# ASSESSMENT OF NUTRIENTS, SUSPENDED SEDIMENT, AND PESTICIDES IN SURFACE WATER OF THE UPPER SNAKE RIVER BASIN, IDAHO AND WESTERN WYOMING, WATER YEARS 1991–95

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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 consequence 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, river, 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 achieve through ongoing and proposed investigation 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 system 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, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

| Multiply | By | To obtain |
|---|---|---|
| acre-foot (acre-ft) | 1,233 | cubic meter |
| cubic foot ($ft^3$) | 0.02832 | cubic meter |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second |
| foot (ft) | 0.3048 | meter |
| inch (in.) | 2.54 | centimeter |
| mile (mi) | 1.609 | kilometer |
| pound | 0.4536 | kilogram |
| square mile ($mi^2$) | 2.590 | square kilometer |
| ton | 907.18 | kilogram |

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

$$°C = 5/9\,(°F - 32)$$

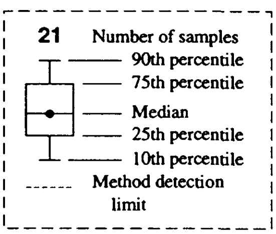
**Sea level:** In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

**Abbreviated water-quality units:**

µg/L microgram per liter
mg/L milligram per liter
ng/L nanogram per liter

## EXPLANATION FOR BOXPLOTS

(Figures 6, 7, 9, and 13)



# Assessment of Nutrients, Suspended Sediment, and Pesticides in Surface Water of the Upper Snake River Basin, Idaho and Western Wyoming, Water Years 1991–95

*By* Gregory M. Clark


## Abstract

A water-quality investigation of the upper Snake River Basin began in 1991 as part of the U.S. Geological Survey's National Water-Quality Assessment Program. As part of the investigation, intensive monitoring was conducted during water years 1993 through 1995 to assess surface-water quality in the basin. Sampling and analysis focused on nutrients, suspended sediments, and pesticides because of nationwide interest in these constituents.

Concentrations of nutrients and suspended sediment in water samples from 19 sites in the upper Snake River Basin, including nine on the main stem, were assessed. In general, concentrations of nutrients and suspended sediment were smaller in water from the 11 sites upstream from American Falls Reservoir than in water from the 8 sites downstream from the reservoir where effects from land-use activities are most pronounced. Median concentrations of dissolved nitrite plus nitrate as nitrogen at the 19 sites ranged from less than 0.05 to 1.60 milligrams per liter; total phosphorus as phosphorus, less than 0.01 to 0.11 milligrams per liter; and suspended sediment, 4 to 72 milligrams per liter. Concentrations of nutrients and suspended sediment in the main stem of the Snake River, in general, increased downstream. The largest concentrations in the main stem were in the middle reach of the Snake River between Milner Dam and the outlet of the upper Snake River Basin at King Hill.

Significant differences ($p<0.05$) in nutrient and suspended sediment concentrations were noted among groups of sites categorized by the quantity of agricultural land in their upstream drainage basins. Water samples collected from sites in drainage basins where agricultural land constituted less than 10 percent of the land use contained significantly smaller concentrations of nutrients and suspended sediment than samples from sites in drainage basins where agricultural land constituted more than 10 percent of the land use. Significant differences in nutrient and suspended sediment concentrations were inconsistent among groups representing 10 to 19 percent, 20 to 29 percent, and greater than 29 percent agricultural land use. Seasonal concentrations of dissolved nitrite plus nitrate, total phosphorus, and suspended sediment were significantly different among most of the agricultural land-use groups. Concentrations of dissolved nitrite plus nitrate were largest during the nonirrigation season, October through March. Concentrations of total phosphorus and suspended sediment, in general, were largest during high streamflow, April through June.

Nutrient and suspended sediment inputs to the middle Snake reach were from a variety of sources. During water year 1995, springs were the primary source of water and total nitrogen to the river and accounted for 66 and 60 percent of the total input, respectively. Isotope and water-table information indicated that the springs derived most of their nitrogen from agricultural activities along the margins of the Snake River. Aquacultural effluent was a major source of ammonia (82 percent), organic

nitrogen (30 percent), and total phosphorus (35 percent). Tributary streams were a major source of organic nitrogen (28 percent) and suspended sediment (58 percent). In proportion to its discharge (less than 1 percent), the Twin Falls sewage-treatment plant was a major source of total phosphorus (13 percent). A comparison of discharge and loading in water year 1995 with estimates of instream transport showed a good correlation (relative difference of less than 15 percent) for discharge, total organic nitrogen, dissolved nitrite plus nitrate, total nitrogen, and total phosphorus. Estimates of dissolved ammonia and suspended sediment loads correlated poorly with instream transport; relative differences were about 79 and 61 percent, respectively.

The pesticides EPTC, atrazine, desethylatrazine, metolachlor, and alachlor were the most commonly detected in the upper Snake River Basin and accounted for about 75 percent of all pesticide detections. All pesticides detected were at concentrations less than 1 microgram per liter and below water-quality criteria established by the U.S. Environmental Protection Agency. In samples collected from two small agriculturally dominated tributary basins, the largest number and concentrations of pesticides were detected in May and June following early growing season applications. At one of the sites, the pesticide atrazine and its metabolite desethylatrazine were detected throughout the year.

On the basis of 37 samples collected basinwide in May and June 1994, total annual subbasin applications and instantaneous instream fluxes of EPTC and atrazine showed logarithmic relations with coefficients of determination ($R^2$ values) of 0.55 and 0.62, respectively. At the time of sampling, the median daily flux of EPTC was about 0.0001 percent of the annual quantity applied, whereas the median daily flux of atrazine was between 0.001 and 0.01 percent.

## INTRODUCTION

In 1991, the U.S. Geological Survey (USGS) began full-scale implementation of the National Water-Quality Assessment (NAWQA) Program. The long-term goals of the program are to provide a nationally consistent description of current water-quality conditions for a large part of the Nation's water resources, detect long-term trends (or lack of trends) in water quality, and identify and describe major factors that affect observed water-quality conditions and trends (Hirsch and others, 1988). The design of the program enables integration of information into a nationally consistent data base for comparisons of water-quality data over a large range of geographic and hydrologic conditions. Sixty study units, comprising the Nation's most important river basins and aquifer systems, were selected for investigation. These study units represent between 60 and 70 percent of the Nation's usable water supply. Investigations will be done in three phases: the first 20 study units began in 1991, the second 20 in 1994, and the final 20 are scheduled to begin in 1997.

The upper Snake River Basin (USNK) in eastern Idaho and western Wyoming was selected as one of the first-phase study units. Assessment of water quality in the basin began in water year (WY) 1991 (October 1, 1990, through September 30, 1991) with an analysis of data collected during WY's 1975–89. Intensive monitoring during WY's 1993–95 helped fill gaps in the historical data and assess the most current water-quality conditions. A low-level monitoring phase followed the intensive monitoring phase. Data from the low-level monitoring phase will be used to detect temporal changes in water quality. The purpose of this report is to describe the quality of surface water in the USNK, primarily on the basis of data collected during the intensive monitoring phase. Elevated nutrient, suspended sediment, and pesticide concentrations are usually the result of land-use activities and, because of national interest in these constituents, they are the primary focus of this report.

## DESCRIPTION OF THE UPPER SNAKE RIVER BASIN

The Snake River in the USNK drains an area of about 35,800 mi² from its headwaters near the southern border of Yellowstone National Park in Wyoming to the basin outlet at King Hill in south-central Idaho (fig. 1). The basin includes parts of 4 States and 24 major subbasins tributary to the Snake River. Land surface elevation ranges from about 2,500 ft above sea level at the western edge of the USNK to 13,800 ft in the Teton Range in western Teton County, Wyoming. Much of the

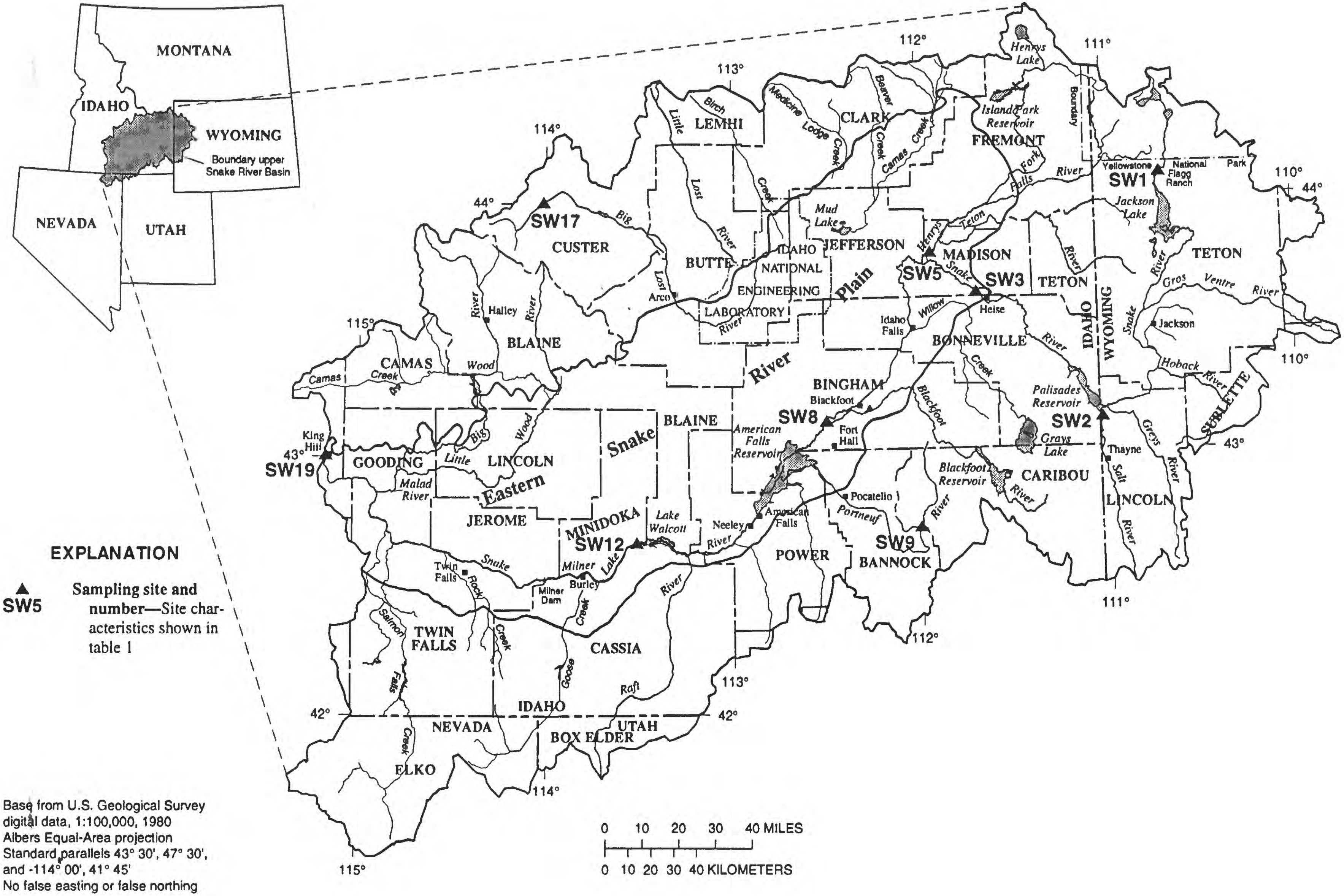



**Figure 1.** Location of the upper Snake River Basin and selected surface-water sampling sites.

eastern and northern parts of the basin are characterized by mountains that exceed 7,500 ft in elevation (Lindholm, 1996) and intermontane valleys composed of volcanic and sedimentary rocks. A predominant feature in the basin is the relatively flat eastern Snake River Plain, a structural downwarp filled with Quaternary basaltic lava flows and bounded by interbedded sedimentary deposits (Whitehead, 1986, sheet 1).

The climate in most of the USNK is semiarid; mean annual precipitation from 1961 to 1990 ranged from 8.2 to 16.4 in. (Maupin, 1995). The source of most precipitation is airmasses moving inland from the Pacific Ocean (Kjelstrom, 1995). During summer months, the central and eastern parts of the basin are affected by sporadic thunderstorms resulting from the subtropical flow of air from the Gulf of Mexico and the Pacific Ocean. Mean annual air temperature from 1948 to 1990 at Idaho Falls and Twin Falls was 43.7° and 47.3°F, respectively. January is typically the coldest month and July the warmest month of the year. The growing season averages about 120 to 160 days per year, depending on latitude and elevation.

Population in the basin in 1990 was about 425,000 (Maupin, 1995), an increase of about 5 percent from 1980. Population is expected to increase by about 55,000, or 13 percent, from 1990 to 2010 (Maupin, 1995). Principal cities include Idaho Falls (population 43,900), Pocatello (46,100), and Twin Falls (27,600). A comprehensive description of the environmental setting of the USNK is given in a report by Maupin (1995).

## Surface-Water Hydrology

The elevation of the Snake River in the USNK ranges from about 6,800 ft at the southern boundary of Yellowstone National Park in Wyoming to about 2,500 ft at the basin outlet at King Hill. The average gradient in this 453-mi reach is about 9.5 ft/mi. From Jackson Lake to Milner Dam, the average gradient is 7.6 ft/mi, and the elevation of the river surface is generally within 100 ft of the elevation of the adjacent land surface. From Milner Dam to King Hill (the middle reach of the Snake River), the average gradient increases to 17.1 ft/mi, and the river is entrenched in canyons as deep as 700 ft below the adjacent land surface (Kjelstrom, 1986, sheet 1). Numerous dams and waterfalls characterize this reach of the river.

In WY 1995, streamflow was measured at 98 gaging stations in the USNK, including 20 on the main stem of the Snake River. According to the gaging-station record (WY's 1935–95) for the Snake River immediately downstream from Palisades Reservoir, 4.6 million acre-ft of water per year enters Idaho from Wyoming. As the Snake River flows onto the Snake River Plain, it is joined by the Henrys Fork, the largest tributary in the USNK, which contributes about 1.5 million acre-ft of water per year (WY's 1909–95) to the Snake River. Downstream from the confluence of the Snake River and Henrys Fork, the six largest south-side tributaries (Willow Creek, Blackfoot River, Portneuf River, Goose Creek, Rock Creek, and Salmon Falls Creek) contribute about 0.7 million acre-ft of water per year to the Snake River (Kjelstrom, 1986, sheet 2). Another 1.1 million acre-ft of water per year is contributed by northern tributaries between the Henrys Fork and the Big Wood and Little Wood Rivers (Kjelstrom, 1986, sheet 2). Streamflow from northern tributaries, primarily the Big Lost and Little Lost Rivers and Birch and Camas Creeks, does not reach the Snake River directly as surface water. Instead, water percolates into a regional aquifer and eventually discharges as spring flow to the Snake River near the outlet of the basin. The Big Wood and Little Wood Rivers, which drain the northwestern part of the basin and join to form the Malad River, contribute about 0.2 million acre-ft of water per year (WY's 1916–95). The volume of water that leaves the basin in the Snake River at King Hill averaged 7.8 million acre-ft per year from 1909 to 1995.

Monthly water budgets based on streamflow records were used to quantify the interaction between surface and ground water along the main stem of the Snake River between gaging stations near Heise and at King Hill (Kjelstrom, 1995). In WY 1980, estimated streamflow gains from ground-water discharge totaled about 7.2 million acre-ft between Heise and King Hill. Of this total, about 1.9 million acre-ft (26 percent) was gained between gaging stations near Blackfoot and at Neeley, and 4.7 million acre-ft (65 percent) was gained between gaging stations at Milner Dam and King Hill. In WY 1995, ground-water discharge to the Snake River between Milner Dam and King Hill decreased to about 4.1 million acre-ft because of (1) increased ground-water withdrawals for irrigation, (2) more efficient irrigation practices, and (3) antecedent drought conditions. Streamflow losses to ground water between Heise and King Hill totaled about 0.8 million acre-ft, of which more than 85 percent was lost between gaging stations at Heise and near Blackfoot.

Streamflow in the USNK during WY's 1980–95 was variable (fig. 2). In most of the USNK, streamflow exceeded the long-term average during WY's 1982–86. WY's 1988–92 were extremely dry years in the USNK and streamflow was less than average throughout the basin. During WY's 1993–95, streamflow in many parts of the USNK continued to be less than average, whereas in other parts of the basin, streamflow was near or exceeded the average. Streamflow at most gaging stations (gaging stations and surface-water sampling sites hereafter are referred to as "sites") on the main stem of the Snake River was less than average during WY's 1993–95.

## Land Use

The predominant land-use/land-cover categories in the USNK are rangeland, forest land, and agricultural land, which account for about 94 percent of the basin area (Maupin, 1995). Activities such as grazing, logging, and mining on range and forested land, which account for about 73 percent of the total area, can affect water quality by increasing suspended sediment loads and concentrations of metals and nutrients. Range and forested land receives most of the precipitation that recharges the ground-water system (Lindholm and Goodell, 1986).

About 21 percent of the USNK, or more than 7,000 mi$^2$, is used for agricultural purposes. Farming is concentrated on the Snake River Plain, primarily along the Snake River and near the mouths of tributary drainage basins. Principal crops grown in the basin in 1994 were grains, alfalfa, potatoes, and sugar beets (Idaho Agricultural Statistics Service, 1995). Numerous agriculture-related activities such as application of synthetic fertilizers and pesticides and storage and application of manure, and activities that cause enhanced erosion and sediment transport can affect surface-water quality in the USNK. Other activities that affect water quality include tourism and recreation, particularly in the Wyoming part of the basin; rangeland grazing; feedlots; and various municipal and industrial operations. The Nation's largest commercial trout farms are located along the Snake River between Milner Dam and King Hill. These farms produce more than 70 percent of the Nation's commercial trout (Idaho Agricultural Statistics Service, 1995).

## Surface-Water Use

Streamflow in the Snake River is highly regulated by dams and diversions, primarily for agricultural use and hydroelectric-power generation. The combined storage capacity of the five main reservoirs on the main stem of the Snake River is 4.1 million acre-ft (Kjelstrom, 1995). Storage capacity in the largest main-stem reservoir, American Falls, is 1.7 million acre-ft. In addition, eight reservoirs, with storage capacities of more than 50,000 acre-ft each, and numerous smaller reservoirs are located on Snake River tributaries.

In 1990, about 8 million acre-ft of water was diverted from the Snake River and its tributaries by canals and pumps, primarily for agricultural use (Maupin, 1995). Of this total, 1.6 million acre-ft was diverted between Palisades Reservoir and the mouth of the Henrys Fork, 0.7 million acre-ft was diverted at Minidoka Dam, and 2.8 million acre-ft was diverted at Milner Dam (Idaho Department of Water Resources, 1990). Much of the diverted water eventually returns to the Snake River in tributaries, as irrigation-return flow, or as ground-water discharge.

Mean monthly streamflow at four sites on the main-stem Snake River during WY's 1980–95 exhibited the seasonal effects of water use (fig. 3). The hydrograph for the Snake River at Flagg Ranch (SW1) typifies streamflow unaffected by reservoir control. Streamflow peaks in May and June in response to snowmelt runoff and remains relatively stable during the rest of the year. Downstream from major reservoirs, but upstream from major points of diversion, for example, Snake River near Heise (SW3), streamflow is controlled to meet downstream irrigation demands throughout the summer months. Streamflow in the Snake River at Milner Dam (SW12), which is downstream from all major surface-water diversions, decreases dramatically during July, August, and September when most water is diverted from the river for irrigation. Streamflow in the Snake River at Milner Dam frequently is maintained at 200 ft$^3$/s for most of the summer. At King Hill (SW19), streamflow is also less during the summer because of upstream irrigation diversions. However, because of ground-water discharge and tributary inflow to the Snake River between the Milner Dam and King Hill sites, streamflow leaving the USNK at King Hill is generally about 6,000 to 8,000 ft$^3$/s greater than at Milner Dam.

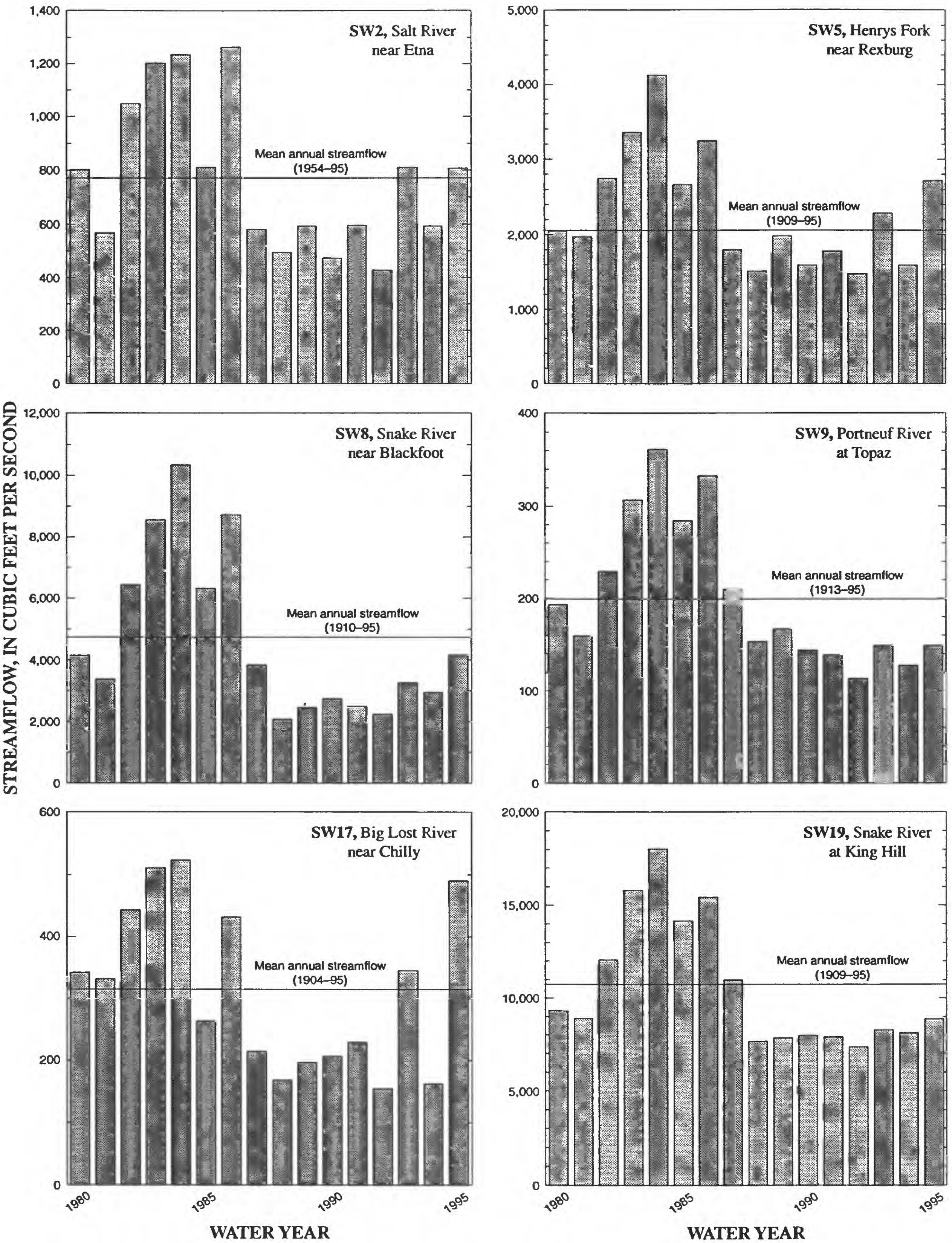



**Figure 2.** Mean annual streamflow at selected sites in the upper Snake River Basin, water years 1980–95. (Site locations shown in figure 1; site characteristics shown in table 1)

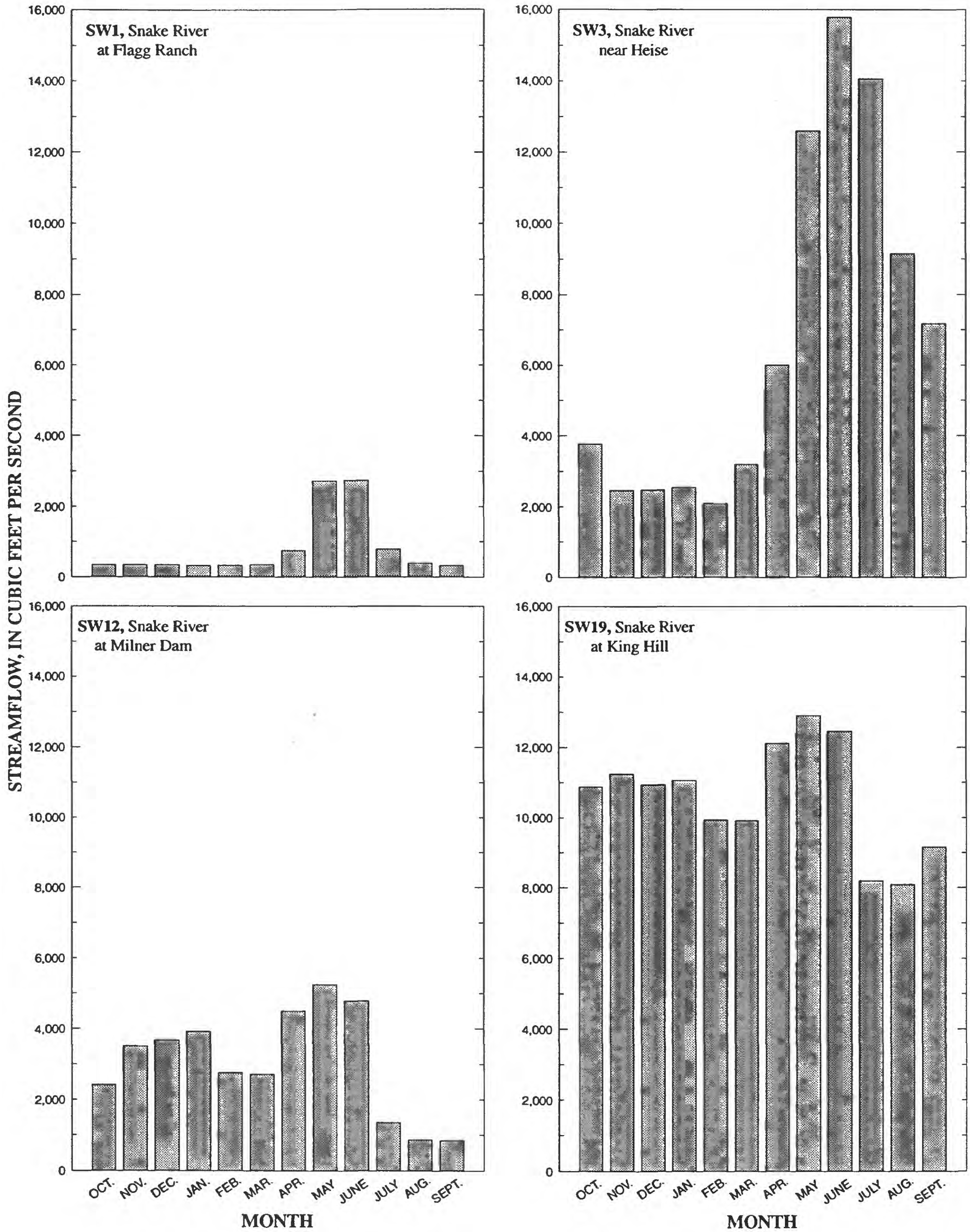



**Figure 3.** Mean monthly streamflow at selected sites on the main-stem Snake River in the upper Snake River Basin, water years 1980–95. (Site locations shown in figure 1; site characteristics shown in table 1)

## ASSESSMENT OF CURRENT CONDITIONS

### Nutrients and Suspended Sediment

In this report, nutrients are defined as compounds containing nitrogen and phosphorus. Forms of nitrogen in water include ammonia, organic nitrogen, nitrite, and nitrate. Natural cycles of nitrogen and phosphorus can be altered by anthropogenic additions of nitrogen and phosphorus to a water body. Anthropogenic sources include applications of synthetic fertilizers, applications of manure from cattle and other farm animals, atmospheric inputs resulting from combustion of fossil fuels, nitrogen fixation by crops, and effluent from industrial facilities and municipal wastewater-treatment plants. In well-oxygenated streams, nitrate is usually the dominant form of nitrogen dissolved in water. Phosphorus exists in water almost exclusively as phosphate or in organic compounds. Unlike nitrogen, phosphorus readily forms insoluble complexes with cationic metals (primarily iron, aluminum, and calcium) and is thereby removed from solution.

Plant production is accelerated in aqueous systems enriched with nitrogen and phosphorus. This increased production can result in excessive algal, periphyton, and aquatic macrophyte growth, especially in water bodies having slow current and suspended sediment concentrations small enough to allow uninhibited penetration of light. When an overabundance of plant material dies and settles, nitrogen and phosphorus are stored as a layer of detritus in the bottom sediments. Decomposition of this material results in a decrease of dissolved oxygen and a release of ammonia and phosphorus compounds. Lack of dissolved oxygen and elevated concentrations of dissolved ammonia can be stressful to aquatic organisms. As a result of this recycling of stored nutrients in bottom sediments, excessive plant production can continue in a river or lake even after outside sources of nitrogen and phosphorus are eliminated (Waite, 1984, p. 126).

On the basis of data from 1990, Rupert (1996) estimated that the mean annual quantity of nitrogen introduced to the USNK from nonpoint sources was about 256,000 tons. Of this total, 45 percent was derived from synthetic fertilizer applications, 29 percent from cattle manure, 20 percent from nitrogen fixation by leguminous crops, 6 percent from precipitation, and less than 1 percent from other sources. Rupert also estimated that the total annual quantity of nitrogen available for leaching to ground water and (or) runoff to surface water was about 82,000 tons, or about 32 percent of the total input. Three of four counties where quantities of leachable nitrogen were largest (Cassia, Gooding, and Twin Falls) are located in the downstream part of the USNK (fig. 1). Point sources introduce only about 3,000 tons of nitrogen annually to the USNK (Clark, 1994a) and, of that quantity, about 1,800 tons originates from aquaculture facilities located on the Snake River between Milner Dam and King Hill.

Clark (1994a) estimated that the mean annual quantity of total phosphorus introduced to the USNK from 1985 to 1990 totaled about 63,000 tons, of which about 71 percent was from synthetic fertilizers, 27 percent was from cattle manure, and about 2 percent was from point-source discharges. The quantity of leachable phosphorus and phosphorus inputs from precipitation was not estimated because of insufficient data. Data based on fertilizer sales and number of cattle indicate that phosphorus inputs, like nitrogen, are largest in counties adjacent to the Snake River in the downstream part of the USNK (Clark, 1994a).

Elevated concentrations of suspended sediment in streams often are associated with land-disturbing activities such as logging, irrigated agriculture, grazing, mining, and recreation. Large concentrations of suspended sediment in water can cause (1) reduction in the aesthetic qualities of the water; (2) reduction of storage capacities of reservoirs and other water bodies; (3) reduction of light penetration to the detriment of many aquatic species; (4) deposition of sediment onto stream bottoms, resulting in decreased spawning habitat for many species of fish and enhanced substrate for growth of rooted aquatic macrophytes; and (5) sorption and transport of insoluble inorganic and organic compounds.

#### OVERALL BASIN ASSESSMENT

Nutrient and suspended sediment data were collected at 19 sites in the USNK, 9 of which are on the main stem of the Snake River (table 1 and fig. 4). The sites consisted of 12 basic fixed sites (BFS), sampled as part of the NAWQA Program, 6 sites sampled as part of the Idaho State Surface-Water-Monitoring Network (SMN), and 2 National Stream Quality Accounting Network (NASQAN) sites. Site SW19 was sampled as both a BFS and a NASQAN site. At least 10 samples were collected at each site during WY's 1993–95. Water-quality samples were collected at the BFS 32 to 40 times during 1993–95 and, in general, were collected

**Table 1.** Locational, hydrological, and land-use/land-cover characteristics of sites in the upper Snake River Basin where at least 10 nutrient and (or) suspended sediment samples were collected, water years 1993–95

[Site locations shown in figure 4; USGS, U.S. Geological Survey; Wy, Wyoming; BFS, National Water-Quality Assessment Program basic fixed site; NQN, National Stream Quality Accounting Network site; SMN, Idaho State Monitoring Network site; mi², square miles; Agricultural land-use groups refer to the percentage of agricultural land in the site drainage basin: A=less than 10 percent agricultural land, B=10 to 19 percent, C=20 to 29 percent, D=greater than 29 percent; Fo, forest; Rg, rangeland; Wt, water; Ag, agricultural land; Tn, tundra; sites are in Idaho unless otherwise indicated]

| Site number | USGS gaging-station number | Gaging-station name | Site type | Drainage area ($mi^2$) | Agricultural land-use group | Major land-use/land-cover categories as a percentage of the drainage basin area | | |
|---|---|---|---|---|---|---|---|---|
| SW1 | 13010065 | Snake River at Flagg Ranch, Wy | BFS | 486 | A | Fo–83%, | Rg–8%, | Wt–4% |
| SW2 | 13027500 | Salt River near Etna, Wy | BFS | 829 | B | Fo–51%, | Rg–31%, | Ag–18% |
| SW3 | 13037500 | Snake River near Heise | NQN | 7,770 | A | Fo–61%, | Rg–26%, | Ag–6% |
| SW4 | 13055000 | Teton River near St. Anthony | BFS | 890 | D | Ag–42%, | Fo–40%, | Rg–12% |
| SW5 | 13056500 | Henrys Fork near Rexburg | BFS | 2,920 | C | Fo–49%, | Ag–26%, | Rg–19% |
| SW6 | 13060000 | Snake River near Shelley | SMN | 9,790 | B | Fo–51%, | Rg–25%, | Ag–19% |
| SW7 | 13068500 | Blackfoot River near Blackfoot | SMN | 1,295 | B | Rg–62%, | Fo–21%, | Ag–13% |
| SW8 | 13069500 | Snake River near Blackfoot | BFS | 11,310 | B | Fo–45%, | Rg–29%, | Ag–19% |
| SW9 | 13073000 | Portneuf River at Topaz | BFS | 570 | D | Rg–54%, | Ag–35%, | Fo–10% |
| SW10 | 13075000 | Marsh Creek near McCammon | SMN | 353 | D | Ag–52%, | Rg–38%, | Fo–9% |
| SW11 | 13075500 | Portneuf River at Pocatello | SMN | 1,250 | D | Rg–52%, | Ag–37%, | Fo–10% |
| SW12 | 13081500 | Snake River near Minidoka | BFS | 18,700 | C | Rg–38%, | Fo–34%, | Ag–23% |
| SW13 | 13088000 | Snake River at Milner Dam | SMN | 22,200 | C | Rg–39%, | Fo–31%, | Ag–23% |
| SW14 | 13090000 | Snake River near Kimberly | SMN | 22,600 | C | Rg–39%, | Fo–30%, | Ag–23% |
| SW15 | 13092747 | Rock Creek at Twin Falls | BFS | 241 | C | Rg–52%, | Fo–24%, | Ag–24% |
| SW16 | 13094000 | Snake River near Buhl | BFS | 29,200 | C | Rg–46%, | Fo–26%, | Ag–22% |
| SW17 | 13120500 | Big Lost River near Chilly | BFS | 450 | A | Rg–52%, | Fo–30%, | Tn–18% |
| SW18 | 13152500 | Malad River near Gooding | BFS | 2,990 | B | Rg–64%, | Ag–14%, | Fo–13% |
| SW19 | 13154500 | Snake River at King Hill | BFS, NQN | 35,800 | C | Rg–50%, | Fo–23%, | Ag–21% |

over a wide range of streamflows (fig. 5). At least four samples collected at all the BFS were within both the lower and upper quartiles of historical streamflow, and at least one sample was within both the lower and upper tenth percentile. Samples were collected on a less frequent basis at the NASQAN and SMN sites (excluding SW19), and the range of streamflow during sampling was less complete than at the BFS. All samples were collected and preserved using standard equipment and procedures employed by the USGS (Shelton, 1994). Nutrient samples were analyzed by the USGS National Water Quality Laboratory in Arvada, Colorado, using colorimetric methods (Fishman, 1993). Suspended sediment samples were analyzed by the USGS sediment laboratory in Vancouver, Washington, using standard techniques (Guy, 1969).

In general, concentrations of nutrients and suspended sediment were smaller in water samples collected upstream from American Falls Reservoir (upper part of the USNK) than in samples collected downstream (table 2). Samples from sites SW9, SW10, and SW11 in the Portneuf River Basin generally contained the largest concentrations of nutrients and suspended sediment in the upper part of the basin and support a study by Minshall and Andrews (1973) that documented the effects of agricultural activities on water quality and benthic invertebrates in the Portneuf River. Samples from site SW1 on the Snake River, a site minimally affected by land-use activities, contained small median concentrations of nutrients and suspended sediment. However, samples collected at SW1 during spring snowmelt in WY's 1993 and 1995 contained some of the largest concentrations of total ammonia plus organic nitrogen as nitrogen (Kjel-N), total phosphorus as phosphorus (Tot-P), and suspended sediment of all samples collected in the USNK during the study.

Downstream from American Falls Reservoir (lower part of the USNK), effects of land-use activities on concentrations of nutrients and suspended sediments in water are more pronounced than in the upper part of the USNK. The largest median concentrations of dissolved nitrite plus nitrate as nitrogen ($NO_2$+$NO_3$) were detected in streams receiving significant quantities of discharge from agriculturally affected ground water (sites SW2, SW14, SW15, SW16, and SW19).

Specific conductance and concentrations of nutrients and suspended sediment at sites on the main stem of the Snake River generally increased downstream (fig. 6).

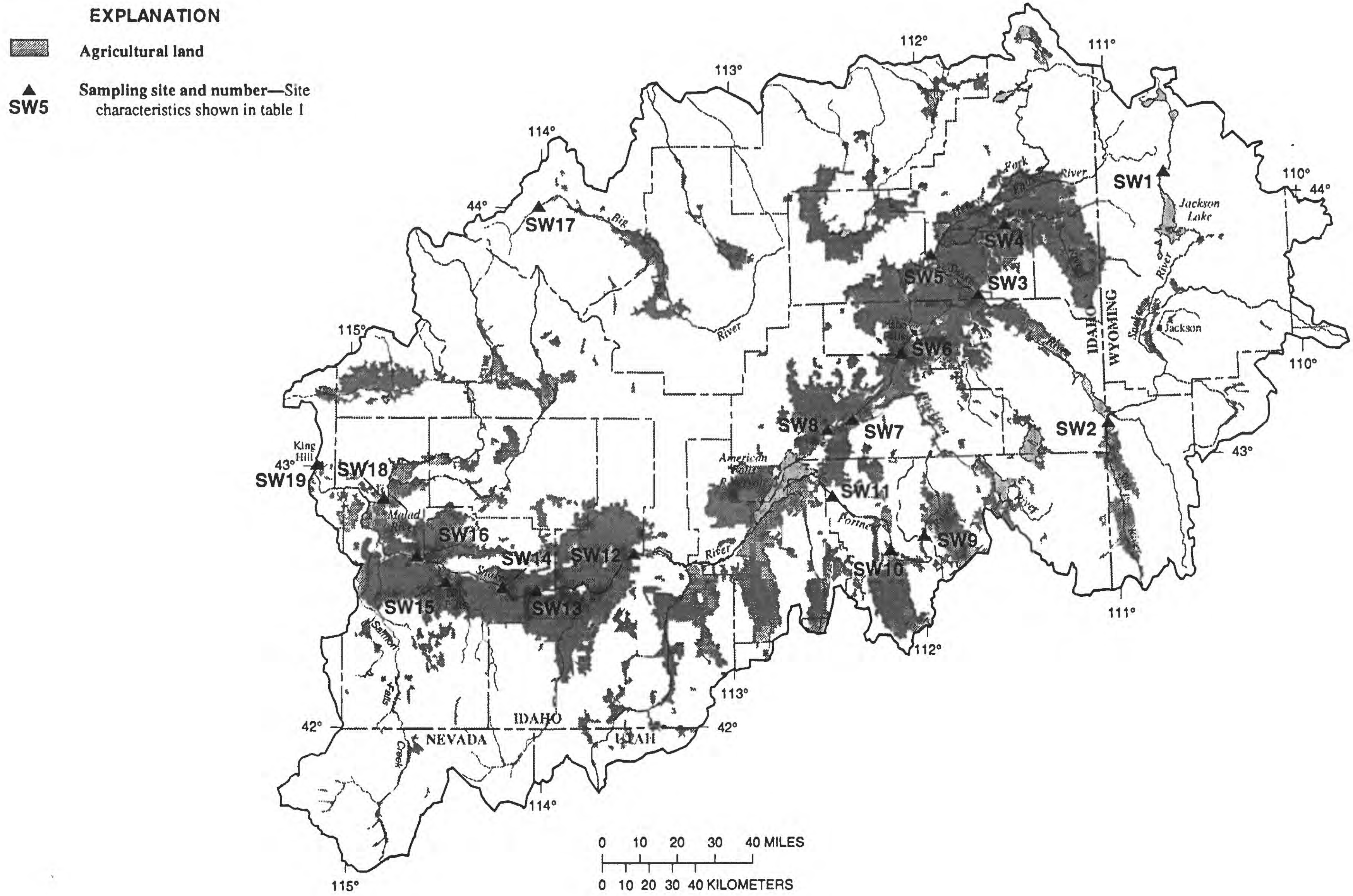



**Figure 4.** Locations of sampling sites in the upper Snake River Basin where at least 10 nutrient and (or) suspended sediment samples were collected, water years 1993–95.

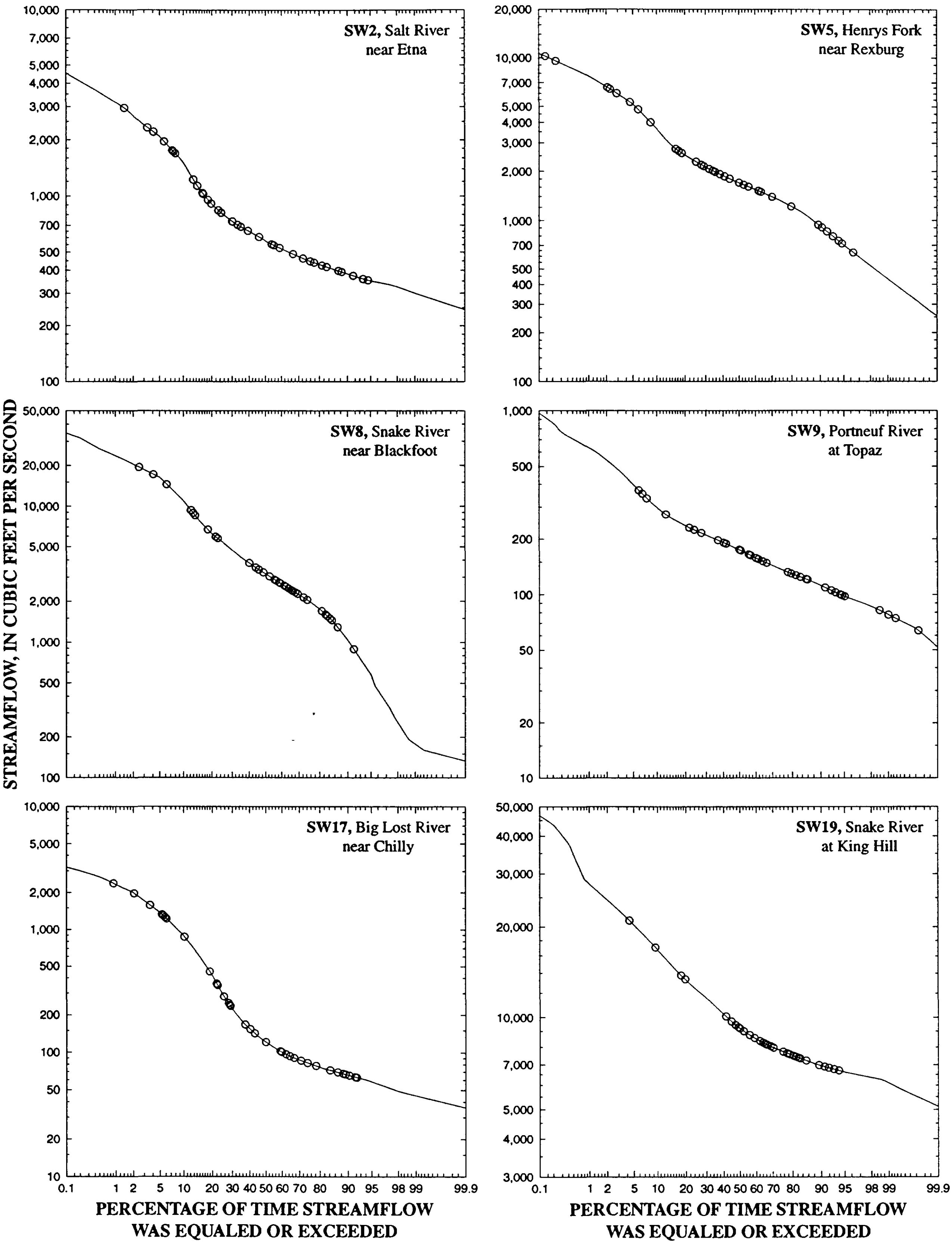



**Figure 5.** Distribution of nutrient and (or) suspended sediment samples collected over the range of historical streamflow at selected sites in the upper Snake River Basin, water years 1993–95. (Site locations shown in figure 4; site characteristics shown in table 1)

**Table 2.** Statistical summary of nutrient and suspended sediment concentrations at sites in the upper Snake River Basin with at least 10 samples, water years 1993–95

[Site locations shown in figure 4; No., number; mg/L, milligrams per liter; Wy, Wyoming; N, nitrogen; P, phosphorus; USNK, upper Snake River Basin; <, less than; —, values for the 10th and 90th percentiles not included for sites with fewer than 15 observations; sites are in Idaho unless otherwise indicated]

| Site No. | Gaging-station name | No. of samples | Concentration at indicated percentile: 10 | 25 | 50 | 75 | 90 | Maximum concentration |
|---|---|---|---|---|---|---|---|---|
| | | | **Ammonia, dissolved, mg/L as N ($NH_4$)** | | | | | |
| | | | *Upper part of USNK* | | | | | |
| SW1 | Snake River at Flagg Ranch, Wy | 40 | <0.010 | 0.015 | 0.020 | 0.030 | 0.030 | 0.070 |
| SW2 | Salt River near Etna, Wy | 35 | <.010 | .015 | .020 | .030 | .030 | .040 |
| SW3 | Snake River near Heise | 22 | <.012 | .015 | .020 | .022 | .037 | .040 |
| SW4 | Teton River near St. Anthony | 37 | <.010 | .015 | .020 | .030 | .042 | .060 |
| SW5 | Henrys Fork near Rexburg | 34 | <.010 | .015 | .020 | .022 | .040 | .050 |
| SW6 | Snake River near Shelley | 13 | — | .025 | .040 | .045 | — | .110 |
| SW7 | Blackfoot River near Blackfoot | 19 | <.010 | .015 | .020 | .030 | .110 | .130 |
| SW8 | Snake River near Blackfoot | 35 | <.010 | .015 | .020 | .030 | .034 | .040 |
| SW9 | Portneuf River at Topaz | 34 | .020 | .020 | .030 | .040 | .045 | .110 |
| SW10 | Marsh Creek near McCammon | 12 | — | .032 | .055 | .170 | — | .790 |
| SW11 | Portneuf River at Pocatello | 12 | — | .019 | .040 | .072 | — | .370 |
| | | | *Lower part of USNK* | | | | | |
| SW12 | Snake River near Minidoka | 32 | .012 | .020 | .025 | .038 | .050 | .060 |
| SW13 | Snake River at Milner Dam | 12 | — | .020 | .030 | .040 | — | .070 |
| SW14 | Snake River near Kimberly | 14 | — | .020 | .020 | .050 | — | .130 |
| SW15 | Rock Creek at Twin Falls | 32 | .040 | .050 | .055 | .120 | .140 | .320 |
| SW16 | Snake River near Buhl | 37 | .028 | .040 | .060 | .070 | .122 | .170 |
| SW17 | Big Lost River near Chilly | 34 | <.010 | <.010 | .015 | .020 | .020 | .030 |
| SW18 | Malad River near Gooding | 35 | <.010 | .015 | .020 | .040 | .084 | .250 |
| SW19 | Snake River at King Hill | 38 | .015 | .020 | .030 | .060 | .060 | .110 |
| | | | **Ammonia + Organic Nitrogen, total, mg/L as N (Kjel-N)** | | | | | |
| | | | *Upper part of USNK* | | | | | |
| SW1 | Snake River at Flagg Ranch, Wy | 40 | <0.20 | <0.20 | <0.20 | <0.20 | 0.20 | 1.30 |
| SW2 | Salt River near Etna, Wy | 35 | <.20 | <.20 | <.20 | .20 | .40 | .50 |
| SW3 | Snake River near Heise | 22 | <.20 | <.20 | <.20 | <.20 | .27 | .40 |
| SW4 | Teton River near St. Anthony | 37 | <.20 | <.20 | <.20 | .20 | .30 | .30 |
| SW5 | Henrys Fork near Rexburg | 34 | <.20 | <.20 | <.20 | .22 | .30 | .40 |
| SW6 | Snake River near Shelley | 13 | — | .20 | .20 | .30 | — | 2.80 |
| SW7 | Blackfoot River near Blackfoot | 19 | .20 | .30 | .30 | .50 | .70 | .80 |
| SW8 | Snake River near Blackfoot | 35 | <.20 | <.20 | .20 | .20 | .40 | .50 |
| SW9 | Portneuf River at Topaz | 34 | <.20 | <.20 | .20 | .40 | .60 | .70 |
| SW10 | Marsh Creek near McCammon | 12 | — | .42 | .60 | .80 | — | 1.60 |
| SW11 | Portneuf River at Pocatello | 12 | — | .30 | .40 | .58 | — | .80 |
| | | | *Lower part of USNK* | | | | | |
| SW12 | Snake River near Minidoka | 32 | <.20 | .30 | .30 | .40 | .50 | .50 |
| SW13 | Snake River at Milner Dam | 12 | — | .30 | .40 | .68 | — | 1.60 |
| SW14 | Snake River near Kimberly | 14 | — | .30 | .30 | .42 | — | .70 |
| SW15 | Rock Creek at Twin Falls | 32 | .30 | .30 | .40 | .50 | .70 | 1.10 |
| SW16 | Snake River near Buhl | 38 | .29 | .30 | .40 | .50 | .60 | .90 |
| SW17 | Big Lost River near Chilly | 34 | <.20 | <.20 | <.20 | <.20 | .20 | .40 |
| SW18 | Malad River near Gooding | 35 | .20 | .30 | .40 | .60 | .84 | 1.20 |
| SW19 | Snake River at King Hill | 38 | <.20 | <.20 | .20 | .32 | .40 | 1.00 |

**Table 2.** Statistical summary of nutrient and suspended sediment concentrations at sites in the upper Snake River Basin with at least 10 samples, water years 1993–95—Continued

| Site No. | Gaging-station name | No. of samples | Concentration at indicated percentile | | | | | Maximum concentration |
|---|---|---|---|---|---|---|---|---|
| | | | 10 | 25 | 50 | 75 | 90 | |
| | **Nitrite + Nitrate, dissolved, mg/L as N ($NO_2$+$NO_3$)** | | | | | | | |
| | *Upper part of USNK* | | | | | | | |
| SW1 | Snake River at Flagg Ranch, Wy | 40 | <0.05 | <0.05 | <0.05 | 0.07 | 0.12 | 0.57 |
| SW2 | Salt River near Etna, Wy | 35 | .42 | .56 | .90 | 1.00 | 1.14 | 1.20 |
| SW3 | Snake River near Heise | 22 | .06 | .09 | .12 | .19 | .20 | .39 |
| SW4 | Teton River near St. Anthony | 37 | .13 | .18 | .36 | .66 | .87 | 1.00 |
| SW5 | Henrys Fork near Rexburg | 34 | .08 | .11 | .20 | .30 | .37 | .46 |
| SW6 | Snake River near Shelley | 13 | — | .12 | .22 | .34 | — | .39 |
| SW7 | Blackfoot River near Blackfoot | 19 | <.05 | <.05 | .14 | .46 | .81 | 1.00 |
| SW8 | Snake River near Blackfoot | 35 | .06 | .09 | .14 | .27 | .36 | .45 |
| SW9 | Portneuf River at Topaz | 34 | .26 | .42 | .61 | .95 | 1.10 | 1.20 |
| SW10 | Marsh Creek near McCammon | 12 | — | .38 | .54 | 1.35 | — | 1.60 |
| SW11 | Portneuf River at Pocatello | 12 | — | .19 | .64 | .88 | — | 1.10 |
| | *Lower part of USNK* | | | | | | | |
| SW12 | Snake River near Minidoka | 32 | <.05 | .06 | .13 | .30 | .51 | .56 |
| SW13 | Snake River at Milner Dam | 12 | — | .12 | .25 | 1.22 | — | 1.40 |
| SW14 | Snake River near Kimberly | 14 | — | .43 | 1.25 | 1.62 | — | 2.20 |
| SW15 | Rock Creek at Twin Falls | 32 | .85 | 1.04 | 1.60 | 2.22 | 2.77 | 5.30 |
| SW16 | Snake River near Buhl | 37 | .48 | 1.20 | 1.50 | 2.00 | 2.30 | 2.70 |
| SW17 | Big Lost River near Chilly | 34 | <.05 | <.05 | <.05 | .06 | .07 | .09 |
| SW18 | Malad River near Gooding | 35 | <.05 | <.05 | .12 | .67 | 1.14 | 1.40 |
| SW19 | Snake River at King Hill | 38 | .91 | 1.10 | 1.30 | 1.50 | 1.70 | 2.30 |
| | **Orthophosphorus, dissolved, mg/L as P ($PO_4$)** | | | | | | | |
| | *Upper part of USNK* | | | | | | | |
| SW1 | Snake River at Flagg Ranch, Wy | 40 | <0.01 | <0.01 | <0.01 | <0.01 | 0.01 | 0.02 |
| SW2 | Salt River near Etna, Wy | 35 | <.01 | <.01 | <.01 | .02 | .02 | .04 |
| SW3 | Snake River near Heise | 22 | <.01 | <.01 | <.01 | <.01 | .01 | .03 |
| SW4 | Teton River near St. Anthony | 37 | <.01 | <.01 | <.01 | .01 | .01 | .01 |
| SW5 | Henrys Fork near Rexburg | 34 | <.01 | <.01 | <.01 | .01 | .02 | .02 |
| SW6 | Snake River near Shelley | 13 | — | <.01 | .02 | .02 | — | .04 |
| SW7 | Blackfoot River near Blackfoot | 19 | <.01 | <.01 | <.01 | .01 | .03 | .05 |
| SW8 | Snake River near Blackfoot | 35 | <.01 | <.01 | <.01 | .01 | .02 | .03 |
| SW9 | Portneuf River at Topaz | 34 | <.01 | .01 | .02 | .02 | .04 | .05 |
| SW10 | Marsh Creek near McCammon | 12 | — | .02 | .04 | .05 | — | .12 |
| SW11 | Portneuf River at Pocatello | 12 | — | <.01 | .02 | .04 | — | .07 |
| | *Lower part of USNK* | | | | | | | |
| SW12 | Snake River near Minidoka | 32 | .01 | .01 | .02 | .03 | .04 | .05 |
| SW13 | Snake River at Milner Dam | 12 | — | .01 | .06 | .15 | — | .22 |
| SW14 | Snake River near Kimberly | 14 | — | .03 | .05 | .10 | — | .28 |
| SW15 | Rock Creek at Twin Falls | 32 | .03 | .04 | .05 | .06 | .06 | .08 |
| SW16 | Snake River near Buhl | 37 | .03 | .05 | .06 | .08 | .11 | .19 |
| SW17 | Big Lost River near Chilly | 34 | <.01 | <.01 | <.01 | <.01 | .01 | .01 |
| SW18 | Malad River near Gooding | 35 | <.01 | .01 | .03 | .04 | .07 | .22 |
| SW19 | Snake River at King Hill | 38 | .03 | .04 | .05 | .06 | .07 | .17 |

**Table 2.** Statistical summary of nutrient and suspended sediment concentrations at sites in the upper Snake River Basin with at least 10 samples, water years 1993–95—Continued

| Site No. | Gaging-station name | No. of samples | Concentration at indicated percentile 10 | 25 | 50 | 75 | 90 | Maximum concentration |
|---|---|---|---|---|---|---|---|---|
| | | | **Phosphorus, total, mg/L as P (Tot-P)** | | | | | |
| | | | *Upper part of USNK* | | | | | |
| SW1 | Snake River at Flagg Ranch, Wy | 40 | <0.01 | <0.01 | <0.01 | 0.02 | 0.06 | 0.34 |
| SW2 | Salt River near Etna, Wy | 35 | .01 | .01 | .02 | .06 | .13 | .22 |
| SW3 | Snake River near Heise | 22 | <.01 | <.01 | .01 | .02 | .03 | .05 |
| SW4 | Teton River near St. Anthony | 37 | <.01 | <.01 | .01 | .03 | .03 | .05 |
| SW5 | Henrys Fork near Rexburg | 34 | .01 | .02 | .02 | .03 | .04 | .11 |
| SW6 | Snake River near Shelley | 13 | — | .02 | .02 | .04 | — | .05 |
| SW7 | Blackfoot River near Blackfoot | 19 | .01 | .01 | .04 | .07 | .16 | .43 |
| SW8 | Snake River near Blackfoot | 35 | <.01 | <.01 | .02 | .03 | .04 | .11 |
| SW9 | Portneuf River at Topaz | 34 | <.01 | .03 | .04 | .06 | .10 | .15 |
| SW10 | Marsh Creek near McCammon | 12 | — | .04 | .08 | .16 | — | .21 |
| SW11 | Portneuf River at Pocatello | 12 | — | .02 | .04 | .11 | — | .14 |
| | | | *Lower part of USNK* | | | | | |
| SW12 | Snake River near Minidoka | 32 | .01 | .02 | .04 | .06 | .08 | .09 |
| SW13 | Snake River at Milner Dam | 12 | — | .04 | .11 | .23 | — | .33 |
| SW14 | Snake River near Kimberly | 14 | — | .06 | .08 | .14 | — | .29 |
| SW15 | Rock Creek at Twin Falls | 32 | .04 | .07 | .08 | .11 | .16 | .18 |
| SW16 | Snake River near Buhl | 38 | .07 | .09 | .11 | .13 | .16 | .19 |
| SW17 | Big Lost River near Chilly | 34 | <.01 | <.01 | <.01 | .02 | .04 | .08 |
| SW18 | Malad River near Gooding | 35 | .03 | .04 | .07 | .11 | .15 | .33 |
| SW19 | Snake River at King Hill | 38 | .05 | .06 | .07 | .09 | .21 | .34 |
| | | | **Suspended sediment, mg/L** | | | | | |
| | | | *Upper part of USNK* | | | | | |
| SW1 | Snake River at Flagg Ranch, Wy | 38 | 2 | 3 | 4 | 21 | 101 | 925 |
| SW2 | Salt River near Etna, Wy | 35 | 6 | 15 | 36 | 82 | 159 | 357 |
| SW3 | Snake River near Heise | 19 | 2 | 3 | 6 | 19 | 33 | 48 |
| SW4 | Teton River near St. Anthony | 36 | 3 | 5 | 8 | 15 | 32 | 38 |
| SW5 | Henrys Fork near Rexburg | 34 | 6 | 8 | 14 | 26 | 41 | 53 |
| SW7 | Blackfoot River near Blackfoot | 13 | — | 16 | 49 | 174 | — | 427 |
| SW8 | Snake River near Blackfoot | 35 | 4 | 6 | 13 | 17 | 57 | 94 |
| SW9 | Portneuf River at Topaz | 34 | 18 | 32 | 52 | 90 | 132 | 282 |
| | | | *Lower part of USNK* | | | | | |
| SW12 | Snake River near Minidoka | 32 | 3 | 5 | 8 | 11 | 24 | 32 |
| SW15 | Rock Creek at Twin Falls | 32 | 16 | 32 | 72 | 129 | 263 | 648 |
| SW16 | Snake River near Buhl | 37 | 11 | 16 | 22 | 38 | 83 | 162 |
| SW17 | Big Lost River near Chilly | 34 | 1 | 2 | 4 | 40 | 76 | 169 |
| SW18 | Malad River near Gooding | 32 | 3 | 10 | 21 | 47 | 81 | 162 |
| SW19 | Snake River at King Hill | 37 | 10 | 12 | 18 | 26 | 72 | 319 |

Between SW1 and SW12, concentrations of nutrients and suspended sediment were generally small. Concentrations of nutrients in the Snake River in the upper part of the USNK were largest at SW6, about 6.5 mi downstream from the Idaho Falls sewage-treatment plant. The plant discharges more than 1 million $ft^3$ of treated effluent daily (Maupin, 1995). From SW13 to SW16, water quality in the Snake River deteriorates as the river receives nutrients and suspended sediments from multiple point and nonpoint sources. Between SW16 and

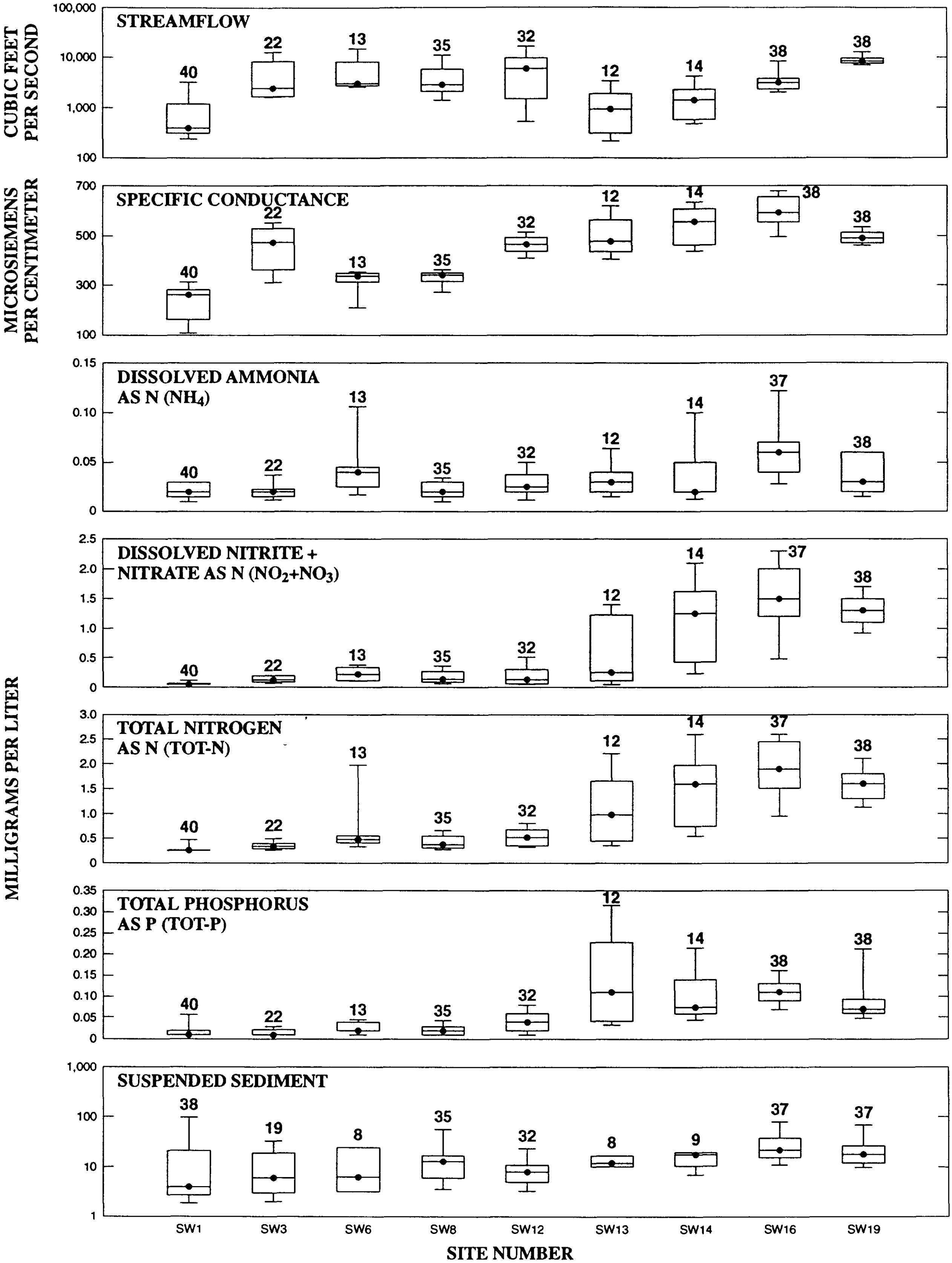



**Figure 6.** Concentrations of selected constituents in the main-stem Snake River in the upper Snake River Basin, water years 1993–95. (Site locations shown in figure 4; site characteristics shown in table 1)

SW19 at the outlet of the basin, specific conductance and concentrations of nutrients and suspended sediment in the river decreased in response to gains in streamflow from more dilute ground-water discharge (fig. 6).

To evaluate effects of agricultural land use on concentrations of nutrients and suspended sediment, sampling sites were grouped into four categories on the basis of quantity of agricultural land in the upstream drainage basin. The quantity of agricultural land in each drainage basin was determined by digitizing the drainage basin boundary and overlaying it on a map of land use derived from remotely sensed data (U.S. Geological Survey, 1986). Group A consisted of sites at the outlet of drainage basins where agricultural land constitutes less than 10 percent of the land use (sites SW1, SW3, and SW17); group B, 10 to 19 percent of the land use (sites SW2, SW6, SW7, SW8, and SW18); group C, 20 to 29 percent of the land use (sites SW5, SW12, SW13, SW14, SW15, SW16, and SW19); and group D, greater than 29 percent of the land use (sites SW4, SW9, SW10, and SW11). Statistically significant differences between agricultural land-use groups were assessed using the Wilcoxon rank-sum test (Helsel and Hirsch, 1992) with a confidence level of 95 percent (two-sided test with an alpha value of 0.05).

Agricultural effects on water quality are demonstrated by significant increases in specific conductance, nutrients, and suspended sediment between groups A and B (fig. 7). Although specific conductance values were significantly different among all groups, increasing as the percentage of agricultural land increased, differences in concentrations of nutrients and suspended sediment among groups B, C, and D were not consistent. Concentrations of dissolved ammonia as nitrogen ($NH_4$), $NO_2$+$NO_3$, and total nitrogen (Tot-N) were significantly larger at group C and D sites compared with concentrations at group B sites but were not significantly different among groups C and D. Concentrations of suspended sediment were significantly smaller and concentrations of Tot-P and dissolved orthophosphorus as phosphorus ($PO_4$) were significantly larger at group C sites than at group B and D sites. Normally, a decrease in suspended sediment would correspond with a decrease in Tot-P in USNK streams (Clark, 1994a). Because many of the group C sites are located on the main stem of the Snake River in the lower part of the basin, they are affected by land and water uses in addition to agriculture. For instance, group C sites SW16 and SW19 are affected by discharge from the Twin Falls sewage-treatment plant and numerous aquaculture facilities, which contribute a large quantity of Tot-P but little suspended sediment. Group C sites SW12, SW13, and SW14 are located directly downstream from sediment-trapping impoundments that reduce instream concentrations of suspended sediment. Group D sites SW16 and SW19 receive a large quantity of sediment-free spring water in the middle Snake reach, which reduces instream suspended sediment concentrations at those sites. Sediment in the lower reaches of the Snake River is transported primarily during periods of high streamflow when flow velocities in the river are large enough to resuspend sediments that were impounded in reservoirs.

Individual sites in each of the four agricultural land-use groups showed similar patterns in the relations between selected nutrient and suspended sediment concentrations and streamflow (fig. 8). Concentrations of $NO_2$+$NO_3$ at SW1, where there is no upstream agricultural land use, showed little response to increased streamflow. In contrast, concentrations of $NO_2$+$NO_3$ at SW2, SW9, and SW19, where agricultural land constitutes 18 percent or more of the upstream land use, generally exhibited an inverse relation with streamflow. An inverse relation between $NO_2$+$NO_3$ and streamflow is characteristic of basins in which nonpoint sources of nutrients dominate and ground water is an important contributor of water and nutrients to streams (Mueller and others, 1995). Data from all sites in figure 8 indicated that concentrations of Tot-P and suspended sediment increase with increased streamflow. Such direct relations are common in undisturbed and nonpoint-source dominated watersheds where most of the phosphorus is transported attached to sediment particles rather than dissolved in water (Mueller and others, 1995). As streamflow increases, Tot-P and suspended sediment concentrations increase as sediment is washed into streams and retained in suspension at elevated stream velocities. SW1 (fig. 8) is an example of a site in a relatively undisturbed upstream watershed where concentrations of Tot-P and suspended sediment increase dramatically during periods of high streamflow.

The Kruskal-Wallis test (Helsel and Hirsch, 1992) was used to assess seasonal differences among agricultural land-use groups. The Kruskal-Wallis test is like the Wilcoxon rank-sum test except that it is designed to compare population distributions for several independent groups of data for similarity. For comparisons, the year was divided into quarters on the basis of climatic and water-use considerations in the USNK. The first (January through March) and fourth (October through

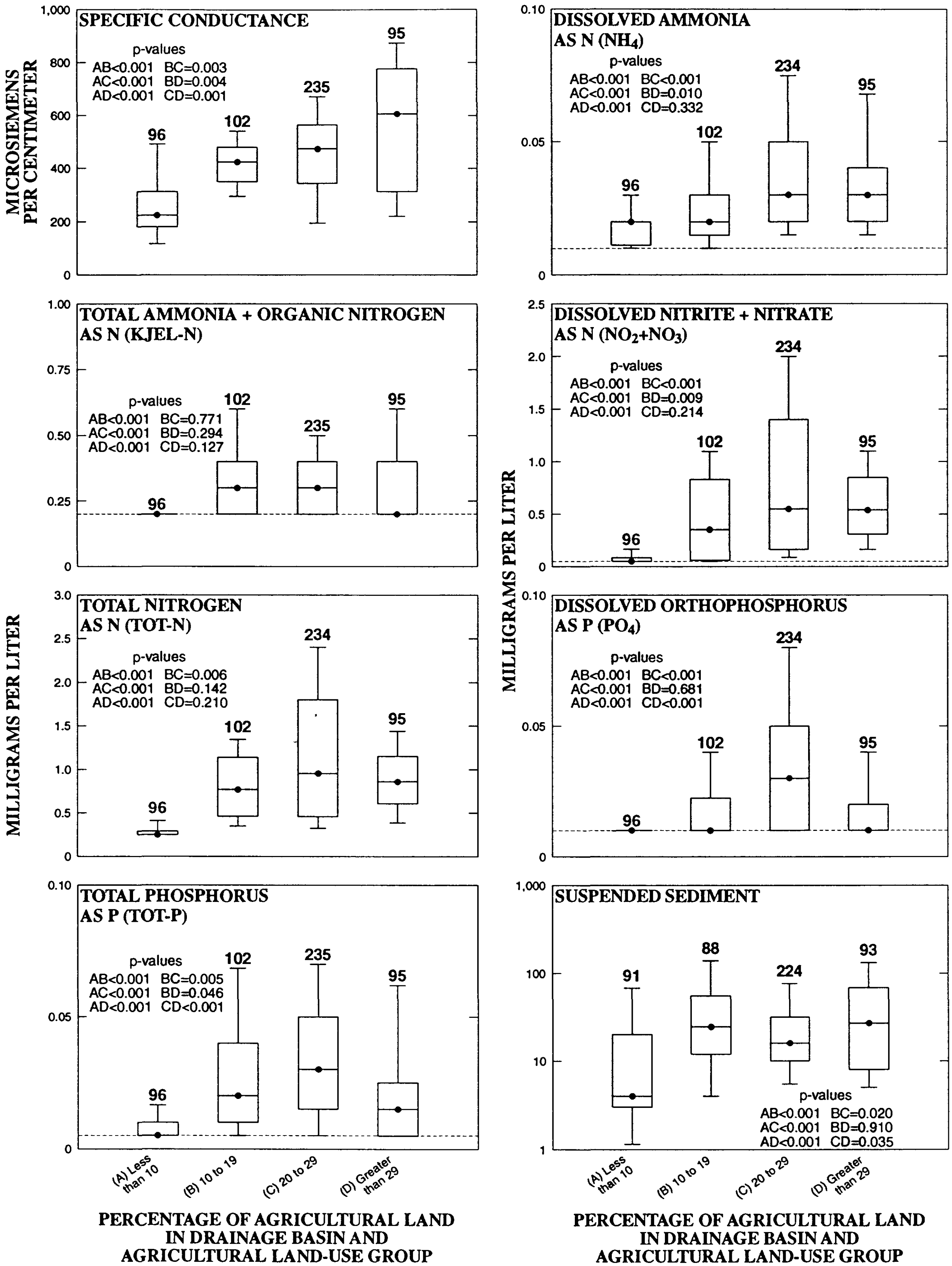



**Figure 7.** Specific conductance and concentrations of nutrients and suspended sediment by agricultural land-use group, upper Snake River Basin. (p-values less than 0.05 indicate significant difference between indicated groups)

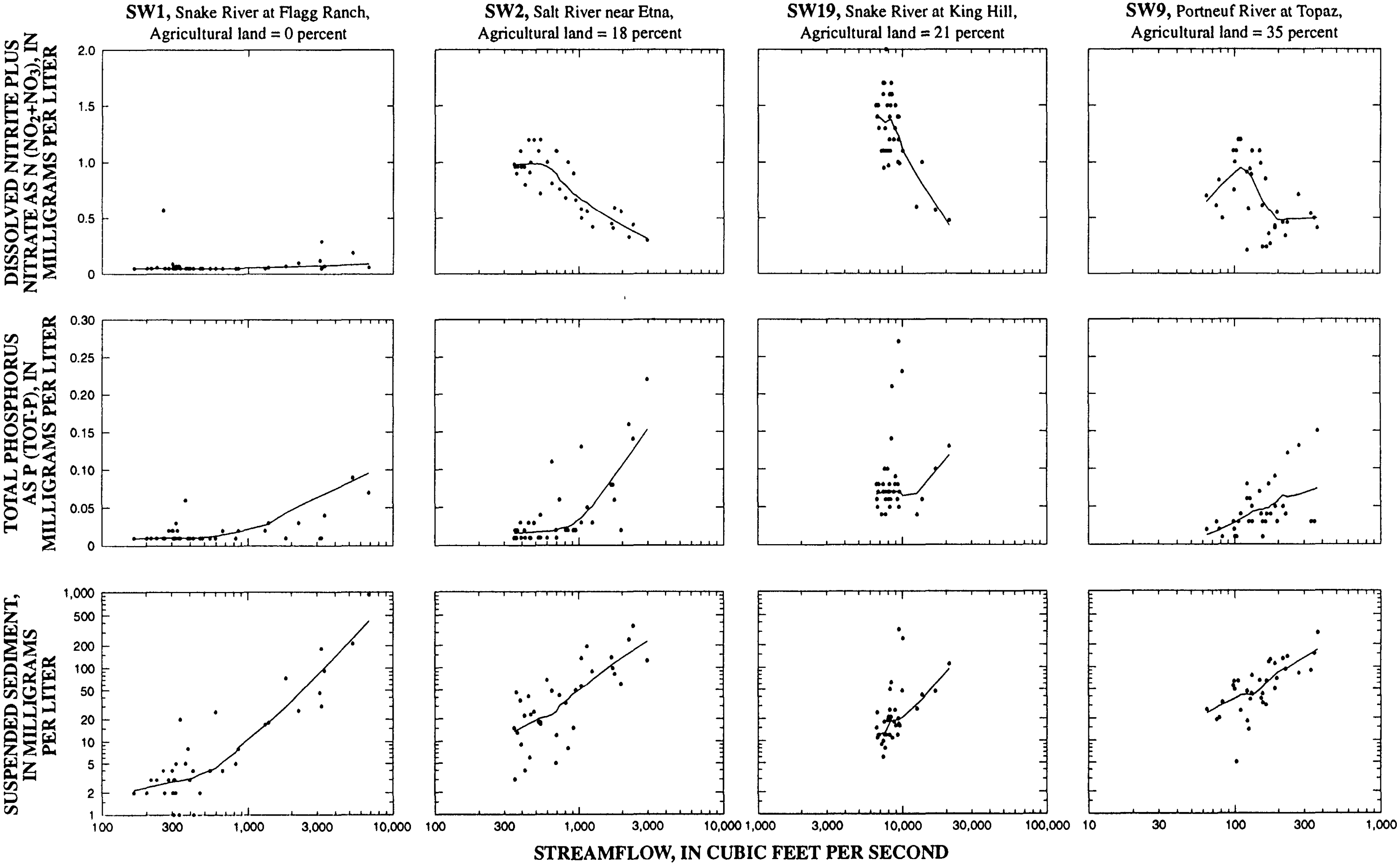



**Figure 8.** Relations between selected constituents and streamflow for selected sites in the upper Snake River Basin, water years 1993–95. [Site locations shown in figure 4; site characteristics shown in table 1; LOWESS, locally weighted scatterplot smoothing (Helsel and Hirsch, 1992)]

December) quarters are characterized by cool temperatures, relatively low streamflow, and little agricultural water use. The second quarter (April through June) is characterized by snowmelt and high streamflow in most of the basin, although air temperatures are still relatively cool and precipitation is common. The third quarter (July through September) is the hottest and driest of the year, and large quantities of water are diverted from streams to irrigate crops.

Seasonal differences in concentrations of $NO_2$+$NO_3$, Tot-P, and suspended sediment were evident in all of the agricultural land-use groups, although differences were not always statistically significant at the 95-percent confidence interval (fig. 9). At group A sites, $NO_2$+$NO_3$ concentrations were consistently small throughout the year, whereas at group B, C, and D sites, $NO_2$+$NO_3$ concentrations were significantly larger during the fall and winter months (October through March) when ground-water influences on streams are most apparent. At group A and B sites, Tot-P concentrations were significantly larger during the April through June high streamflow period. Seasonal Tot-P concentrations were not significantly different at group C sites but were at group D sites. Ratios of $PO_4$ to Tot-P can be used to evaluate the distribution of phosphorus between the dissolved and particulate phases. The $PO_4$ to Tot-P ratios for all groups were smallest during the second quarter, indicating that a greater percentage of the phosphorus was in the particulate phase during April through June than during the rest of the year. Suspended sediment concentrations for all groups were largest during April through June when high streamflows scour and transport sediment and sediment-bound nutrients.

## THE MIDDLE REACH OF THE SNAKE RIVER

Water quality in the 92-mi reach of the Snake River between SW13 at Milner Dam and SW19 at King Hill (herein referred to as the "middle Snake," fig. 10) has deteriorated because of the cumulative effects of decades of industrial and agricultural activities. Since 1990, the middle Snake has been listed by the Idaho Division of Environmental Quality as "water-quality limited" under the Clean Water Act. Excessive aquatic vegetation, low dissolved oxygen, and high water temperatures, all symptomatic of a eutrophic system, prevent water in the middle Snake from meeting State water-quality standards. Research and monitoring indicate that the deteriorating water quality results from a combination of excessive nutrient and sediment inputs and reduced streamflows (Minshall and others, 1993; Falter and Carlson, 1994). Specific sources of nutrients and (or) suspended sediment include ground-water discharge, irrigation returns, agriculturally affected tributaries, aquaculture facilities, and sewage-treatment plants.

Streamflow in the middle Snake is augmented by discharge from the Snake River Plain aquifer, an unconfined system of fractured Quaternary basalt flows (Whitehead, 1986, sheet 1). The Snake River intersects the aquifer about 20 mi downstream from Milner Dam and remains below the regional water table throughout the remainder of the middle Snake reach. Discharge from the aquifer is primarily from springs clustered along the north canyon wall of the river. North-side springs along the middle Snake supplied between 30 and 80 percent of the mean annual streamflow at SW19 during WY's 1980–95, depending on conditions in the USNK (fig. 11). During dry years and during the irrigation season, when Snake River water is being stored in upstream reservoirs or is diverted for agricultural use upstream from SW13, springs along the middle Snake reach supply most of the streamflow in the river.

Most recharge to the Snake River Plain aquifer is from infiltration of excess irrigation water applied on the Snake River Plain (Lindholm, 1996). Garabedian (1992, pl. 8) estimated that, during 1976–80, the annual recharge rate to the aquifer was 4 to 20 in. in surface-water-irrigated areas compared with less than 2 in. in most nonirrigated areas of the plain. Accordingly, discharge from the aquifer to the middle Snake has fluctuated in response to water use for irrigation since the early 1900's, reaching a high of about 6,800 $ft^3/s$ in the early 1950's. Since then, annual discharge from the aquifer to the middle Snake has decreased as a result of a combination of increased ground-water withdrawals, increased efficiency in irrigation practices, decreased surface-water diversions, and local droughts (Rupert, 1994, p. 11). In 1995, the aquifer discharged about 5,300 $ft^3/s$ to the Snake River, or about 60 percent of the total streamflow at SW19 (fig. 11). Individual spring discharge also varies seasonally in response to irrigation (fig. 12) and declines during the nonirrigation season (November through April), is at a minimum in late April, increases during the irrigation season (May through October), and is at a maximum in late October.

Data collected by the USGS from three springs along the middle Snake indicate that concentrations of $NO_2$+$NO_3$ may be affected by the seasonal input of irrigation water. Although long-term concentrations of

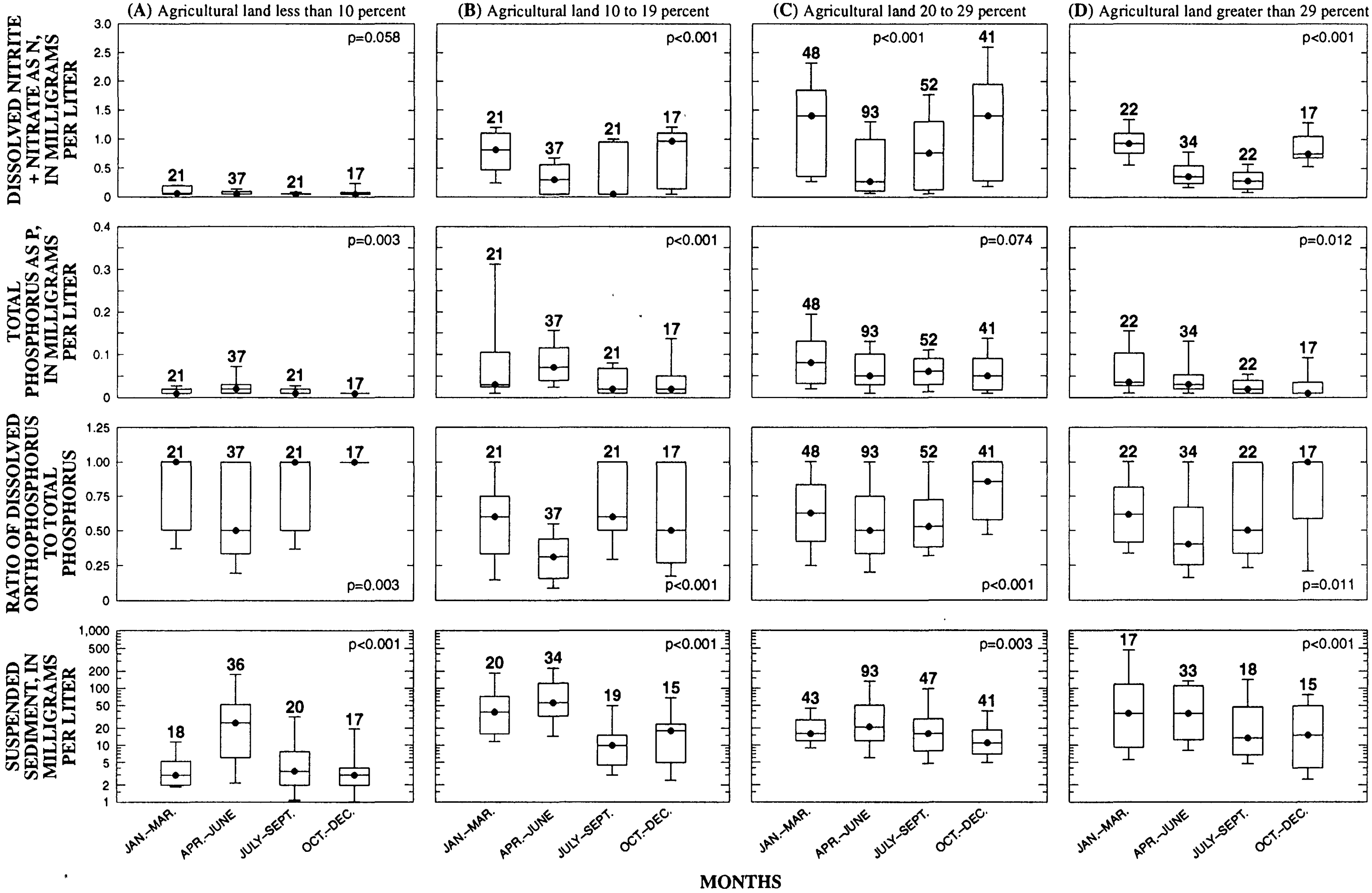



**Figure 9.** Seasonal concentrations of selected nutrients and suspended sediment by agricultural land-use group, upper Snake River Basin. (p-values less than 0.05 indicate that at least one 3-month period is significantly different from the others)

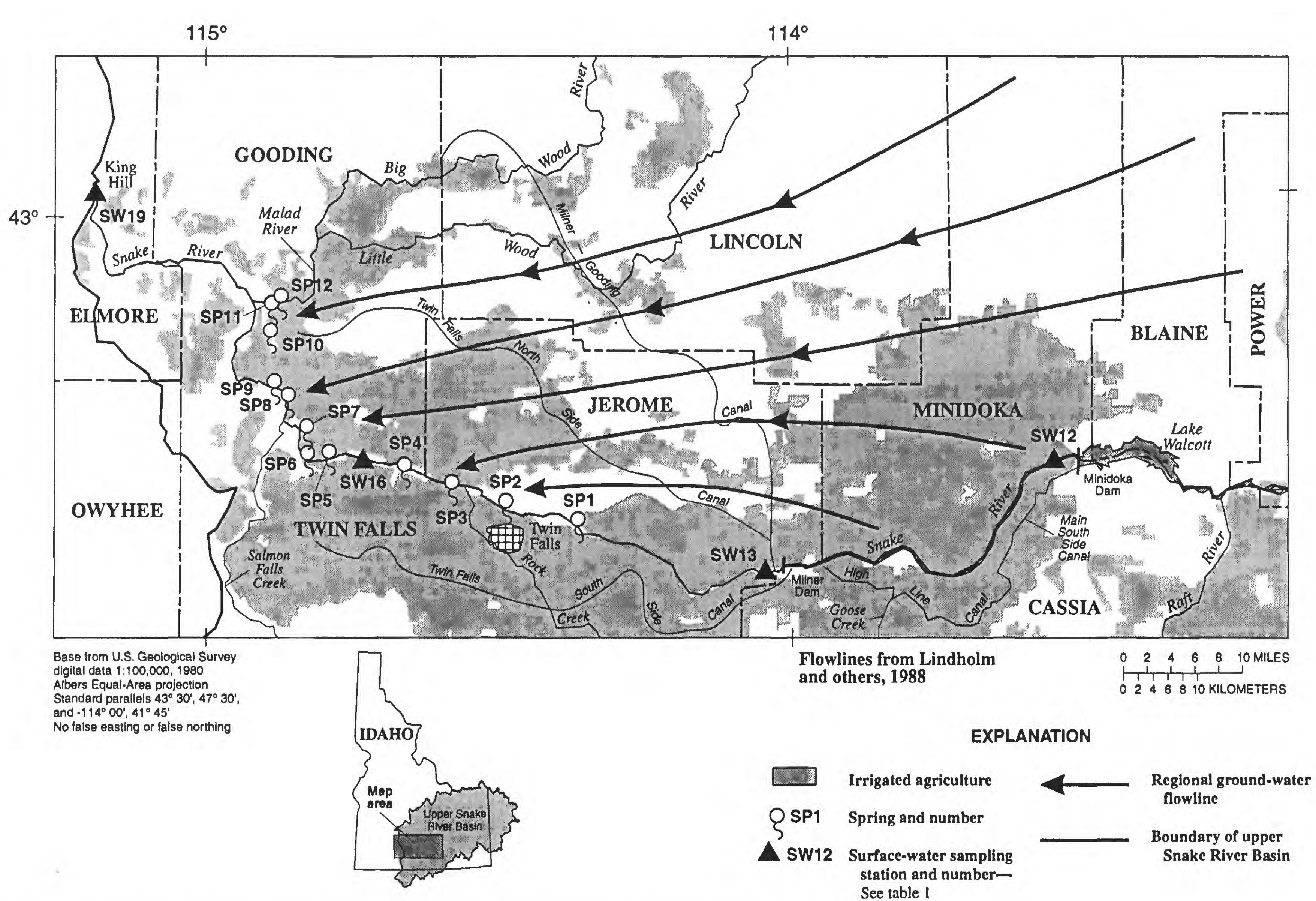



**Figure 10.** Locations of springs and surface-water sampling stations along the middle Snake River and generalized ground-water flow in the surrounding area.

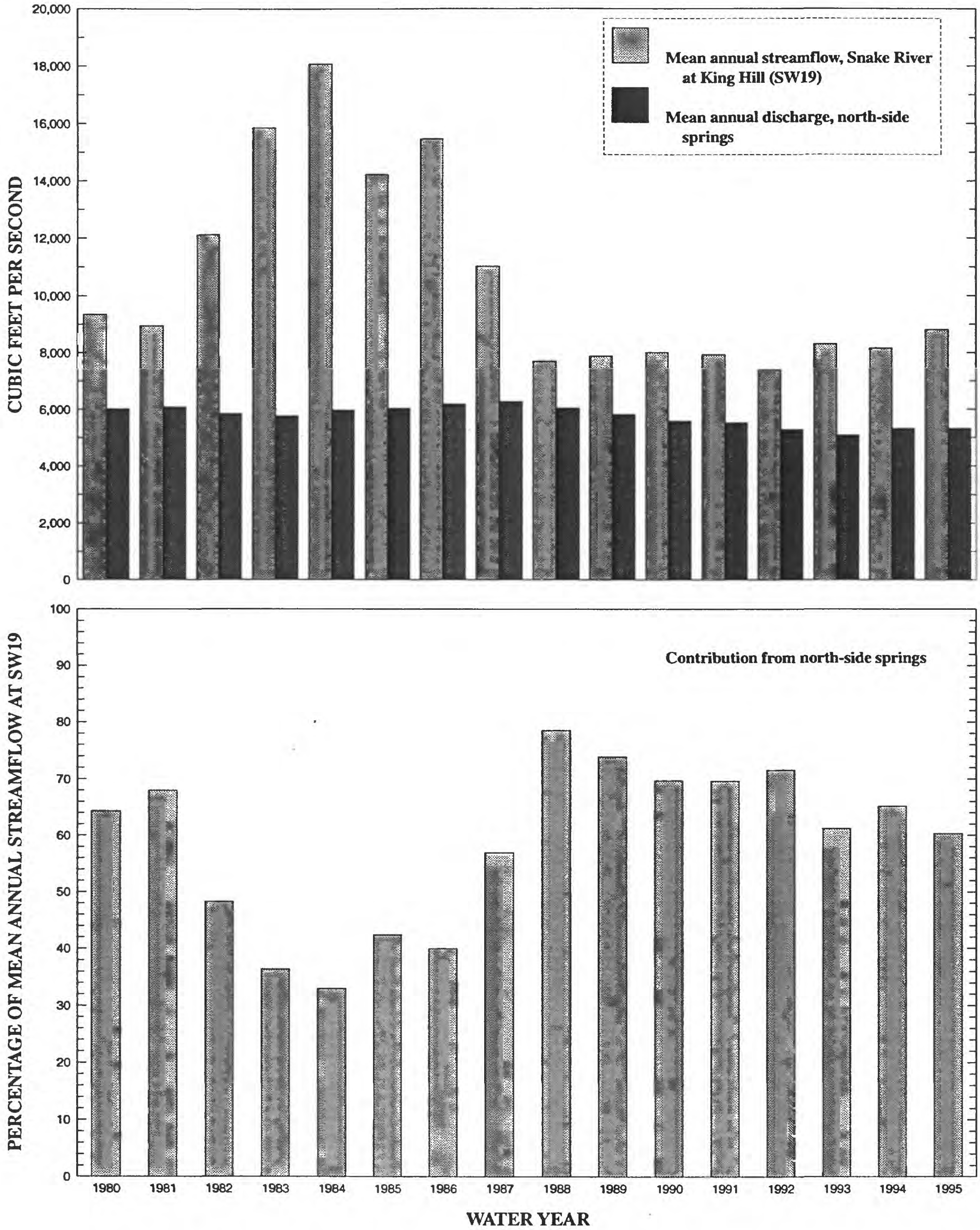



**Figure 11.** Mean annual streamflow at SW19, mean annual discharge of north-side springs, and percentage of contribution from north-side springs along the middle Snake River reach, water years 1980–95.

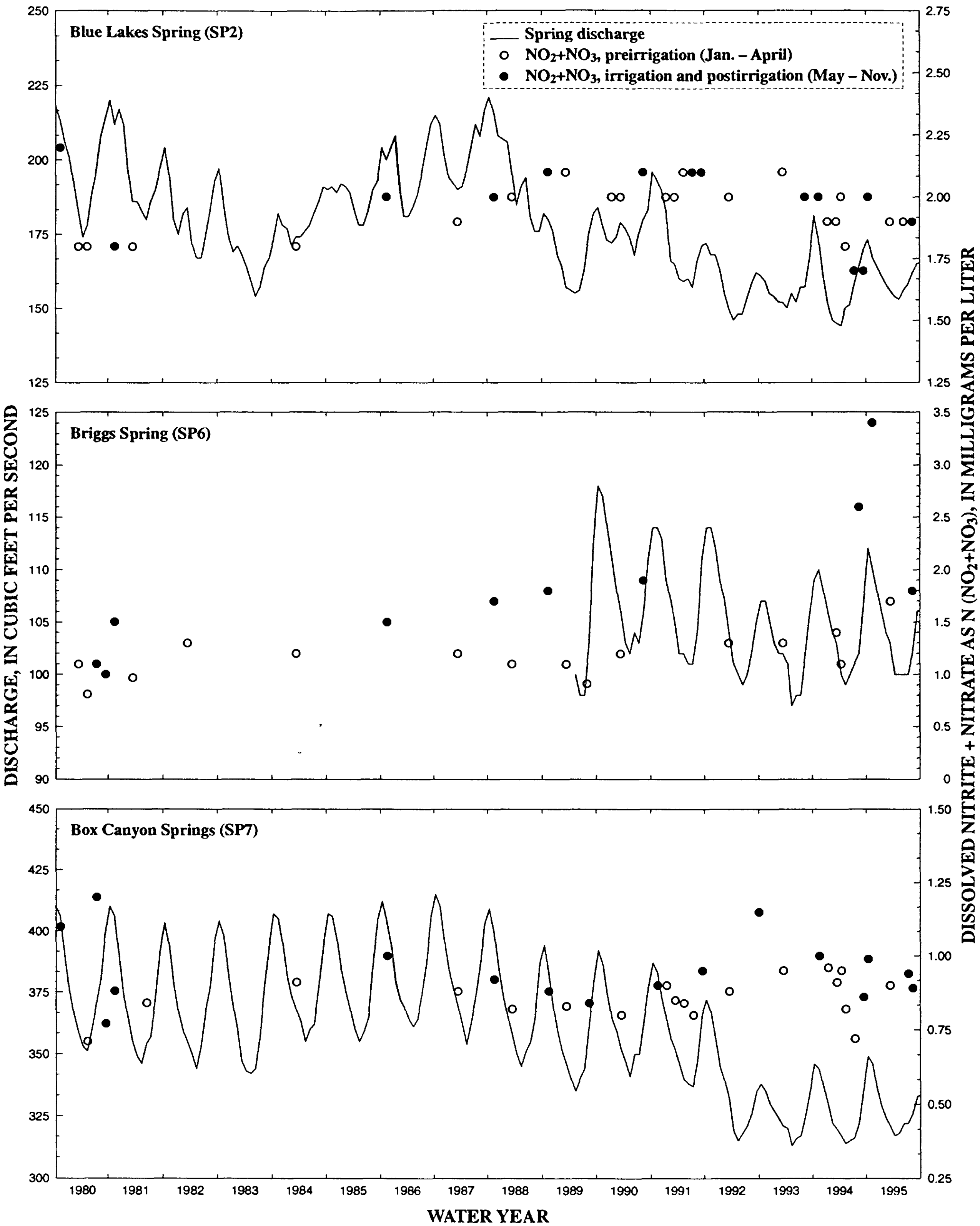



**Figure 12.** Spring discharge and dissolved nitrite plus nitrate concentrations in selected north-side springs along the middle Snake River reach, water years 1980–95. (Spring locations shown in figure 10)

$NO_2+NO_3$ in the springs do not appear to have increased dramatically since 1980, a seasonal variation in the $NO_2+NO_3$ concentrations at SP6 and SP7 is apparent, where larger concentrations coincide with higher discharges during and immediately following the irrigation season. Seasonal variation is especially apparent at SP6, where samples collected during the irrigation season indicate a steady increase in $NO_2+NO_3$ concentrations since the mid-1980's. Concentrations of $NO_2+NO_3$ in preirrigation samples at SP6 do not indicate an increase.

Numerous studies have reported distinct differences in the chemistry of individual springs discharging to the middle Snake (Mann, 1989; Brockway and Robison, 1992; Mann and Low, 1995; Clark and Ott, 1996). The differences result from differences in the source water for the spring and spatial variations in land and water use on lands under which contributing water flows. A flow-net analysis by Mundorff and others (1964) and a water-table map by Lindholm and others (1988), indicate that springs SP1 through SP5 (upstream springs) derive water primarily from local surface-water recharge in agricultural areas between Minidoka Dam and Twin Falls (fig. 10). Conversely, discharge from downstream springs (SP6 through SP12) is derived primarily from regional ground water, most of which entered the aquifer as snowmelt and intermontane basin stream recharge. On the basis of tritium and stable isotope data, Clark and Ott (1996) estimated that the upstream springs receive more than 90 percent of their water from irrigation recharge, whereas the downstream springs receive less than 20 percent from irrigation recharge. As a result, specific conductance values and $NO_2+NO_3$ concentrations were significantly ($p<0.05$) larger in the upstream springs than in the downstream springs (fig. 13). Phosphorus is generally less mobile than $NO_2+NO_3$ in ground water; consequently, concentrations of Tot-P, primarily as $PO_4$, were not significantly different between the upstream and downstream springs. Concentrations of Tot-P were generally near the method detection limits in most of the springs.

Because springs supply so much water to the middle Snake, they have a large effect on the chemical quality of water in the river. Specific conductance values and concentrations of $NO_2+NO_3$ in the Snake River increased between SW13 and SW16 in response to discharge from the upstream springs, and decreased between SW16 and SW19 in response to discharge from the more dilute downstream springs (fig. 6). Clark and Ott (1996) estimated that, in WY 1994, the north-side

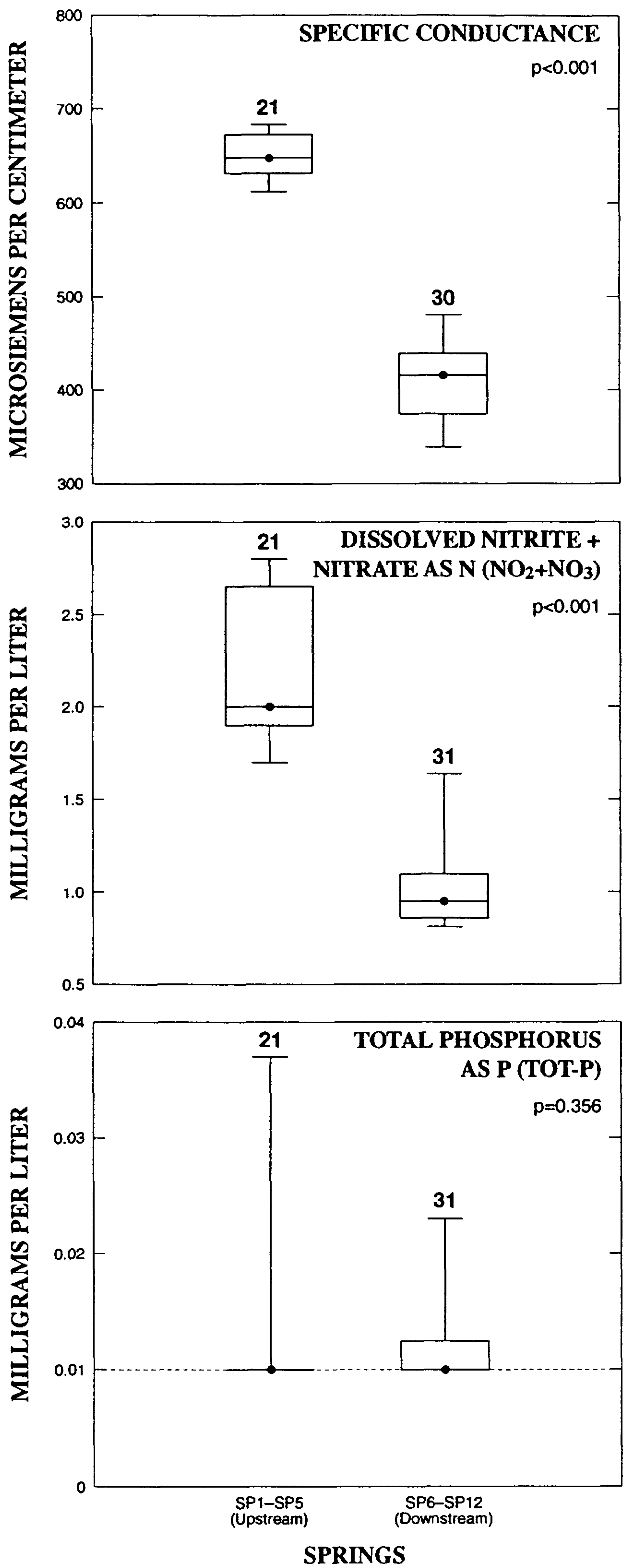



**Figure 13.** Concentrations of selected constituents in springs along the middle Snake River reach, water years 1993–95. (Spring locations shown in figure 10; p-values less than 0.05 indicate significant difference between upstream and downstream springs)

springs discharged about 6,500 tons of Tot-N and 100 tons of Tot-P to the middle Snake.

Nutrient and suspended sediment concentrations in the Snake River at the downstream end of the middle Snake at SW19 fluctuated considerably between WY 1980 and WY 1995 (fig. 14). However, most of the variation resulted from differences in streamflow, as evidenced by the streamflow-adjusted concentrations. Concentrations of $NO_2$+$NO_3$ were largest during the late 1980's and early 1990's when mean annual streamflow at SW19 was less than the historical average (fig. 2) and spring discharge to the middle Snake constituted most of the streamflow (fig. 11). Concentrations of $NO_2$+$NO_3$ were smallest from 1982 to 1986 when the mean annual streamflow at SW19 was larger than the historical average and springs contributed less than 50 percent of the annual total. In contrast, suspended sediment concentrations were largest during the high streamflow years from 1982 to 1986 and smallest during the low streamflow years from 1988 to 1992. Concentrations of Tot-P were largest in samples collected from 1993 to 1995, even though the streamflow during those years was smaller than the historical average. However, streamflow-adjusted Tot-P showed no increasing or decreasing trend. Some of the Tot-P and suspended sediment concentrations were largest during isolated periods of high streamflow, when velocities were large enough to scour stored sediments and associated nutrients that had accumulated in the middle Snake during the period of low streamflow from 1988 to 1992. Concentrations of Kjel-N decreased throughout the 1980's and early 1990's, although the downward trend in Kjel-N was hardly apparent after concentrations were adjusted for differences in streamflow.

Nutrient and suspended sediment loads leaving the middle Snake at SW19 during WY's 1980–95 were estimated using a constituent transport model (Cohn and others, 1992). The model was used to derive constituent loads by multiple regression of constituent concentrations to predictor variables of streamflow, seasonal variability, and long-term trends. The coefficients of determination, which represent the fraction of the variance in the data that is explained by the regression model, ranged from 40 to 69 percent for transport of $NH_4$, Kjel-N, $NO_2$+$NO_3$, Tot-P, and suspended sediment (table 3). Transport of $PO_4$ from the reach was not calculated because of a poor relation with streamflow and, subsequently, a low coefficient of determination (19 percent).

Because increased streamflow results in increased transport of material, the annual transport of nitrogen, phosphorus, and suspended sediment during WY's 1980–95 was similar to the variation in annual streamflow at SW19 during the same period (fig. 15). However, because of the consistent input of $NO_2$+$NO_3$ from springs, the decrease in the load of $NO_2$+$NO_3$ from 1984 to 1988 was proportionally smaller than decreases in streamflow and the loads of other constituents shown in table 3 and figure 15. For example, the load of $NO_2$+$NO_3$ at SW19 decreased by only 33 percent from WY 1984 to WY 1988, whereas streamflow decreased by 57 percent and loads of $NH_4$, Kjel-N, Tot-P, and suspended sediment decreased by 85, 78, 67, and 87 percent, respectively. From WY 1980 to WY 1984, annual loads of Kjel-N at SW19 were about equal to loads of $NO_2$+$NO_3$, each contributing about half of the total nitrogen load in the river. From WY 1984 to WY 1995, Kjel-N loads decreased by 85 percent, whereas $NO_2$+$NO_3$ loads decreased by only 20 percent. Consequently, during WY 1995, Kjel-N made up only about 16 percent of the total nitrogen load at SW19, whereas $NO_2$+$NO_3$ made up about 84 percent.

### Sources of Nutrients and Sediment in the Middle Snake

Discharge and loadings of selected nutrients and suspended sediment from springs, tributary streams, irrigation drains, aquaculture facilities, and sewage-treatment plants were estimated to determine the primary sources of streamflow and chemical loads in the middle Snake. Estimates were made using data collected by various agencies in WY 1995. Loading estimates were compared with instream transport estimates for the Snake River calculated using the constituent transport model of Cohn and others (1992) at sites SW13, SW16, and SW19. Estimates of load sources during the irrigation season were examined during a synoptic study conducted in the summer of 1995 to determine how loadings during the irrigation season compared with annual loadings.

Loading estimates indicate that, during WY 1995, different sources provided variable quantities of nutrients and suspended sediment to the Snake River (table 4). On the basis of the WY 1995 estimates, springs were the major source of Tot-N to the middle Snake reach, aquacultural effluent was the major source of Tot-P, and tributary streams contributed most of the suspended sediment. Irrigation returns and the Twin

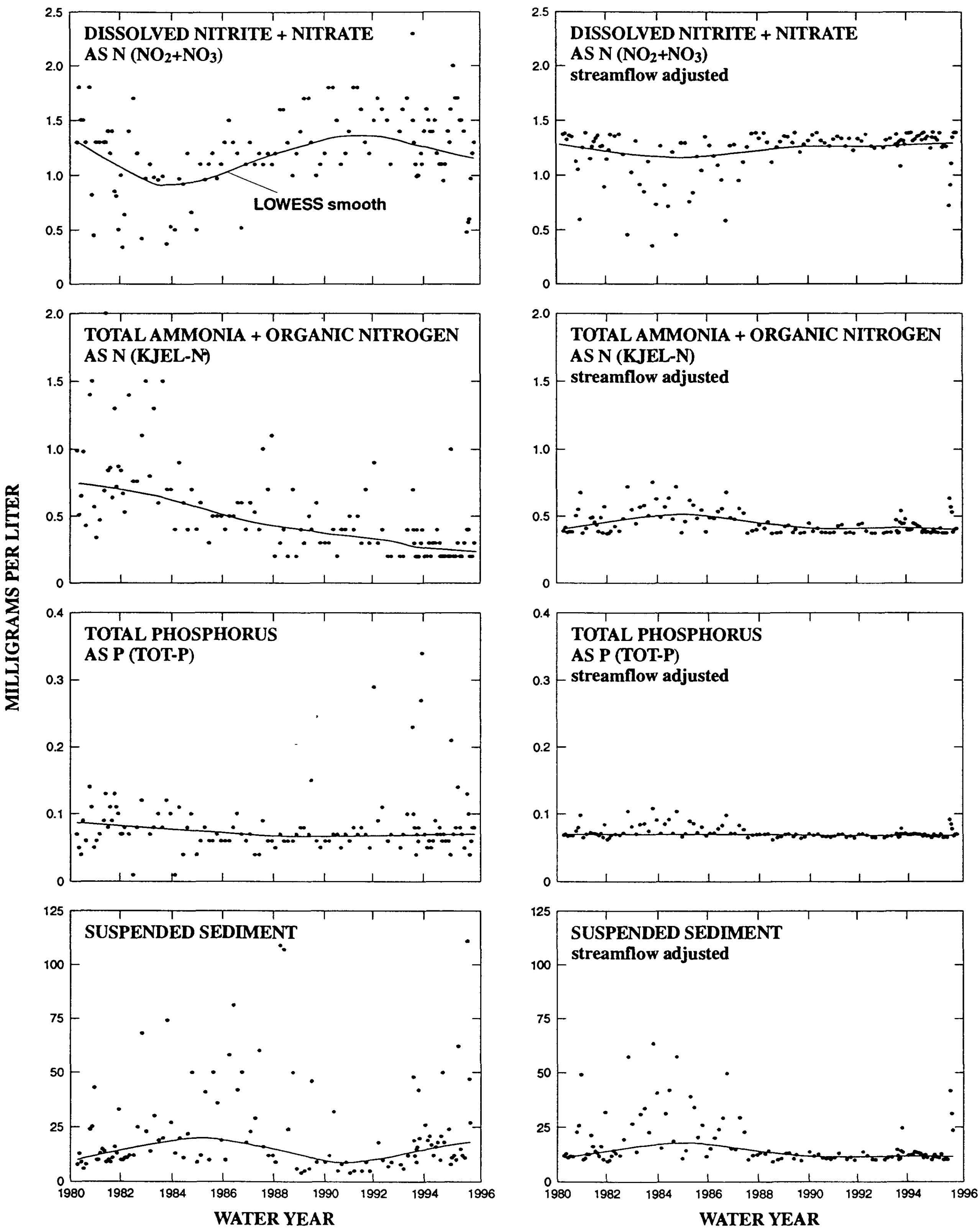



**Figure 14.** Concentrations and streamflow-adjusted concentrations of selected constituents in water from the Snake River at King Hill (SW19), water years 1980–95. [Streamflow adjustments were made using LOWESS, locally weighted scatterplot smoothing (Helsel and Hirsch, 1992)]

**Table 3.** Annual loads of nutrients and suspended sediment in the Snake River at King Hill (SW19), water years 1980–95

[ft³/s, cubic feet per second; N, nitrogen; P, phosphorus; the coefficient of determination ($R^2$) represents the fraction of the variance in the data that is explained by the regression model used to calculate loads]

| | | Annual load and 90-percent confidence interval, in tons per year | | | | |
|---|---|---|---|---|---|---|
| Water year | Mean annual streamflow (ft³/s) | Dissolved ammonia as N ($NH_4$) ($R^2$=40%) | Total ammonia plus organic nitrogen as N (Kjel-N) ($R^2$=69%) | Dissolved nitrite plus nitrate as N ($NO_2$+$NO_3$) ($R^2$=62%) | Total phosphorus as P (Tot-P) ($R^2$=48%) | Suspended sediment ($R^2$=59%) |
| 1980 | 9,340 | 490±100 | 9,320±1,450 | 9,560±670 | 770±80 | 202,400±46,650 |
| 1981 | 8,940 | 420±75 | 8,020±1,160 | 9,780±630 | 710±70 | 159,700±30,000 |
| 1982 | 12,100 | 800±200 | 11,200±1,630 | 11,400±630 | 1,090±140 | 387,200±91,080 |
| 1983 | 15,850 | 1,500±350 | 14,600±2,360 | 14,100±910 | 1,490±230 | 615,400±143,800 |
| 1984 | 18,070 | 1,980±540 | 16,100±3,060 | 15,400±1,130 | 1,780±320 | 884,300±245,000 |
| 1985 | 14,210 | 1,030±270 | 10,900±1,610 | 14,100±840 | 1,280±180 | 498,400±104,060 |
| 1986 | 15,460 | 1,240±230 | 11,100±1,880 | 14,400±860 | 1,490±240 | 709,000±189,940 |
| 1987 | 11,020 | 650±140 | 6,530±800 | 12,700±600 | 920±100 | 294,300±53,540 |
| 1988 | 7,680 | 300±55 | 3,550±380 | 10,300±470 | 580±60 | 118,100±16,500 |
| 1989 | 7,880 | 310±57 | 3,350±350 | 10,600±480 | 600±60 | 128,300±17,740 |
| 1990 | 8,000 | 320±58 | 3,160±340 | 11,000±500 | 610±60 | 135,800±19,220 |
| 1991 | 7,930 | 320±57 | 2,850±330 | 11,100±540 | 600±60 | 135,500±20,300 |
| 1992 | 7,380 | 280±53 | 2,400±300 | 10,900±580 | 550±58 | 119,100±19,500 |
| 1993 | 8,300 | 360±66 | 2,570±340 | 11,600±650 | 650±62 | 180,100±36,050 |
| 1994 | 8,150 | 330±59 | 2,300±330 | 12,000±730 | 630±61 | 156,900±29,210 |
| 1995 | 8,900 | 420±79 | 2,360±390 | 12,300±820 | 710±69 | 230,700±58,340 |

Falls sewage-treatment plant also contributed nutrients and sediment to the reach.

Most of the aquaculture facilities along the middle Snake use spring discharge as influent water and discharge directly to the Snake River after water has moved through the facility. Thus, the aquaculture facilities have no net effect on the quantity of water discharging to the middle Snake. However, aquaculture facilities do contribute nutrients and other constituents as water moves through raceways and settling ponds. Data from four large aquaculture facilities located on the middle Snake (MacMillan, 1992) show that mean concentrations of about 0.35 mg/L of $NH_4$, 0.25 mg/L of Org-N, and 0.115 mg/L of Tot-P are added to the spring water as it moves through the facilities. Aquaculture facility officials estimate that contributions of Tot-P declined about 20 to 25 percent from 1991 to 1995 as a result of changes in feeding practices and implementation of better management techniques (Randy MacMillan, Clear Springs Foods, oral commun., 1996).

As discussed previously, the large contribution of $NO_2$+$NO_3$ from north-side springs is primarily from land-use activities on the north side of the Snake River that supply nutrients to the underlying Snake River Plain aquifer and ultimately to the Snake River. Springs on the south side of the river probably also derive their $NO_2$+$NO_3$ from land-use activities. Tributary streams (which consist primarily of irrigation water during the growing season) and irrigation drains deliver most of the suspended sediment to the middle Snake, primarily during the 6-month growing season from mid-April to mid-October. Tributaries were also the second-largest source of Org-N and Tot-N to the middle Snake in WY 1995.

Although the Twin Falls sewage-treatment plant discharged only about 8.7 thousand acre-ft of water to the Snake River in WY 1995, its contribution of nutrients was disproportionately larger than its discharge. In WY 1995, the contribution of Tot-N discharging from the plant was 268 tons. From WY 1993 to WY 1995, the annual contribution of $NH_4$ from the plant decreased by 123 tons (Kim Bartee, Operations Management International, Inc., written commun., 1995) and the contribution of $NO_2$+$NO_3$ increased by 119 tons, resulting in little net change in Tot-N loads from the plant. The sewage-treatment plant was also the third-largest contributor of Tot-P to the middle Snake, supplying the river with 109 tons in WY 1995.

Correlations between estimated input and instream transport were good for some constituents and poor for

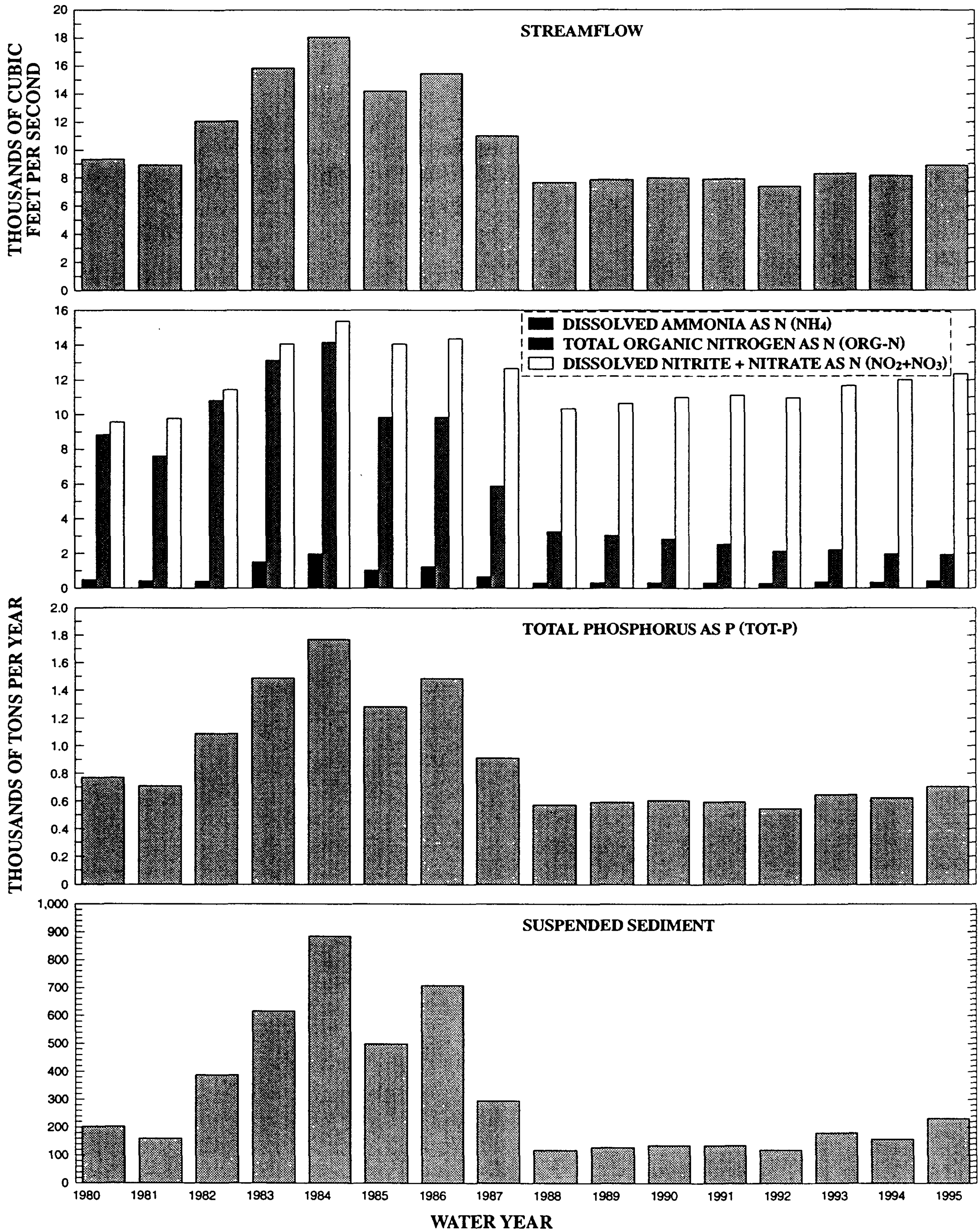



**Figure 15.** Mean annual streamflow and nutrient and suspended sediment loads in the Snake River at King Hill (SW19), water years 1980–95.

others. The large differences between input and instream transport of some constituents probably result from instream chemical processes, whereas for other constituents, the differences probably reflect variations in the techniques of data collection and analysis.

In WY 1995, the relative difference between total estimated discharge to the middle Snake and measured streamflow differences between SW13 and SW19 was within 4 percent (table 4). The largest source of water was north-side springs, which accounted for about 3.75 million acre-ft, or 60 percent of the annual total entering the river between SW13 and SW19. During the 1995 summer synoptic study (table 5), the relative difference between estimated discharge to the river and

**Table 4.** Input sources to and instream transport of nutrients and suspended sediment in the middle reach of the Snake River, water year 1995

[Site locations shown in figure 4; estimates for springs are based on reports by Clark and Ott (1996), Kjelstrom (1995), and unpublished USGS data; estimates for tributary streams are based on data from Don Essig (Idaho Department of Environmental Quality, written commun., 1996); estimates for irrigation drains are based on calculations by Barry (1996); estimates for aquaculture effluent are based on water-quality data from MacMillan (1992) and an estimated discharge through hatcheries of 1.83 million acre-feet per year; estimates for Twin Falls sewage-treatment plant effluent are based on data from Kim Bartee (Operations Management International, Inc., written commun., 1995); instream transport was estimated by subtracting the upstream site load from the downstream site load using constituent transport modeling (Cohn and others, 1992) and USGS and University of Idaho (Clarence Robison, University of Idaho, written commun., 1996) water-quality data and USGS streamflow data; N, nitrogen; P, phosphorus; relative percent difference is calculated as absolute value of [(I–T) / ((I+T) / 2)] x 100, where I = total reach input and T = instream transport]

| Input source | Discharge, in thousands of acre-feet per year, and percent of discharge input to reach | Water year 1995 load, in tons and percent of constituent input to reach | | | | | |
|---|---|---|---|---|---|---|---|
| | | Dissolved ammonia as N ($NH_4$) | Total organic nitrogen as N (Org-N) | Dissolved nitrite plus nitrate as N ($NO_2$+$NO_3$) | Total nitrogen as N (Tot-N) | Total phosphorus as P (Tot-P) | Suspended sediment |
| **SW13 to SW16** | | | | | | | |
| Inflow at SW13 | 1,259.8 (50) | 42 (11) | 341 (33) | 542 (11) | 925 (14) | 170 (34) | 29,415 (39) |
| Springs (north-side) | 698.7 (27) | 10 (3) | 101 (10) | 1,985 (39) | 2,096 (32) | 24 (5) | 0 (0) |
| Springs (south-side) | 256.6 (10) | 4 (1) | 66 (6) | 1,396 (28) | 1,466 (23) | 7 (1) | 0 (0) |
| Tributary streams | 261.7 (10) | 20 (5) | 220 (21) | 745 (15) | 985 (15) | 60 (12) | 28,448 (38) |
| Irrigation drains | 57.0 (2) | 2 (1) | 43 (4) | 74 (2) | 119 (2) | 24 (5) | 15,500 (21) |
| Aquaculture effluent | 0 (0) | 287 (73) | 224 (21) | 116 (2) | 627 (10) | 103 (22) | 1,793 (2) |
| Twin Falls sewage-treatment plant effluent | 8.7 (<1) | 26 (7) | 47 (5) | 195 (4) | 268 (4) | 109 (21) | 250 (<1) |
| Total estimated input | 2,542.5 | 391 | 1,042 | 5,054 | 6,486 | 497 | 75,406 |
| Estimated instream transport | 2,591.2 | 170 | 1,259 | 4,827 | 6,256 | 376 | 168,610 |
| Relative percent difference | 1.9 | 78.8 | 18.9 | 4.6 | 3.6 | 27.7 | 76.4 |
| **SW16 to SW19** | | | | | | | |
| Springs (north-side) | 3,060.0 (83) | 42 (7) | 215 (21) | 3,993 (68) | 4,250 (57) | 70 (20) | 0 (0) |
| Springs (south-side) | 108.6 (3) | 2 (<1) | 28 (3) | 591 (10) | 620 (8) | 3 (1) | 0 (0) |
| Tributary streams | 490.7 (13) | 23 (4) | 346 (34) | 1,096 (19) | 1,465 (20) | 76 (22) | 42,525 (91) |
| Irrigation drains | 28.3 (1) | 2 (<1) | 23 (2) | 2 (<1) | 27 (<1) | 9 (3) | 1,208 (3) |
| Aquaculture effluent | 0 (0) | 511 (88) | 399 (40) | 208 (4) | 1,118 (15) | 184 (54) | 3,193 (7) |
| Total estimated input | 3,687.6 | 580 | 1,011 | 5,890 | 7,481 | 342 | 46,926 |
| Estimated instream transport | 3,856.7 | 253 | 674 | 7,504 | 8,431 | 332 | 62,174 |
| Relative percent difference | 4.5 | 78.5 | 40.0 | 24.1 | 11.9 | 2.8 | 28.0 |
| **Totals, SW13 to SW19** | | | | | | | |
| Inflow at SW13 | 1,259.8 (20) | 42 (4) | 341 (17) | 542 (5) | 925 (7) | 170 (21) | 29,415 (24) |
| Springs (north-side) | 3,758.7 (60) | 52 (5) | 316 (15) | 5,978 (55) | 6,346 (45) | 94 (11) | 0 (0) |
| Springs (south-side) | 365.2 (6) | 6 (1) | 94 (5) | 1,987 (18) | 2,086 (15) | 10 (1) | 0 (0) |
| Tributary streams | 752.3 (12) | 43 (4) | 566 (28) | 1,841 (17) | 2,450 (18) | 136 (16) | 70,973 (58) |
| Irrigation drains | 85.4 (1) | 4 (<1) | 66 (3) | 76 (<1) | 146 (1) | 33 (4) | 16,708 (14) |
| Aquaculture effluent | 0 (0) | 798 (82) | 623 (30) | 324 (3) | 1,745 (12) | 287 (34) | 4,986 (4) |
| Twin Falls sewage-treatment plant effluent | 8.7 (<1) | 26 (3) | 47 (2) | 195 (2) | 268 (2) | 109 (13) | 250 (<1) |
| Total estimated input | 6,230.1 | 971 | 2,053 | 10,944 | 13,967 | 839 | 122,332 |
| Estimated instream transport | 6,447.9 | 423 | 1,933 | 12,331 | 14,687 | 708 | 230,784 |
| Relative percent difference | 3.4 | 78.6 | 6.0 | 11.9 | 5.0 | 16.9 | 61.4 |

measured streamflow differences between SW13 and SW19 was within 150 ft³/s, or 1.8 percent.

Comparisons of estimated input and instream transport indicate loss of $NH_4$ in the Snake River and a relatively good correlation for Org-N, $NO_2$+$NO_3$, and Tot-N. The relative difference between input and transport of $NH_4$ indicates that about 60 percent of the $NH_4$ discharged to the middle Snake in WY 1995 was lost before it reached SW19 (table 4). $NH_4$ losses probably can be attributed to a combination of oxidation to $NO_2$+$NO_3$, cation exchange with sediment, and uptake by the abundant aquatic growth in the Snake River. Although Org-N input did not correlate well with instream transport in subreaches of the middle Snake, the relative difference over the entire reach was only 6 percent. Estimates also indicate slightly more $NO_2$+$NO_3$ and Tot-N were input than were transported between SW13 and SW16, and that less were input than were

**Table 5.** Input sources to and instream transport of nutrients and suspended sediment in the middle reach of the Snake River, August 7–11, 1995

[Site locations shown in figure 4; estimates for springs are based on reports by Clark and Ott (1996), Kjelstrom (1995), and unpublished USGS data; estimates for tributary streams, irrigation returns, and Snake River sites are based on data collected August 7–11, 1995; estimates for aquaculture effluent are based on water-quality data from MacMillan (1992) and an estimated discharge through hatcheries of 2,530 cubic feet per second; estimates for Twin Falls sewage-treatment plant effluent are based on data from Kim Bartee (Operations Management International, Inc., written commun., 1995); instream transport was estimated by subtracting the instantaneous upstream site load from the instantaneous downstream site load; N, nitrogen; P, phosphorus; relative percent difference is calculated as absolute value of [(I–T) / ((I+T) / 2)] x 100, where I = total reach input and T = instream transport]

| Input source | Discharge, in cubic feet per second, and percent of discharge input to reach | Daily load, in pounds and percent of constituent input to reach: Dissolved ammonia as N ($NH_4$) | Total organic nitrogen as N (Org-N) | Dissolved nitrite plus nitrate as N ($NO_2$+$NO_3$) | Total nitrogen as N (Tot-N) | Total phosphorus as P (Tot-P) | Suspended sediment |
|---|---|---|---|---|---|---|---|
| **SW13 to SW16** | | | | | | | |
| Inflow at SW13 | 1,540 (45) | 83 (4) | 3,241 (42) | 499 (2) | 3,823 (11) | 415 (18) | 132,957 (13) |
| Springs (north-side) | 965 (28) | 52 (3) | 552 (7) | 10,879 (43) | 11,483 (33) | 130 (6) | 0 (0) |
| Springs (south-side) | 360 (10) | 19 (1) | 369 (5) | 7,769 (31) | 8,158 (23) | 39 (2) | 0 (0) |
| Tributary streams | 442 (13) | 59 (3) | 1,407 (18) | 4,254 (17) | 5,719 (16) | 470 (21) | 440,853 (42) |
| Irrigation returns | 140 (4) | 17 (1) | 644 (8) | 882 (3) | 1,543 (5) | 288 (12) | 457,903 (44) |
| Aquaculture effluent | 0 (0) | 1,571 (83) | 1,227 (16) | 638 (3) | 3,437 (10) | 565 (25) | 9,819 (1) |
| Twin Falls sewage-treatment plant effluent | 12 (<1) | 85 (5) | 340 (4) | 215 (1) | 640 (2) | 379 (16) | 757 (<1) |
| Total estimated input | 3,459 | 1,886 | 7,780 | 25,136 | 34,803 | 2,286 | 1,042,289 |
| Estimated instream transport | 3,510 | 379 | 3,409 | 24,622 | 28,410 | 1,325 | 416,680 |
| Relative percent difference | 1.5 | 133 | 78.1 | 2.1 | 20.2 | 53.2 | 85.8 |
| **SW16 to SW19** | | | | | | | |
| Springs (north-side) | 4,227 (87) | 231 (7) | 1,165 (26) | 21,876 (74) | 23,272 (63) | 384 (23) | 0 (0) |
| Springs (south-side) | 152 (3) | 8 (<1) | 156 (3) | 3,280 (11) | 3,444 (9) | 16 (1) | 0 (0) |
| Tributary streams | 355 (7) | 29 (1) | 724 (16) | 3,266 (11) | 4,019 (11) | 141 (9) | 147,942 (83) |
| Irrigation returns | 123 (3) | 15 (<1) | 323 (7) | 19 (<1) | 357 (10) | 105 (6) | 13,212 (7) |
| Aquaculture effluent | 0 (0) | 2,799 (91) | 2,186 (48) | 1,137 (4) | 6,122 (16) | 1,006 (61) | 17,492 (10) |
| Total estimated input | 4,857 | 3,082 | 4,554 | 29,578 | 37,215 | 1,652 | 178,646 |
| Estimated instream transport | 4,660 | 62 | 4,967 | 28,280 | 33,310 | 2,201 | 112,345 |
| Relative percent difference | 4.1 | 192 | 8.7 | 4.5 | 11.1 | 28.5 | 45.6 |
| **Totals, SW13 to SW19** | | | | | | | |
| Inflow at SW13 | 1,540 (19) | 83 (2) | 3,241 (26) | 499 (1) | 3,823 (5) | 415 (11) | 132,957 (11) |
| Springs (north-side) | 5,192 (62) | 283 (6) | 1,717 (14) | 32,755 (60) | 34,755 (48) | 514 (13) | 0 (0) |
| Springs (south-side) | 512 (6) | 28 (1) | 525 (4) | 11,049 (20) | 11,602 (16) | 55 (1) | 0 (0) |
| Tributary streams | 797 (10) | 88 (2) | 2,131 (17) | 7,519 (14) | 9,738 (14) | 611 (16) | 588,795 (48) |
| Irrigation returns | 263 (3) | 32 (1) | 967 (8) | 902 (2) | 1,901 (3) | 393 (10) | 471,116 (39) |
| Aquaculture effluent | 0 (0) | 4,370 (88) | 3,414 (28) | 1,775 (3) | 9,559 (13) | 1,570 (40) | 27,311 (2) |
| Twin Falls sewage-treatment plant effluent | 12 (<1) | 85 (2) | 340 (3) | 215 (<1) | 640 (<1) | 379 (10) | 757 (<1) |
| Total estimated input | 8,316 | 4,968 | 12,334 | 54,714 | 72,018 | 3,938 | 1,220,935 |
| Estimated instream transport | 8,170 | 441 | 8,376 | 52,902 | 61,180 | 3,526 | 529,025 |
| Relative percent difference | 1.8 | 167 | 38.2 | 3.4 | 16.3 | 11.0 | 79.1 |

transported between SW16 and SW19. Instream conversion of $NH_4$ to $NO_2$+$NO_3$ probably accounts for some of the increase in $NO_2$+$NO_3$ in the lower reach, although the quantity of $NH_4$ lost was not sufficient to account for all of the increase in $NO_2$+$NO_3$. In the entire reach from SW13 to SW19, the relative difference between input and instream transport of $NO_2$+$NO_3$ was about 12 percent. Assuming that all of the ammonia lost in the river was converted to $NO_2$+$NO_3$, the relative difference would be 7 percent. The relative difference between Tot-N input and instream transport was 5 percent, indicating excellent correlation.

Input of Tot-P in WY 1995 exceeded instream transport, indicating uptake and (or) sedimentation once phosphorus entered the Snake River. Input of Tot-P over the entire reach from SW13 to SW19 was 839 tons, whereas instream transport was 708 tons, or about 16 percent less. If, as aquaculture facility officials estimate, WY 1995 loadings of Tot-P from aquaculture were reduced 25 percent from the estimates in table 4, total input of Tot-P in WY 1995 would be reduced to 767 tons and mean annual transport would be only about 8 percent less than input.

Estimates of suspended sediment in WY 1995 indicate that about twice as much suspended sediment was transported between SW13 and SW19 as was input to the river. The large discrepancy probably can be attributed to differences in the sampling and analytical methods used and not to instream processes. Grab-sampling techniques were used by agencies other than the USGS for sampling most of the tributaries and all of the irrigation drains. In contrast, standard width- and depth-integrating techniques were used by the USGS (Shelton, 1994) to collect samples from the Snake River. Because a large part of the sediment load moves along the bottom of a stream channel, especially sand-sized material, grab samples may result in underestimation of the actual quantity of sediment being transported, thus imparting a low bias to the results. Samples collected by agencies other than the USGS were analyzed using U.S. Environmental Protection Agency (EPA) guidelines for determination of total suspended solids (American Public Health Association and others, 1976, p. 94). This technique involves subsampling in the laboratory, which typically leads to additional underestimation of concentrations when sand-sized material is present.

All synoptic-study samples were collected in August 1995 by USGS personnel using width- and depth-integrating techniques and were analyzed at USGS laboratories. Data indicate that relative differences between input and instream transport during the 1995 growing season (table 5) were not the same as relative differences noted for the entire water year (table 4). Although streamflow in the Snake River correlated well with total input at the time of the synoptic study, load inputs of all constituents exceeded those transported in the reach between SW13 and SW19. Loads of $NH_4$ and suspended sediment differed the most over the reach; input exceeded transport by more than 10 times for $NH_4$ and more than 2 times for suspended sediment. As previously mentioned, losses of $NH_4$ probably can be attributed to a combination of oxidation to $NO_2$+$NO_3$, cation exchange, and uptake by aquatic plants. All of these processes are enhanced during the summer when streamflow and streamflow velocities are low, air and water temperatures are warm, and aquatic plant growth is at its peak. During the growing season, input of suspended sediment from agricultural activities is at a maximum and, because stream velocities are low, suspended sediment quickly settles to the river bottom. Sediment and associated nutrients probably are scoured from the river bottom during spring runoff when streamflow velocities are sufficiently large to resuspend bottom sediment.

## Pesticides

Intensive use of pesticides in many parts of the country poses a potential for serious nonpoint-source contamination. More than 1,400 compounds are present in various pesticide products used throughout the country to control crop pests in agriculture and silviculture (Rao and others, 1988). In addition, new pesticides continually are being formulated and introduced to improve safety and minimize adverse environmental effects. The rapidly expanding and evolving nature of the agrochemical industry necessitates ongoing sampling efforts to provide a better understanding of pesticide behavior in the environment. However, in many watersheds, data on pesticide concentrations in water are lacking.

Although pesticide use on agricultural crops in the USNK is extensive, little information exists on pesticide concentrations in surface water. Collection of most pesticide data in the USNK since 1975 has been directed primarily toward detecting compounds in fish tissue and bed sediments (Clark, 1994b). Results from fish-tissue and bed-sediment studies are good indicators of the historical use of water-insoluble pesticides resistant to degradation, many of which have been banned from use in the United States. However, pesticides in current (1996) use are generally more water soluble, more mobile, and degrade more rapidly than historically used pesticides. Because of these properties, most of the currently used pesticides remain primarily in the water column and probably do not accumulate in large quantities in tissue and sediments (Smith and others, 1988).

Numerous pesticides are applied to a variety of crops in the USNK (table 6). Of the top 16 pesticides used in the USNK, 11 are herbicides and 5 are insecticides. Most of the pesticide use in the basin is from mid-April to mid-June, depending on crop type and the action of the pesticide used. Many of the most commonly used pesticides, including the pre-emergent herbicides alachlor, EPTC, and metolachlor, are applied to soils prior to planting. Other herbicides and most insecticides are applied later during the growing season to control weeds and insects during and after crop emergence.

The herbicide EPTC, which is applied primarily for weed control in dry beans, potatoes, and sugar beets is the most extensively used pesticide in the basin (Gianessi and Puffer, 1991, 1992). Use estimates of the herbicides triallate and 2,4-D, second and third most extensively used, are probably overstated (Charlotte Eberline and Paul Patterson, University of Idaho, Agricultural Extension Service, oral commun., 1995). Triallate, which is applied primarily to control wild oats, has been discontinued in recent years in favor of other post-emergent herbicides and is applied extensively only in isolated areas of the USNK. Pasture applications presumably account for almost 60 percent of the total annual 2,4-D applications, and although it is used on a number of crops in the USNK, 2,4-D is not applied extensively to irrigated pasture.

**Table 6.** Estimated total annual applications of pesticides used in the largest quantity in the upper Snake River Basin

[Estimates are from reports by Gianessi and Puffer (1991, 1992) and are based on average application rates (tons of active ingredient) by crop cover in each county, 1989–91. The first 16 pesticides are those used in the largest quantity. Atrazine is number 31 in terms of total basin use; t/yr, tons per year]

| Pesticide | Quantity applied (t/yr) | Type of pesticide | Primary crop |
|---|---|---|---|
| EPTC | 340 | Herbicide | Dry beans, potatoes, sugar beets |
| Triallate | 270 | Herbicide | Barley, wheat |
| 2,4-D | 240 | Herbicide | Pasture, barley, wheat |
| Phorate | 220 | Insecticide | Dry beans, potatoes |
| Ethoprop | 110 | Insecticide | Potatoes |
| Disulfoton | 110 | Insecticide | Barley, dry beans, potatoes |
| Terbutryn[1] | 90 | Herbicide | Sorghum |
| Dicamba | 90 | Herbicide | Wheat |
| Cycloate[1] | 80 | Herbicide | Sugar beets |
| Chlorpyrifos | 80 | Insecticide | Alfalfa, sugar beets |
| Metribuzin | 70 | Herbicide | Alfalfa, potatoes |
| Alachlor | 70 | Herbicide | Dry beans, corn |
| MCPA | 70 | Herbicide | Barley, wheat |
| Bromoxynil | 60 | Herbicide | Barley, alfalfa, wheat |
| Fonofos | 40 | Insecticide | Dry beans, sugar beets |
| Metolachlor | 40 | Herbicide | Corn, dry beans, potatoes |
| Atrazine | 10 | Herbicide | Corn |

[1] Not analyzed in samples for this study.

Two approaches were used to study pesticides in the USNK. The first was to collect pesticide samples for at least 1 full year at the outlets of two drainage basins in which agriculture was the predominant land use. This approach was designed to examine temporal variability with respect to the types and concentrations of pesticides used in small agricultural basins. Results from one of the study sites were reported by Clark (1994b). The second approach involved a basinwide synoptic study conducted during the heaviest pesticide-use period of the year. The purpose of the synoptic study was to assess the occurrence, distribution, and concentrations of pesticides in surface water in the USNK and to relate recent pesticide applications to pesticide fluxes at subbasin outlets. Results of the synoptic study were reported by Clark (in press).

### SMALL-BASIN STUDIES

Twenty-five pesticide samples from site SW4 (fig. 4 and table 1) on the Teton River were collected and analyzed from May 1993 through May 1994, and 43 samples from SW15 on Rock Creek were collected and analyzed from April 1993 through June 1995. At both sites, samples were collected weekly during the 1993 growing season and at least monthly thereafter. Pesticides detected at the two sites are listed in table 7. Concentrations of pesticides detected at both sites were extremely small in relation to EPA water-quality criteria.

About 375 $mi^2$, or 42 percent of the Teton River drainage basin upstream from SW4, is agricultural land (fig. 4); the primary crops are barley, potatoes, and wheat. According to 1991 pesticide use statistics (Gianessi and Puffer, 1991, 1992), triallate (for barley and wheat) and EPTC (for potatoes) are the most heavily used pesticides in the basin, and annual applications exceed 28 and 15 tons, respectively. Of the pesticides

**Table 7.** Pesticides in water samples at two sites in the upper Snake River Basin, water years 1993–95

[Site locations shown in figure 4; method detection limits are from reports by Zaugg and others (1995) and Werner and others (1996) and are calculated on the basis of procedures described by the U.S. Environmental Protection Agency (1992b); some pesticides may be identified and quantified at concentrations smaller than the method detection limit and should be used primarily on a qualitative basis; EPA, U.S. Environmental Protection Agency; criteria for human health are based on report by EPA (1992a); criteria for aquatic organisms are based on report by EPA (1991); ng/L, nanograms per liter or parts per trillion; —, median not calculated or criteria not established]

| Pesticide | Number of detections | Maximum concentration detected (ng/L) | Median concentration detected (ng/L) | Method detection limit (ng/L) | EPA water-quality criteria (ng/L): Human health | EPA water-quality criteria (ng/L): Aquatic organisms (freshwater): Acute | EPA water-quality criteria (ng/L): Aquatic organisms (freshwater): Chronic |
|---|---|---|---|---|---|---|---|
| **SW4, Teton River near St. Anthony (Based on 25 samples collected from May 5, 1993, to May 24, 1994)** | | | | | | | |
| Triallate | 12 | 6 | 4 | 1 | — | — | — |
| EPTC | 9 | 8 | 4 | 2 | — | — | — |
| Atrazine | 4 | 3 | 2 | 1 | 3,000 | — | — |
| Simazine | 2 | 3 | 3 | 5 | 4,000 | — | — |
| 2,4-D | 1 | 160 | — | 35 | 70,000 | — | — |
| p,p'-DDE | 1 | 2 | — | 6 | — | — | — |
| Malathion | 1 | 20 | — | 5 | — | — | 100 |
| **SW15, Rock Creek at Twin Falls (Based on 43 samples collected from April 20, 1993, to June 30, 1995)** | | | | | | | |
| Atrazine | 38 | 31 | 9 | 1 | 3,000 | — | — |
| Atrazine, desethyl- | 30 | 14 | 5 | 2 | — | — | — |
| EPTC | 22 | 180 | 15 | 2 | — | — | — |
| Metolachlor | 21 | 57 | 4 | 2 | — | — | — |
| Alachlor | 9 | 13 | 5 | 2 | 2,000 | — | — |
| DCPA | 6 | 3 | 2 | 2 | — | — | — |
| Metribuzin | 6 | 37 | 8 | 4 | — | — | — |
| p,p'-DDE | 5 | 4 | 2 | 6 | — | — | — |
| Ethalfluralin | 4 | 16 | 14 | 4 | — | — | — |
| Trifluralin | 4 | 8 | 6 | 2 | — | — | — |
| Simazine | 4 | 3 | 2 | 5 | 4,000 | — | — |
| 2,4-D | 3 | 260 | 90 | 35 | 70,000 | — | — |
| Carbaryl | 2 | 24 | 13 | 3 | — | — | — |
| Chlorpyrifos | 2 | 10 | 8 | 4 | — | 83 | 41 |
| Napropamide | 2 | 28 | 18 | 3 | — | — | — |
| Prometon | 2 | 5 | 5 | 18 | — | — | — |
| Carbofuran | 1 | 55 | — | 3 | 40,000 | — | — |
| Pendimethalin | 1 | 9 | — | 4 | — | — | — |
| Propachlor | 1 | 2 | — | 7 | — | — | — |

analyzed, triallate and EPTC also were detected most frequently, accounting for 70 percent of the total number of detections. Although its use has declined dramatically in most of the USNK since 1991, triallate still is applied heavily in the Teton River drainage basin (Charlotte Eberline, University of Idaho, Agricultural Extension Service, oral commun., 1995). Only five pesticides other than triallate and EPTC were detected at SW4; of those, only the triazine herbicides atrazine and simazine were detected more than once. All pesticide detections at SW4 were in samples collected from May through August.

Although only about 24 percent of the 241-$mi^2$ Rock Creek drainage basin is agricultural land (fig. 4), the diversity of crops is larger and the variety of pesticides applied is much greater than in the Teton River drainage basin. In contrast to the Teton River drainage basin, where a large part of the agricultural land is used for dryland crops, nearly all of the agricultural land in the Rock Creek drainage basin is furrow irrigated by a network of canals and lateral ditches that deliver surface water from the Snake River. This method of irrigation results in large quantities of runoff from fields, which transports sediment and agricultural chemicals to streams. The most heavily used pesticides in the Rock Creek drainage basin are EPTC (for beans, potatoes, and sugar beets) and alachlor (for beans and corn); annual applications are about 7 and 4 tons, respectively (Gianessi and Puffer, 1991, 1992).

Nineteen different pesticides were detected during 27 months of sampling at SW15 (table 7). In only one sample, collected on May 11, 1993, were no pesticides detected in the Rock Creek water. Atrazine, its breakdown product desethylatrazine, EPTC, metolachlor, and alachlor accounted for about 75 percent of all detections. The presence of EPTC and alachlor might be expected on the basis of their annual application rates and their solubility in water. EPTC and alachlor, with solubilities of about 375 and 242 mg/L at 25°C, respectively (Meister, 1992), are also more water soluble than most pesticides and are, therefore, more easily transported in water. Use statistics indicate that less than 0.5 ton of both metolachlor and atrazine is applied annually in the Rock Creek drainage basin. However, metolachlor and atrazine also are relatively water soluble—530 mg/L at 20°C and 34 mg/L at 25°C, respectively (Meister, 1992). Metolachlor is applied early in the growing season as a pre-emergent herbicide and can persist in soils and water for as long as 3 months following application (Nash, 1988). Because of its solubility, metolachlor also is very mobile and is transported to streams throughout the growing season. Atrazine and desethylatrazine can persist in soils for as long as 10 months following application (Verschueren, 1983). Studies by Goolsby and others (1991) and Thurman and others (1991) have shown that atrazine and desethylatrazine are very mobile, leach readily into ground water, and are subsequently transported to streams throughout the year.

The time of year at which pesticides are detected in surface water can be helpful in determining their source. In 1993, the number and concentrations of the pesticides in Rock Creek increased rapidly following the first major flush of water in mid-May (fig. 16). In general, the number of pesticides and concentrations of EPTC and metolachlor decreased following peaks in late May through mid-June. Although EPTC and metolachlor were not detected from September 1993 through April 1994, atrazine and (or) desethylatrazine persisted throughout the winter and into 1994. The same seasonal pattern was repeated through 1994 and into 1995. Results indicate, at least for the Rock Creek drainage basin, that most pesticide residues in surface water probably result from recent applications. However, atrazine and desethylatrazine residues probably leach to the ground water and subsequently discharge to Rock Creek throughout the year.

## BASINWIDE SYNOPTIC STUDY

Thirty-one sites, including 18 of the sites assessed for nutrients, were selected for pesticide sampling during May and June 1994 as part of a basinwide synoptic study (fig. 17). Sites were selected to represent drainage from subbasins affected and unaffected by irrigated agriculture. Thirty-seven water samples were collected at the selected sites during two 1-week periods to span the time when pesticides are most heavily applied and are most likely to be detected in surface water. Water samples from sites upstream from American Falls Reservoir (upper part of the USNK) were collected May 23 to 26, 1994; samples from sites downstream from the reservoir (lower part of the USNK) were collected June 13 to 17, 1994. Water samples from six sites (three upstream and three downstream from the reservoir) were collected during both weeks to assess the variability between the two collection periods.

Results from the synoptic study indicate that the types of pesticides detected in the USNK as a whole (table 8) were similar to those detected in Rock Creek during 1993–95. As was the case for Rock Creek, EPTC, atrazine, desethylatrazine, metolachlor, and alachlor were the most commonly detected pesticides, accounting for 76 percent of the total number of detections. Of the 16 pesticides most extensively applied in the USNK (table 6), nine were detected at least once during the synoptic study. Thirty of the 37 samples contained at least one detectable pesticide (fig. 17), and 16 of the samples contained three or more. However, all pesticide detections were at concentrations less than 1 µg/L (1,000 ng/L), and all were well below EPA water-quality criteria.

Most pesticides detected were in samples from the lower part of the USNK (fig. 17), where 17 different pesticides were detected at least once. The largest numbers of pesticides, and in general, the largest pesticide concentrations, were in agriculturally affected tributaries to the middle Snake. Only four different pesticides were detected in samples from the upper part of the USNK, and no samples from the upper part contained more than two different pesticides. Pesticides were not detected in samples collected upstream from the confluence of the Snake River and the Henrys Fork. Pesticides detected in the upper part of the USNK were EPTC

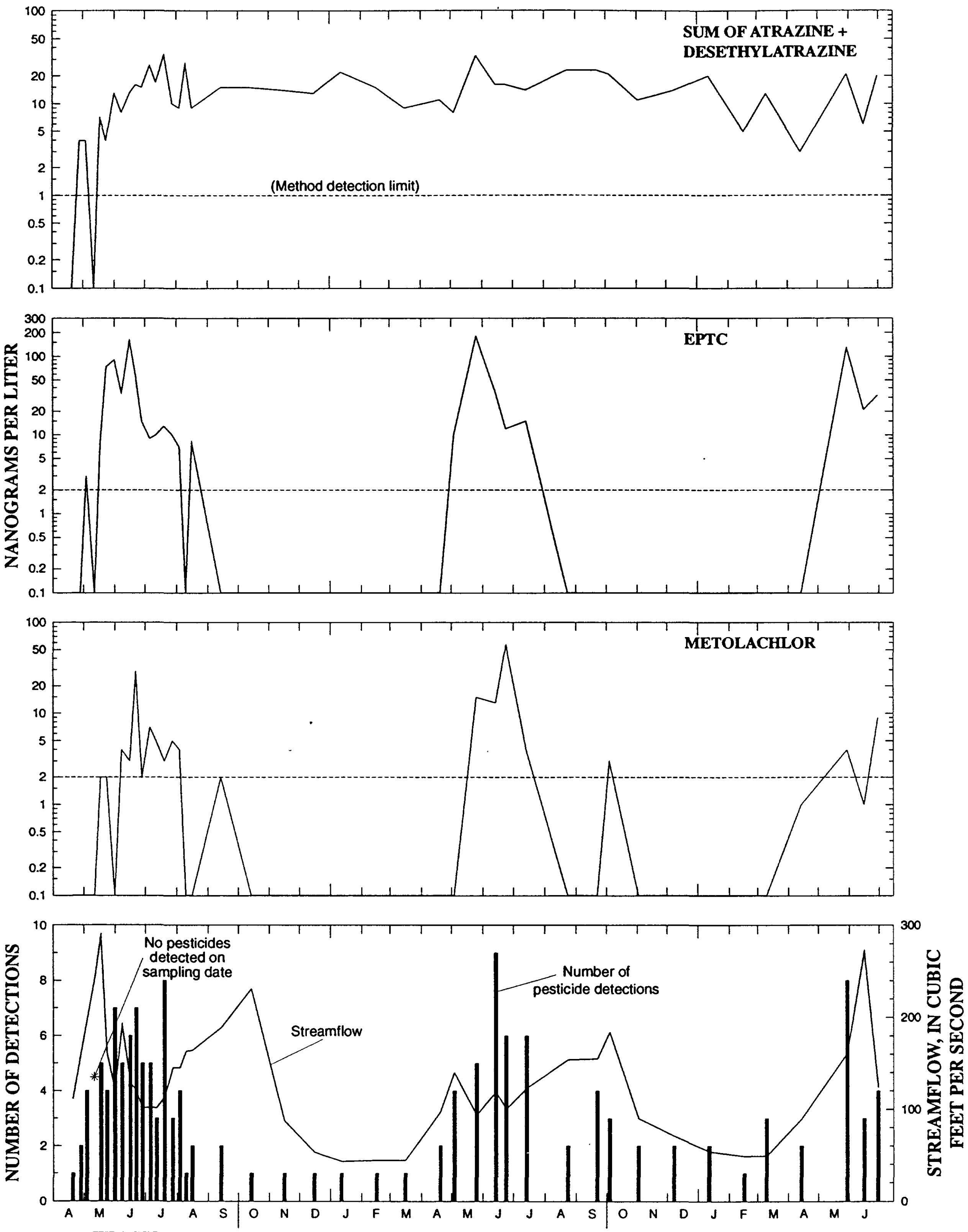



**Figure 16.** Streamflow and temporal distribution of pesticide detections, and concentrations of selected pesticides in samples collected from Rock Creek at Twin Falls (SW15), April 20, 1993, to June 30, 1995. (Concentrations of 0.1 nanograms per liter indicate samples for which pesticide was not detected)

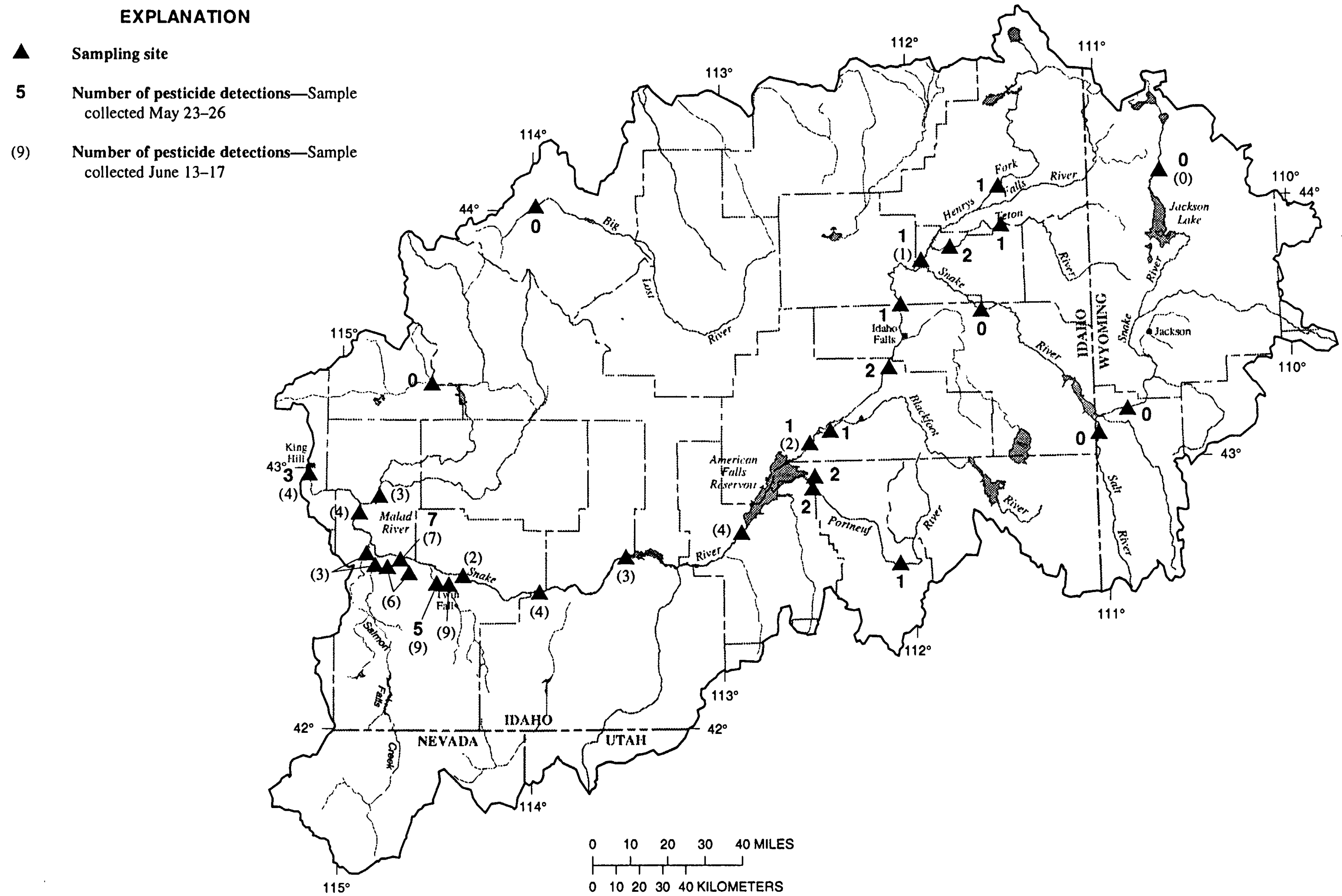



Figure 17. Pesticide detections in water samples collected during a synoptic study in the upper Snake River Basin, May and June 1994.

**Table 8.** Pesticides in upper Snake River Basin water samples, May and June 1994

[Number of detections based on 37 samples; method detection limits are from reports by Zaugg and others (1995) and Werner and others (1996) and are calculated on the basis of procedures described by the U.S. Environmental Protection Agency (1992b); some pesticides may be identified and quantified at concentrations smaller than the method detection limit and should be used primarily on a qualitative basis; EPA, U.S. Environmental Protection Agency; criteria for human health are based on report by EPA (1992a); criteria for aquatic organisms are based on report by EPA (1991); ng/L, nanograms per liter or parts per trillion; —, median not calculated or criteria not established]

| Pesticide | Number of detections | Maximum concentration detected (ng/L) | Median concentration detected (ng/L) | Method detection limit (ng/L) | EPA water-quality criteria (ng/L) | | |
|---|---|---|---|---|---|---|---|
| | | | | | Human health | Aquatic organisms (freshwater) | |
| | | | | | | Acute | Chronic |
| EPTC | 30 | 310 | 38 | 2 | — | — | — |
| Atrazine | 20 | 38 | 8 | 1 | 3,000 | — | — |
| Atrazine, desethyl- | 13 | 10 | 6 | 2 | — | — | — |
| Metolachlor | 7 | 17 | 8 | 2 | — | — | — |
| Alachlor | 6 | 40 | 6 | 2 | 2,000 | — | — |
| 2,4-D | 6 | 160 | 100 | 35 | 70,000 | — | — |
| Diazinon | 3 | 3 | 3 | 2 | — | — | — |
| Ethoprop | 3 | 4 | 4 | 3 | — | — | — |
| Metribuzin | 2 | 8 | 7 | 4 | — | — | — |
| Triallate | 1 | 3 | 3 | 1 | — | — | — |
| Trifluralin | 2 | 5 | 4 | 2 | — | — | — |
| Carbofuran | 1 | 55 | — | 3 | 40,000 | — | — |
| Chlorpyrifos | 1 | 10 | — | 4 | — | 83 | 41 |
| p,p'-DDE | 1 | 2 | — | 6 | — | — | — |
| Ethalfluralin | 1 | 9 | — | 4 | — | — | — |
| Fonofos | 1 | 1 | — | 3 | — | — | — |
| Simazine | 1 | 10 | — | 5 | 4,000 | — | — |
| Tebuthiuron | 1 | 55 | — | 10 | — | — | — |

(13 detections), atrazine (3 detections), triallate (2 detections), and diazinon (1 detection). At three of the six sites sampled in both May and June, more pesticides were detected in June (fig. 17). At the other three sites, the same number of pesticides were detected in both sampling periods.

EPTC was detected at 25 of the 31 sites and in 30 of the 37 samples (fig. 18). The largest concentration of EPTC was 310 ng/L at the mouth of the Blackfoot River just upstream from American Falls Reservoir. Although the total number of pesticides detected was generally larger in June than in May, concentrations of EPTC were larger in May (fig. 18). At five of the six sites sampled in both May and June, EPTC concentrations were larger in May. Used as a pre-emergent herbicide in the USNK, EPTC is applied to most fields in the spring prior to planting. EPTC concentrations in surface water probably are largest soon after application when early season irrigation transports sediment and chemicals from farmlands to streams. Although EPTC is relatively water soluble compared with most other pesticides, it is also one of the most volatile (Taylor and Glotfelty, 1988) and can dissipate entirely from soils and water within 4 weeks of application (Verschueren, 1983). Cliath and others (1980) determined that 74 percent of the EPTC in irrigation water applied to alfalfa dissipated within 52 hours of application. Because of timing of application and physical characteristics, peak concentrations probably are present in streams for only a short period of time following application. Results from the Rock Creek sampling at SW15 support this conclusion (fig. 16).

Relations between estimated total annual applications and daily EPTC and atrazine flux at the time of the synoptic sampling were assessed for a subset of the 31 subbasins. Other compounds were detected too infrequently for quantitative assessment. A subbasin was excluded from assessment when EPTC or atrazine was not applied in the subbasin and was not detected in the water sample at the subbasin outlet. Accordingly, 13 subbasin samples were excluded for atrazine and 6 were excluded for EPTC. Neither EPTC nor atrazine was detected in subbasin samples when it was not applied in the subbasin. In subbasins where the pesti-

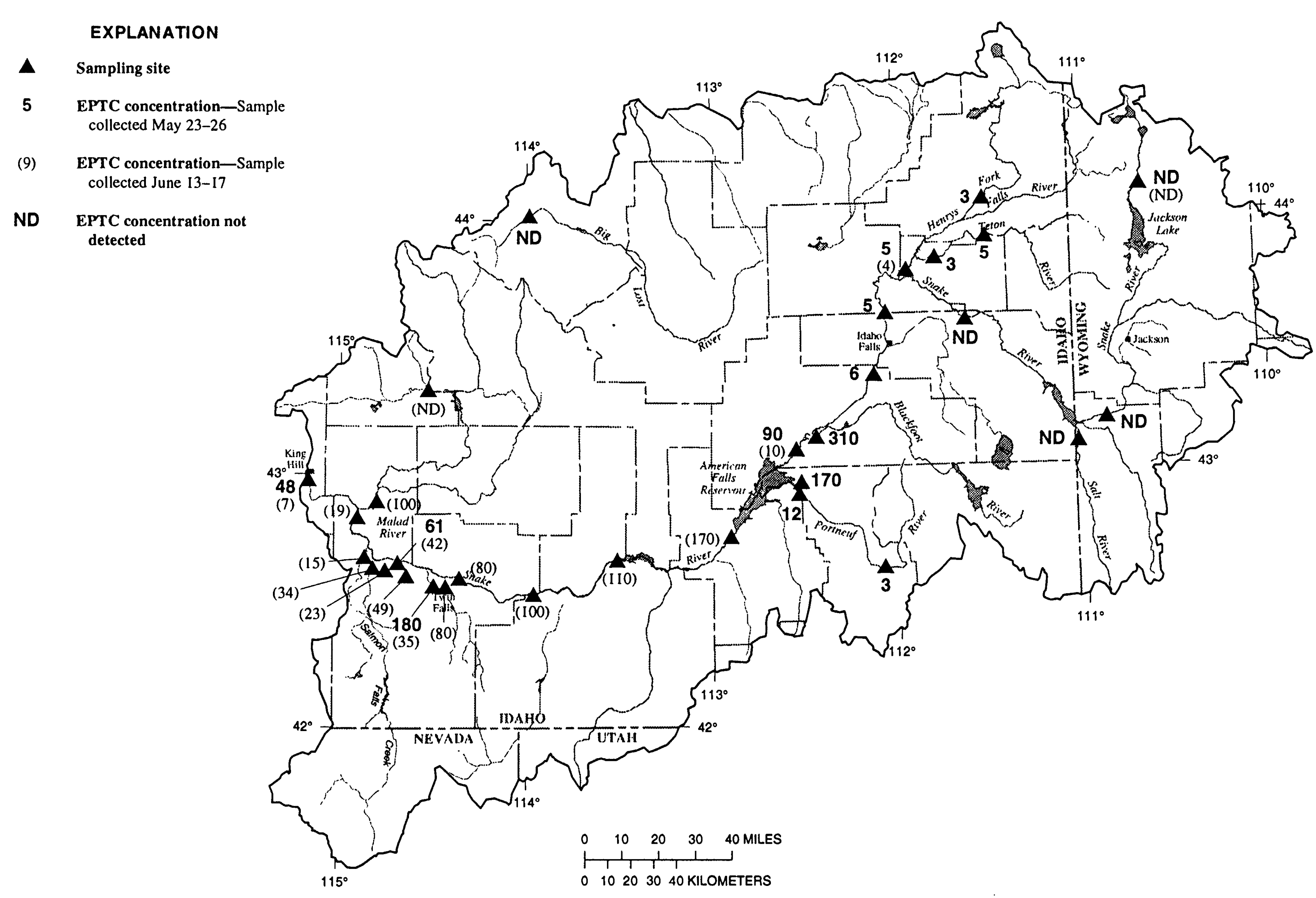



**Figure 18.** EPTC concentrations in water samples collected during a synoptic study in the upper Snake River Basin, May and June 1994.

cide was applied but not detected (censored data value), a range of values was used to determine how substituting different values less than the method detection limit would affect application-flux relations.

A geographic information system, in combination with county-level pesticide-use data (Gianessi and Puffer, 1991, 1992), was used to calculate annual pesticide applications in each of the subbasins assessed. The technique for estimating applications is described in a report by Clark (in press).To calculate daily EPTC and atrazine subbasin fluxes, concentrations of EPTC, atrazine, and desethylatrazine were assumed to remain constant during the day in which the samples were collected. Concentrations then were corrected on the basis of laboratory-spike recoveries (U.S. Geological Survey National Water Quality Laboratory, written commun., 1995). Corrected atrazine and desethylatrazine concentrations were summed to calculate a total corrected atrazine concentration. Because laboratory-spike recoveries are, in general, larger than field-spike recoveries, correcting sample data by laboratory recoveries may slightly underestimate true sample concentrations and, thus, lead to conservative estimates of subbasin flux.

Log-log plots of the total annual quantities of EPTC and atrazine applications in relation to daily flux at the subbasin outlet show a linear correlation for both compounds (fig. 19). Coefficients of determination, which represent the fraction of the variance explained by the regression between annual applications and daily flux, ranged from 0.54 to 0.56 for EPTC and 0.57 to 0.62 for atrazine, depending on the values used for the censored data. Slope estimates ranged from 0.83 to 0.85 for EPTC and 0.83 to 0.95 for atrazine. Regression slopes of less than 1.0 indicate that daily fluxes of EPTC and atrazine from a subbasin become a smaller percentage of the total applied as application quantities increase. The regression for EPTC also indicates that on the date of sampling, a median daily flux of about 0.0001 percent of the EPTC applied annually in a subbasin was being transported from the subbasin. The median daily flux of atrazine from the subbasins was between 0.001 and 0.01 percent of the annual total applied. Because samples were collected only on 1 day, it is impossible to calculate total seasonal fluxes on the basis of these data. However, because the samples were collected during the maximum-use period, these fluxes for EPTC proba-

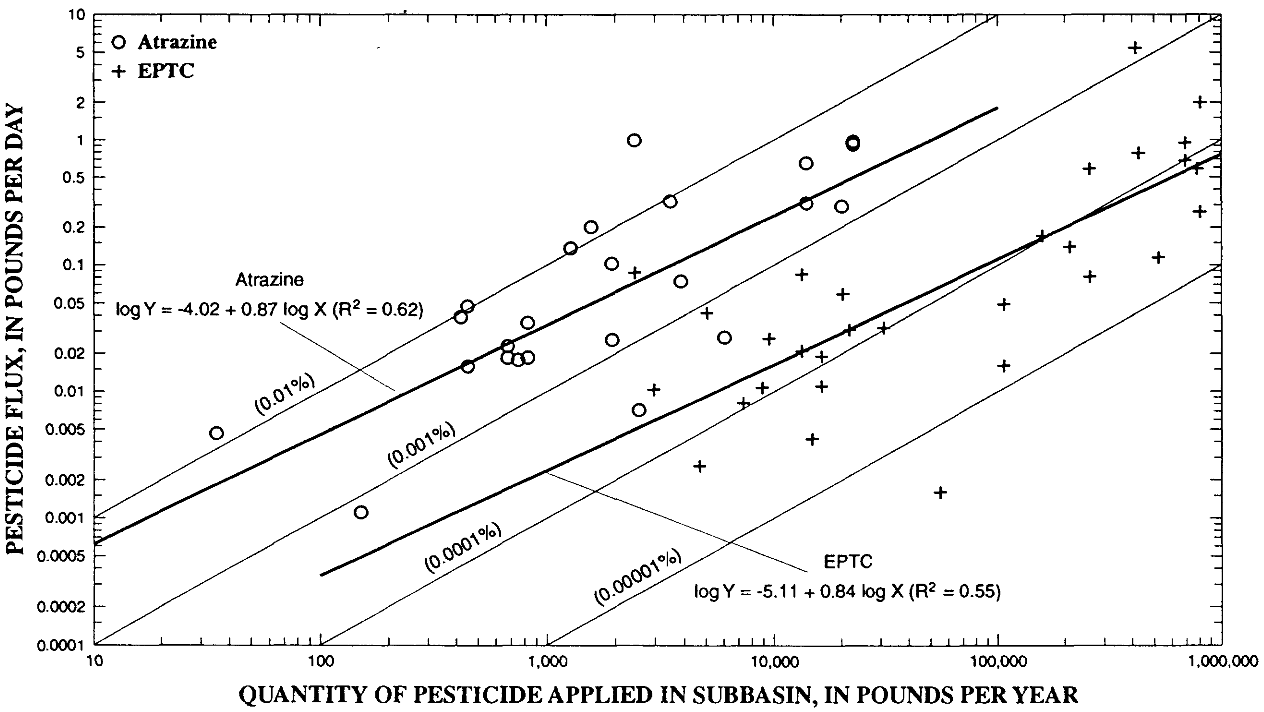



**Figure 19.** Relations of EPTC and atrazine applications to daily fluxes in subbasins of the upper Snake River Basin. (Percentage lines represent daily flux as a percentage of the total annual application; regression lines reflect values for censored data as one-half the method detection limit)

bly represent near-maximum daily values for the entire year.

The relative differences in subbasin fluxes between EPTC and atrazine, in general, support findings by Wauchope (1978), who determined that losses of EPTC from individual fields were about 10 times smaller than losses of atrazine. Wauchope estimated that mean seasonal losses of EPTC from fields were less than 0.3 percent of the annual total applied, whereas mean losses of atrazine were 2 to 3 percent. The seasonal losses of EPTC estimated by Wauchope are larger than those determined for this basinwide study, even if daily fluxes of EPTC determined during application periods were assumed to remain constant over a 4-month growing season. The EPTC loss is probably smaller because the increased distance that a pesticide is transported in a large watershed allows for a longer period of degradation and storage compared with field-scale studies. Larson and others (1995) determined that, in nine large (about 12,000 to 1,200,000 mi$^2$) subbasins of the Mississippi River, annual fluxes of EPTC ranged from nondetectable to 0.05 percent of the annual amount applied, indicating that EPTC had degraded or volatilized prior to reaching the sampling point. Results from the Mississippi River study showed that 0.62 to 1.9 percent of the annually applied atrazine was delivered to streams, and upon reaching streams, was transported with relatively little loss. In the USNK, Clark (1994b) determined that

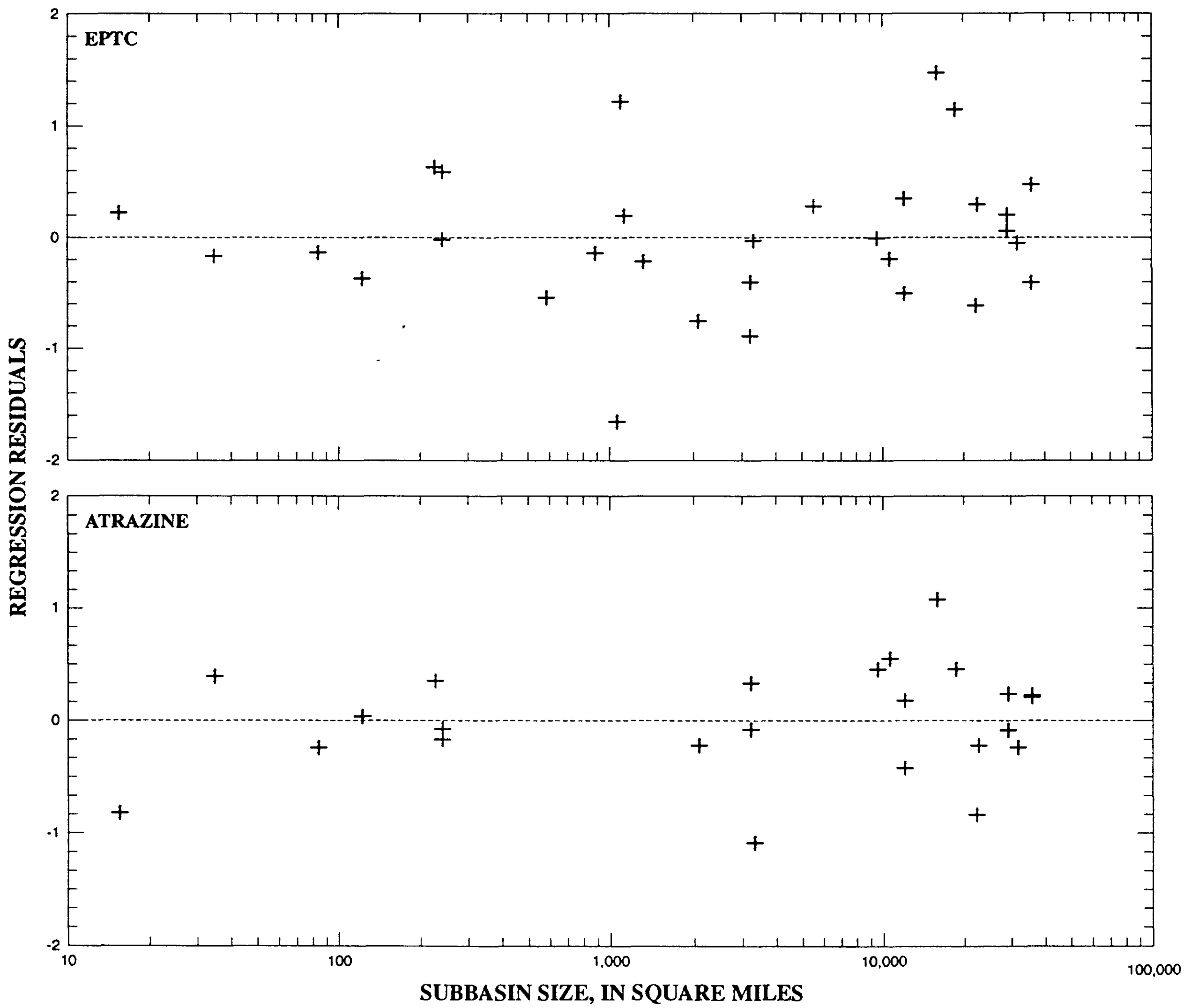



**Figure 20.** Residuals from regressions of daily fluxes and total annual applications of EPTC and atrazine in subbasins of the upper Snake River Basin.

fluxes of atrazine in Rock Creek remained relatively constant throughout the year because of large contributions of atrazine-laden ground water. Assuming that daily fluxes of atrazine are relatively constant in other subbasins of the USNK, the annual subbasin losses of atrazine determined for this study (0.2 to 14 percent) are similar to those reported for Mississippi River subbasins.

For the range of subbasin sizes sampled in the USNK (about 15 to 36,000 $mi^2$), subbasin size did not appear to be an important factor in the relation between total annual application and daily flux. When plotted against subbasin size, residuals from the regressions for both EPTC and atrazine showed a uniform scatter around the zero residual line (fig. 20), indicating that the relations between total annual applications of EPTC and atrazine and daily subbasin flux are fairly constant regardless of subbasin size. The wider range of scatter at larger subbasin sizes suggests that the relation between total annual application and daily flux may be less accurate as subbasin size increases.

## SUMMARY

The Snake River in the USNK drains an area of about 35,800 $mi^2$, encompassing parts of four States. Elevation of the Snake River over its 453-mi course ranges from about 6,800 ft above sea level near its headwaters at the southern boundary of Yellowstone National Park in Wyoming to about 2,500 ft at the basin outlet at King Hill. Major types of land use/land cover in the basin are rangeland, forest land, and agricultural land. Streamflow in the Snake River is highly regulated by dams and diversions, primarily for agricultural use and hydroelectric-power generation. Factors that affect water quality in the USNK include irrigated agriculture, aquaculture, rangeland grazing, feedlots, industrial and municipal point sources, and recreation.

Concentrations of nutrients and suspended sediment were assessed quantitatively using data collected at 19 sites in the USNK, 9 located on the main stem of the Snake River. In general, concentrations of nutrients and suspended sediment were smaller in water samples collected at the 11 sites upstream from American Falls Reservoir than in samples collected at the 8 sites downstream from the reservoir where effects of land-use activities are most pronounced. Median concentrations at the 19 sites ranged from less than 0.05 to 1.60 mg/L of $NO_2$+$NO_3$, less than 0.01 to 0.11 mg/L of Tot-P, and 4 to 72 mg/L of suspended sediment. Concentrations of nutrients and suspended sediment in the main stem of the Snake River, in general, increased in a downstream direction. The largest concentrations in main-stem samples were from the middle reach of the Snake River between Milner Dam and King Hill.

Because agriculture is the major factor influencing water quality in most of the USNK, sampling sites were grouped according to the quantity of agricultural land in each of their subbasins. Significant differences in nutrient and suspended sediment concentrations were noted between sites where agricultural land constitutes less than 10 percent of the upstream land use and sites where agricultural land constitutes more than 10 percent of the upstream land use. Because of factors in addition to agriculture, differences in nutrient and suspended sediment concentrations among the 10 to 19, 20 to 29, and greater than 29 percent agricultural land-use groups were inconsistent.

Individual sites in each of the agricultural land-use groups showed similar patterns in the relations between selected nutrient and suspended sediment concentrations and streamflow. Concentrations of $NO_2$+$NO_3$ were largest when streamflow was low and ground water was an important source of water to streams. Conversely, concentrations of Tot-P and suspended sediment were largest when streamflow was high and sediments and associated nutrients were washed into streams and transported at elevated stream velocities.

Seasonal concentrations of $NO_2$+$NO_3$, Tot-P, and suspended sediment also were significantly different in most of the agricultural land-use groups. Concentrations of $NO_2$+$NO_3$ were largest during the nonirrigation season October through March. Concentrations of Tot-P and suspended sediment generally were largest during the high-streamflow months April through June.

The poorest quality water in the USNK is in the 92-mi reach of the Snake River between Milner Dam and King Hill (middle Snake). A variety of point and nonpoint sources, including agriculturally affected springs and tributaries, irrigation-return flows, aquaculture facilities, and sewage-treatment plants, contribute nutrients and suspended sediment to the reach. During WY's 1980–95, the middle Snake received between 30 and 80 percent of its streamflow from ground water, mainly discharging from springs along the north side of the Snake River. In WY 1994, north-side springs supplied about 6,500 tons of Tot-N, primarily as $NO_2$+$NO_3$, and 100 tons of Tot-P to the river. Isotope and water-table information indicated that the springs derived most of their nitrogen from agricultural activities along the margins of the Snake River.

Nutrient and suspended sediment concentrations and annual loads in the Snake River at King Hill fluctuated considerably during WY's 1980–95, primarily in response to fluctuations in streamflow. Annual loads of all constituents were largest during WY's 1982–86, when streamflow exceeded the historical average, and smallest during WY's 1988–92, when streamflow was less than the historical average. Loads of $NO_2$+$NO_3$ did not vary as dramatically as other constituents during WY's 1980–95 because of the large input of $NO_2$+$NO_3$ from ground water discharging to the river.

A variety of sources contribute nutrients and suspended sediment to the middle Snake. During WY 1995, springs discharging to the river were the primary source of water (66 percent) and Tot-N (60 percent); aquacultural effluent was a major source of $NH_4$ (82 percent), Org-N (30 percent), and Tot-P (34 percent); and tributary streams were a major source of Org-N (28 percent) and suspended sediment (58 percent). In proportion to its discharge (less than 1 percent), the Twin Falls sewage-treatment plant was a major source of Tot-P (13 percent). A comparison of discharge and nutrient and suspended sediment loading in WY 1995 with estimates of instream transport showed that some constituents correlated well and others correlated poorly. Synoptic sampling during the growing season indicated that, for all constituents, input exceeded instream transport, suggesting instream retention during low streamflow.

The occurrence and distribution of pesticides in the USNK were assessed by analyzing samples from two agricultural subbasins for at least 1 year and by analyzing basinwide samples collected synoptically during the annual period of heaviest pesticide use. EPTC, atrazine, desethylatrazine, metolachlor, and alachlor were the most commonly detected pesticides in Rock Creek (an agriculturally affected subbasin) and accounted for about 75 percent of all detections basinwide. All pesticides detected were at concentrations less than 1 µg/L and well below EPA established water-quality criteria.

The number and concentrations of pesticides in water from two agricultural basins were largest in May and June following early growing season applications. In 1 year, 7 different pesticides and 30 total pesticide detections were found in 25 samples from the Teton River near St. Anthony. The herbicides triallate and EPTC were the most commonly detected pesticides in Teton River samples. Over more than 2 years, 19 different pesticides and 163 total pesticide detections were found in 43 samples from Rock Creek near Twin Falls. The herbicides atrazine and its breakdown product desethylatrazine, EPTC, and metolachlor were the most commonly detected pesticides in Rock Creek samples. Atrazine and desethylatrazine were the only pesticides detected throughout the year in Rock Creek.

Basinwide, EPTC was the most commonly detected pesticide in surface water during the heavy pesticide-use period, May and June. EPTC was present in 30 of 37 samples; the maximum concentration was 310 ng/L. Atrazine and desethylatrazine were the second and third most commonly detected pesticides, respectively. No pesticides were detected in the Snake River or Snake River tributaries upstream from its confluence with the Henrys Fork. The largest numbers of pesticides and, in general, the largest pesticide concentrations, were in agriculturally affected tributaries in the middle Snake.

On the basis of basinwide synoptic sampling, total annual applications of EPTC and atrazine were related to instantaneous instream fluxes with coefficients of determination ($R^2$ values) of 0.55 and 0.62, respectively. At the time of sampling, the median daily flux of EPTC was about 0.0001 percent of the annual quantity applied, whereas the median daily flux of atrazine was between 0.001 and 0.01 percent. The difference in fluxes between EPTC and atrazine probably results from differences in their chemical and physical properties and the methods in which they are applied.

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