WATER-QUALITY ASSESSMENT OF THE UPPER SNAKE RIVER BASIN, IDAHO AND WESTERN WYOMING—ENVIRONMENTAL SETTING, 1980–92

By MOLLY A. MAUPIN

U.S. GEOLOGICAL SURVEY

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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for a specific contamination problem; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.0283	cubic meter per second
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.3048	meter per mile
foot squared per second[1] (ft^2/s)	0.09290	meter squared per second
gallon (gal)	0.003785	cubic meter
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
megawatthour (MWh)	3,600,000,000	joule
mile (mi)	1.609	kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second
pound, avoirdupois (lb)	0.4536	kilogram
square mile (mi^2)	2.590	square kilometer

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

°C = 5/9(°F-32)

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

[1] The standard unit for transmissivity is cubic foot per second per square foot times foot of aquifer thickness. This mathematical expression reduces to foot squared per second, which is used in this report.

Water-Quality Assessment of the Upper Snake River Basin, Idaho and Western Wyoming—Environmental Setting, 1980–92

By Molly A. Maupin

ABSTRACT

The 35,800-square-mile upper Snake River Basin is one of 20 areas studied as part of the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey. Objectives of NAWQA are to study ground- and surface-water quality, biology, and their relations to land-use activities. Major land and water uses that affect water quality in the basin are irrigated agriculture, grazing, aquaculture, food processing, and wastewater treatment. Data summarized in this report are used in companion reports to help define the relations among land use, water use, water quality, and biological conditions.

The upper Snake River Basin is located in southeastern Idaho and northwestern Wyoming and includes small parts of Nevada and Utah. Total population in the basin was about 425,000 in 1990. Major urban areas are Idaho Falls, Pocatello, Rexburg, and Twin Falls, Idaho, which make up 10, 11, 3, and 6 percent of the total population, respectively. Climate in the basin is mostly semiarid and mean annual precipitation ranges from 8 to more than 60 inches. The eastern Snake River Plain is the major geologic feature in the basin and is delineated mostly by Quaternary and Tertiary basalt flows. It is about 55 to 62 miles wide and 320 miles long and bisects the basin in a northeast-southwest direction.

The Snake River is the dominant surface-water feature and flows about 453 miles from the southern border of Yellowstone National Park in Wyoming to King Hill, Idaho, where it leaves the basin. The Snake River flows through five reservoirs that provide a total storage capacity of more than 4 million acre-feet. Gravity-flow diversions are predominant in the upper part of the basin and totaled 8.8 million acre-feet in 1980. Pumped diversions occur mainly in the lower part of the basin and totaled 408,500 acre-feet in 1980.

The Snake River Plain aquifer is the predominant ground-water feature in the upper Snake River Basin and underlies the eastern Snake River Plain. The upper 500 feet of the aquifer may store 200 to 300 million acre-feet of water. Ground-water resources that supply agricultural lands are sustained by recharge from surface-water irrigation, precipitation, and tributary inflow. Major ground-water discharges are at springs and seeps or from ground-water pumpage for irrigation.

Water use in the basin is dominated by irrigated agriculture, which is the largest consumptive water use in the basin. Major crops in the basin include potatoes, wheat, sugar beets, hay, and barley. Most irrigation needs are supplied from surface-water sources through a series of canals and laterals. In 1990, about 2.5 million acres were irrigated with more than 14.2 million acre-feet of surface and ground water. About 21 percent of the basin is agricultural land and 50 percent is rangeland.

Idaho leads the Nation in trout production for commercial sale. Combined mean annual discharges from 12 aquacultural facilities in the basin (1985–90) were about 787,000 acre-feet. These facilities are clustered in a reach of the Snake River between Milner Dam and King Hill where ground-water discharge is from many seeps and springs that provide sufficient quantities of good-quality water. Other facilities that release effluent to the Snake River include 13 municipal wastewater treatment plants and 3 industrial facilities.

INTRODUCTION

The National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey became fully implemented in 1991 and is designed as a long-term effort to describe status and trends in the quality of surface and ground water for large regions of the Nation. Goals of the program are to describe water-quality conditions in a consistent manner, define long-term trends or the lack thereof in water quality, and study major issues that affect water-quality trends and conditions (Hirsch and others, 1988). Water-quality information provided by the program will assist water-resource policymakers and managers at national, State, and local levels. Sixty study units were selected nationwide that incorporate 60 to 70 percent of the total water use, as measured by total withdrawals and population served by public water supplies (Hirsch and others, 1988).

In 1991, the upper Snake River Basin was among the first 20 units selected for study. The basin includes eastern Idaho, northwestern Wyoming, and small parts of northern Utah and Nevada (fig. 1). As part of the NAWQA Program, existing and new data will be intensively collected and analyzed in the first 20 selected study units from 1993 through 1995. After this period of intensive study, low-intensity monitoring will continue for 5 years.

Major ground- and surface-water-quality issues in the upper Snake River Basin are sediment, nutrients, and organic compounds. Biological concerns are focused on habitat and species occurrences in stream channels and riparian zones. Major land and water uses that affect water quality are irrigated agriculture, grazing, aquaculture, food processing, and municipal and industrial wastewater treatment.

Purpose and Scope

This report describes physical and environmental characteristics in the upper Snake River Basin that may affect current and future water-quality conditions and provides information to define areas for possible future water-quality monitoring. Data summarized in this report are used in companion reports to help define the relations among land use, water use, water quality, and biological conditions. Most data have been compiled into a geographic information system (GIS), which allows spatial and tabular data to be combined and analyzed. Data were obtained from Federal, State, and local agencies and examined for content, pertinence, and reliability. Descriptions of the upper Snake River Basin are based on information from 1980 to about 1992 and include geology, land use, surface- and ground-water characteristics, water use, and sources of pollution in the basin.

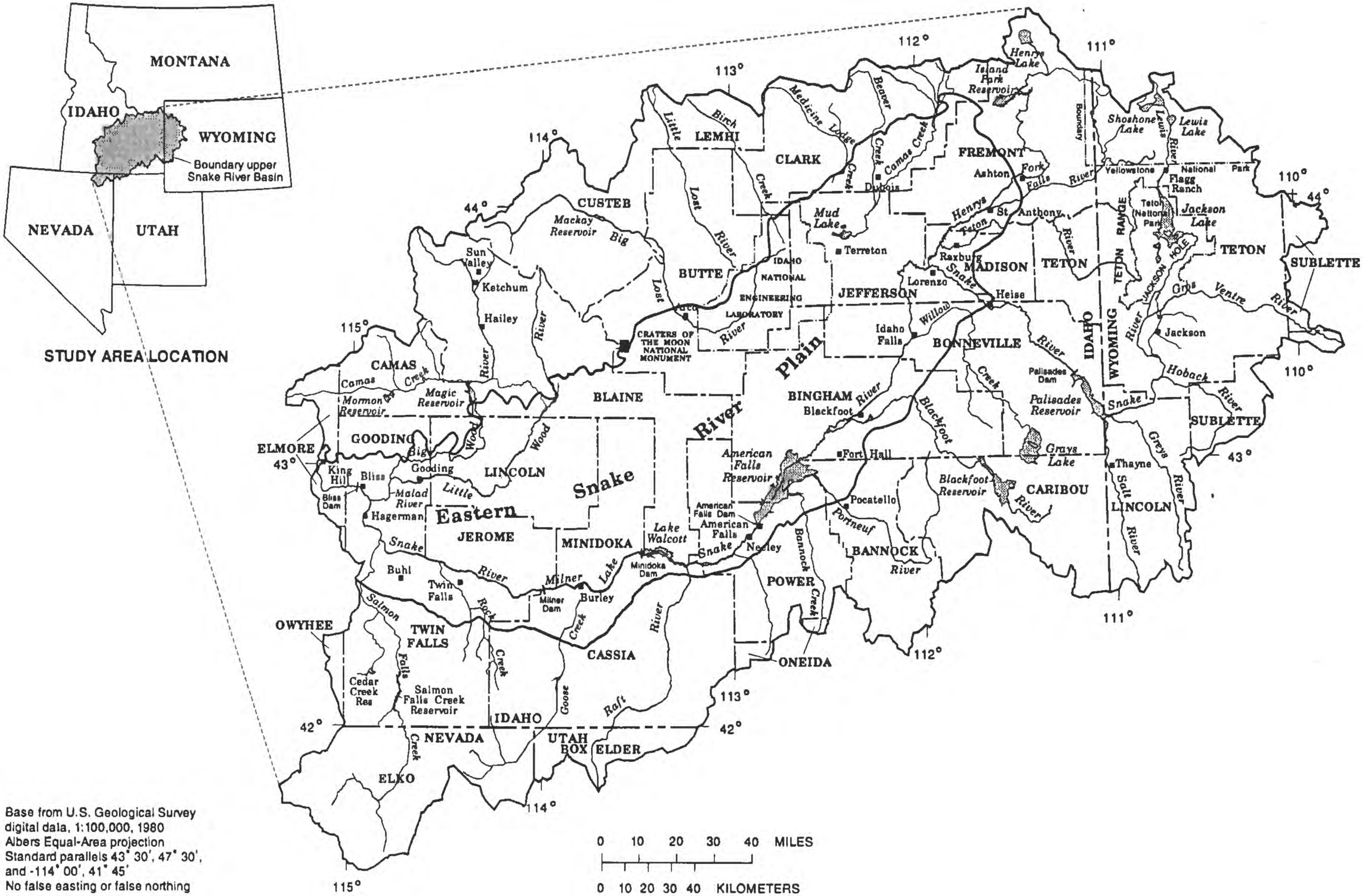
Acknowledgments

The author wishes to thank the Federal and State agencies and organizations who provided much of the data discussed and illustrated in this report. Data used for this study were obtained from the Upper Snake River Basin Liaison Committee; the Idaho Department of Agriculture; the Idaho Department of Commerce; the Idaho Department of Fish and Game; the Idaho Department of Health and Welfare, Division of Environmental Quality (IDHW/DEQ); the Idaho Department of Water Resources (IDWR); the Idaho Power Company; the National Atmospheric Deposition Program, National Trends Network (NADP/NTN); the U.S. Department of Agriculture, Agricultural Research Service; the U.S. Department of Agriculture, Soil Conservation Service; the U.S. Environmental Protection Agency (USEPA), Regions VIII and X; the U.S. Fish and Wildlife Service; and the University of Idaho, Kimberly Research and Extension Center.

ENVIRONMENTAL SETTING

Location and Physiography

The upper Snake River Basin is the largest in Idaho and covers 35,800 mi^2 from western Wyoming to south-central Idaho (fig. 1). Elevations range from about 13,770 ft above sea level in the Teton Mountains, Wyoming, to 2,500 ft above sea level at King Hill, Idaho. Eighty percent of the study area is in Idaho and 14 percent is in Wyoming; Nevada and Utah constitute the remaining 6 percent. The study area consists of 24 subbasins that create subregion 1704 on the U.S. Geological Survey (USGS) Hydrologic Unit Maps of Idaho, Nevada, Utah, and Wyoming (1975a, 1975b, 1975c, 1976). The largest tributaries in the northeastern part of the basin are the Henrys Fork and Teton River.



Base from U.S. Geological Survey
digital data, 1:100,000, 1980
Albers Equal-Area projection
Standard parallels 43° 30', 47° 30',
and -114° 00', 41° 45'
No false easting or false northing

Figure 1. Upper Snake River Basin study area.

The Blackfoot and Portneuf Rivers flow into the Snake River in the southeastern section of the basin, and Rock Creek and Salmon Falls Creek are the two largest tributaries in the southwest. The Little Wood and Big Wood Rivers flow from the north to meet the Snake River just before it leaves the basin at King Hill. The Big Lost and Little Lost Rivers and Birch and Camas Creeks also flow from the north but are absorbed into porous basalts and recharge the eastern Snake River Plain aquifer system. Discharge from the aquifer system is mostly from springs and seeps along the Snake River between Milner Dam (Milner Lake) and King Hill. The basin includes all of the eastern Snake River Plain, which is about 55 to 62 mi wide and 320 mi long. It also includes parts of four northwestern ecoregions: the Snake River Basin/High Desert, the Northern and Middle Rocky Mountains, and the Basin and Range (Omernik and Gallant, 1986). The basin includes all of Bannock, Bingham, Blaine, Bonneville, Butte, Cassia, Clark, Fremont, Gooding, Jefferson, Jerome, Lincoln, Madison, Minidoka, Power, Teton, Twin Falls, and parts of Camas, Caribou, Custer, Elmore, Lemhi, Oneida, and Owyhee Counties in Idaho. Parts of Lincoln, Sublette, and Teton Counties in Wyoming, parts of Box Elder County in Utah, and parts of Elko County in Nevada also are included in the basin.

Population

Population of the upper Snake River Basin in 1990 was about 425,000, about 20,000 more than in 1980. Major urban areas in the basin are Idaho Falls, Pocatello, Rexburg, and Twin Falls, Idaho, which make up 10, 11, 3, and 6 percent of the total population, respectively (table 1). Jackson, Wyoming, does not have a large resident population but is an area

Table 1. County and major urban area population totals in the upper Snake River Basin, 1980 and 1990

[Counties and cities are in Idaho, unless otherwise specified; population data from Idaho Department of Commerce (1992) and Wyoming Department of Administration and Information (1992); —, no data available]

County	Population		Percent urban		City	Population	
	1980	1990	1980	1990		1980	1990
Bannock	65,421	66,026	81.6	83.6	Pocatello	46,340	46,062
Bingham	36,489	37,583	36.6	38.6			
Blaine	9,841	13,552	0	45.8			
Bonneville	65,980	72,207	67.1	78.0	Idaho Falls	39,739	43,929
Butte	3,342	2,918	0	0			
Camas[1]	818	727	0	0			
Caribou[1]	8,695	6,963	46.6	44.7			
Cassia	19,427	19,531	43.9	43.1			
Clark	798	762	0	0			
Custer[1]	3,385	4,133	0	0			
Fremont	10,813	10,937	29.7	27.5			
Gooding	11,874	11,633	24.8	24.2			
Jefferson	15,304	16,543	17.1	16.2			
Jerome	14,840	15,138	46.4	43.1			
Lemhi[1]	7,460	6,899	44.3	42.6			
Lincoln	3,436	3,308	0	0			
Lincoln, Wyo.[1]	12,177	12,625	—	—			
Madison	19,480	23,674	59.3	60.4	Rexburg	11,559	14,302
Minidoka	19,718	19,361	43.6	43.6			
Power	6,844	7,086	53.0	53.8			
Sublette, Wyo.[1]	4,648	4,843	—	—			
Teton	2,897	3,439	0	0			
Teton, Wyo.[1]	9,355	11,172	—	—	Jackson, Wyo.	4,511	4,472
Twin Falls	52,927	53,580	56.4	58.1	Twin Falls	26,209	27,591
Total	405,969	424,641					

[1]County not totally within study area.

where a significant influx occurs each summer because of tourism and recreational opportunities. In 1990, about 2.8 million people visited the Grand Teton and Yellowstone National Parks (Walton Low, U.S. Geological Survey, written commun., 1992). Population totals for Wyoming counties accounted for about 7 percent of the total basin population. Populations for Nevada and Utah parts of the basin were negligible.

Between 1980 and 1990, Blaine County had the largest population increase of 38 percent. Blaine County also had the highest percentage of urbanization. In 1980, the county was 100 percent rural and, in 1990, was almost 46 percent urban (Idaho Department of Commerce, 1992). The Sun Valley resort is located in Blaine County north of the town of Hailey. Most development has occurred in and around Sun Valley and its neighboring community, Ketchum.

Butte County experienced the largest population decline of 13 percent between 1980 and 1990. This county was 100 percent rural in 1980 and 1990 census reports, but the net migration out of the county increased between 1980 and 1990, and the total number of farms decreased from 247 in 1982 to 224 in 1987 (Idaho Department of Commerce, 1992). Jerome County reported the largest rural growth in the basin with about 54 percent in 1980 and almost 57 percent in 1990. The total number of farms in this county increased from 867 to 909 between 1980 and 1990.

Most of the urban communities are clustered near the Snake River or along its flood plain, and rural communities are scattered in tributary valleys and farther from the Snake River on the eastern Snake River Plain. Blackfoot, Burley, Idaho Falls, Pocatello, Rexburg, and Twin Falls have population densities of more than 1,000 people/mi^2 and represent some of the larger urban cities in the basin (K. Hitt, U.S. Geological Survey, written commun., 1992).

Population totals are projected to increase in Idaho counties by more than 20 percent by 2000. Population in the basin by 2000 is projected to be about 436,000. By 2010, population is projected to increase by another 9 percent and equal about 480,000 (Idaho Power Company, 1992). Blaine and Camas Counties are projected to experience the largest population increase of about 2.2 and 2.4 percent, respectively, between 1990 and 2000.

Geology

The upper Snake River Basin is characterized largely by young basalt flows in the lowlands of the central and southern parts; older intrusive, volcanic, and sedimentary and metamorphic rocks dominate in the uplands and mountains to the north, south, and east. The eastern Snake River Plain bisects the upper Snake River Basin in a northeast-southwest direction and is delineated mostly by Quaternary and Tertiary basalt flows. Northern and southern drainage basins tributary to the plain include uplands underlain by Quaternary and Tertiary sedimentary rocks. Uplands to the northwest are dominated by Tertiary and Cretaceous intrusive rocks, and uplands to the southwest are underlain mostly by Tertiary basalt, silicic volcanics, and volcanic rocks (fig. 2). Mountains in the southeastern part of the basin are composed of complexly folded and faulted pre-Cretaceous undifferentiated sedimentary and metamorphic rocks and Tertiary and Cretaceous undifferentiated sedimentary rocks. Quaternary alluvial, fluvial, lacustrine, and eolian deposits are located along the southeastern and northeastern margins of the plain and in the lowlands of the tributary valleys. Bare basalt is present mostly in the central part of the eastern Snake River Plain. A report by Whitehead (1986) gives a detailed description of the geology of the upper Snake River Basin.

Basalt flows in the central part of the plain measure several thousand feet thick and taper to less than 100 ft thick along the margins of the plain (fig. 3). Individual Quaternary basalt flows of the eastern Snake River Plain average about 20 to 25 ft thick and 50 to 100 mi^2 in area (Garabedian, 1992). The top 6 ft or so is typically fine-grained, vesicular, highly fractured basalt. Topographically, the basalt is highest in the middle of the plain and forces the Snake River to flow along the southern margin. The basalt high prevents northern streams from reaching the Snake River.

The Snake River and other tributary streams deposited fluvial sediments between basalt flows along the margins of the plain. Occasionally, basalt flows created temporary dams and fine-grained lacustrine sediments were deposited behind them (Garabedian, 1992). Fluvial and lacustrine deposits near the margins of the plain and along the Snake River are well suited for agriculture and are important aquifers locally.

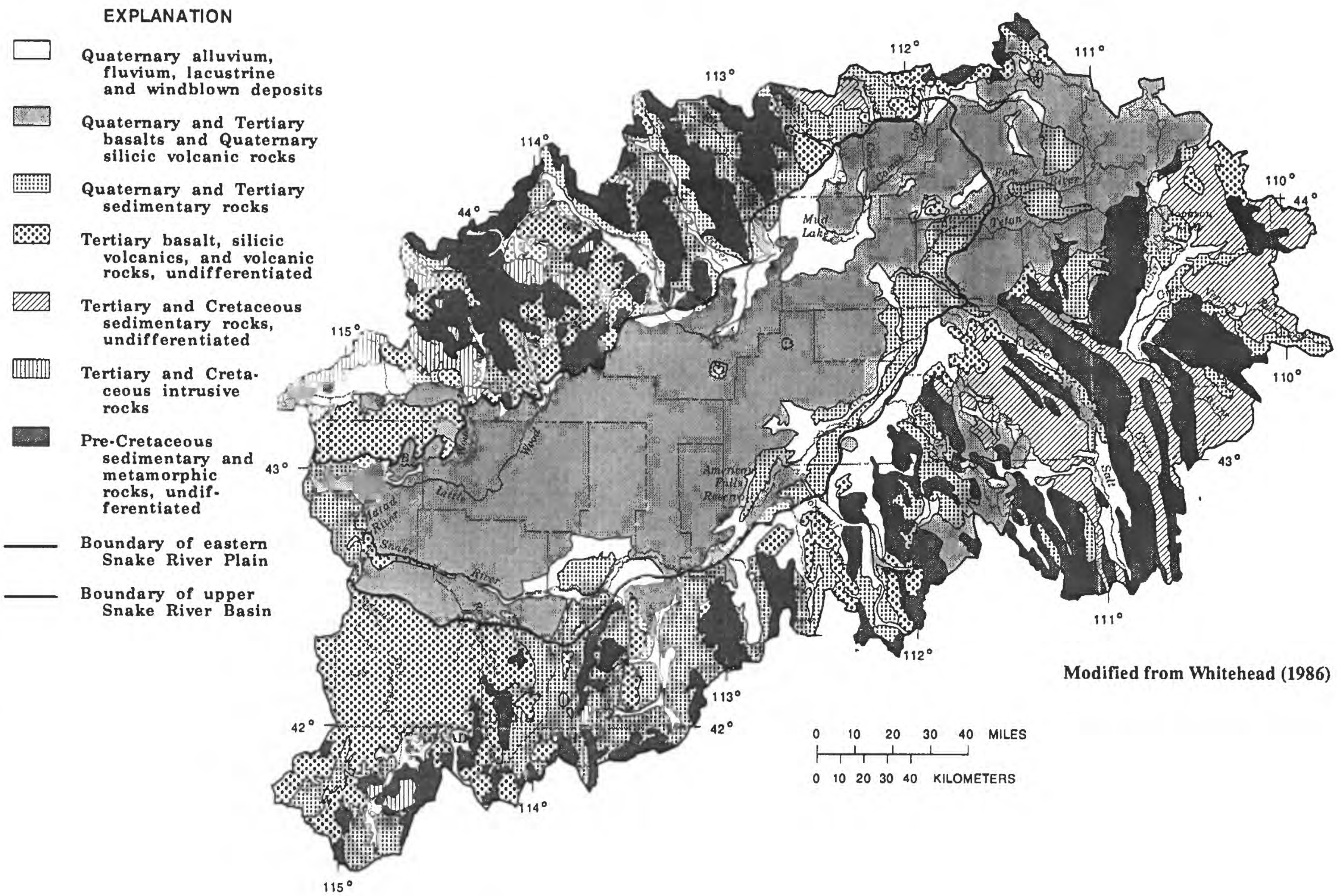


Figure 2. Surficial geology in the upper Snake River Basin.

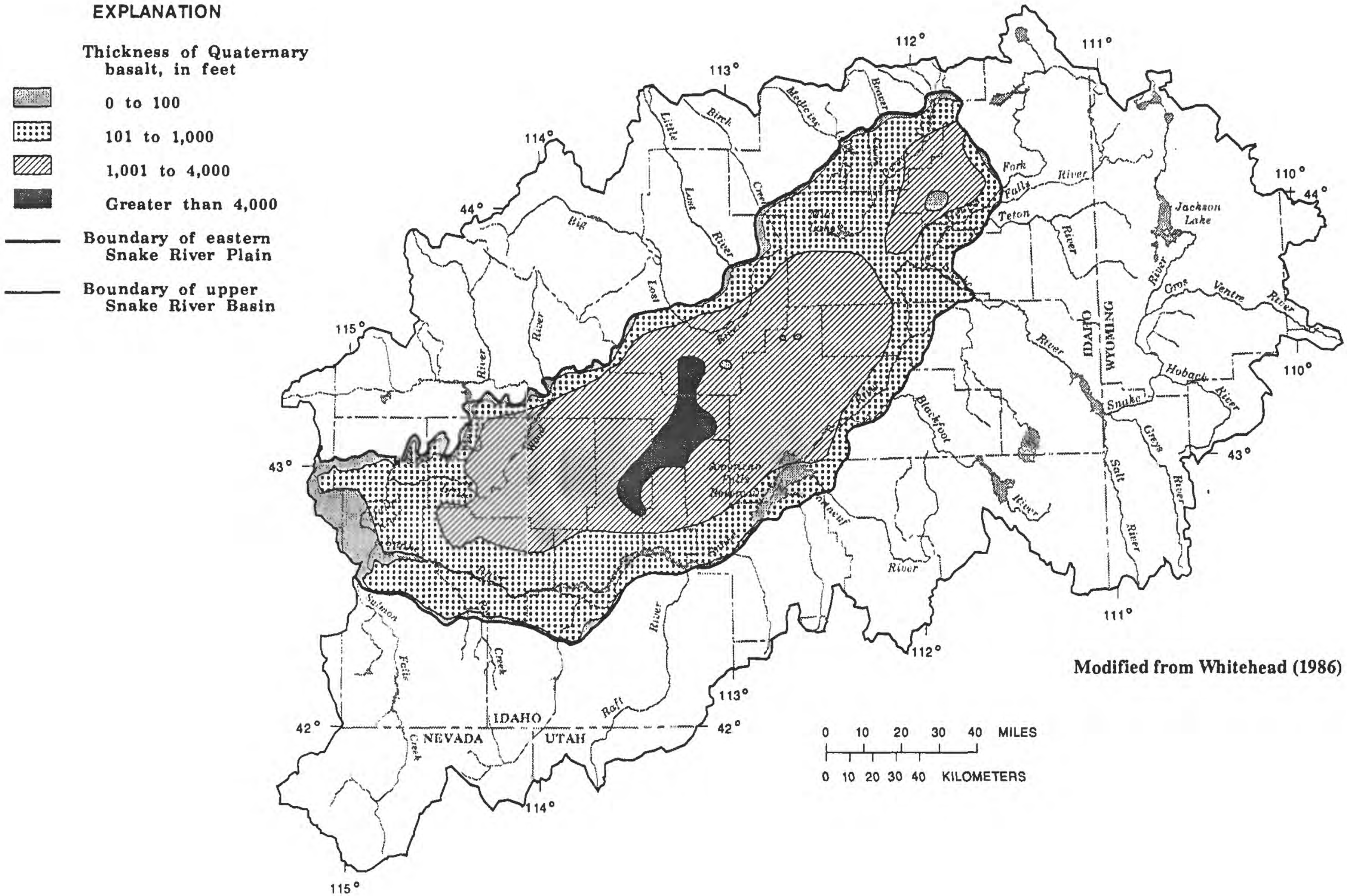


Figure 3. Thickness of Quaternary basalt in the eastern Snake River Plain.

Climate

Climate in the upper Snake River Basin is influenced predominantly by eastward-moving airmasses from the Pacific Ocean. In the summer, airmasses occasionally move up from the Gulf of Mexico and the Caribbean region and produce thunderstorms in eastern Idaho (Kjelstrom, 1992). The semiarid eastern Snake River Plain receives 8 to 10 in. of precipitation annually. The semihumid mountainous parts of the basin receive the greatest amount of precipitation as snow, generally between November and March. Mountains to the northeast may receive more than 60 in. of precipitation annually (fig. 4). January is usually the coldest month and July the warmest; the first freeze is usually in September and the last in May.

Mean monthly (1961–90) precipitation, recorded at weather stations in the basin, ranged from 0.14 to 1.97 in. (fig. 5). Mean annual precipitation for the same period ranged from 8.19 to 16.36 in. The wettest months of the year are usually November through February; however, some areas in the basin receive much precipitation during March through June. Runoff is greatest from April through July. Mean annual air temperature at Idaho Falls from 1948 to 1990 was 43.7°F and daily extremes ranged from -38 to +102°F; at Twin Falls from 1963 to 1990, mean annual air temperature was 47.3°F and daily extremes ranged from -19 to +101°F. The growing season averages 120 to 160 days, depending on elevation and latitude; higher elevations and latitudes experience shorter growing seasons.

Total mean annual precipitation in the basin was estimated using the mean annual (1930–57) precipitation index map of Thomas and others (1963) and GIS techniques. An estimated 35 million acre-ft of water was precipitated in the basin. The eastern slopes of the Teton Range and parts of the basin eastward received the largest amount, about 9.7 million acre-ft, which accounted for about 28 percent of the total mean annual precipitation in 16 percent of the basin area.

Gebert and others (1989) estimated that mean annual runoff (1951–80) ranged from 0.2 to 30 in. in the basin. The magnitude of runoff from tributary drainage basins varies as a result of orographic effects, slope, and melting of winter snowpack (fig. 6). Runoff is greatest in the eastern mountainous parts of the basin where the largest amounts of precipitation fall and is least in the central part of the eastern Snake River Plain where fractured basalts aid infiltration and precipitation is negligible.

Evaporation from standard Class-A pans ranges from 20 to 45 in/yr in the upper Snake River Basin (Farnsworth and others, 1982) (fig. 6). Mean open-water evaporation on the eastern Snake River Plain was estimated at 34 in/yr in a study of 17 Western States. Goodell (1988, p. E44) estimated that evaporation from 107,000 acres of water on the plain was 320,000 acre-ft in 1980. For 1990, estimated evaporation from about 110,000 acres of water on the plain was about 400,000 acre-ft.

Evapotranspiration (ET) rates were estimated in the eastern Snake River Plain as part of ground-water flow models and ground-water budgets. Garabedian (1992, appendix B) used ET rates ranging from 1 to 6 ft/yr. Average ET rates of 1.6 acre-ft/acre for surface-water-irrigated crops and 1.4 acre-ft/acre for ground-water-irrigated crops were estimated by Kjelstrom (1992, p. 49) using crop type, type of irrigation system, and geographic area as determinants. Goodell (1988, p. E8) estimated that, in 1980, almost 3.5 million acre-ft was evapotranspired from surface-water-irrigated crops. More water per acre is applied to crops irrigated with surface water (usually flood irrigated) than with ground water (usually sprinkler irrigated). Goodell also documented potential ET rates on the eastern Snake River Plain that ranged from 1.5 to 2.5 ft/yr. ET on nonirrigated lands is dictated by precipitation, and ET rates in the Raft River Valley south of the eastern Snake River Plain were estimated to be 89 percent of precipitation in 1980 (Goodell, 1988).

Flooding in the upper Snake River Basin is the result of prolonged rainfall, intense summer thunderstorms, spring snowmelt (usually from March through June), and ice jams in river channels. Rainfall on frozen ground in winter or early spring augmented by spring runoff has produced the most damaging and severe floods, and large reservoir capacities have been used to contain floodwaters (Kjelstrom, 1991). Major floods and droughts for the basin are listed in table 2. Probably the most publicized flood was caused by the breach of the Teton Dam near St. Anthony on June 5, 1976. Unprecedented flows occurred on the Teton River, lower Henrys Fork, and Snake River upstream from American Falls Reservoir. The floodwaters affected an area of more than 180 mi^2, and parts of Rexburg and several small communities were

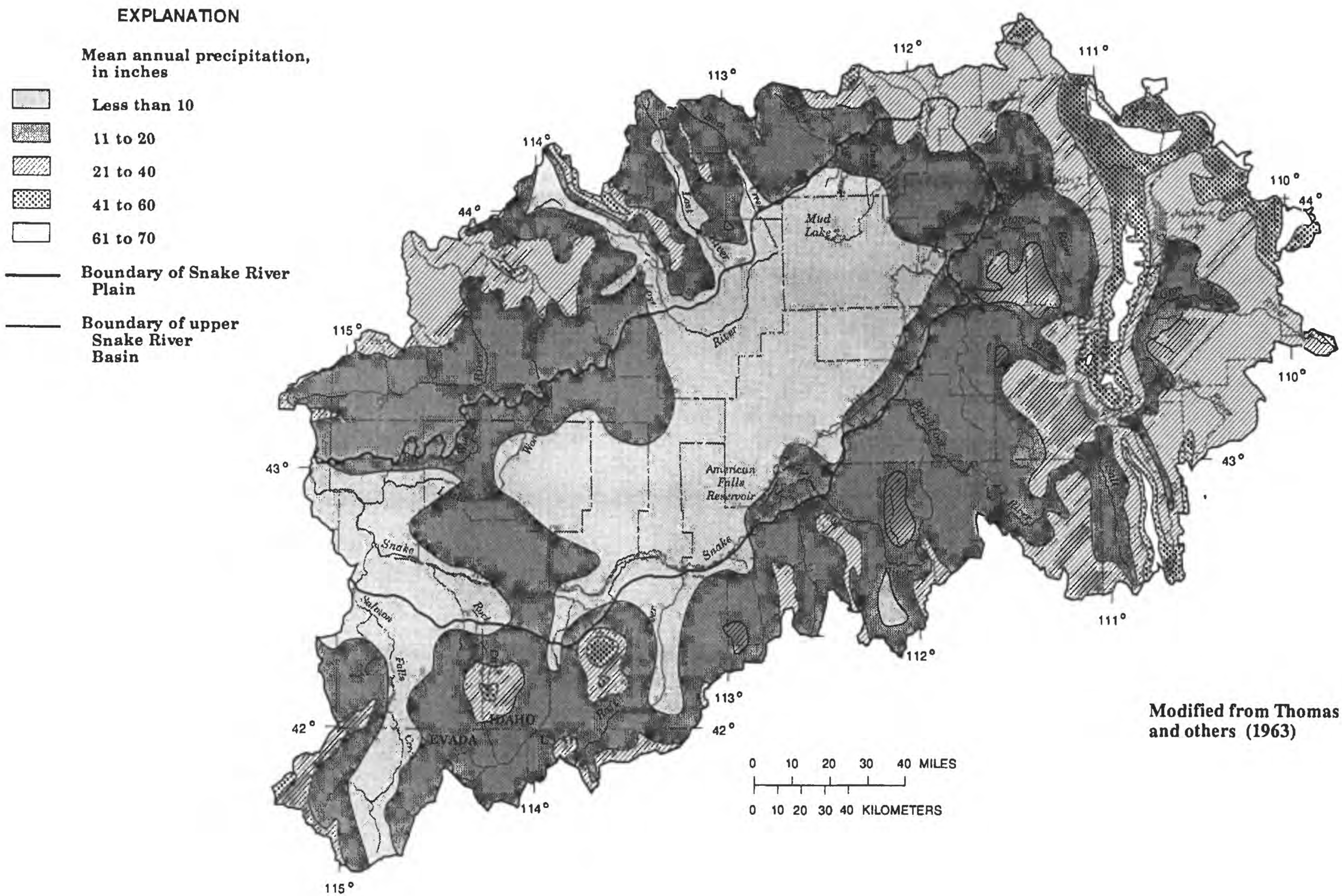


Figure 4. Mean annual precipitation in the upper Snake River Basin.

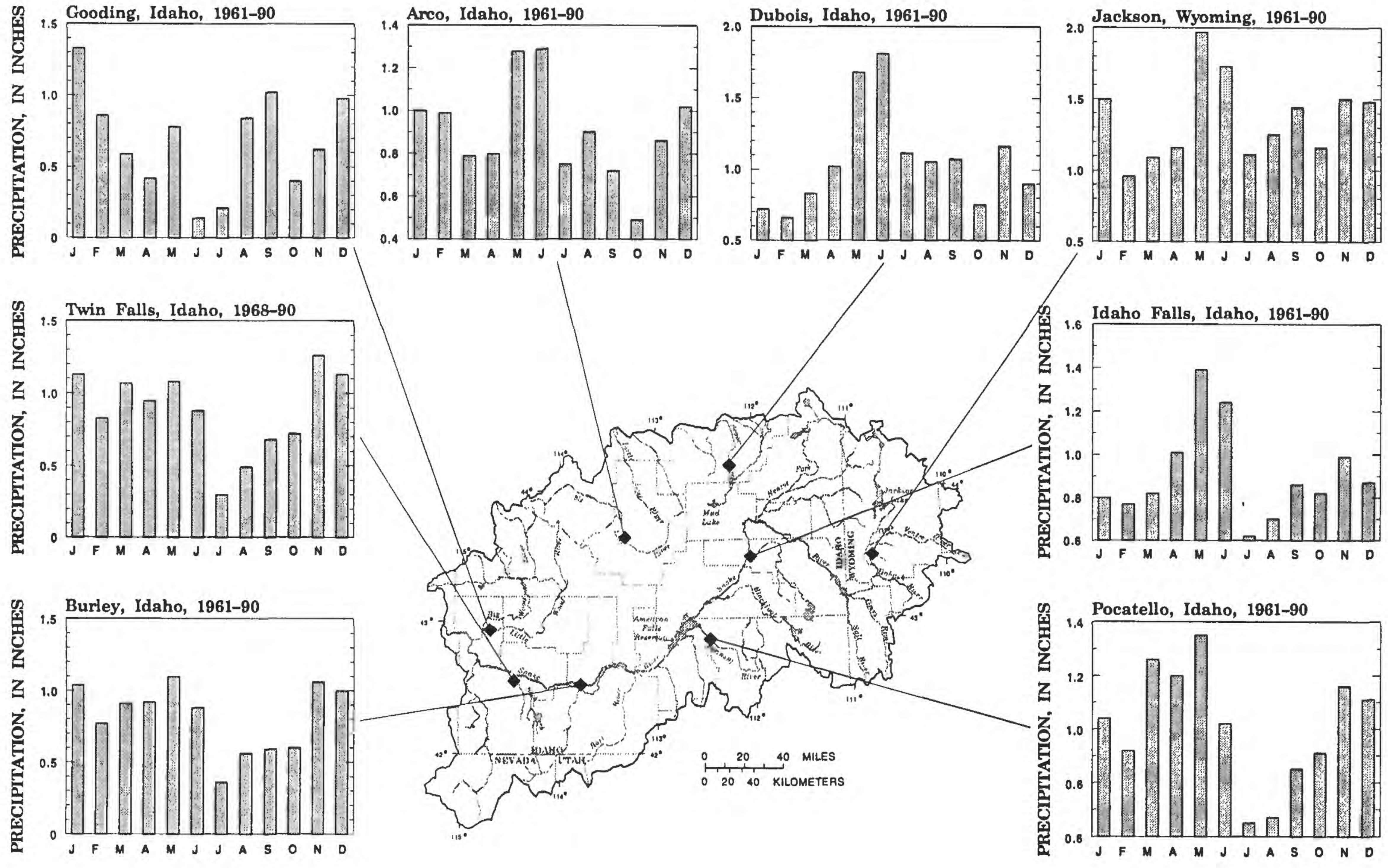


Figure 5. Mean monthly precipitation at selected sites in the upper Snake River Basin, 1961–90.

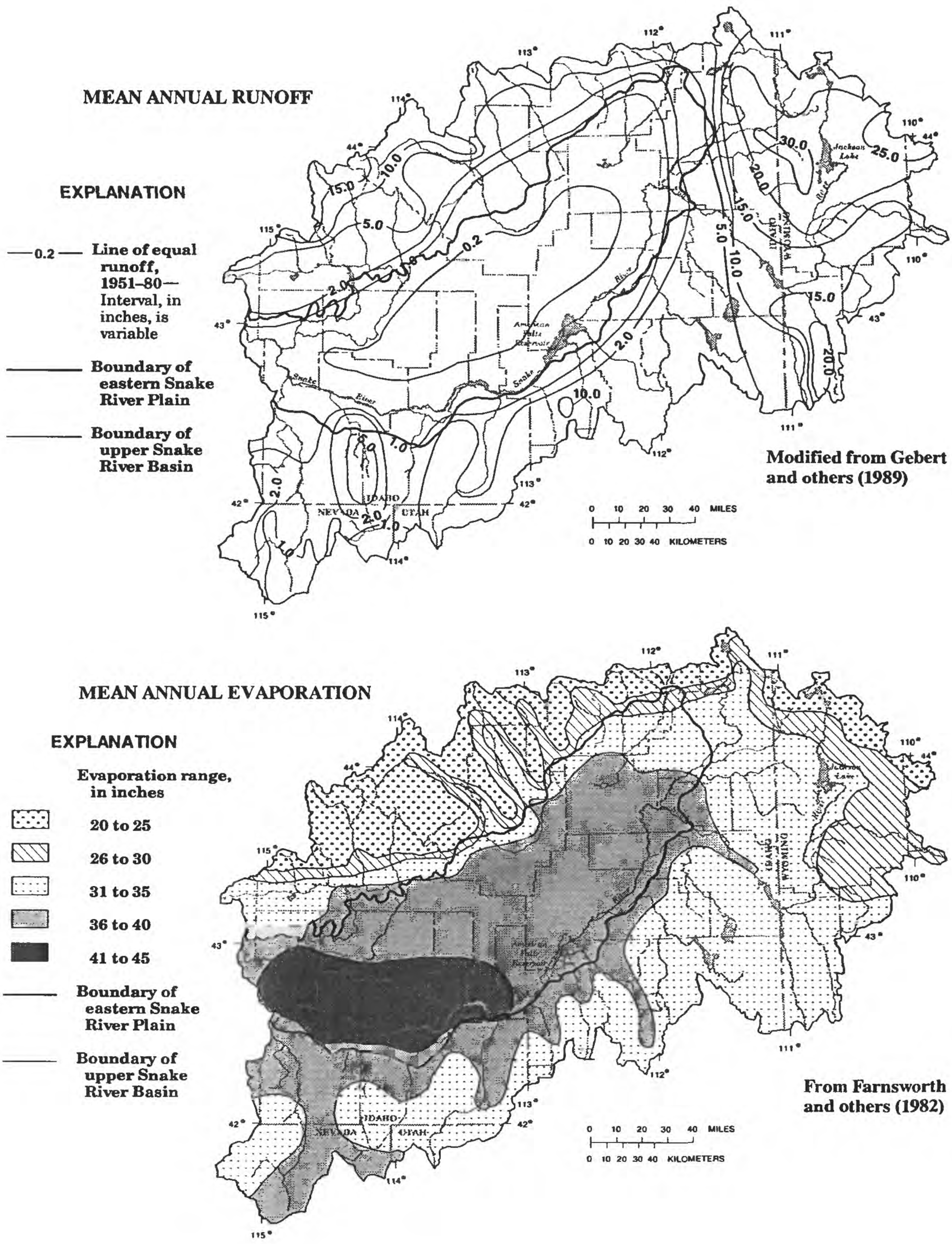


Figure 6. Mean annual runoff, 1951–80, and evaporation, 1956–70, in the upper Snake River Basin.

inundated. The Teton River near the gaging station at St. Anthony recorded flows of 1.06 million ft^3/s.

Chemical analyses of precipitation were obtained from the NADP (National Atmospheric Deposition Program, 1989). The NADP analyzed wet (precipitation) and dry (deposition) samples for major anion and cation constituents from the Craters of the Moon National Monument and Yellowstone National Park monitoring sites. Boxplots of annual and seasonal precipitation-weighted concentrations and dry deposition totals of nitrate and ammonia are illustrated in figure 7. The Craters of the Moon National Monument is the only site entirely within the upper Snake River Basin (fig. 1).

Surface-Water Hydrology

The Snake River is the predominant hydrologic feature in the upper Snake River Basin. It originates in the high mountains of Wyoming near the southern border of Yellowstone National Park and stretches about 453 mi, leaving the basin at King Hill. The average hydraulic gradient is 9.5 ft/mi, and the river is usually within 100 ft of the surrounding land elevation except in the Milner Dam to King Hill reach, where the river is entrenched in a canyon as deep as 700 ft. Successive basalt flows from nearby vents repeatedly altered the course of the river in this reach. The river is offset to the south almost 19 mi from historical channel courses.

The main-stem Snake River flows through five reservoirs between Flagg Ranch and King Hill; the reservoirs provide a total storage capacity of more than 4 million acre-ft (Kjelstrom, 1992). In downstream order, they are Jackson Lake, Palisades Reservoir, American Falls Reservoir, Lake Walcott, and Milner Lake (fig. 1; table 3). All were constructed primarily for agricultural purposes and secondarily for flood control and hydroelectric power development. Milner Lake fills a 34.5-mi-long canyon upstream from Milner Dam and its storage fluctuates due to large irrigation diversions and return flows upstream (Kjelstrom, 1988, p. 54). Eight other reservoirs, each having at least 50,000 acre-ft capacity, and several smaller reservoirs have been built on Snake River tributaries.

The eastern Snake River Plain constitutes about 30 percent of the upper Snake River Basin. Surface water in the basin is described using streamflow records for the Snake River and its major tributaries that flow onto and into the plain. Kjelstrom (1986) used streamflow records from 1934 to 1980 to estimate that mean annual inflow to the eastern Snake River Plain was about 10.2 million acre-ft. Most of the inflow was from the Snake River as measured at Heise, where mean annual discharge was about 5.1 million acre-ft. Just downstream from Heise, the Snake River is joined by the Henrys Fork, which contributed a mean annual discharge of about 1.5 million acre-ft. Farther down-

Table 2. Chronology of major floods and droughts in the upper Snake River Basin

[Modified from Kjelstrom (1991) and Druse (1991); >, greater than]

Event	Date	Location	Recurrence interval (years); remarks
Flood	June 12–18, 1918	Northwest and west-central Wyoming	30 to >100; snowmelt and rainfall.
Flood	May 19, 1927	Upper Snake River Basin	Unknown; washout of landslide in upstream tributary.
Drought	1929–42	Upper Snake River Basin	>50 in Idaho; from 10 to >25 in Wyoming parts of basin.
Drought	1948–62	Upper Snake River Basin	10 to >25.
Flood	Feb. 10–14, 1962	Southern and eastern Idaho	20 to >100.
Flood	Feb. 1–3, 1963	Portneuf River Basin	Unknown; ice jams aggravated flooding.
Flood	Dec. 21–23, 1964	Statewide, Idaho	20 to >100; precipitation on frozen ground; $15.5 million damages.
Flood	June 6–19, 1974	Statewide, Idaho	40 to >100.
Flood	June 5, 1976	Eastern Idaho	Unknown; Teton Dam breached; $400 million damages; 25,000 people homeless.
Drought	1976–82	Western Wyoming	10 to >25; less-than-average streamflow for 2–4 consecutive years.
Flood	June 9, 1981	Upper Snake River Basin	40 to >100; rainfall combined with snowmelt.
Flood	May 15–June 21, 1984	Eastern and central Idaho	50 to >100; rapid snowmelt in mountains.
Drought	1987–88	Upper Snake River Basin	10 to >25.

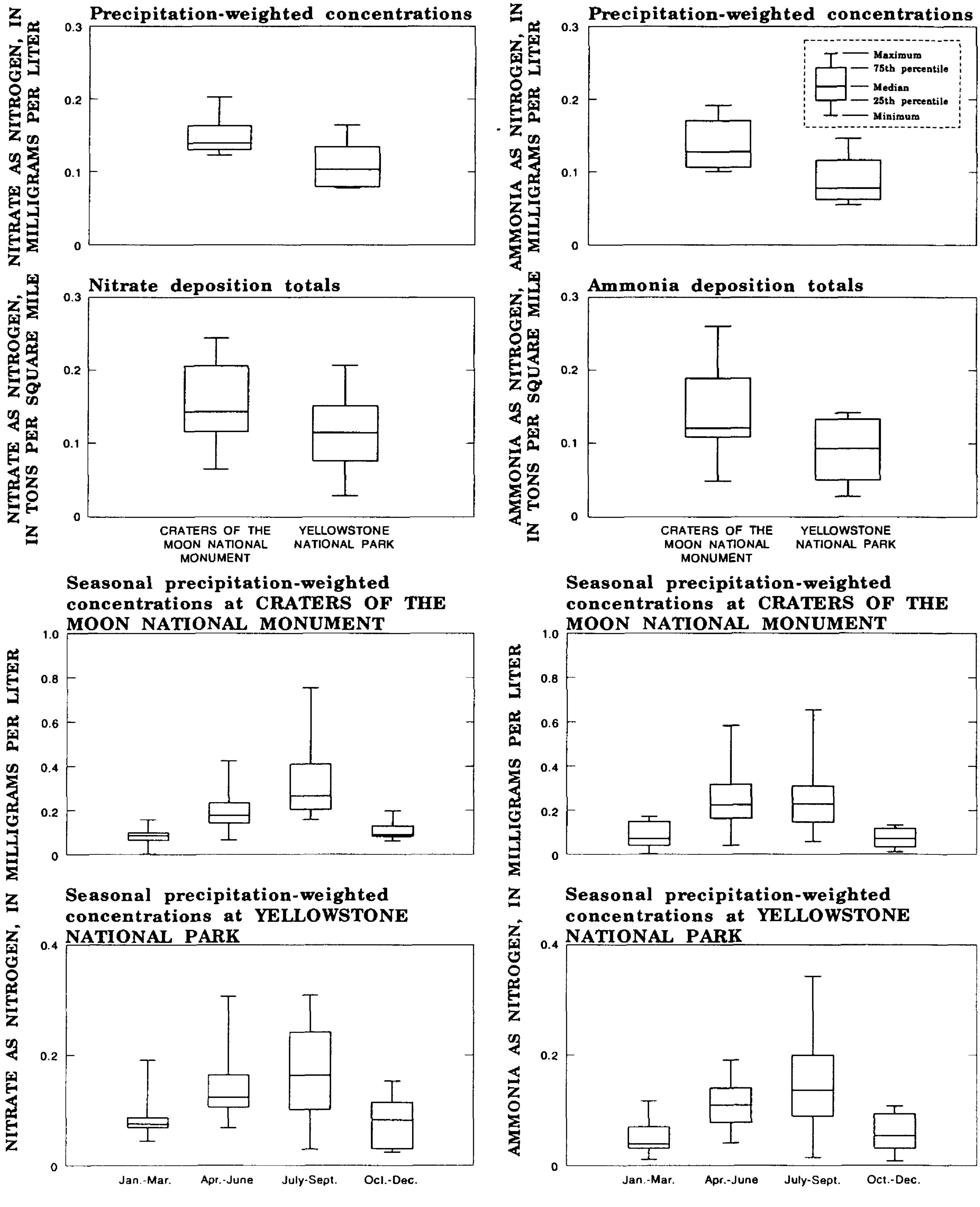


Figure 7. Atmospheric nitrate and ammonia concentrations in precipitation and dry deposition totals at selected sites in the upper Snake River Basin, 1981–90.

Table 3. Names and descriptions of major reservoirs in the upper Snake River Basin

[Modified from Kjelstrom (1992)]

Reservoir name (fig. 1)	Year built	Storage capacity (acre-feet)
Jackson Lake	1906	847,000
Palisades Reservoir	1956	1,400,000
American Falls Reservoir	[1]1927	1,700,000
Lake Walcott	1906	104,000
Milner Lake	1905	Varies

[1]Dam replaced in 1978.

stream, the six largest tributaries from the south are Willow Creek; Blackfoot and Portneuf Rivers; and Goose, Rock, and Salmon Falls Creeks. Mean annual discharge from these tributaries was about 0.7 million acre-ft. Northern tributaries that do not flow directly into the Snake River include the Big and Little Lost Rivers and Birch and Camas Creeks. About 1.1 million acre-ft of water flowed annually from these tributaries and either evaporated or percolated into the regional aquifer. The Big and Little Wood Rivers contributed about 0.2 million acre-ft to the Snake River just upstream from King Hill. Mean annual discharge of the Snake River at King Hill was about 7.5 million acre-ft.

Gravity-flow and pumped diversions are predominant in different parts of the upper Snake River Basin. In 1980, total gravity-flow and pumped diversions from the Snake River and its tributaries were almost 8.8 million acre-ft (Bigelow and others, 1987; Goodell, 1988). Gravity-flow diversions occur mainly in the upper part of the basin (Henrys Fork, Falls, and Teton Rivers) and along the Snake River between Heise and Milner Dam. More than 98 percent of all gravity-flow diversions are accounted for upstream from Milner Dam (Goodell, 1988, p. E19). Pumped diversions occur mainly in the Milner Dam to King Hill reach where the Snake River is deeply entrenched. In this reach, 90 percent of all withdrawals from the Snake River are pumped.

In 1980, gravity-flow diversions from the Snake River and tributaries between Heise and Milner Dam were about 7.0 million acre-ft (Goodell, 1988). Gravity-flow diversions near Heise were about 1.7 million acre-ft, and diversions at Milner and Minidoka Dams to five canals were about 2.9 million acre-ft in 1980. Some canals and laterals deliver water to agricultural lands more than 40 mi away from the Snake River. The largest canals servicing agricultural lands north of the Snake River are the Great Western, Peoples, Aberdeen-Springfield, Main North Side, Milner-Gooding, and Twin Falls North Side (fig. 8). These canals alone transported roughly 2.0 million acre-ft of water in 1980 (Garabedian, 1992, appendix A). The largest canals delivering water to agricultural lands south of the river include the Idaho, Snake River Valley, Reservation, Fort Hall North, Fort Hall Main, Main South Side, and Twin Falls South Side. About 3.0 million acre-ft of water was diverted to the south in 1980. Total gravity-flow diversions in the upper part of the basin (Henrys Fork, Falls, and Teton Rivers) were 1.1 million acre-ft in 1980.

High-lift pump diversions make up 90 percent of withdrawals from the Snake River and tributaries between Milner Dam and King Hill. Total pumped withdrawals from the Snake River and tributaries in this reach were 408,500 acre-ft in 1980. The largest pumped withdrawals on the Snake River are at King Hill, where 88 pumps lifted 256,800 acre-ft of water in 1980 (Bigelow and others, 1987). Pumps between Heise and Milner Dam diverted less than 0.2 million acre-ft in 1980.

Fluctuations in streamflow near Heise and at Milner Dam are greatly affected by irrigation diversions. Mean monthly streamflow (1980–89) near Heise was greatest during April through August to supply large downstream diversions; from September through March, streamflow was relatively constant (Clark, 1994) (fig. 9). The Milner Dam gaging station also reflects large streamflow fluctuations because of upstream diversions during July through September when irrigation is most intense. Downstream from Milner Dam, irrigation diversions typically reduce streamflow to less than 10 ft^3/s during these months. Ground-water discharge from springs restored more than 6,500 ft^3/s of streamflow to the Snake River between Milner Dam and King Hill in 1980 (Kjelstrom, 1992, p. 41).

Agricultural and industrial return flows to the Snake River replenish streamflow and provide additional water that can be diverted downstream. Sometimes return flows represent most of the water in the Snake River during drought years. During times of low flow, instream water quality may be greatly affected by return flows containing suspended sediments, nutrients, and pesticides. Garabedian (1992, appendix A) compiled surface-water return-flow estimates for the eastern Snake River Plain from

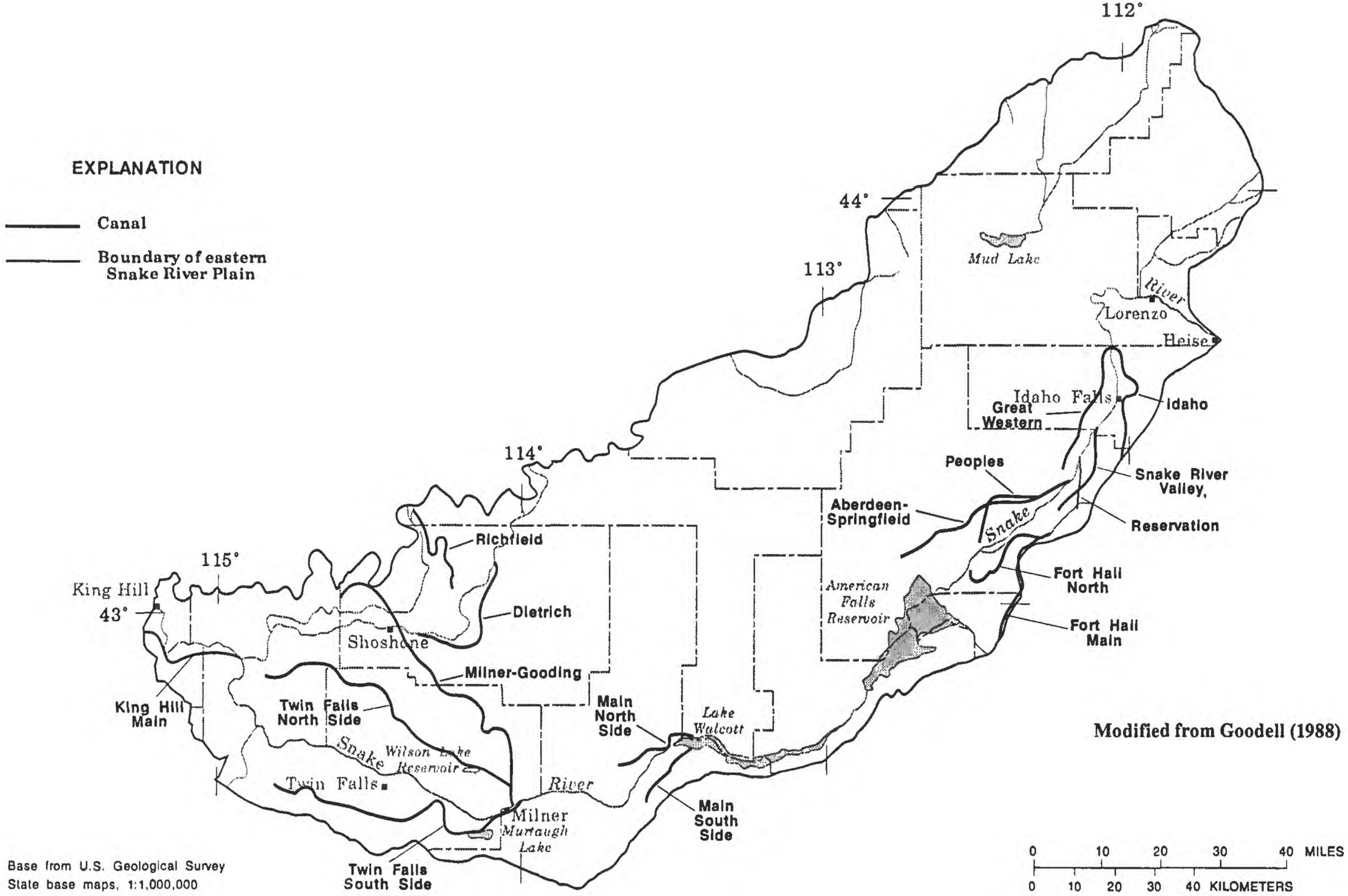


Figure 8. Locations of major canals in the eastern Snake River Plain.

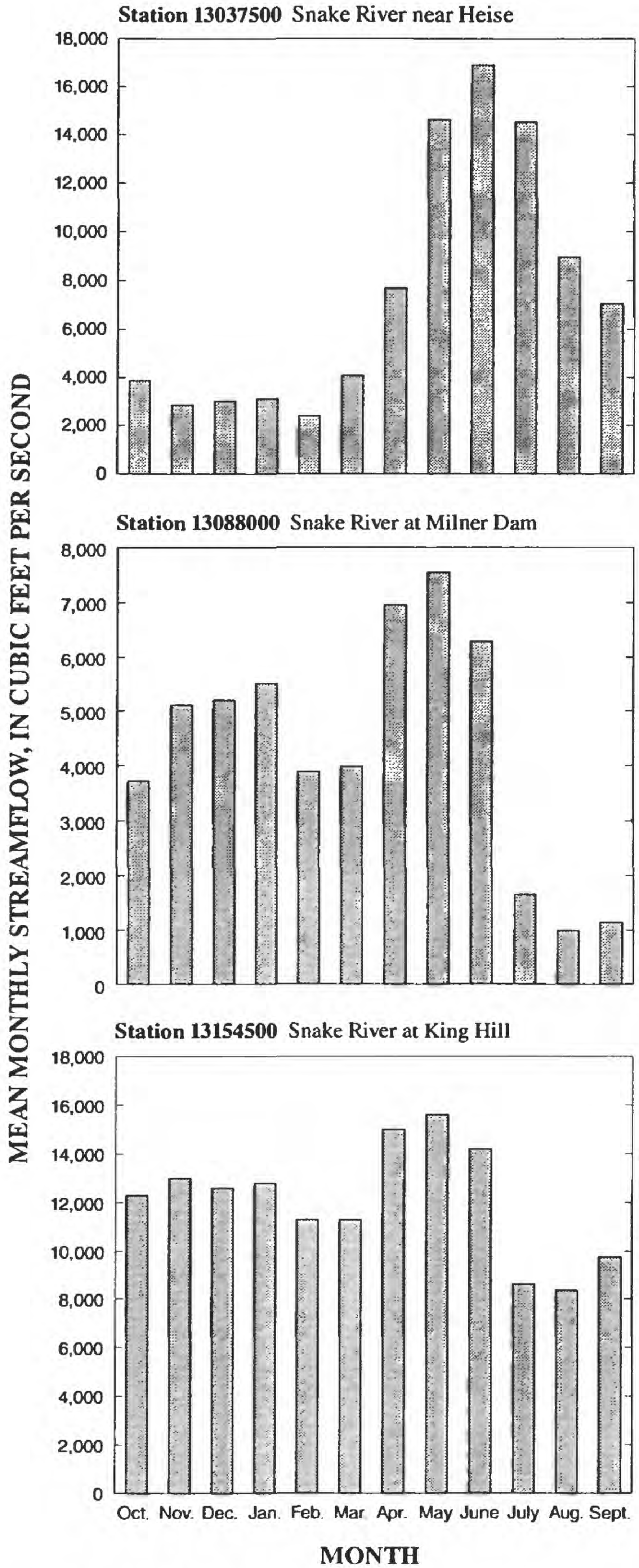


Figure 9. Mean monthly streamflow at selected gaging stations in the upper Snake River Basin, water years 1980–89 (Clark, 1994).

various sources. In 1980, an estimated 1.4 million acre-ft of water returned to the Snake River between Heise and Milner Dam, and 1.2 million acre-ft of water returned between Milner Dam and King Hill. Return flows to the Henrys Fork, Falls, and Teton Rivers in 1980 were about 0.3 million acre-ft.

Mapping efforts using aerial photography are underway to accurately locate points of tributary inflow and agricultural and industrial return flows throughout the entire reach of the Snake River and Henrys Fork. Points of tributary inflow are identified for most springs, rivers, creeks, or streams; points of return flow are identified for most agricultural drains, canals, and outflows from industrial facilities. So far (1993), mapping has been completed from Buhl to Milner Dam, where 243 springs and 105 agricultural points of return flow have been located. Most of the agricultural return flows are between Milner Dam and Twin Falls.

Ground-Water Hydrology

The Snake River Plain aquifer underlies the eastern Snake River Plain and is one of the most productive aquifers in the world. It stores and transmits water through permeable basalt and interlayered sedimentary rocks. The upper 500 ft of the aquifer may store 200 to 300 million acre-ft of water (Lindholm, 1986, p. 105). Most water moves horizontally except in areas of recharge or discharge, where vertical movement was recorded (Lindholm and others, 1988). Ground water generally flows from northeast to southwest. Most recharge is from surface water diverted for irrigation. Major discharge areas are near American Falls Reservoir and springs and seeps on the north side of the Snake River between Milner Dam and King Hill (fig. 10) (Garabedian, 1992). Ground-water pumpage also is considered a major discharge.

Garabedian (1992) used numerical models to simulate regional ground-water flow and estimated that average transmissivity of the Snake River Plain aquifer ranged from 0.05 to 120 ft^2/s. Well yields and transmissivity are highest in basalt flows of Quaternary and late Tertiary age. Water generally moves horizontally through rubble at the top of and between these flows. Water moves vertically through joints and contacts between adjacent flows. Hydraulic gradients range from 5 to 10 ft/mi in the central parts of the plain and increase to about 30 ft/mi in the western parts of the plain (Lindholm and others, 1988).

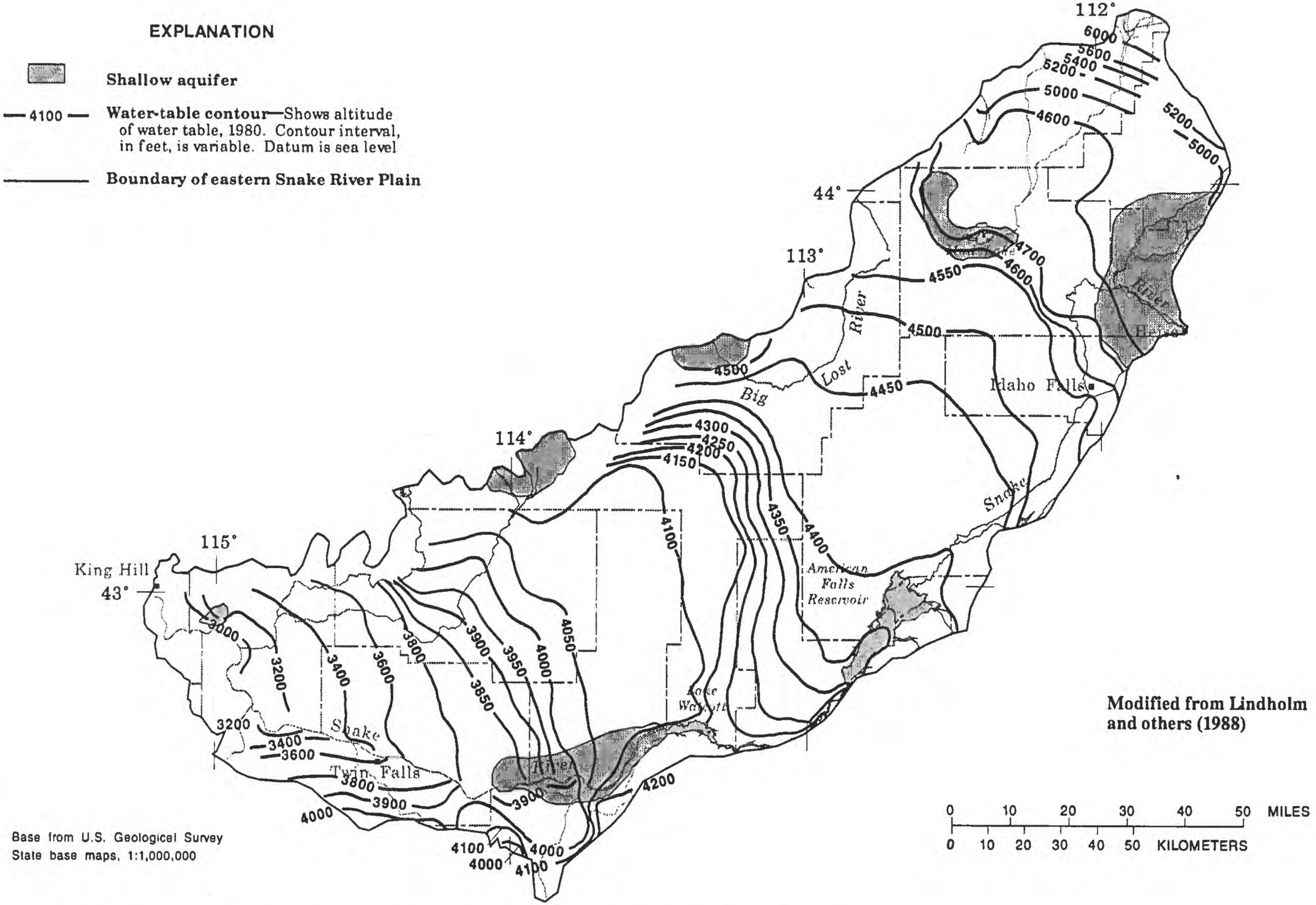


Figure 10. Configuration of the water table and areas of shallow aquifers in the eastern Snake River Plain, 1980.

Sand and gravel aquifers are common along the border of the plain, in alluvial fans, and along streams. They yield substantial amounts of water and are locally important for irrigation and domestic supplies. In places such as the Mud Lake area and where the Big Lost River enters the plain, relatively impermeable lacustrine silt and clay deposits retard horizontal and vertical movement in that part of the aquifer nearest land surface (fig. 10).

Depth to water in the upper Snake River Basin was mapped for selected areas on the eastern Snake River Plain and surrounding tributary valleys. Water in the eastern Snake River Plain is deepest in the central parts and shallowest near the margins and along the Snake River (Maupin, 1991) (fig. 11). Depth to water in the central parts of tributary valleys is also shallow.

Sources of recharge are infiltration of surface water applied for irrigation, infiltration of streamflow and underflow from tributary drainage basins, precipitation, and streamflow losses from the Snake River (Kjelstrom, 1992). Estimated water budgets for the eastern Snake River Plain aquifer (1980) showed that 60 percent of recharge was from surface water diverted for irrigation, 25 percent was from tributary inflow, 10 percent was from precipitation, and 5 percent was from Snake River streamflow losses (Lindholm and others, 1988).

Most canals on the eastern Snake River Plain are unlined and seepage loss has been estimated at 3 to 40 percent of diverted flow (Garabedian, 1992). Recharge from surface-water diversions is greatest from canals that divert water from the Snake River between Heise and Neeley; 3.1 million acre-ft was diverted in 1980 (Kjelstrom, 1992, p. 52). Northern tributary drainage basins represent the largest ground-water recharge source with 1.1 million acre-ft of water in 1980 (Kjelstrom, 1986). Garabedian (1992, p. F16) estimated that, in 1980, about 700,000 acre-ft of water from precipitation recharged the ground-water system in the eastern Snake River Plain. Kjelstrom (1992) offered the most complete water budget of the eastern Snake River Plain.

From 1880 to 1952, ground-water storage in the eastern Snake River Plain increased about 24 million acre-ft (Kjelstrom, 1992, p. 54, 55). Increases were the result of additional surface-water diversions. From 1952 to 1980, ground-water storage decreased about 6 million acre-ft. Decreases were caused by below-normal precipitation, increased ground-water pumpage, and more efficient irrigation practices.

Ground-water discharge to the Snake River from seeps and springs in the reaches between Blackfoot and Neeley and between Milner Dam and King Hill and ground-water pumpage for irrigation are major sources of discharge. These two spring reaches contributed 85 percent of the total ground-water discharge to the Snake River in 1980 (Kjelstrom, 1992). Ground-water discharges between Blackfoot and Neeley were estimated to be about 1.9 million acre-ft and, between Milner Dam and King Hill, about 4.4 million acre-ft. Changes in water use, irrigation practices, and precipitation have caused ground-water discharge to the Snake River to decrease steadily since 1987. Bigelow and others (1987) used power consumption data, discharge measurements, total head, and type of distribution system to estimate that 1.9 million acre-ft of ground water was pumped from the eastern Snake River Plain in 1980.

Soils

Soils are classified on the basis of physical conditions such as depth, texture, structure, and slope, and qualities such as permeability, porosity, water-bearing capability, and suitability for land-use activities. Land uses commonly are based on the existing soil types (Pacific Northwest River Basins Commission, 1972, p. 29). Soils in the upland areas of the upper Snake River Basin are suited mostly for rangeland, pasture, woodland, or wildlife habitat. Soils along the Snake River and in tributary valleys are suited mostly for agriculture. Where lava flows are exposed, soils are suited only for recreation, wildlife habitat, water supply, or esthetic purposes. About 76 percent of all soil classes in the basin are susceptible to relatively rapid water or wind erosion.

In the upper Snake River Basin, silty soils predominate on plateaus, in canyons, and on mountains; sandy soils from volcanic ash or pumice are common on terraces, foothills, plateaus, and mountains in the eastern and southern parts of the basin. The bottomlands and low terraces along the Snake River north of American Falls Reservoir and the open valley south of Jackson Lake are composed of silty and sandy alluvium. In intermontane valleys north of the eastern Snake River Plain, silty and sandy soils with coarse, angular fragments originated from glacial material. At higher elevations in the intermontane valleys, silty

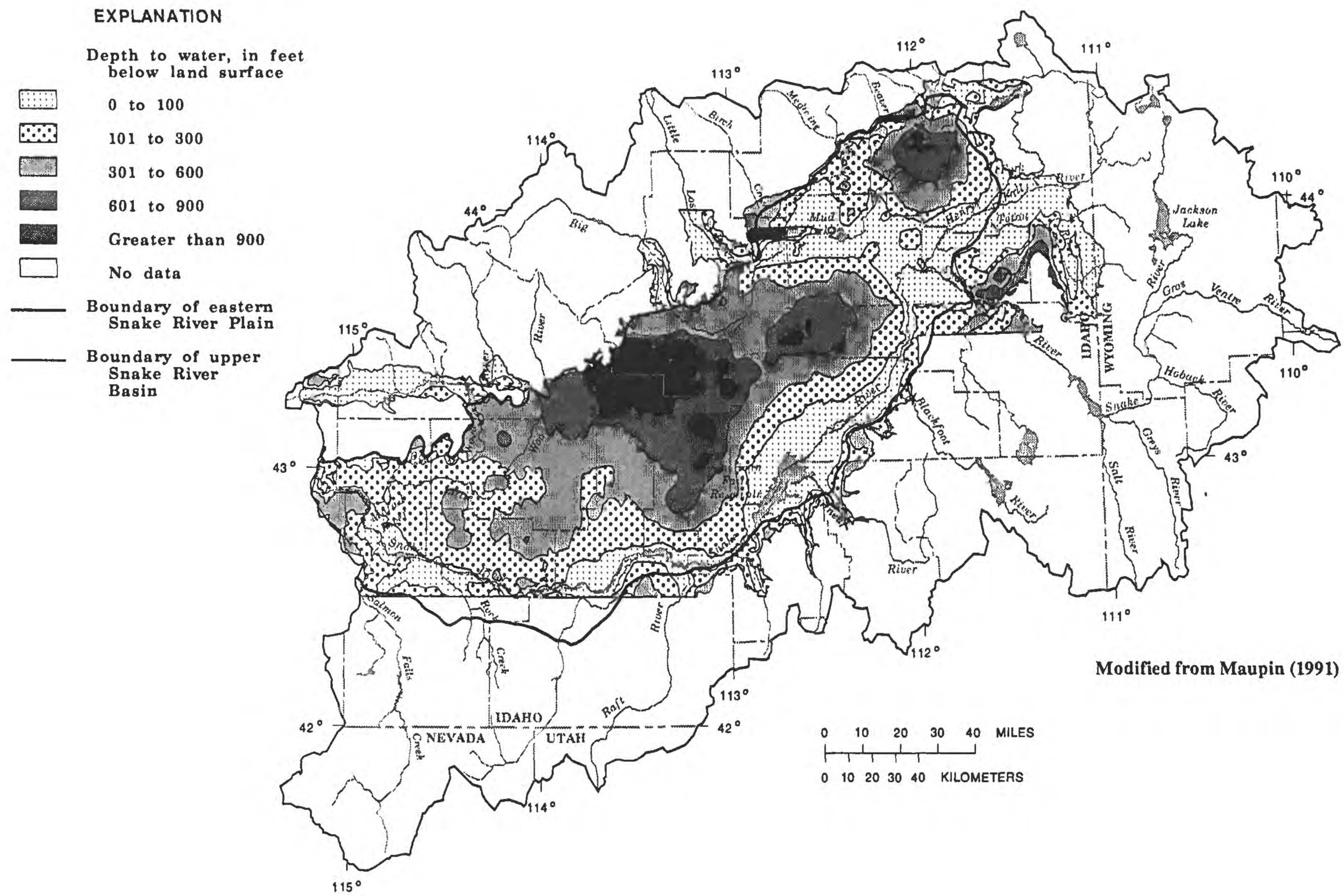


Figure 11. Depth to water in parts of the eastern Snake River Plain and surrounding tributary valleys, 1980–88.

soils mixed with gravelly residuum-colluvium have developed from sedimentary bedrock. Southeast and east of the plain, silty or sandy soils on the uplands have developed from eolian deposits (Pacific Northwest River Basins Commission, 1970, p. 144).

The potential for high or low infiltration rates on the eastern Snake River Plain was determined using depth and soil type data (Garabedian, 1992; Kjelstrom, 1992). Recent basalt flows with shallow soil deposits are featured in localized areas of the eastern Snake River Plain and have high infiltration-rate potential (fig. 12). Areas with thin soil deposits (less than 40 in.) also are classified with high infiltration-rate potential. These types of soil conditions are common mostly in the northeastern tip, along the southern margins, and in some northern and western parts of the plain. Low infiltration-rate potentials are common in most of the central parts of the plain where soils are thick (greater than 40 in.). In these areas, vertical water movement is impeded.

Ecoregions

Ecoregions are areas with similar combinations of soils, potential natural vegetation, landforms, and land use (Omernik and Gallant, 1986). Ecoregions provide a standardized classification scheme that enables comparative assessment of water-quality and biological

Table 4. Characteristics of ecoregions in the upper Snake River Basin

[Modified from Omernik and Gallant (1986); —, no appropriate pattern was discernible from the component map for this characteristic; <, less than]

Ecoregion	Percentage surface area of study basin	Land surface form	Potential natural vegetation	Land use	Soils
Snake River Basin/ High Desert	50	Tablelands with moderate to high relief; plains with hills or low mountains.	Sagebrush steppe (sagebrush, wheatgrass, saltbush, and greasewood).	Desert shrubland grazed; some irrigated agriculture.	Aridisols, aridic Mollisols.
Middle Rockies	23	High mountains.	Douglas fir, western spruce and fir, alpine meadows (bentgrass, sedge, fescue, and bluegrass).	Grazed and ungrazed forest and woodland.	Alfisols.
Northern Basin and Range	18	Plains with low to high mountains; open high mountains.	Great Basin sagebrush, saltbush, and greasewood.	Desert shrubland grazed.	Aridisols.
Northern Rockies	9	High mountains.	Cedar, hemlock, pine, western spruce, fir, grand fir, and Douglas fir.	Forest and woodland mostly grazed.	Eastern interior mountain soils with acidic rock types; Inceptisols.
Wyoming Basin	<1	Plains with hills or low mountains.	Sagebrush steppe (sagebrush, wheatgrass, and needlegrass). Shrub steppe (saltbush, greasewood, juniper, and pinyon woodland).	Desert shrubland grazed; some irrigated agriculture.	Argids, Orthents.
Montana Valley and Foothill Prairies	<1	—	Foothills prairie (wheatgrass, fescue, and needlegrass).	Subhumid grassland and semiarid grazing land; some irrigated land.	Dark-colored soils of semiarid regions.

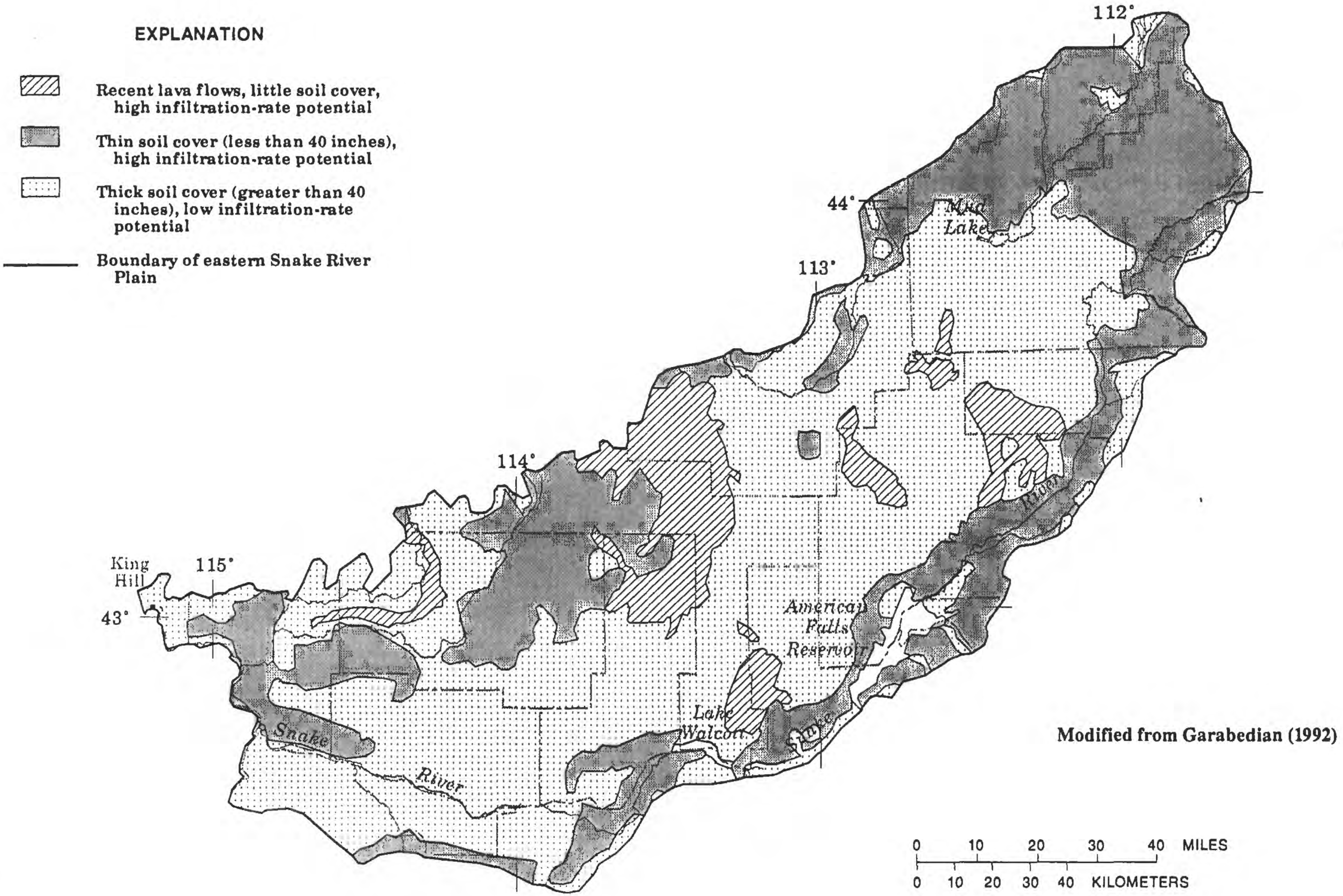


Figure 12. Distribution of generalized soil types and infiltration-rate potential in the eastern Snake River Plain.

communities across large areas that exhibit common environmental patterns. Ecosystem potentials in areas of spatial and environmental diversity may be understood using ecoregions as the stratification framework.

Ecoregions were used to stratify the upper Snake River Basin into geographic areas (table 4 and fig. 13) where water-quality and biological data-collection sites described in companion reports were selected. Relations between water-quality conditions and biological communities will be associated with ecoregion characteristics in final reports from the upper Snake River Basin NAWQA.

LAND USE AND LAND OWNERSHIP

Three congressional mandates helped establish the land uses and land ownership in the upper Snake River Basin. The Desert Land Act of 1877 and the Carey Act of 1894 began the movement to settle the arid West and develop many of the agricultural communities along the Snake River. The Reclamation Act of 1902 assisted the transfer of Federal land to private ownership and initiated the construction of dams, canals, and reservoirs to help expand irrigated lands and extend the irrigation season. Today, rangeland and agricultural and forest lands constitute most of the land uses; the Federal Government has guardianship over twice as much land as have private ownerships.

Land-use data consisted of digital line graph (DLG) files for 1:250,000-scale maps in the study area; the DLG data format enabled a GIS land-use data layer to be constructed. Source materials for land-use classifications included National Aeronautics and Space Administration high-altitude aerial photographs and National High-Altitude Photography program photographs, commonly at 1:60,000-scale or smaller (U.S. Geological Survey, 1986). Dates of the source materials for the maps in the study area were 1977 and 1980. The GIS land-use data layer showed that rangeland constitutes about 50 percent, or 11.5 million acres, of the basin. Forest lands compose about 23 percent, or 5.3 million acres, and agricultural lands represent about 21 percent, or 4.7 million acres (fig. 14). Rangeland and forest lands may be used for grazing and provide most of the area by which precipitation can recharge the ground-water system (Lindholm and Goodell, 1986). Open water, wetlands, barren lands, tundra, and ice compose almost 6 percent, or 1.3 million acres, and urban areas compose less than 1 percent, or 54,000 acres. A report by Anderson and others (1976) gives a complete description of land-use classification definitions and how they were determined.

Activities such as grazing, logging, and mining on rangeland and forest lands may affect water quality by increasing suspended sediment loads and concentrations of metals or nutrients. Agricultural lands represent areas where pesticide and fertilizer applications and crop rotation and tillage practices may affect both surface-water and ground-water quality. Urban lands represent areas where runoff, pesticide and fertilizer usage, and waste disposal may affect water quality.

Land cover describes the potential natural vegetative cover, which is a classification of dominant plant species that would be found naturally if human influences were removed and plant succession were accelerated into a single moment (Kuchler, 1964). Sixty-five percent of the basin is classified as sagebrush steppe (fig. 15), most of which corresponds with rangeland in the Snake River Basin/High Desert ecoregion. About 27 percent is classified as forest land, principally in the Middle and Northern Rockies ecoregions. Saltbush, greasewood, and juniper constitute about 4 percent of potential natural total vegetation basinwide, mostly in the Northern Basin and Range ecoregion. The remaining 4 percent is classified as barren land with little vegetative cover and corresponds with bare basalt flows in the central parts of the eastern Snake River Plain.

In 1990, the Federal Government owned about 15.0 million acres, or about 65 percent of the basin; in 1968, it owned about 15.3 million acres (Pacific Northwest River Basins Commission, 1970, p. 143; Idaho Department of Commerce, 1992; Wyoming Department of Administration and Information, 1992). The State owned about 1.1 million acres in 1968 and, in 1990, owned about 0.9 million acres, or 4 percent of the basin. Private ownership increased from 6.3 to about 7.0 million acres between 1968 and 1990 and accounts for about 31 percent of the total ownership. The U.S. Forest Service and the Bureau of Land Management were the largest Federal landowners, and State endowment lands dominated State-owned lands.

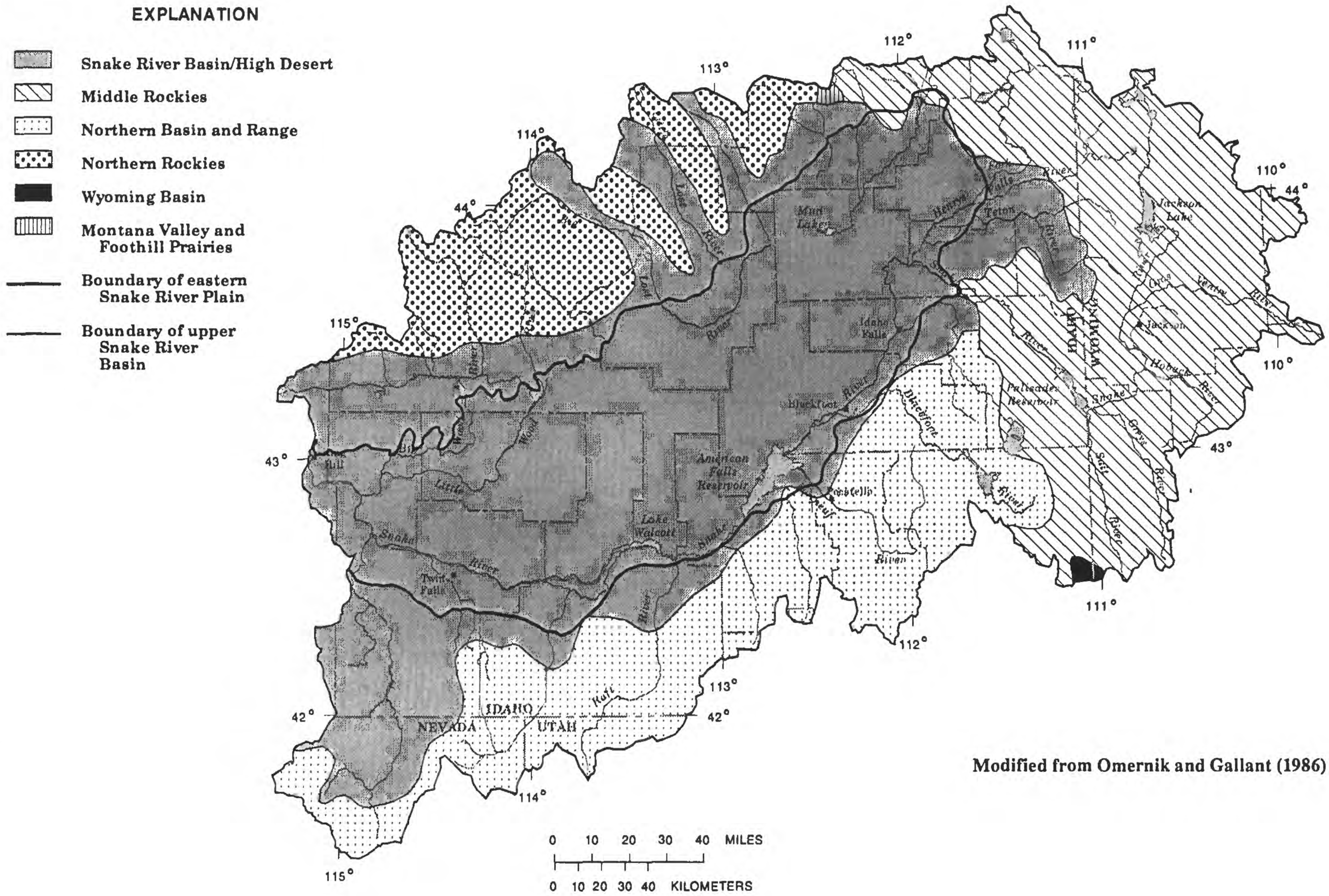


Figure 13. Locations of major ecoregions in the upper Snake River Basin.

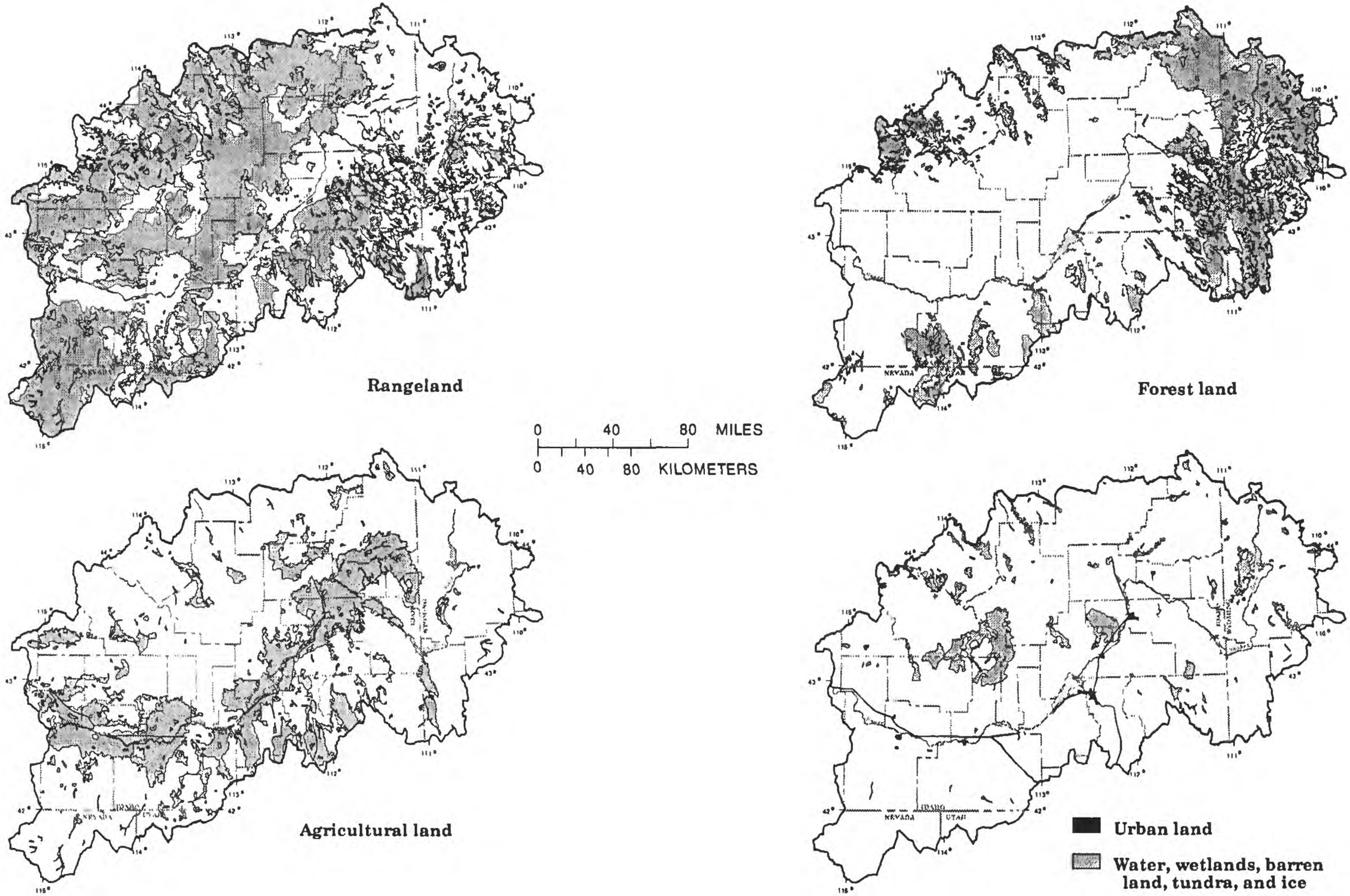


Figure 14. Distribution of major land-use classifications in the upper Snake River Basin. (Data modified from mid-1970's Geographic Information Retrieval and Analysis System, U.S. Geological Survey, 1986)

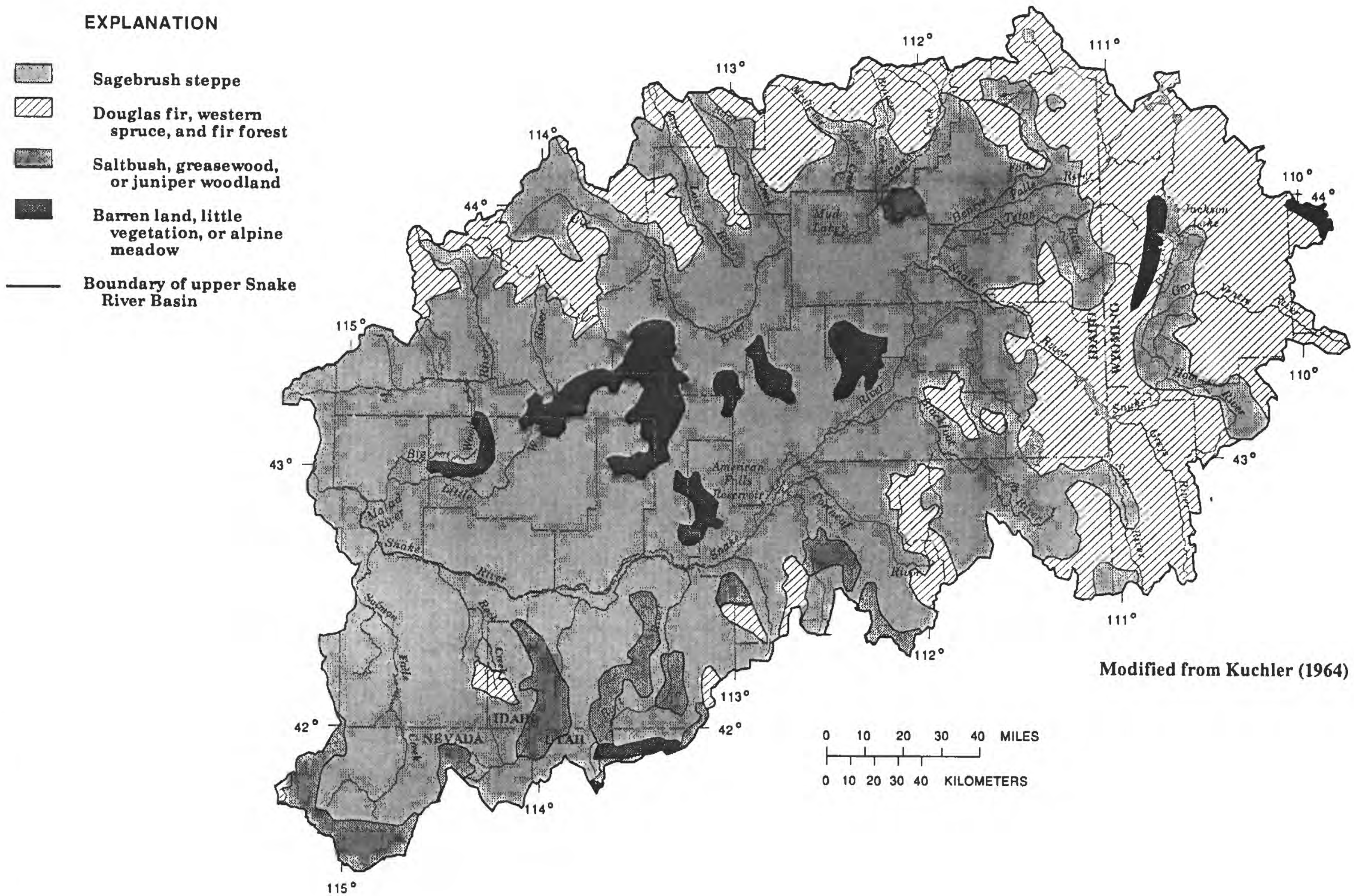


Figure 15. Potential natural vegetative land cover in the upper Snake River Basin.

WATER USE

A description of how water is used in the upper Snake River Basin is necessary to understand hydrologic conditions. In general, water use refers to the interaction between human activities and the hydrologic environment using terms such as withdrawal, delivery, consumptive use, and return. Specific human activities, or categories such as irrigated agriculture, industrial, municipal, aquaculture, and hydroelectric power generation, define purposes for which water is withdrawn or delivered, consumed, and returned.

Withdrawals are quantities of water removed from ground- or surface-water sources and are considered to be self-supplied. Delivery is water withdrawn from a ground- or surface-water source by a municipal water supply and conveyed to customers. Consumptive use is water evaporated, transpired, combined into products or crops, or consumed by humans or livestock and not immediately available for reuse. Water that reaches a ground- or surface-water source after leaving the point of use is considered a return. Consumptive use is a percentage of total withdrawals or, from another perspective, a withdrawal equals a return plus some amount of consumptive use. A complete glossary of water-use terms and an explanation of all water uses in the United States are available in a report by Solley and others (1993).

Water-use data for this report, unless otherwise stated, are stored in the USGS National Water Information System (NWIS) computerized data base. Data stored in NWIS were determined by estimates and inventories coordinated with the Idaho Department of Water Resources. Estimates were calculated and stored yearly between 1985 and 1990; afterwards they were calculated and stored every 5 years. There are 12 water-use categories; each contains estimates for withdrawals, deliveries, and consumptive use at the county, catalogue unit, and subregion level. Some categories contain ancillary data such as acres irrigated, population served, and reclaimed wastewater.

The five largest water-use categories in the basin are irrigated agriculture, industrial, municipal, aquaculture, and hydroelectric power generation. These categories are grouped into offstream or instream classes. Irrigated agriculture, industrial, and municipal are offstream water uses because water is withdrawn from the source and conveyed to the point of use. Aquaculture and hydroelectric power generation are instream water uses because use takes place within the river channel. In this report, aquaculture is considered an instream water use because most hatcheries are situated at the outlet of springs along the Snake River. Water is not diverted or conveyed appreciable distances away from the river or springs, and all water is returned to the Snake River.

Water withdrawals in the upper Snake River Basin between 1980 and 1990 represented a large percentage of Idaho's total water withdrawals. Most of the basin withdrawals were for irrigated agriculture. Comparison of total Idaho withdrawals, total basin withdrawals, and total basin agricultural withdrawals indicates that total basin withdrawals accounted for more than 50 percent of total Idaho withdrawals. More than 90 percent of total basin withdrawals were used for irrigated agriculture (table 5). Total basin withdrawals in 1980 were lower than actual withdrawals because large water-use categories such as aquaculture were not estimated. Withdrawals in the Wyoming part of the basin between 1980 and 1990 were negligible compared with total basin withdrawals.

Ground-water withdrawals steadily increased between 1980 and 1990 and surface-water withdrawals peaked in 1985 (fig. 16). Irrigated agricultural withdrawals were predominantly from surface-water sources. Industrial and municipal withdrawals were predominantly from ground-water sources. Aquacultural water uses were supplied by springs along the Snake River. All hydroelectric power generation was from surface-water sources.

Table 5. Relation between total estimated withdrawals in Idaho and estimated withdrawals in the upper Snake River Basin, 1980, 1985, and 1990

[Values in millions of acre-feet per year]

Distribution	Year 1980	1985	1990
Total Idaho ground-water and surface-water withdrawals	20.5	24.9	22.0
Basin ground-water withdrawals	2.6	4.4	7.1
Basin surface-water withdrawals	9.2	10.6	8.0
Total basin withdrawals	11.8	15.0	15.1
Basin agricultural withdrawals	11.6	13.7	14.5

Offstream Water Use

IRRIGATED AGRICULTURE

Idaho's economy relies on irrigated agriculture, which subsequently relies on adequate supplies of water. Agricultural profits in 1980 exceeded $2 billion and reach $2.9 billion in 1990 (Idaho Crop and Livestock Reporting Service, 1982, p. 14; Idaho Agricultural Statistics Service, 1992, p. 16). In 1990, 71 percent of all irrigated acreage in Idaho was in the upper Snake River Basin, where potatoes, wheat, sugar beets, hay, and barley are the predominant crops.

Irrigation began on the eastern Snake River Plain during the 1880's and agricultural land has expanded rapidly since then. By 1980, 1.2 million acres on the plain (Garabedian, 1992) were irrigated with 1.9 million acre-ft of ground water and 8.8 million acre-ft of surface water (Goodell, 1988). In 1990, 2.5 million acres on the plain were irrigated with 6.6 million acre-ft of ground water and 7.6 million acre-ft of surface water. Irrigated agriculture is the largest consumptive water use in the basin; it was 28 percent and 35 percent of total withdrawals in 1980 and 1990, respectively.

Changes in irrigation practices toward more efficient systems have decreased the amount of

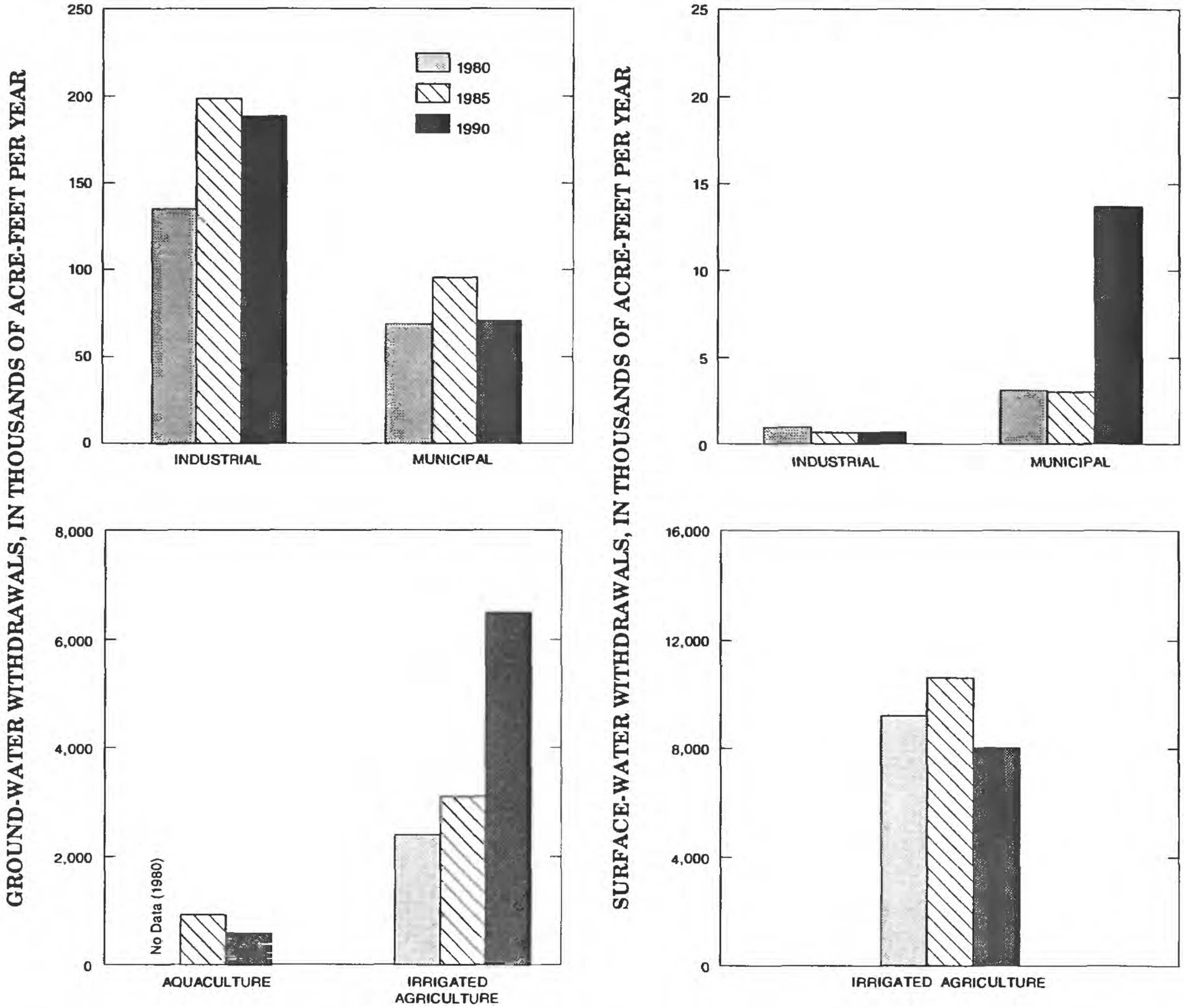


Figure 16. Relations between major water-use categories and ground-water and surface-water withdrawals in the upper Snake River Basin, 1980, 1985, and 1990. (Data from U.S. Geological Survey National Water Data Storage and Retrieval System)

surface- and ground-water withdrawals. Kjelstrom (1986) estimated that sprinkler irrigation systems were used on 20 percent of surface-water-irrigated lands and 90 percent of ground-water-irrigated lands. Sprinkler irrigation systems apply water more efficiently than gravity irrigation systems and are used in areas where gravity irrigation is not feasible.

INDUSTRIAL

Industrial facilities in the basin use water for food processing, washing, transporting, cooling, and employee sanitation. Major industrial facilities in the basin include food-processing, fertilizer, and concrete plants. Food-processing plants are concentrated in the Idaho Falls, Burley, and Twin Falls areas (Goodell, 1988, p. E37); fertilizer and concrete plants are located in the Pocatello area.

Industrial water-use estimates were derived using data collected from permit records maintained by the USEPA Idaho office. Discharge information contained on permit records was used in conjunction with employee and facility information to derive withdrawal estimates. Accuracy of self-supplied withdrawal estimates for facilities in the upper Snake River Basin is considered fair.

In the upper Snake River Basin, industrial withdrawals were a small percentage of total withdrawals for all water uses. Ground water was the main source of water and mostly self-supplied, but some industrial facilities reported municipal deliveries. Self-supplied withdrawals accounted for about 1 percent of total basin withdrawals between 1985 and 1990. Total industrial withdrawals were about 178 Mgal/d in 1985 and 170 Mgal/d in 1990. Consumptive use for industrial purposes was about 3 percent of total industrial withdrawals in 1990.

MUNICIPAL

Municipal withdrawals are delivered to domestic, commercial, and industrial users. Domestic use includes drinking water, food preparation, washing, and watering lawns and gardens at homes, schools, and municipal parks (Goodell, 1988, p. E40). Commercial use includes water for office buildings, motels, hotels, restaurants, and other commercial facilities. Municipal water suppliers serve at least 25 people or have at least 15 hookups (Solley and others, 1993). Total deliveries were less than total withdrawals due to water losses through distribution systems and water for fighting fires, washing streets, and other public uses.

Municipal withdrawals were less than 1 percent of total basin withdrawals between 1980 and 1990. The source and distribution of municipal withdrawals are shown in table 6. Ground water accounted for 84 percent or more of total municipal withdrawals from 1980 to 1990. More than 60 percent of municipal withdrawals from 1985 to 1990 were delivered for domestic use. In 1990, about 60 percent of all deliveries for domestic use were in the Idaho Falls, Pocatello, and Twin Falls areas. Deliveries for commercial use accounted for about 4 percent of total municipal withdrawals in 1985 and more than 5 percent in 1990; about 37 percent of total commercial use was in the Idaho Falls area. Industrial use accounted for less than 5 percent of total municipal withdrawals between 1985 and 1990; about 60 percent of the industrial deliveries for 1990 were in the Twin Falls area. Distribution system losses and water used for public facilities accounted for about 21 percent of total municipal withdrawals.

Table 6. Source and distribution of municipal withdrawals in the upper Snake River Basin, 1980, 1985, and 1990

[Withdrawals and deliveries in millions of gallons per day; —, no data]

Withdrawals	Year 1980	1985	1990
Ground-water withdrawals	61.6	85.3	63.3
Surface-water withdrawals	2.8	2.6	12.1
Total basin withdrawals	64.4	87.9	75.4
Domestic deliveries	—	63.5	51.3
Commercial deliveries	—	3.3	4.1
Industrial deliveries	—	2.6	3.7
Delivery system losses and public use	—	18.5	16.3

Instream Water Use

AQUACULTURE

Idaho was ranked first in the Nation for commercial trout production. About 45 million pounds, or 78 percent of the total number of trout nationally, was produced in Idaho (Idaho Agricultural Statistics Service, 1992, p. 42). All of Idaho's major aquacultural facilities are in the upper Snake River Basin; most are located on the Snake River between Milner Dam and

King Hill. The springs that flow from the canyon walls along this reach of the river provide adequate water supplies of suitable quality for aquacultural practices. Trout production uses at least 40 to 45 percent of total spring discharge to the Snake River between Milner Dam and King Hill (Clarence Robison, University of Idaho, Kimberly Research Center, oral commun., 1993). At least 140 other smaller aquacultural facilities are located along the Snake River and its tributaries between Twin Falls and Hagerman (J. Courtwright, Idaho Department of Health and Welfare, unpubl. data, Boise, Idaho, 1992).

Discharges from major aquacultural facilities to the Snake River were representative of aquacultural water use. Aquaculture is a nonconsumptive water use because the only measurable amount of water loss is from evaporation of pond and raceway surfaces. Goodell (1988, p. E39) used pond and raceway size and replacement schedules from 32 aquacultural facilities in Idaho to estimate that total use in 1980 for aquacultural facilities in the upper Snake River Basin was 1.9 million acre-ft. Mean annual discharge was estimated using data from the USEPA Permit Compliance System, which contains records of average monthly flows from points of discharge for major facilities. During 1985–90, the 12 major aquacultural facilities in the basin discharged about 787,000 acre-ft/yr to the Snake River.

HYDROELECTRIC POWER GENERATION

Fifteen large hydroelectric powerplants in the upper Snake River Basin constitute about half of Idaho's large facilities. The first Federal hydroelectric powerplant in the Pacific Northwest was at Minidoka Dam (fig. 1) (Lindholm and Goodell, 1986) and is still in operation. In 1990, the hydroelectric powerplant at Palisades Dam generated 503,000 MWh. In 1990, the powerplants at Bliss and American Falls Dams generated 336,000 and 239,500 MWh, respectively. These three powerplants generated about 80 percent of the total hydroelectric power produced in the basin in 1990.

Hydroelectric power generation is the largest nonconsumptive water use in the basin. Goodell (1988) estimated that 39.4 million acre-ft of water was used to generate about 2 million MWh of electricity in 1980 in the eastern Snake River Plain. After 6 years of drought and increasing demands on surface-water resources, water use for hydroelectric power generation decreased in 1990—18 million acre-ft was used to generate 1.2 million MWh.

SOURCES OF POLLUTION

Point Sources

Point source pollution is defined as a recognizable point of release for pollutants from a pipe, ditch, channel, leaking underground tank, surface spill, or landfill that may affect surface- or ground-water quality (IDHW/DEQ, 1989). The USEPA classifies wastewater treatment and industrial facilities as major or minor. A major facility is issued a permit on the basis of a rating system that considers the volume of effluent discharged, the streamflow characteristics of the receiving water, the potential public health risk factors, and the chemical content of the effluent. A facility that is permitted to discharge 1 Mgal/d or process wastewater for 10,000 people per day or more is considered a major facility in the permit system. The USEPA maintains the National Pollutant Discharge Elimination System (NPDES), which is administered in cooperation with the IDHW/DEQ. The NPDES provides the guidelines to administer permits and to develop treatment requirements to maintain permit compliance. Currently, discharges of nutrients and solids from major facilities must be monitored to retain a permit, and permits can be modified on the basis of the data (A.E. Murrey, Idaho Department of Health and Welfare, Division of Environmental Quality, written commun., 1991). Numerous monitoring programs have been implemented to address sediment, nutrient, and temperature conditions in streams and rivers in the upper Snake River Basin.

Three industrial, 13 wastewater treatment, and 12 aquacultural facilities are permitted to release effluent in the upper Snake River Basin (table 7 and fig. 17). Combined mean annual discharges from industrial, wastewater treatment, and aquacultural facilities during 1985–90 totaled about 8,500, 29,700, and 787,000 acre-ft/yr, respectively.

Point sources that may affect water quality are monitored by IDHW/DEQ on a computerized log of spills and leaks. Most reported spills and leaks are of petroleum; 108 cases were reported in Idaho as of April 1, 1988. Similarly, 102 hazardous material spills and 69 leaking underground petroleum storage tanks were reported in Idaho as of April 1, 1988 (Idaho

Department of Health and Welfare, Division of Environmental Quality, 1989, p. 100).

Nonpoint Sources

Nonpoint source pollution is a diffuse and intermittent activity that may introduce individually insignificant amounts of contaminants to a large geographic area. The cumulative effect of these pollutants in surface and ground water over a period of time may be significant. Nonpoint source pollution is present when the concentration of pollutants exceeds natural levels in surface or ground water. Nonpoint source pollution to surface water may occur when pollutants enter the water through overland flow. Activities such as agriculture, grazing, atmospheric deposition, mining, and logging are examples of nonpoint source pollution to surface water. Nonpoint source pollution to ground water may occur when pollutants enter the water through infiltration. Activities such as agriculture, land application of wastewater, and improper installation or usage of septic-tank systems are examples of nonpoint source pollution to ground water (Idaho Department of Health and Welfare, Division of Environmental Quality, 1989, p. vi).

Nonpoint source pollution to surface water in the upper Snake River Basin predominantly includes sediment, nutrients, and bacteria from agricultural runoff and nonirrigated cropland. Stream channel and riparian zone degradation may result from overgrazing. Surface-water monitoring for nonpoint source pollution was first addressed by IDHW/DEQ in 1979 by a statewide Agricultural Pollution Abatement Plan. The plan was developed to reduce nonpoint source pollution from agricultural lands and related activities (Idaho Department of Health and Welfare, Division of Environmental Quality, 1989, p. 116).

Nonpoint source pollution from irrigation-return flows that contained large amounts of sediment, agricultural chemicals, and nutrients affected surface-water quality in the Rock Creek drainage basin. However, water-quality and habitat conditions in this drainage basin have improved considerably since IDHW/DEQ implemented the Rock Creek Rural Clean Water Program in 1981. The program monitored sediment, nutrients, bacteria, metals, minerals, pesticides, fish populations, and habitat conditions (Idaho Department of Health and Welfare, Division of Environmental Quality, 1989, p. 119–120). The program was the only previously conducted assessment in the study area with extensive data on stream habitat and aquatic life. NAWQA studies are planned in the Rock Creek drainage basin during 1994.

Nonpoint source pollution to ground water in the basin predominantly includes nutrients, bacteria, petroleum compounds, and industrial solvents. It is frequently impossible to determine the source of contamination in ground water because of the dispersed nature of nonpoint source pollution (Idaho

Table 7. Estimated mean annual discharges from major industrial, wastewater treatment, and aquaculture facilities in the upper Snake River Basin, 1985–90

[Data from U.S. Environmental Protection Agency Permit Compliance System; all discharge values reported in millions of gallons]

Map No. (fig. 17)	Type of facility	Mean annual discharge	Map No. (fig. 17)	Type of facility	Mean annual discharge
1	Wastewater treatment	73.0	13	Wastewater treatment	3,029.5
2	Wastewater treatment	401.5	14	Aquaculture	10,950.0
3	Aquaculture	11,242.0	15	Wastewater treatment	219.0
4	Wastewater treatment	365.0	16	Aquaculture	9,471.0
5	Aquaculture	2,511.0	17	Industrial	693.5
6	Aquaculture	42,230.5	18	Wastewater treatment	73.0
7	Aquaculture	49,165.5	19	Industrial	2,051.3
8	Aquaculture	49,348.0	20	Aquaculture	29,857.0
9	Aquaculture	22,739.5	21	Wastewater treatment	2,263.0
10	Wastewater treatment	109.5	22	Aquaculture	7,081.0
11	Wastewater treatment	584.0	23	Wastewater treatment	511.0
12	Aquaculture	22,046.0	24	Wastewater treatment	1,642.5
			25	Wastewater treatment	401.5

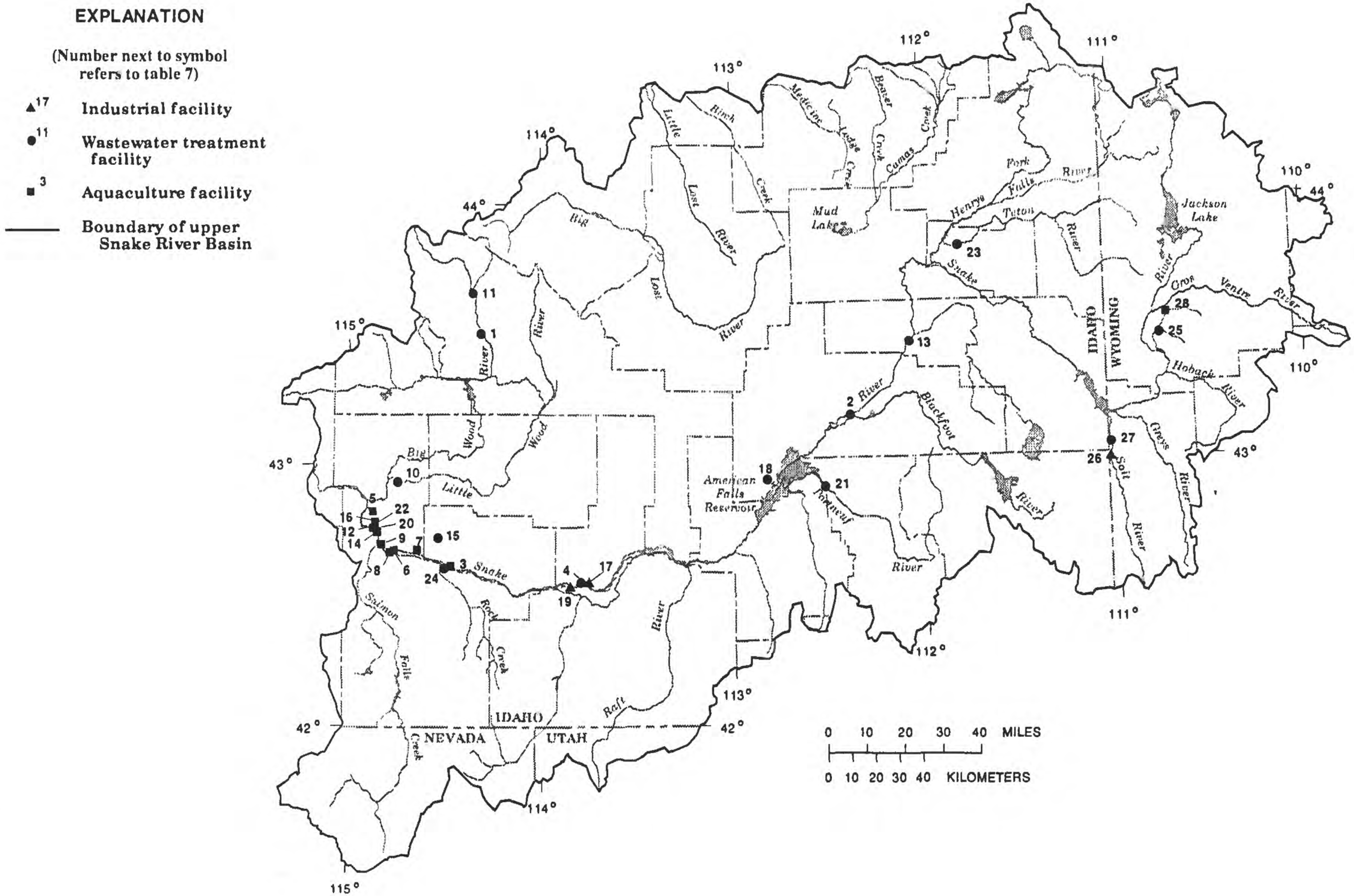


Figure 17. Locations of major industrial, wastewater treatment, and aquaculture facilities in the upper Snake River Basin.

Department of Health and Welfare, Division of Environmental Quality, 1989, p. 102). The Idaho Ground-Water Quality Monitoring Network began in 1991 and is an ongoing program conducted by the IDWR and the USGS to monitor and define the ambient ground-water quality conditions of major aquifers in the State using a 400-well network. In any given year, about 120 wells will be monitored in the upper Snake River Basin. The IDWR Underground Injection Control Program regulates the use of injection wells, which are used in many areas for urban runoff and agricultural purposes (Idaho Department of Health and Welfare, Division of Environmental Quality, 1989, p. 113; Helen Thorton, Idaho Department of Water Resources, oral commun., 1992).

Nitrate concentrations in drinking-water supplies are monitored to ensure that safe levels are maintained. Nitrate concentrations that exceed 10 milligrams per liter (mg/L) violate safe drinking-water standards and may cause serious health problems. In Idaho, estimated background nitrate concentrations in nonthermal ground water were about 1 mg/L. Concentrations greater than 2 mg/L most likely indicate effects on ground-water quality from land- and water-use activities. Basalt aquifers of the eastern Snake River Plain exhibited the largest median nitrate concentrations (Parliman, 1988).

Elevated nitrate levels (greater than 1 mg/L) were identified in wells on the eastern Snake River Plain during studies in 1970 and 1985. The studies showed that about half the sampled wells had elevated nitrate concentrations, and a small percentage of the concentrations exceeded the drinking-water standard of 10 mg/L (Idaho Department of Health and Welfare, Division of Environmental Quality, 1989, p. 104). Petroleum releases from underground storage tanks, above-ground bulk storage facilities, and buried pipelines were reported in the Twin Falls area. Land applications of wastewater in many areas were a source of iron, manganese, nitrate, total organic carbon, and total dissolved solids. Ground water at the Idaho National Engineering Laboratory was found to contain radioactive substances and synthetic organic compounds. Arsenic, petroleum products, solvents, and heavy metals have been detected in ground water near Pocatello. In Ketchum, a geothermal pipeline caused fluoride contamination in nearby public and private water supplies (Idaho Department of Health and Welfare, Division of Environmental Quality, 1989, p. 101).

Septic-tank systems are common in sparsely populated areas in the upper Snake River Basin. Septic-tank systems are potential sources of ground-water contamination in areas where ground water is shallow and soil conditions are inappropriate for the septic-tank design and use. A study conducted in Minidoka County in 1985 verified that several domestic wells were affected by local septic-tank systems, resulting in elevated nitrate concentrations greater than 10 mg/L (Idaho Department of Health and Welfare, Division of Environmental Quality, 1989, p. 108).

SUMMARY

The upper Snake River Basin was selected as a National Water-Quality Assessment Program study unit in 1991 to assess ground- and surface-water quality and biological conditions and their relations to land-use activities. Major ground- and surface-water-quality issues are sediment, nutrients, and organic compounds. Land and water uses that affect water quality in the basin are irrigated agriculture, grazing, aquaculture, food processing, and municipal and industrial wastewater treatment.

The upper Snake River Basin covers about 35,800 mi^2 and includes parts of Idaho, Wyoming, Nevada, and Utah. Major urban areas are Idaho Falls, Pocatello, Rexburg, and Twin Falls, Idaho; and Jackson, Wyoming. The Snake River flows 453 mi from its headwaters south of Yellowstone National Park and exits the basin at King Hill, Idaho. Tributaries in mountainous regions that surround the plain to the east, north, and south contribute large amounts of runoff to the main stem of the Snake River and recharge to the ground-water system. The main-stem Snake River flows through five reservoirs between Flagg Ranch and King Hill; the reservoirs provide a total storage capacity of more than 4 million acre-ft.

Total population in the basin was about 425,000 in 1990. Climate in the basin is mostly semiarid and mean annual precipitation ranges from 8 to more than 60 in. The eastern Snake River Plain is the major geologic feature in the basin and is delineated mostly by Quaternary and Tertiary basalt flows. The plain is about 55 to 62 mi wide and 320 mi long and bisects the basin in a northeast-southwest direction. The eastern Snake River Plain constitutes about 30 percent of the upper Snake River Basin.

Streamflow records (1934–80) for the Snake River and its major tributaries were used to estimate that mean annual inflow to the eastern Snake River Plain was about 10.2 million acre-ft. Mean annual discharges to the Snake River from north and south tributaries were 7.3 million acre-ft, and ground-water recharge from northern tributaries that do not flow directly to the Snake River was almost 1.1 million acre-ft. Mean annual discharge of the Snake River at King Hill was about 7.5 million acre-ft.

Total gravity-flow and pumped diversions from the Snake River and its tributaries were almost 8.8 million acre-ft in 1980. Gravity-flow diversions occur mainly in the upper part of the basin and along the Snake River between Heise and Milner Dam. In 1980, gravity-flow diversions between Heise and Milner Dam were about 7.0 million acre-ft. Pumped diversions occur mainly in the Milner Dam to King Hill reach where the Snake River is deeply entrenched. In 1980, total pumped withdrawals from the Snake River and tributaries in this reach were 408,500 acre-ft.

Return flows to the Snake River replenish streamflow so that water can be diverted again downstream. In 1980, an estimated 1.4 million acre-ft of water returned to the Snake River between Heise and Milner Dam, and 1.2 million acre-ft of water returned between Milner Dam and King Hill.

The Snake River Plain aquifer underlies the eastern Snake River Plain and is one of the most productive aquifers in the world. An estimated 200 to 300 million acre-ft of water is stored in the upper 500 ft of the aquifer. Ground-water flow is generally from northeast to southwest, and average transmissivity ranges from 0.05 to 120 ft^2/s. Well yields and transmissivity are highest in basalt flows of Quaternary and late Tertiary age.

Sources of recharge are infiltration of surface water applied for irrigation, infiltration of streamflow and underflow from tributary drainage basins, precipitation, and streamflow losses from the Snake River. Estimated water budgets for the eastern Snake River Plain in 1980 showed that 60 percent of recharge was from surface water diverted for irrigation, 25 percent was from tributary inflow, 10 percent was from precipitation, and 5 percent was from Snake River streamflow losses.

The aquifer discharges principally in two reaches of the Snake River: between Blackfoot and Neeley (1.9 million acre-ft) and between Milner Dam and King Hill (4.4 million acre-ft). Ground-water pumpage for irrigation is also a major discharge. In 1980, an estimated 1.9 million acre-ft of ground water was pumped from the eastern Snake River Plain. In 1990, about 6.6 million acre-ft was pumped.

Areas with recent porous basalt flows and shallow soil deposits exhibit high infiltration-rate potential. Low infiltration-rate potentials are common in areas where soils are thick or where dense basalt is present.

Rangeland, irrigated agriculture, and forest lands constitute most of the land uses in the basin. Rangeland constitutes 50 percent of total land use; forest lands, about 23 percent; and agricultural lands, about 21 percent. The Federal Government owns 65 percent of the basin, mostly through the U.S. Forest Service and the Bureau of Land Management. State ownership totals about 4 percent and private ownership, 31 percent.

Water use in the upper Snake River Basin consists largely of irrigated agriculture, industrial, municipal, aquaculture, and hydroelectric power generation. Irrigated agriculture is the largest consumptive water use and hydroelectric power generation is the largest nonconsumptive water use. Major crops in the basin include potatoes, wheat, sugar beets, hay, and barley. In 1980, 1.2 million acres on the eastern Snake River Plain were irrigated with 1.9 million acre-ft of ground water and 8.8 million acre-ft of surface water. In 1990, 2.5 million acres on the plain were irrigated with 6.6 million acre-ft of ground water and 7.6 million acre-ft of surface water.

Water for industrial uses is supplied mostly from ground-water sources. Large industrial facilities include food-processing, fertilizer, concrete, and phosphate production plants. Self-supplied industrial withdrawals accounted for about 1 percent of the total basin withdrawals between 1985 and 1990. Municipal withdrawals were also less than 1 percent of total withdrawals in the basin between 1980 and 1990. Ground water supplied 84 percent or more of total municipal withdrawals for the same time period.

Most aquacultural facilities in the upper Snake River Basin are located on the Snake River between Milner Dam and King Hill. Trout production uses at least 40 to 45 percent of the spring flows to the Snake River between Milner Dam and King Hill. Combined mean annual discharge estimates (1985–90) from 12 aquacultural facilities were 787,000 acre-ft/yr.

Fifteen large hydroelectric powerplants are in the upper Snake River Basin. In 1990, three of the powerplants generated about 80 percent of the total hydroelectric power produced in the basin. A total power generation of 1.2 million MWh used 18 million acre-ft of water.

Three industrial and 13 wastewater treatment facilities are permitted to release effluent in the upper Snake River Basin. Combined mean annual discharges from the industrial and wastewater treatment facilities (1985–90) were about 8,500 and 29,700 acre-ft/yr, respectively.

Nonpoint source pollution to surface water in the basin includes sediment, nutrients, and bacteria from agricultural runoff and nonirrigated cropland. Nonpoint source pollution to ground water in the basin includes nutrients, bacteria, petroleum compounds, and industrial solvents.

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