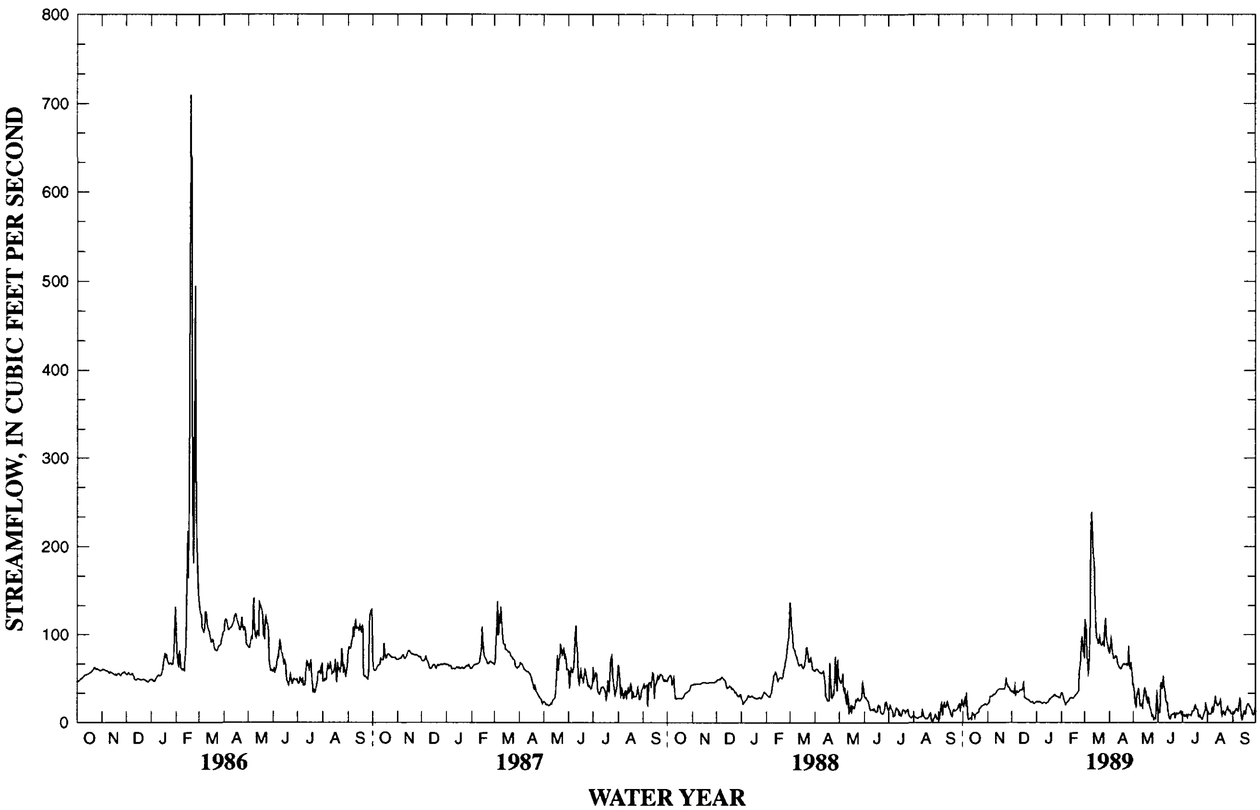


Figure 7. Daily mean streamflow at Bannock Creek near Pocatello (station 0762), 1985–89.

when diversions of streamflow for irrigation began in the late 1940's. Only part of the water diverted for irrigation is returned to the stream; the remainder evaporates, is used consumptively by crops, or recharges the ground-water system. The streamflow regimen was assumed to be in a state of change from the time that diversions began until irrigation projects in the basin were completed in 1964. After the irrigation projects were completed, effects of irrigation on streamflow were assumed to be relatively constant.

Streamflow was measured periodically at several sites on Bannock Creek and Rattlesnake Creek from 1927 to 1967 as reported by Decker and others (1970) and from 1955 to 1959 and from 1985 to 1989 as reported in annual hydrologic data reports published by the U.S. Geological Survey (Harenberg and others, 1987). Flows in Bannock Creek and tributaries from 1973 to 1978 were reported by Balmer and Noble (1979).

Streamflow was measured continuously at West Fork Creek near Pauline (station 07599660), Rattlesnake Creek near Arbon (station 0761), and Bannock Creek below Rattlesnake Creek near Arbon (station 076110) (fig. 6) from January 1988 through September 1989. Streamflow was measured continuously at Bannock Creek near Pocatello (station 0762) since May 1985, but measurements at station 0762 (fig. 7) were affected by water imported for irrigation from the Portneuf River (fig. 1) and did not represent runoff derived solely from within the basin.

Mean annual 1965–89 discharge was needed to estimate average 1965–89 surface-water runoff, which was used to develop water budgets, presented later in this report, for subbasins of the Bannock Creek drainage. Streamflow discharge records for 1988–89 at stations 07599660, 0761, and 076110 were extended to represent average 1965–89 streamflow discharges using ratios of mean daily discharge from records at Marsh Creek near McCammon (station 0750) about 15 mi east of Bannock Creek Basin. Basin size (330 mi^2 upstream from the Marsh Creek gage compared with 435 mi^2 upstream from the Bannock Creek gage) and altitude of the stream gage (4,610 ft for Marsh Creek compared with 4,400 ft for Bannock Creek) are similar for each drainage. Average 1965–89 streamflow discharge was calculated for the three Bannock Creek stations by multiplying the mean daily 1988–89 streamflow discharge at each station by the ratio of mean daily 1965–89 streamflow discharge divided by 1988–89 streamflow discharge at station 0750. Average streamflow discharge at station 0750 was 100 ft^3/s for 1965–89 and 99.7 ft^3/s for 1988–89 (average 1988–89 streamflow discharge was computed on the basis of records for the period January 1988 to September 1989). Average streamflow discharge reported for station 076110 (Bannock Creek below Rattlesnake Creek near Arbon) in table 2 represents remaining streamflow discharge after subtracting the discharges at station 07599660 and 0761.

Average 1965–89 surface-water runoff was calculated by division of average 1965–89 streamflow discharge by drainage area (table 2). Average runoff values computed on the basis of average streamflow discharges for stations 0761 (Rattlesnake Creek drainage) and 07599660 (West Fork drainage) (table 2) represent estimates for the drainage areas upstream from those gages. The average runoff value computed on the basis of remaining streamflow at station 076110 on Bannock Creek represents estimated runoff for drainage areas upstream from that gage but excludes the gaged drainage areas of West Fork and Rattlesnake Creek (fig. 6).

In the calculation of average surface-water runoff, no distinction was made between overland runoff to streams and ground-water discharge to streams (base flow). Long-term data needed to estimate average annual discharge of ground water to streams within different parts of the basin were not available. Miscellaneous streamflow measurements made during this study indicate, however, that some reaches of Bannock Creek gain flow from ground water. Flow in other streams also may be affected by gains from ground water. It should be assumed, therefore, that estimates of average runoff listed in table 2 represent both overland runoff and ground water that discharges to streams through the streambed.

IRRIGATION DIVERSIONS AND RETURN FLOWS

Water was first diverted from Bannock Creek in 1948 to irrigate 800 acres of cropland (Davis and others, 1978, p. 6–8). Records on file with the watermaster for the Fort Hall Irrigation Project show that, in 1988, six canals diverted 3,650 acre-ft of water from Bannock Creek to irrigate 1,280 acres in the Bannock Creek minor irrigation unit (fig. 8). Of the amount diverted, 2,460 acre-ft was consumptively used as crop ET, and 427 acre-ft became ground-water recharge. These values were calculated by a recharge program developed by Johnson and Brockway (1983). The difference between diversions for irrigation and the sum of crop ET and ground-water recharge, 763 acre-ft, represents the estimated return flow from the Bannock Creek minor irrigation unit.

About 13,800 acres in the Michaud irrigation unit have been irrigated since 1964 with water diverted from the Portneuf River and pumped over the topographic divide into Bannock Creek Basin (fig. 8). Diversions (Andy Cates, Watermaster, Fort Hall Project, Fort Hall, Idaho, written commun., 1989) ranged from 18,200 to 44,000 acre-ft/yr and averaged 32,500 acre-ft/yr from

Table 2. Average annual streamflow discharge for 1988–89 and 1965–89 and average annual streamflow runoff for 1965–89 at selected streamflow-gaging stations in Bannock Creek Basin

[Average annual streamflow discharge for 1965–89 was calculated from the ratio of average annual discharge for 1965–89 of 100 cubic feet per second divided by average annual streamflow discharge for 1988–89 of 99.7 cubic feet per second for Marsh Creek near McCammon (station 13075000) 15 miles east of Bannock Creek Basin]

Streamflow-gaging station name and number (fig. 6)	Average annual 1988–89 streamflow discharge (cubic feet per second)	Average annual 1965–89 streamflow discharge (cubic feet per second)	Drainage area (square miles)	Average annual 1965–89 runoff (acre-feet per square mile per year)
West Fork Creek near Pauline (07599660)	8.71	8.73	17	372
Rattlesnake Creek near Arbon (0761)	12.5	12.5	79	115
Bannock Creek below Rattlesnake Creek near Arbon (076110)	[1]14.3	[1]14.4	[2]222	[2]47

[1] Represents remaining discharge at station after subtracting discharges at stations 0761 and 07599660.

[2] Excludes drainage areas gaged by stations 0761 and 07599660.

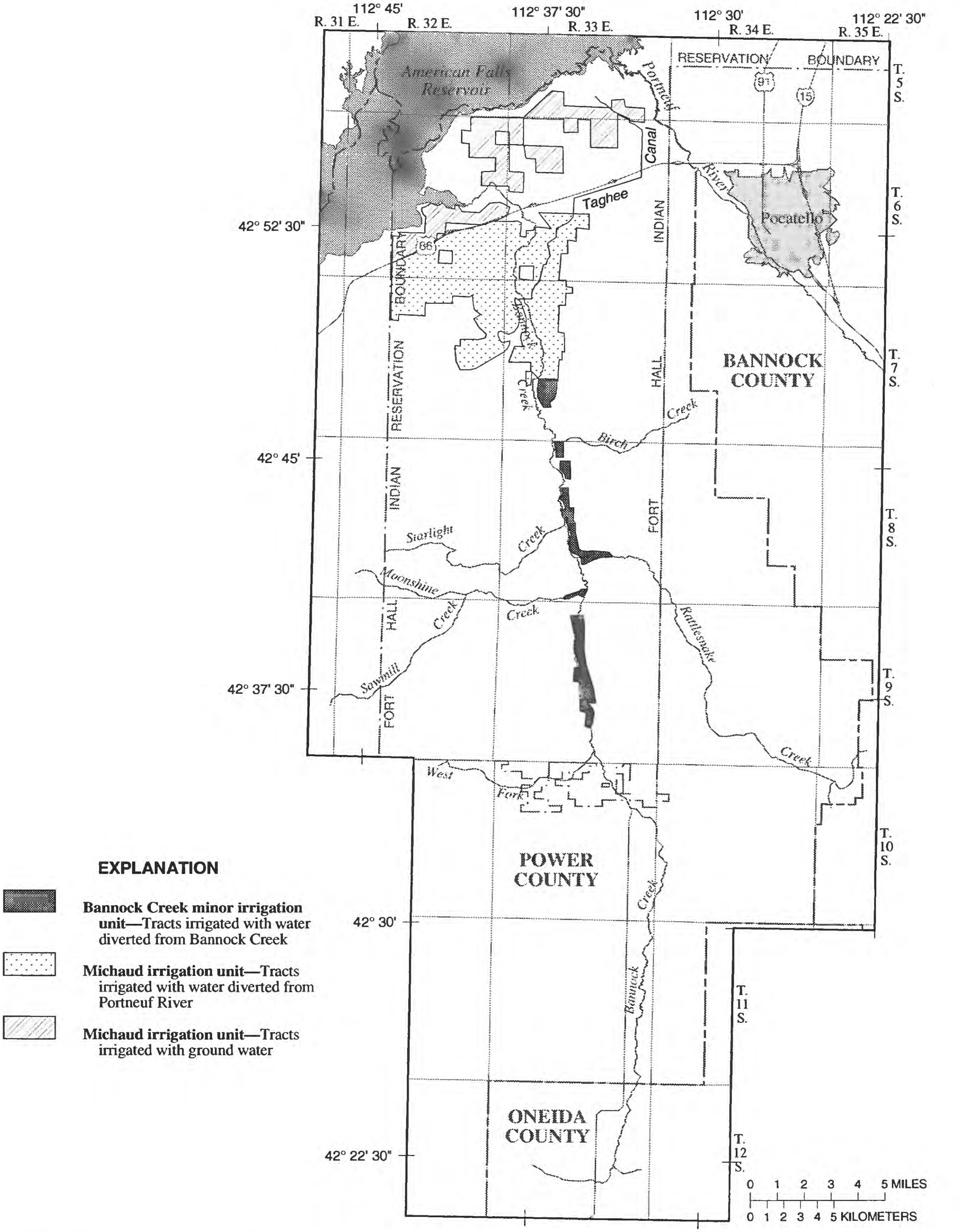


Figure 8. Location of Bannock Creek minor and Michaud irrigation units.

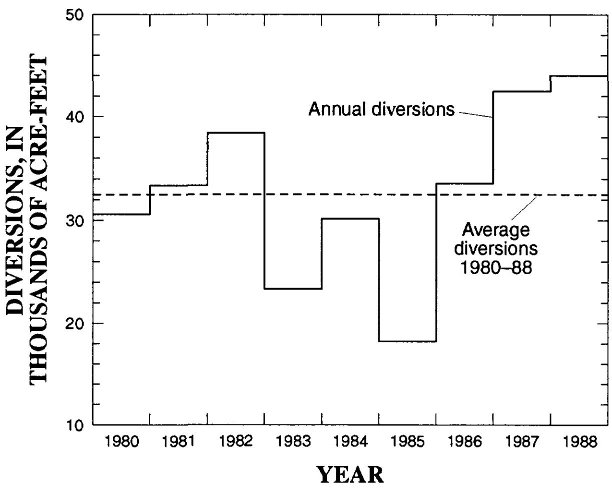


Figure 9. Portneuf River diversions to the Michaud irrigation unit, 1980–88.

1980 through 1988 (fig. 9). Water is transferred to the Michaud irrigation unit through the Taghee Canal (fig. 8). Before reaching the unit, about 25 percent of the water diverted into the canal is lost to ground water (Andy Cates, Watermaster, Fort Hall Project, Fort Hall, Idaho, written commun., 1989). Return flows to Bannock Creek from the Michaud irrigation unit vary seasonally. A combined return flow of 9.7 ft^3/s was measured on August 26, 1987, from Bannock Canal Waste at Siphon (station 076138); Big Siphon Wasteway (station 076140); and Bannock Drain (station 076147) (Harenberg and others, 1987, p. 410). A return flow of 1.5 ft^3/s was measured from Bannock Canal Waste at Siphon (station 076138) on October 21, 1987; return flows from the two other drains were zero.

SPRINGS

Water supplies are available from many springs in the Bannock Creek Basin. Discharge was measured at 30 springs (fig. 6) in 1988. About 3,200 gal/min was measured from the major springs that constitute the headwaters of West Fork; about 400 gal/min was measured from all other springs (table 3). Higher average annual precipitation in the West Fork drainage (table 1) is the likely source of spring discharge to West Fork and is responsible for greater average runoff from this drainage compared with runoff from other parts of the basin (table 2).

Discharge from most springs, except those that contribute to flow in West Fork, does not travel far from the point of origin before percolating into the ground. For example, streamflow at station 07599910, Sawmill Creek near Arbon (fig. 10), a tributary to Moonshine Creek, is maintained throughout the year by springs that discharge within 1,000 ft of the gaging station (fig. 6). Measurements at one of the springs that discharge to Sawmill Creek are listed in table 3 (9S-32E-16ADC1S). Although flow was recorded at the gaging station most of the time from January 1988 through June 1989, Sawmill Creek usually loses most of its flow before joining Moonshine Creek about 2 mi downstream.

Table 3. Discharge of springs measured in 1988, Bannock Creek Basin

[—, unnamed; Do., ditto; e, estimated; Q, water-quality analysis available in table 12; NA, not available]

Spring number (fig. 6)	Spring name	Date of measurement (month-day)	Discharge (gallons per minute)	Water-quality analysis
7S-33E- 3BDD1S	—	6-30	12.6	Q
	—	11- 1	4.25	Q
15ADA1S	—	6-30	2.15	NA
8S-32E-23ABC1S	Fisher	5-24	.15	NA
23ADA1S	Lower Fisher	5-24	0	NA
25DDD1S	—	5-25	.05	NA
26DDA1S	Study North	5-24	.2	NA
26DDA2S	Study South	5-24	18	Q
	Do.	11- 1	18.7	Q
32CCB1S	—	5-25	18	Q
	—	11- 2	13.5	Q
8S-33E- 1ABD1S	—	7- 1	12.6	Q
10ADA1S	—	5-28	13.5e	Q
11DBC1S	Warm	5-28	.5e	Q
28ACB1S	Officer	11- 4	31	Q
30CCC1S	—	5-25	NA	Q
	—	11- 1	.2	Q
34E-31BAC1S	—	5-28	55.2	Q
	—	11- 3	49.8	Q
9S-32E- 4CBB1S	—	5-25	1.6	Q
	—	11- 2	.8	Q
9DCA1S	—	5-25	160	Q
	—	11- 2	22.9	Q
10CCC1S	—	5-25	32.3	Q
16ADC1S	Sawmill	5-25	12.1	Q
	Do.	11- 2	2	Q
20CCD1S	—	5-25	.35	NA
23BCA1S	Corral	5-27	21.5	Q
	Do.	11- 2	15.7	Q
23CBD1S	—	5-27	13.5	Q
	—	11- 2	16.5	Q
9S-34E- 2DDC1S	—	5-28	.9e	Q
35E-18BDD1S	—	5-28	1e	Q
	—	11- 3	.4	Q
10S-33E- 5CDA1S	West Fork	5-27	3,170	Q
	Do.	11- 2	3,160	Q
8ADC1S	Waylett	5-27	1.5	Q
11S-32E- 1CDC1S	—	5-27	2	Q
	—	11- 3	2	Q
33E-21ABC1S	—	7- 1	28.7	Q
	—	11- 3	31	Q
34E- 4ABC1S	—	5-28	2.25	Q
	—	11- 3	.15	Q
4CCB1S	—	5-28	0	NA
12S-33E- 5BAC1S	—	5-28	10	Q

Ground Water

OCCURRENCE AND MOVEMENT

The valley-fill aquifer is the primary source of ground water in most parts of the basin. The aquifer consists principally of sand, gravel, and basalt that underlie the valley along Bannock Creek and sand and gravel that underlie the valley along Rattlesnake Creek. Secondary sources of water include pediment gravel, loess, fractures in rhyolitic tuff, and fractures and dissolution channels in Paleozoic and Precambrian rocks that provide local supplies to many springs and some wells in the basin.

The primary aquifer under Michaud Flats consists of sand, gravel, and basalt (Jacobson, 1984, p. 6); it is part of the Snake River Plain aquifer (Garabedian, 1989, p. 16). Water in the aquifer under Michaud Flats is artesian (Jacobson, 1984, p. 6). The southern extent of the Snake River Plain aquifer is assumed to be the inferred fault about 3 mi south of Interstate Highway 86 (fig. 3). The Snake River Plain aquifer under Michaud Flats is in hydraulic connection with the overlying valley-fill aquifer (Jacobson, 1984, p. 14).

The water-table map in figure 11 indicates the hydraulic gradient and direction of water movement in the valley-fill aquifer for fall 1987. "The hydraulic gradient is the change in static head per unit distance in a given direction" (Lohman and others, 1972, p. 8). Changes in static head were calculated from the differences in altitude between water-table contours con-

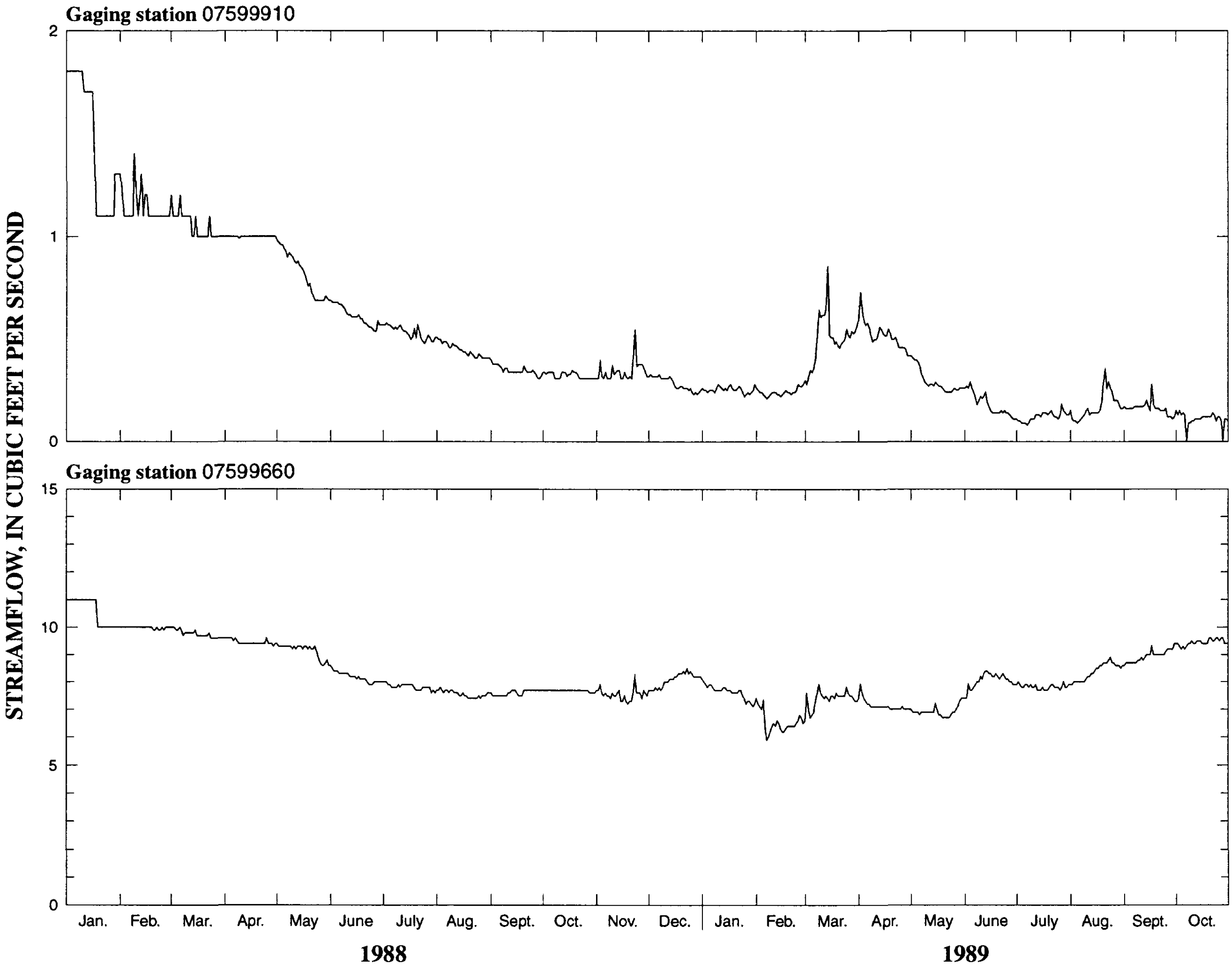


Figure 10. Daily mean streamflow at Sawmill Creek near Arbon (station 07599910) and at West Fork near Pauline (station 07599660), 1988–89.

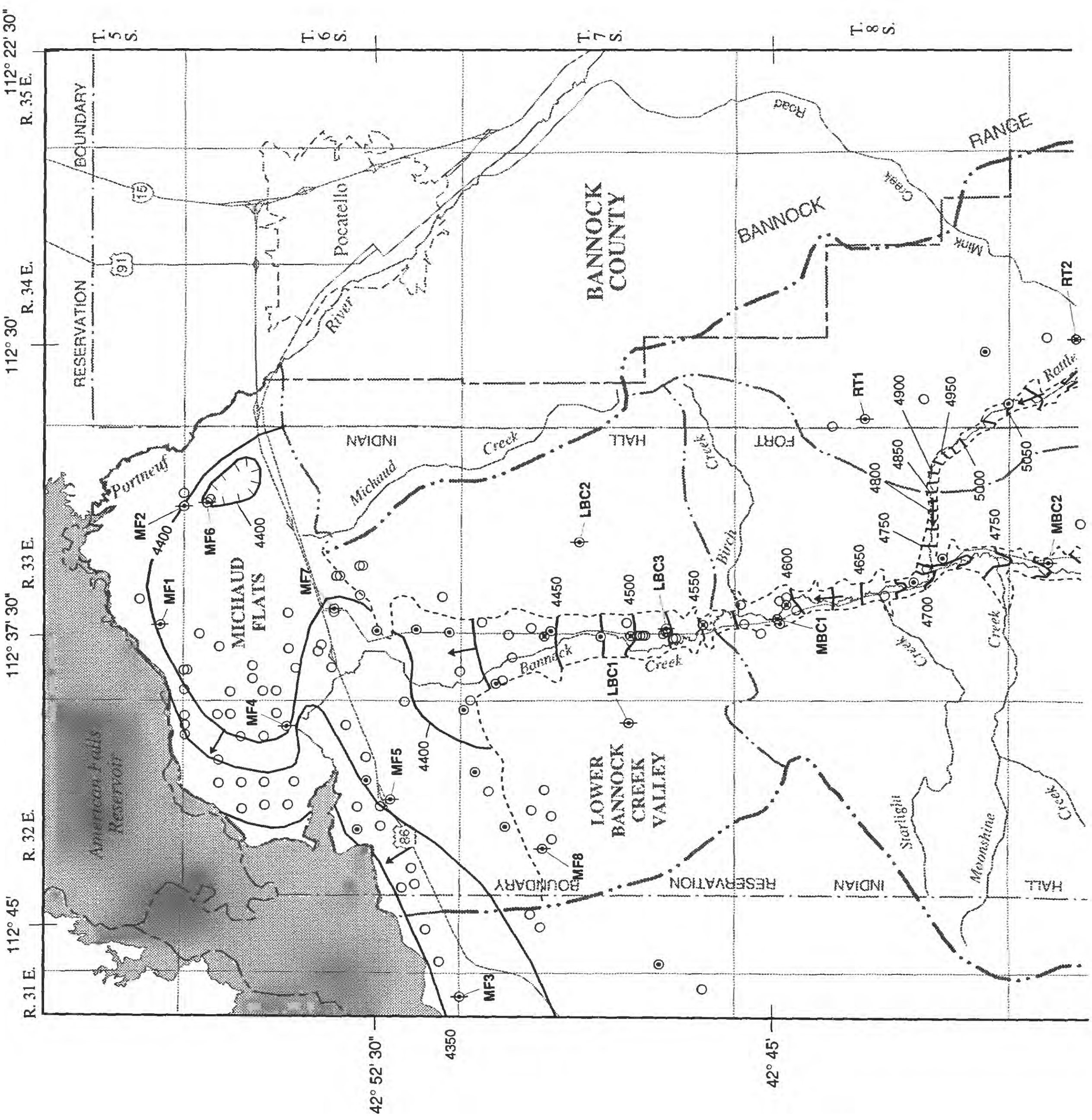
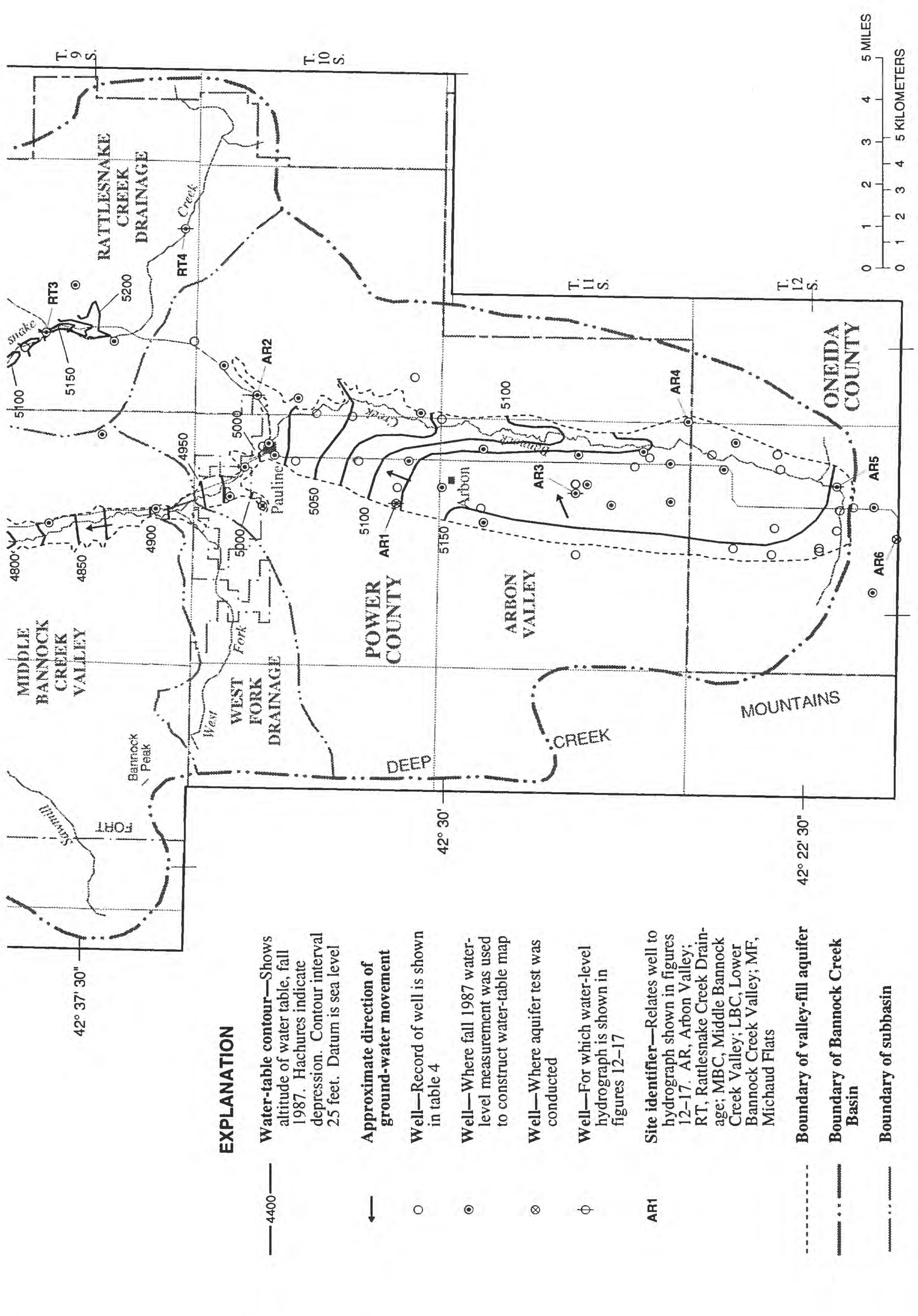


Figure 11. Water-table contours for valley-fill aquifer and



location of wells in Bannock Creek Basin, fall 1987.

structed using water levels measured in 68 wells during September and October 1987 (table 4, back of report). Hydraulic gradients generally follow topographic gradients in the valley and range from 3 ft/mi beneath the relatively flat bench of Michaud Flats to 125 ft/mi along Rattlesnake Creek. Ground water generally moves perpendicular to water-table contours and generally flows from south to north toward American Falls Reservoir. Water in the valley-fill aquifer merges with water in the Snake River Plain aquifer beneath Michaud Flats.

WATER LEVELS

Water levels were measured at various frequencies described below in 23 wells during 1987 and 1988 (figs. 12–17); 17 of the 23 wells are completed in the valley-fill or the Snake River Plain aquifers. Of eight wells completed in the Snake River Plain aquifer under Michaud Flats, five were measured monthly and two were equipped with continuous water-level recorders. A recorder was installed on one well in the lower Bannock

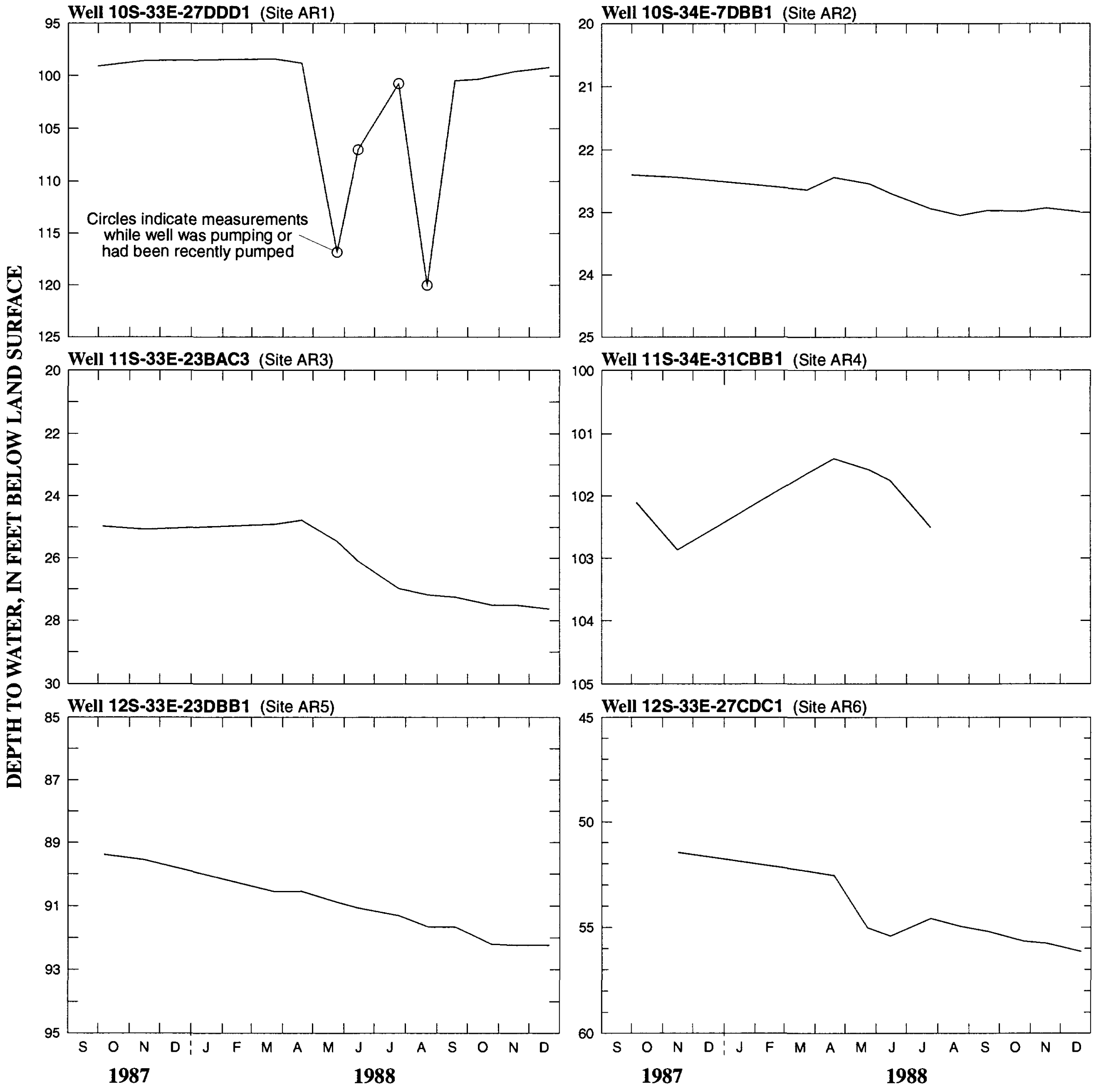


Figure 12. Water levels in selected wells in Arbon Valley, September 1987 to December 1988. (Locations of wells are shown by site identifier in figure 11)

Creek Valley. Monthly water-level measurements were made in two wells in middle Bannock Creek Valley, one well in the Rattlesnake Creek drainage, and four wells in Arbon Valley. Seven wells completed in other aquifers were measured monthly; two in lower Bannock Creek Valley, three in the Rattlesnake Creek drainage, and two in Arbon Valley.

Generally, water levels measured in observation wells in the Bannock Creek Basin change in response to the intensity and duration of recharge and discharge and are affected only locally by withdrawals from wells. Ground-water withdrawals from wells in the Bannock Creek Basin are minimal, compared with the total water budget for the basin, and generally have no substantial effect on water levels except in the vicinity of a pumping well. Water budgets and estimated withdrawals from wells in the basin are discussed in detail later in this report.

Ranges cited in this section indicate differences between minimum and maximum water-level measurements in wells from different parts of the basin. Annual changes from December 1987 through December 1988 indicate relations between recharge and discharge during the 1988 calendar year. Water-level rises indicate that recharge exceeded discharge; declines indicate the reverse. Water levels in all observation wells were measured from September 1987 through December 1988. Measurements in some wells on Michaud Flats extend back to 1955.

Water-level changes in wells in the valley-fill aquifer in Arbon Valley ranged from about 2.5 to 20 ft from September 1987 through December 1988 (fig. 12). Large changes in well 10S-33E-27DDD1 were due to pumping at the time of measurement. Water levels were highest in April in wells 11S-33E-23BAC3 and 11S-34E-31CBB1 and likely indicate the response of the aquifer to recharge from precipitation. Water levels in these wells declined from less than 1 ft to about 2.5 ft from December 1987 through December 1988.

In the Arbon Valley area, well 10S-34E-7DBB1 was completed in Paleozoic rock, and well 12S-33E-27CDC1 was completed in alluvial deposits (sand and gravel) in the Deep Creek drainage. Water levels in well 10S-34E-7DBB1 varied less than 1 ft from September 1987 through December 1988 and decreased less than 1 ft from December 1987 through December 1988. Water levels in well 12S-33E-27CDC1 varied about 3.5 ft and declined about 3 ft from December 1987 through December 1988. Water levels in these wells most likely respond to local variations in recharge from precipitation.

Water levels in well 9S-34E-17ADA1, completed in the valley-fill aquifer in the Rattlesnake Creek drainage, varied about 1 ft from September 1987 through December 1988 (fig. 13). Water levels were highest in June when water flowed naturally from the well. Water-level changes most likely indicate response of the aquifer to recharge from precipitation.

Three wells in the Rattlesnake Creek drainage were completed in Paleozoic rocks. Water levels in well 8S-34E-18CCA1 varied about 13 ft from September 1987 through December 1988 and rose 10 ft from December 1987 through December 1988. Water levels in well 9S-34E-8ADD1 varied about 3 ft and declined about 3 ft from December 1987 through December 1988. Water levels in well 9S-34E-35CAD1 varied about 6 ft and declined about 2.5 ft from December 1987 through December 1988. Water levels show no appreciable seasonal high or low periods, except for effects most likely due to pumping at the time of measurement. Water levels in these wells most likely respond to local variations in recharge from precipitation.

Water levels in well 8S-33E-5DDC1 varied about 5 ft from September 1987 through December 1988, and water levels in well 9S-33E-3CCB1 varied about 3 ft during the same time period (fig. 14). Both wells are completed in the valley-fill aquifer in middle Bannock Creek Valley. Measurements made while the wells were being pumped preclude a description of aquifer response to recharge from precipitation or infiltration of surface water diverted in the area. Water levels in both wells varied less than 1 ft from December 1987 through December 1988.

Water levels in observation well 7S-33E-29DBB2, completed in the valley-fill aquifer in lower Bannock Creek Valley, varied about 5 ft (fig. 15) from September 1987 through December 1988. Water-level changes indicate the response of the aquifer to recharge from infiltration of surface water diverted to the Michaud irrigation unit. Water levels are highest during the irrigation season, from April through September, when recharge to the aquifer is greatest. Water levels are lowest from December to April in the absence of diversions for irrigation. Water levels in this well changed less than 1 ft from December 1987 through December 1988 and indicate that recharge was nearly balanced by discharge in 1988.

Well 7S-32E-24DBC1, completed in alluvial deposits (sand and gravel), and well 7S-33E-15DBB1,

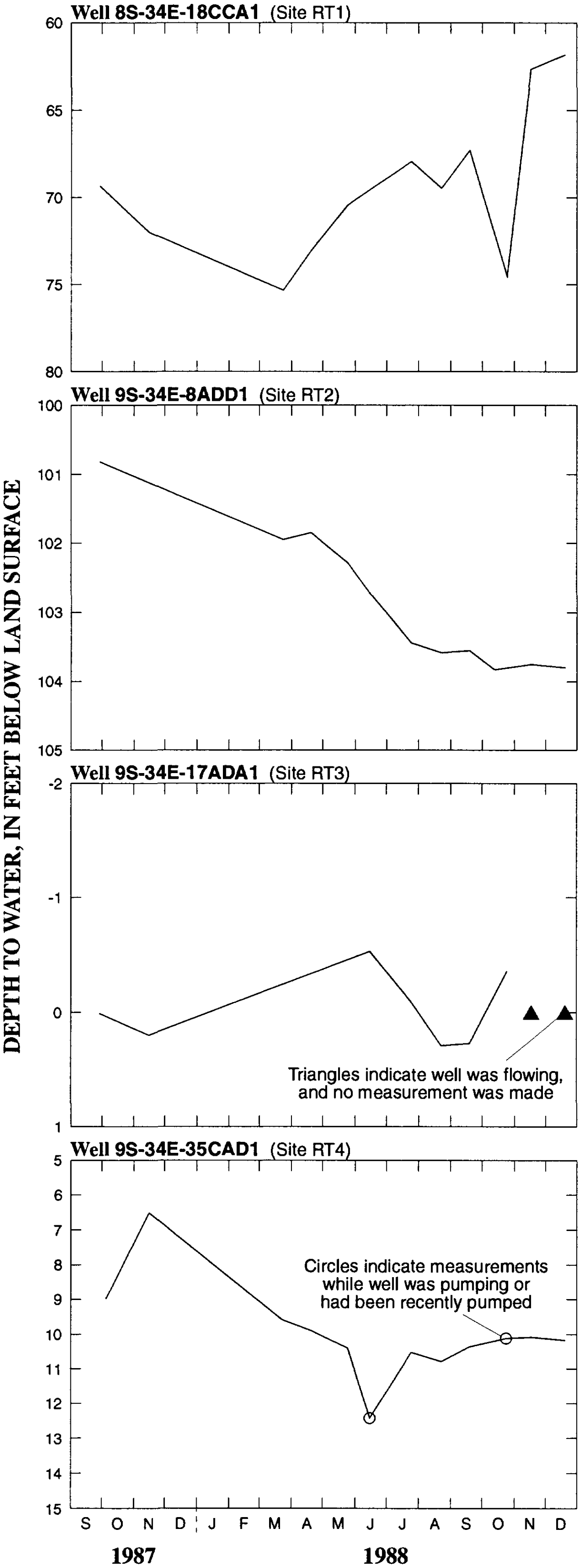


Figure 13. Water levels in selected wells in Rattlesnake Creek drainage, September 1987 to December 1988. (Locations of wells are shown by site identifier in figure 11)

completed in loess, are outside of the area underlain by the valley-fill aquifer in lower Bannock Creek Valley. Water levels in well 7S-32E-24DBC1 varied less than 1 ft from September 1987 through December 1988, and the increase in water levels of less than 1 ft from December 1987 through December 1988 (fig. 15) indicates that recharge slightly exceeded discharge during 1988. Water levels in this well gradually rose from September 1987 through December 1988. Water levels in well 7S-33E-15DBB1 varied about 4 ft from September 1987 through December 1988 and rose about 1.5 ft from December 1987 through December 1988. Water-level rises indicate that recharge took place from March through June 1988. Water levels in these wells most likely respond to local variations in recharge from precipitation.

Water-level changes for wells completed in the Snake River Plain aquifer under Michaud Flats ranged from about 4 to 35 ft from September 1987 through

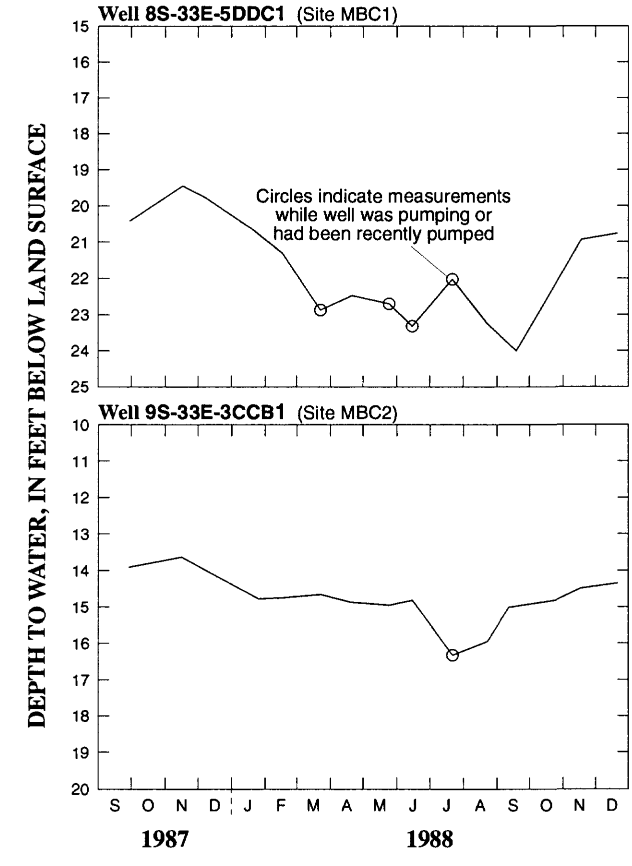


Figure 14. Water levels in selected wells in middle Bannock Creek Valley, September 1987 to December 1988. (Locations of wells are shown by site identifier in figure 11)

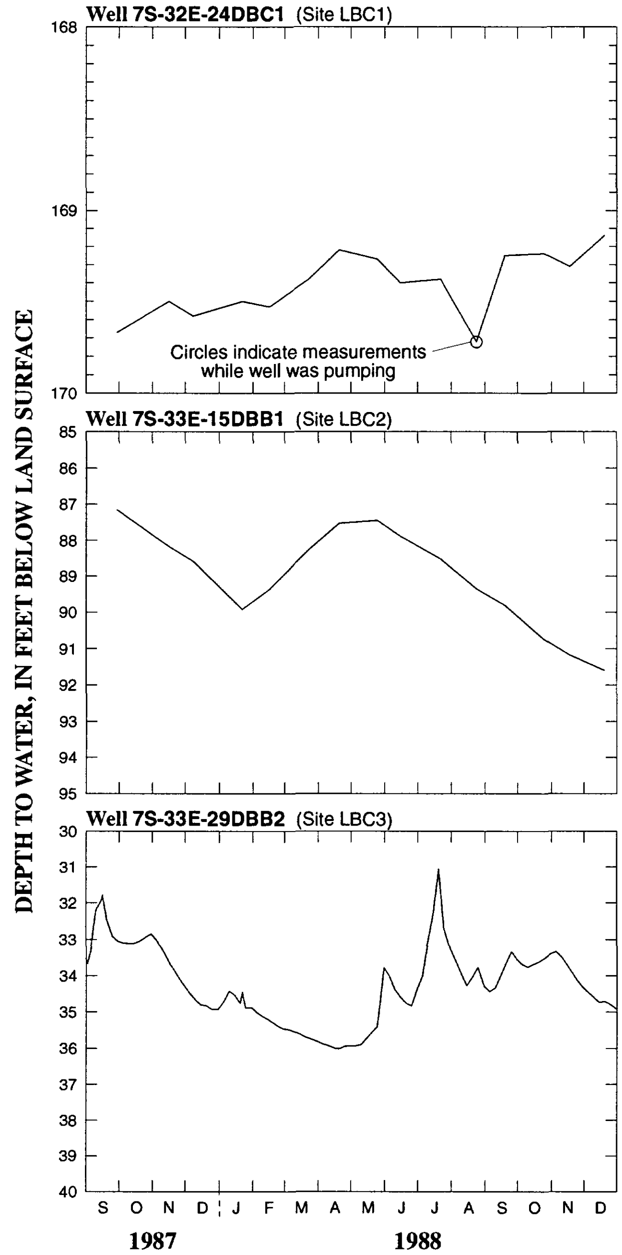


Figure 15. Water levels in selected wells in lower Bannock Creek Valley, September 1987 to December 1988. (Locations of wells are shown by site identifier in figure 11)

December 1988 (fig. 16). The range in irrigation wells 5S-33E-32ACD1, 6S-31E-36DCC1, 6S-32E-13BAD1, and 6S-33E-21BCB1 included pumping water levels and averaged about 23 ft, whereas the range in wells 5S-33E-35CDC1, 6S-32E-27ADC1, 7S-32E-9DDB1, and 6S-33E-2BDD1 excluded pumping water levels and averaged about 4 ft. These water-level changes indicate the response of the aquifer to pumping for irrigation.

Water levels were lowest during the irrigation season from April through September and highest from January through March in the absence of pumping for irrigation.

Long-term water-level data were available for three wells on Michaud Flats that were completed in the Snake River Plain aquifer. Water levels in well 6S-31E-36DCC1 varied from 1955 through 1961. Water-level changes in wells 5S-33E-35CDC1 and 6S-32E-27ADC1 ranged from 6.5 to 12 ft during 1955 through 1988. Monthly water levels measured from September 1987 through December 1988 were within minimum and maximum monthly levels measured from 1955 through 1988, except for levels in well 6S-31E-36DCC1 during 2 months. Water levels in this well in January 1987 and October 1988 were the lowest ever measured.

Water levels in wells completed in the Snake River Plain aquifer under Michaud Flats varied less than 1 ft from December 1987 through December 1988. Declines in water levels of less than 1 ft in irrigation well 6S-31E-36DCC1 and domestic well 6S-33E-2BDD1 and about 1 ft in other wells indicate that discharge exceeded recharge in 1988.

Hydrographs of March water-level measurements show annual water-level changes in two wells on Michaud Flats from 1955 through 1988 (fig. 17). March was selected because pumping for irrigation is rare at this time of year, and water levels during the month are near the annual high. Water levels in wells 5S-33E-35CDC1 and 6S-32E-27ADC1 generally were higher during the mid- to late 1980's than they were during the early 1960's and late 1970's. Water levels in well 5S-33E-35CDC1 have varied about 2.5 ft since 1955. Water levels in well 6S-32E-27ADC1 have risen about 5 ft since the early 1960's; the rise likely is due to increased recharge from infiltration of water diverted to the Michaud irrigation unit, which was completed in 1964.

AQUIFER PROPERTIES

Estimates of transmissivity and hydraulic conductivity were determined from aquifer tests conducted in seven domestic wells completed in the valley-fill aquifer and one well that probably taps water in Paleozoic rocks. Pump discharge and water-level drawdown and recovery were recorded for at least 2 hours at each site. Test data were analyzed with three methods—the straight line method for confined conditions (Lohman, 1979, p. 19–23), the curve-matching method for leaky confined conditions (Lohman, 1979, p. 30–32), and the

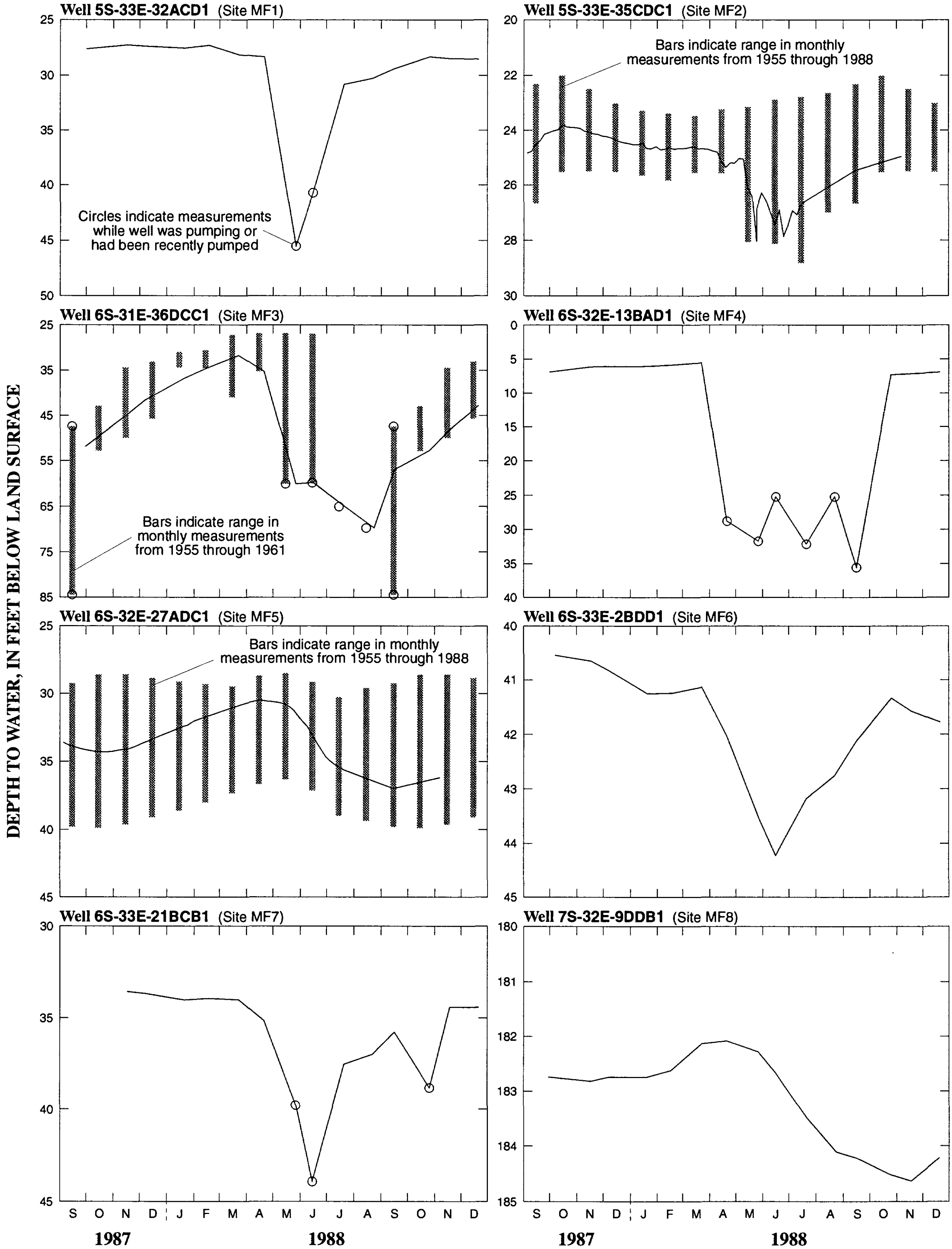


Figure 16. Water levels in selected wells on Michaud Flats, September 1987 to December 1988. (Locations of wells are shown by site identifier in figure 11)

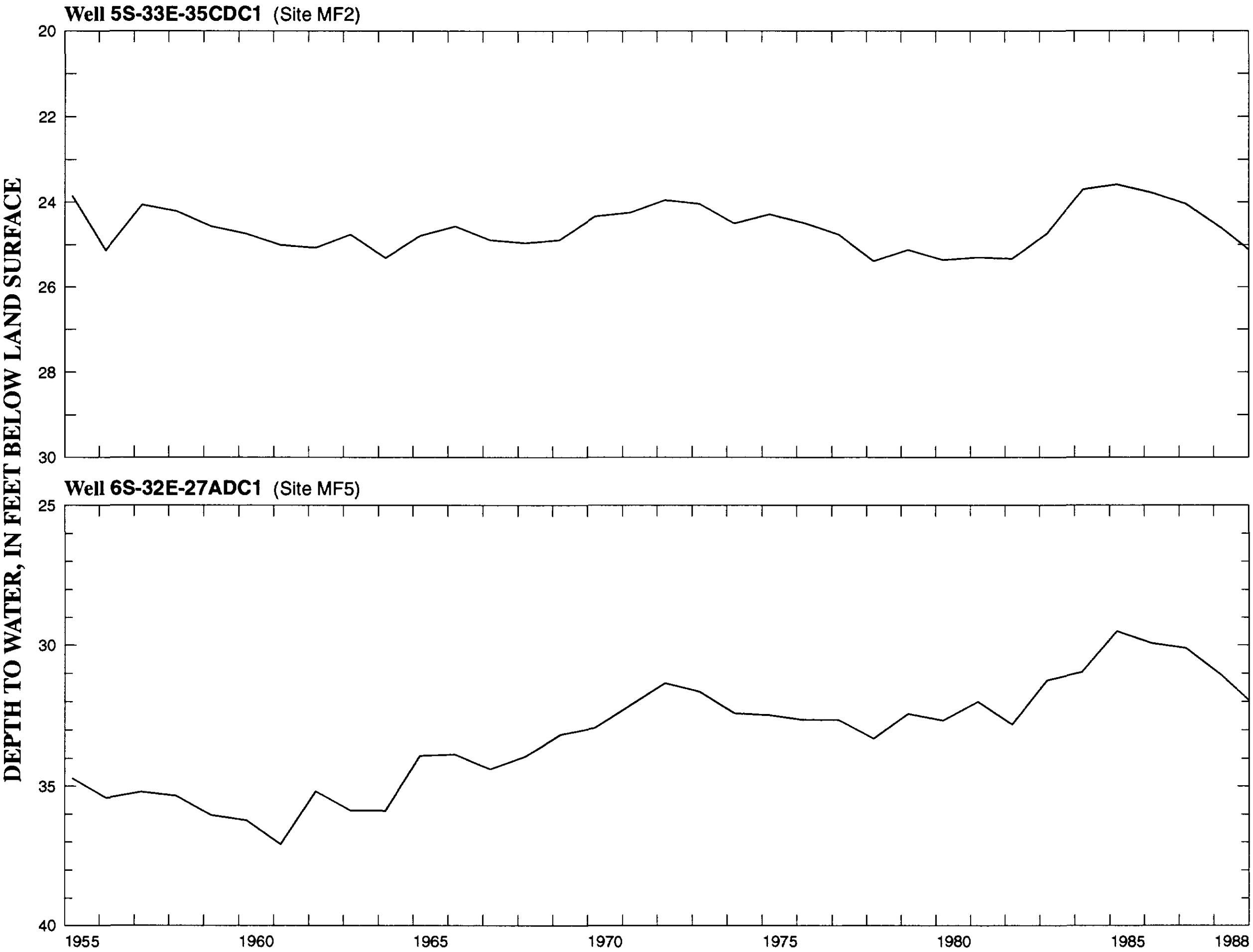


Figure 17. March water levels for two wells on Michaud Flats, 1955–88. (Locations of wells are shown by site identifier in figure 11)

curve-matching method for unconfined conditions with vertical movement (Lohman, 1979, p. 34–40). Analyses were corrected for the effects of partial penetration if the well withdrew water from less than the full thickness of the aquifer (Jacob, 1963, p. 272–273). For some tests, the analysis of data did not clearly indicate which of the three methods was the most appropriate to use. Because of the limited period of time that the tests were run and the uncertainty, in some cases, of the appropriateness of the methods used, a general range of estimated transmissivity is reported for each test (table 5). Transmissivity values estimated from the aquifer tests ranged from 50 to 3,000 ft^2/d (table 5), and the average was about 800 ft^2/d. Hydraulic conductivity was estimated by dividing average transmissivity by the length of the well open to the aquifer.

Most tested wells yielded water from sand and gravel. Two wells were completed in basalt, and one well probably was completed in limestone, although a lithologic log for the site was unavailable. The transmissivity value estimated for one of the wells completed in basalt was near the middle of the range of transmissivity values estimated for sand and gravel.

Specific capacity of a well is "the rate of discharge of water from the well divided by the drawdown of water level within the well" (Lohman and others, 1972, p. 11). Specific capacity of a well is affected by the transmissive properties of the aquifer; characteristics of the drilled hole; characteristics of the well casing, well screen, or pump; or a combination of these factors. Specific capacities of tested wells ranged from 1 to 55 (gal/min)/ft (table 5).

Jacobson (1982, p. 23; 1984, p. 14–15) calculated that transmissivity of the confined aquifer under Michaud Flats ranged from 19,600 to 444,000 ft^2/d for storage coefficients that ranged from 0.001 to 0.0001.

Table 5. Aquifer properties determined from aquifer-test data for selected wells in Bannock Creek Basin

[SG, sand and gravel; BT, basalt; LS?, probably limestone. Test methods (Lohman, 1979): 1, straight-line for confined conditions; 2, curve-matching for leaky confined conditions; 3, curve-matching for unconfined conditions with vertical movement. Data analyzed: d, drawdown; r, recovery; —, data unavailable]

Well number	Length of screened interval (feet)	General lithology of screened interval	Test methods and data analyzed	Range of estimated transmissivity (feet squared per day)	Average estimated hydraulic conductivity (feet per day)	Specific capacity (gallons per minute per foot)
7S-33E- 8CDA1	—	SG	2d, 3d	40–60	—	6
20CAD1	—	SG	1dr, 2d, 3d	300–3,000	—	4
32ACA1	32	SG	2d, 3dr	70–80	2	1
8S-33E- 5DDC1	2	BT	1dr, 2d, 3dr	500–900	350	2
9BB1	—	BT	—	—	—	55
9S-34E- 8ADD1	—	LS?	2d, 3dr	2,000	—	2
10S-33E-10DAC1	—	SG	2d, 3d	2,000	—	4
27DDD1	11	SG	2d, 3dr	100–200	14	1

Specific capacity ranged from 65 to 1,400 (gal/min)/ft (Jacobson, 1984, p. 15). Hydraulic conductivity was calculated by dividing estimated transmissivity by the perforated interval of the well casing (Jacobson, 1982, p. 18–20). Hydraulic conductivity ranged from 163 to 6,780 ft/d and averaged about 1,770 ft/d. Most wells yielded water from sand and gravel, but basalt was noted in drillers' logs for some of the wells. Greater transmissivity, hydraulic conductivity, and specific capacity for the Snake River Plain aquifer under Michaud Flats compared with those properties for the valley-fill aquifer probably can be attributed to differences in the texture of rocks in each area. Gravel is much coarser under Michaud Flats than in other parts of the Bannock Creek Basin.

UNDERFLOW

Underflow was calculated using Darcy's law and measured or estimated values for aquifer properties and other hydrologic characteristics. Darcy's law is stated as:

$$Q = 0.0084 \times K \times i \times w \times b, \quad (1)$$

where

Q = underflow, in acre-feet per year;
0.0084 = a conversion constant to reconcile units of measurement;
K = hydraulic conductivity, in feet per day;
i = hydraulic gradient, in feet per mile;
w = aquifer width, in miles; and
b = aquifer thickness, in feet.

Underflow from Arbon Valley, Rattlesnake Creek drainage, and middle Bannock Creek Valley (table 6) was computed using equation 1. An average value of 120 ft/d for hydraulic conductivity (table 5) was used for each subbasin. Values for hydraulic gradient were estimated from the water-table map (fig. 11), and values for aquifer width and thickness were estimated from the geologic sections (fig. 4). Calculations of underflow from lower Bannock Creek Valley were omitted because determinations of aquifer width and thickness were uncertain where the valley-fill aquifer and the Snake River Plain aquifer under Michaud Flats are hydraulically connected. Results obtained from calculations using equation 1 are compared with results obtained from water-budget analysis in the section "Water Yield."

Water Budgets

Water budgets were prepared to quantify the source and disposal of water within five subbasins of the Bannock Creek drainage that were affected in different ways by the presence or absence of irrigation. Sour-ces of water to subbasins include precipitation and water imported from outside the basin. Water was disposed

Table 6. Underflow calculated for selected subbasins in the Bannock Creek drainage

Subbasin (fig. 1)	Underflow (acre-feet per year)	Hydraulic gradient (feet per mile)	Aquifer width (miles)	Aquifer thickness (feet)
Arbon Valley	280	30	0.62	15
Rattlesnake Creek drainage	640	85	.15	50
Middle Bannock Creek Valley	3,100	31	1	100

as runoff to streams; consumptive use by ET from phreatophytes, native vegetation, and dryland and irrigated crops; withdrawals from domestic and irrigation wells; and ground-water recharge to the valley-fill aquifer.

Water budgets were determined by identification of the quantity of water associated with each term in the following general equation:

$$P + I = RO + GWET + ETDRY + ETIRR + PUMPD + PUMPI + GWRECH, \qquad (2)$$

where

P = precipitation, in acre-feet per year;
I = surface-water imports from outside the basin, in acre-feet per year;
RO = surface-water runoff, in acre-feet per year;
$GWET$ = ground-water evapotranspiration by phreatophytes, in acre-feet per year;
$ETDRY$ = evapotranspiration from nonirrigated areas of native vegetation or dryland crops, in acre-feet per year;
$ETIRR$ = evapotranspiration from irrigated areas, in acre-feet per year;
$PUMPD$ = ground-water withdrawals for domestic use, in acre-feet per year;
$PUMPI$ = ground-water withdrawals for irrigation, in acre-feet per year; and
$GWRECH$ = net ground-water recharge, in acre-feet per year.

The quantity of water available from precipitation was estimated by multiplying average annual precipitation for 1965–89 by surface area (table 1). Surface-water imports were obtained from available records. Surface-water runoff was estimated by multiplying average annual 1965–89 runoff (table 2) by surface area (table 1). Average runoff from representative streamflow-gaging stations was used to calculate runoff for some parts of the basin that did not have a gaging station at their outlet. Ground-water ET by phreatophytes was estimated by multiplying area supporting phreatophytes by calculated crop ET rate of 23.1 in/yr. Areas supporting phreatophytes were planimetered from 1:24,000-scale U.S. Geological Survey topographic maps. ET from nonirrigated areas of native vegetation and (or) dryland crops was estimated by multiplying nonirrigated area, minus the area that supports phreatophytes, by the initial ET rate of 17.3 in/yr. ET from surface-water irrigated tracts was estimated by multiplying irrigated area by calculated crop ET of 23.1 in/yr, which was determined with the recharge program developed by Johnson and Brockway (1993). Ground-water withdrawals from domestic wells were estimated by multiplying the number of domestic wells in each subbasin by a well factor. The well factor was determined by multiplying average measured pump discharge of 8 gal/min by the average amount of time a domestic well might be expected to be in use, assumed to be 2 hours per day throughout the year. Ground-water withdrawals for irrigation were estimated as consumptive use or estimated from electrical power-consumption and related information and are explained in the discussion for individual subbasins in the following paragraphs.

Net ground-water recharge was estimated as a residual from all other terms in equation 2. Net ground-water recharge represents recharge to the valley-fill aquifer that leaves the subbasin as underflow and does not include ground-water recharge that leaves the subbasin as discharge to streams. Ground water that eventually discharges to streams (base flow) was included in estimates of average streamflow and surface-water runoff discussed earlier in this report (table 2).

After an initial water budget for each subbasin was generated with the preceding approach, the initial ET rate of 17.3 in/yr for nonirrigated areas of native vegetation and dryland crops was adjusted to obtain a value of cumulative ground-water underflow for each subbasin that was reasonable compared with underflow values determined in the "Underflow" section of this report. Cumulative ground-water underflow from Arbon Valley, Rattlesnake Creek drainage, and West Fork drainage was defined equal to ground-water recharge. Cumulative ground-water underflow from middle and lower Bannock Creek Valleys was defined to equal ground-water recharge in each subbasin plus cumulative ground-water underflow from the subbasin immediately upstream from the subbasin of interest. The adjusted ET rate for nonirrigated areas never exceeded the precipitation rate in each subbasin.

ARBON VALLEY

Arbon Valley covers 92,200 acres, of which 24,500 acres are underlain by the valley-fill aquifer. Average precipitation in Arbon Valley was estimated to be 156,000 acre-ft/yr (table 7). There is no streamflow-gaging station on Bannock Creek at the outlet of Arbon Valley, and it was assumed that a weighted average of

Table 7. Water budget for Arbon Valley

[All values are in acre-feet per year rounded to three significant figures; —, not applicable]

Budget item	Source	Disposal
Precipitation	156,000	—
Surface-water runoff	—	11,700
Evapotranspiration by phreatophytes	—	741
Evapotranspiration from nonirrigated areas	—	140,000
Withdrawals from wells		
Domestic	—	19
Irrigation	—	2,400
Net ground-water recharge	—	1,090
Total	156,000	156,000

surface-water runoff at stations 07599660, 0761, and 076110 best represented average runoff in the valley. A weighted average runoff of 81 (acre-ft/mi^2)/yr was computed for the three stations (table 2) and multiplied by surface area (table 1) to obtain an average runoff value of 11,700 acre-ft/yr for Arbon Valley. For comparison, average runoff for the valley also was computed using only average runoff at station 076110 on Bannock Creek (table 2). However, the computed value for net ground-water recharge (equation 2) and underflow based on this estimate did not reasonably match the estimate of underflow determined using Darcy's law (table 6).

ET by phreatophytes on 385 acres was estimated to consume 741 acre-ft/yr of ground water. ET from nonirrigated areas of native vegetation and dryland crops was estimated to be 140,000 acre-ft/yr using an ET rate of 18.3 in/yr. Ground-water withdrawals from 18 domestic wells were estimated to total 19 acre-ft/yr. Withdrawals for irrigation were estimated to be 2,400 acre-ft/yr under the assumption that an average of 1.5 acre-ft/acre of water was applied to an average 200-acre irrigated field by each of eight irrigation wells. Crop ET was assumed to consume all ground water pumped for irrigation. Ground-water underflow was defined equal to the net ground-water recharge residual of 1,090 acre-ft/yr.

RATTLESNAKE CREEK DRAINAGE

The Rattlesnake Creek drainage covers 50,600 acres, of which 1,750 acres are underlain by the valley-fill aquifer. Average precipitation in the Rattlesnake Creek drainage was estimated to be 86,000 acre-ft/yr (table 8). Average runoff at streamflow-gaging station 0761 (table 2) was used to calculate surface-water runoff of 9,090 acre-ft/yr for the Rattlesnake Creek drainage (table 8). ET by phreatophytes on 30 acres was estimated to consume 58 acre-ft/yr of ground water. ET from nonirrigated areas of native vegetation and dryland crops was estimated to be 75,800 acre-ft/yr using an ET rate of 18 in/yr. Ground-water withdrawals from seven domestic wells were estimated to total 8 acre-ft/yr. Ground-water underflow was defined equal to the net ground-water recharge residual of 1,010 acre-ft/yr.

WEST FORK DRAINAGE

The West Fork drainage covers 10,900 acres. A significant valley-fill aquifer is not present in the drainage. Average precipitation in the drainage was estimated to be 21,900 acre-ft/yr (table 9). Average runoff at streamflow-gaging station 07599660 (table 2) was used to calculate a surface-water runoff of 6,320 acre-ft/yr for West Fork drainage. ET from nonirrigated areas of native vegetation was estimated to be 15,500 acre-ft/yr using an ET rate of 17.1 in/yr. No crops are grown in the drainage.

MIDDLE BANNOCK CREEK VALLEY

Middle Bannock Creek Valley covers 76,800 acres, of which 5,030 acres are underlain by the valley-fill aquifer. The Bannock Creek minor irrigation unit overlies 1,280 acres of the valley-fill aquifer. Average precipitation in middle Bannock Creek Valley was estimated to be 122,000 acre-ft/yr (table 10). Average runoff for streamflow-gaging station 076110 (table 2), the nearest gaging station on Bannock Creek, was used to calculate surface-water runoff of 5,640 acre-ft/yr. ET by phreatophytes on 735 acres was estimated to consume 1,410 acre-ft/yr of ground water. ET from nonirrigated areas of native vegetation and dryland crops was estimated to be 107,000 acre-ft/yr using an ET rate of

Table 8. Water budget for Rattlesnake Creek drainage

[All values are in acre-feet per year rounded to three significant figures; —, not applicable]

Budget item	Source	Disposal
Precipitation	86,000	—
Surface-water runoff	—	9,090
Evapotranspiration by phreatophytes	—	58
Evapotranspiration from nonirrigated areas	—	75,800
Withdrawals from wells		
Domestic	—	8
Net ground-water recharge	—	1,010
Total	86,000	86,000

Table 9. Water budget for West Fork drainage

[All values are in acre-feet per year rounded to three significant figures; —, not applicable. Column totals do not match because of rounding]

Budget item	Source	Disposal
Precipitation	21,900	—
Surface-water runoff	—	6,320
Evapotranspiration from nonirrigated areas	—	15,500
Total	21,900	21,800

17.1 in/yr. ET from crops grown on 1,280 acres in the Bannock Creek minor irrigation unit was estimated to be 2,460 acre-ft/yr. Ground-water withdrawals from 28 domestic wells were estimated to total 30 acre-ft/yr. Net ground-water recharge was estimated by residual to equal 5,480 acre-ft/yr. Cumulative underflow to lower Bannock Creek Valley was 7,580 acre-ft/yr.

LOWER BANNOCK CREEK VALLEY

Lower Bannock Creek Valley covers 48,000 acres, of which 11,400 acres are underlain by the valley-fill aquifer. The Michaud irrigation unit overlies all of the valley-fill aquifer in this part of the basin and 2,400 acres that lie above the valley floor on Wheatgrass Bench, a total of 13,800 acres. The total average precipitation in lower Bannock Creek Valley was 64,800 acre-ft/yr (table 11). Streamflow diversions from Bannock Creek were supplemented with streamflow transferred in the Taghee Canal from the Portneuf River (fig. 8) and with ground-water withdrawals from wells completed in the Snake River Plain aquifer under Michaud Flats to supply water for the Michaud irrigation unit. Average streamflow transfers from 1980 through 1988 were 32,500 acre-ft/yr, but about 8,120 acre-ft/yr, or 25 percent, of the transferred water is lost through the canal bottom, as explained earlier in this report.

Table 10. Water budget for middle Bannock Creek Valley

[All values are in acre-feet per year rounded to three significant figures; —, not applicable]

Budget item	Source	Disposal
Precipitation	122,000	—
Surface-water runoff	—	5,640
Evapotranspiration by phreatophytes	—	1,410
Evapotranspiration from nonirrigated areas	—	107,000
Evapotranspiration from irrigated areas	—	2,460
Withdrawals from wells		
Domestic	—	30
Net ground-water recharge	—	5,480
Total	122,000	122,000

Most of the canal traverses Michaud Flats, and water lost through the canal bottom recharges the Snake River Plain aquifer under Michaud Flats. Average withdrawals from nine supplemental wells were calculated to be about 3,830 acre-ft/yr; the method used to calculate irrigation withdrawals is explained later in this section. Average runoff for streamflow-gaging station 076110 (table 2), the nearest gaging station on Bannock Creek not affected by imported water, was used to calculate surface-water runoff of 3,530 acre-ft/yr for lower Bannock Creek Valley. ET from nonirrigated areas of native vegetation and dryland crops was estimated to be 46,200 acre-ft/yr using an ET rate of 16.2 in/yr. All land that overlies the valley-fill aquifer is irrigated in this part of the basin, and crop ET from the Michaud irrigation unit was about 26,600 acre-ft/yr. Ground-water withdrawals from 10 domestic wells were estimated to total 11 acre-ft/yr. Net ground-water recharge was estimated by residual to equal 16,700 acre-ft/yr. Cumulative underflow from lower Bannock Creek Valley was 24,300 acre-ft/yr.

Table 11. Water budget for lower Bannock Creek Valley

[All values are in acre-feet per year rounded to three significant figures; —, not applicable. Column totals do not match because of rounding]

Budget item	Source	Disposal
Precipitation	64,800	—
Imported water from outside of basin		
Portneuf River water	24,400	—
Ground water from nine supplemental wells in Michaud Flats	3,830	3,530
Evapotranspiration from nonirrigated areas	—	46,200
Evapotranspiration from irrigated areas	—	26,600
Withdrawals from wells		
Domestic	—	11
Net ground-water recharge	—	16,700
Total	93,000	93,000

Withdrawals from nine supplemental wells in Michaud Flats were calculated using the relation:

$$Withdrawals = \frac{power\ consumption}{pump\ efficiency \times total\ head} . \quad (3)$$

Average power consumption of about 388,000 kWh/yr was obtained from records made available by the agency that provided electrical power to the wells (M.E. Van

Den Berg, Bureau of Reclamation, Burley, Idaho, written commun., 1989). A value of 1.69 was used for efficiency, which is the number of kilowatthours used to lift 1 acre-ft of water 1 ft. An efficiency of 1.69 also was reported for irrigation wells on the Snake River Plain (Bigelow and others, 1986). An average value of 60 ft was used for total hydraulic head, which is the sum of pumping lift (depth to water), drawdown, and pressure head. Depth to water in the area averaged about 40 ft (table 4, back of report); average drawdown was about 20 ft, as indicated by water-level measurements in selected wells on Michaud Flats (fig. 16). Pressure head is the additional hydraulic head due to the type of irrigation system and was determined to be zero because all wells discharge directly into canals and no additional pressure was incurred.

Surface-Water and Ground-Water Relations

A stream gains water from an adjacent aquifer when ground-water levels are higher than stream stage. Conversely, a stream loses water to an adjacent aquifer when ground-water levels are lower than stream stage. The connection between surface water and ground water within subbasins can affect the ratio between the quantity of surface-water runoff and ground-water underflow that leaves the subbasin. Long-term data needed to identify the effects of streamflow gains and losses within different parts of the basin were not available. However, miscellaneous streamflow measurements were made during August and October 1987 to identify the magnitude of gains and losses for stream reaches along the length of Bannock Creek (Harenberg and others, 1987, p. 409–410). Measurements were made at selected points on the main stem of Bannock Creek between its headwaters in Arbon Valley and streamflow-gaging station 0762, Bannock Creek near Pocatello (fig. 6), and at all points of tributary inflow, diversion, and irrigation-return flow. Bannock Creek mostly gained flow from ground water during both August and October upstream from the confluence of Bannock Creek with Rattlesnake Creek (station 076120, fig. 18). Downstream from Rattlesnake Creek, Bannock Creek gained flow from ground water during August but lost flow to ground water during October.

Measurements indicate that streamflow gains generally were less and losses greater during August than during October for most reaches upstream from the confluence of Rattlesnake Creek with Bannock Creek. Scant precipitation was recorded at the Arbon weather station (fig. 5) between measurements; therefore, increased streamflow gains and decreased streamflow losses during October are attributed to a reduction in ET that resulted when phreatophytes along Bannock Creek went dormant following a killing frost that preceded the October measurements.

Downstream from Rattlesnake Creek, decreased streamflow gains and increased streamflow losses during October are attributed to changes in gradients between stream stage and water levels in the adjacent valley-fill aquifer associated with changes in irrigation. A hydrograph showing water levels in well 7S-33E-29DBB2 (fig. 15) along this reach of the stream indicates that ground-water levels increased during the April-September irrigation season when the aquifer received recharge from irrigation; levels decreased when the irrigation season ended. Higher water levels in the aquifer produced gradients from the aquifer to the stream during the irrigation season that resulted in stream gains; lower water levels in the aquifer produced gradients from the stream to the aquifer after the irrigation season that resulted in stream losses. Phreatophytes had little, if any, effect on surface-water and ground-water relations in the downstream reach. Bannock Creek flows in an incised channel that is 10 to 20 ft below land surface from Rattlesnake Creek to gaging station 0762. The incised channel through most of the lower reach does not provide a favorable habitat for phreatophyte growth compared with the low, marshy areas that are present along the reach upstream from Rattlesnake Creek.

WATER YIELD

Water yield is defined in this report as the annual quantity of surface-water runoff and ground-water underflow that results from precipitation in excess of ET by crops and native vegetation. Neglecting ET by crops and other effects from irrigation, water yield from Bannock Creek Basin, excluding Michaud Flats, was calculated as the difference between average 1965–89 precipitation of 19.4 in/yr and weighted average ET by native vegetation of 17.5 in/yr, or 1.9 in/yr. In comparison, water yield from other drainage basins in eastern and southeastern Idaho and south of the Snake River ranges from 1.4 to 5.5 in/yr (Williams and Young, 1982, p. 18). A water yield of 1.9 in/yr converts to about

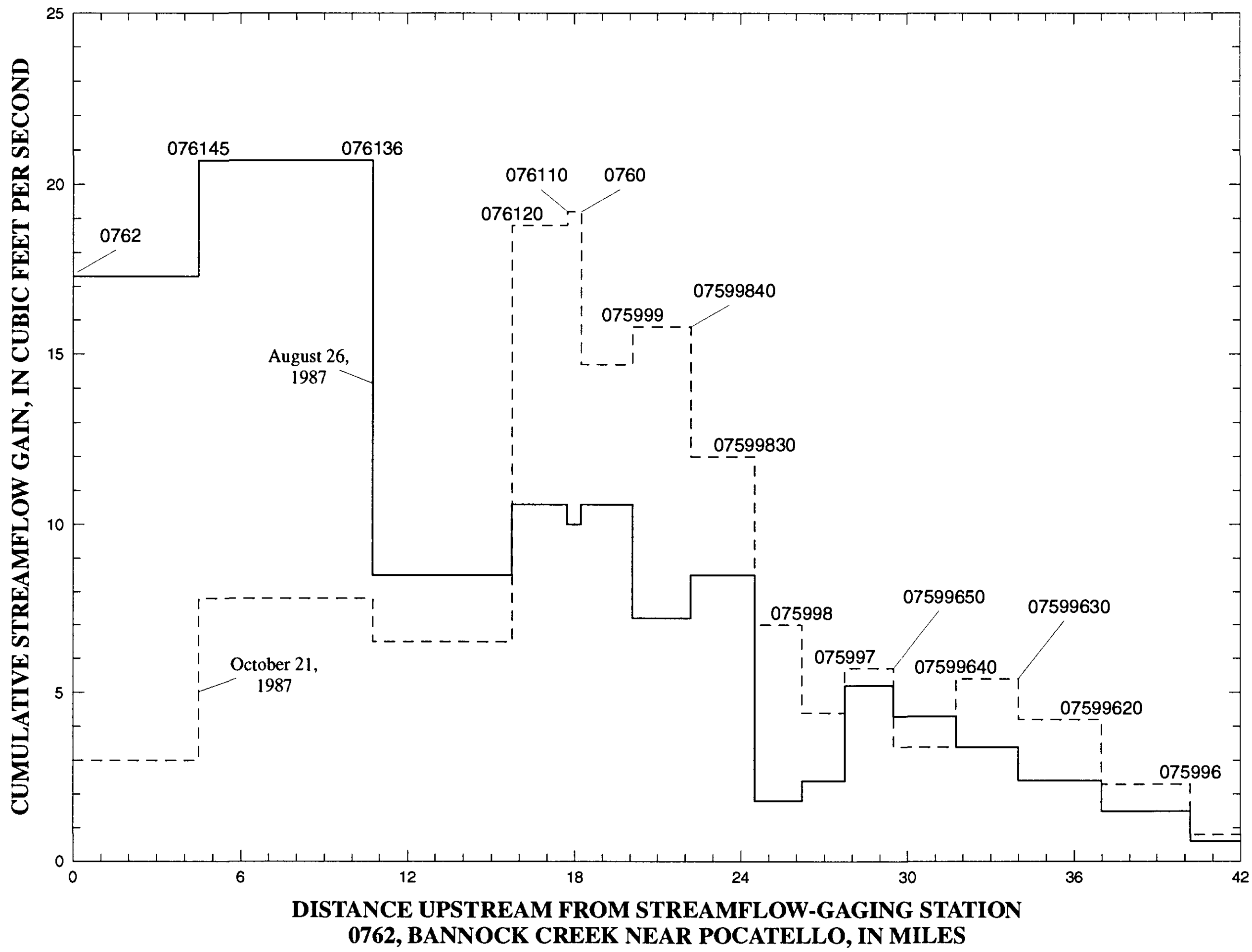


Figure 18. Cumulative streamflow gains between miscellaneous streamflow-measurement sites along Bannock Creek, August 26 and October 21, 1987. (Streamflow gains are accumulated starting at measurement site 075996; locations of measurement sites are shown in figure 6)

44,100 acre-ft/yr for the 435 mi^2 in the five subbasins of Bannock Creek Basin.

Irrigation has changed water yield from the basin. Water yield has decreased and ET has increased in parts of the basin as a result of diversion of surface water for irrigation and pumping of ground water for domestic and irrigation uses. Water yield has increased in other parts of the basin as a result of water imported from the Portneuf River for irrigation. The water budgets presented in tables 7 through 11 can be used to determine water yield when the effects of irrigation between 1965 and 1989 are considered. Water yield from any part of the Bannock Creek Basin can be determined from water budgets (tables 7–11) as the sum of surface-water runoff and underflow from ground-water recharge for that part of the basin and all parts tributary. Total surface-water runoff was 36,300 acre-ft/yr, and total underflow was 24,300 acre-ft/yr for a water yield of 60,600 acre-ft/yr from the Bannock Creek Basin.

Regression equations that related drainage area, precipitation, and forest cover to runoff in southern Idaho were developed in two other studies. Using values for drainage area and precipitation cited elsewhere in this report and forest cover from land-cover maps (U.S. Geological Survey, 1986), water yields for Bannock Creek Basin calculated from the previously published regression equations were 47,000 acre-ft/yr (Horn, 1988, p. 465, equation 4) and 63,000 acre-ft/yr (Quillian and Harenberg, 1982, p. 16, region 8). Low and high water yields obtained from the regression equations varied about 6 percent and less than 4 percent from respective results obtained in this study.

Water yield from water derived solely within the Bannock Creek Basin was best represented by the sums of runoff and underflow from net ground-water recharge for Arbon Valley (table 7), Rattlesnake Creek drainage (table 8), West Fork drainage (table 9), and middle Bannock Creek Valley (table 10). Runoff totaled 32,800 acre-ft/yr, and underflow totaled 7,580 acre-ft/yr for a water yield of 40,400 acre-ft/yr from these subbasins. Water yield from lower Bannock Creek Valley was not derived solely from within Bannock Creek Basin and included surface water imported from the Portneuf River and ground water pumped from the Snake River Plain aquifer under Michaud Flats.

Water yield from the Fort Hall Indian Reservation part of Bannock Creek Basin was calculated as the sum of runoff and underflow from net ground-water recharge for West Fork drainage (table 9), middle Bannock Creek Valley (table 10), and lower Bannock Creek Valley (table 11). Runoff totaled 15,500 acre-ft/yr, and underflow totaled 22,200 acre-ft/yr for a water yield of 37,700 acre-ft/yr from these subbasins. Runoff was 11,700 acre-ft/yr, and underflow was 1,090 acre-ft/yr for a water yield of 12,800 acre-ft/yr from Arbon Valley. Runoff was 9,090 acre-ft/yr, and underflow was 1,010 acre-ft/yr for a water yield of 10,100 acre-ft/yr from the Rattlesnake Creek drainage.

Underflow values reported in this section are different from values reported in the "Underflow" section of this report. Underflow values (table 6) calculated using Darcy's law as stated in equation 1 were about 75 percent less for Arbon Valley, 35 percent less for Rattlesnake Creek drainage, and 52 percent less for middle Bannock Creek Valley than underflow values derived from the water budgets (tables 7–11). Differences between underflow calculated using Darcy's law and underflow obtained from water budgets may be the result of uncertainty in estimates of aquifer thickness and average hydraulic conductivity at the outlets of subbasins. The contacts between the base of the valley-fill aquifer and the underlying Tertiary volcanic rock near the outlets of Arbon Valley, Rattlesnake Creek drainage, and middle Bannock Creek Valley (fig. 4) were delineated on the basis of limited data from test drilling and surface geophysics. Thus, the accuracy of the cross-sectional area used in equation 1 to calculate underflow for these basins is unknown. Also, estimates of hydraulic conductivity were obtained from aquifer tests in domestic wells that are screened in only part of the aquifer. The hydraulic conductivity of the valley fill may change substantially with depth. Although corrections for partial penetration were made when interpreting the test data, the corrections cannot compensate for unknown changes in hydraulic conductivity with depth.

The accuracy of the hydraulic conductivity values reported in table 5 is unknown, and the values may not represent the actual distribution of hydraulic conductivity in the valley-fill aquifer. Therefore, calculations were made to examine whether the underflow values obtained from water budgets would be determined with hydraulic conductivity values that varied within acceptable limits. Equation 1 was rearranged to solve for hydraulic conductivity by supplying the underflow values reported earlier in this section. Calculated hydraulic conductivity values were about 465 ft/d for Arbon Valley, 189 ft/d for the Rattlesnake Creek drainage, and 291 ft/d for middle Bannock Creek Valley. Calculated hydraulic conductivity values then were compared with values reported for different textures of unconsolidated deposits. Calculated values were within the range of values reported for sand and gravel (Freeze and Cherry, 1979, p. 29, table 2.2). Sand and gravel were predominant in samples from test drilling along sections $A-A'$ and $C-C'$ in the valley-fill deposits along Bannock Creek (fig. 4). Although no subsurface data were available for the area near the mouth of Rattlesnake Creek, the valley-fill deposits were assumed to be similar to those along Bannock Creek. Because underflow could be calculated using values of hydraulic conductivity that varied within acceptable limits, the underflow values derived from the water budgets were considered to be reasonable.

CHEMICAL CHARACTERISTICS OF WATER

Water samples were collected in 1988 from 16 wells, 23 springs, and at 3 measurement sites on streams. Ground and surface water in the Bannock Creek Basin is a calcium bicarbonate type, as indicated by the plots of water analyses on the trilinear diagram in figure 19. The trilinear diagram differentiates the major ionic species in a water sample in terms of percentages of the total milliequivalents of major cations and anions per liter of water (Hem, 1989, p. 177). Total major cations in most water samples ranged from 50 to 70 percent calcium. Total major anions in most samples were more than 50 percent carbonate plus bicar-

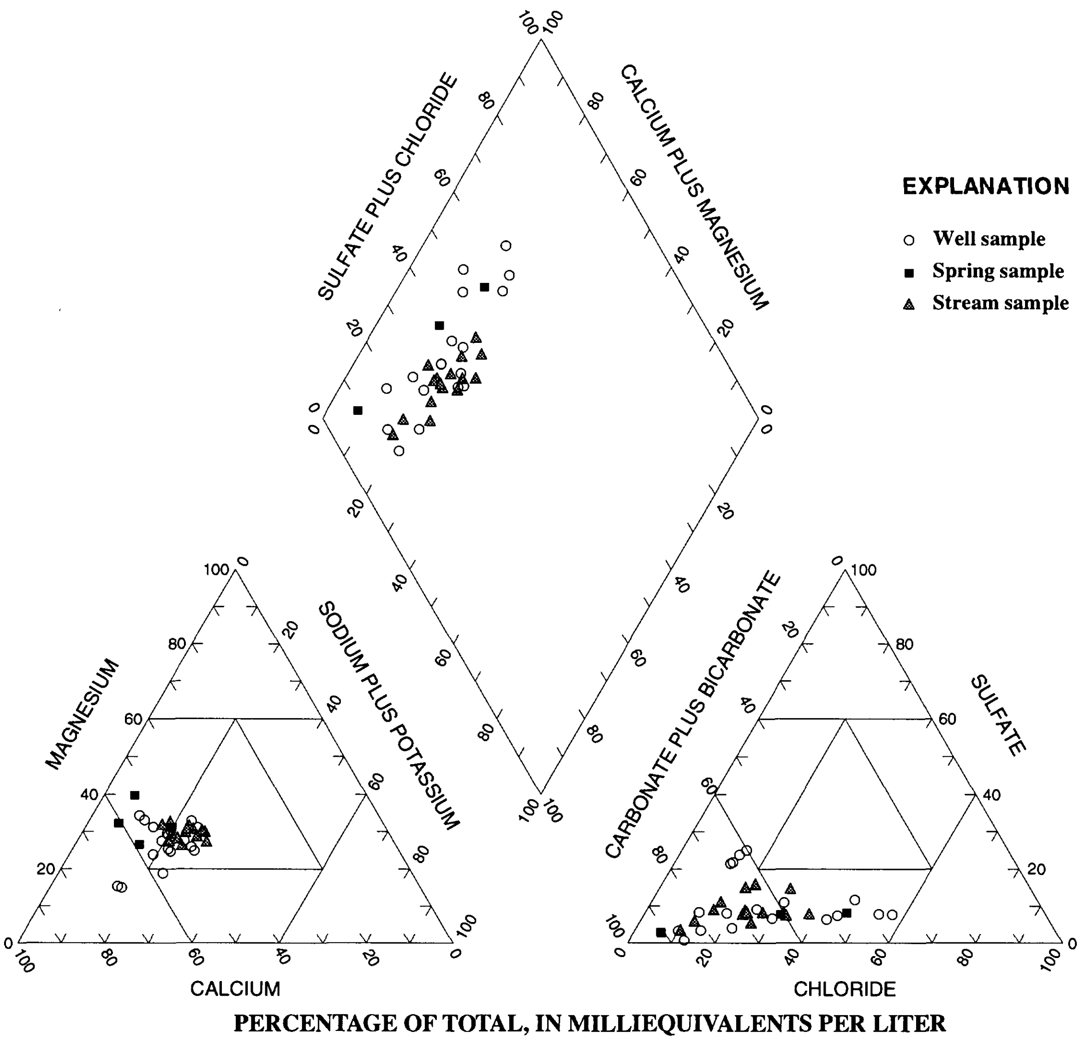


Figure 19. Chemical composition of water from selected wells, springs, and streams in Bannock Creek Basin, 1988.

bonate. Because pH of the stream samples is near 8.3 (table 12), bicarbonate predominates over carbonate (Hem, 1985, p. 107).

Stable-isotope ratios of δdeuterium and δ^{18}oxygen can be used to infer the source of water in the basin. Stable-isotope ratios from surface- and ground-water samples collected in the study area are plotted in figure 20 in relation to the world meteoric line. The world meteoric line defines the standard, called V-SMOW, to which isotopic analyses are compared. Stable-isotope ratios in water samples collected for this study are enriched in δdeuterium and δ^{18}oxygen compared with V-SMOW and plot below the world meteoric line. Stable-isotope ratios from water samples are similar to ratios reported for other parts of eastern Idaho (Wood and Low, 1988, p. 15). Water that is enriched with oxygen has evaporated at or near land surface in a semiarid environment prior to running off into streams or recharging the aquifer (Gat, 1981, p. 223) and implies that, like water in the eastern Snake River Plain (Wood and Low, 1988, p. 15), water in the Bannock Creek Basin is derived from local precipitation.

Water from wells, springs, and streams did not show an appreciable difference in ionic composition (fig. 19 and table 12). Concentrations of nitrite plus nitrate as nitrogen and fluoride in water from wells and springs were less than Maximum Contaminant Levels for public drinking-water supplies (U.S. Environmental Protection Agency, 1988a, b).

Water samples from wells and streams that plot on the anion triangle, on the lower right in figure 19, are bounded by lines of 60 percent carbonate plus bicarbonate to 40 percent chloride, 40 percent chloride to 60 percent chloride, and 60 percent chloride to 40 percent

Table 12. Water-quality analyses for selected wells, springs, and streams in Bannock Creek Basin

[µS/cm, microsiemens per centimeter at 25°C; °C, degrees Celsius; mg/L, milligrams per liter; δdeuterium, deuterium/hydrogen ratio; $\delta^{18}O$, oxygen-18/oxygen-16 ratio; permil, per thousand; —, data unavailable; ft^3/s, cubic feet per second; f, onsite determination; <, less than]

Well, spring, or gaging-station number (fig. 6 or 11)	Sample date (month-day-year)	Specific conductance (µS/cm)	pH (standard units)	Water temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Sulfate (mg/L as SO_4)	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Silica (mg/L as SiO_2)	Nitrogen, $NO_2 + NO_3$ (mg/L as N)	Phosphorus (mg/L as P)	δ deuterium (permil)	$\delta^{18}O$ (permil)
Wells																	
6S-31E-36DCC1	6- 2-55	—	—	15.0	—	32	14	19	5.0	42	18	—	—	—	—	—	—
	6-21-88	375	8.1	15.5	126	36	12	20	6.1	39	16	0.5	46	0.23	0.01	-139.0	-18.35
33E- 9CAC1	8-31-76	—	—	11.5	—	51	16	19	3.9	60	23	.7	26	.71	.03	—	—
	6-21-88	452	8.1	12.5	153	49	17	20	3.6	48	18	.6	27	.83	<.01	-137.5	-18.15
32DCA1	6-21-88	1,250	7.3	10.5	258	120	42	67	5.5	70	190	.2	31	5.2	.04	-127.0	-16.60
7S-33E-29CAD1	6-21-88	732	7.6	12.0	251	76	28	31	7.0	34	67	.3	42	.28	.03	—	—
8S-33E- 5ABD1	6-21-88	571	7.5	13.0	219	60	21	22	7.4	23	38	.4	110	.16	.04	-134.5	-17.75
27CBA1	6-22-88	1,170	7.4	12.5	308	130	37	59	9.5	65	130	.3	49	1.1	.05	—	—
34E-30ABD1	6-22-88	488	7.6	12.5	211	58	22	12	1.8	8.5	25	.2	27	.79	.02	-131.5	-17.40
9S-33E- 3CCB1	6-22-88	493	7.6	17.5	207	46	21	23	9.1	21	22	.3	79	<.10	.02	—	—
34E- 8ADD1	6-22-88	787	7.6	16.0	189	84	31	18	7.2	28	120	.2	62	1.2	.03	—	—
21AAA1	6-22-88	688	7.4	11.5	174	73	26	20	7.4	21	100	.3	62	.77	.03	-136.0	-17.60
10S-33E-11ADB1	6-22-88	587	7.5	14.0	190	56	18	33	9.3	19	59	.3	61	.96	.02	—	—
27DDD1	6-23-88	365	7.6	11.5	164	52	6.9	12	3.9	6.1	12	.2	50	.42	.02	-136.5	-18.05
34E-19BBB1	6-23-88	484	7.4	11.0	221	55	16	22	7.0	1.8	22	.3	67	<.10	.03	—	—
11S-33E-10ABB2	6-23-88	429	7.6	14.0	158	61	8.2	14	2.4	8.5	32	.3	51	.29	.01	—	—
12S-33E- 1CAB1	6-23-88	1,060	7.6	13.0	190	120	24	56	2.8	40	190	.2	26	3.9	.05	-133.0	-17.10
22CAA1	6-23-88	1,200	7.4	11.5	202	130	33	48	3.7	43	220	.2	32	4.6	.04	—	—
Springs																	
7S-33E- 3BDD1S	6-30-88	514	7.6	18.5	167f	—	—	—	—	—	—	—	—	—	—	—	—
	11- 1-88	1,080	—	11.0	—	—	—	—	—	—	—	—	—	—	—	—	—
8S-32E-26DDA2S	5-24-88	521	7.8	12.0	166	62	17	15	4.5	18	52	0.3	49	0.42	0.06	-137.0	-17.95
	11- 1-88	488	7.8	11.0	159f	—	—	—	—	—	—	—	—	—	—	—	—
32CCB1S	5-25-88	533	—	9.0	—	—	—	—	—	—	—	—	—	—	—	—	—
	11- 2-88	513	7.0	10.0	182f	—	—	—	—	—	—	—	—	—	—	—	—
33E- 1ABD1S	7- 1-88	—	8.3	10.5	—	—	—	—	—	—	—	—	—	—	—	—	—
10ADA1S	5-28-88	261	—	24.0	—	—	—	—	—	—	—	—	—	—	—	—	—
11DBC1S	5-28-88	426	7.7	15.0	249f	—	—	—	—	—	—	—	—	—	—	—	—
28ACB1S	11- 4-88	531	7.7	17.0	234f	—	—	—	—	—	—	—	—	—	—	—	—
30CCC1S	5-25-88	504	—	12.5	—	—	—	—	—	—	—	—	—	—	—	—	—
	11- 1-88	523	8.0	9.5	202f	—	—	—	—	—	—	—	—	—	—	—	—
34E-31BAC1S	5-28-88	833	7.6	12.0	179	80	31	36	1.7	32	130	.2	20	1.5	.02	-130.0	-17.30
	11- 3-88	729	7.7	12.0	181f	—	—	—	—	—	—	—	—	—	—	—	—
9S-32E- 4CBB1S	5-25-88	1,130	—	10.0	—	—	—	—	—	—	—	—	—	—	—	—	—
	11- 2-88	1,020	—	10.0		—	—	—	—	—	—	—	—	—	—	—	—
9DCA1S	5-25-88	449	7.7	15.0	218	53	24	7.0	1.8	6.9	9.6	.2	13	.21	.01	-131.0	-17.50
	11- 2-88	425	7.5	15.0	224f	—	—	—	—	—	—	—	—	—	—	—	—
10CCC1S	5-25-88	588	—	14.0	—	—	—	—	—	—	—	—	—	—	—	—	—
16ADC1S	5-25-88	541	—	15.5	—	—	—	—	—	—	—	—	—	—	—	—	—
	11- 2-88	583	—	10.5	—	—	—	—	—	—	—	—	—	—	—	—	—
23BCA1S	5-27-88	595	—	10.0	—	—	—	—	—	—	—	—	—	—	—	—	—
	11- 2-88	680	7.5	10.0	280f	—	—	—	—	—	—	—	—	—	—	—	—
23CBD1S	5-27-88	415	—	8.5	—	—	—	—	—	—	—	—	—	—	—	—	—
	11- 2-88	438	7.3	9.0	226f	—	—	—	—	—	—	—	—	—	—	—	—
34E- 2DDC1S	5-28-88	332	—	8.5	—	—	—	—	—	—	—	—	—	—	—	—	—
35E-18BDD1S	5-28-88	457	7.3	7.0	222f	—	—	—	—	—	—	—	—	—	—	—	—
	11- 3-88	475	7.5	8.0	220f	—	—	—	—	—	—	—	—	—	—	—	—
10S-33E- 5CDA1S	5-27-88	431	7.7	13.5	181	59	19	7.2	1.1	6.1	9.4	.2	10	.29	<.01	-130.5	-17.35
	11- 2-88	372	7.7	14.5	223f	—	—	—	—	—	—	—	—	—	—	—	—
8ADC1S	5-27-88	575	—	14.0	—	—	—	—	—	—	—	—	—	—	—	—	—
11S-32E- 1CDC1S	5-27-88	505	7.6	6.5	269f	—	—	—	—	—	—	—	—	—	—	—	—
	11- 3-88	512	7.4	7.0	267f	—	—	—	—	—	—	—	—	—	—	—	—
33E-21ABC1S	7- 1-88	—	8.2	9.5	233f	—	—	—	—	—	—	—	—	—	—	—	—
21ABC1S	11- 3-88	452	7.3	9.5	187f	—	—	—	—	—	—	—	—	—	—	—	—
34E- 4ABC1S	5-28-88	937	7.3	10.0	241f	—	—	—	—	—	—	—	—	—	—	—	—
	11- 3-88	1,000	7.4	9.0	243f	—	—	—	—	—	—	—	—	—	—	—	—
12S-33E- 5BAC1S	5-28-88	526	—	9.0	—	—	—	—	—	—	—	—	—	—	—	—	—

Table 12. Water-quality analyses for selected wells, springs, and streams in Bannock Creek Basin—Continued

Well, spring, or gaging-station number (fig. 6 or 11)	Sample date (month-day-year)	Discharge (ft^3/s)	Specific conductance (μS/cm)	pH (standard units)	Water temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Sulfate (mg/L as SO_4)	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Silica (mg/L as SiO_2)	Nitrogen, $NO_2 + NO_3$ (mg/L as N)	Phosphorus (mg/L as P)	δ deuterium (permil)	$\delta^{18}O$ (permil)
Streams																		
Bannock Creek at reservation boundary 075997	8- 2-88	—	688	8.6	16.5	193	67	22	35	5.6	28	96	0.2	26	0.12	0.03	-132.0	-17.20
Rattlesnake Creek 0761	7-28-88	8.0	542	8.5	24.0	197	60	23	21	3.7	16	51	.2	29	.46	.08	-130.0	-17.20
Bannock Creek near Pocatello 0762	10-11-67	—	—	—	10.0	—	73	30	39	6.4	33	64	.3	26	—	—	—	—
	4-12-68	—	—	—	8.0	—	65	28	36	5.2	29	67	.2	24	—	—	—	—
	10-29-68	—	—	—	7.0	—	77	27	37	5.5	32	64	.2	26	—	—	—	—
	4- 3-69	—	—	—	10.0	—	54	21	37	10	23	71	.2	22	—	—	—	—
	12-15-69	29.7	—	—	2.0	—	72	26	31	4.9	28	57	.3	27	—	—	—	—
	6-10-70	52.8	—	—	14.0	—	54	19	25	5.9	30	30	.4	23	—	—	—	—
	8-11-70	—	—	—	—	—	73	29	45	9.3	62	59	.8	27	—	—	—	—
	1-18-71	—	—	—	.5	—	42	8.6	9.1	8.9	5.8	10	.3	14	.50	.34	—	—
	8- 6-71	—	—	—	23.0	—	59	25	34	6.7	29	32	.7	26	.83	.30	—	—
	9-29-71	—	—	—	9.0	—	56	23	22	4.3	18	25	.6	22	.09	.08	—	—
	5-19-82	40.0	508	7.9	10.5	174	52	17	22	3.8	23	40	.2	21	.57	.34	-128.0	-17.00
	10-20-87	30.3	806	7.9	5.0	—	79	31	42	6.8	34	93	.2	—	.38	—	—	—
	7-11-88	24.5	692	8.3	20.0	240	64	28	43	6.6	56	48	.4	—	1.6	—	—	—
	7-28-88	6.1	796	8.4	19.0	235	71	31	51	5.6	62	88	.3	26	1.6	.21	—	—

sulfate, and had greater percentages of chloride than most other samples had. Samples with greater percentages of chloride also exhibited relatively greater-than-background concentrations of nitrite plus nitrate as nitrogen (table 12). Larger concentrations of chloride and nitrogen in water samples from several wells, springs, and streams likely are due to waste from septic tanks or stock animals (Hem, 1989, p. 125).

Water samples from the Snake River Plain aquifer under Michaud Flats contained sulfate in excess of one standard deviation of the regression relation between specific conductance and sulfate for all wells and springs. The regression relation between specific conductance and sulfate for 12 water samples from wells and springs in the basin is expressed as:

$$SO_4 = 0.04 \times SC - 3.825, \qquad (4)$$

where

SO_4 = concentration of sulfate, in milligrams per liter; and

SC = specific conductance, in microsiemens per centimeter at 25°C.

The standard deviation for sulfate is 20.0 mg/L. Larger concentrations of sulfate relative to specific conductance in water samples from wells that tap the Snake River Plain aquifer under Michaud Flats indicate that recharge water to Michaud Flats is different from recharge water to the rest of the basin, and (or) that geochemical reactions between ground water and rocks under Michaud Flats are different from geochemical reactions in the rest of the basin. The difference indicates that water in the Snake River Plain aquifer under Michaud Flats is not derived entirely from Bannock Creek Basin. Ground water under Michaud Flats is part of the Snake River Plain regional aquifer system (Garabedian, 1989).

SUSPENDED SEDIMENT

Suspended-sediment load is the amount of fine-grained sediment, measured in tons, that is transported past a specific location in a stream over a specified time period. Suspended-sediment load was estimated from measurements of instantaneous streamflow and suspended-sediment concentration (table 13) and records of daily mean streamflow at station 0762, Bannock Creek near Pocatello (fig. 7), from December 1988 through July 1989. Suspended-sediment concentrations were determined in 25 water samples collected from Bannock Creek at gaging station 0762 (fig. 6) during the first 6 months of 1989. First, calculations were performed to convert measurements of instantaneous streamflow and suspended-sediment concentration to instantaneous sediment discharge. Then, because of the

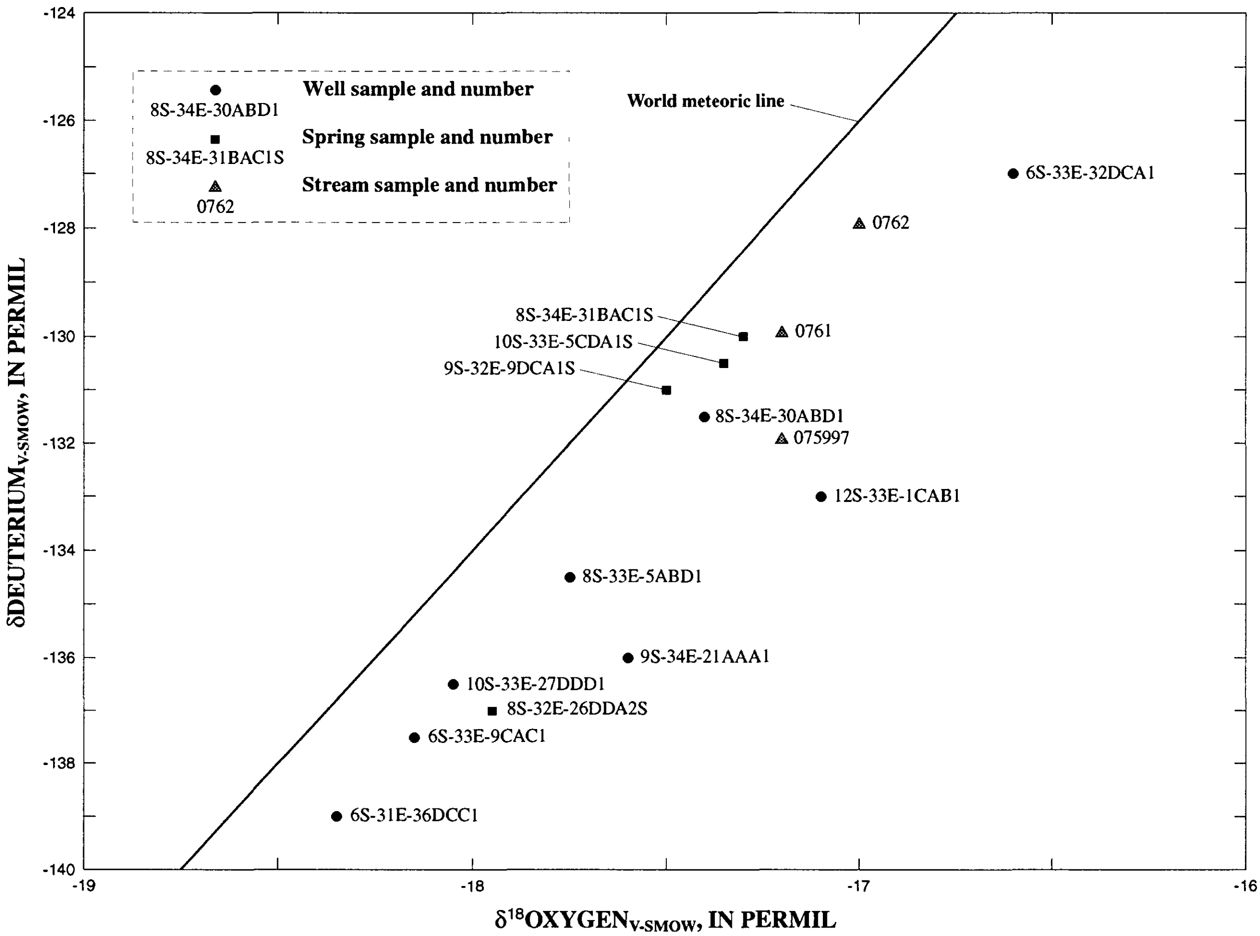


Figure 20. δdeuterium and δ^{18}oxygen ratios in water from selected wells, springs, and streams in Bannock Creek Basin, 1988. (Analyses are listed in table 12)

limited number of measurements of suspended-sediment concentration, a relation was established by linear regression between instantaneous sediment discharge and daily mean streamflow and was used to calculate daily mean sediment discharge.

Instantaneous sediment discharge was calculated using the equation:

$$Si = Qi \times Ss \times 0.0027, \quad (5)$$

where

Si = instantaneous sediment discharge, in tons per day;

Qi = instantaneous streamflow, in cubic feet per second;

Ss = suspended-sediment concentration, in milligrams per liter; and

0.0027 = a conversion constant to reconcile units of measurement.

Calculations of instantaneous sediment discharge were made under the assumption that instantaneous streamflow and suspended-sediment concentration did not change appreciably during the day of measurement.

The regression between instantaneous sediment discharge and daily mean streamflow resulted in the following equation:

$$S = 0.0007 \times Q^{2.687}, \quad (6)$$

where

S = daily mean sediment discharge, in tons per day;

Q = daily mean streamflow, in cubic feet per second; and

0.0007 and $^{2.687}$ = regression coefficients.

Table 13. Instantaneous streamflow, suspended-sediment concentration, and instantaneous sediment discharge for Bannock Creek near Pocatello (station 0762), December 1988 through July 1989

[Location of gaging station shown in figure 6]

Measurement date	Instantaneous streamflow (cubic feet per second)	Suspended-sediment concentration (milligrams per liter)	Instantaneous sediment discharge (tons per day)
12-19-88	26.8	41	3.0
1-17-89	27.3	60	4.4
1-31-89	33.8	56	5.1
2-07-89	21.1	20	1.1
2-14-89	29.4	33	2.6
2-23-89	52.8	361	52
2-28-89	72.6	1,150	225
3-07-89	66.0	665	118
3-13-89	186	3,310	1,660
3-21-89	85.7	587	136
4-04-89	76.3	512	105
4-11-89	65.1	354	62
4-18-89	66.3	371	66
4-25-89	102	1,090	300
5-02-89	32.5	81	7.1
5-09-89	17.0	25	1.1
5-16-89	35.5	24	2.3
5-23-89	9.64	37	.96
5-30-89	47.5	73	9.4
6-06-89	29.8	27	2.2
6-13-89	17.9	25	1.2
6-20-89	12.4	21	.70
6-27-89	11.6	22	.70
7-05-89	9.88	18	.48
7-11-89	8.68	11	.26

Instantaneous suspended-sediment discharge correlated to daily mean streamflow in the regression relation with an r^2 value of 0.91. The sum of the daily mean sediment discharges yielded a suspended-sediment load of 13,300 tons for 8 months from December 1988 through July 1989.

The uncertainty of the estimate of suspended-sediment load made on the basis of the relation defined in equation 6 is unknown. On the basis of this analysis, most of the suspended-sediment load from the Bannock Creek Basin during December 1988 through July 1989 was transported during a relatively short period of time. Examination of daily mean streamflow and calculated daily mean sediment discharge values revealed that, although 35 percent of the streamflow from December 1988 through July 1989 occurred during the 31 days of March (fig. 7), 45 percent of the suspended-sediment load from December 1988 through July 1989 occurred during only 5 days of high streamflow in early March. Because a large percentage of the suspended-sediment load was transported during a few high-flow events, the collection of multiple suspended-sediment samples over the course of one or more such events would have significantly reduced the uncertainty associated with the calculation of total load. Suspended-sediment samples collected throughout the year, and especially during periods of high streamflow, could be used to develop an improved understanding of the causes and sources of suspended-sediment load from Bannock Creek Basin.

SUMMARY AND CONCLUSIONS

The potential for development of water resources on the Fort Hall Indian Reservation part of Bannock Creek Basin is limited by water supply. The Shoshone-Bannock Tribes need an accurate determination of water yield to plan and implement a sustainable level of water use. Geologic setting, quantities of precipitation, ET, surface-water runoff, recharge, and ground-water underflow were used to determine water yield.

Bannock Creek Basin covers 475 mi^2 and, for this study, was separated into six subbasins: Arbon Valley, Rattlesnake Creek drainage, West Fork drainage, middle Bannock Creek Valley, lower Bannock Creek Valley, and Michaud Flats. Middle and lower Bannock Creek Valleys and Michaud Flats are part of the Fort Hall Indian Reservation. Arbon Valley and most of the Rattlesnake Creek drainage are privately owned.

Basin-and-range-type faulting formed the mountain ranges that bound the present valley of Bannock Creek. Rhyolitic tuff, associated with volcanic activity on the Snake River Plain, forms the bedrock surface from the margin of the plain to Arbon Valley.

During 1964–88, average annual precipitation on the basin, excluding Michaud Flats, was estimated to be 19.4 in. Calculated crop ET was estimated to be 23.1 in/yr.

The primary source of ground water in most of the basin is the valley-fill aquifer in deposits of sand and gravel and basaltic rocks. Secondary sources of water include pediment gravel, loess, rhyolite, and Paleozoic and Precambrian rocks, which provide local supplies. The primary aquifer under Michaud Flats consists of sand, gravel, and basalt; it is part of the Snake River Plain aquifer. The Snake River Plain aquifer under Michaud Flats is in hydraulic connection with the valley-fill aquifer. Hydraulic gradients in the valley-fill aquifer generally follow topographic gradients and range from 3 ft/mi on Michaud Flats to 125 ft/mi in the Rattlesnake Creek drainage. Water levels in the Snake

River Plain aquifer under Michaud Flats were lowest between April and September in response to ground-water withdrawals for irrigation. Water levels in three wells measured monthly from September 1987 through December 1988 were within minimum and maximum monthly levels measured from 1955 through 1988 with two exceptions. Ground-water levels in one well in January 1987 and October 1988 were the lowest ever measured since 1955. Water levels in the valley-fill aquifer in lower Bannock Creek Valley were highest between April and September in response to recharge from applications of surface water for irrigation. Water levels in other parts of the basin responded to local variations in recharge from precipitation.

Water budgets were prepared to quantify precipitation; runoff to streams; consumptive use by ET from phreatophytes, native vegetation, and dryland and irrigated crops; withdrawals from domestic and irrigation wells; and net ground-water recharge to the valley-fill aquifer for five subbasins in the Bannock Creek Basin. Surface-water and ground-water relations within subbasins can affect the ratio between the quantity of surface-water runoff and ground-water underflow identified from each water budget as leaving the subbasin.

Water budgets quantify the source and disposal of water in subbasins for recent climatic conditions but do not indicate the amount of ground water stored in the aquifer. The amount of ground water in storage in a subbasin is affected by geologic setting, which controls the physical capacity to store ground water, and long-term water budgets, which control the accumulation of ground water in storage. Ground-water withdrawals by wells could temporarily exceed the quantities described as sources in the water budgets if an appreciable amount of ground water is stored in a subbasin. In this case, however, unless unappropriated surface water is used to replace ground-water withdrawals when supplies are available, ground-water levels would decline, well yields eventually would be reduced, and even marginal declines in ground-water storage likely would reduce streamflow gains and the supply of surface water to Bannock Creek and points downstream.

Water yield is defined as the annual quantity of surface-water runoff and underflow that results from precipitation in excess of ET by crops and native vegetation. Water yield from Bannock Creek Basin determined from water budgets was 60,700 acre-ft/yr. Irrigation has changed water yield from the basin. Water yield from water derived solely within the Bannock Creek Basin was estimated to be 40,400 acre-ft/yr. Water yield from the Fort Hall Indian Reservation part of Bannock Creek Basin was estimated to be 37,700 acre-ft/yr.

Water from wells, springs, and streams sampled during 1988 was a calcium bicarbonate type. Concentrations of nitrite plus nitrate as nitrogen and fluoride were less than Maximum Contaminant Levels established for public drinking-water supplies by the U.S. Environmental Protection Agency. Larger concentrations of nitrogen and chloride in several water samples from wells, springs, and streams likely are due to waste from septic tanks or stock animals.

Suspended-sediment load was estimated to be 13,300 tons from December 1988 through July 1989 at Bannock Creek near Pocatello. Suspended-sediment discharge was greatest during periods of high streamflow.

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Table 4

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Table 4. Records of wells in Bannock Creek Basin, 1987

[Well finish: P, perforated; X, open hole; S, screened. Use of water: I, irrigation; U, unused; H, domestic; P, public supply; S, stock. Remarks: D, driller's log; Q, water-quality analysis. —, data unavailable]

Well number (fig. 11)	Measurement date (month-day)	Depth to water (feet below land surface)	Well depth (feet below land surface)	Land-surface altitude (feet above sea level)	Casing depth (feet below land surface)	Casing diameter (inches)	Well finish	Use of water	Remarks
5S-32E-36DCC1	—	—	225	4,415	210	16	P, X	I	D
33E-31CDC1	—	—	—	4,415	—	—	—	I	—
31DDC1	—	—	185	4,420	185	20	P	I	D
32ACD1	10- 1	27.62	200	4,430	200	18	P	I	D
33BAB1	—	—	—	4,430	—	—	—	I	—
35CDC1	10-18	23.83	60	4,425	60	6	—	U	—
35DCC1	—	—	—	4,420	—	—	—	I	—
6S-31E-36DCC1	9-30	51.89	258	4,400	258	12	X	1	Q
32E- 1ABB1	—	—	193	4,415	193	16	P	I	D
1BAB1	—	—	—	4,400	—	—	—	I	—
1DBD1	—	—	—	4,411	—	—	—	I	—
2CDB1	—	—	205	4,381	205	16	P	I	D
2DDB1	—	—	209	4,406	200	18	P	I	D
10ACA1	—	—	180	4,388	180	18	P	I	D
10DCA1	—	—	192	4,397	192	16	P	I	D
11BDB1	—	—	—	4,395	—	—	—	I	—
11CDB1	—	—	182	4,394	182	—	P	I	—
12ABA1	—	—	—	4,420	—	—	—	I	—
12BDB1	—	—	200	4,410	200	20	P	I	D
12CAD1	—	—	—	4,406	—	—	—	I	—
12DDC1	—	—	—	4,415	—	—	—	I	—
13BAD1	10- 1	6.92	183	4,408	183	18	—	I	D
13BAD2	—	—	—	4,408	—	—	—	I	—
14BCA1	—	—	200	4,406	200	18	P	I	D
15ADB1	—	—	200	4,399	200	20	P	I	D
22CAC1	10- 1	45.91	207	4,407	204	16	P	I	D
22DDB1	—	—	240	4,410	240	18	P	I	D
23CDC1	10- 1	33.73	224	4,410	223	16	P	I	D
23DCC1	—	—	419	4,425	419	16	P	I	D
24BDD1	—	—	—	4,427	—	—	—	I	—
27ADB1	—	—	220	4,409	220	18	P	I	D
27ADC1	10-15	34.28	63	4,417	83	6	P	U	D
27BDB1	—	—	200	4,410	200	16	P	I	D
28CDD1	—	—	220	4,413	214	16	P	I	D
29DDA1	—	—	223	4,404	200	24	P	I	D
31CAB1	—	—	—	4,400	—	—	—	I	—
32BCB1	—	—	—	4,400	—	—	—	I	—
33BBB1	—	—	—	4,411	—	—	—	I	—
33E- 2BDC1	—	—	150	4,440	150	8	—	U	D
2BDD1	10- 7	40.54	150	4,440	150	6	—	H	D
2CAA1	—	—	—	4,435	—	—	—	U	—
5CCA1	—	—	255	4,423	255	16	P	I	D
6AAB1	—	—	238	4,419	238	16	—	I	D
6CCD1	—	—	193	4,415	193	16	P	I	D
7ADC1	—	—	—	4,410	—	—	—	I	—

Table 4. Records of wells in Bannock Creek Basin, 1987—Continued

Well number (fig. 11)	Measurement date (month-day)	Depth to water (feet below land surface)	Well depth (feet below land surface)	Land-surface altitude (feet above sea level)	Casing depth (feet below land surface)	Casing diameter (inches)	Well finish	Use of water	Remarks
6S-33E- 7BDC1	—	—	200	4,415	200	16	P	I	D
7CAC1	—	—	—	4,415	—	—	—	I	—
9CAC1	—	—	—	—	—	—	—	—	Q
17ADD1	—	—	191	4,430	191	16	P	I	D
17BBD1	—	—	—	4,427	—	—	—	I	—
17CBB1	—	—	198	4,425	198	16	P	I	D
17CCD1	—	—	—	4,430	—	—	—	I	—
18ADC1	—	—	435	4,420	422	12	P, X	I	D
18BAB1	—	—	—	4,420	—	—	—	I	—
19AAC1	—	—	324	4,422	324	18	P	I	D
20AAD1	—	—	—	4,440	—	—	—	I	—
20ABB2	10- 6	38.30	249	4,435	248	6	X	H	—
21ACA1	—	—	300	4,472	—	—	—	I	—
21ADB1	—	—	158	4,470	—	—	—	H	—
21BCB1	11-17	33.55	227	4,435	225	20	P	I	D
21CDB1	—	—	—	4,450	—	—	—	I	—
21DDA1	—	—	—	4,555	—	—	—	H	—
22CCB1	—	—	530	4,508	512	12	—	I	D
29DCC1	9-30	35.75	—	4,440	—	—	—	H	—
30CCB1	—	—	282	4,440	282	—	P	I	D
31DCD1	—	—	—	4,430	—	—	—	I	—
32CAA1	—	—	—	4,460	—	—	—	H	—
32DCA1	9-30	51.66	—	4,460	—	—	—	H	Q
33CAB1	—	—	—	4,550	—	—	—	I	—
7S-31E- 1CBC1	—	—	441	4,404	—	—	—	I	—
2AAA1	—	—	—	4,396	—	—	—	I	—
11AAB1	—	—	608	4,402	—	—	—	I	—
36ACA1	—	—	—	4,542	—	—	—	I	—
32E- 1AAB1	9-30	40.19	315	4,445	—	—	—	I	—
2BDA1	9-30	46.30	300	4,440	—	—	—	I	—
2CBB1	—	—	—	4,440	—	—	—	I	—
3CDC1	9-30	48.50	480	4,440	—	—	—	I	—
8BDC1	—	—	—	4,408	—	—	—	I	—
8CBC1	—	—	398	4,400	—	—	—	I	—
9DDB1	9-30	182.74	445	4,575	401	20	X	U	D
9DDD1	—	—	550	4,610	—	—	—	U	—
10DBB1	—	—	450	4,572	—	—	—	U	—
11CCB1	—	—	750	4,583	—	—	—	I	—
15BAA1	—	—	515	4,636	—	—	—	U	—
24DBC1	9-29	169.67	215	4,610	108	6	—	S	D
30BCA1	9-30	115.99	885	4,498	—	—	—	I	—
33E- 5ACD1	—	—	—	4,500	—	—	—	I	—
5BDA1	—	—	220	4,432	220	18	P	I	D
6BBC1	—	—	330	4,460	—	—	—	I	—
6CDA1	9-29	38.04	735	4,460	532	16	X	I	D

Table 4. Records of wells in Bannock Creek Basin, 1987—Continued

Well number (fig. 11)	Measurement date (month-day)	Depth to water (feet below land surface)	Well depth (feet below land surface)	Land-surface altitude (feet above sea level)	Casing depth (feet below land surface)	Casing diameter (inches)	Well finish	Use of water	Remarks
7S-33E- 6CDA2	9-29	43.91	405	4,460	401	—	X	I	D
6CDD1	—	—	—	4,520	—	—	—	H	—
7AAD1	—	—	235	4,460	—	—	—	H	—
8BAA1	—	—	—	4,480	—	—	—	U	—
8CDA1	—	—	—	4,500	—	—	—	H	—
8DBA1	—	—	—	4,500	—	—	—	U	—
8DCC1	9-29	64.66	105	4,500	101	6	S	H	D
15DBB1	9-29	87.15	—	4,880	—	—	—	U	—
20BAA1	—	—	—	4,500	—	—	—	H	—
20BAA2	9-27	35.20	260	4,500	171	6	X	U	D
20CAD1	—	—	100	4,560	99	6	—	H	D
20CDA1	—	—	81	4,560	80.7	6	X	H	D
20CDA2	—	—	—	4,560	—	—	—	H	—
20CDD1	—	—	—	4,560	—	—	—	H	—
20CDD2	—	—	—	4,560	—	—	—	H	—
20DBD1	—	—	—	4,560	—	—	—	U	—
29ACC1	—	—	—	4,560	—	—	—	U	—
29ACC2	—	—	—	4,560	—	—	—	H	—
29CAD1	—	—	96	4,540	92	6	—	H	D, Q
29CAD2	—	—	—	4,540	—	—	—	U	—
29CAD3	—	—	—	4,540	—	—	—	U	—
29DBB1	—	—	77	4,550	73	6	X	U	D
29DBB2	9-30	33.06	100	4,550	99	6	X	H	D
32ACA1	—	—	125	4,560	93	6	X	H	D
8S-33E- 4BBA1	—	—	130	4,600	38	6	X	U	D
4CCD1	—	—	—	4,620	—	—	—	U	—
5ABD1	—	—	157	4,600	157	6	—	H	D, Q
5DCD1	9-29	40.16	156	4,620	—	—	—	H	—
5DDC1	9-29	20.43	91	4,600	—	6	X	H	D
9BAC1	—	—	—	4,620	—	—	—	U	—
9BB1	—	—	150	4,600	40	6	X	H	D
9BCB1	—	—	—	4,640	—	—	—	H	—
21BDB1	—	—	—	4,680	—	—	—	H	—
21DCD1	10-7	9.59	—	4,700	—	—	—	H	—
27CBA1	9-28	10.28	—	4,740	—	—	—	H	Q
8S-33E-28AAD1	—	—	—	4,740	—	—	—	U	—
34E-18BBC1	—	—	—	5,400	—	—	—	H	—
18CCA1	9-28	66.74	180	5,280	—	—	—	H	—
30ABD1	—	—	340	5,300	—	—	—	H	Q
31DCC1	9-28	12.93	—	5,060	—	—	—	U	—
8S-34E-32ACD1	9-29	38.77	—	5,414	—	—	—	U	—
9S-33E- 3CCB1	9-29	13.91	157	4,800	151	6	X	H	D, Q
10DAA1	—	—	—	5,180	—	—	—	U	—
15CAB1	9-29	7.16	—	4,840	—	—	—	U	—
24CDA1	10-7	54.03	—	5,520	—	—	—	—	—

Table 4. Records of wells in Bannock Creek Basin, 1987—Continued

Well number (fig. 11)	Measurement date (month-day)	Depth to water (feet below land surface)	Well depth (feet below land surface)	Land-surface altitude (feet above sea level)	Casing depth (feet below land surface)	Casing diameter (inches)	Well finish	Use of water	Remarks
9S-33E-34ABA1	9-29	22.24	—	4,925	—	—	—	U	—
34E- 5DDA1	—	—	—	5,310	—	—	—	U	—
8ADD1	9-28	100.82	—	5,290	—	—	—	H	Q
9CCC1	9-28	111.72	—	5,280	—	—	—	H	—
17ADA1	9-28	.01	—	5,160	—	—	—	U	—
21AAA1	9-28	18.61	—	5,300	—	—	—	H	Q
29ABA1	10- 1	9.63	—	5,230	—	—	—	U	—
32DCD1	—	—	—	5,240	—	—	—	U	—
35CAD1	10- 5	8.98	—	5,430	—	—	—	H	—
10S-33E- 2CCC1	9-29	37.64	200	5,020	60	6	X	H	D
10DAC1	9-29	84.0	—	5,100	—	—	—	H	—
11ADB1	9-29	23.72	—	5,010	—	—	—	H	Q
12CDB1	9-29	49.33	200	5,050	52.6	6	X	H	D
12CDB2	—	—	—	5,040	—	—	—	H	—
13BBB1	10- 2	29.73	—	5,050	—	—	—	P	—
14DAA1	—	—	—	5,100	—	—	—	U	—
26AAA1	—	—	—	5,160	—	—	—	U	—
26DDC1	—	—	—	5,200	—	—	—	H	—
27DDD1	10- 1	99.09	260	5,220	189	6	X	H	D, Q
35AAD1	10- 1	31.16	—	5,150	—	—	—	H	—
10S-34E- 5CDB1	10- 1	50.71	—	5,190	—	—	—	U	—
7DBB1	10- 1	22.40	300	5,110	20	18	X	I	D
18CAA1	10- 1	60.43	—	5,080	—	—	—	I	—
18CCC1	—	—	—	5,040	—	—	—	H	—
19BBB1	—	—	—	5,040	—	—	—	H	Q
31CBA1	10- 2	37.13	—	5,100	—	—	—	H	—
31CCC1	—	—	175	5,086	175	16	P	U	D
32BCB1	—	—	—	5,280	—	—	—	U	—
11S-33E- 2BAB1	10- 5	53.11	200	5,200	200	6	—	H	D
3DDD1	—	—	—	5,180	—	—	—	U	—
10ABB2	10- 5	87.45	610	5,240	—	—	—	H	Q
12BAA1	10- 5	12.54	180	5,120	180	16	P	I	D
23ACB1	—	—	—	5,160	—	—	—	U	—
23ACB2	—	—	—	5,160	—	—	—	H	—
23BAC1	—	—	—	5,180	—	—	—	I	—
23BAC2	—	—	—	5,180	—	—	—	I	—
23BAC3	10- 5	24.97	—	5,170	—	—	—	U	—
23DBB1	10- 5	10.11	—	5,170	—	—	—	I	—
24BBD1	10- 5	9.01	203	5,140	203	16	P	U	D
25CDB1	10- 5	11.04	—	5,140	—	—	—	U	—
26BBC1	10- 5	73.68	—	5,220	—	—	—	U	—
26DAA1	—	—	—	5,140	—	—	—	U	—
35CBB1	10- 5	59.45	—	5,200	—	—	—	I	—
36BBA1	—	—	162	5,140	160	16	P	I	D
36CBB1	10- 5	8.33	—	5,140	—	—	—	U	—

Table 4. Records of wells in Bannock Creek Basin, 1987—Continued

Well number (fig. 11)	Measure-ment date (month-day)	Depth to water (feet be-low land surface)	Well depth (feet be-low land surface)	Land-surface altitude (feet above sea level)	Casing depth (feet be-low land surface)	Casing diameter (inches)	Well finish	Use of water	Remarks
11S-34E-31CBB1	10- 5	102.11	—	5,240	—	—	—	U	—
12S-33E- 1CAB1	—	—	183	5,160	180	16	P	I	D, Q
2DDA1	10- 6	22.02	—	5,160	—	—	—	I	—
9AAA1	—	—	—	5,300	—	—	—	U	—
9DDC1	—	—	300	5,320	190	6	X	U	—
10CDD1	—	—	—	5,280	—	—	—	H	—
12ABB1	10- 6	84.12	95	5,224	—	—	—	U	—
13BAB1	—	—	218	5,320	—	—	—	U	—
14AAA1	—	—	—	5,240	—	—	—	U	—
21AAA1	—	—	340	5,380	245	6	X	U	—
21AAA2	—	—	—	5,380	—	—	—	H	—
22CAA1	—	—	215	5,300	—	—	—	H	Q
22DAA1	—	—	—	5,260	—	—	—	U	—
23CCC1	—	—	—	5,260	—	—	—	U	—
23DBB1	10- 6	89.39	147	5,240	—	—	—	U	—
26BCC1	10- 6	71.07	150	5,260	—	—	—	—	—
27CDC1	11-16	51.48	—	5,240	—	—	—	U	—
27CDC2	—	—	—	5,240	—	—	—	H	—
28BCC1	10- 6	24.71	184	5,300	—	—	—	—	—