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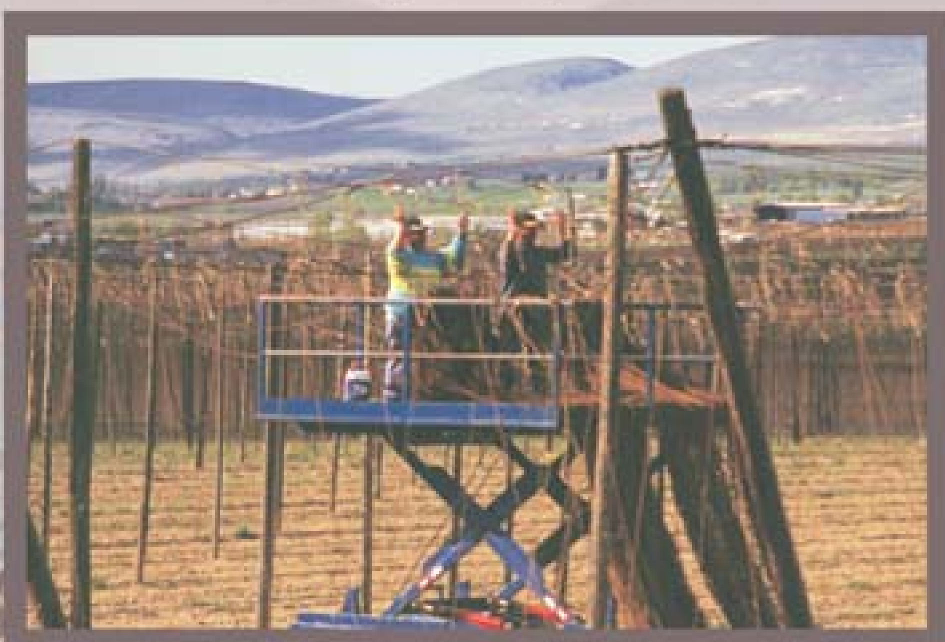
Concentrations and Loads of Suspended Sediment and Nutrients in Surface Water of the Yakima River Basin, Washington, 1999-2000 – With an Analysis of Trends in Concentrations

Water-Resources Investigations Report 03-4026



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Concentrations and Loads of Suspended Sediment and Nutrients in Surface Water of the Yakima River Basin, Washington, 1999-2000 – With an Analysis of Trends in Concentrations

By James C. Ebbert, Sandra S. Embrey, *and* Janet A. Kelley

U.S. GEOLOGICAL SURVEY

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NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Portland, Oregon
2003

U.S. DEPARTMENT OF THE INTERIOR

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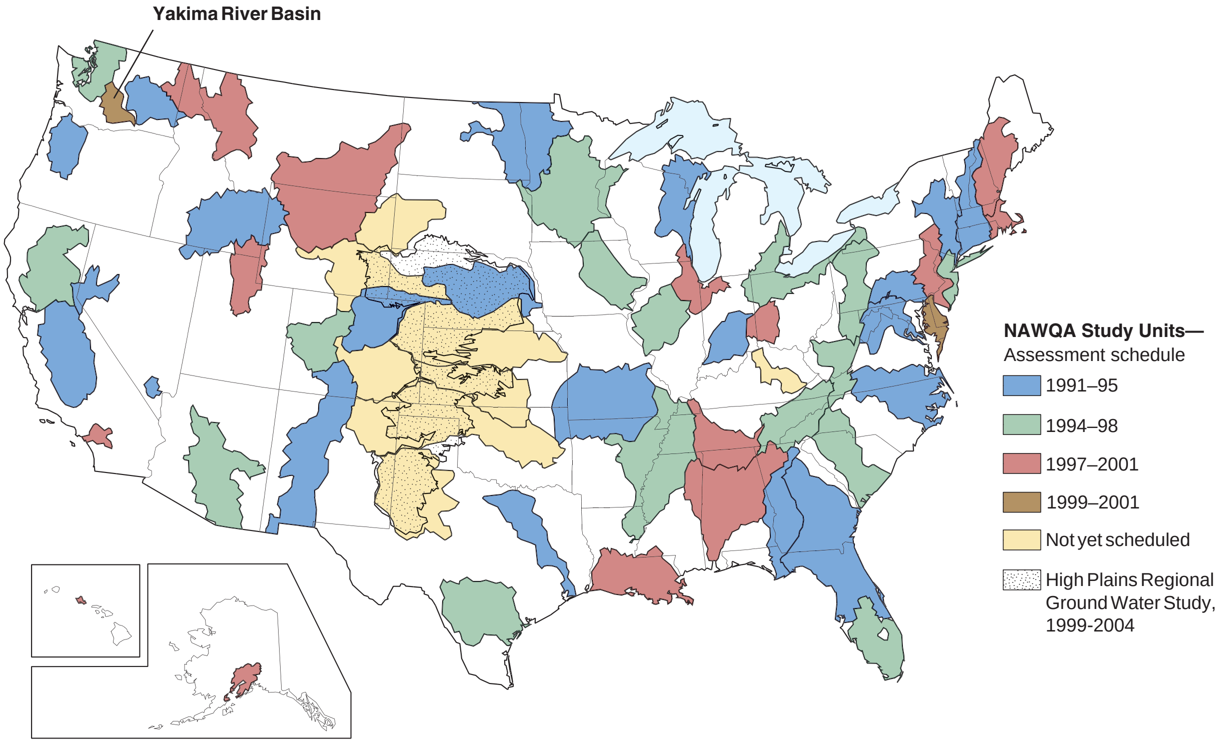
National Water-Quality Assessment Program

In 1991, the U.S. Congress began to appropriate funds to the USGS to conduct the **National Water-Quality Assessment (NAWQA) Program**. Since that time, NAWQA has evaluated the quality of streams, ground water, and aquatic ecosystems in more than 50 major river basins and aquifer systems across the Nation, referred to as "Study Units." As indicated on the map, timing of the assessments varies within the Program's rotational design: about one-third of all Study Units are intensively investigated for 3 to 4 years, which is followed by 6 to 7 years of low-level monitoring.



In 2001, the NAWQA Program entered its second decade of investigations and an intensive reassessment of water conditions was begun to determine trends, based on 10 years of comparable monitoring data collected at selected streams and ground-water sites. The next 10 years of study also will fill critical gaps in characterizing water-quality conditions, and increase understanding of processes that control water-quality conditions, which will better establish critical links among *sources* of contaminants, their *transport* through the hydrologic system, and the potential *effects* of contaminants on ecological health and on the quality of drinking water.

The Yakima River Basin assessment is one of two special studies activated in 1999 for the purpose of piloting study techniques for use in NAWQA's second decade of investigations. Specifically, the Yakima River Basin assessment piloted techniques to (1) monitor trends in surface water, (2) evaluate transport of agricultural chemicals to streams, and (3) assess the possible effects of agricultural chemicals from irrigated farmland on stream ecosystems. The Yakima River Basin assessment builds upon monitoring data that the NAWQA Program collected previously in the basin from 1987 through 1991, as part of pilot studies conducted before full Program implementation in 1991. These data provided a baseline characterization of pesticides, nutrients, trace elements, suspended solids, and aquatic life in streams.

What kind of water-quality information does the NAWQA Program provide?

The NAWQA Program assesses the quality of the Nation's water resources, which is integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and also suitable for industry, irrigation, and habitat for fish and wildlife. Assessments in the major river basins and aquifer systems include water resources available to more than 60 percent of the population and cover about one-half of the land area of the conterminous United States. Scientists in the NAWQA Program work with partners in government, research, and public-interest groups to assess the spatial extent of water-quality conditions, the way water quality changes with time, and the effects of human activities and natural factors on water quality. This information is useful for guiding water-management and protection strategies, research, and monitoring in different hydrologic and land-use settings across the Nation.

Water-quality assessments by a single program cannot possibly address all of the Nation's water-resources needs and issues. Therefore, it is necessary to define the most pertinent context for NAWQA information.

- **Total resource assessment**—NAWQA assessments are long-term and interdisciplinary, and include information on water chemistry, hydrology, land use, stream habitat, and aquatic life. Assessments are not limited to a specific geographic area or water-resource problem at a specific time. Therefore, the findings describe the general health of the total water resource, as well as emerging water issues, thereby helping managers and decision makers to set priorities.
- **Source-water characterization**—Assessments focus on the quality of the available, untreated resource and thereby complement (rather than duplicate) Federal, State, and local programs that monitor drinking water. Findings are compared to drinking-water standards and health advisories, if available, as a way to characterize the resource.
- **Compounds studied**—Assessments focus on chemical compounds that have well-established methods of investigation. It is not financially or technically feasible to assess all the contaminants in our Nation's waters. In general, the NAWQA Program investigates those pesticides, nutrients, volatile organic compounds, and metals that have been or are currently used commonly in agricultural and urban areas across the Nation. A complete list of compounds studied is on the NAWQA Web site at http://water.usgs.gov/nawqa.
- **Detection versus risk**—Compounds are measured at very low concentrations, often 10 to 100 times lower than Federal or State standards and health advisories. Detection of compounds, therefore, does not necessarily translate to risks to human health or aquatic life. However, these analyses are useful for identifying and evaluating emerging issues, such as the presence of new contaminants or the occurrence of mixtures, as well as for tracking contaminant levels over time.
- **Consistent approach**—Assessments are guided by a nationally consistent study design and uniform methods of sampling and analysis. Findings thereby pertain not only to water quality of a particular stream or aquifer, but also contribute to the larger picture of how and why water quality varies regionally and nationally. This consistent approach helps to determine if a water-quality issue is isolated or pervasive. It also allows direct comparisons of how human activities and natural processes affect water quality in the Nation's diverse environmental settings.

Introduction to this report

This report contains the major findings of a 1999-2001 assessment of water quality in streams in the Yakima River Basin. It is one of a series of reports by the NAWQA Program that present major findings on water resources in 51 major river basins and aquifer systems across the Nation.

In these reports, water quality is assessed at many scales-from large rivers that drain many land uses to small agricultural catchments, and is discussed in terms of local, State, and regional issues. Conditions in the Yakima River Basin are compared to conditions found elsewhere and to selected national benchmarks, such as those for drinking-water quality and the protection of aquatic organisms.

This report is intended for individuals working with water-resource issues in Federal, State, or local agencies, universities, public interest groups, or the private sector. The information will be useful in addressing a number of current issues, such as source-water protection, pesticide registration, human health, drinking water, hypoxia and excessive growth of algae and plants, the effects of agricultural land use on water quality, and monitoring and sampling strategies. This report is also for individuals who wish to know more about the quality of water resources in areas near where they live, and how that water quality compares to other areas across the Nation.

Other products describing water-quality conditions in the Yakima River Basin are available. Detailed technical information, data and analyses, methodology, models, graphs, and maps that support the findings presented in this report can be accessed from http://oregon.usgs.gov/yakima. Other reports in this series and data collected from other basins can be accessed from the national NAWQA Web site (http://water.usgs.gov/nawqa).

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USGS hydrologists collect samples from a cableway across the Yakima River at Kiona

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CONVERSION FACTORS, DATUM, ABBREVIATIONS, AND DEFINITIONS

CONVERSION FACTORS

Multiply	By	To obtain
Length		
inch (in)	2.54	centimeter
inch (in)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
Area		
acre	0.004047	square kilometer
square mile (mi^2)	2.590	square kilometer
Flow rate		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
Mass		
pound, avoirdupois (lb)	0.4536	kilogram
pound per day, avoirdupois (lb/d)	0.4536	kilogram per day
ton per day (ton/d)	0.9072	metric ton per day
ton per day (ton/d)	0.9072	megagram per day

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

DATUM

Vertical datum: Vertical coordinate information is referenced to the North American Vertical Datum of 1929 (NAVD 29).

Horizontal datum: Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above or below sea level.

ABBREVIATIONS

BMP	Best management practice
BOR	Bureau of Reclamation
Ecology	Washington State Department of Ecology
EQIP	Environmental Quality Incentives Program
LRL	Laboratory reporting level
NAWQA	National Water-Quality Assessment Program
NWQL	National Water Quality Laboratory
PAM	Polyacrylamide
RM	River mile
RSBOJC	Roza-Sunnyside Board of Joint Control
USGS	U.S. Geological Survey
WWTP	Wastewater treatment plant

DEFINITIONS

Agricultural return flows include 1) canal water; 2) irrigation water, rain, and snowmelt transported from agricultural fields to streams and surface drains via overland flow; and 3) shallow ground water discharged to surface drains and streams, either directly or from subsurface tile drains.

Canal water (in the context of this report) is irrigation water diverted from the Yakima or Naches River for delivery via canals, laterals, and pipes to farm land. During irrigation season, canal water in excess of the amount needed to irrigate crops in a particular area or drainage basin is returned through drains and streams to the rivers. Concentrations of suspended sediment and nutrients in canal water usually are lower than concentrations in shallow ground water beneath agricultural fields and in irrigation water that runs off of agricultural fields and flows to drains and streams.

Water year in U.S. Geological Survey reports is the 12-month period October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1999, is called the "1999 water year."

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ABSTRACT

Spatial and temporal variations in concentrations and loads of suspended sediment and nutrients in surface water of the Yakima River Basin were assessed using data collected during 1999–2000 as part of the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program. Samples were collected at 34 sites located throughout the Basin in August 1999 using a Lagrangian sampling design, and also were collected weekly and monthly from May 1999 through January 2000 at three of the sites. Nutrient and sediment data collected at various time intervals from 1973 through 2001 by the USGS, Bureau of Reclamation, Washington State Department of Ecology, and Roza-Sunnyside Board of Joint Control were used to assess trends in concentrations.

During irrigation season (mid-March to mid-October), concentrations of suspended sediment and nutrients in the Yakima River increase as relatively pristine water from the forested headwaters moves downstream and mixes with discharges from streams, agricultural drains, and wastewater treatment plants. Concentrations of nutrients also depend partly on the proportions of mixing between river water and discharges: in years of ample water supply in headwater reservoirs, more water is released during irrigation season and there is more dilution of nutrients discharged to the river downstream. For example, streamflow from river mile (RM) 103.7 to RM 72 in August 1999 exceeded streamflow in July 1988 by a factor of almost 2.5, but loads of total nitrogen and phosphorus discharged to the reach from streams, drains, and wastewater treatment plants were only 1.2 and 1.1 times larger.

In years of ample water supply, canal water, which is diverted from either the Yakima or Naches River, makes up more of the flow in drains and streams carrying agricultural return flows. The canal water dilutes nutrients (especially nitrate) transported to the drains and streams in runoff from fields and in discharges from subsurface field drains and the shallow ground-water system. The average concentration of total nitrogen in drains and streams discharging to the Yakima River from RM 103.7 to RM 72 in August 1999 was 2.63 mg/L, and in July 1988 was 3.16 mg/L; average concentrations of total phosphorus were 0.20 and 0.26 mg/L.

After irrigation season, streamflow in agricultural drains decreases because irrigation water is no longer diverted from the Yakima and Naches Rivers. As a result, concentrations of total nitrogen in drains increase because nitrate, which constitutes much of total nitrogen, continues to enter the drains from subsurface drains and shallow ground water. Concentrations of total

phosphorus and suspended sediment often decrease, because they are transported to the drains in runoff of irrigation water from fields. In Granger Drain, concentrations of total nitrogen ranged from 2-4 mg/L during irrigation season and increased to about 6 mg/L after irrigation season, and concentrations of total phosphorus, as high as 1 mg/L, decreased to about 0.2 mg/L.

In calendar year 1999, Moxee Drain transported an average of 28,000 lb/d (pounds per day) of suspended sediment, 380 lb/d of total nitrogen, and 46 lb/d of total phosphorus to the Yakima River. These loads were about half the average loads transported by Granger Drain during the same period. Average streamflows were similar for the two drains, so the difference in loads was due to differences in constituent concentrations: those in Moxee Drain were about 40-60 percent less than those in Granger Drain.

Loads of suspended sediment and total phosphorus in Moxee and Granger Drains were nearly four times higher during irrigation season than during the non-irrigation season because with increased flow during irrigation season, concentrations of suspended sediment and total phosphorus are usually higher. Loads of nitrate in the drains were about the same in both seasons because nitrate concentrations are higher during the non-irrigation season.

Loads of nutrients in the Yakima River at Kiona were similar during irrigation and non-irrigation season, generally differing by less than 20 percent. This is because average streamflows and concentrations of nutrients were similar between the two seasons. Average streamflow during the irrigation season was within about 6 percent of the average streamflow during the non-irrigation season and average nutrient concentrations differed by less than 13 percent. Loads of suspended sediment were about 60 percent larger during irrigation season. Large fractions of the total annual loads were transported during the first half of the irrigation season. For example, 38 percent or more of the annual loads of suspended sediment, total nitrogen, ammonia-plus-organic nitrogen, total phosphorus, and orthophosphate were transported from March through June.

Departure from relations between average daily loads and annual mean streamflow suggests some reduction in loads of suspended sediment, ammonia-plus-organic nitrogen, and total nitrogen in the Yakima River at Kiona in water years 1999 and 2000. The relation between loads and streamflow was established using loads previously estimated for water years 1974, 1977, 1980, 1988, and 1989 and loads estimated by this study for other water years from 1974 through 1994.

The summary of trend statistics for concentration data collected from 1991–2000 indicates that some of the factors affecting constituent transport to surface water may be common to many agricultural subbasins in the Yakima Basin. For example, concentrations of nitrate and total nitrogen increased in five of six streams and drains while concentrations of suspended solids and total phosphorus either did not change or decreased. This difference is consistent with no change, or a decrease, in amounts of suspended solids and phosphorus transported to surface water in runoff and an increase in the amount of nitrate transported to streams and drains from ground-water discharges and subsurface drains. Decreased transport of sediment and associated phosphorus to streams and drains likely results from increased use of agricultural best management practices that reduce runoff from cropland. Nitrate is less affected because much of it enters from subsurface drains and shallow ground water. Increasing concentrations of nitrate in some drains over the period 1991–2000 suggest that concentrations of nitrate in ground water are increasing.

Data collected from 1997–2001 also indicate a decrease in concentrations in suspended solids and total phosphorus in some drains and streams receiving agricultural return flows. Turbidity has decreased in drains where concentrations of suspended solids have decreased. The data also indicate that concentrations of nitrate in some streams and drains have leveled off and may be decreasing. This observation does not conflict with the trend statistics for 1991–2000, but suggests that a slow increase over a decade may be leveling off.

Trend statistics computed using both unadjusted and flow-adjusted data indicate small, but significant, increases in turbidity and concentrations of total phosphorus in the Yakima River at Kiona from 1991 through 2000. There also was an increase in flow-adjusted concentrations of nitrate, which is consistent with increasing concentrations of nitrate in some streams and drains flowing to the Yakima River. Although nitrogen discharged from streams and drains is a large fraction of the nitrogen load in the river, a relation between increasing concentrations of nitrate in streams and drains and increasing concentrations in the Yakima River at Kiona was not established. The trend test using flow-adjusted concentrations showed no trend in the concentration of suspended solids. This seems reasonable because concentrations of suspended solids correlated with streamflow, and higher values of both were observed after 1995.

INTRODUCTION

In 1986, the U.S. Geological Survey (USGS) implemented a pilot program to test and refine the concepts for what was to become the National Water-Quality Assessment (NAWQA) Program. The Yakima River Basin was included in the pilot program as one of four river basins selected for the study of surface-water quality. Using pilot-study data collected from 1987 to 1991, along with data collected earlier by the USGS and other agencies, the study significantly advanced the understanding of the effects of land use on the quality of surface water in the Yakima River Basin. The study showed that agricultural practices in the Basin can greatly increase concentrations of suspended sediment, nutrients, trace metals, pesticides, and fecal-indicator bacteria in streams that receive agricultural return flows. In examining the effects of agricultural practices on water resources, the pilot study provided some information about the effectiveness of various best management practices in reducing erosion of soil, nutrients, and pesticides from agricultural fields, thereby improving the quality of surface water draining agricultural land (Morace and others, 1999).

In 1991, the NAWQA Program was fully implemented, and by 2001 the Program had assessed the quality of streams and ground water in more than 50 study units throughout the Nation (U.S. Geological Survey, 2001). The NAWQA Program in the Yakima River Basin began its second cycle (cycle II) in 1999, when surface water throughout the Basin was sampled for concentrations of suspended sediment, nutrients, pesticides, and other constituents. Cycle II has provided an opportunity to reassess water quality and study the effectiveness of best management and other land-use practices on the quality of surface water. Part of the reassessment included determining spatial and temporal variations in concentrations and loads of suspended sediment and nutrients in surface water in the Yakima River Basin and assessing trends in concentrations.

Manure, from animal feeding operations, is commonly spread on crops including corn, asparagus, and hops.

Purpose and Scope

This report describes (1) spatial and temporal changes in concentrations and loads of suspended sediment and nutrients in surface water of the Yakima River Basin, and (2) trends in concentrations of these constituents. The report also discusses some of the factors that have caused changes in concentrations and loads. Data collected by the USGS as part of the cycle II study were obtained from a basinwide sampling of surface-water sites and wastewater discharges in August 1999, and from weekly and monthly sampling of three surface-water sites from May 1999 through January 2000. Additional data collected January 2001 through August 2002 at the Yakima River at Kiona were used to help assess the results of estimating loads with regression models. Nutrient and sediment data dating from 1973 through 2001 and collected at different time intervals within that period by the USGS, Bureau of Reclamation (BOR), Washington State Department of Ecology (Ecology), and Roza-Sunnyside Board of Joint Control (RSBOJC) were used to assess trends in concentrations.

Availability of Data Used in This Report

U.S. Geological Survey data used in this report can be obtained from the Yakima River Basin NAWQA Web site at the URL <http://oregon.usgs.gov/yakima>.

Acknowledgments

We gratefully acknowledge the individuals and agencies who provided support and assistance to this project. Chris Coffin and Ryan Anderson, Washington State Department of Ecology, provided technical advice and assistance in the field during sample collection. Moses Squeochs and James Thomas, Yakama Indian Nation, worked with the Yakama Indian Nation Council to grant us access to sampling sites and accompanied us during site visits. William Rice, who was with the Roza-Sunnyside Board of Joint Control at the time of this study, helped with selection of sampling sites, installed water-quality monitors, gaged streams, collected samples, and made turbidity measurements. Steve Fanciullo, Bureau of Reclamation, allowed us access to their stream gages and provided streamflow data and advice on the mass balance of water discharges needed for computing constituent loads. Robert Stevens, soil scientist with Washington State University, provided helpful advice on sampling design and provided land-use maps of the Granger Basin. Scott Manley, Director of Benton Conservation District, provided water-quality data for Spring and Snipes Creeks. Assistance during sample collection was provided by Jennifer Key, student at Central Washington University; Paivikki "Vickie" Pihl, student at Tampere University of Technology, Finland; and Brent Morace, USGS volunteer. Wastewater treatment-plant operators in Cle Elum, Ellensburg, Selah, Yakima, Sunnyside, and Prosser collected effluent samples during the basinwide sampling.

We would like to thank Ecology, the BOR, and the RSBOJC for providing water-quality data for the analysis of trends. David Hallock, Ecology, provided historical data not available online for the Yakima River at Kiona. William Rice, formerly with the RSBOJC, provided statistical summaries of quality-control data in addition to the raw data. William Stroud, BOR, provided the quality-assurance plan for the collection and analysis of water-quality samples.

We gratefully acknowledge the individuals who provided information and data about the use of agricultural best management practices in the Yakima River Basin. Those individuals and agencies are cited throughout the report.

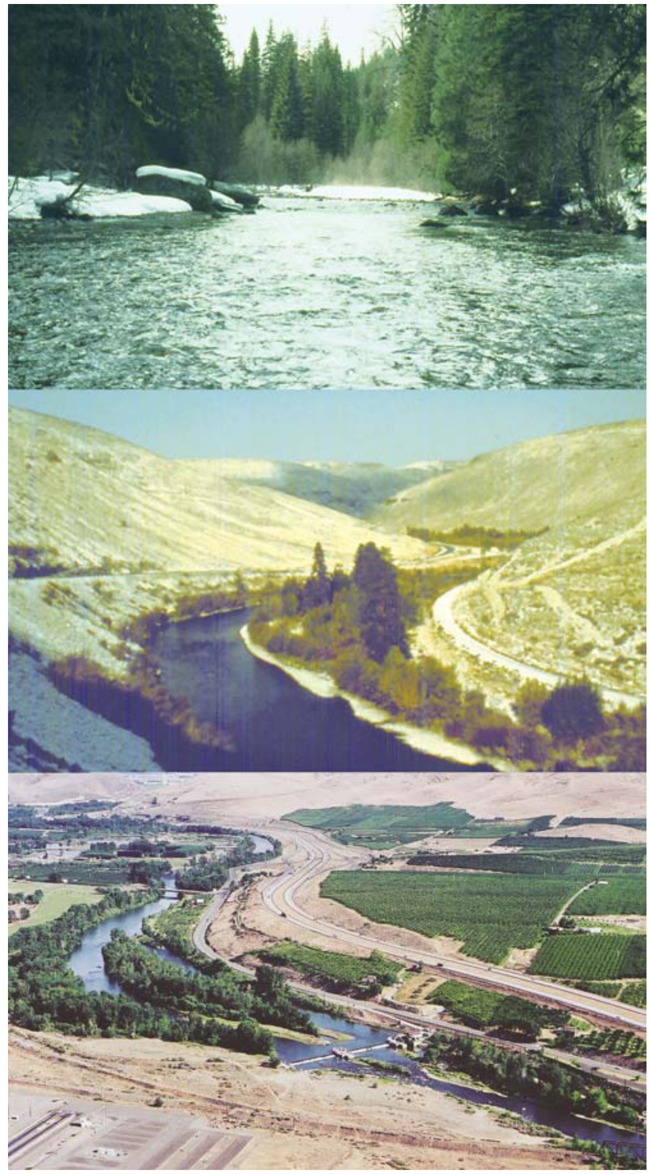
Finally, we would like to thank Joe Joy and Steve Butkus, Ecology, and Onni Perala, Roza Irrigation District, for their help and comments on technical aspects of data analysis and report content.

DESCRIPTION OF BASIN

The Yakima River flows 214.5 mi (miles) from the outlet of Keechelus Lake in the central Washington Cascade Range to the Columbia River, draining an area of 6,155 mi^2 (square miles) (fig. 1). The altitude of the Basin ranges from 8,184 ft (feet) above sea level in the Cascade Range to about 340 ft at the Columbia River. The Basin contains a variety of landforms, including the glaciated peaks and deep valleys of the Cascade Range, broad river valleys, and the lowlands of the Columbia Plateau. Mean annual precipitation ranges from 140 in. (inches) in the Cascade Range to less than 10 in. near the mouth of the Basin.

Because the lower valleys are arid during summer, most agricultural land in the Basin is irrigated. Reservoirs in the upper Yakima and Naches River Basins (fig. 1) are used to augment flows for irrigation and instream uses. Reservoir releases provide most of the water used for irrigation during the July-October period, when natural streamflows are lowest and irrigation demand is highest. About 450,000 acres of cropland in the Yakima River Basin are irrigated, and annual surface-water diversions from the Yakima River system for irrigation are equivalent to about 60 percent of the mean annual streamflow leaving the Basin. During the summer months, the quality of agricultural return flows affects the quality of water in the Yakima River downstream from the city of Yakima because return flows contribute as much as 80 to 90 percent of the streamflow (Rinella and others, 1999). Agricultural return flows enter the Yakima River through agricultural drains and wasteways and through the lower reaches of some streams (fig. 2).

The chemical quality of the agricultural return flows is influenced by the amount of streamflow in the Yakima River during irrigation season, which is determined to a large extent by the amount of water released from headwater reservoirs. In years when the water supply is plentiful, more water is available for irrigation, and water in agricultural drains and the lower reaches of some streams contains a higher percentage of canal water (Onni Perala, Roza Irrigation District, written commun., July 2002). The canal water tends to dilute dissolved constituents, like nitrate, in drain water, thereby reducing their concentrations.



The Yakima River integrates a variety of hydrologic landscapes including forested head waters, deeply incised basalt canyons in the mid valley, and rich sedimentary and loess deposits in the lower valley.

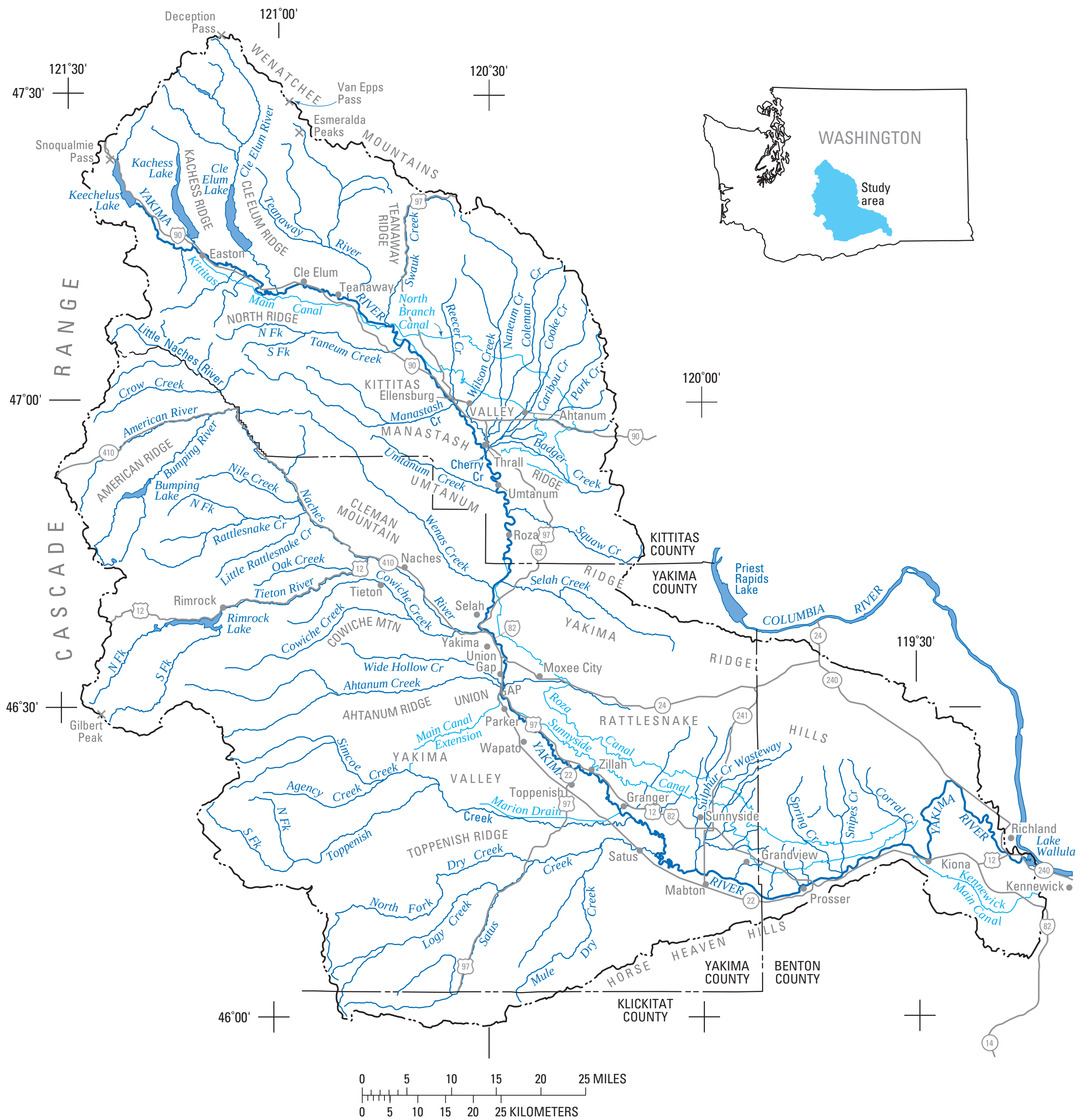


Figure 1. The Yakima River Basin, Washington.

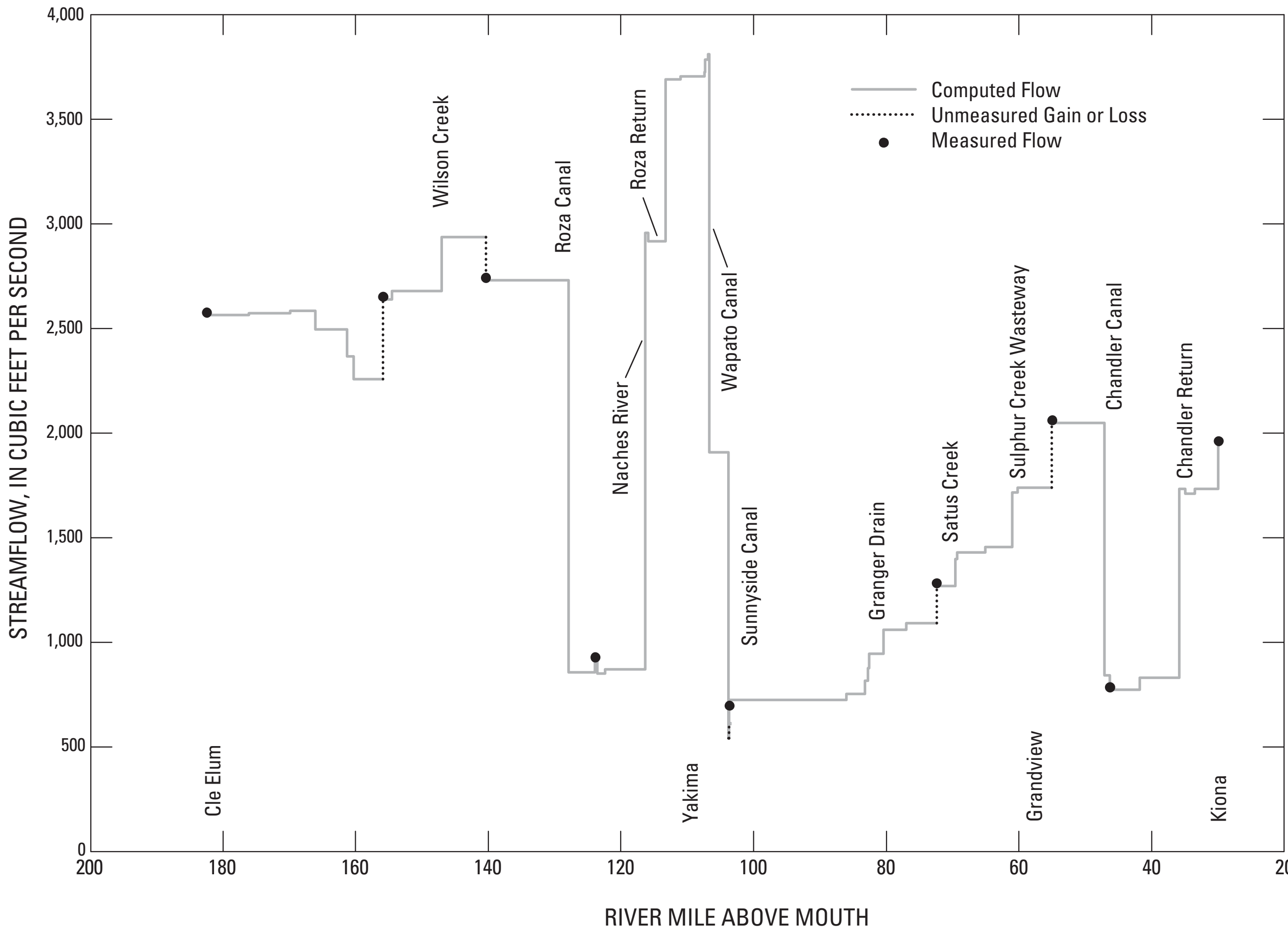


Figure 2. Streamflow in the Yakima River during irrigation, August 2-6, 1999.

Land Use and Water Quality

Land use and land cover in the Yakima River Basin grade from the forested headwaters in the upper basin to agriculture and rangeland in the lower basin (fig. 3). In a summary of the pilot study, Morace and others (1999) described how the quality of surface water in the Yakima River Basin varied with the gradation in land use. The pilot study divided the Yakima River into three reaches based on changes in water quality as influenced by differences in geology and land use. The study determined that the quality of water in the upper reach, which extends from the foot of Keechelus Dam at river mile (RM) 214.5 to just upstream of Umtanum (RM 140.5) was better than the quality of water in both the middle (RM 140.5 to RM 107.2) and lower (RM 107.2 to the mouth) reaches.

The pilot study concluded that erosion of soil from agricultural lands during irrigation season, which extends from mid-March until mid-October, was the major source of suspended sediment and turbidity in surface water of the Yakima River Basin. Although most suspended sediment is transported to the Yakima River during irrigation season, much of it is deposited on the riverbed and not transported downstream until it is resuspended during winter storms and spring snowmelt. Concentrations of suspended sediment were highest in agricultural drains during irrigation season, but were highest in the Yakima River during snowmelt in April and May (Morace and others, 1999). During irrigation season, the highest rates of sediment transport to drains generally were associated with the growing of hops. Soil erosion from apple and pear orchards had been reduced through the use of sprinkler irrigation and grass cover.

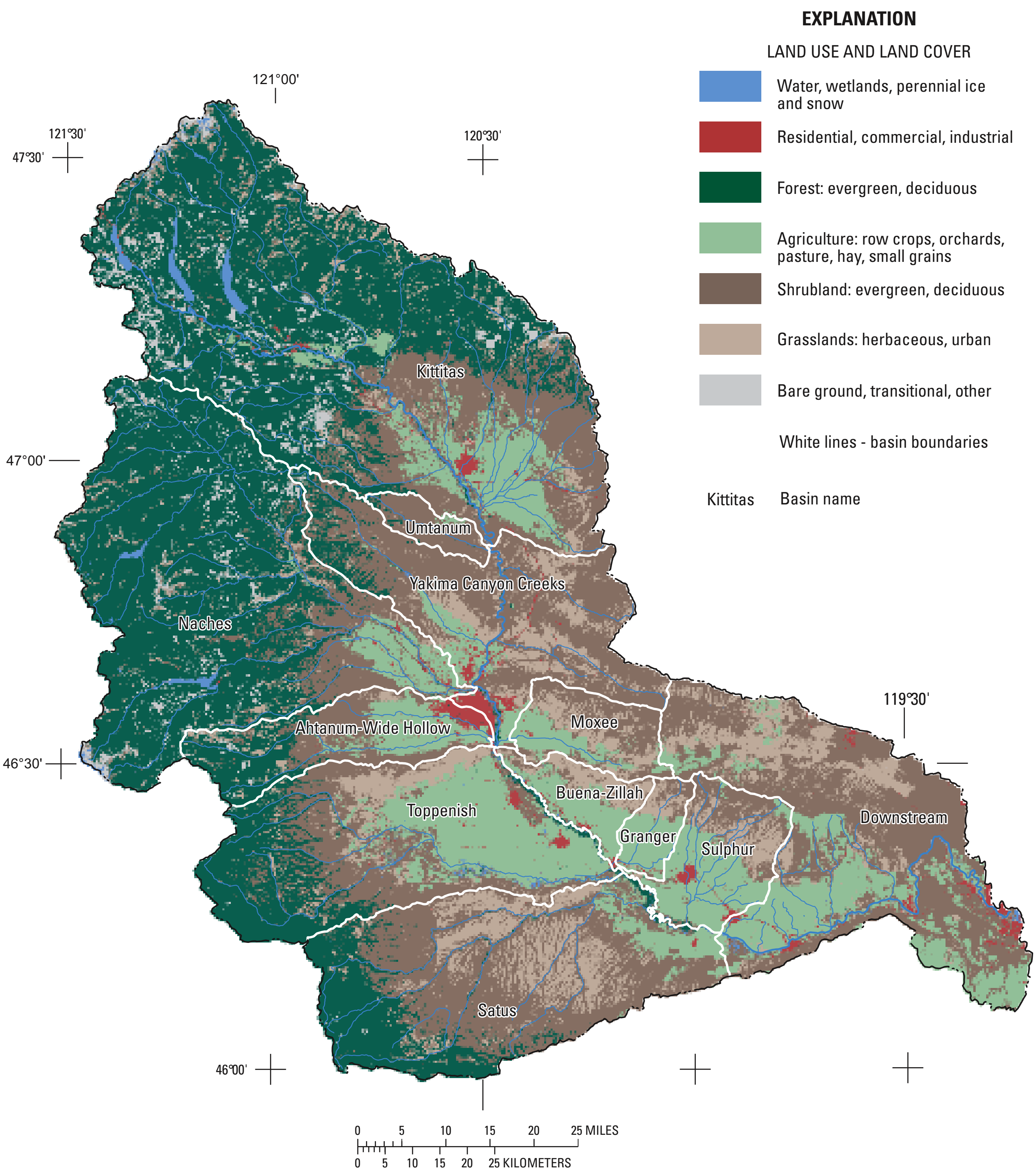


Figure 3. Land use and land cover in the Yakima River Basin, Washington, 1999.

Because soil erosion also transports nutrients and pesticides along with sediment to surface water, limiting erosion is an important aspect of improving surface-water quality. For example, because of significant correlations between turbidity and concentrations of total suspended solids and total DDT in the Yakima River, the Washington State Department of Ecology established target levels for turbidity as a way to reduce concentrations of total suspended solids and total DDT in the Yakima River (Joy and Patterson, 1997). The target turbidity levels were established to reduce concentrations of total DDT below 1 nanogram per liter (0.001 microgram per liter), which is the chronic toxicity criterion for the protection of aquatic life (State of Washington, 1997).

The pilot study concluded that cropland, dairies, feedlots, and wastewater treatment plants were important sources of nutrients in the Yakima River. Although nutrient loads discharged to the Yakima River from some wastewater treatment plants equaled those in some of the agricultural drains and wasteways, the drains and wasteways were considered the major source of nitrogen and phosphorus in the middle and lower reaches of the Yakima River (Pogue and others, 1999).

Because drains and wasteways are a major source of nitrogen and phosphorus in the middle and lower reaches of the Yakima River, the effects of increased use of nitrogen and phosphorus fertilizers on agricultural land in the Basin is of interest. Rinella and others (1992) reported that concentrations of nitrate in the Yakima River at Kiona (near the terminus of the Basin) almost doubled from 1965 to 1985 in response to a two-fold increase in the use of nitrogen fertilizers during the same period. In contrast, concentrations of total phosphorus in the Yakima River at Kiona decreased over the same period, even though the use of phosphorus fertilizers also increased by about a factor of two. This difference serves to illustrate the complex relation between land-use practices and the transport of nutrients to surface water.

Use of Agricultural Best Management Practices

Best management practices (BMPs) are defined as techniques and measures that prevent or reduce water pollution from nonpoint sources by using the most effective and practicable means of achieving water-quality goals. In the Yakima River Basin, agricultural BMPs focus primarily on farming techniques that reduce the transport of sediment, nutrients, and pesticides from cropland to surface water, and their use is encouraged as a way to reduce the environmental effects of agriculture on surface-water quality and to help meet the goals recommended for total maximum daily loads of suspended sediment and DDT (Joy and Patterson, 1997). BMPs are implemented by a landowner, often in conjunction with the local conservation agency or irrigation district, and most of the BMPs in the Yakima River Basin entail changes in the way irrigation water is applied. As an example, rill irrigation is discouraged in favor of less-erosive methods, such as sprinkler and drip irrigation. Other types of BMPs include diversion of irrigation runoff to ponds and wetlands where sediments settle out before the runoff is released to drains, and the addition of polyacrylamide (PAM) to irrigation water to increase the cohesiveness of soil particles, making the soil less subject to erosion. “Best Management Practices to reduce or control runoff can range from sophisticated drip-irrigation systems, sprinkler systems, and constructed wetlands to simpler practices such as gated pipe, PAM, and small sediment detention ponds. Some of these BMPs are partially funded through government cost-share and loan programs while others are paid for entirely by the landowner” (Marie Zuroske, South Yakima Conservation District, written commun., February 2003.)

Farmers have voluntarily constructed small ponds at low points in their fields in an attempt to remove sediment from runoff.

Drip irrigation system with buried line.

Farmers and ranchers in the Yakima River Basin have been encouraged to apply to local, State, and Federal agencies for grants and low-interest loans to help implement BMPs. For example, the Environmental Quality Incentives Program (EQIP) is a Federally funded cost-share program offered by the Farm Service Agency and the Natural Resources Conservation Service for farmers and ranchers in environmentally sensitive areas (U.S. Department of Agriculture, 1997). Created by Congress in 1996, EQIP provides technical, financial, and educational assistance. The Kittitas County, North Yakima, South Yakima, and Benton Conservation Districts (fig. 4) have prioritized areas for implementing BMPs. Prioritization has allowed conservation districts to optimally direct funds where needed and, together with EQIP funding, has resulted in grants of more than 4 million dollars since 1997. The effects of these funds on application of new irrigation methods alone covered more than 11,000 acres, or nearly 4 percent of the total agricultural acreage in the Basin.

The implementation of EQIP-sponsored BMPs varies throughout the Yakima River Basin (fig. 5). In 1996, Yakima Basin farmers competed for EQIP cost-share funds under a single Geographic Priority Area. Farms using furrow irrigation were identified as the dominant resource issue and received a higher priority for BMP conversions. Farmers in the lower Basin generally had higher cash-value crops and consequently were able to finance larger proportions of their EQIP cost share. The North Yakima and South Yakima Conservation Districts are located in the lower Basin, and through the EQIP program they assisted farmers by paying an average of 23 percent of the BMP cost (Alan Fulk, Natural Resource Conservation Service, oral commun., January 2002). Farms in the upper Basin would have required approximately 55 percent of the BMP cost to make the conversion economically feasible (Anna Lael, Kittitas County Conservation District, oral commun., April 2002). As a result, BMPs were underway in the lower Basin earlier than in the upper Basin. In 1997, the Kittitas Conservation District formed a single Geographic Priority Area for upper Basin farmers, and EQIP-sponsored BMPs were initiated in 1998.

Because detailed records of EQIP-sponsored BMPs are maintained for administering loan funds, EQIP-program data can serve as an indicator of BMP activity in subbasins of the Yakima River Basin. The data are only an indicator, because some BMPs, like the addition of PAM to irrigation water and the construction of sediment basins at the downslope end of fields, are financed entirely by farmers and ranchers and are not included in the EQIP records. In this report, the chronology of the implementation of BMPs in the Yakima River Basin (table 1) is compared in a qualitative way with data showing trends, or the lack of trends, in concentrations of suspended solids and nutrients. More specific information about BMP activity within subbasins is presented in the section "Trends in Concentrations."

Table 1. Chronology of implementation of best management practices sponsored by the Environmental Quality Incentives Program in the Yakima River Basin, Washington, 1996–2001

[**Subbasin**: Number following name of subbasin corresponds to map identification No. in table 2 and figure 6. BMP, best management practice. –, no data available]

Year	BMP usage, in acres		BMP usage, percentage of total cropland	
	Yearly	Cumulative	Yearly	Cumulative
Wilson Creek above Cherry Creek at Thrall (201)				
1996	–	–	–	–
1997	–	–	–	–
1998	191	191	0.9	0.9
1999	134	325	.6	1.5
2000	288	613	1.3	2.8
2001	–	–	–	–
Cherry Creek at Thrall (202)				
1996	–	–	–	–
1997	–	–	–	–
1998	337	337	0.9	0.9
1999	1,398	1,735	3.8	4.7
2000	395	2,130	1.1	5.8
2001	130	2,260	.4	6.2
Moxee Drain at Birchfield Road near Union Gap (69)				
[1]1996	1,148	1,148	6.2	6.2
1997	590	1,738	3.2	9.4
1998	344	2,082	1.9	11.3
1999	297	2,379	1.6	12.9
2000	527	2,906	2.9	15.8
2001	370	3,276	2.0	17.8
Granger Drain at Granger (67)				
1996	532	532	2.4	2.4
1997	328	860	1.4	3.8
1998	189	1,049	.8	4.6
1999	105	1,154	.5	5.1
2000	397	1,551	1.8	6.9
2001	1,753	3,304	7.7	14.6
Marion Drain at Indian Church Road at Granger (210)				
1996	121	121	0.2	0.2
1997	627	748	1.2	1.4
1998	267	1,015	.5	1.9
1999	243	1,258	.5	2.4
2000	180	1,438	.4	2.8
2001	1,051	2,489	2.1	4.9

Table 1. Chronology of implementation of best management practices sponsored by the Environmental Quality Incentives Program in the Yakima River Basin, Washington, 1996–2001—*Continued*

Year	BMP usage, in acres		BMP usage, percentage of total cropland	
	Yearly	Cumulative	Yearly	Cumulative
Toppenish Creek at Indian Church Road near Granger (211)				
1996	121	121	0.1	0.1
1997	1,080	1,201	1.1	1.2
1998	373	1,574	.4	1.5
1999	746	2,320	.7	2.2
2000	574	2,894	.6	2.8
2001	1,223	4,117	1.2	4.0
Sulphur Creek Wasteway near Sunnyside (215)				
1996	138	138	0.4	0.4
1997	634	772	1.7	2.1
1998	813	1,585	2.2	4.3
1999	579	2,164	1.5	5.8
2000	517	2,681	1.4	7.2
2001	1,449	4,130	3.9	11.1

[1]Includes acreage from 1995.

Figure 4. Conservation districts in the Yakima River Basin, Washington.

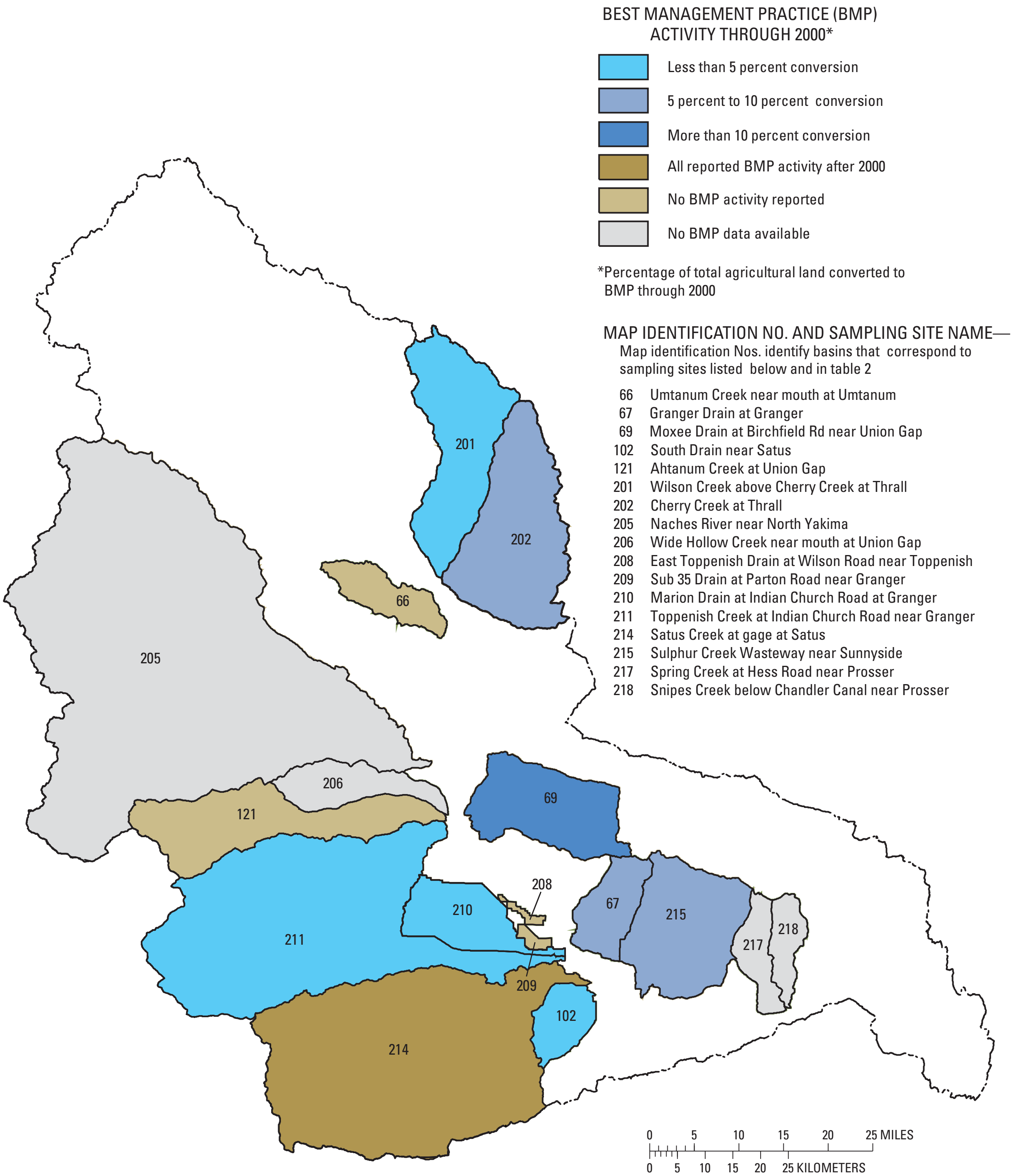


Figure 5. Status of agricultural best management practices sponsored by the Environmental Quality Incentives Program in subbasins of the Yakima River Basin through 2000.

METHODS

Surface-water sites and selected wastewater treatment-plant (WWTP) discharges throughout the Yakima River Basin were sampled for suspended sediment and nutrients on August 2-6, 1999, during dry weather at the peak of the irrigation season (fig. 6, table 2). Sampling of the Yakima River extended from Cle Elum (RM 182.5) to Kiona (RM 29.9). Other sampled surface-water sites and WWTP discharges were located along the reach of the Yakima River extending from RM 179.6 near Cle Elum to Spring and Snipes Creeks at RM 41.8 (fig. 6), but not all of them discharge directly to the Yakima River. Some discharge to tributaries of the Yakima River.

To the extent possible, basinwide sampling was timed according to the velocity of water as it moved downstream in the Yakima River. This is sometimes referred to as Lagrangian sampling, which can be visualized as sampling a distinct unit or "parcel" of water as it moves downstream. The advantage of this design is that it is possible to account for additions and losses of water, suspended sediment, nutrients, or any constituent, as the unit moves downstream. Some sites were sampled more than once during the basinwide sampling (table 2) to assess daily variations in concentrations and to bracket targeted sampling times if they were at night.

In addition to the basinwide sampling, the Yakima River at Kiona, Moxee Drain, and Granger Drain were sampled at fixed intervals (monthly or more frequently) from May 1999 through January 2000 to assess changes in concentrations of suspended sediment and nutrients over a longer period (fig. 6, table 2). Data from these samples also were used to estimate loads of sediment and nutrients transported during the sampling period. Additional data collected January 2001 through August 2002 at the Yakima River at Kiona, which are not included with the sample counts in table 2, were used to help evaluate the results of the regression models used to estimate loads.

This section presents an overview of standard USGS and NAWQA procedures governing sample collection, handling, and analysis in the field and laboratory. Procedures used by the BOR, Ecology, and RSBOJC to collect, process, and analyze samples are not presented here, but are discussed or referenced in Appendix A (at back of report). This section also includes information about quality assurance, methods used to estimate loads and test for trends, and sources of ancillary data. Additional information can be found in the publications cited in this section, some of which can be accessed on-line at the URLs <http://water.usgs.gov/>, <http://nwql.usgs.gov/Public/pubs-public.html>, and <http://nwql.usgs.gov/Public/nwql_memo.html>.

Sample Collection, Field Procedures, and Sample Preparation

The use of standard USGS sampling equipment, cleaning of equipment in preparation for the field, and the collection, processing, and handling of water samples generally followed the protocols and guidelines described in Ward and Harr (1990), Shelton (1994), and the National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, 1997-99). Samples representative of the flow in the stream cross section were obtained by collecting depth-integrated subsamples at equally spaced verticals across the stream using either the US DH-81 or US D-77TM sampler as described by Edwards and Glysson (1988) and Shelton (1994). Both samplers hold 3-liter Teflon sample bottles, and all parts of the sampler coming into contact with sample water were constructed of Teflon. Samples of the effluent from wastewater treatment plants were collected directly into 3-liter Teflon bottles. All equipment used to collect and process samples was cleaned with a 0.2-percent non-phosphate detergent, rinsed with deionized water, and then rinsed with native water prior to collection and processing.

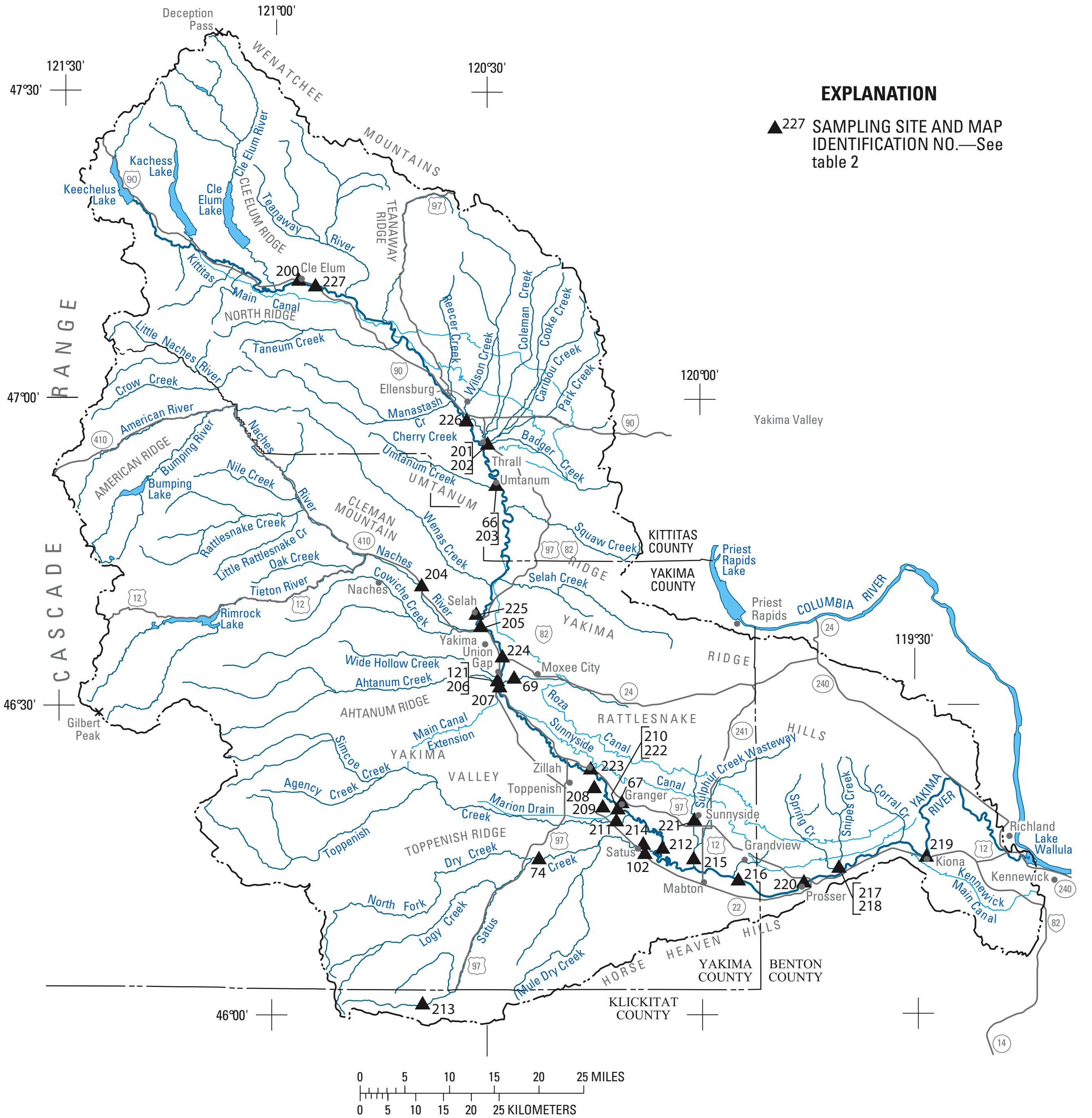


Figure 6. Location of surface-water sites and wastewater treatment plants sampled for suspended sediments and nutrients in the Yakima River Basin, Washington, 1999–2000.

Table 2. Surface-water sites and wastewater treatment plants sampled for suspended sediment and nutrients in the Yakima River Basin, Washington, 1999–2000

[**River mile sampled on Yakima River** or where tributary or wastewater treatment plant (WWTP) discharges to Yakima River. **Abbreviations**: USGS, U.S. Geological Survey; RM, river mile; –, not applicable]

Map identification No. (see fig. 6)	USGS site identification No.	Sampling site	River mile sampled: On Yakima River	River mile sampled: On tributary	Number of samples collected: During basinwide sampling August 1999	Number of samples collected: At fixed sites, May 1999 through January 2000
200	12479500	Yakima River at Cle Elum	182.5	–	1	–
227	471121120543400	Cle Elum WWTP	179.6	–	1	–
226	465748120325200	Ellensburg WWTP	151.6	–	1	–
201	12484100	Wilson Creek above Cherry Creek at Thrall	147	1.1	1	–
202	12484480	Cherry Creek at Thrall[1]	147	.1	1	–
203	12484500	Yakima River at Umtanum	140.4	–	1	–
66	12484550	Umtanum Creek near mouth at Umtanum	139.8	.1	1	–
225	463856120313000	Selah WWTP	117	–	1	–
204	12496510	Pacific Power and Light Company Wasteway[2]	116.3	.1	1	–
205	12499000	Naches River near North Yakima	116.3	.1	1	–
224	463447120275200	Yakima WWTP	111	–	1	–
206	12500445	Wide Hollow Creek near mouth at Union Gap	107.4	.8	1	–
69	12500420	Moxee Drain at Birchfield Road near Union Gap	107.3	1.4	2	25
207	12500450	Yakima River above Ahtanum Creek at Union Gap	107.3	–	1	–
121	12502500	Ahtanum Creek at Union Gap	106.9	.8	1	–
223	462357120153200	Zillah WWTP	89.5	–	1	–
208	12505350	East Toppenish Drain at Wilson Road near Toppenish	86	1.3	1	–
209	12505410	Sub 35 Drain at Parton Road near Granger	83.2	1.7	1	–
222	462013120113700	Granger WWTP	82.8	–	1	–
67	12505450	Granger Drain at Granger	82.8	.8	2	24
210	12505510	Marion Drain at Indian Church Road at Granger	82.6	1.4	1	–
211	12507508	Toppenish Creek at Indian Church Road near Granger	80.4	2.4	1	–
212	12507585	Yakima River at RM 72 above Satus Creek near Sunnyside	72	–	1	–
213	12507595	Satus Creek above Shinando Creek near Toppenish	69.6	41.3	1	–
74	12508500	Satus Creek below Dry Creek near Toppenish	69.6	15	1	–
214	12508620	Satus Creek at gage at Satus	69.6	2.7	1	–
102	12508630	South Drain near Satus	69.3	1.8	2	–
221	461850120005800	Sunnyside WWTP[3]	61	–	1	–
215	12508850	Sulphur Creek Wasteway near Sunnyside	61	.8	2	–
216	12509050	Yakima River at Euclid Bridge at RM 55 near Grandview	55	–	1	–
220	461246119454700	Prosser WWTP	47	–	1	–
217	461404119410400	Spring Creek at Hess Road near Prosser	41.8	.4	1	–
218	461414119404200	Snipes Creek below Chandler Canal near Prosser	41.8	.4	1	–
219	12510500	Yakima River at Kiona	29.9	–	3	16

[1]Cherry Creek discharges to Wilson Creek at RM 1.1.
[2]Pacific Power and Light Wasteway discharges to the Naches River at RM 9.7.
[3]Sunnyside WWTP discharges to Drainage Improvement District drain number 3, which discharges to Sulphur Creek.

Because more than 3 liters of water was needed for all types of analyses performed, several Teflon sample bottles were filled at each site. Water from all of the sample bottles was composited and split into aliquots for the various laboratory procedures using a Teflon cone splitter, as described by Shelton (1994). Sample water to be analyzed for determining concentrations of suspended sediment was collected from the cone splitter in glass bottles, which were shipped to the USGS Cascades Volcano Observatory Sediment Laboratory in Vancouver, Wash. Sample water to be analyzed for determining concentrations of nutrients was collected from the cone splitter in polypropylene receiving bottles. Sub-samples needed for determining concentrations of nutrients using unfiltered sample water were obtained by pouring water in one or more of the receiving bottles back through the cone and capturing the required sample volume. Sub-samples for determining concentrations of nutrients using filtered sample water (formerly referred to as a dissolved concentration) were obtained by filtering sample water through a polypropylene-encapsulated filter with a 0.45-micrometer pore size. The unfiltered nutrient samples were preserved with sulfuric acid and shipped, along with the filtered nutrient samples, on ice to the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colo.

Field Measurements

Water temperature, specific conductance, pH, and concentrations of dissolved oxygen (DO), alkalinity, and bicarbonate were measured in the field using procedures described in the National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, 1997-99). Water temperature and the concentration of dissolved oxygen were measured instream using an electronic thermistor and a DO meter. Specific conductance and pH were measured using unfiltered sample water taken from the cone splitter. Alkalinity, bicarbonate, and carbonate concentrations were determined by titrating filtered sample water with sulfuric acid using a digital titrator.

Laboratory Procedures

Suspended-sediment samples were analyzed using the filtration method (Guy, 1969) at the USGS Cascades Volcano Observatory Sediment Laboratory in Vancouver, Wash. Turbidity was measured using the nephelometric method (American Public Health Association and others, 1998) in field laboratories operated by RSBOJC in Sunnyside, Wash., and by the USGS in Pasco, Wash. Nutrient samples were analyzed using colorimetric methods (table 3) at the NWQL. Because concentrations of nitrite in surface water usually were very low or below laboratory reporting levels (see table A1), nitrite was not a significant fraction of the concentration of nitrite-plus-nitrate. Therefore, "nitrite-plus-nitrate" is often shortened to "nitrate" in this report.

Quality Assurance

In order to interpret water-quality data properly, information is needed to estimate bias and variability that result from sample collection, processing, and analysis. Data used for this purpose include field blanks to measure bias from contamination, replicate samples to measure variability, and blank water spiked in the laboratory to measure bias from recovery of analytes. Quality-control charts and reports published by the USGS Branch of Quality Systems (see Appendix A) also were used to assess bias and variability. For more about the collection of quality-control samples, see Shelton (1994).

Table 3. Laboratory methods used to determine concentrations of nutrient compounds in samples collected by the U.S. Geological Survey in the Yakima River Basin, Washington, 1999–2000

Analyte	Analytical method	Laboratory reporting level (milligrams per liter)	Reference
Nitrogen, ammonia	Colorimetric, salicylate-hypochlorite	0.041	Fishman, 1993
Nitrogen, ammonia-plus-organic filtered	Colorimetric, Kjeldahl digestion	.10	Patton and Truitt, 2000
Nitrogen, ammonia-plus-organic unfiltered	Colorimetric, Kjeldahl digestion	.10	Patton and Truitt, 2000
Nitrogen, nitrite	Colorimetric, diazotization	.008	Fishman, 1993
Nitrogen, nitrite-plus-nitrate	Colorimetric, cadmium reduction	.047	Fishman, 1993
Phosphorus, filtered	Colorimetric, Kjeldahl digestion	.004	Patton and Truitt, 1992
Phosphorus, unfiltered	Colorimetric, Kjeldahl digestion	.004	Patton and Truitt, 1992
Orthophosphate, filtered	Colorimetric, phosphomolybdate	.018	Fishman, 1993

Data collected by the RSBOJC, the BOR, and Ecology were used in this report to assess trends. Quality-control data provided by the RSBOJC are included in Appendix A. References and links to quality-control data and quality-assurance plans for the BOR and Ecology also are listed in Appendix A.

An evaluation of quality-control data (see Appendix A) indicates that bias and variability resulting from sample collection, processing, and analysis usually were much smaller than differences in concentration upon which conclusions about spatial and temporal changes in water quality were based. Although numerical information about the quality of data from the BOR and Ecology are not presented in Appendix A, both agencies were contacted to confirm that sampling and analytical methods had not changed over the period that trend analyses were performed.

Methods Used to Compute Concentrations and Estimate Loads

Concentrations of all nutrient compounds were determined by laboratory analysis except for total nitrogen, which was computed as the sum of concentrations of filtered nitrite-plus-nitrate and unfiltered ammonia-plus-organic nitrogen. Low concentrations are sometimes estimated or censored (reported as less than the laboratory reporting level). Estimated values were used for computing concentrations of total nitrogen, but censored values were not and thus were treated as a zero value.

Substitutions were made for missing laboratory data for two samples. In one, the concentration of ammonia-plus-organic nitrogen in a filtered sample was substituted for the concentration in an unfiltered sample. In the other, the concentration of phosphorus in a filtered sample was substituted for the concentration in an unfiltered sample.

Concentrations of suspended sediment and total nitrogen and phosphorus in samples collected during basinwide sampling in August 1999 were compared with a similar set of data collected in July 1988. For sites sampled more than once (tables 9 and 13 in Morace and others, 1999; table 2 in this report), mean concentrations were used. Instantaneous loads of total nitrogen and phosphorus in 1999 also were compared with those in 1988. They were computed as the product of a single or mean concentration and an instantaneous or daily mean water discharge.

Suspended-sediment and nutrient loads were estimated by the rating-curve method (Cohn and others, 1989; Crawford, 1991), which uses instantaneous sample concentrations and daily or unit streamflow data. The Loadest2 computer program was used to compute rating-curve estimates of annual, seasonal, and daily constituent loads. Rating-curve parameters are computed by the maximum-likelihood estimation (MLE) method (Dempster and others, 1977; Wolynetz, 1979) or the linear attribution estimation (LAE) method (Chatterjee and McLeish, 1986); either method can accommodate concentration data reported with multiple detection limits. The MLE method assumes that the rating-curve errors (regression-equation residuals) are normally distributed, whereas the LAE method does not (Charles Crawford, USGS, written commun., 1999). Output from Loadest2 includes statistics using the Turnbull-Weiss likelihood ratio normality test (Turnbull and Weiss, 1978) to help evaluate the validity of the normality assumption. The program allows the user to define the period of interest by not restricting the load estimate to calendar or water year, and the user can specify a rating-curve equation or allow the program to choose the regression equation that best describes the data using Aikaike's information criterion (Charles Crawford, USGS, written commun., 1999).

For estimating uncertainty in the average loads obtained by the MLE method, the program uses the method described by Likes (1980), which provides a minimum-variance unbiased estimate of the variance of a sum of lognormal variables, and Gilroy and others (1990), which calculates the exact variance of average constituent loads obtained by the rating-curve method when the rating-curve parameters and residual-error variance are known with certainty. For estimating uncertainty with the LAE method, the program uses the jackknife method (Efron, 1982), which is a robust method for examining sampling properties of a statistic with no requirement for distributional assumptions (Crawford, 1996). These methods and descriptions are detailed in Crawford (1996).

If there is no strong evidence of non-normality in the distribution of the residuals or the MLE and LAE methods result in similar estimates, then the results from the MLE method are typically selected for final load calculations (Charles Crawford, USGS, written commun., 1999). For these reasons, the MLE results were used for final load estimates of all constituents at Moxee Drain, Granger Drain, and Yakima River. The estimated average loads, standard deviations of the average loads, comparisons between measured and predicted loads, and the regression equations used to calculate suspended sediment and nutrient loads are in Appendix B, tables B1, B2, and B3 (at back of report).

Data sets used to calibrate the Loadest2 regression equations (see Appendix B) consisted of suspended-sediment and nutrient data collected by USGS during calendar years 1999–2000 and daily streamflow values for water years 1999–2000. For Moxee Drain, daily streamflows were available only from January 1999 to early June 2000. Annual and seasonal load estimates were reported for the period 1999–2000, water years 1999 and 2000, and calendar year 1999; loads for Moxee Drain were reported only for calendar year 1999. Seasonal loads for Granger Drain and Yakima River were calculated for the non-irrigation season using the period October 20 through March 20 and the irrigation season from the period March 21 through October 19. For Moxee Drain, seasonal loads for calendar year 1999 were calculated for the non-irrigation season using the periods January 1 to March 20, 1999, plus October 20, 1999 through December 31, 1999, and the irrigation season from the period March 21 through October 19, 1999.

Methods Used to Test for Trends

Data collected by the BOR, the RSBOJC, and Ecology at seven sites corresponding to, or near, those sampled by the USGS were used to assess trends in concentrations. The seasonal Kendall test (Crawford and others, 1983) was used to analyze for trends in concentration data provided by the BOR and Ecology for water years 1991–2000. Because data collected by the RSBOJC covered a shorter period (1997–2001), time-series graphs of concentrations were inspected to detect potential trends, but no statistical tests were performed using their data. To eliminate a potential source of error, data sets used to test for trends in concentrations represented one agency and one laboratory. Sample collection and analytical methods were verified as consistent over the period that trend data were collected. When more than one agency collected samples at the same location, the data were analyzed separately.

The seasonal Kendall test is a nonparametric test that compares the relative ranks of the data rather than the actual concentration values. Because monthly data were available, the seasons were defined to be the 12 months; therefore, only January data were compared with January data and so forth for the rest of the months. If more than one sample was collected during a month, the mean concentration was used determine the rank. All possible pairs of monthly data are compared in the test. If a value later in time is higher, then a plus is recorded; if a value later in time is lower, then a minus is recorded. If the values are the same, they are assigned an equal rank and neither a plus or minus is recorded. If an upward trend is present, there will be many more pluses than minuses. If no trend is present, then the numbers of pluses and minus are about equal. Because the seasonal Kendall test uses ranks instead of concentration values, it easily handles censored (less-than) values (Crawford and others, 1983), but none of the data used to test for trends was censored.

Using flow-adjusted concentrations to test for trends is recommended if there is an indication that streamflow has a considerable influence on concentrations (Helsel and Hirsch, 1992). Streamflow is often a major source of variability in concentrations, and removing that variability can make it easier to detect a trend. Even though scatter plots indicated that the influence of streamflow on constituent concentrations varied by site and by constituent (the scatter plots are presented in section "Trends in Concentrations"), all trend tests were performed using both flow-adjusted concentrations and unadjusted concentrations.

The process of computing flow-adjusted concentrations involves modeling the effect of streamflow on concentration using regression or some other curve-fitting technique. For this study, the locally weighted scatter plot smoothing (LOWESS) technique (Cleveland, 1979) was used to fit a curve (the middle smooth line) to a scatter plot of concentrations and corresponding stream discharges. Flow-adjusted concentrations were computed by subtracting concentrations defined by the middle smooth line from corresponding measured concentrations, and then adding the results (the residuals) to the mean of the measured concentrations. In effect, this is the same as performing the trend tests on the residuals. Adding the residuals to the mean concentration was done so that trend slopes could be expressed in concentration units.

Scatter plots of the residuals versus corresponding values on the middle smooth line were used to check the fit of the LOWESS curve to the data. This was done by visual inspection to determine if the residuals trended upward or downward with concentration or if the scale of the residuals increased or decreased with concentration. If the residuals showed a trend or appeared to be scale dependent, the value of the smoothness factor, which was set to 0.5 initially, was changed and the fit with the LOWESS curve was checked. The smoothness factor alters the number of data points included in each iteration of the regressions used to obtain the LOWESS curve (Helsel and Hirsch, 1992).

A trend was considered to be statistically significant if the *p*-value from the seasonal Kendall test was less than or equal to 0.10; however, the *p*-values are listed in this report so that it is possible for the reader to assign a different level of significance. Because no more than 10 years of data were used for trend testing, the *p*-values were not adjusted for serial correlation (Hirsch and Slack, 1984); however, keeping the number of seasons relatively small, such as the selection of 12 seasons, helps to reduce problems resulting from serial correlation (Crawford and others, 1983).

Sources of Streamflow and Precipitation Data

Daily streamflow data were available from gaging stations at the three sites sampled at fixed intervals. The streamflow gaging station on the Yakima River at Kiona (station 12510500) is operated by the USGS. Data for Moxee Drain at Birchfield Road near Union Gap (station 12500420) were collected in cooperation with the North Yakima Conservation District and the BOR. Discharge records for the station on Granger Drain at Granger (station 12505450) were provided by the Sunnyside Valley Irrigation District and reviewed by the USGS.

Daily precipitation data from National Weather Service data-collection sites were obtained from monthly publications of climatological data by the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (National Oceanic and Atmospheric Administration, 1999 and 2000). For Yakima River at Kiona, the weather site at Richland was the primary source of precipitation data and data from weather sites at Prosser or Smyrna were used for estimating brief periods of missing data at the Richland site. For Granger Drain, the weather site at Sunnyside was the primary source of precipitation data, and data from Wapato and Yakima Airport were substituted for missing data at the Sunnyside site. For Moxee Drain, the weather site at Moxee City was the primary source of data and precipitation data from Yakima Airport were used for estimating missing data at Moxee City.

Water leaking from the Roza Canal is captured and returned by an electrical pump.

CONCENTRATIONS AND LOADS

Because streamflow in agricultural drains in the Yakima River Basin is controlled mostly by the irrigation cycle, base flows are in winter and high flows are in spring and summer. As illustrated by data from Moxee and Granger Drains, variations in concentrations of nutrients and suspended sediment are linked to the irrigation cycle and resulting changes in streamflow (figs. 7*A* and 7*B*). Concentrations of nitrate and total nitrogen in both drains increase as streamflow decreases in late October and early November at the end of the irrigation season. After the irrigation season, water is not diverted from the Yakima River, and the drains carry no canal water, which dilutes nitrate discharged to them from the shallow ground-water system. Most of the total nitrogen in these drains is in the form of dissolved nitrate. Variations in streamflow and concentrations of nitrate and total nitrogen in Moxee and Granger Drains are typical of those in drains and wasteways in other irrigated parts of the Central Columbia Plateau (Williamson and others, 1998).

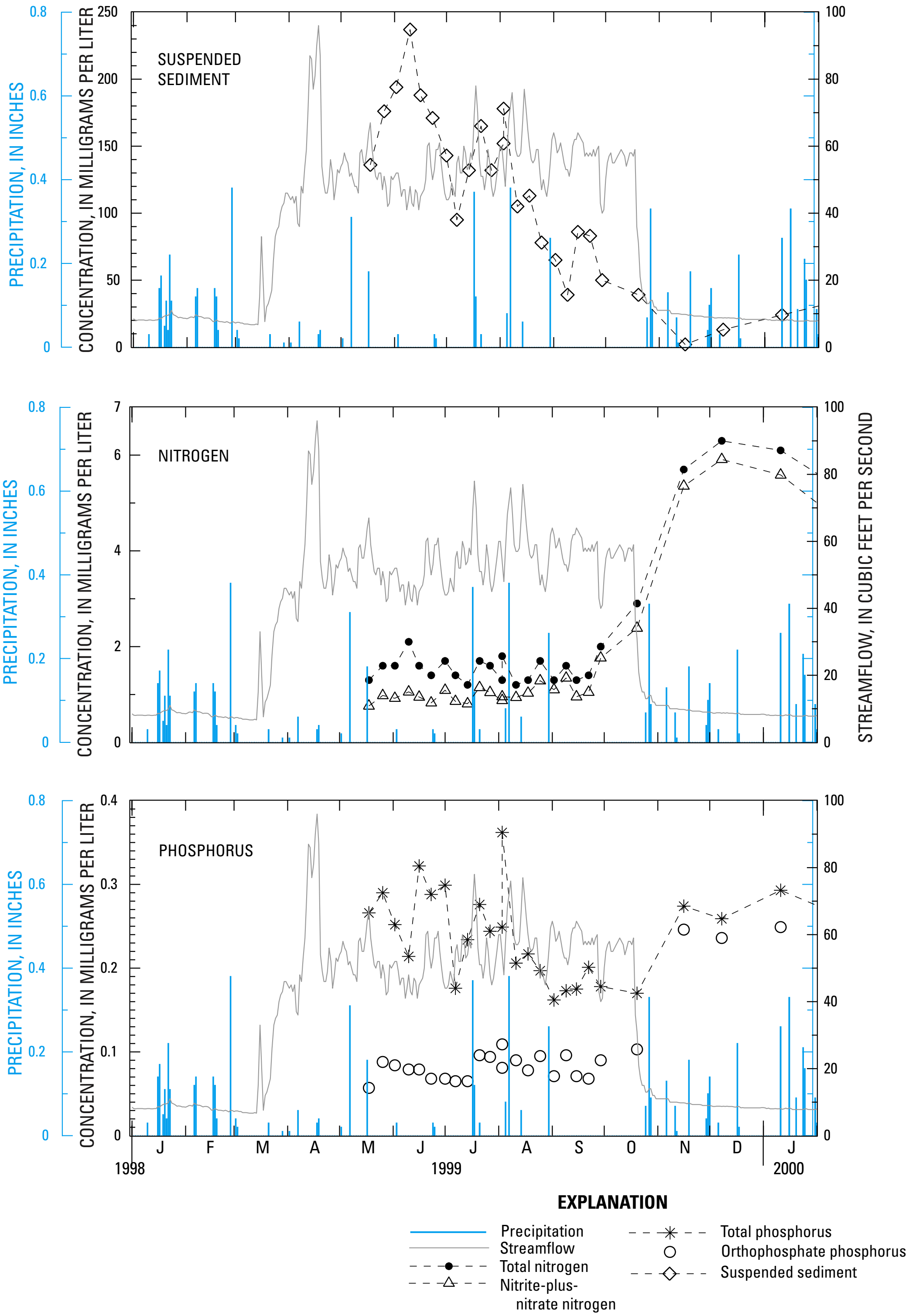
There also was an inverse relation between streamflow and concentrations of nitrate and total nitrogen in the Yakima River at Kiona (fig. 7*C*). Because of diversions, flow regulation in the headwaters, and dry summers, the Yakima River at Kiona differs hydrologically from Moxee and Granger Drains, with a low-flow period during late summer instead of during winter and streamflows that generally vary more in magnitude during the remainder of the year. Nitrate and total nitrogen in the Yakima River are diluted by increased streamflow from storm runoff and snowmelt (Pogue and others, 1999).

Concentrations of suspended sediment in Moxee and Granger Drains were highest during the irrigation season because runoff of applied irrigation water transports soil from fields to the drains. Rainfall runoff also can transport sediment to drains, but there was no evidence of a large rain event in the streamflow record for November 1999 through January 2000 and concentrations of suspended sediment were relatively low during that period (figs. 7*A* and 7*B*). The highest concentration of suspended sediment in the Yakima River at Kiona was during high flow in June 1999 (fig. 7*C*). High flows resulting from snowmelt in the spring and early summer scour sediment deposited in the river during the previous irrigation season (Bramblett and Fuhrer, 1999).

Because of the association between phosphorus and suspended sediment (Litke, 1999), concentrations of total phosphorus often increased when concentrations of suspended sediment increased (fig. 7). For example, the highest concentration of total phosphorus in the Yakima River at Kiona coincided with the highest concentration of suspended sediment (fig. 7*C*), and most of the phosphorus in that sample was in the form of sediment-sorbed phosphorus.

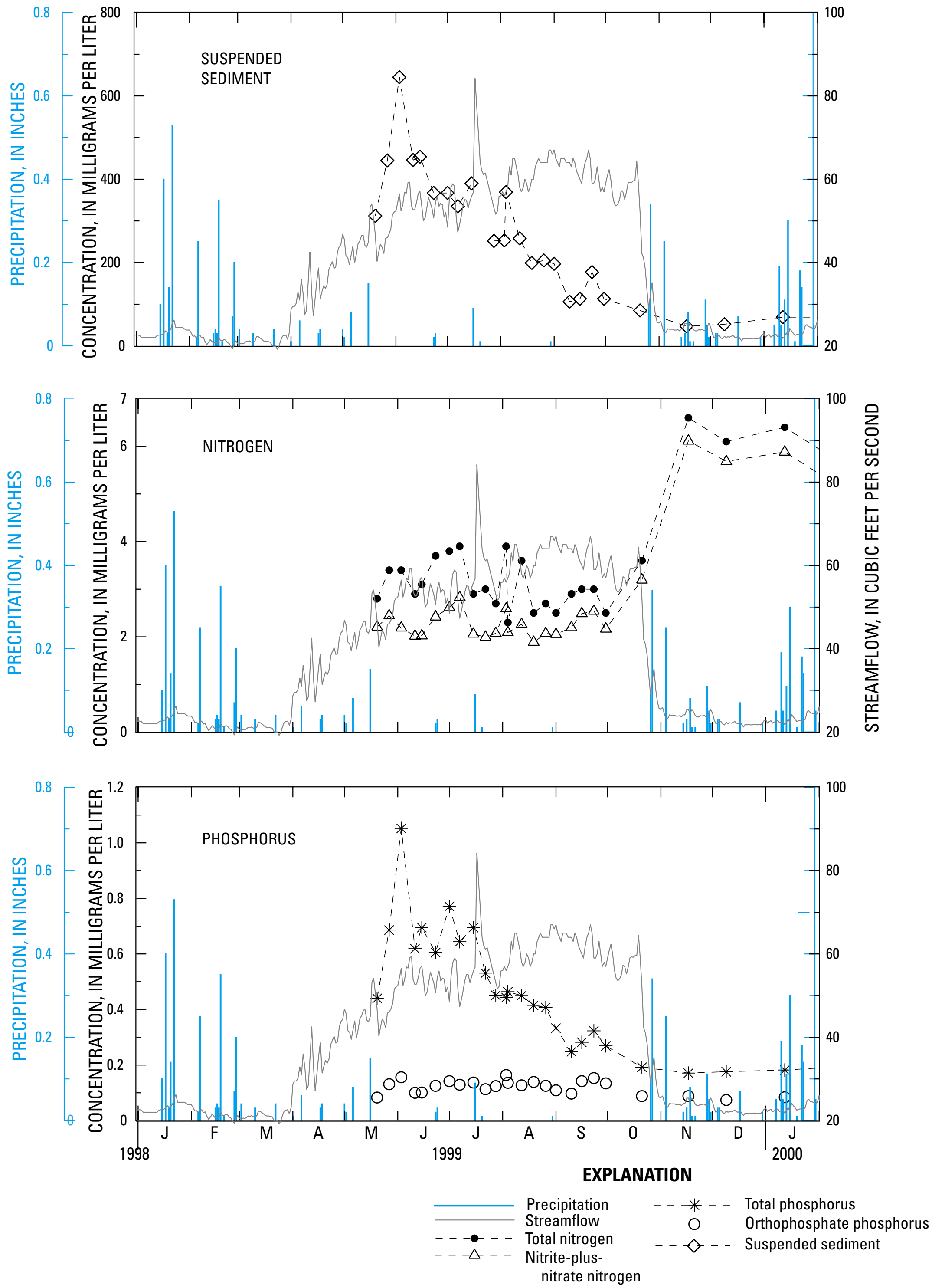
At lower flows when concentrations of suspended sediment generally were lower, concentrations of total phosphorus were also lower and dissolved orthophosphate made up a larger fraction of the total phosphorus (fig. 7). In Moxee Drain, however, concentrations of total phosphorus and dissolved orthophosphate increased after the irrigation season (fig. 7*A*), possibly because the drain receives effluent from the Moxee City wastewater treatment plant. After the irrigation season, there is less streamflow in the drain to dilute the orthophosphate.

Rill irrigation can mobilize sediment to adjacent water ways.



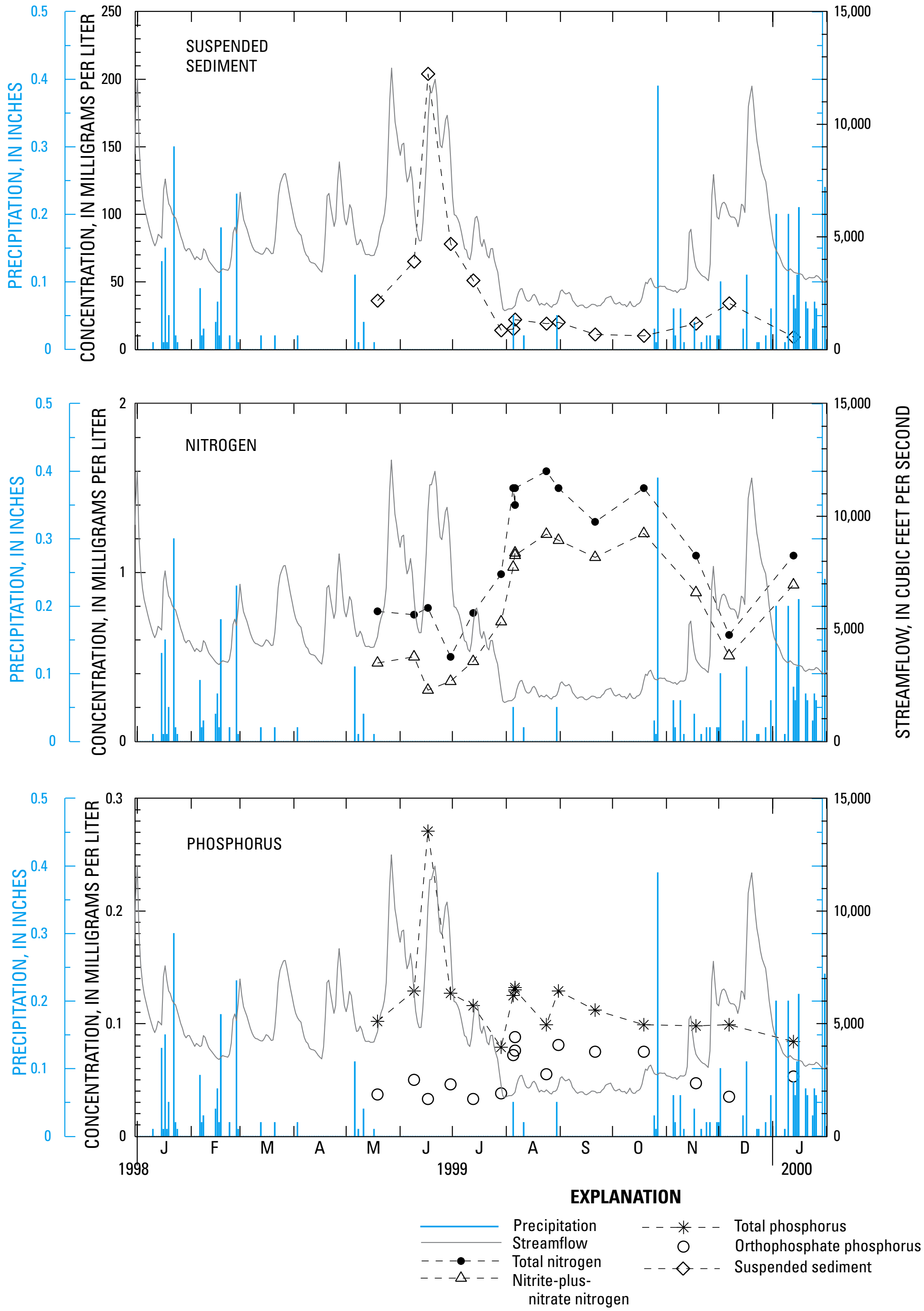
***A.* Moxee Drain at Birchfield Road near Union Gap**

Figure 7. Daily streamflow and concentrations of suspended sediment, total and nitrite-plus-nitrate nitrogen, total phosphorus and orthophosphate (as P) in samples collected from selected surface-water sites in the Yakima River Basin, Washington, May 1999-January 2000.



***B.* Granger Drain at Granger**

Figure 7.—*Continued.*



***C.* Yakima River at Kiona**

Figure 7.—*Continued.*

Results of Basinwide Sampling, August 1999 and July 1988

Data collected during basinwide sampling on August 2-6, 1999, when streamflow in the Yakima River was relatively steady, were used to develop profiles of concentrations and instantaneous loads of suspended sediment and nutrients in surface water. Streamflow in the Yakima River during 1999 was above average. The annual mean streamflow in the Yakima River at Kiona during the 1999 water year was 4,374 ft^3/s (cubic feet per second), compared with the mean annual flow of 3,569 ft^3/s for water years 1934-99 (Zembrzuski and others, 2001). Except for some differences in constituents analyzed for and sites sampled, sampling in August 1999 was a repeat of basinwide sampling conducted by the USGS on July 26-29, 1988, when streamflow in the Yakima River was much less than average. The annual mean streamflow in the Yakima River at Kiona during the 1988 water year was only 1,905 ft^3/s (Miles and others, 1989).

Relatively pristine water is captured in the upper basin to meet demands during peak irrigation.

Morace and others (1999) observed that during July and August, concentrations of suspended sediment and nutrients in the Yakima River increase as the relatively pristine water from the forested headwaters flows into the areas of agricultural and urban land use (fig. 3) where streams, agricultural drains, and wastewater treatment plants discharge suspended sediment and nutrients to the river. When streamflow in the Yakima River is relatively steady and there is little or no scour of streambed sediment, concentrations of nutrients and suspended sediment in the river should be governed to some degree by the proportion of water from the forested headwaters that mixes with water discharged to the river from streams, drains, and wastewater treatment plants. When there is more flow from forested headwaters, concentrations of constituents discharged to the river should be lower because of dilution. A comparison of constituent concentrations in the Yakima River in August 1999 with concentrations in July 1988 provides a test of this hypothesis.

For the most part, the data from August 1999 and July 1988 are consistent with the predictions of a simple dilution model. Except for concentrations of suspended sediment in the Yakima River at RM 72 and concentrations of total nitrogen in the Yakima River above Ahtanum Creek at Union Gap (RM 107.3) and Kiona (RM 29.9), concentrations of suspended sediment and total nitrogen and phosphorus in the middle and lower reaches of the Yakima River (RM 140.5 to the mouth) were lower in August 1999 than in July 1988 (table 4, fig. 8). Although the data are consistent with predictions of a simple dilution model, a more detailed analysis is needed to examine how dilution affects constituent concentrations in the Yakima River because the amount of flow and the quality of water in agricultural drains discharging to the river are affected by the availability of irrigation water. Compared with 1999, irrigation water was in short supply in 1988.

Table 4. Comparison of concentrations of suspended sediment, total nitrogen, and total phosphorus in surface water of the Yakima River Basin, Washington, during basinwide sampling, July 26–29, 1988, and August 2–6, 1999

[**Date sampled:** 1988 and 1999 samples were collected at the same site unless otherwise indicated. Some samples were collected outside the July 26–29, 1988 period. Relative percentage of difference (RPD) = (1999 value – 1988 value) × 100/(0.5 × (1999 value + 1988 value)). **Abbreviations**: USGS, U.S. Geological Survey; WWTP, wastewater treatment plant; RM, river mile; nc, not computed; –, no sample]

USGS site identification No.	Sampling site (map identification No. in fig. 6)	Date sampled and relative percentage of difference (RPD)	Concentration, in milligrams per liter		
			Suspended sediment	Total nitrogen	Total phosphorus
12479500	Yakima River at Cle Elum (200)	July 26, 1988[1]	5	0.16	0.01
		August 2, 1999	3	.16	.01
		RPD	-50	0	0
471121120543400	Cle Elum WWTP (227)	July 25, 1988	–	5.7	2.3
		August 2, 1999	46	4.6	3.8
		RPD	nc	-21	49
465748120325200	Ellensburg WWTP (226)	July 26, 1988	–	2.2	1.2
		August 2, 1999	4	4.3	1.2
		RPD	nc	65	0
12484100	Wilson Creek above Cherry Creek at Thrall (201)	July 26, 1988	10	1.1	.16
		August 2, 1999	16	.97	.12
		RPD	46	-13	-29
12484480	Cherry Creek at Thrall (202)	July 26, 1988	82	3.8	.25
		August 2, 1999	38	.65	.25
		RPD	-73	-142	0
12484500	Yakima River at Umtanum (203)	July 27, 1988[2]	20	.15	.04
		August 2, 1999	10	.41	.04
		RPD	-67	93	0
12484550	Umtanum Creek near mouth at Umtanum (66)	September 18, 1990	–	.20	.08
		August 2, 1999	3	.18	.11
		RPD	nc	-11	32
463856120313000	Selah WWTP (225)	July 26, 1988	–	12	6.3
		August 3, 1999	6	9.5	5.4
		RPD	nc	-23	-15
12499000	Naches River near North Yakima (205)	July 16, 1988	3	.16	.02
		August 3, 1999	9	.05	.02
		RPD	100	-105	0
463447120275200	Yakima WWTP (224)	July 26, 1988	–	12	3.7
		August 3, 1999	5	8.1	1.7
		RPD	nc	-39	-74
12500445	Wide Hollow Creek near mouth at Union Gap (206)	July 27-28, 1988[2]	8	1.4	.14
		August 3, 1999	6	2.1	.11
		RPD	-29	40	-24

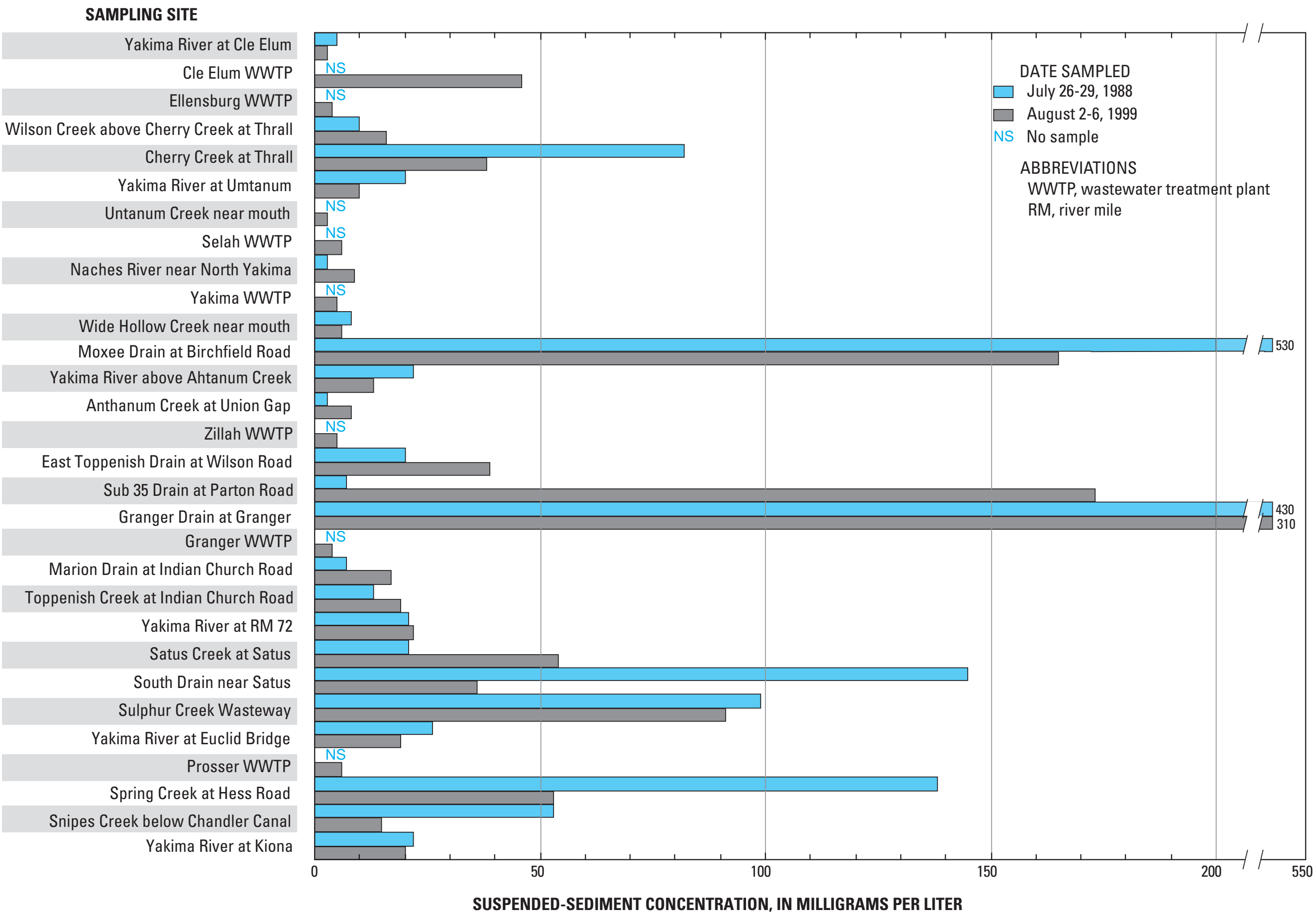
Table 4. Comparison of concentrations of suspended sediment, total nitrogen, and total phosphorus in surface water of the Yakima River Basin, Washington, during basinwide sampling, July 26–29, 1988, and August 2–6, 1999—*Continued*

USGS site identification No.	Sampling site (map identification No. in fig. 6)	Date sampled and relative percentage of difference (RPD)	Concentration, in milligrams per liter		
			Suspended sediment	Total nitrogen	Total phosphorus
12500430	Moxee Drain at Thorp Road	July 26-29, 1988[3]	530	1.8	0.32
12500420	Moxee Drain at Birchfield Road near Union Gap (69)	August 3, 1999[2]	170	1.5	.31
		RPD	-107	-18	-3.2
12500450	Yakima River above Ahtanum Creek at Union Gap (207)	July 27, 1988	22	0.16	.09
		August 3, 1999	13	.25	.05
		RPD	-51	44	-57
12502500	Ahtanum Creek at Union Gap (121)	July 26, 1988	3	.87	.13
		August 3, 1999	8	.47	.13
		RPD	-91	-60	0
462357120153200	Zillah WWTP (223)	July 27, 1988	–	8.0	9.7
		August 3, 1999	5	21	5.0
		RPD	nc	90	-64
12505350	East Toppenish Drain at Wilson Road near Toppenish (208)	July 27, 1988	20	4.5	.31
		August 3, 1999	39	3.2	.19
		RPD	64	-34	-48
12505410	Sub 35 Drain at Parton Road near Granger (209)	July 27, 1988	7.0	2.4	.09
		August 3, 1999	170	2.5	.17
		RPD	184	4.1	62
12505460	Granger Drain at mouth	July 28, 1988[2]	430	3.4	.52
12505450	Granger Drain at Granger (67)	August 3-4, 1999[2]	310	3.1	.45
		RPD	-32	-9.2	-14
462013120113700	Granger WWTP (222)	July 27, 1988	–	4.0	3.7
		August 4, 1999	4	22	1.2
		RPD	nc	138	-102
12505510	Marion Drain at Indian Church Road at Granger (210)	July 28, 1988[2]	7	2.8	.11
		August 4, 1999	17	2.7	.12
		RPD	83	-3.6	8.7
12507508	Toppenish Creek at Indian Church Road near Granger (211)	July 28, 1988	13	2.9	.11
		August 4, 1999	19	2.5	.13
		RPD	38	-15	17
12507585	Yakima River at RM 72 above Satus Creek near Sunnyside (212)	July 28, 1988	21	1.5	.10
		August 4, 1999	22	1.0	.06
		RPD	4.6	-40	-50

Table 4. Comparison of concentrations of suspended sediment, total nitrogen, and total phosphorus in surface water of the Yakima River Basin, Washington, during basinwide sampling, July 26–29, 1988, and August 2–6, 1999—*Continued*

USGS site identification No.	Sampling site (map identification No. in fig. 6)	Date sampled and relative percentage of difference (RPD)	Concentration, in milligrams per liter		
			Suspended sediment	Total nitrogen	Total phosphorus
12508620	Satus Creek at gage at Satus (214)	July 29, 1988	21	2.6	.13
		August 4, 1999	54	1.9	.17
		RPD	88	-31	27
12508630	South Drain near Satus[4] (102)	August 16, 1986	140	3.7	0.13
		August 4-5, 1999[2]	36	2.6	.22
		RPD	-118	-35	51
12508850	Sulphur Creek Wasteway near Sunnyside (215)	July 28, 1988[2]	99	3.8	.27
		August 4-5, 1999[2]	91	2.6	.24
		RPD	-8.4	-38	-12
12509050	Yakima River at Euclid Bridge at RM 55 near Grandview (216)	July 28, 1988[2]	26	1.9	.14
		August 5, 1999	19	1.4	.10
		RPD	-31	-30	-33
461246119454700	Prosser WWTP (220)	July 29, 1988	–	4.1	17
		August 5, 1999	6	1.5	2.7
		RPD	nc	-93	-145
12509710	Spring Creek at mouth	July 29, 1988[2]	140	1.2	.14
461404119410400	Spring Creek at Hess Road near Prosser (217)	August 5, 1999	53	0.84	.12
		RPD	-90	-35	-15
12509829	Snipes Creek at mouth	July 29, 1988	53	.38	.09
461414119404200	Snipes Creek below Chandler Canal near Prosser (218)	August 5, 1999	15	.83	.07
		RPD	-112	74	-25
12510500	Yakima River at Kiona (219)	July 29, 1988	22	1.5	.14
		August 5-6, 1999[5]	20	1.5	.13
		RPD	-9.5	0	-7.4
		Median of the absolute value of RPD	66	35	24

[1]Total nitrogen and phosphorus concentrations in a sample collected July 12, 1988.
[2]Two samples collected. Concentrations are mean values.
[3]Four samples collected. Concentrations are mean values.
[4]Concentration of suspended sediment in a sample collected June 27, 1989.
[5]Three samples collected. Concentrations are mean values.

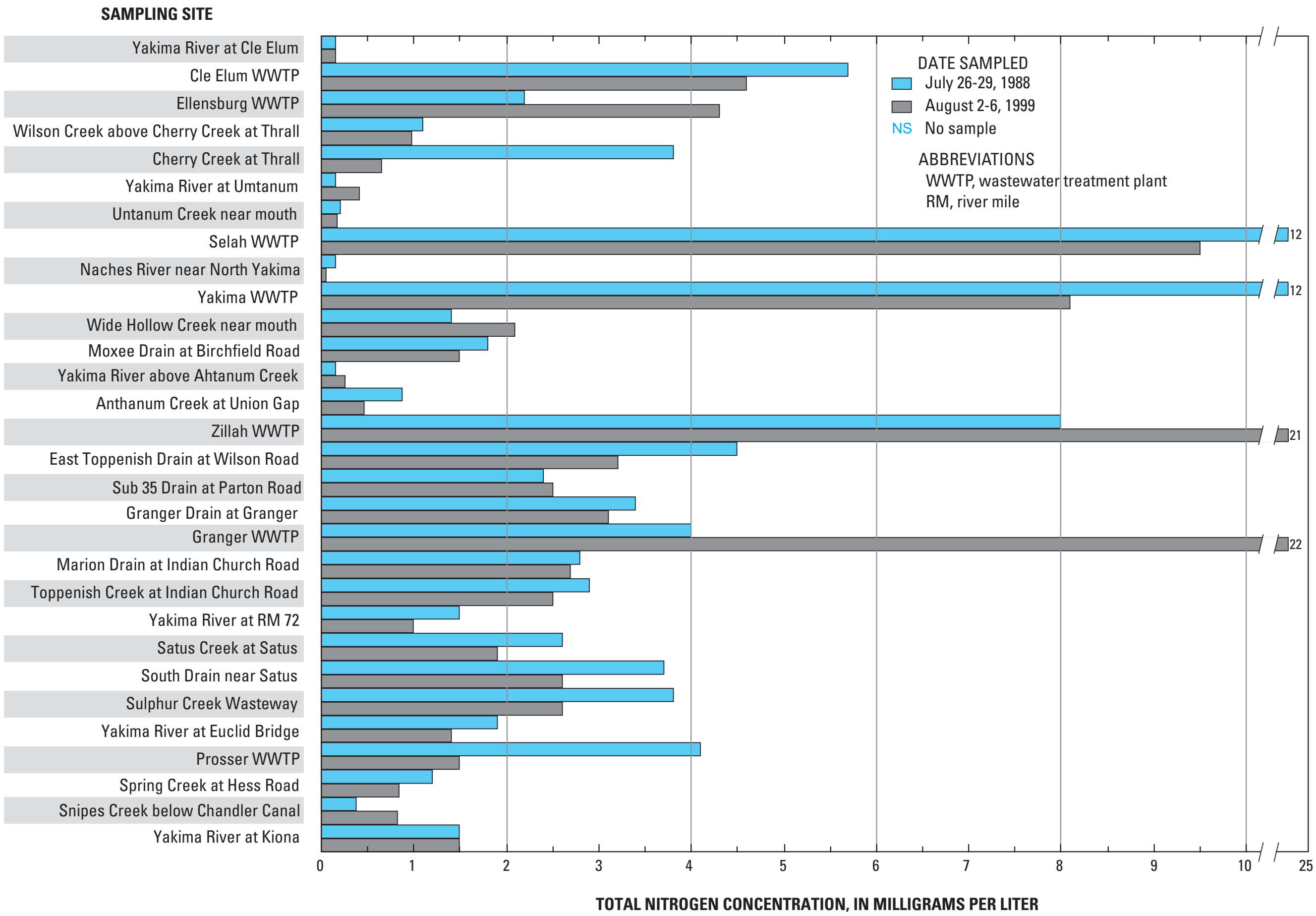


***A.* Suspended sediment**

Figure 8. Concentrations of suspended sediment, total nitrogen, and total phosphorus in the main stem Yakima River, selected major tributaries, and discharges from wastewater treatment plants, Yakima River Basin, Washington, July 26-29, 1988, and August 2-6, 1999.

In plentiful water-supply years, some irrigation water is spilled directly into agricultural drains.

Morace and others (1999) used mass-balance analyses to study the dynamics of suspended-sediment and nutrient transport in the Yakima River in July 1988. For selected reaches of the river, loads of suspended sediment and nutrients were computed at the downstream end of a reach by subtracting loads leaving the reach through diversions from loads entering the upstream end of the reach plus loads discharged to the reach from drains, streams, and wastewater treatment plants. Computed loads were compared with loads measured at the downstream ends of reaches to determine how well the mass-balance computations accounted for gains and losses. If a measured load was greater than a computed load, the analysis suggested the presence of unmeasured contributions. If a measured load was less than a computed load, the



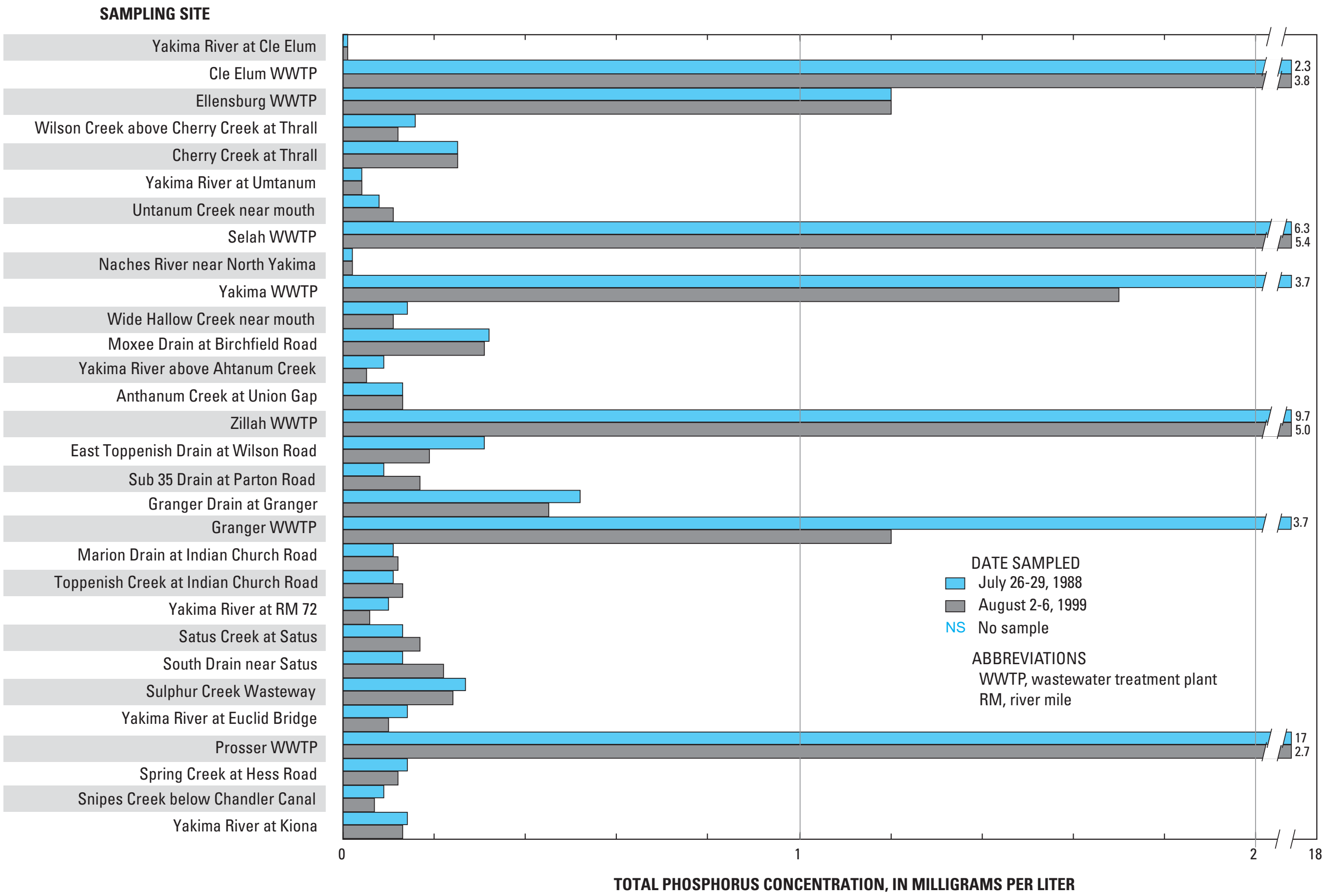
***B.* Total nitrogen**

Figure 8.—*Continued.*

analysis suggested unmeasured losses. Other factors, including temporal variability (non-steady state conditions), measurement errors, settling or scouring of sediment and associated nutrients, and uptake and(or) degradation of nutrients, also could account for differences.

A comparison of the results of mass-balance analyses performed using the August 1999 nutrient data with the results of the analyses performed by Pogue and others (1999) using the July 1988 nutrient data indicates that nitrogen and phosphorus loads discharged to the river were diluted more in August 1999 than in July 1988 (table 5 and table C1, Appendix C, at back of report). In August 1999, for example, streamflow in the reach of the Yakima River extending from river mile 103.7 to river mile 72 exceeded streamflow in July 1988 by a factor of almost 2.5, but loads of total nitrogen and phosphorus discharged to this reach from streams, drains, and wastewater treatment plants were only 1.2 and 1.1 times larger (table 5). The higher ratio of streamflow to loads of nitrogen and phosphorus discharged to this reach of the river in August 1999 resulted in lower concentrations.

Overall, the mass-balance analyses indicate that more of the flow in the reach of the Yakima River extending from river mile 103.7 to river mile 55 was derived from tributary discharges in July 1988 than in August 1999 (table 5). This, coupled with the fact that average concentrations of total nitrogen and phosphorus in the tributaries were higher than concentrations in the Yakima River (tables 5 and C1), means that in July 1988, more of the nitrogen and phosphorus in this reach of the Yakima River was derived from tributary discharges.



***C*. Total phosphorus**

Figure 8.—*Continued.*

The fact that average concentrations of total nitrogen in tributaries discharging to the Yakima River were lower in August 1999 than in 1988 (table 5) indicates that there is increased dilution of nitrogen in drain water during years when the water supply is relatively good. In years when the water supply is plentiful, there is more water available for irrigation, and water in agricultural drains contains a higher percentage of canal water. Because irrigation water is diverted from the Yakima and Naches Rivers, the concentration of total nitrogen in canal water is relatively low compared with concentrations in ground water and excess irrigation water collected at the downslope ends of fields. The reason that there was little or no difference between average concentrations of total phosphorus in the tributaries in July 1988 and August 1999 (table 5) is that concentrations of phosphorus in ground water in irrigated areas are much lower than concentrations of nitrate (Williamson and others, 1998), and nitrate makes up much of the total nitrogen in the drain water (figs. 7*A* and 7*B*).

Concentrations of phosphorus are of interest because phosphorus is often the nutrient that limits undesirable plant growth in streams (Wetzel, 1983). Even with more dilution, concentrations of total phosphorus in all but one sample (at RM 72) collected from the middle and lower reaches of the river in August 1999 were greater than 0.1 mg/L, which is the recommended maximum concentration for limiting undesirable plant growth in streams (U.S. Environmental Protection Agency, 1986). Revised nutrient criteria are being developed on a regional basis (U.S. Environmental Protection Agency, 1998), but they are not yet available for the Yakima River Basin, and it is not known how the criterion for phosphorus might change.

Table 5. Results of mass-balance computations comparing streamflow and loads of total nitrogen and phosphorus in the reach of the Yakima River extending from river mile 103.7 to river mile 55, Yakima River Basin, Washington

[Tributaries include streams, agricultural drains, and wastewater treatment plants. Details of mass-balance computations appear in table C1. **Streamflow, Concentration, Load**: Measured at downstream end of reach; data for 1988 are from Pogue and others (1999). **Fraction of flow and load**: From tributaries discharging to the reach. **Abbreviations:** ft^3/s, cubic feet per second; mg/L; milligrams per liter; lb/d, pounds per day; RM, river mile]

Reach of Yakima River	Year	Measured			Inflow to reach (ft^3/s)			Fraction of flow (percent)	Loading to reach (lb/d)			Fraction of load (percent)	Average concentration in tributary inflows (mg/L)
		Streamflow (ft^3/s)	Concentration (mg/L)	Load (lb/d)	River	Tributaries	Unmeasured		River	Tributaries	Unmeasured		
Total nitrogen													
RM 103.7 –72	1988	513	1.5	4,100	163	235	115	45.7	440	4,000	-339	97.5	3.16
	1999	1,270	1.03	7,060	725	337	209	26.5	993	4,770	1,290	67.6	2.63
RM 72 – 55	1988	972	1.9	10,000	513	403	56	41.5	4,100	6,960	-1,060	69.6	3.20
	1999	2,050	1.41	15,600	1,270	421	359	20.5	7,060	5,340	3,200	34.2	2.35
Total phosphorus													
RM 103.7 – 72	1988	513	0.10	280	163	235	115	45.7	44	335	-99	120	0.26
	1999	1,270	.06	440	725	337	209	26.5	199	370	-131	84.3	.20
RM 72 –55	1988	972	.14	680	513	403	56	41.5	280	432	-32	63.5	.20
	1999	2,050	.10	1,150	1,270	421	359	20.5	439	454	258	39.5	.20

Nuisance algal growth in a Yakima River Basin agricultural drain.

In July 1988, concentrations of total phosphorus in all samples collected from the reach of the Yakima River from RM 72 to Kiona at RM 29.9 were greater than or equal to 0.1 mg/L (fig. 8C). Pogue and others (1999) reported that although conditions conducive to accelerated plant growth existed in this reach of the river, measurements of phytoplankton density and biovolume made in 1992 did not indicate eutrophication of the water column. They postulated that stream turbidity may inhibit phytoplankton growth, and that if turbidity were to decrease significantly, increased sunlight penetration would promote accelerated plant growth. Sampling to determine phytoplankton density and biovolume was not repeated in 1999.

Loads During 1999–2000 Water Years and Comparisons With Historical Load Estimates

Loads of suspended sediment, total nitrogen, and total phosphorus in Granger Drain, Moxee Drain, and Yakima River at Kiona were estimated for water years 1999 and 2000 and for the irrigation and non-irrigation seasons during those years. Over the 2 years, Granger Drain transported an average of 42,000 lb/d (pounds per day) of suspended sediment, 860 lb/d of total nitrogen, and 78 lb/d of total phosphorus (table 6).

Table 6. Suspended-sediment and nutrient loads transported during water years 1999–2000 in Granger Drain and Yakima River at Kiona, Yakima River Basin, Washington

[Total nitrogen is based on the sum of total ammonia-plus-organic and nitrite-plus-nitrate nitrogen concentrations. **Average Loads**: Loads during irrigation season are averages for March 21–October 19, and during the non-irrigation season for October 20–March 20]

Sampling site	Annual total loads, in tons		Average loads, in pounds per day		
	1999 water year	2000 water year	1999–2000 water years	Irrigation season	Non-irrigation season
Suspended sediment					
Granger Drain	13,000	3,000	42,000	58,000	21,000
Yakima River at Kiona	200,000	110,000	850,000	1,130,000	468,000
Total nitrogen					
Granger Drain	160	160	860	910	790
Yakima River at Kiona	3,800	3,600	20,000	20,000	21,000
Ammonia-plus-organic nitrogen					
Granger Drain	30	21	140	190	75
Yakima River at Kiona	1,100	990	5,800	6,000	5,600
Nitrite-plus-nitrate nitrogen					
Granger Drain	120	130	690	690	680
Yakima River at Kiona	2,700	2,600	14,000	13,000	16,000
Total phosphorus					
Granger Drain	19	9.6	78	110	37
Yakima River at Kiona	570	450	2,800	2,900	2,600
Orthophosphate phosphorus					
Granger Drain	4.3	4.4	24	33	11
Yakima River at Kiona	200	190	1,100	1,000	1,100

Loads transported in the Yakima River at Kiona averaged 850,000 lb/d (about 430 tons per day) of suspended sediment, 20,000 lb/d of total nitrogen, and 2,800 lb/d of total phosphorus. Generally, loads transported in Granger Drain and in the Yakima River at Kiona during water year 1999 were greater than those during 2000. In 1999, Granger Drain transported to the Yakima River a total of 13,000 tons of suspended sediment and 19 tons of total phosphorus, and in water year 2000 transported 3,000 tons of suspended sediment and 9.6 tons of total phosphorus. Total nitrogen loads, however, were 160 tons during both years. With daily streamflows averaging about 40 ft^3/s each year, the higher loads of suspended sediment and total phosphorus corresponded to concentrations of suspended sediment and total phosphorus that were, on average, at least two times greater in 1999 than in 2000.

During water year 1999, the Yakima River at Kiona transported 200,000 tons of suspended sediment, 3,800 tons of total nitrogen, and 570 tons of total phosphorus. In 2000, the river transported 110,000 tons of suspended sediment, 3,600 tons of total nitrogen, and 450 tons of total phosphorus. Loads in the Yakima River for all constituents in 1999 ranged from 4 to 45 percent higher than in 2000 (table 6) and corresponded to streamflows that were about 14 percent higher in 1999.

Rinella and others (1992) determined that loads of suspended sediment and nutrients transported by the Yakima River were related to hydrologic events and annual mean streamflow. They showed that annual loads of suspended sediment, total nitrogen, and total phosphorus in the Yakima River at Kiona increased progressively as a function of annual mean streamflow for water years 1977 (low-flow year), 1980 (median-flow year), and 1974 (high-flow year). Loads of suspended sediment and nutrients in the Yakima River at Kiona were computed by Morace and others (1999) for water years 1988 and 1989, but they did not compare them with other years.

Loads of suspended sediment and nutrients in the Yakima River at Kiona were estimated for water years 1999 and 2000 (table 6) using data collected from May 1999 through January 2000 to calibrate the regression models. When the loads for water years 1999 and 2000 are overlain on graphs showing the relation between average daily loads and annual mean streamflow during previous years (fig. 9), loads of suspended sediment, ammonia-plus-organic nitrogen, and total nitrogen in 1999 and 2000 (circles on fig. 9) are lower than those in other water years with similar annual mean streamflow. Because the data used to calibrate the regression models affect model results (see discussion in section "Effects of Calibration Period on Load Computation" and in Appendix B), loads for water years 1999 and 2000 also were estimated using calibration data from two other periods—May 1999 through January 2000 plus part of water year 2001, and water years 1974–2001— to compare with the initial results. For most constituents, the difference between loads in water years 1999 and 2000 and loads in other water years with similar streamflow decreased when the models were calibrated using all available data from water years 1974 through 2001 (fig. 9).

The effect of calibration data on the load estimates introduced some uncertainty as to whether the loads of suspended sediment, ammonia-plus-organic nitrogen, and total nitrogen in water years 1999 and 2000 are low compared to those in previous years with similar streamflows. From an analysis of the effects of calibration data on model results (Appendix B), it was determined that loads computed using calibration data collected from May 1999 through January 2000 provided the best estimate of loads in the Yakima River at Kiona for water years 1999 and 2000. Therefore, it seems reasonable to conclude that loads of the three constituents in water years 1999 and 2000 were indeed low when compared with corresponding loads in other water years with similar streamflow.

Because daily streamflow data for Moxee Drain were not available for all of water years 1999 and 2000, calendar year 1999 was the only annual period common to all three sites. Rinella and others (1992) stressed the importance of comparing loads among sites during the same water year or at least during periods with similar flow conditions, therefore suspended-sediment and nutrient loads for the three fixed sites were estimated for calendar year 1999 so that loads could be compared. In calendar year 1999, Moxee Drain transported an average of 28,000 lb/d of suspended sediment, 380 lb/d of total nitrogen, and 46 lb/d of total phosphorus to the Yakima River (table 7). These loads were about half the average loads transported by Granger Drain during the same period. Average streamflows were similar for the two streams (40 ft^3/s at Granger Drain and 35 ft^3/s at Moxee Drain), therefore the difference in loads was due to differences in concentrations. Constituent concentrations in Moxee Drain ranged from about 40 to 60 percent less than concentrations in Granger Drain.

Except for nitrate, more nutrients and suspended sediment were transported in Moxee and Granger Drains during irrigation season than during the non-irrigation season (tables 6 and 7). There is more flow in the drains during irrigation season, and concentrations of suspended sediment and some nutrients are higher during irrigation season (figs. 7*A* and 7*B*). Loads of suspended sediment and total phosphorus in Moxee and Granger Drains were nearly four times higher during irrigation season; however, loads of nitrate were about the same in both seasons. There is little difference in nitrate loads between seasons because much of the nitrate enters the drains from subsurface field drains and in discharges from the shallow ground-water system. Higher concentrations of nitrate in the drains during non-irrigation season illustrate the influence of ground-water discharges on nitrate concentrations (figs. 7*A* and 7*B*).

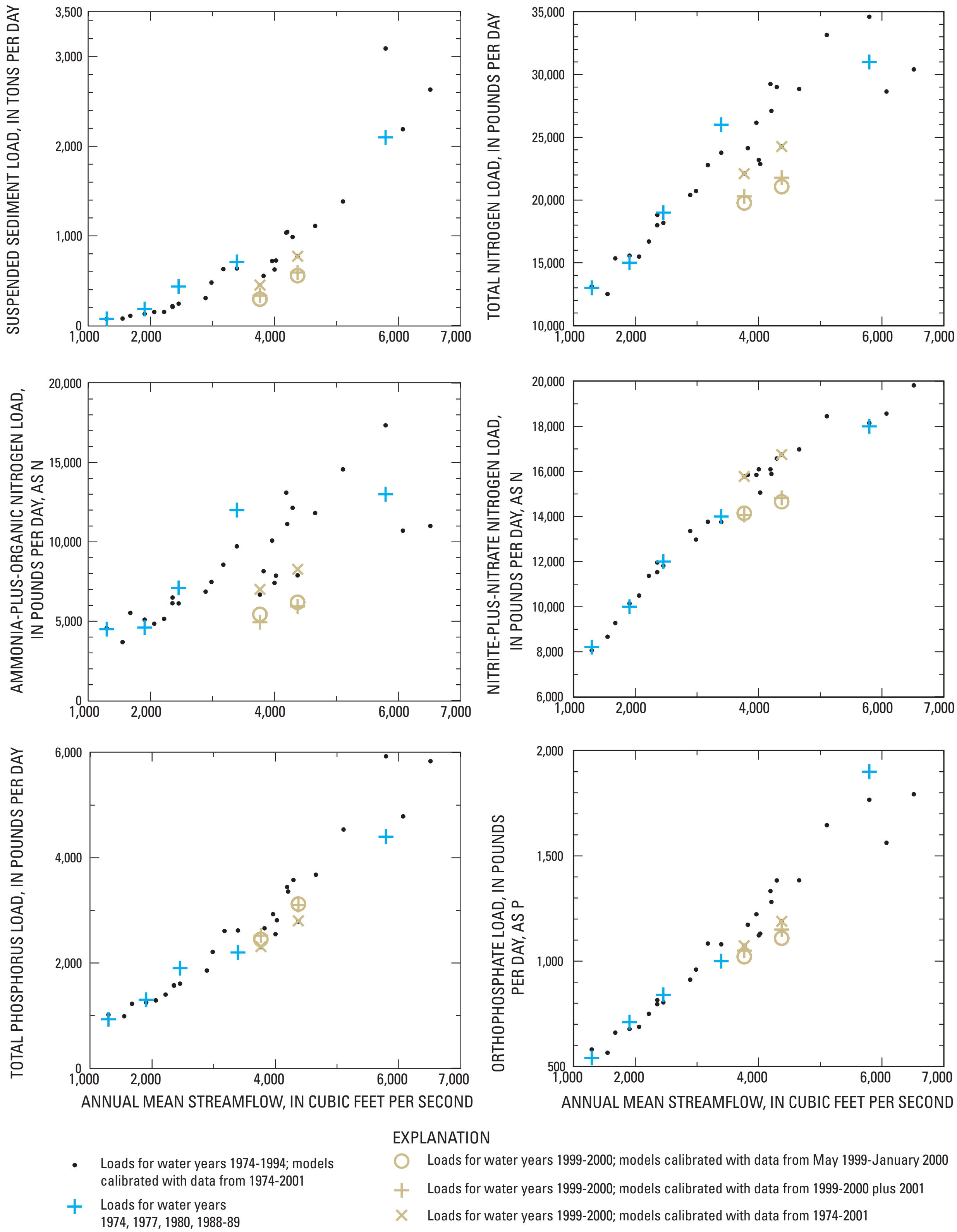


Figure 9. Average daily loads of suspended sediment and nutrients in the Yakima River at Kiona for selected water years from 1974–2001, Yakima River Basin, Washington.

Loads for water years 1974, 1977, and 1980 were estimated by Rinella and others (1992). Loads for water years 1988 and 1989 were estimated by Morace and others (1999).

Table 7. Annual and seasonal average suspended-sediment and nutrient loads transported during calendar year 1999 in Moxee Drain, Granger Drain, and Yakima River at Kiona, Yakima River Basin, Washington

[Total nitrogen is based on the sum of total ammonia-plus-organic and nitrite-plus-nitrate nitrogen concentrations. **Average loads**: Loads during irrigation season are averages for March 21 – October 19; Loads during non-irrigation season are averages from January 1, 1999–March 20, 1999, plus October 20, 1999–December 31, 1999. **Abbreviations:** ft^3/s, cubic feet per second; mg/L, milligrams per liter]

Sampling site	Annual streamflow (ft^3/s)	Average concentration (mg/L)	Average loads, in pounds per day		
			Annual	Irrigation season	Non-irrigation season
Suspended sediment					
Moxee Drain	35.4	116	28,000	46,000	1,200
Granger Drain	39.9	269	60,000	86,000	23,000
Yakima River at Kiona	4,820	41	1,240,000	1,630,000	690,000
Total nitrogen					
Moxee Drain	35.4	2.1	380	430	290
Granger Drain	39.9	3.37	860	910	790
Yakima River at Kiona	4,820	1.11	22,000	21,000	23,000
Ammonia-plus-organic nitrogen					
Moxee Drain	35.4	0.51	100	150	28
Granger Drain	39.9	0.78	160	220	75
Yakima River at Kiona	4,820	0.3	6,700	6,800	6,600
Nitrite-plus-nitrate nitrogen					
Moxee Drain	35.4	1.59	280	310	260
Granger Drain	39.9	2.59	670	660	680
Yakima River at Kiona	4,820	0.81	15,000	14,000	17,000
Total phosphorus					
Moxee Drain	35.4	0.24	46	67	18
Granger Drain	39.9	.47	96	140	37
Yakima River at Kiona	4,820	.12	3,500	3,600	3,400
Orthophosphate phosphorus					
Moxee Drain	35.4	0.1	17	22	11
Granger Drain	39.9	.12	24	33	11
Yakima River at Kiona	4,820	.06	1,200	1,100	1,200

Loads of nutrients in the Yakima River at Kiona were similar during irrigation and non-irrigation season, generally differing by less than 20 percent (tables 6 and 7). This is because average streamflows and concentrations of nutrients were similar between the two seasons. Average streamflow during the irrigation season was within about 6 percent of the average streamflow during the non-irrigation season and average nutrient concentrations differed by less than 13 percent. The suspended-sediment load during irrigation season was about 60 percent larger than the load transported during the non-irrigation season. Large fractions of the total annual loads in the Yakima River were transported during the first half of the irrigation season. For example, 38 percent or more of the annual loads of suspended sediment, total nitrogen, ammonia-plus-organic nitrogen, total phosphorus, and orthophosphate were transported in the spring, from March through June (table 8).

In Moxee Drain, monthly loads of suspended sediment, ammonia-plus-organic nitrogen, and total phosphorus were highest from April through July (fig. 10*A*), and in Granger Drain, from May through August (fig. 10*B*). In the Yakima River at Kiona, transport of suspended sediment, total nitrogen, organic-plus-ammonia nitrogen, and total phosphorus peaked during January, May, June, and December 1999 and in April 2000 (fig. 10*C*), coinciding with high streamflows at these times. Large loads of phosphorus and ammonia-plus-organic nitrogen at Kiona in the winter and spring of water years 1988 and 1989 also generally coincided with high streamflows generated by storm events and spring snowmelt (Pogue and others, 1999). The increase of suspended-sediment and nutrient concentrations because of re-suspension of sediments contributes to the large loads during high streamflows (Morace and others, 1999).

Water from a series of detention ponds is discharged to Sunnyside Canal for reuse; prior to 1998, this water would have flowed untreated to Granger Drain.

Effect of Calibration Period on Load Computations

As noted by Rinella and others (1992), the accuracy of the load models and the estimated loads depends on collecting representative samples over the range of hydrologic conditions that control constituent transport. In practice, this is rarely achieved, so the actual errors associated with the load computations are undefined and the results depend on how well the calibration data represent the range of hydrologic conditions.

Table 8. Spring (March through June) suspended-sediment and nutrient loads and their fraction of the annual loads transported in the Yakima River at Kiona, Yakima River Basin, Washington

[Total nitrogen is based on the sum of unfiltered organic-plus-ammonia and filtered nitrite-plus-nitrate nitrogen concentrations]

Constituent	1999 water year		2000 water year	
	March–June load, in tons	March–June load, percentage of annual total	March–June load, in tons	March–June load, percentage of annual total
Suspended sediment	150,000	73	64,000	59
Total nitrogen	1,500	40	1,400	38
Ammonia-plus-organic nitrogen	540	48	380	38
Nitrite-plus-nitrate nitrogen	880	33	810	31
Total phosphorus	320	57	180	41
Orthophosphate phosphorus	85	42	74	39

Rinella and others (1992) illustrated this effect by comparing loads of suspended sediment and nutrients for water years 1974, 1977, and 1980 that were estimated using load models calibrated with streamflow and concentration data from two different periods: (1) water years 1970-85, and (2) the specified water year (1974, 1977, or 1980) and 3 months prior to and following the specified water year. Relative percent differences in loads for a given water year that were computed using models calibrated with data from the two different periods ranged from 0.0 to 92.8 percent; the mean and median relative percent differences were 22.4 and 18.5 percent, respectively.

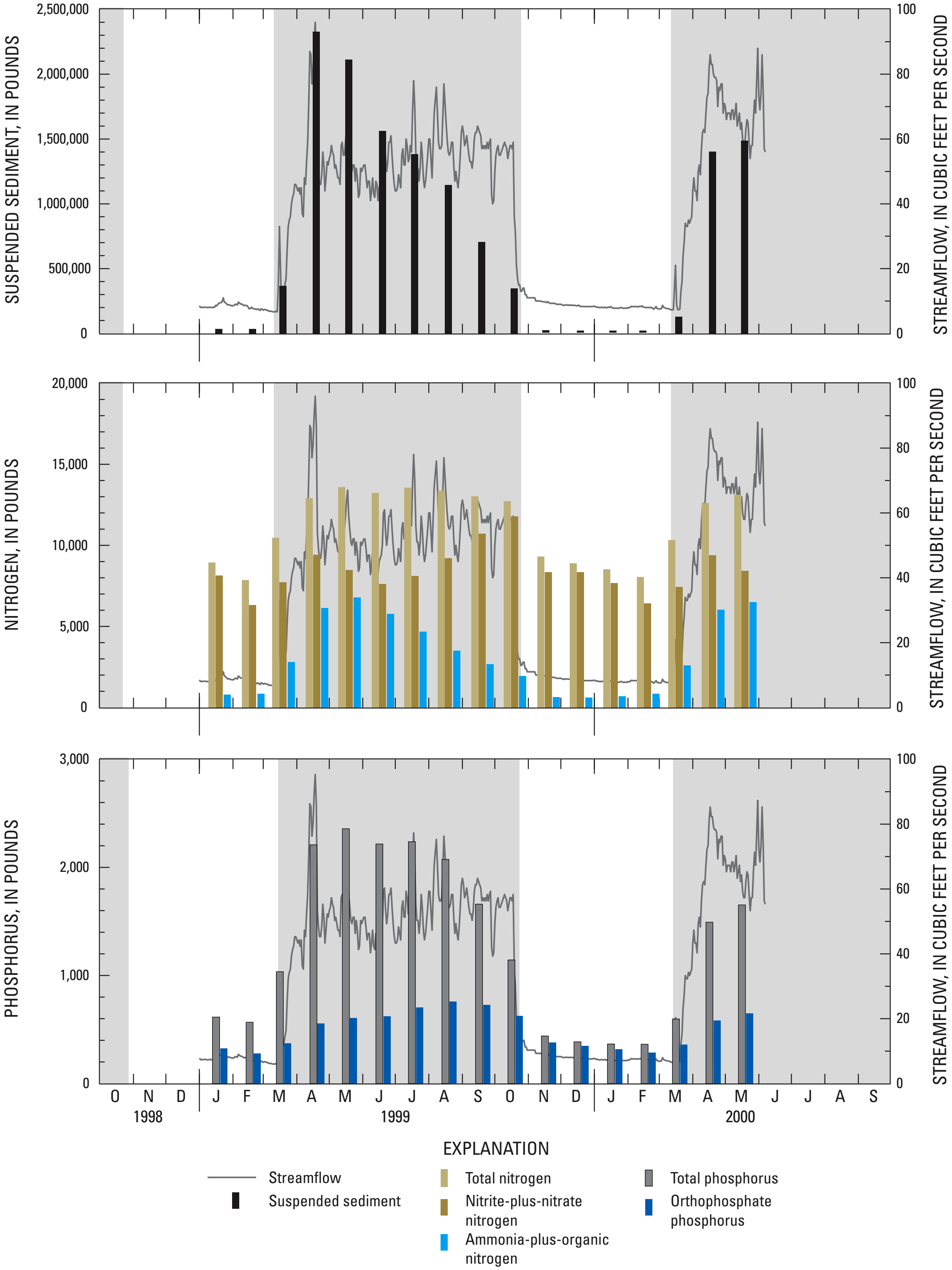
The dependency of the model results on the calibration data is an important factor in assessing the validity of the observed departure of 1999–2000 water-year loads of suspended sediment, ammonia-plus-organic nitrogen, and total nitrogen from the historical relation between streamflow and loads in the Yakima River at Kiona (fig. 9). To help assess the variation in loads calculated for the 1999–2000 water years that is caused by selection of calibration data, average daily loads of suspended sediment and nutrients in the Yakima River at Kiona were estimated using load models calibrated with streamflow and concentration data from three different periods: May 1999–January 2000; May 1999–January 2000 plus January 2001–September 2001; and October 1974–September 2001 (table 9). Consistent with the findings of Rinella and others (1992), the calibration period did affect model results, so models calibrated with data for the period May 1999–January 2000 were selected to represent loads of suspended sediment and nutrients in the Yakima River at Kiona during water years 1999–2000. The selection of this calibration period was based on several criteria (discussed in Appendix B), including minimizing the differences between measured and predicted loads and between measured concentrations and concentrations predicted by the regression models.

Table 9. Estimates of average daily loads of suspended sediment and nutrients in the Yakima River at Kiona, computed using streamflow and concentration data from three different periods to calibrate the load models, Yakima River Basin, Washington, water years 1999–2000

[**Bold** values indicate loads used for data interpretation in this report. **Abbreviations**: ft^3/s, cubic feet per second]

Water years	Annual mean discharge (ft^3/s)	Suspended sediment, tons per day			Total nitrogen, pounds per day			Ammonia-plus-organic nitrogen as N, pounds per day		
		Calibration period								
		May 1999–Jan. 2000	May 1999–Jan 2000 plus Jan. 2001–Sept. 2001	Oct. 1974 - Sept. 2001	May 1999–Jan. 2000	May 1999–Jan 2000 plus Jan. 2001–Sept. 2001	Oct. 1974 - Sept. 2001	May 1999–Jan. 2000	May 1999–Jan 2000 plus Jan. 2001–Sept. 2001	Oct. 1974 - Sept. 2001
1999–2000	4,070	**426**	463	613	**20,419**	21,039	23,179	**5,808**	5,433	7,637

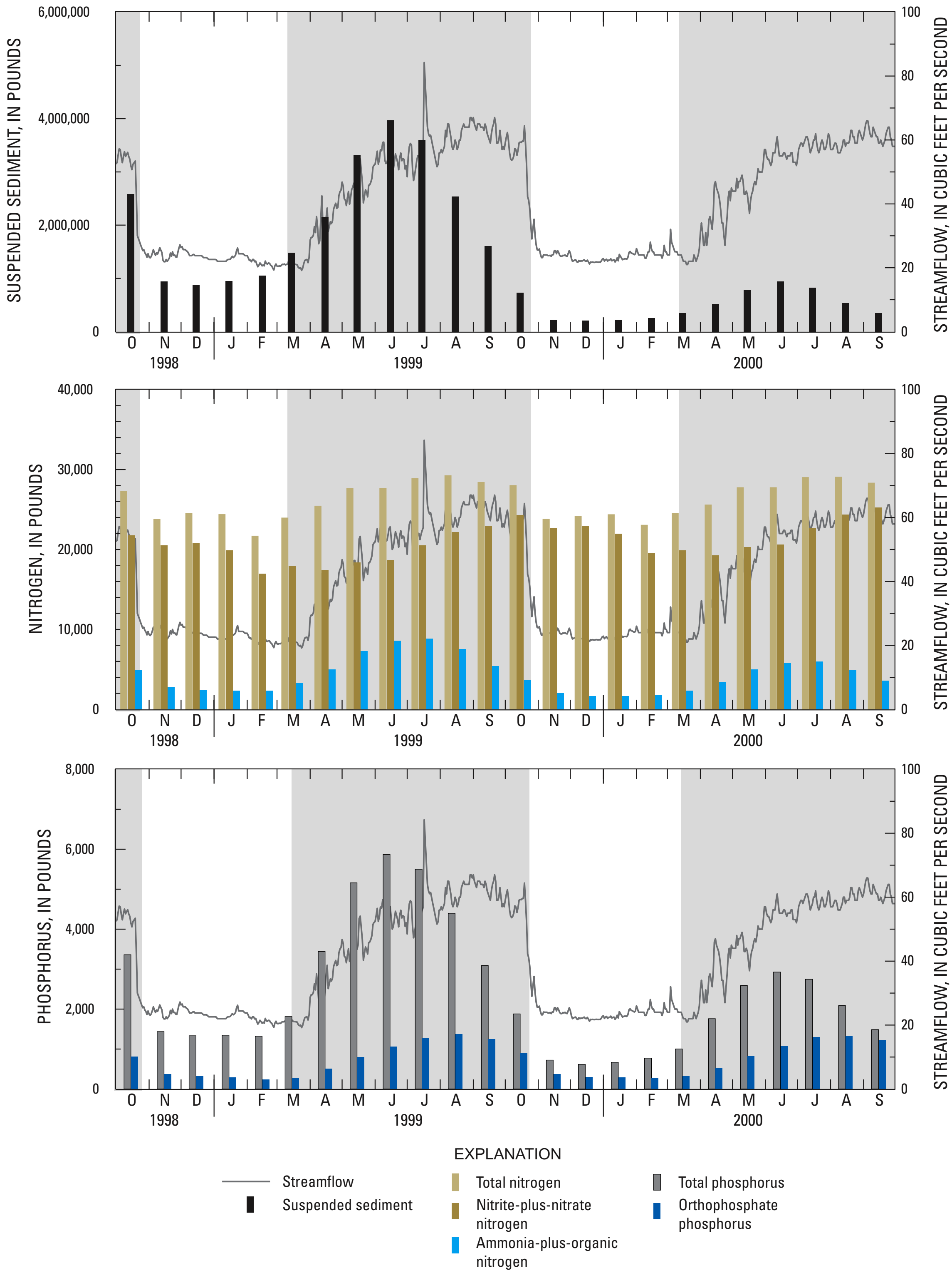
Water years	Annual mean discharge (ft^3/s)	Nitrite-plus-nitrate as N, pounds per day			Total phosphorus, pounds per day			Orthophosphate as P, pounds per day		
		Calibration period								
		May 1999–Jan. 2000	May 1999–Jan 2000 plus Jan. 2001–Sept. 2001	Oct. 1974 - Sept. 2001	May 1999–Jan. 2000	May 1999–Jan 2000 plus Jan. 2001–Sept. 2001	Oct. 1974 - Sept. 2001	May 1999–Jan. 2000	May 1999–Jan 2000 plus Jan. 2001–Sept. 2001	Oct. 1974 - Sept. 2001
1999–2000	4,070	**14,398**	14,446	16,263	**2,785**	2,808	2,556	**1,065**	1,097	1,131



***A.* Moxee Drain at Birchfield Road at Union Gap**

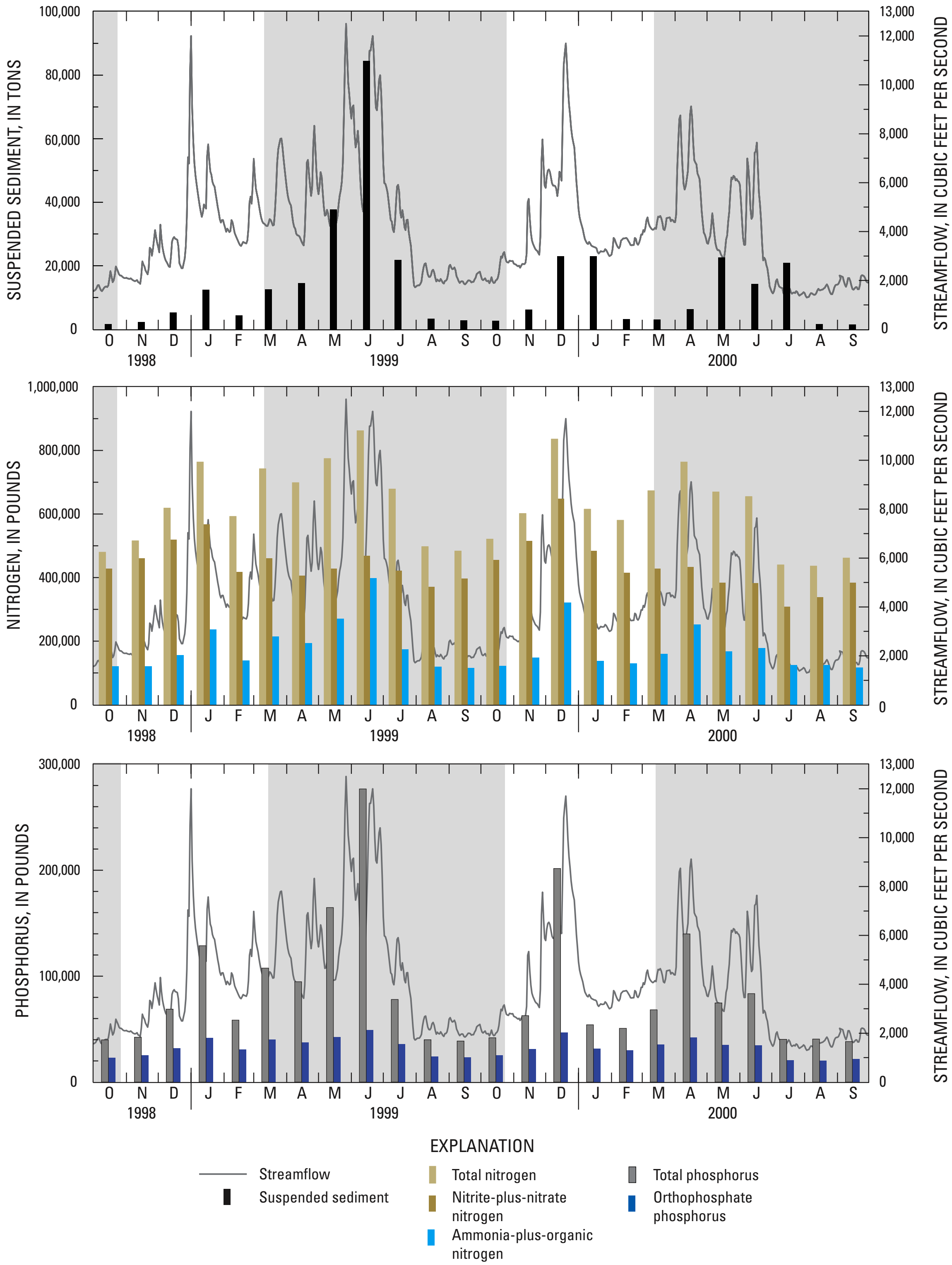
Figure 10. Monthly total suspended-sediment and nutrient loads, and daily streamflows in selected surface-water sites, Yakima River Basin, Washington.

(Shaded areas bracket the irrigation season.)



B. **Granger Drain at Granger**

Figure 10.—*Continued.*



***C.* Yakima River at Kiona**

Figure 10.—*Continued.*

TRENDS IN CONCENTRATIONS

Trends in turbidity and concentrations of suspended solids, total nitrogen, nitrate, and total phosphorus were assessed using data collected by the BOR, RSBOJC, and Ecology at nine sites corresponding to, or near, those sampled by the USGS (table 10). The seasonal Kendall test (Crawford and others, 1983) was used analyze for trends in concentration data provided by the BOR and Ecology for water years 1991–2000. Trends in streamflow measured at the time of sample collection also were determined. Because data collected by the RSBOJC covered a shorter period (1997–2001), time-series graphs of concentrations were inspected to detect potential trends, but no statistical tests were performed using their data.

Table 10. Proximity of surface-water sites sampled during 1999–2000 by the U.S. Geological Survey to sites sampled by the Bureau of Reclamation, Roza-Sunnyside Board of Joint Control, and Washington State Department of Ecology in the Yakima River Basin, Washington

[**Degrees, minutes, seconds**: Rounded to whole seconds. **River mile**: Approximate for trend-assessment sites that do not correspond to USGS sites. **Abbreviations:** USGS, U.S. Geological Survey; BOR, Bureau of Reclamation; RSBOJC, Roza-Sunnyside Board of Joint Control; Ecology, Washington State Department of Ecology]

USGS sampling site 1999–2000				Site assessed for trends				
Site name and USGS identification No. (map identification No. in fig. 6)	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	River mile	Site name and identification No.	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	River mile	Agency
Wilson Creek above Cherry Creek at Thrall 12484100 (201)	46 55 35	120 30 01	1.1	Wilson Creek at Thrall Road YAV146	46 55 36	120 30 02	1.1	BOR
Cherry Creek at Thrall 12484480 (202)	46 55 34	120 29 51	0.1	Cherry Creek SE 1/4, Section 29, R.17N., T.19E. YAV022	46 56 15	120 29 00	1.4	BOR
Wide Hollow Creek near mouth at Union Gap 12500445 (206)	46 32 35	120 28 27	0.8	Wide Hollow Creek at West Washington Avenue YAV107	46 34 16	120 31 56	4	BOR
Moxee Drain at Birchfield Road near Union Gap 12500420 (69)	46 32 46	120 26 13	1.4	Moxee Drain at Birchfield Road YAV104	46 32 47	120 26 14	1.4	BOR
Granger Drain at Granger 12505450 (67)	46 20 37	120 11 09	0.8	Granger Drain at Highway 223 above Granger YAV137	46 20 36	120 11 03	0.8	BOR, RSBOJC
Sulphur Creek Wasteway near Sunnyside 12508850 (215)	46 15 03	120 01 07	0.8	Sulfur Creek Wasteway none	46 15 03	120 01 07	0.8	RSBOJC
Spring Creek at Hess Road near Prosser 461404119410400 (217)	46 14 04	119 41 04	0.4	Spring Creek none	46 14 04	119 41 04	0.4	RSBOJC
Snipes Creek below Chandler Canal near Prosser 461414119404200 (218)	46 14 15	119 40 42	0.4	Snipes Creek at Old Inland Empire Road[1] YAV139	46 14 03	119 41 02	0.7	BOR, RSBOJC
Yakima River at Kiona 12510500 (219)			29.9	Yakima River at Kiona 37A090	46 15 13	119 28 37	29.9	Ecology

[1]Location sampled by BOR. RSBOJC and USGS sampled below Chandler Canal.

Trend statistics were computed using both unadjusted (unmodified) concentration data and flow-adjusted concentration data (see section "Methods" for an explanation of the procedure used to compute flow-adjusted concentrations). In this report, inferences about trends in concentrations usually are based on statistics obtained using flow-adjusted concentration data, unless streamflow data were not available to compute flow-adjusted concentrations. Trend statistics computed using both unadjusted and flow-adjusted concentrations are reported because they facilitate interpretation of the results. For example, if statistics indicate significant increases in streamflow and unadjusted concentrations of a constituent but no significant change in flow-adjusted concentrations, then the increase in unadjusted concentrations is not independent of streamflow. If the indicated increase in streamflow represented an actual trend, then it would be correct to conclude that constituent concentrations were increasing over time along with streamflow, but not independent of streamflow. If the indicated increase in streamflow did not represent an actual trend, but was simply an artifact of the sample collection schedule, then it would be incorrect to conclude that constituent concentrations were increasing over time.

The summary of trend statistics for 1991–2000 indicates that some of the factors affecting constituent transport to surface water may be common to multiple subbasins (table 11). For example, concentrations of nitrate and total nitrogen increased in five of six streams and drains while concentrations of suspended solids and total phosphorus either did not change or decreased. This difference is consistent with no change, or a decrease, in amounts of suspended solids and phosphorus transported to surface water in runoff and an increase in the amount of nitrate transported to surface water from ground-water discharges and subsurface drains, as discussed in previous sections of the report.

Some agreement was found between trend statistics for the 1991–2000 data and graphical analysis of data collected 1997–2001 by the RSBOJC (as shown in subsequent figures), in that the RSBOJC data show a decrease in turbidity and concentrations of suspended solids and total phosphorus in some drains and streams receiving agricultural return flows. The RSBOJC data also suggest that in some instances concentrations of nitrate in streams and drains have leveled off or may be decreasing. Trends in streamflow, turbidity, and concentrations of nutrients and suspended solids at individual sampling sites are discussed in more detail in this section.

Differences between statistics for turbidity, which either did not change or increased, and statistics for concentrations of suspended solids, which either did not change or decreased (table 11), were somewhat unexpected because previous work showed that they are highly correlated in the Yakima River Basin (Joy and Patterson, 1997). However, significant trends in concentrations of these constituents were small, as indicated by the magnitude of their trend slopes (table 11), and the relation between turbidity and concentrations of suspended solids is affected by changes in the ratio of suspended mineral particles to fine particulate organic matter (Packman and others, 2000). An increase in low-mass fine particulate organic matter can increase turbidity without having much effect on the concentration of suspended solids.

Another factor complicating the comparison between statistics for turbidity and suspended solids is the use of the analytical method that reports suspended-sediment concentrations as concentrations of total suspended solids (TSS). All suspended-sediment (solids) data used for trend analyses in this report were produced using the TSS analytical method, rather than the traditional suspended-sediment concentration (SSC) analysis method used to determine concentrations of suspended sediment in samples collected by the USGS. An evaluation of data collected and analyzed by the USGS and others has shown that the variation in TSS analytical results is considerably larger than that for SSC analytical results (Glysson and Gray, 2002). A TSS analysis generally entails withdrawal of an aliquot of the original sample for subsequent analysis, whereas the SCC analysis uses the entire sample for analysis. The withdrawal step, usually done by pipette or pouring, is an additional source of variation in the TSS analysis.

Table 11. Trend statistics for streamflow, turbidity, and concentrations of suspended solids, total nitrogen, nitrite-plus-nitrate nitrogen, and total phosphorus for data collected during the 1991–2000 water years at surface-water sites in the Yakima River Basin, Washington

[Seasonal Kendall tests were performed using 12 seasons, and trends are considered significant if *p*-values are less than or equal to 0.1. All data were provided by Bureau of Reclamation except those for the Yakima River at Kiona, which were provided by Washington State Department of Ecology. **Stream discharge:** Discharge at the time of sample collection. **Turbidity FTU**, formazin turbidity unit; nephelometric turbidity units (NTU) for Yakima River at Kiona. **Abbreviations**: unadj, unadjusted concentration data tested for trends; adj, flow-adjusted concentrations tested for trends. ft^3/s, cubic feet per second; mg/L, milligrams per liter; nt, no trend; <, less than; SE, southeast; N, north; E, east; –, unable to compute because streamflow was not determined]

Site name and trend (map identification No. in fig. 6)	Stream discharge (ft^3/s)	Turbidity FTU		Suspended solids (mg/L)		Total nitrogen (mg/L)		Nitrate as N (mg/L)		Total phosphorus (mg/L)	
		unadj	adj	unadj	adj	unadj	adj	unadj	adj	unadj	adj
Wilson Creek above Cherry Creek at Thrall (201)											
Trend	up	nt	nt	down	down	up	up	up	up	down	down
p-value	0.01	0.87	0.66	0.03	0.01	0.01	0.03	0.01	<0.01	0.03	0.08
Slope, in units per year	5.0	<.01	-.02	-.75	-.81	.020	.022	.017	.021	-.002	-.003
Cherry Creek at SE 1/4, Section 29, T. 17N, R. 19E											
Trend	up	up	nt	nt	down	up	up	nt	up	nt	nt
p-value	0.01	<0.01	0.11	0.95	0.06	0.05	<0.01	0.87	0.01	0.73	0.71
Slope, in units per year	7.0	.33	.23	<.01	-1.1	.033	.047	<.001	.022	<-.001	-.001
Wide Hollow Creek at West Washington Avenue											
Trend	no data	up	–	nt	–	up	–	up	–	nt	–
p-value	–	<0.01	–	0.89	–	<0.01	–	<0.01	–	0.67	–
Slope, in units per year	–	.17	–	<.01	–	.065	–	.050	–	<-.001	–
Moxee Drain at Birchfield Road near Union Gap (69)											
Trend	nt	nt	nt	down	down	up	up	up	up	down	down
p-value	0.40	0.16	0.11	<0.01	0.02	0.04	0.07	<0.01	0.01	<0.01	<0.01
Slope, in units per year	-.17	-.14	-.42	-1.9	-3.3	.050	.058	.048	.038	-.010	-.009
Granger Drain at Highway 223											
Trend	down	nt	nt	down	nt	up	up	up	up	down	nt
p-value	0.10	0.39	0.73	0.01	0.27	<0.01	0.07	<0.01	<0.01	<0.01	0.12
Slope, in units per year	-.80	-.29	.22	-6.9	-3.1	.11	.084	.16	.13	-.029	-.016
Snipes Creek at Old Inland Empire Road											
Trend	nt	up	up	nt	nt	nt	nt	nt	nt	nt	nt
p-value	.56	<.01	.01	.24	.91	.19	.27	.82	.86	.73	.86
Slope, in units per year	.67	.20	.22	.25	<.01	.020	.035	<.001	.004	<.001	<.001
Yakima River at Kiona[1] (219)											
Trend	up	up	up	up	nt	down	nt	nt	up	up	up
p-value	<0.01	<0.01	<0.01	0.04	0.26	0.10	0.16	0.82	0.01	0.06	0.01
Slope, in units per year	142	.65	.42	.90	.35	-.034	-.013	-.004	.27	.0032	.0035

[1]Total nitrogen samples collected 1994–2000 water years at Yakima River at Kiona.

Wilson Creek

An upward trend in streamflow (table 11, fig. 11), coupled with downward trends in corresponding concentrations of suspended solids and total phosphorus (table 11, fig. 12), suggest some reduction in the transport of sediment to Wilson Creek. In contrast, concentrations of both total nitrogen and nitrate have increased slowly at a similar rate (table 11), which is an indication that the increase in concentrations of total nitrogen is caused by an increase in concentrations of nitrate.

Nitrate concentrations in Wilson Creek, which were usually 1 mg/L or less, are low compared with other streams and drains sampled during this study. For example, concentrations of nitrate in nearby Cherry Creek ranged between 0.5 and 3.0 mg/L (see fig. 13). Low concentrations of nitrate in Wilson Creek probably can be attributed to several factors (Anna Lael, Kittitas County Conservation District, oral commun., October 2002). Only about 19 percent of the land in the Wilson Creek Basin is used for agricultural purposes, compared with about 27 percent in the Cherry Creek Basin. Also, the agricultural land in the Cherry Creek Basin is more extensively developed, with deeply incised drains and ditches that discharge shallow ground water to the creek.

In 2000, EQIP-sponsored BMPs were used on only 2.8 percent of the cropland in the Wilson Creek Basin (table 1). However, if the trend statistics showing a decrease in concentrations of suspended solids and total phosphorus are an indication of less erosion and transport of sediment to Wilson Creek, the improvement may be the result of the widespread use of polyacrylamide (PAM) on cropland in the Basin (Anna Lael, Kittitas County Conservation District, oral commun., April, 2002). Data on the use of PAM are not included in table 1.

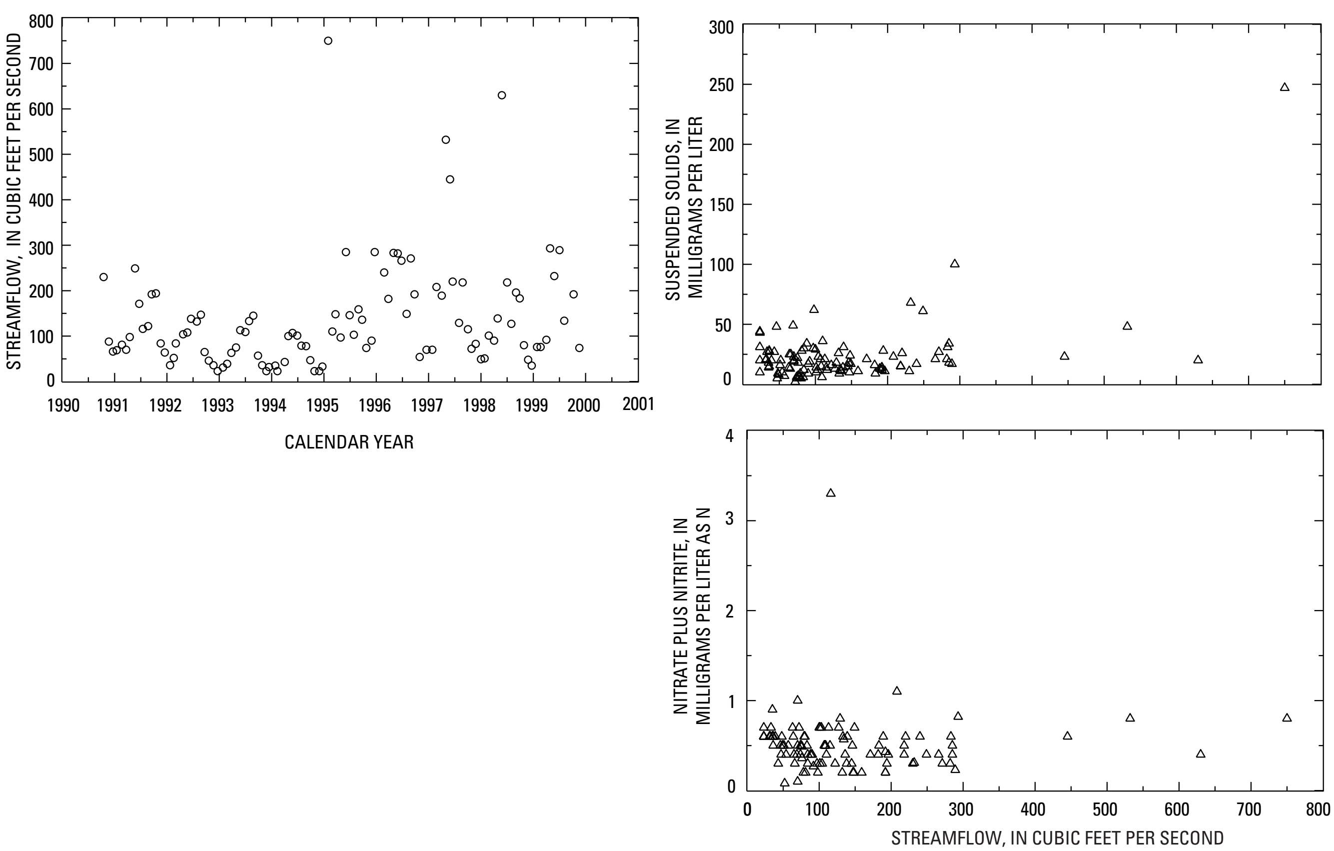


Figure 11. Temporal variations in streamflow and variations in concentrations of suspended solids and nitrate with streamflow in Wilson Creek above Cherry Creek at Thrall, Yakima River Basin, Washington, 1991–2000 water years.

(Data provided by the Bureau of Reclamation.)

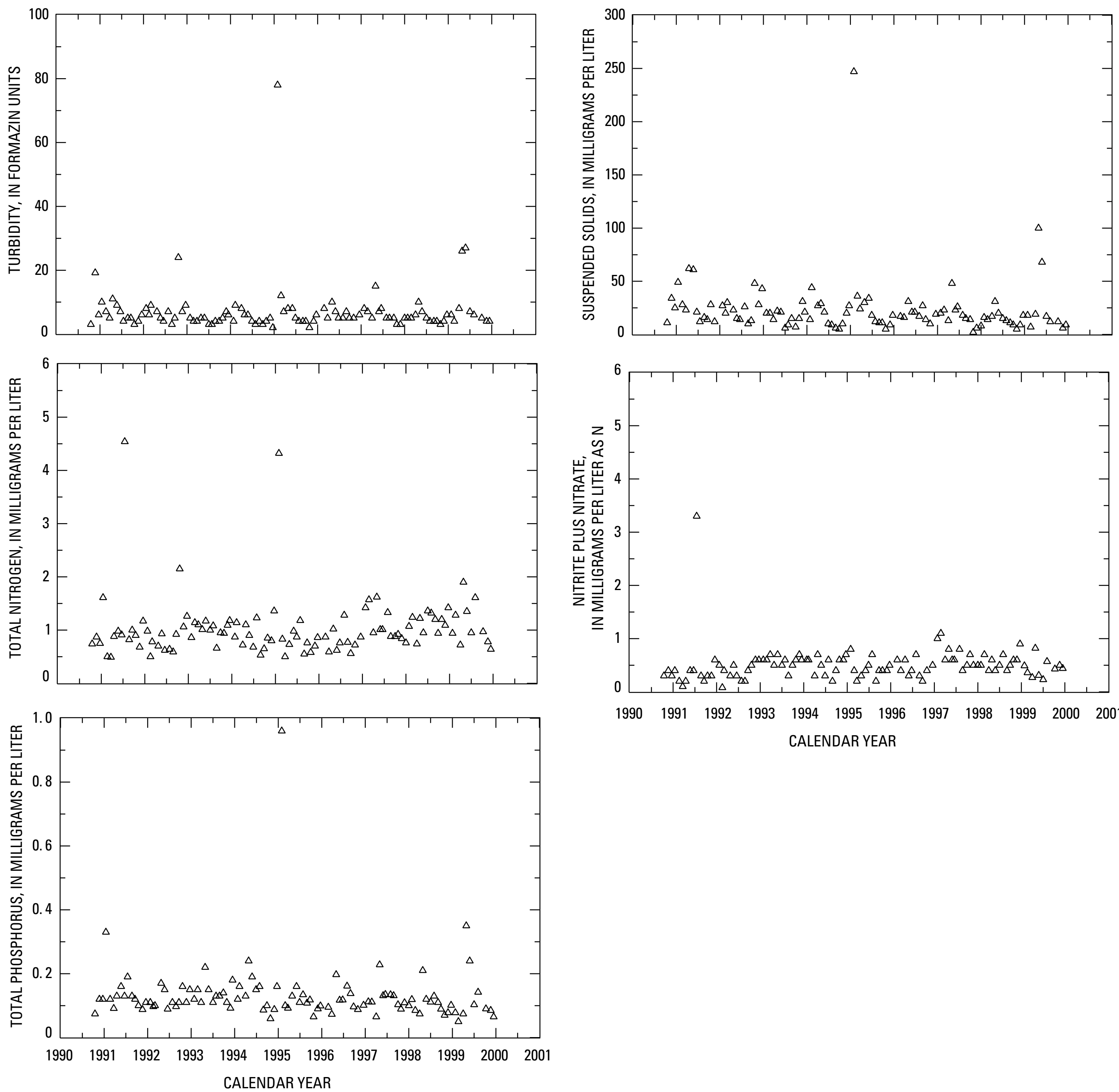


Figure 12. Temporal variations in turbidity and concentrations of suspended solids, total nitrogen, nitrite-plus-nitrate nitrogen, and total phosphorus in Wilson Creek above Cherry Creek at Thrall, Yakima River Basin, Washington, 1991–2000 water years.
(Data provided by the Bureau of Reclamation.)

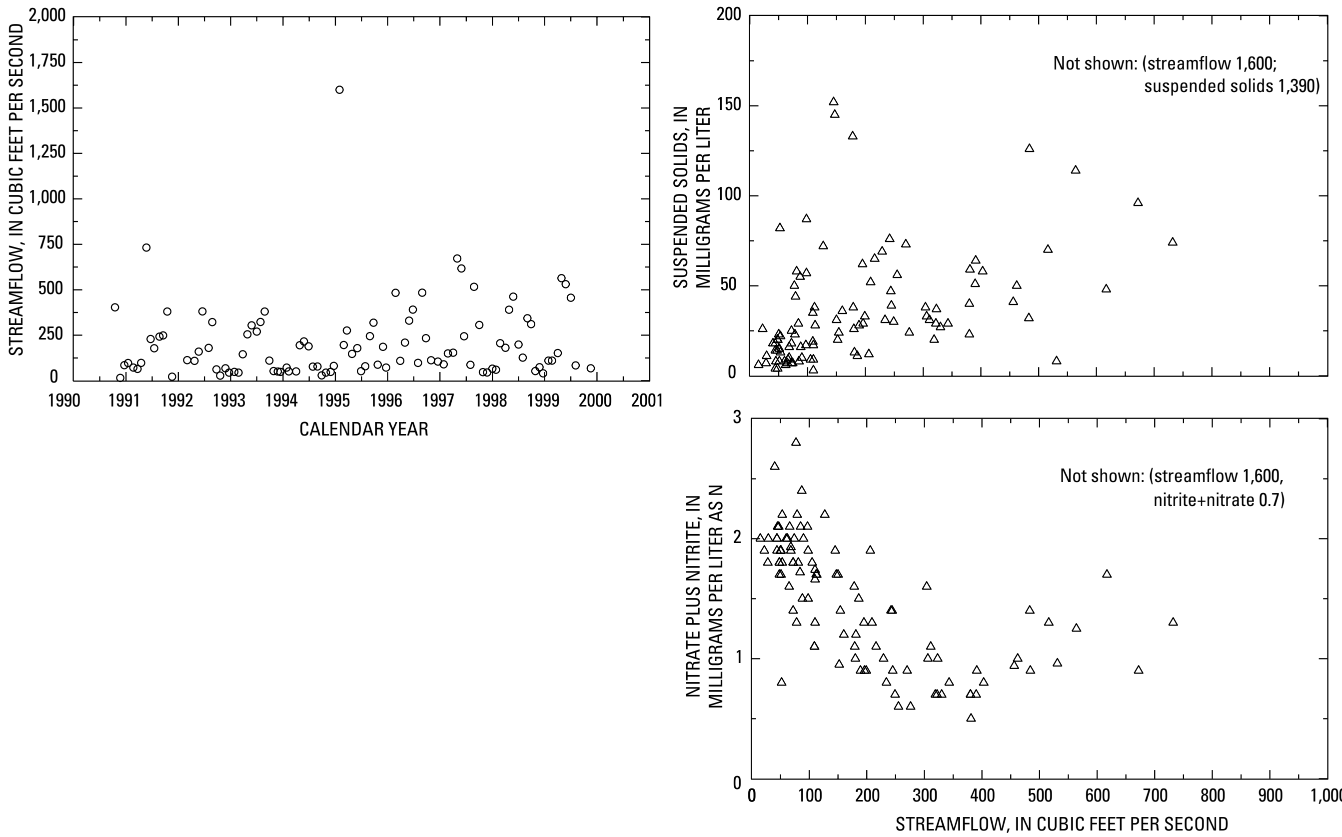


Figure 13. Temporal variations in streamflow and variations in concentrations of suspended solids and nitrite-plus-nitrate nitrogen with streamflow in Cherry Creek at Southeast 1/4, Section 29, Township 17N, Range 19E, Yakima River Basin, Washington, 1991–2000 water years.
(Data provided by Bureau of Reclamation.)

Cherry Creek

Small, but significant, increases in streamflow and concentrations of total nitrogen in Cherry Creek from 1991 to 2000 (table 11) appear to be part of upward trends starting in 1995 (figs. 13 and 14). A significant increase in flow-adjusted concentrations of total nitrogen suggests that the increase in concentrations is independent of the increase in streamflow. The increase in concentrations of total nitrogen at a rate of 0.047 mg/L per year is probably caused, in part, by an upward trend in concentrations of nitrate, which increased at a rate of 0.022 mg/L per year (table 11).

The trend statistics computed using flow-adjusted concentrations indicate a significant decrease in concentrations of suspended solids in Cherry Creek but no change in concentrations of total phosphorus (table 11). It is not known if the decrease in concentrations of suspended solids in Cherry Creek is related to the application of BMPs. By the end of 2000, EQIP-sponsored BMPs were applied to 5.8 percent of cropland in the Cherry Creek Basin (table 1). Conversion of rill-irrigation of timothy hay and alfalfa to sprinkler and gated-pipe irrigation methods represents most of the 5.8 percent. Also, like Wilson Creek, the Cherry Creek Basin is in the Kittitas Conservation District, where there has been widespread use of PAM on cropland (Anna Lael, Kittitas County Conservation District, oral commun., April, 2002).

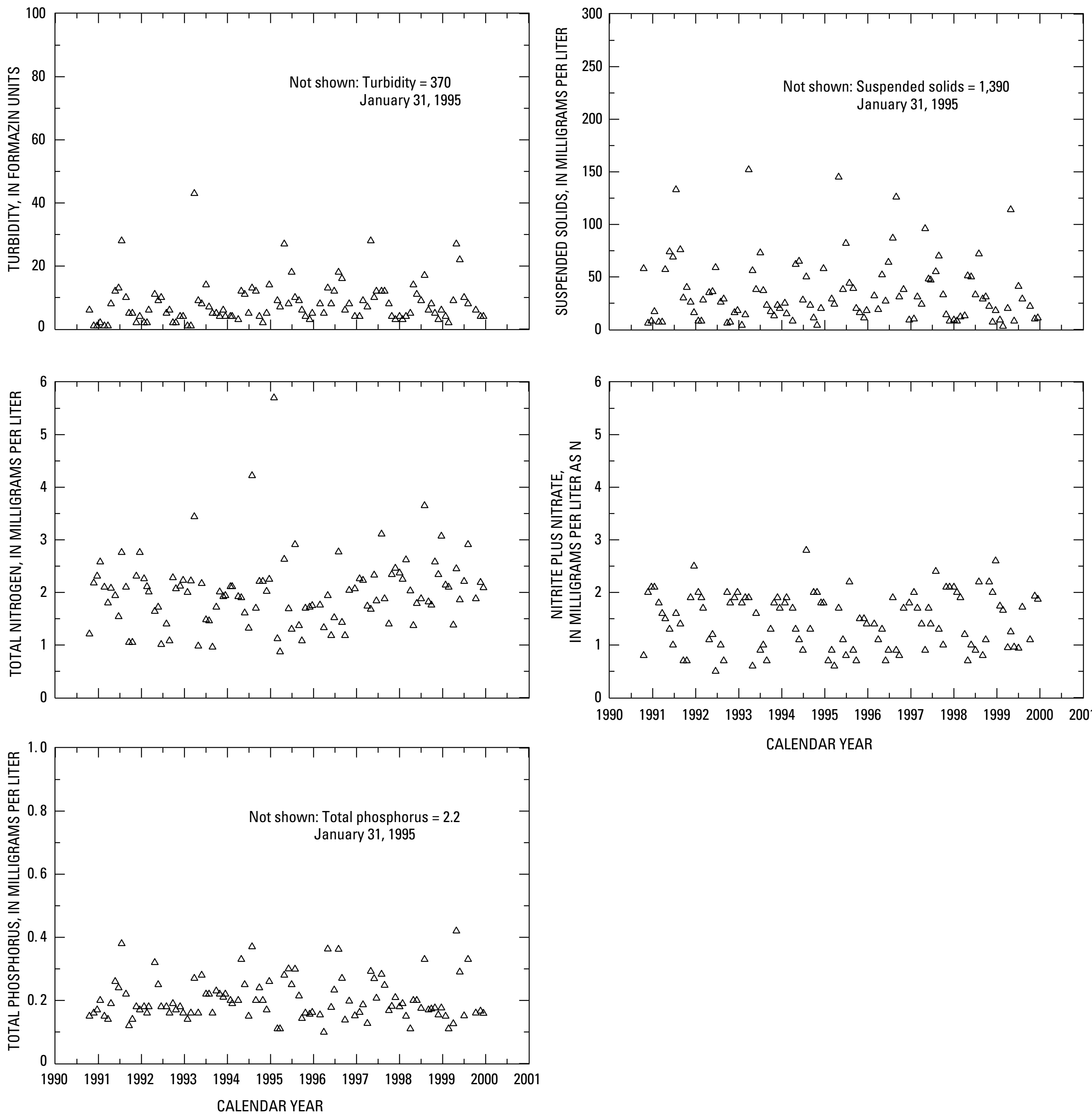


Figure 14. Temporal variations in turbidity and concentrations of suspended solids, total nitrogen, nitrite-plus-nitrate nitrogen, and total phosphorus in Cherry Creek Southeast 1/4, Section 29, Township 17N, Range 19E, Yakima River Basin, Washington, 1991–2000 water years.
(Data provided by Bureau of Reclamation.)

Wide Hollow Creek

No streamflow data were available for Wide Hollow Creek, so trend statistics were based on tests using unadjusted concentration data. Results indicate that concentrations of nitrate and total nitrogen increased at similar rates (table 11), and concentrations of both constituents form two distinct trend lines (fig. 15), with lower concentrations occurring during the irrigation season when canal water in the creek dilutes nitrate discharged to Wide Hollow Creek.

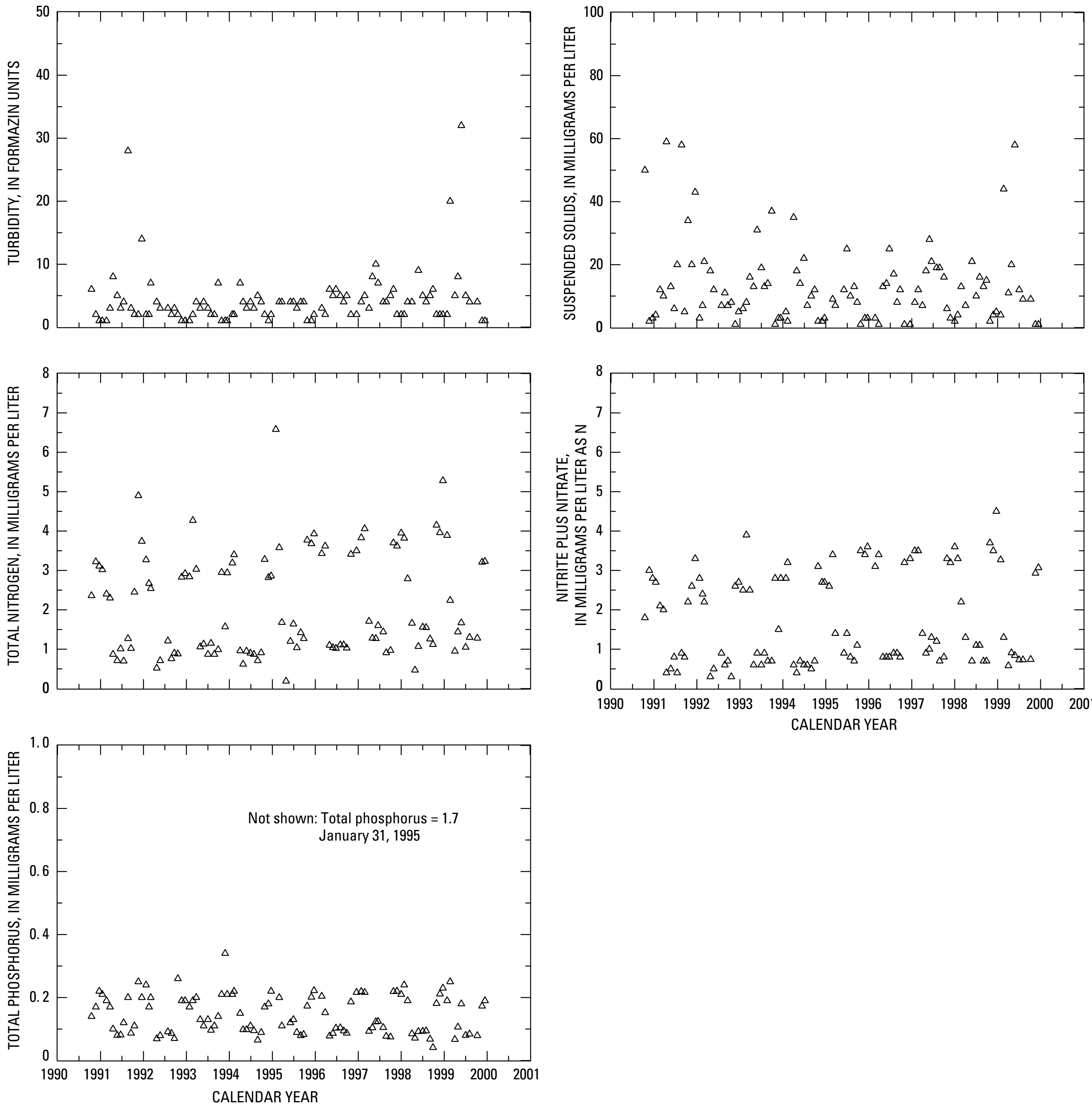


Figure 15. Temporal variations in turbidity and concentrations of suspended solids, total nitrogen, nitrite-plus-nitrate nitrogen, and total phosphorus in Wide Hollow Creek at West Washington Avenue, Yakima River Basin, Washington, 1991–2000 water years.

(Data provided by the Bureau of Reclamation.)

Higher concentrations of nitrate in Wide Hollow Creek during the non-irrigation season are indicative of a ground-water source, and the trend showing increasing concentrations in the creek means that the concentration of nitrate in ground water discharging to the creek is increasing.

Like nitrate, concentrations of total phosphorus in Wide Hollow Creek also are lower during the irrigation season, indicating dilution of phosphorus by canal water. It is not known if the source of phosphorus is from ground water or some other source, but there was no overall trend in concentrations (table 11).

No BMP data were available for the Wide Hollow Creek Basin, but the North Yakima Conservation District has reported the use of PAM on cropland in the Basin (Mike Tobin, North Yakima Conservation District, oral commun., April 2002).

Moxee Drain

Significant downward trends in concentrations of suspended solids and total phosphorus (table 11) are probably indicative of the widespread use of BMPs in the Moxee subbasin (table 1). The dominant EQIP-sponsored BMP in Moxee subbasin is the conversion of rill irrigation of hops to drip irrigation. By the end of 1999, this practice accounted for more than 90 percent of EQIP-sponsored BMPs in the Basin, and by the end of 2001, the percentage of drip-irrigated hops had increased from less than 1 to 63 percent. These BMPs, coupled with the earlier adoption of sprinkler technology in orchards and the use of PAM on rill-irrigated hops, have markedly lowered sediment deliveries to Moxee Drain (Mike Tobin, North Yakima Conservation District, oral commun., April, 2002).

Like many of the agricultural drains sampled during this study, the inverse relation between streamflow and concentrations of nitrate in Moxee Drain (fig. 16) indicates that nitrate, derived from ground-water discharges, is diluted during the irrigation season by canal water in the drain. This results in a seasonal pattern with higher concentrations of nitrate and total nitrogen in Moxee Drain during the non-irrigation season, reflected by the upper row of data points in figure 17. Trend statistics (table 11) indicate that concentrations of nitrate and total nitrogen in Moxee Drain are increasing, and inspection of the trend plots shown in figure 17 indicate that the increasing trends are a result of the increase in concentrations of nitrate during the non-irrigation season.

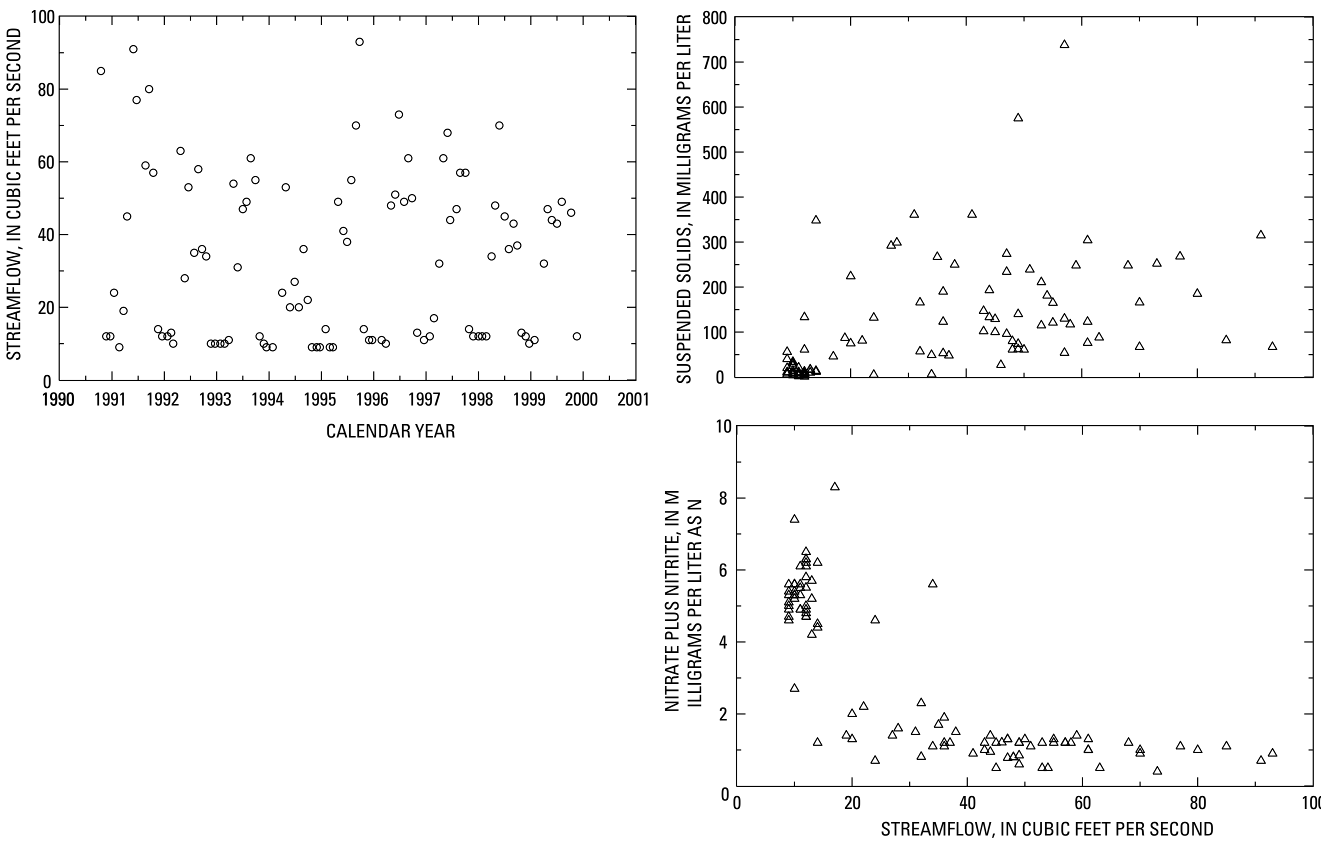


Figure 16. Temporal variations in streamflow and variations in concentrations of suspended solids and nitrite-plus-nitrate nitrogen with streamflow in Moxee Drain at Birchfield Road near Union Gap, Yakima River Basin, Washington, 1991–2000 water years.

(Data provided by the Bureau of Reclamation.)

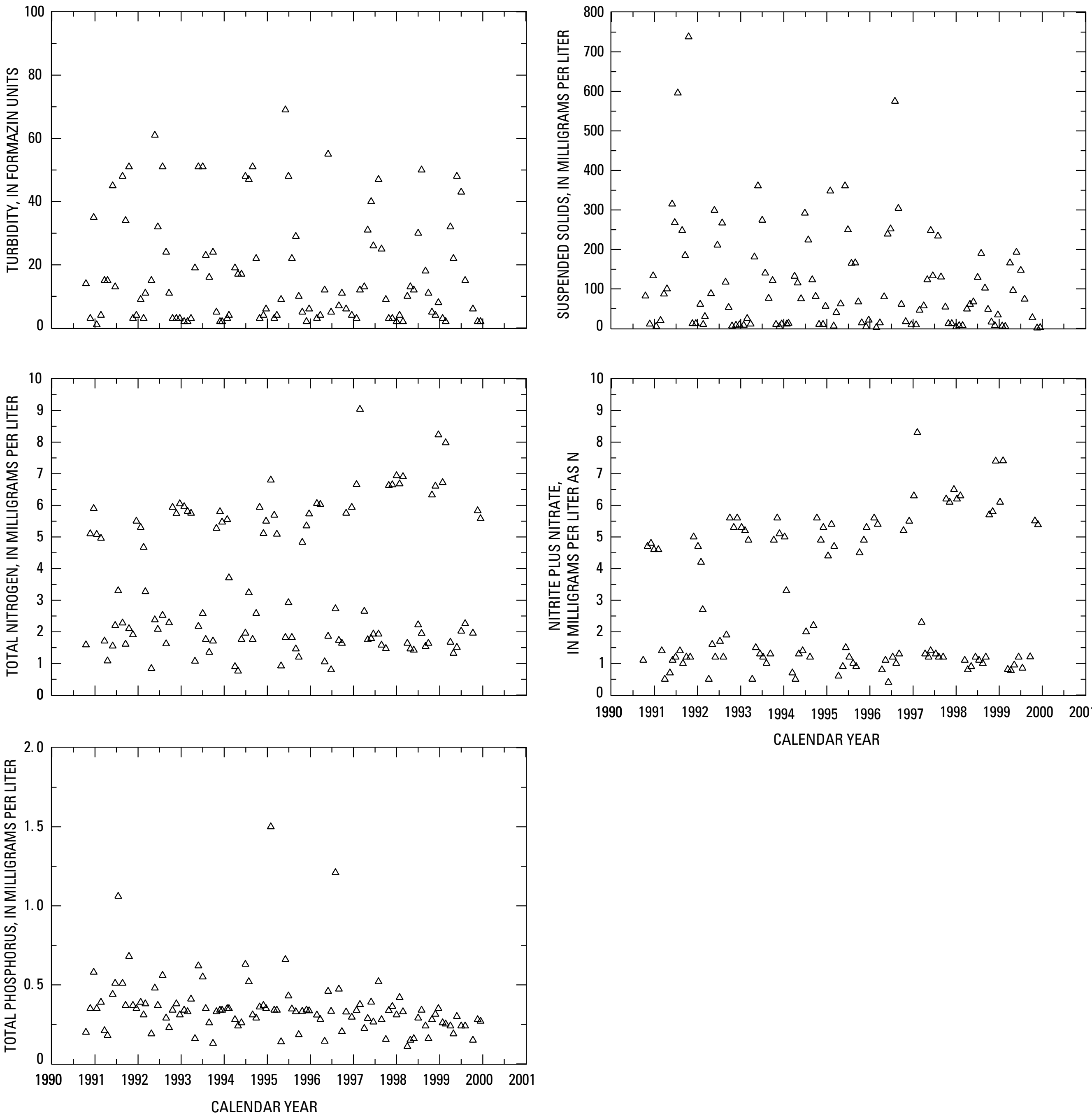


Figure 17. Temporal variations in turbidity and concentrations of suspended solids, total nitrogen, nitrite-plus-nitrate nitrogen, and total phosphorus in Moxee Drain at Birchfield Road near Union Gap, Yakima River Basin, Washington, 1991–2000 water years.

(Data provided by the Bureau of Reclamation.)

Granger Drain

Trend statistics for 1991–2000 indicate a decrease in streamflow, an increase in concentrations of total nitrogen and nitrate, and no trend in flow-adjusted concentrations of suspended solids and total phosphorus (table 11, figs. 18 and 19).

Trend statistics for 1991–2000 may not be indicative of recent improvements in the quality of water in Granger Drain because the implementation of BMPs in the Basin has been recent. After a slow increase during the years 1996-99, the acres under new BMPs nearly tripled to 14.6 percent by the end of 2001 (table 1). The positive effects of the BMPs may be indicated by RSBOJC data showing no change in streamflow but a consistent decrease in concentrations of suspended solids and total phosphorus in 1997-99, followed by a large decrease in 2000-01 (figs. 20 and 21). Also, the RSBOJC data suggest that concentrations of nitrate and total nitrogen, which increased over the period 1991–2000, have leveled off and may be decreasing.

According to William Rice (Roza-Sunnyside Joint Board of Control, oral commun., March 2002), the BMP data in table 1 do not include many of the management practices that are in place in the Basin. BMPs applied but not reflected in table 1 include some changes in the way irrigation water is applied, diversion of irrigation runoff to ponds and wetlands where sediments settle out before the runoff is released to drains, and the addition of polyacrylamide (PAM) to irrigation water to increase the cohesiveness of soil particles, making the soil less subject to erosion.

The Roza-Sunnyside Board of Joint Control routes agricultural-return flow into two separate networks of inter-connected ponds (constructed wetland) to reduce sediment and nutrients in Yakima River.

Another project designed to improve the quality of water in Granger Drain was the construction of a 12.5-acre wetland by RSBOJC (see photo). The wetland, which can capture up to 2 ft^3/s of incoming flow, diverts the water through stands of plants including cattail and bulrush, which reduce sediment load by lowering flow velocities and promote uptake of nutrients. Currently, 0.6 ft^3/s of agricultural runoff is being diverted to the wetland and retained for 9 to 10 days. Preliminary data show reductions in turbidity and concentrations of fecal coliform, total phosphorus, and nitrite-plus-nitrate (Mark Barnett, Roza Irrigation District, written commun., November 2001).

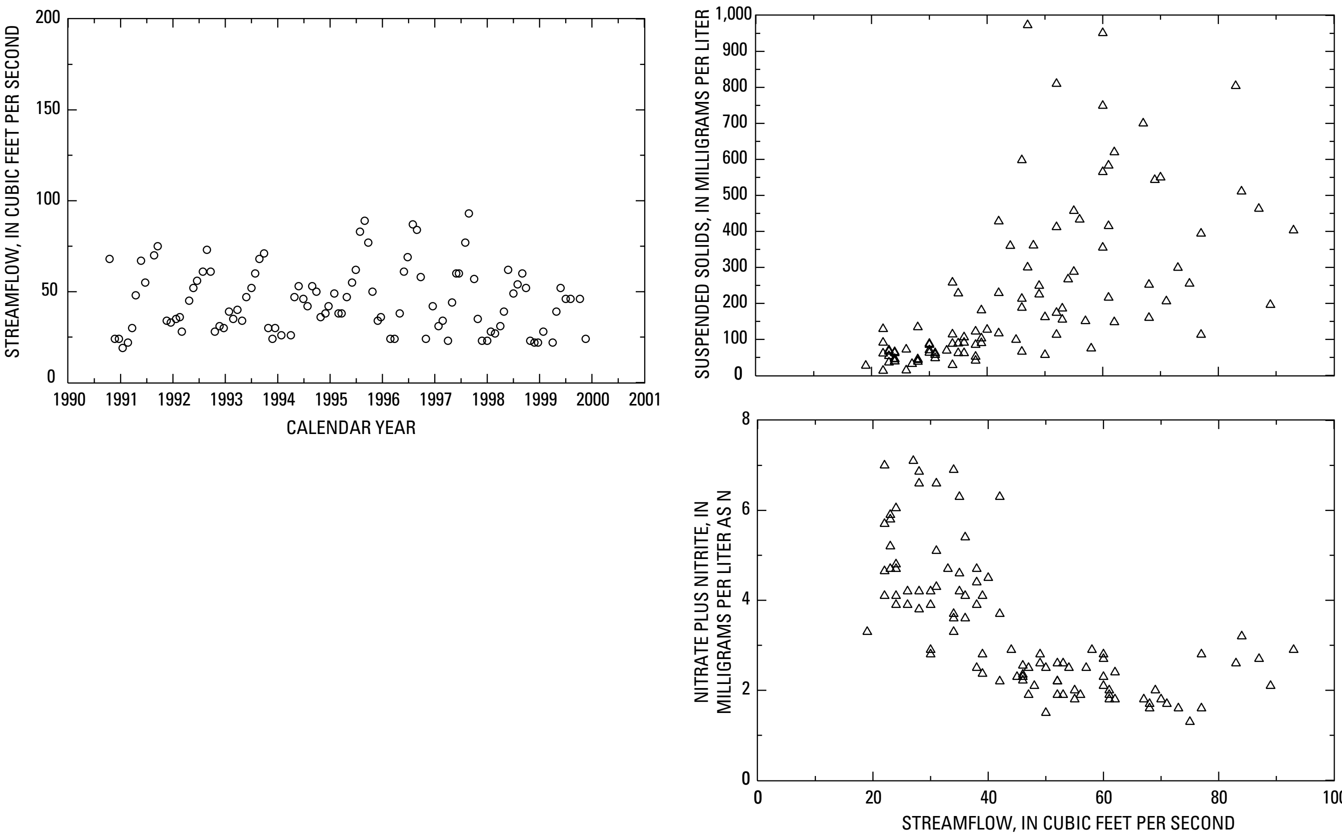


Figure 18. Temporal variations in streamflow and variations in concentrations of suspended solids and nitrite-plus-nitrate nitrogen with streamflow in Granger Drain at Highway 223 near Granger, Yakima River Basin, Washington, 1991–2000 water years.

(Data provided by the Bureau of Reclamation.)

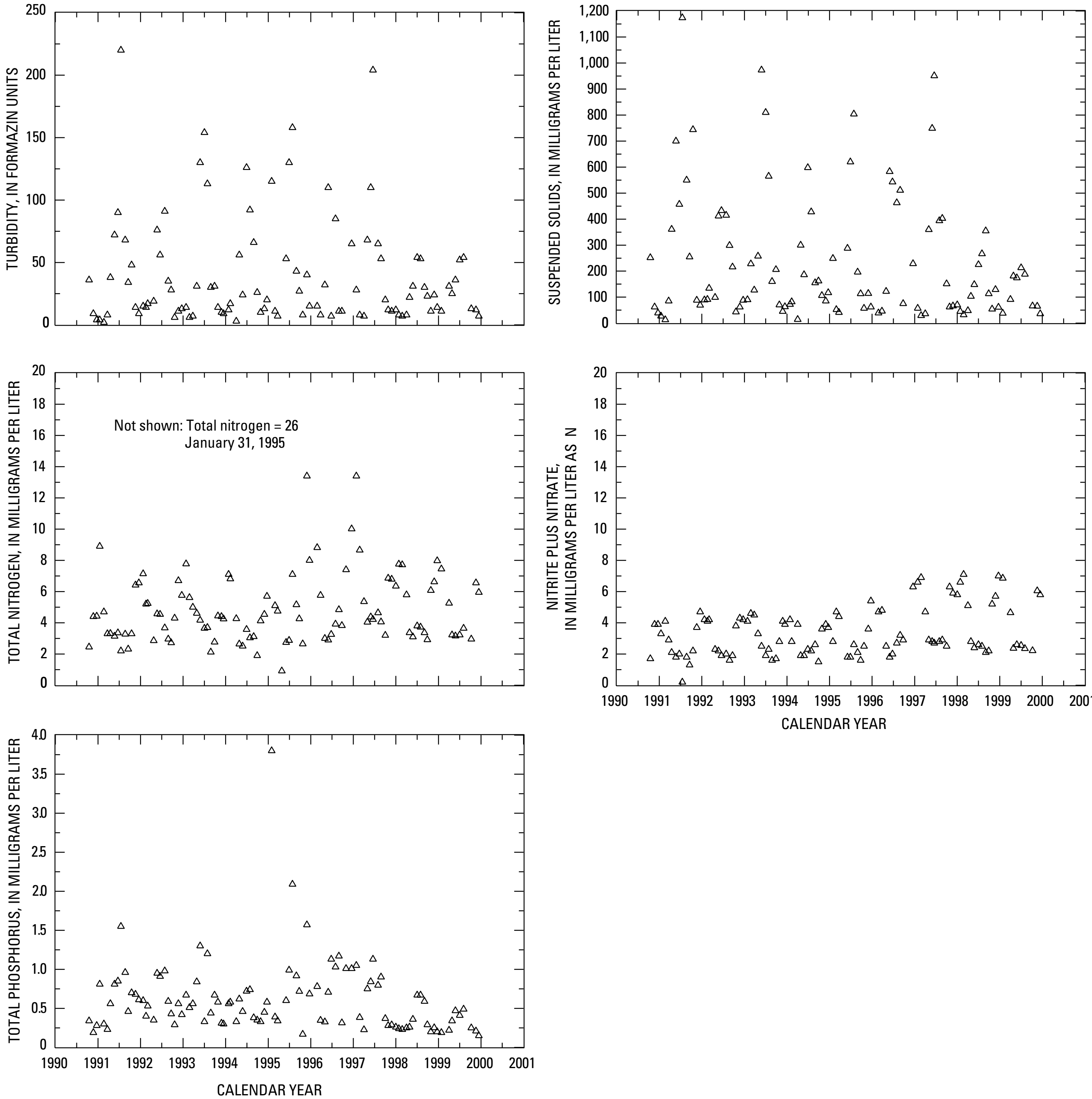


Figure 19. Temporal variations in turbidity and concentrations of suspended solids, total nitrogen, nitrite-plus-nitrate nitrogen, and total phosphorus in Granger Drain at Highway 223 near Granger, Yakima River Basin, Washington, 1991–2000 water years.

(Data provided by the Bureau of Reclamation.)

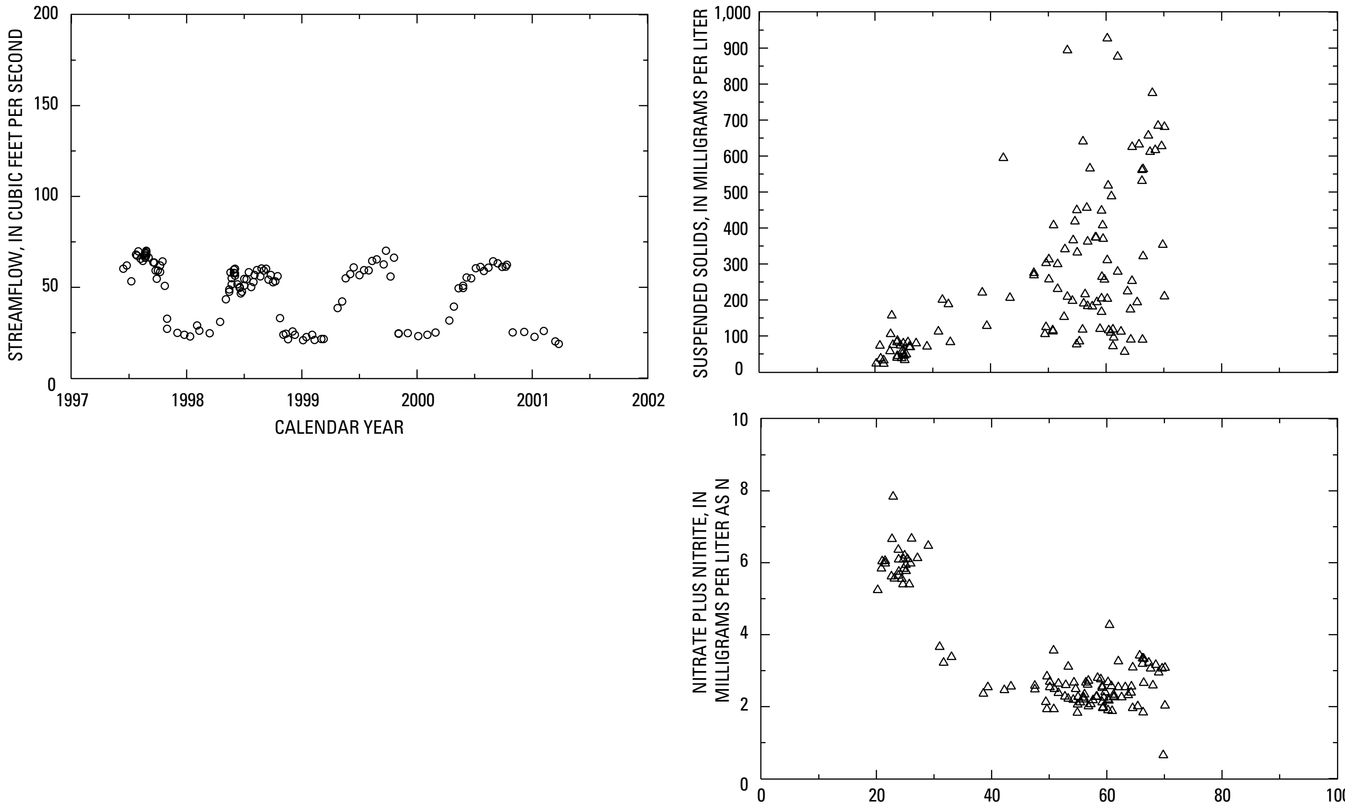


Figure 20. Temporal variations in streamflow and variations in concentrations of suspended solids and nitrite-plus-nitrate nitrogen with streamflow in Granger Drain at Granger, Yakima River Basin, Washington, 1997–2001.

(Data provided by Roza-Sunnyside Board of Joint Control.)

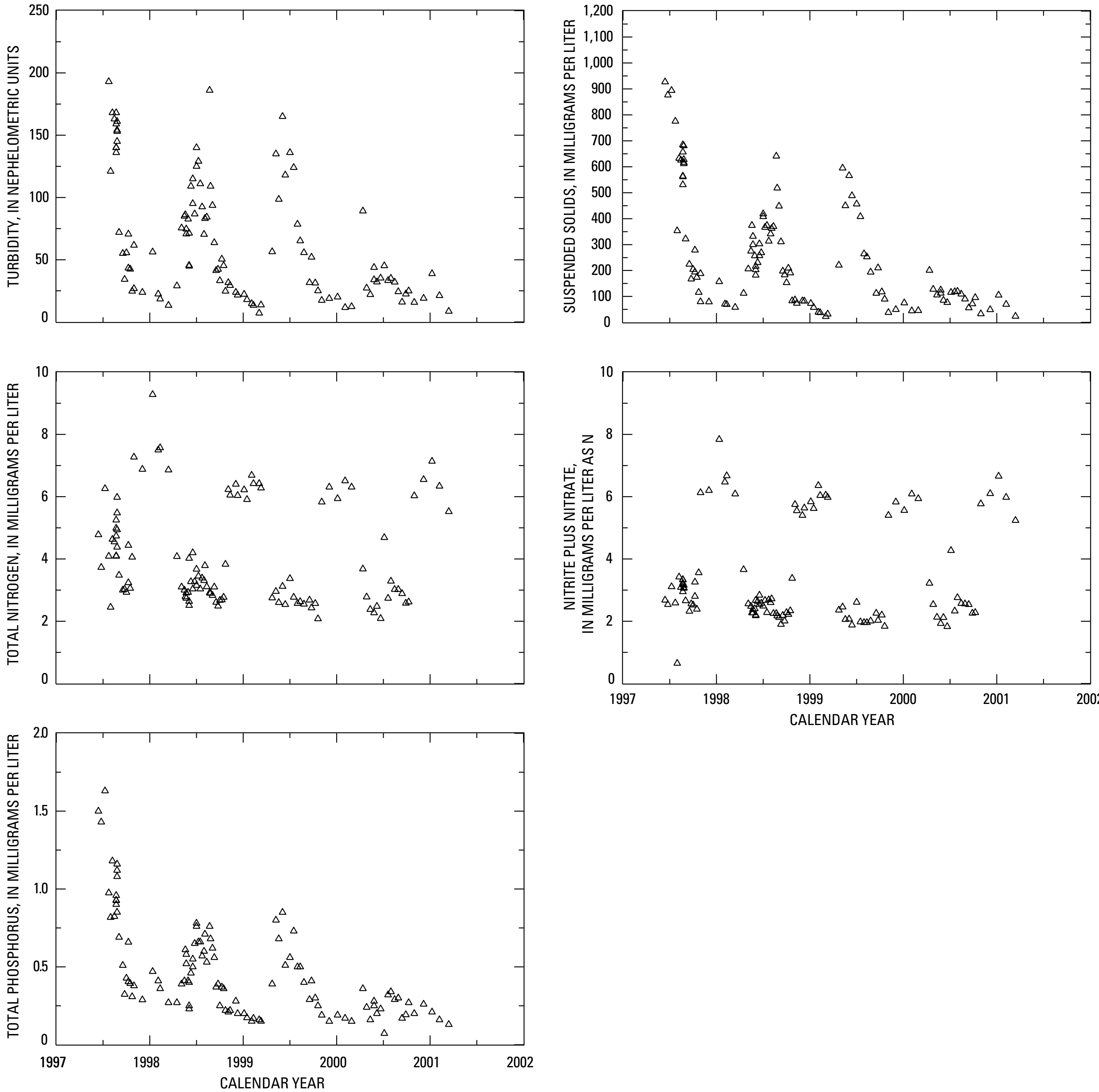


Figure 21. Temporal variations in turbidity and concentrations of suspended solids, total nitrogen, nitrite-plus-nitrate nitrogen, and total phosphorus in Granger Drain at Granger, Yakima River Basin, Washington, 1997–2001.

(Data provided by Roza-Sunnyside Board of Joint Control.)

Sulphur Creek Wasteway

Data collected over a 10-year period were not available to compute trend statistics for Sulphur Creek Wasteway, but an inspection of graphs showing temporal variations in streamflow (fig. 22) and concentration data (fig. 23) suggests that even though streamflow measured during irrigation season (the higher flows shown on figure 22) appears to be increasing, concentrations of suspended solids are decreasing. Concentrations of total nitrogen, nitrate, and total phosphorus also appear to be decreasing. Similar to some of the other streams, concentrations of nitrate and total nitrogen form two distinct trend lines, with lower concentrations occurring during the irrigation season when canal water in the wasteway dilutes nitrate discharged to Sulphur Creek Wasteway from field drains and ground water. From 1996 through 2000, there has been a consistent increase in the use of BMPs in the Sulphur Creek Basin (table 1).

A small tributary to Sulphur Creek Wasteway receives runoff from rill-irrigated corn.

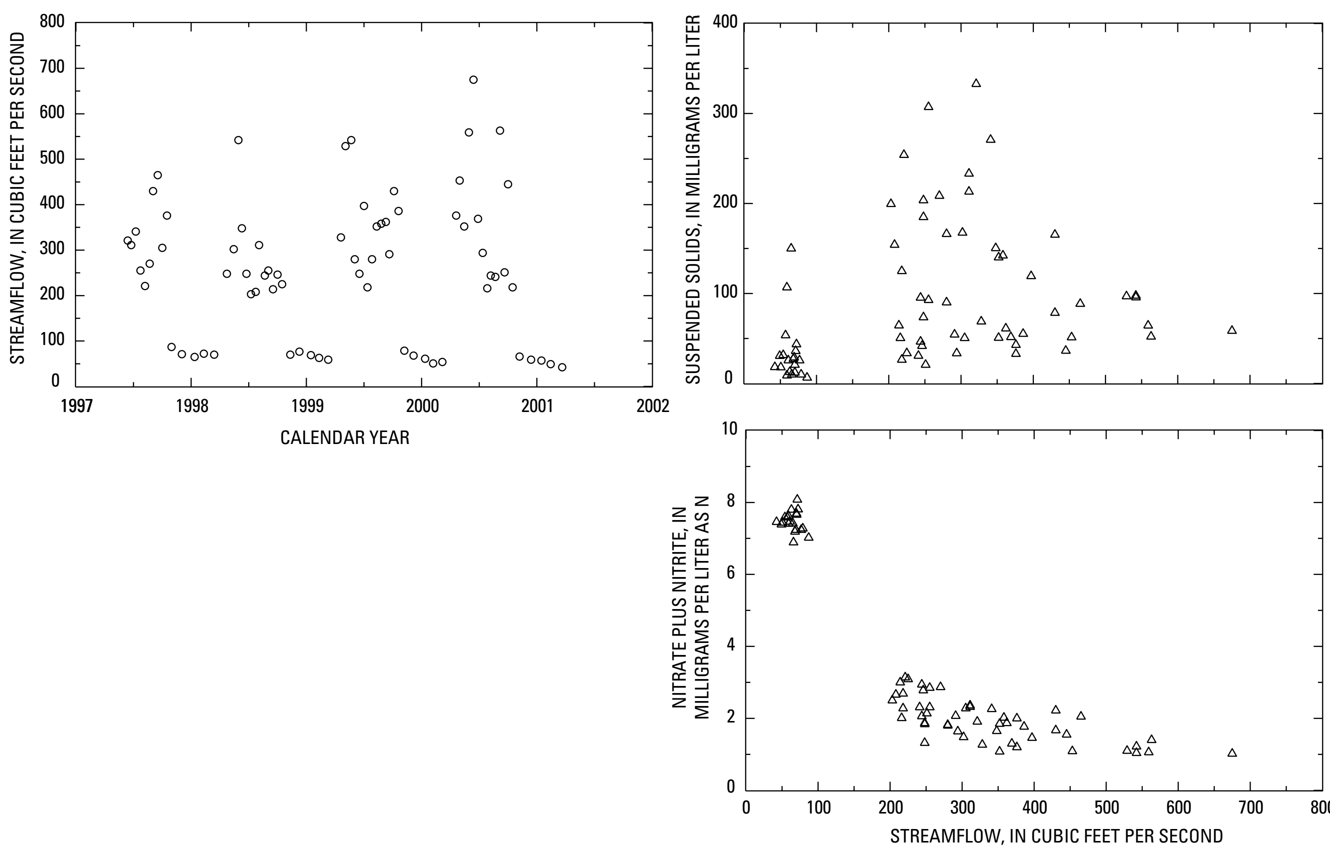


Figure 22. Temporal variations in streamflow and variations in concentrations of suspended solids and nitrite-plus-nitrate nitrogen with streamflow in Sulphur Creek Wasteway near Sunnyside, Yakima River Basin, Washington, 1997–2001.

(Data provided by Roza-Sunnyside Board of Joint Control.)

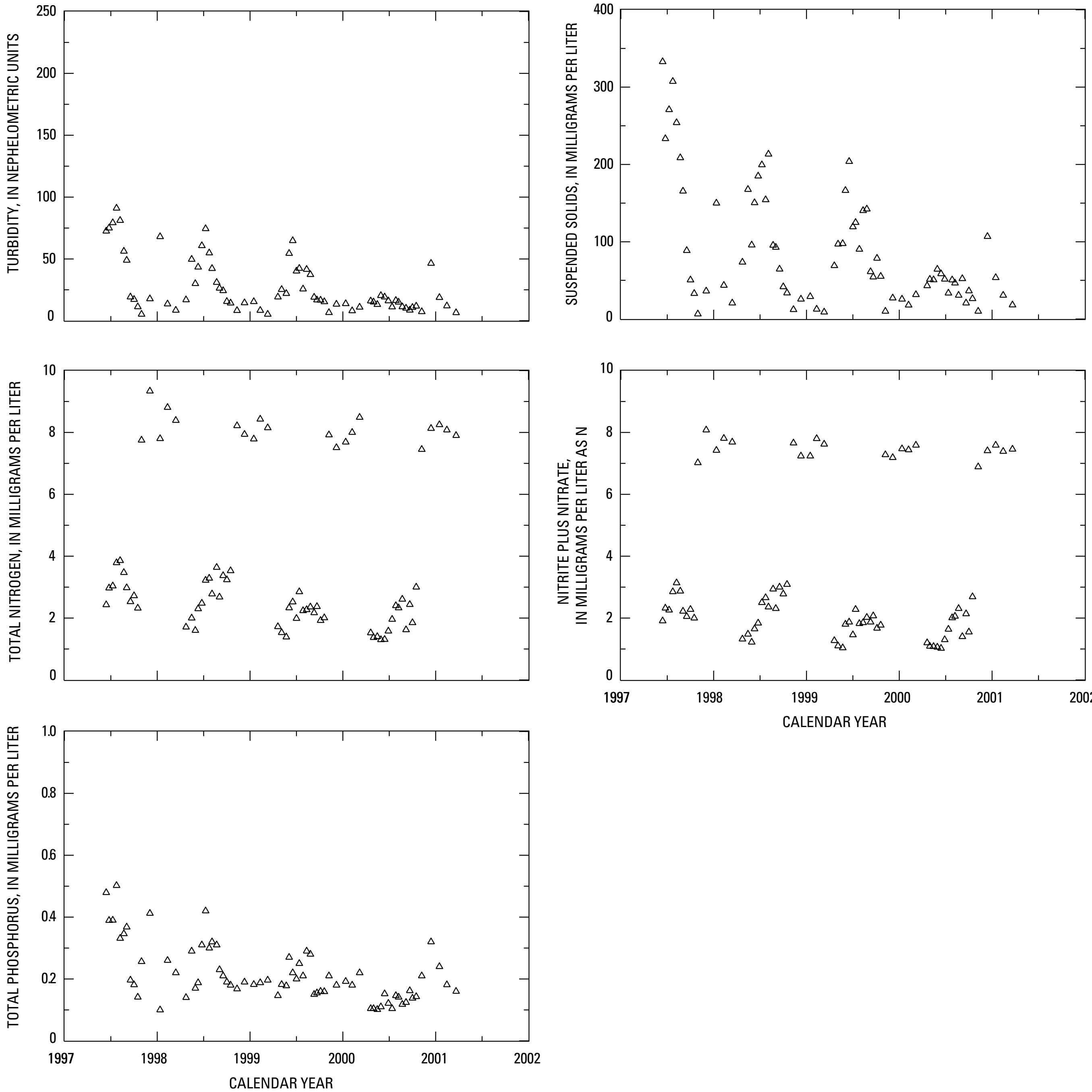


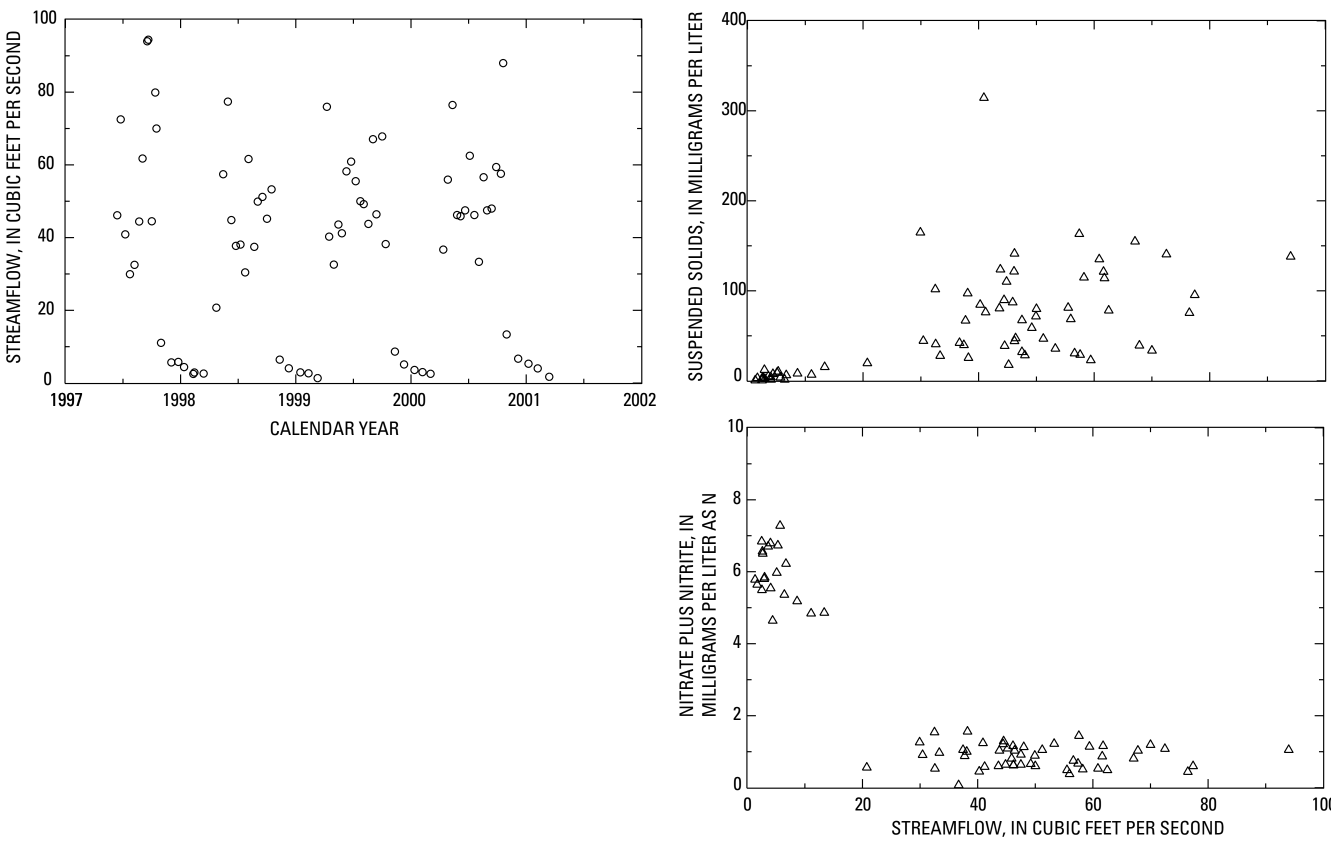
Figure 23. Temporal variations in turbidity and concentrations of suspended solids, total nitrogen, nitrite-plus-nitrate nitrogen, and total phosphorus in Sulphur Creek Wasteway near Sunnyside, Yakima River Basin, Washington, 1997–2001.

(Data provided by Roza-Sunnyside Board of Joint Control.)

Spring and Snipes Creeks

Data collected over a 10-year period were not available to compute trend statistics for Spring Creek, and no BMP data were available for the drainage basin. Graphs showing temporal variations in streamflow (fig. 24*A*), turbidity (fig. 25*A*), and concentrations of suspended solids and nutrients (fig. 25*A*) suggest that there might be a slight decrease in turbidity and concentrations of suspended solids. No change is evident in concentrations of nitrate, total nitrogen, and total phosphorus.

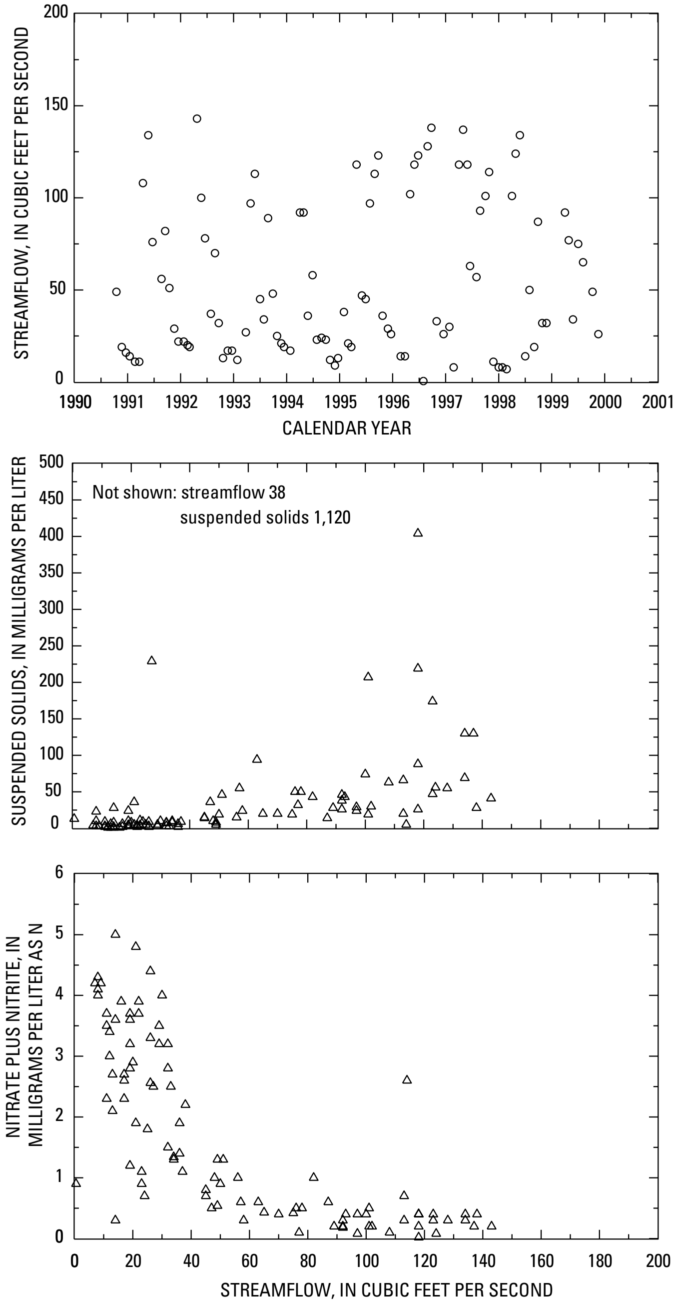
Ten-year trend statistics for Snipes Creek indicate an upward trend in turbidity and no trend in concentrations of suspended solids and nutrients (table 11). Ten-year records for Snipes Creek (figs. 24*B* and 25*B*) are complemented by data collected 1997–2001 by the RSBOJC (figs. 24*C* and 25*C*). The RSBOJC data indicate that concentrations of nitrate and total nitrogen may be decreasing during the non-irrigation season when concentrations are higher. No BMP data were available for the Snipes Creek subbasin. Turbidity and concentrations of suspended solids and total phosphorus also appear to be decreasing.



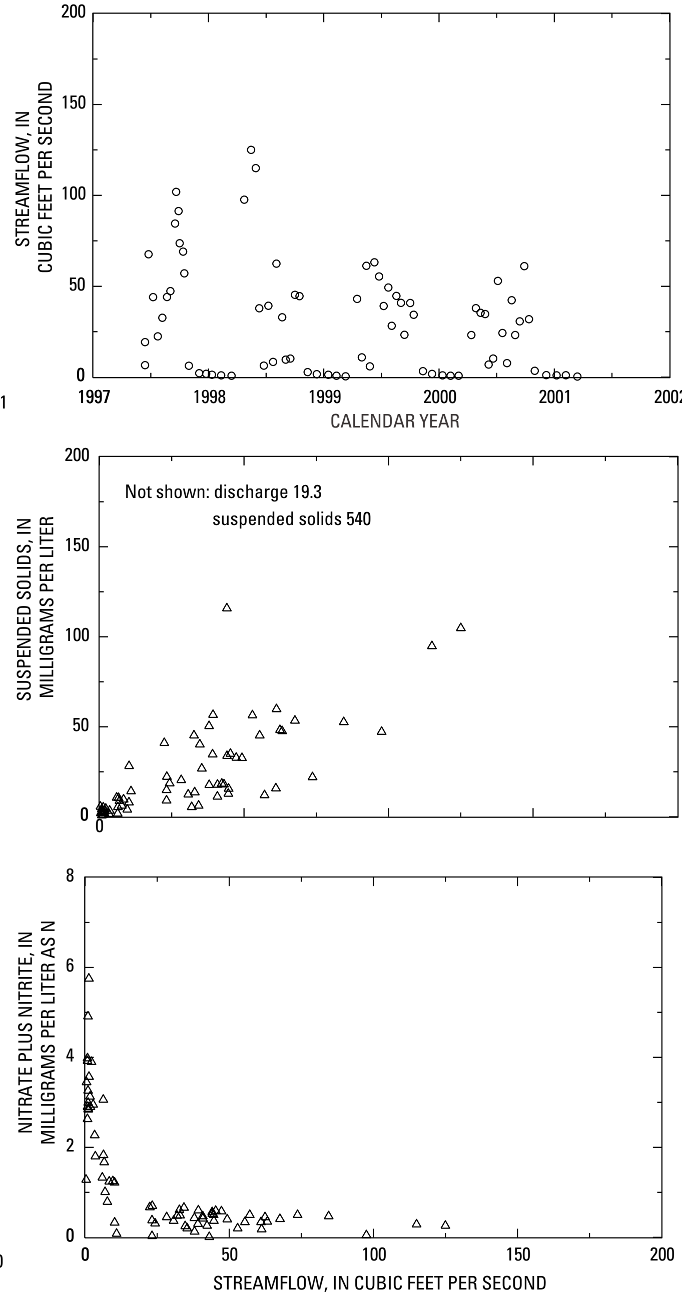
***A.* Spring Creek at mouth at Whitstran**

Figure 24. Temporal variations in streamflow and variations in concentrations of suspended solids and nitrite-plus-nitrate nitrogen with streamflow in selected surface-water sites in Yakima River Basin, Washington, 1997–2001.

(Data provided by Roza-Sunnyside Board of Joint Control.)

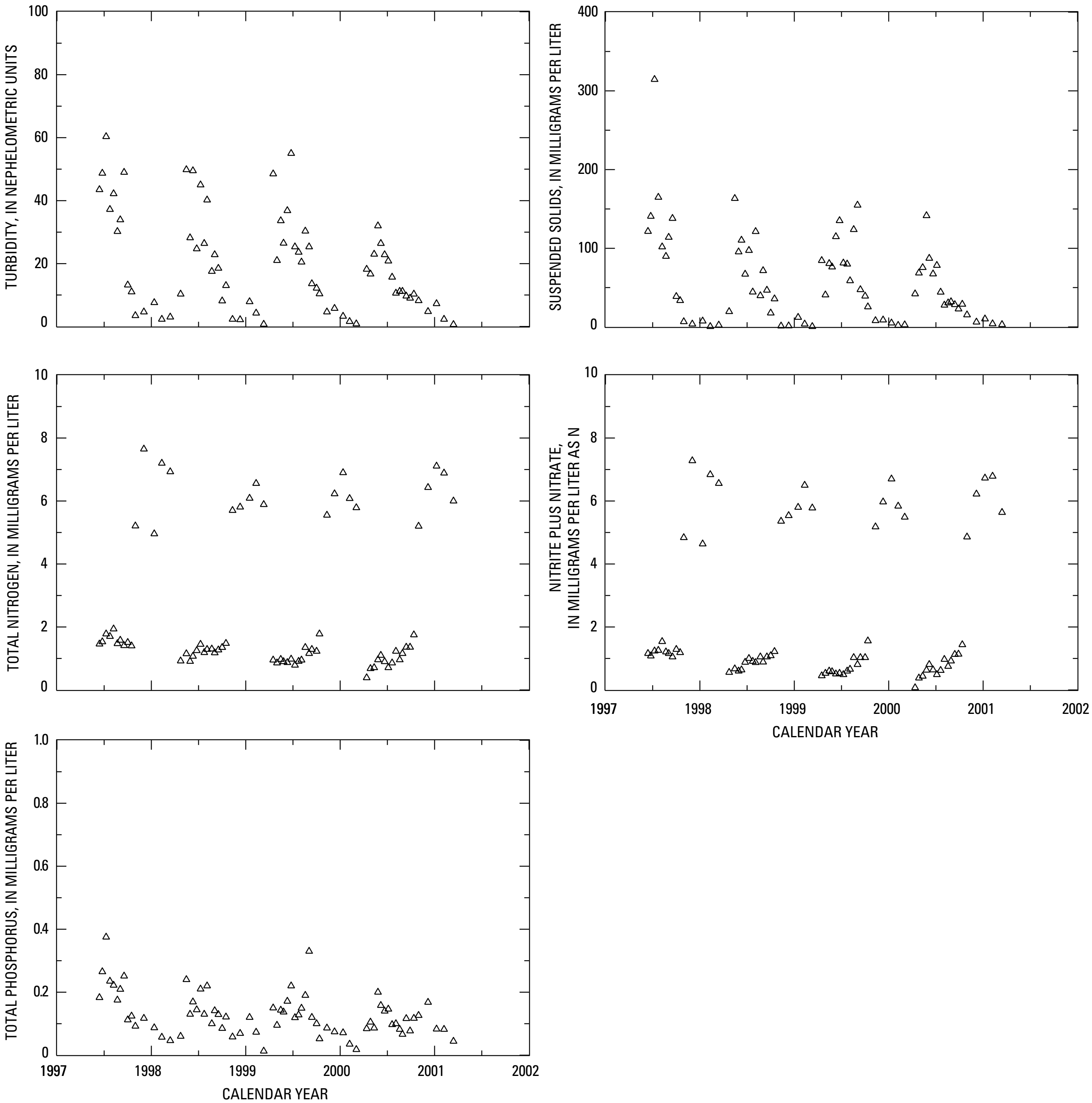


B. **Snipes Creek at Old Inland Empire Road**
(Data provided by the Bureau of Reclamation)



C. **Snipes Creek at mouth at Whitstran**
(Data provided by Roza-Sunnyside Board of Joint Control)

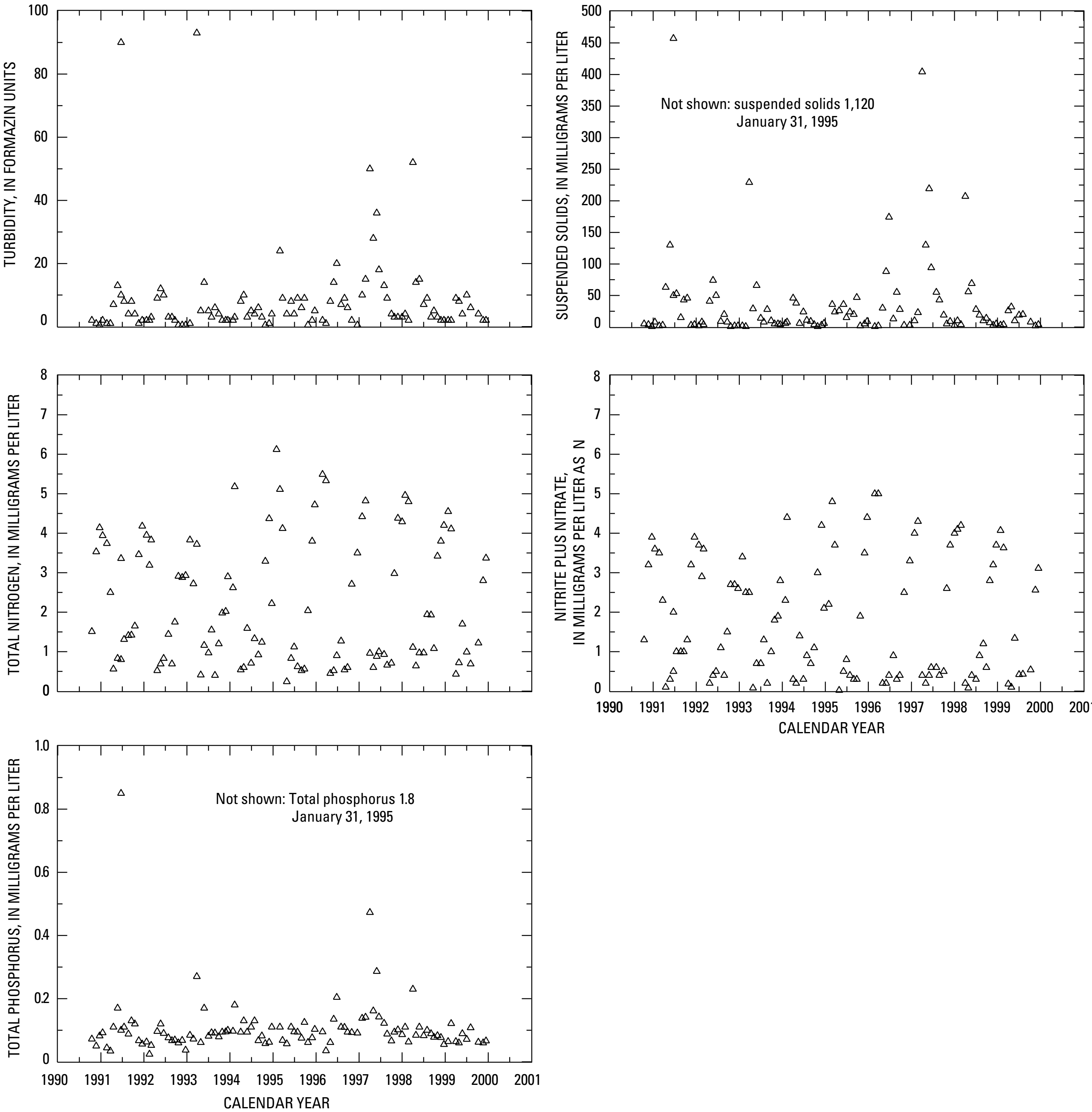
Figure 24.—*Continued.*



***A.* Spring Creek at mouth at Whitstran**

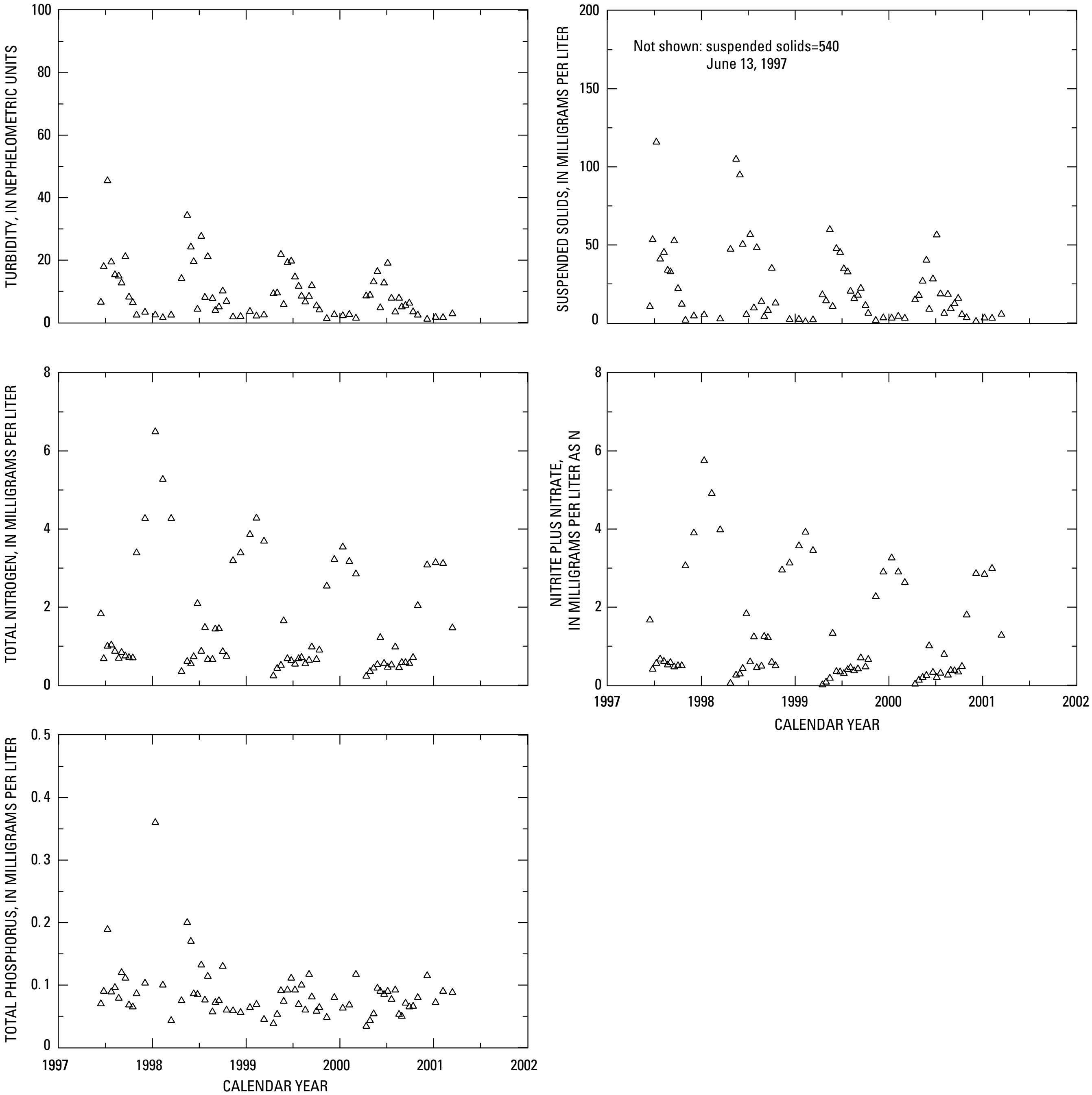
Figure 25. Temporal variations in turbidity and concentrations of suspended solids, total nitrogen, nitrite-plus-nitrate nitrogen, and total phosphorus, in Spring Creek at mouth at Whitstran, Yakima River Basin, Washington 1997–2001.

(Data provided by Roza-Sunnyside Board of Joint Control.)



***B.* Snipes Creek at Old Inland Empire Road**
(Data provided by the Bureau of Reclamation)

Figure 25.—*Continued.*



C. **Snipes Creek at mouth at Whitstran**
(Data provided by the Roza-Sunnyside Board of Joint Control)

Figure 25.—*Continued.*

Yakima River at Kiona

Trend statistics computed using both unadjusted and flow-adjusted data indicate small, but significant, increases in turbidity and concentrations of total phosphorus in the Yakima River at Kiona from 1991 to 2000 (table 11). The rates of increase in flow-adjusted values of turbidity and flow-adjusted concentrations of total phosphorus were similar to those reported by Butkus and others (2001) (table 12). However, they did not consider the increase in concentrations of total phosphorus significant because their test for significance was based on a *p*-value of 0.05 or less, rather than 0.10 as used in this study. Both studies used the same data to test for trends, but Butkus and others (2001) used a different regression model to obtain flow-adjusted concentrations.

Butkus and others (2001) also tested flow-adjusted concentrations of total nitrogen for trends and found none, which agrees with the results of the trend test performed in this study (table 12). This study found a significant increase in flow-adjusted concentrations of nitrate in the Yakima River at Kiona, a result that is consistent with increasing concentrations of nitrate in some streams and drains flowing to the Yakima River (table 11). Even though nitrogen discharged from the streams and drains makes up a significant fraction of the nitrogen load in the Yakima River (see table 5), a relation between increasing concentrations of nitrate in streams and drains and increasing concentrations in the Yakima River at Kiona was not established by this study.

Based on the trend test performed using flow-adjusted concentrations, there was no trend in the concentration of suspended solids over the 1991–2000 water years (table 11). This result seems reasonable because concentrations of suspended solids correlated with streamflow (fig. 26), and higher values of both were observed after 1995 (figs. 26 and 27).

Table 12. Comparison of trend statistics for turbidity and concentrations of total nitrogen and total phosphorus in samples collected from the Yakima River at Kiona, Yakima River Basin, Washington

[Ecology, trend statistics computed by the Washington State Department of Ecology from samples collected monthly October 1990–September 2000 (Butkus and others, 2001). Total nitrogen samples were collected during 1994–2000 water years only. USGS, U.S. Geological Survey statistics computed for this report (see table 11) using the same data but different methods to compute flow-adjusted concentrations. NTU, nephelometric turbidity unit; <, less than]

	Turbidity (NTU)		Total nitrogen (milligrams per liter)		Total phosphorus (milligrams per liter)	
	p-value	Slope units per year	*p*-value	Slope units per year	*p*-value	Slope units per year
Ecology (flow-adjusted concentrations)	0.002	0.509	0.957	0.0008	0.063	0.0035
USGS (flow-adjusted concentrations)	<.01	.42	.16	-.013	.01	.0035
USGS (unadjusted concentrations)	<.01	.65	.10	-.034	.06	.0032

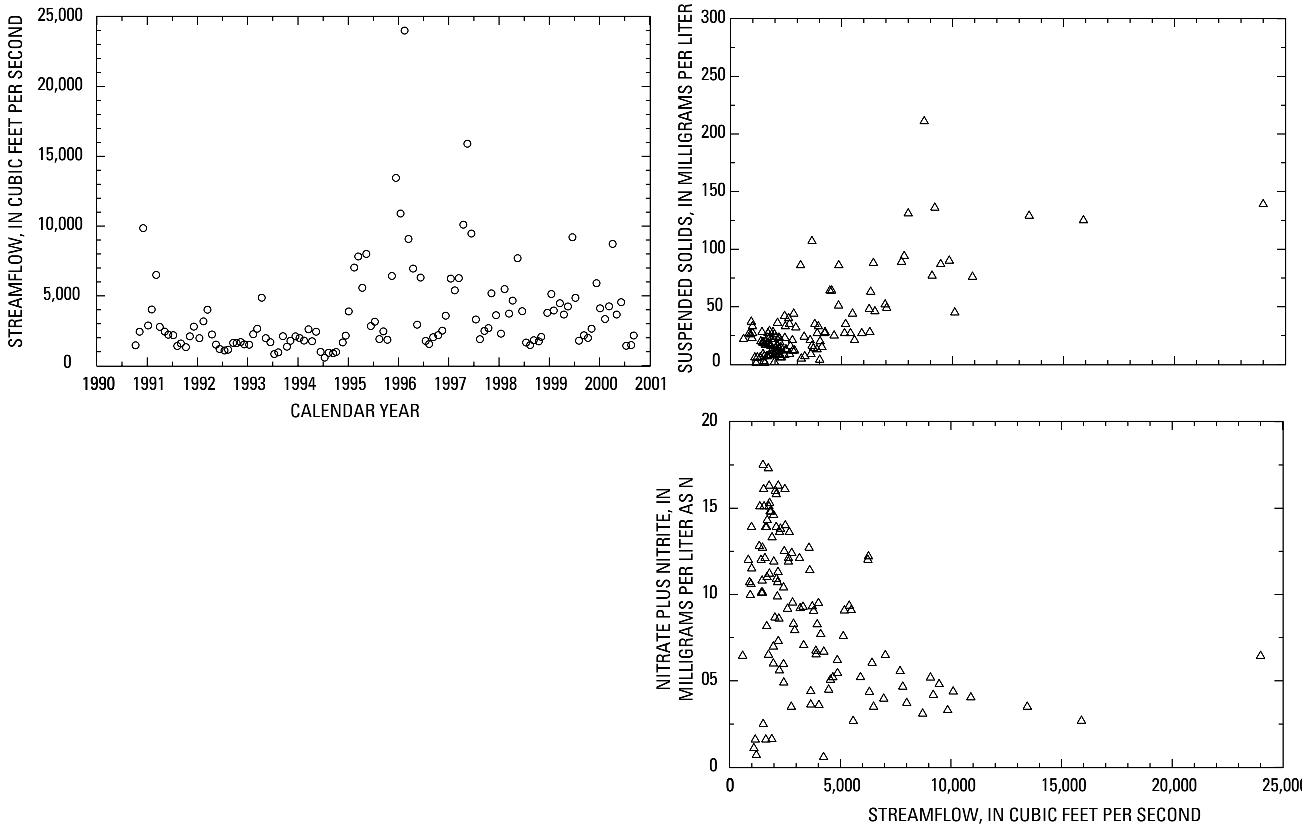


Figure 26. Temporal variations in streamflow and variations in concentrations of suspended solids and nitrite-plus-nitrate nitrogen with streamflow in Yakima River at Kiona, Yakima River Basin, Washington, 1991–2000 water years.

(Concentration data provided by the Washington State Department of Ecology.)

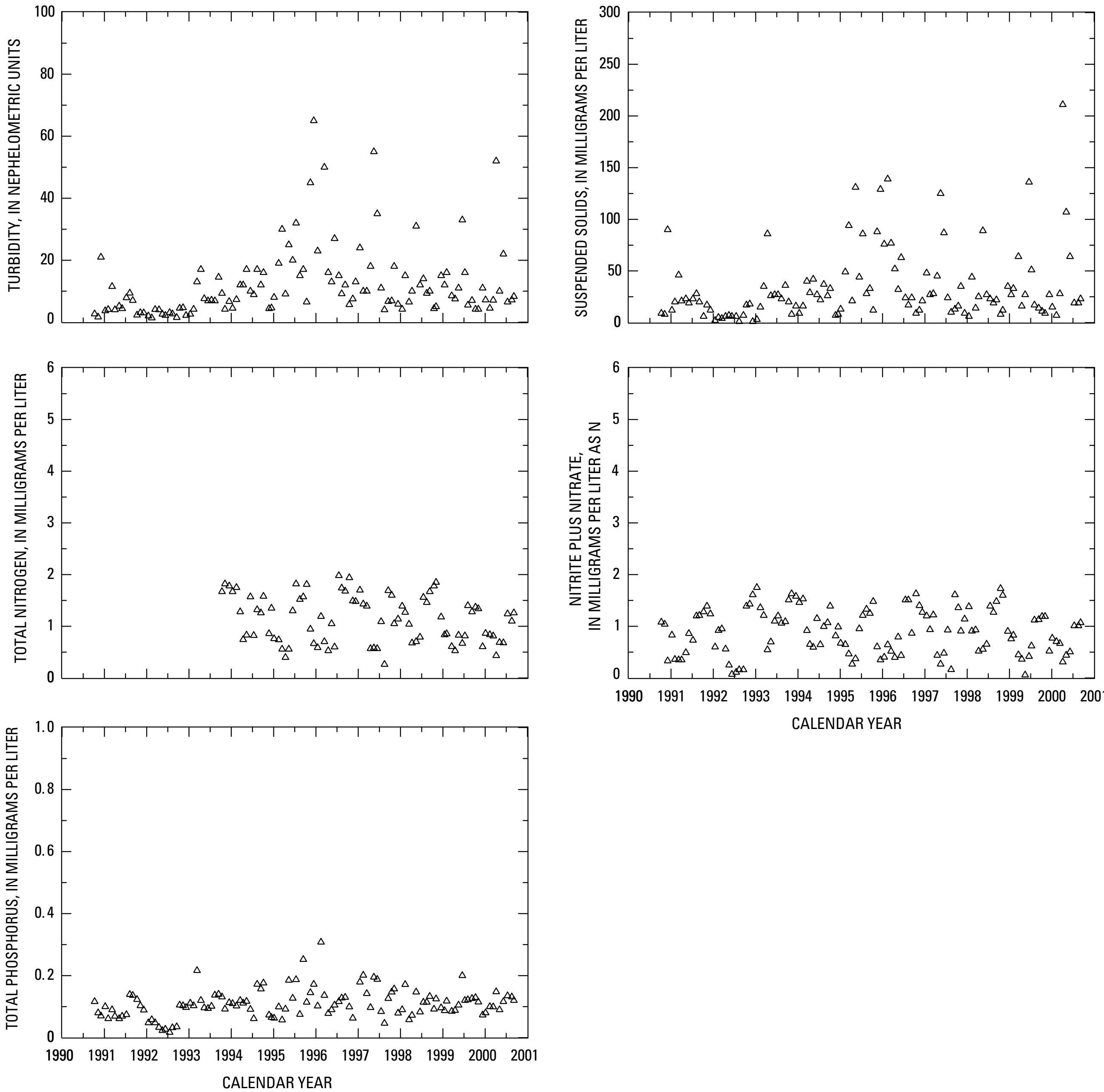


Figure 27. Temporal variations in turbidity and concentrations of suspended solids, total nitrogen, nitrite-plus-nitrate nitrogen, and total phosphorus in Yakima River at Kiona, Yakima River Basin, Washington, 1991–2000 water years.

(Data provided by the Washington State Department of Ecology.)

SUMMARY AND CONCLUSIONS

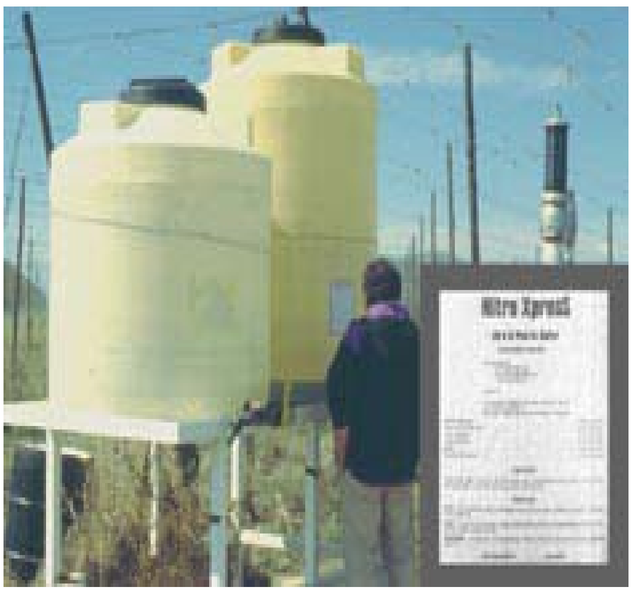
Spatial and temporal variations in concentrations and loads of suspended sediment and nutrients in surface water of the Yakima River Basin were assessed using data collected during 1999–2000 as part of the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program. Samples were collected at 34 sites located throughout the Basin in August 1999 using a Lagrangian sampling design, and were collected weekly and monthly from May 1999 through January 2000 at three of the sites (Granger Drain, Moxee Drain, and Yakima River at Kiona). Additional data collected by the USGS January 2001 through August 2002 at the Yakima River at Kiona were used to help assess the results of estimating suspended-sediment and nutrient loads for water years 1999–2000 using regression equations. Nutrient and sediment data collected at various time intervals from 1973 through 2001 by the USGS, Bureau of Reclamation (BOR), Washington State Department of Ecology (Ecology), and Roza-Sunnyside Board of Joint Control (RSBOJC) were used to assess trends in concentrations.

During irrigation season (mid-March to mid-October) concentrations of suspended sediment and nutrients in the Yakima River increase as relatively pristine water from the forested headwaters moves downstream and mixes with discharges from streams, agricultural drains, and wastewater treatment plants. Concentrations of nutrients in the Yakima River depend partly on the proportions of mixing between river water and discharges, and in years when ample water is stored in headwater reservoirs, more water is released during irrigation season, and nutrients discharged to the river downstream are more diluted. In August 1999, streamflow in the reach of the Yakima River extending from river mile (RM) 103.7 to RM 72 exceeded streamflow in July 1988 by a factor of almost 2.5, but loads of total nitrogen and phosphorus discharged to the reach from streams, drains, and wastewater treatment plants were only 1.2 and 1.1 times larger. In August 1999 concentrations of total nitrogen and total phosphorus at RM 72 were 1.0 mg/L (milligrams per liter) and 0.06 mg/L, compared with 1.5 mg/L and 0.10 mg/L in July 1988.

The water supply also affects concentrations of nutrients, especially nitrate, in drains and streams carrying agricultural return flows. Canal water, which is diverted from either the Yakima or Naches River, makes up more of the flow in drains and streams in years with an ample water supply. The canal water dilutes nutrients transported to the drains and streams in runoff from fields and in discharges from subsurface field drains and the shallow ground-water system. In August 1999, the average concentrations of total nitrogen and total phosphorus in drains and streams discharging to the reach of the Yakima River from RM 103.7 to RM 72 were 2.63 mg/L and 0.20 mg/L, compared with 3.16 mg/L and 0.26 mg/L in July 1988.

Streamflow in agricultural drains decreases after irrigation season because irrigation water is no longer diverted from the Yakima and Naches Rivers. As a result, concentrations of total nitrogen in drains increase because nitrate, which makes up much of the total nitrogen, continues to enter the drains from subsurface drains and shallow ground water. In contrast, concentrations of total phosphorus and suspended sediment often decrease after irrigation season because they are transported to the drains in runoff of irrigation water from fields. Also, at the lower flows during the post-irrigation season, dissolved orthophosphate typically makes up a larger fraction of the total phosphorus concentration. In Moxee Drain, concentrations of total nitrogen ranged from about 1.5-2 mg/L during irrigation season and increased to about 6 mg/L after irrigation season. Concentrations of total phosphorus ranged from about 0.2-0.4 mg/L during May-July of the irrigation season, then decreased to about 0.2 mg/L during August-October of the irrigation season. After the irrigation season, total phosphorus concentrations increased to about 0.3 mg/L from November 1999-January 2000 in response to increased concentrations of dissolved orthophosphate. Dissolved orthophosphate concentrations increased because sources of the nutrient (possibly the effluent from the Moxee City wastewater treatment plant) continued to discharge to Moxee Drain during the post-irrigation season when less streamflow is available to dilute the orthophosphate. Concentrations of suspended sediment ranged from about 50-250 mg/L during irrigation season and dropped to less than 50 mg/L after irrigation season. In Granger Drain, concentrations of total nitrogen ranged between 2 and 4 mg/L during irrigation season and increased to about 6 mg/L after irrigation season, and concentrations of total phosphorus decreased to about 0.2 mg/L after being as high as 1 mg/L during irrigation season.

There also was an inverse relation between streamflow and concentrations of nitrate and total nitrogen in the Yakima River at Kiona. Because of diversions, flow regulation in the headwaters, and dry summers, the Yakima River at Kiona differs hydrologically from Moxee and Granger Drains, having a low-flow period during late summer instead of winter and streamflows that generally vary more in magnitude during the remainder of the year. The highest concentrations of suspended sediment and total phosphorus in the Yakima River at Kiona were observed during high flow in June 1999.



Not all crops respond ideally to fertilization with manure; more than 18,000 tons of commercial-nitrogen fertilizer was applied in Yakima County in 1998.

Perhaps because of dilution, concentrations of total phosphorus in the Yakima River from RM 72 to Kiona at RM 29.9 were somewhat lower in August 1999 than in July 1988, when there was less streamflow in this reach of the river. Even with more dilution in August 1999, concentrations of total phosphorus in all but one sample were greater than 0.1 mg/L, the recommended concentration for limiting accelerated plant growth in streams. In July 1988, concentrations of total phosphorus in all samples collected from this reach were greater than or equal to 0.1 mg/L.

A regression model was used to estimate loads in Granger Drain and Yakima River at Kiona for the period October 1, 1998–September 30, 2000. Granger Drain transported an average of 42,000 lb/d (pounds per day) of suspended sediment, 860 lb/d of total nitrogen, and 78 lb/d of total phosphorus. Loads transported in the Yakima River at Kiona averaged 850,000 lb/d (about 430 tons per day) of suspended sediment, 20,000 lb/d of total nitrogen, and 2,800 lb/d of total phosphorus. Lack of streamflow data made it necessary to estimate loads in Moxee Drain for only the 1999 calendar year: it discharged an average of 28,000 lb/d of suspended sediment, 380 lb/d of total nitrogen, and 46 lb/d of total phosphorus to the Yakima River. These loads were about half the average loads transported by Granger Drain during the same period. Average streamflows were similar for the two streams (40 ft^3/s, cubic feet per second, at Granger Drain and 35 ft^3/s at Moxee Drain), therefore the difference in loads was due to differences in concentrations. Constituent concentrations in Moxee Drain ranged from about 40 to 60 percent less than concentrations in Granger Drain.

Departure from relations between average daily loads plotted as a function of annual mean streamflow suggests some reduction in loads of suspended sediment, ammonia-plus-organic nitrogen, and total nitrogen in the Yakima River at Kiona in water years 1999 and 2000. A relation between loads and streamflow was established using loads previously estimated for water years 1974, 1977, 1980, 1988 and 1989 and loads estimated for this study for other water years from 1974 through 1994.

Loads of suspended sediment and total phosphorus in Moxee and Granger Drains were nearly 4 times higher during the irrigation season than during the non-irrigation season. There is more flow in the drains during irrigation season and concentrations of suspended sediment and total phosphorus usually are higher. Loads of nitrate in the drains were about the same in both seasons because nitrate concentrations are higher during the non-irrigation season. Loads of nutrients in the Yakima River at Kiona were similar during irrigation and non-irrigation season, generally differing by less than 20 percent. The suspended-sediment load during irrigation season was about 60 percent larger than during the non-irrigation season. Large fractions of the total annual loads in the Yakima River were transported during the first half of the irrigation season. For example, 38 percent or more of the annual loads of suspended sediment, total nitrogen, ammonia-plus-organic nitrogen, total phosphorus, and orthophosphate were transported from March through June.

The summary of trend statistics for concentration data collected 1991–2000 by the BOR and Ecology indicates that some of the factors affecting constituent transport to surface water may be common to many of the agricultural subbasins. For example, concentrations of nitrate and total nitrogen increased in five of six streams and drains while concentrations of suspended solids and total phosphorus either did not change or decreased. This difference is consistent with no change, or a decrease, in amounts of suspended solids and phosphorus transported to surface water in runoff and an increase in the amount of nitrate transported to streams and drains from ground-water discharges and subsurface drains. Decreased transport of sediment and associated phosphorus to streams and drains is likely due to the increased use of agricultural best management practices that reduce runoff from cropland. Because much of the nitrate in drains enters from subsurface drains and shallow ground water, management practices designed to reduce runoff from cropland have less effect. Increasing concentrations of nitrate in some drains over the period 1991–2000 suggest that concentrations of nitrate in ground water are increasing.

Data collected 1997–2001 by the RSBOJC also indicate a decrease in concentrations in suspended solids total phosphorus in some drains and streams receiving agricultural return flows, as well as a decrease in turbidity. These data indicate that concentrations of nitrate in some of the streams and drains have leveled off and may be decreasing. This observation is not in conflict with the trend statistics for 1991–2000, but suggests that a slow increase over a decade may be leveling off.

Trend statistics computed using both unadjusted and flow-adjusted data indicate small, but significant, increases in turbidity and concentrations of total phosphorus in the Yakima River at Kiona from 1991 through 2000. This study also found a significant increase in flow-adjusted concentrations of nitrate in the Yakima River at Kiona, a result consistent with increasing concentrations of nitrate in some streams and drains flowing to the Yakima River. Even though nitrogen discharged from the streams and drains makes up a significant fraction of the nitrogen load in the Yakima River, a relation between increasing concentrations of nitrate in streams and drains and increasing concentrations in the Yakima River at Kiona was not established.

The trend test using flow-adjusted concentrations showed no trend in the concentration of suspended solids in the Yakima River at Kiona from 1991 through 2000. This result seems reasonable because concentrations of suspended solids correlated with streamflow, and higher values of both were observed after 1995.

The lower basin is host to a variety of agricultural practices, crop types, and irrigation methods.

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APPENDIX A.—EVALUATION OF QUALITY-CONTROL DATA

U.S. Geological Survey Data

Data quality was evaluated using (1) replicate and blank samples (tables A1 and A2) that were prepared in the field and sent to the laboratory for analysis; (2) data provided by the USGS National Water-Quality Laboratory on the recovery of analytes in spiked inorganic blank water (table A3); (3) quality-control charts and reports published by the USGS Branch of Quality Systems Inorganic Blind Sample Project, available online at URL <http://bqs.usgs.gov/bsp/mainpage.html>; and (4) quality-control charts and reports published by the USGS Branch of Quality Systems Quality Assurance Program for Sediment Analysis, available online at URL <http://sedserv.cr.usgs.gov/>.

Because they are available online, the quality-control charts and reports used to help assess data quality are not reproduced in this report. Quality-control charts are graphical displays of the analytical deviation from the most probable concentration of a standard reference sample over time. These samples, which are usually a mixture of natural water collected from different sources, are disguised as environmental samples before they are sent to the laboratory. The most probable concentration is determined by repeated analysis of the sample. The charts show if analytical results are within expected control limits and can illustrate a systematic or sudden shift in bias or variability. The Inorganic Blind Sample Project sets control limits at ± 2 standard deviations of the most probable value. The Quality Assurance Program for Sediment Analysis sets control limits at ±3 F-pseudosigma of the most probable value. For a definition of F-pseudosigma, see table A3.

Median relative percent differences in concentrations of nutrients in replicate surface-water samples ranged from 0.0 to 20.2 percent and were less than 5 percent, except for ammonia and unfiltered and filtered ammonia-plus-organic nitrogen (table A1). The median relative percent difference in concentrations of suspended sediment in replicate samples was 4.6 percent (table A1).

Small concentrations of ammonia and both unfiltered and filtered ammonia-plus-organic nitrogen were reported in some blank samples (table A2), but these very low concentrations are not indicative of a significant bias or contamination problem. Of possible concern are the relatively high concentrations of orthophosphate in two of four blank samples as compared with the laboratory reporting level of 0.01 mg/L (table A2). Recoveries of orthophosphate in spiked laboratory-reagent (blank) water do indicate a positive bias (table A3); however, these samples are spiked to very low concentrations for the determination of laboratory reporting levels. Control charts for orthophosphate indicate a positive bias with higher than expected variability for the period February through June 1999. Beginning in mid-July, the variability for this determination improved and the positive bias was corrected. Overall, however, variability in the determination of orthophosphate was relatively large compared with other nutrients. Control charts for suspended sediment and all other nutrient determinations except nitrite, for which no chart was available, indicate that analytical results were within expected control limits.

Roza-Sunnyside Board of Joint Control Data

The Water-Quality Monitoring Program of RSBOJC used USGS techniques to collect and process samples (see "Methods" section) and measured turbidity and determined concentrations of suspended solids in samples in their laboratory. Samples were sent to the Bureau of Reclamation Laboratory in Boise, Ida., for the determination of nutrient concentrations. The summary of quality-control data (table A4) indicates that errors caused by bias, variability, and potential contamination of samples were small compared with concentrations of analytes in samples.

Table A1. Concentration and precision data for nutrients and suspended sediment in replicate surface-water samples, Yakima River Basin, Washington, 1999–2000

[**Phosphorus, unfiltered**: referred to as total phosphorus in this report; Concentrations are in milligrams per liter; **Abbreviations:** USGS, U.S. Geological Survey; +, plus; <, less than; –, no data; nc, not calculated; RPD, relative percentage of difference; relative percentage of difference = $\frac{(R1 - R2)}{\left(\frac{R1 + R2}{2}\right)} \times 100$, where $R1$ = maximum value and $R2$ = minimum value]

Sample date	Concentration and precision data	Nitrogen, ammonia	Nitrogen, ammonia + organic filtered	Nitrogen, ammonia + organic unfiltered	Nitrogen, nitrite	Nitrogen, nitrite + nitrate	Phosphorus, filtered	Phosphorus, unfiltered	Orthophosphate as P, filtered	Sediment, suspended
USGS site No. 12500420										
Aug. 18, 1999	Concentration	<0.020	0.22	0.26	<0.010	1.03	0.093	0.217	0.078	113
		–	–	–	–	–	–	–	–	116
	RPD	nc	nc	nc	nc	nc	nc	nc	nc	2.6
Sept. 29, 1999	Concentration	<.020	.20	.22	.010	1.76	.106	.178	.090	50
		<.020	.20	–	<.010	1.78	.106	–	.093	–
		<.020	.24	.38	<.010	1.78	.107	.176	.091	–
	RPD	nc	18.2	53.3	nc	1.1	.94	1.1	3.3	nc
USGS site No. 12505420										
Dec. 8, 1999	Concentration	0.021	0.30	0.40	0.026	5.91	0.247	0.259	0.236	13
		.025	.29	.37	.026	5.87	.241	.263	.238	–
	RPD	17.4	3.4	7.8	.0	.68	2.5	1.5	.84	nc
USGS site No. 12505450										
June 3, 1999	Concentration	0.069	0.31	1.2	0.020	2.19	0.160	1.05	0.156	645
		.065	.30	1.1	.020	2.17	.159	1.06	.150	690
	RPD	6.0	3.3	8.7	.0	.92	.63	.95	3.9	6.7
Aug. 3, 1999	Concentration	.096	.92	1.3	<.010	2.59	.154	.443	.164	253
		.102	.91	–	<.010	2.59	.154	–	.185	–
	RPD	6.1	1.1	nc	nc	.0	.0	nc	12.0	nc
Aug. 19, 1999	Concentration	.024	.25	.66	.022	1.89	.152	.415	.139	199
		.022	.21	.59	.022	1.89	.156	.388	.138	–
		.026	.27	.89	.022	1.92	.155	.656	.135	–
	RPD	16.7	25.0	40.5	.0	1.6	2.6	51.3	2.9	nc
Nov. 17, 1999	Concentration	.037	.37	.52	.035	6.12	.109	.171	.088	47
		–	–	–	–	–	–	–	–	44
	RPD	nc	nc	nc	nc	nc	nc	nc	nc	6.6

Table A1. Concentration and precision data for nutrients and suspended sediment in replicate surface-water samples, Yakima River Basin, Washington, 1999–2000—*Continued*

Sample date	Concentration and precision data	Nitrogen, ammonia	Nitrogen, ammonia + organic filtered	Nitrogen, ammonia + organic unfiltered	Nitrogen, nitrite	Nitrogen, nitrite + nitrate	Phos-phorus, filtered	Phos-phorus, unfiltered	Ortho-phos-phate as P, filtered	Sedi-ment, sus-pended
USGS site No. 12510500										
July 13, 1999	Concentration	<0.02	0.16	0.28	<0.010	0.473	0.044	0.116	0.033	51
		–	–	–	–	–	–	–	–	50
	RPD	nc	nc	nc	nc	nc	nc	nc	nc	2.0
Aug. 5, 1999	Concentration	<0.02	0.18	0.49	0.017	1.03	0.083	0.125	0.072	15
		<.02	.15	.40	.017	1.03	.085	.123	.076	20
	RPD	nc	18.2	20.2	.0	.0	2.4	1.6	5.4	28.6
Aug. 31, 1999	Concentration	0.021	0.13	0.34	.010	1.19	.098	0.129	0.081	20
		.027	.14	.34	.010	1.19	.096	.126	.077	–
	RPD	25.0	7.4	.0	.0	.0	2.1	2.4	5.1	nc
USGS site No. 463447120275200										
Aug. 3, 1999	Concentration	0.072	0.91	0.96	<0.010	7.12	1.90	1.68	1.80	5
		.078	.86	1.2	<.010	7.05	1.92	2.12	1.78	5
	RPD	8.0	5.6	22.2	nc	.99	1.0	23.2	1.1	0.0
Summary										
	Minimum RPD	6.0	1.1	0.0	0.0	0.0	0.0	0.95	0.84	0.0
	Maximum RPD	25.0	25.0	53.3	.0	1.6	2.6	51.3	12.0	28.6
	Median RPD	12.3	6.5	20.2	.0	.80	1.6	1.6	3.6	4.6

Table A2. Concentrations of nutrients and suspended sediment in field blank samples, Yakima River Basin, Washington, 1999–2000

[**Phosphorus, unfiltered**: referred to as total phosphorus in this report. Concentrations are in milligrams per liter. **Abbreviations:** <, less than; E, detections above or below the lowest calibration standard, or otherwise less reliable than average because of sample-specific or compound-specific considerations. –, no data]

USGS site identifi-cation No.	Sample date	Nitrogen, ammonia	Nitrogen, ammonia + organic filtered	Nitrogen, ammonia + organic unfiltered	Nitrogen, nitrite	Nitrogen, nitrite + nitrate	Phos-phorus, filtered	Phos-phorus, unifltered	Ortho-phos-phate as P, filtered	Sedi-ment, sus-pended
12505450	July 22, 1999	<0.020	<0.10	E0.07	<0.010	<0.05	<0.004	<0.004	<0.01	–
12508850	August 4, 1999	<.020	E.06	E.08	<.010	<.05	<.004	<.004	.036	2
12510500	May 19, 1999	.023	<.10	<.10	<.010	<.05	<.004	<.004	.011	1
12510500	November 18, 1999	<.020	<.10	<.10	<.010	<.05	<.006	<.008	<.01	–

Table A3. Summary of recoveries for laboratory-reagent-spike nutrient analyses for the period October 1999 through September 2000

[Blind samples were submitted by the U.S. Geological Survey (USGS) Branch of Quality Systems to the USGS National Water Quality Laboratory. **F-pseudosigma**, which is the interquartile range divided by 1.349, is a distribution-free measure of precision comparable to a standard deviation (Woodworth and Conner, 2002). Smaller values of F-pseudosigma indicate better precision. **Abbreviations:** mg/L milligrams per liter)

Analyte name	Count	Spike concen-tration (mg/L)	Mean analytical result (mg/L)	Median analytical result (mg/L)	Mean percent recovery	Standard deviation (mg/L)	F-pseudo-sigma (mg/L)	Relative standard deviation (percent)
Nitrogen, nitrite	24	0.010	0.015	0.016	151	0.002	0.001	14.1
Orthophosphate as P, filtered	24	.038	.044	.044	115	.007	.009	14.8
Nitrogen, nitrite plus nitrate	24	.078	.088	.088	112	.011	.010	12.9
Nitrogen, ammonia	24	.091	.090	.086	98	.011	.007	11.9
Phosphorus, dissolved	21	.181	.181	.181	100	.012	.010	6.9
Phosphorus, unfiltered (total)	20	.181	.181	.182	100	.013	.016	7.3
Nitrogen, ammonia plus organic, filtered	21	.363	.368	.378	101	.037	.035	10.2
Nitrogen, ammonia plus organic, unfiltered	20	.363	.390	.382	107	.079	.021	20.3

Bureau of Reclamation Data

Bureau of Reclamation (BOR) data were used in this report to compute trend statistics for turbidity and concentrations of nutrients and suspended solids at selected surface-water sites. The quality of data produced by the BOR Laboratory in Boise, Ida., is maintained by adhering to procedures outlined in their quality-assurance plan (Bureau of Reclamation, 2000). Also, because this laboratory performed nutrient analyses for the Water-Quality Monitoring Program of RSBOJC, the quality-control data for nutrients presented in table A4 are indicative of the laboratory's performance. The BOR laboratory participates in the USGS standard reference sample program.

Washington State Department of Ecology Data

Data from samples collected by the Washington State Department of Ecology (Ecology) Environmental Assessment Program and analyzed in Ecology's Manchester Environmental Laboratory in Port Orchard, Wash., were used to compute trend statistics for turbidity and concentrations of nutrients and suspended solids at the Yakima River at Kiona. The quality of data published by the Environmental Assessment Program is maintained by adhering to published sampling protocols available online at URL <http://www.ecy.wa.gov/biblio/0103036.html>, and the performance of the Manchester Environmental Laboratory is documented online at URL <http://www.ecy.wa.gov/programs/eap/manchester/melqual.htm>.

Table A4. Summary of quality-control data for samples collected by the Water-Quality Monitoring Program of the Roza-Sunnyside Board of Joint Control, Yakima River Basin, 1997–2000

[Data were provided by William Rice, Roza-Sunnyside Board of Joint Control, February 2002. **Abbreviations:** RPD, relative percentage of difference; mg/L, milligrams per liter; NTU, nephelometric turbidity unit; PR, percentage of recovery; <, less than]

Measured parameter	Quality-control parameter	Quality-control measure	Number	Minimum	Mean	Median	Maximum
Total suspended solids	Field replicate	(RPD)	206	0.0	3.1	2.2	26.7
	Lab replicate	(RPD)	277	.0	1.4	.9	20.3
	Check standard (250 mg/L)	(RPD)	51	.3	1.0	.9	1.6
	Field blank	(mg/L)	79	-3.6	-.6	-.7	2.2
Turbidity	Field replicate	(RPD)	206	.0	1.8	1.2	20.7
	Lab replicate	(RPD)	260	.0	1.1	0.9	7.4
	Check standard (200 NTU)	(RPD)	37	.5	2.6	3.0	4.4
	Field blank	(NTU)	78	.06	.09	.09	.20
Nitrite plus nitrate	Field replicate	(RPD)	208	.0	1.1	.7	12.2
	Field split	(RPD)	190	.0	1.0	.6	6.8
	Field spike	(PR)	66	55.5	97.0	97.2	115
	Field blank	(mg/L as N)	79	<.01	<.01	<.01	.01
Phosphorus, total	Field replicate	(RPD)	208	.0	3.7	3.2	20.4
	Field split	(RPD)	190	.0	3.8	3.5	16.7
	Field blank	(mg/L as P)	79	<.01	<.01	<.01	.02
Nitrogen, ammonia plus organic, unfiltered	Field replicate	(RPD)	208	.0	6.3	4.7	32.5
	Field split	(RPD)	190	.0	6.1	4.7	26.9
	Field blank	(mg/L as N)	79	<.003	<.03	<.03	.06

APPENDIX B.—REGRESSION MODELS USED TO ESTIMATE LOADS

The computer program Loadest2 was used to estimate loads of suspended sediment and nutrients transported in Moxee Drain, Granger Drain, and the Yakima River at Kiona. The regression models used in this study and the criteria used to select them are presented in this appendix.

For Moxee Drain, all estimates of suspended sediment and nutrient loads were based on Loadest2 default regression models selected by Aikaike information criteria. The relative percent difference between the average of the measured load minus the model-predicted load on the days of sample collection from May 1999 through July 2000 (the calibration period) ranged from 0.3 percent for orthophosphate phosphorus to –13 percent for suspended sediment (table B1). The standard deviation expressed as a percentage of the predicted loads for calendar year 1999 was less than 3.6 percent of the nitrite-plus-nitrate and total nitrogen loads, but was 25 percent of the average suspended-sediment load. Using the pattern of measured loads as a guide, the regression models predicted daily loads of orthophosphate, total nitrogen, and ammonia-plus-organic nitrogen that tended to underestimate a peak and overestimate a trough in the early part of the calibration period (fig. B1*A*); however, the average of the relative percentage of differences between the absolute values of measured and predicted daily loads was equal to or less than 18 percent. The pattern of daily loads for the remaining period, as well as the pattern for suspended sediment, total phosphorus, and nitrite-plus-nitrate nitrogen, tended to agree with measured loads.

For Granger Drain, all loads of suspended sediment and nutrients also were estimated by Loadest2 default regression models as selected by Aikaike information criteria. The relative percent difference between the average of the measured load minus the model-predicted load on the days of sample collection from May 1999 through July 2000 (the calibration period) ranged from –0.05 percent or less for total nitrogen, nitrite-plus-nitrate nitrogen, and orthophosphate phosphorus to 0.8 percent for total phosphorus (table B2). The standard deviations expressed as a percentage of the predicted loads for water years 1999-2000 ranged from 3 percent of the nitrite-plus-nitrate load to 9 percent of the ammonia-plus-organic nitrogen load. The pattern of predicted daily loads of suspended sediment, total phosphorus, orthophosphate phosphorus, and nitrite-plus-nitrate nitrogen agreed reasonably well with measured loads (fig. B1*B*). The average of the relative percent differences between the absolute values of measured and predicted daily loads was 16 percent for suspended sediment and 13 percent or less for the nutrients except ammonia-plus-organic nitrogen. The average of the relative percent differences between the absolute values of measured and predicted daily loads of ammonia-plus-organic nitrogen was fairly large (27 percent), which is also reflected in the scattering of the measured loads about the pattern of predicted daily loads in figure B1*B*.

At various times from 1974 through 2002 water years, the USGS has collected water samples for the analysis of suspended-sediment and nutrient concentrations from the Yakima River at Kiona. The resulting data set contains both historical and recent data with gaps of varying length. Data collected from May 1999 through January 2000 were used to estimate loads of suspended sediment and nutrients in the Yakima River at Kiona. However, additional data from January 2001– August 2002, available at the time of data analysis and report preparation, were used to help evaluate the results from the regression models.

Data sets used to calibrate the regression models generated by the Loadest2 computer program were selected to match the period for which loads were estimated. Thus, annual load estimates for water years 1974-2001 were based on a large calibration data set consisting of historical concentration and streamflow data from October 1973 – September 1994 and from May 1999 – September 2001. For estimating annual loads for 1999 through 2000, Loadest2 was run twice—once calibrated with the May 1999 – January 2000 data set and once calibrated with the May 1999 – January 2000 plus the January 2001 – September 2001 data set. Estimates of suspended-sediment, total nitrogen, ammonia-plus-organic nitrogen, and nitrite-plus-nitrate loads were sufficiently different to require a choice between loads based on the two calibration data sets for representing constituent transport in the Yakima River during 1999-2000.

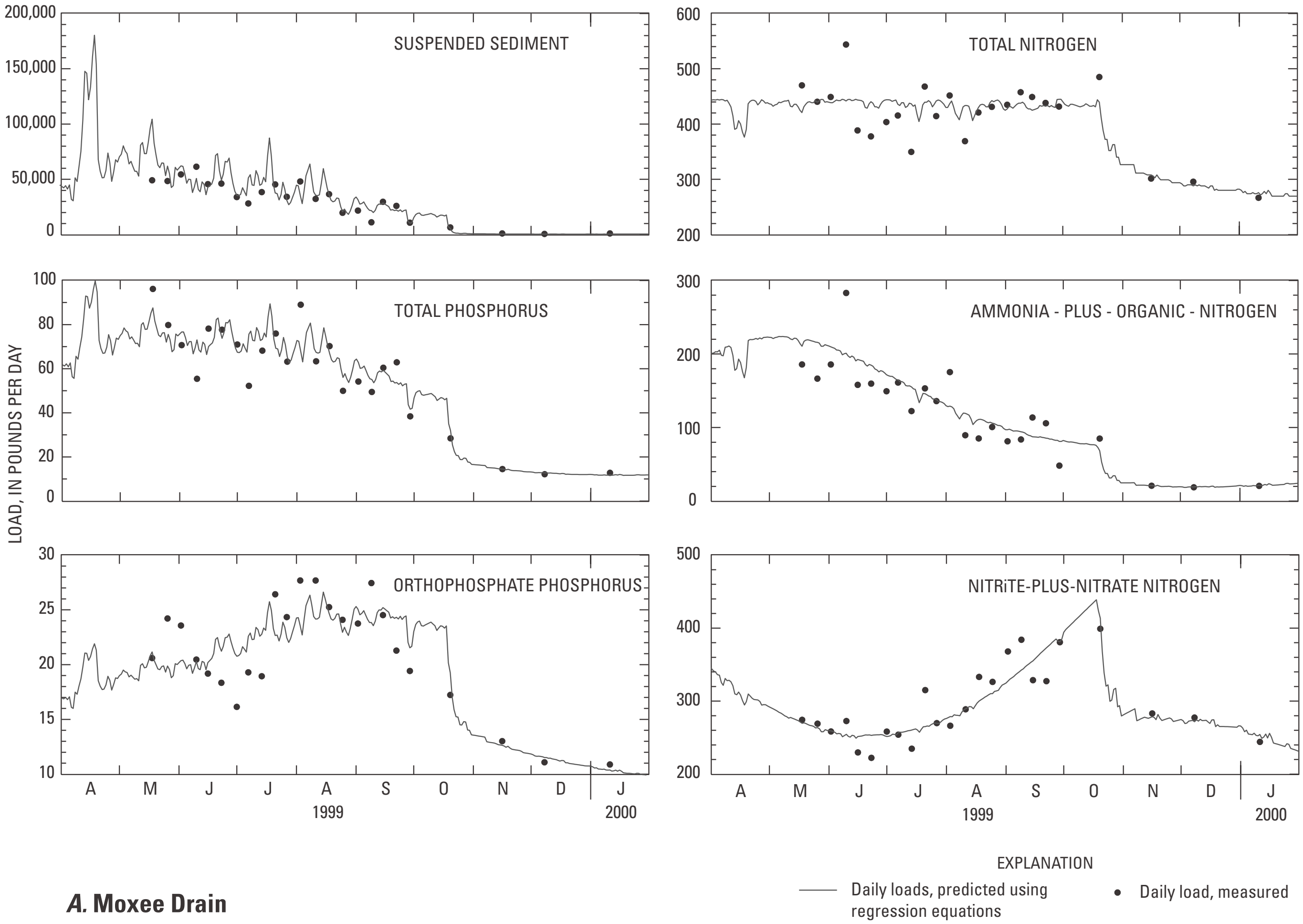
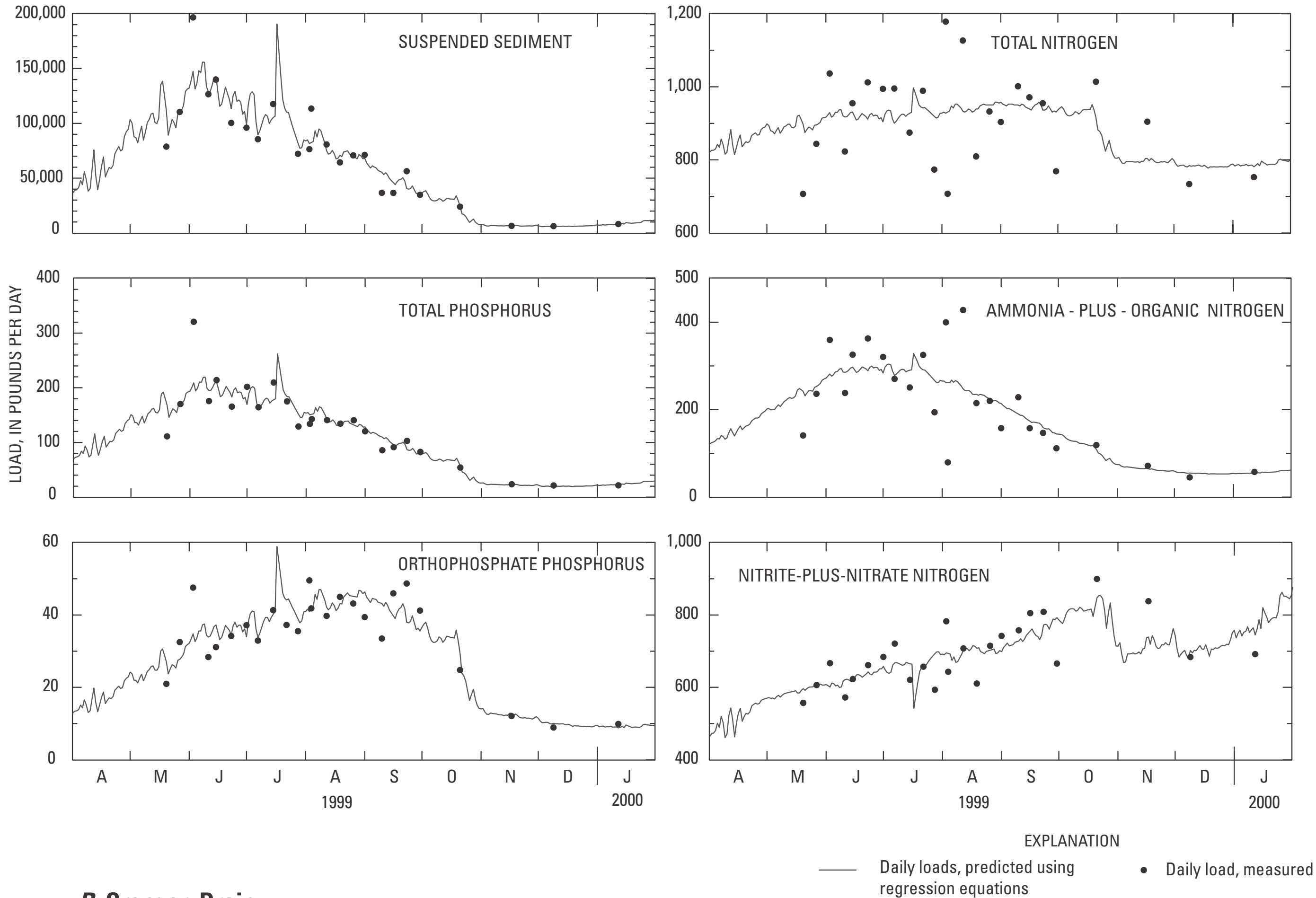


Figure B1. Predicted and measured daily loads of suspended sediment and nutrients for 1999-2000 water years at Moxee and Granger Drains, Yakima River Basin, Washington.



B. **Granger Drain**

Figure B1.—*Continued.*

Table B1. Suspended-sediment and nutrient loads transported during calendar year 1999, standard deviations, differences between measured and predicted loads, regression equations for load estimates, and concentration summary statistics at Moxee Drain, Yakima River Basin, Washington

[Daily loads are in pounds; ln, natural logarithm; Q, streamflow in cubic feet per second; sin, sine; cos, cosine; dectime, time in fractional years; MLE, maximum likelihood estimate; dload, daily load. Total nitrogen is based on the sum of unfiltered ammonia-plus-organic and nitrite-plus-nitrate nitrogen concentrations in the calibration data set, which included data collected from May 1999 through January 2000, June 2000 and July 2000.]

Constituent	Daily load for calendar year 1999 and (standard deviation)	Number of samples (number censored)	Average of the relative percentage of differences between the absolute values of the measured and predicted daily loads for May 1999 through January 2000	Relative percentage of difference between the average of the measured loads minus the average of the predicted loads for May 1999 through January 2000	MLE regression equation
Suspended sediment	28,000 (7,000)	27 (0)	43	–13	ln(dload) = 10.601 + 1.8958 ln(Q) + 0.50252 sin(dectime) – 0.38767 cos(dectime) – 0.6893 (dectime)
Total nitrogen	380 (13)	27 (0)	7.2	–.9	ln(dload) = 6.0752 – 0.10122 ln(Q) – 0.19119 $\ln(Q)^2$
Ammonia-plus-organic nitrogen	100 (11)	27 (0)	18	–4.9	ln(dload) = 4.8532 – 0.016179 ln(Q) – 0.49134 $\ln(Q)^2$ + 0.47316 sin(dectime) – 0.25963 cos(dectime)
Nitrite-plus-nitrate nitrogen	280 (10)	27 (0)	5.8	.5	ln(dload) = 5.9108 + 0.041921 ln(Q) – 0.19438 $\ln(Q)^2$ – 0.063975 sin(dectime) + 0.37723 cos(dectime)
Total phosphorus	46 (3)	27 (0)	11	–1.1	ln(dload) = 4.2599 + 0.57632 ln(Q) + 0.05805 sin(dectime) – 0.26075 cos(dectime) – 0.47549 (dectime)
Orthophosphate phosphorus	17 (1)	27 (0)	10	.3	ln(dload) = 3.0026 + 0.31272 ln(Q) – 0.1314 sin(dectime) – 0.070569 cos(dectime)

Concentration summary statistics (milligrams per liter), calendar year 1999

	Minimum	25th percentile	Median	75th percentile	90th percentile	95th percentile	Maximum
Suspended sediment							
Predicted	10	26	73	170	220	250	350
Measured	2	65	113	165	184	193	237
Total nitrogen							
Predicted	.73	1.5	1.8	6.1	6.3	6.5	6.7
Measured	1.2	1.3	1.6	1.8	4.6	6.0	6.3
Ammonia-plus-organic nitrogen							
Predicted	.24	.40	.50	.70	.84	.89	1.2
Measured	.22	.34	.47	.59	.66	.77	1.1
Nitrite-plus-nitrate nitrogen							
Predicted	.57	1.0	1.4	5.1	5.8	5.9	5.9
Measured	.76	.94	1.0	1.3	4.2	5.5	5.9
Total phosphorus							
Predicted	.15	.23	.27	.29	.44	.49	.54
Measured	.16	.20	.24	.28	.30	.32	.36
Orthophosphate phosphorus							
Predicted	.042	.075	.084	.23	.24	.25	.26
Measured	.057	.071	.084	.096	.185	.244	.249

Table B2. Suspended-sediment and nutrient loads transported during water years 1999–2000, standard deviations, differences between measured and predicted loads, regression equations for load estimates, and concentration summary statistics at Granger Drain, Yakima River Basin, Washington

[Daily loads are in pounds; ln, natural logarithm; Q, streamflow in cubic feet per second; sin, sine; cos, cosine; dectime, time in fractional years; MLE, maximum likelihood estimate; dload, daily load. Total nitrogen is based on the sum of unfiltered ammonia-plus-organic and nitrite-plus-nitrate nitrogen concentrations in the calibration data set, which included data collected from May 1999 through January 2000, June 2000 and July 2000]

Constituent	Daily load for water years 1999 –2000, and (standard deviation)	Number of samples (number censored)	Average of the relative percent differences between the absolute values of the measured and predicted daily loads for 1999 through 2000	Relative percentage of difference between the average of the measured loads minus the average of the predicted loads for 1999 through 2000	MLE regression equation
Suspended sediment	42,000 (3,000)	26 (0)	16	0.2	ln(dload) = 0.11813 + 2.2404 ln(Q) + 1.3185 ln(Q)^2 + 0.38515 sin(dectime) – 0.60583 cos(dectime) – 1.4561 (dectime)
Total nitrogen	860 (31)	27 (0)	11	–.05	ln(dload) = 6.8223 + 0.18547ln(Q)
Ammonia-plus-organic nitrogen	140 (13)	27 (0)	27	.2	ln(dload) = 5.1934 + 0.32399 ln(Q) – 0.0014707 sin(dectime) – 0.61991 cos(dectime) – 0.37393 (dectime)
Nitrite-plus-nitrate nitrogen	690 (20)	27 (0)	6.9	–.04	ln(dload) = 6.4805 + 0.070781 ln(Q) – 0.1004 sin(dectime) + 0.069966 cos(dectime) + 0.098542 (dectime)
Total phosphorus	78 (4)	27 (0)	13	.8	ln(dload) = 5.0541 + 0.91036 ln(Q) + 0.19505 sin(dectime) – 0.52981 cos(dectime) – 0.70337 (dectime)
Orthophosphate phosphorus	24 (1)	27 (0)	13	–.03	ln(dload) = 3.3643 + 0.94708 ln(Q) – 0.17835 sin(dectime) – 0.28399 cos(dectime)

	Concentration summary statistics (milligrams per liter), water years 1999–2000						
	Minimum	25th percentile	Median	75th percentile	90th percentile	95th percentile	Maximum
Suspended sediment							
Predicted	25	69	120	320	410	40	660
Measured	47	113	228	367	446	452	645
Total nitrogen							
Predicted	2.0	3.0	4.0	6.0	7.0	7.0	7.0
Measured	2.3	2.75	3.0	3.65	4.78	6.3	6.6
Ammonia-plus-organic nitrogen							
Predicted	.31	.49	.61	.77	.95	1.0	1.1
Measured	.30	.49	.70	1.02	1.26	1.33	1.4
Nitrite-plus-nitrate nitrogen							
Predicted	2.0	2.0	3.0	5.0	6.0	6.0	6.0
Measured	1.9	2.1	2.2	2.6	4.2	5.8	6.1
Total phosphorus							
Predicted	.13	.22	.33	.45	.63	.67	.70
Measured	.20	.28	.40	.61	.70	.75	1.1
Orthophosphate phosphorus							
Predicted	.072	.080	.099	.12	.13	.13	.14
Measured	.074	.100	.125	.138	.148	.155	.164

The decision was made to use only regression models calibrated with the May 1999 – January 2000 data set and was based in part on keeping the calibration period consistent among the constituents, particularly the nitrogen species. The main impetus, however, that determined the choice of using only the May 1999 – January 2000 data set was based on in-depth examination of several factors.

The factors, alone and in combination, used to evaluate the Loadest2 results included (1) minimizing the relative percent difference between the average of the measured loads minus the average of the predicted loads for the May 1999 – January 2000 period; (2) optimizing for better agreement between the models' summary statistics of predicted concentrations and the summary statistics calculated for the measured concentration data; (3) optimizing for the lower standard deviation of the average daily load estimated for the calibration period; (4) minimizing the average of the relative percent differences between absolute values of the measured daily and predicted daily loads; and (5) using the general pattern of predicted daily loads graphed over time to assist in evaluating whether or not the models' extrapolations of loads for periods outside the calibration data set were reasonable. Some compromises and judgment were also used in choosing the calibration period and selected regression models. Load estimates for the nitrogen species are an example. Results of the Loadest2 default models (selected with Aikaike information criteria) for ammonia-plus-organic and nitrite-plus-nitrate nitrogen using the data set for May 1999 – January 2000 plus January 2001 – September 2001 gave slightly smaller percent differences with measured loads and measured concentration summary statistics than the results with the data set for May 1999 – January 2000. However, the opposite was the case for loads of total nitrogen. The compromise was to use the May 1999 – January 2000 data for all estimates of nitrogen loads, particularly because total nitrogen loads are based on total nitrogen concentrations, which are simply calculated sums from the two other species of nitrogen.

In the case of ammonia-plus-organic nitrogen and nitrite-plus-nitrate, warning messages generated by Loadest2 indicated that the models were overestimating maximum predicted concentrations compared with observed maximum concentrations. The program was calibrated again with the May 1999 – January 2000 concentration data, in combination with specific regression models, and the results were evaluated using the factors listed previously to select a particular model. When no single calibration-concentration data set or specific model fit the data particularly well, some judgments and compromises were made, including using the default model based on the Aikaike information criteria.

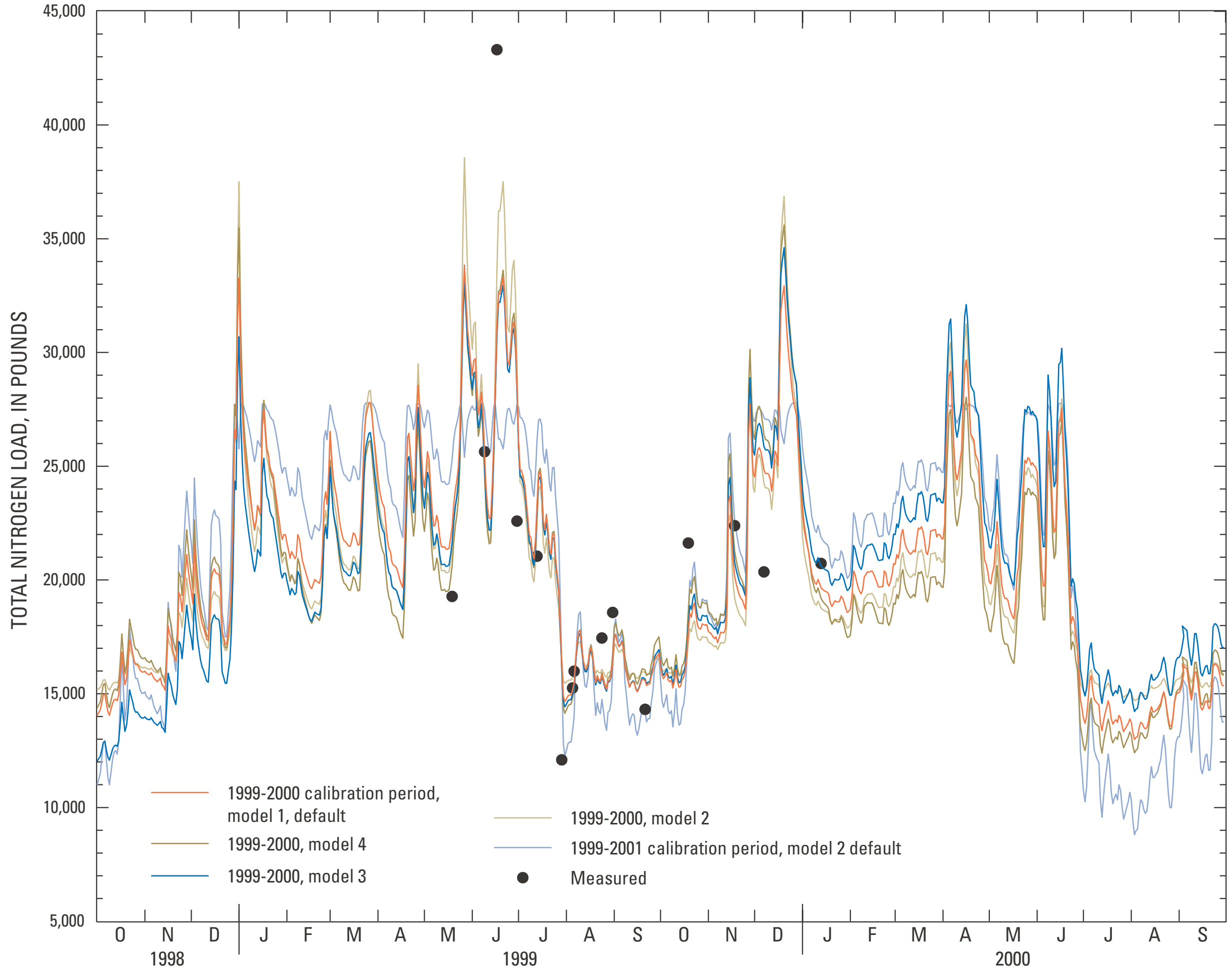
The default model 1 for total nitrogen resulted in a relative percent difference between the average of the measured and the average of predicted loads for 1999-2000 of 0.59, which was third highest among the different models (table B3). However, model 1 had one of the lowest standard deviations (4.6 percent) for the average daily load and one of the lowest average percent difference between measured and predicted concentration percentiles. The similarity in results among the different models and the pattern of daily loads over time (fig. B2*A*) did not warrant selecting a particular model over the Loadest2 default selection.

Regression model estimates of average ammonia-plus-organic nitrogen loads were highly variable, ranging from 5,500 to 6,200 lb/d (pounds per day) for 1999-2000, from 5,900 to 9,500 lb/d for water year 1999, and from 2,900 to 5,600 lb/d for water year 2000. For the purposes of this report, model 2 was selected over the default model (model 3) because of the low relative percent difference between the average of the measured and the average of predicted loads (4.7 percent), a low standard deviation of the average daily load (9.7 percent), and a lower percent difference between measured and predicted concentration percentiles than the default model (table B3). Figure B2*B* shows the daily loads over time for three of the different regression models and different calibration periods, which included the results of the model calibrated with the data set for May 1999 – January 2000 plus January 2001 – September 2001 and the results from a trial model calibrated with all data available from 1999 to 2002. The selection of model 2 was also due partly to the similarity with the 1999-2002 test model in the peaks and troughs of predicted daily loads and the match to the measured loads (fig. B2*B*).

Table B3. Factors used to assist in selecting calibration periods and regression models for loads of total nitrogen, ammonia-plus-organic nitrogen, nitrite-plus-nitrate nitrogen, and suspended sediment in the Yakima River at Kiona, Yakima River Basin, Washington

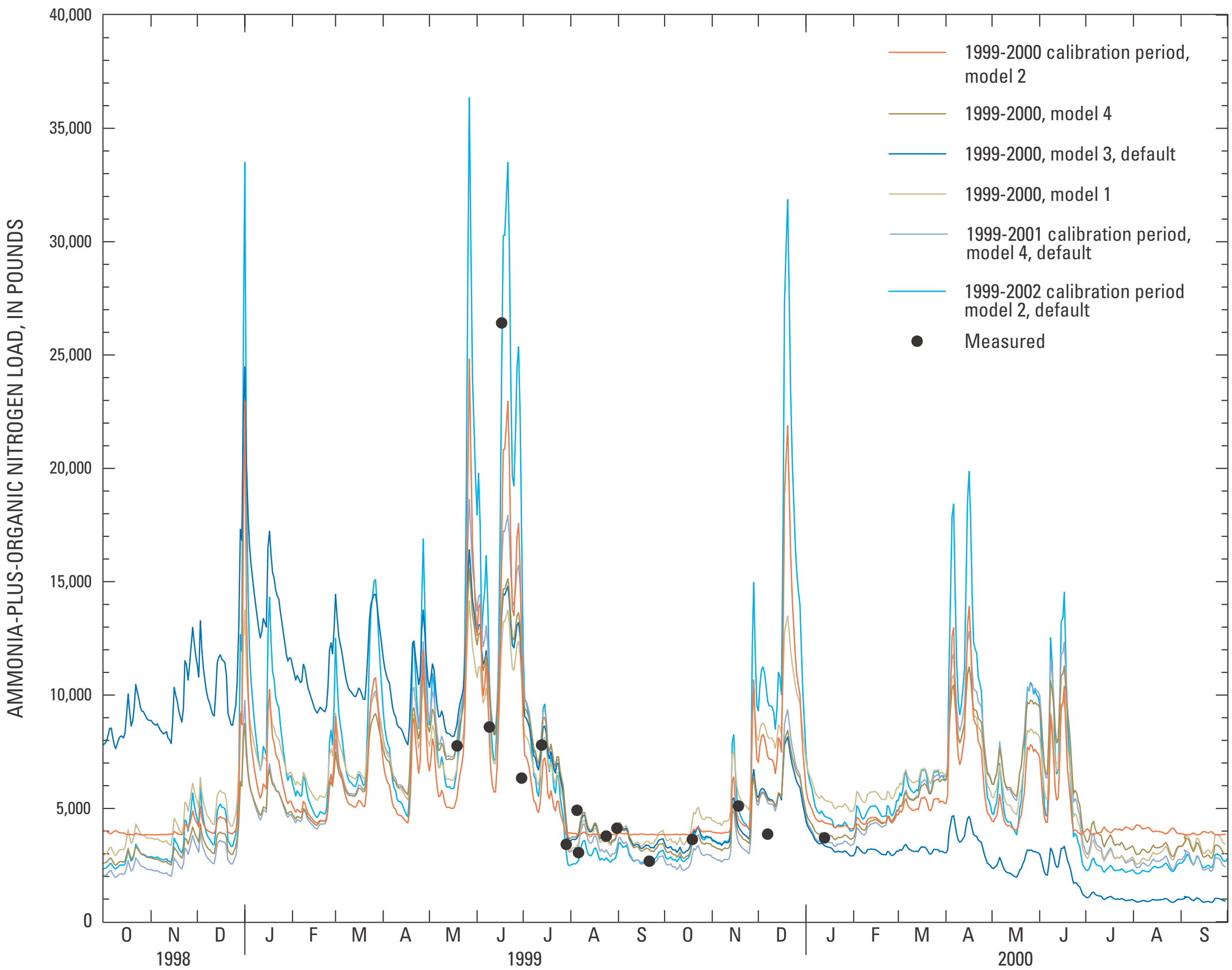
[**Calibration data set:** *, model selected by Aikaike information criteria of Loadest2. **Bold** indicates selected model for this report RPD, relative percentage of difference]

Calibration data set	RPD between average of measured and average of predicted loads, 1999–2000	Average of RPD between absolute values of measured and predicted		Standard deviation of average daily load (percent)
		Daily loads	Concenration percentiles	
Total Nitrogen				
1999–2000, model 1*	0.59	14	8.7	4.6
1999–2000, model 2	.64	14	14	4.6
1999–2000, model 3	.56	13	13	5.7
1999–2000, model 4	.50	13	6.7	7.5
1999–2001, model 2	-.63	17	13	4.8
Ammonia-plus-Organic Nitrogen				
1999–2000, model 1	5.8	28	23	10
1999–2000, model 2	4.7	25	19	9.7
1999–2000, model 3*	5.4	20	43	14
1999–2000, model 4	5.5	20	11	14
1999–2001, model 4	6.0	24	16	11
Nitrite-plus-Nitrate Nitrogen				
1999–2000, model 1	0.20	15	13	4.8
1999–2000, model 2	.03	14	9.4	5.0
1999–2000, model 3*	-.19	11	49	7.5
1999–2000, model 4	-.29	11	11	6.1
1999–2001, model 2	.59	17	23	8.6
Suspended Sediment				
1999–2000, model 1	16	46	20	18
1999–2000, model 2	-5.2	31	35	20
1999–2000, model 3	3.8	30	54	20
1999–2000, model 4	5.9	22	20	12
1999–2000, model 5*	-1.0	22	50	14
1999–2001, model 4	7.3	26	31	11



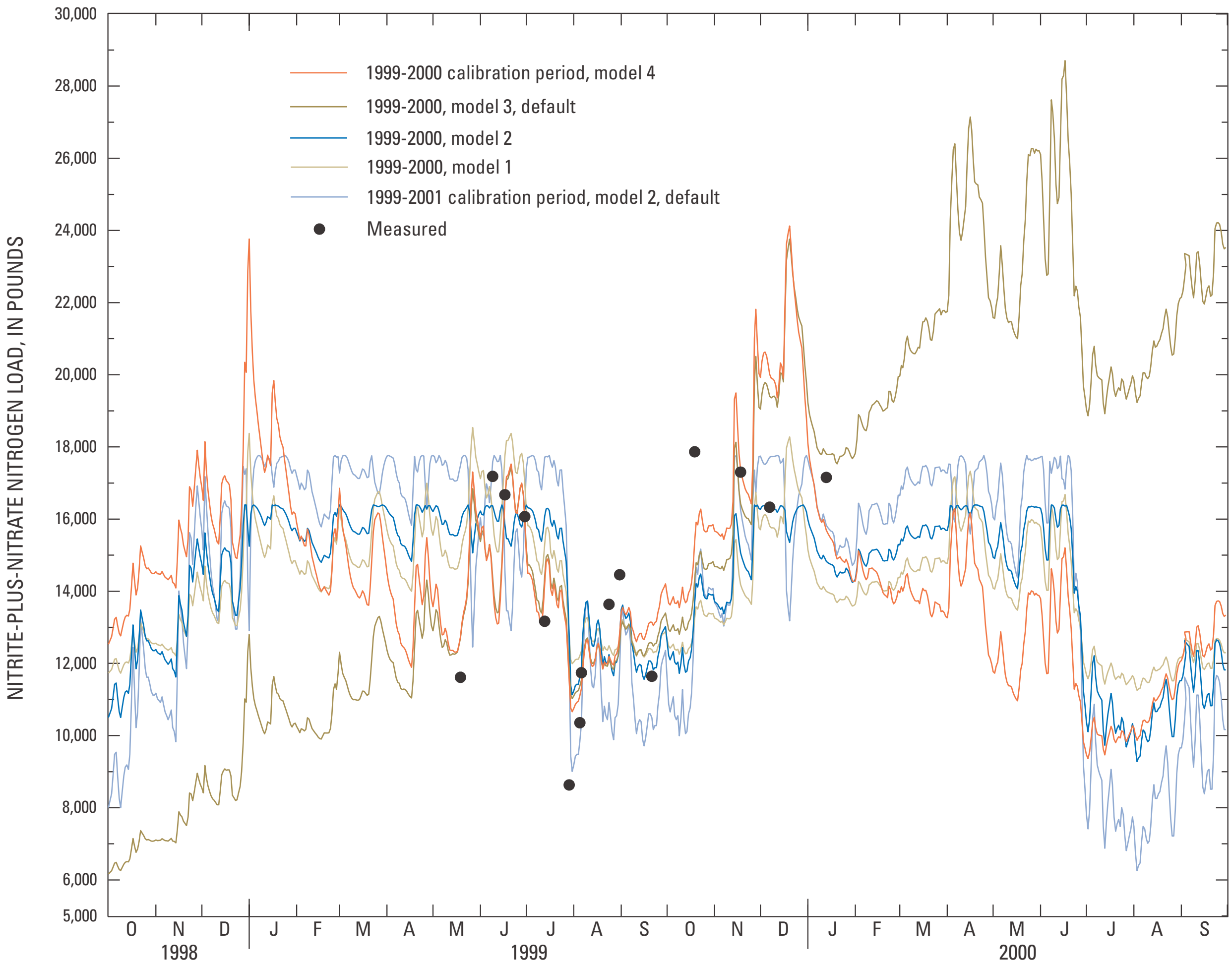
***A.* Total Nitrogen**

Figure B2. Predicted and measured daily loads of total nitrogen, ammonia-plus-organic nitrogen, and nitrite-plus-nitrate nitrogen, and suspended sediment with different regression models and calibration periods for the Yakima River at Kiona, Yakima River Basin, Washington.



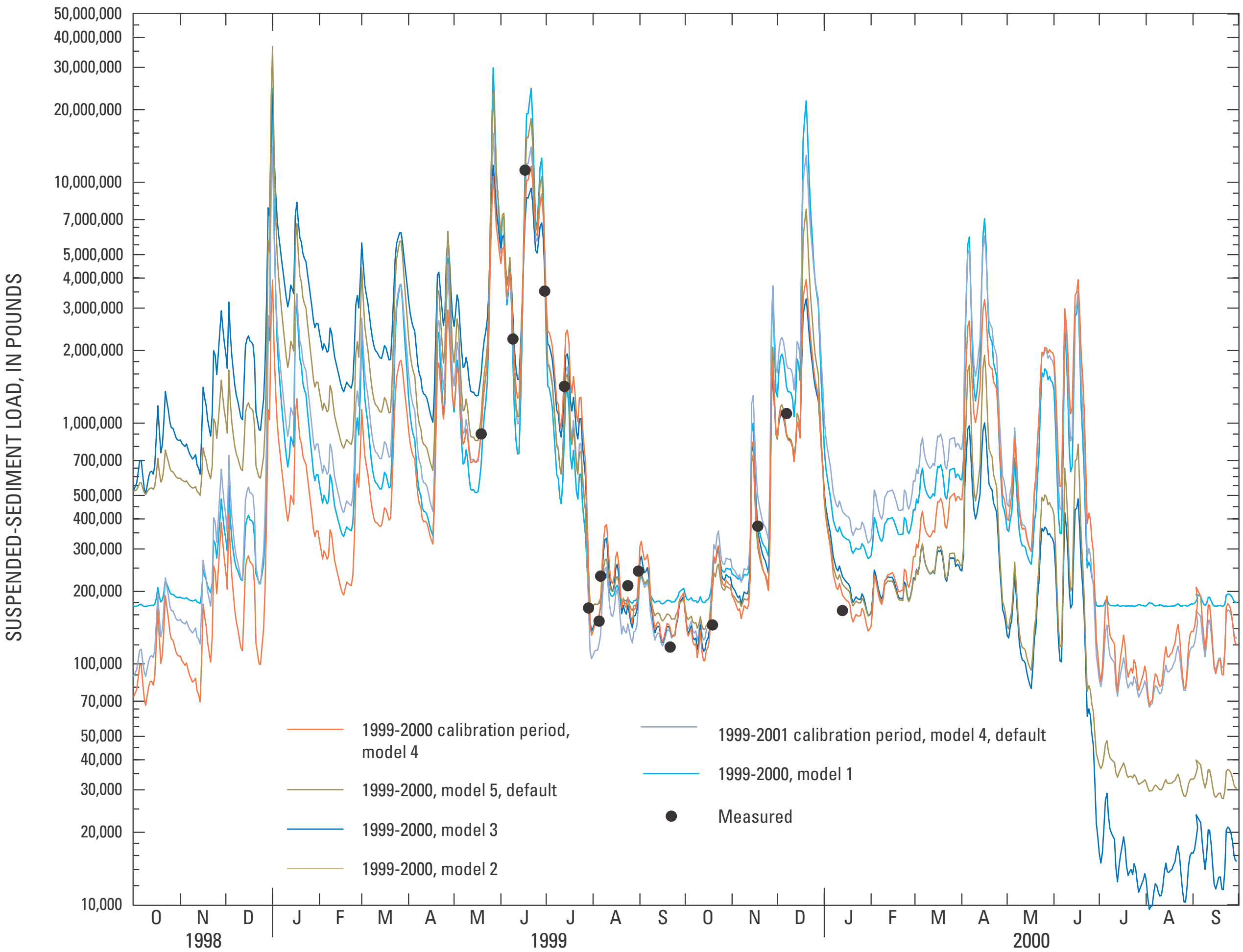
B. **Ammonia-plus-Organic Nitrogen**

Figure B2.—*Continued.*



C. **Nitrite-plus-Nitrate Nitrogen**

Figure B2.—*Continued.*



***D.* Suspended Sediment**

Figure B2.—*Continued.*

Model 4 was selected for nitrite-plus-nitrate load estimates largely because the average of the percent differences between measured and predicted concentration percentiles and the standard deviation of the average daily load were less than those for the default model (model 3) (table B3). The default model was rejected because its pattern of continuously increasing daily loads from the beginning of the 1999-2000 period, culminating in high estimates after February 2000, differed greatly from the patterns of three other regression models (fig. B2*C*). Also, model 4 was selected over models 1 and 2 because of lower percent differences in the concentration percentiles, or lower average difference between measured and predicted daily loads, or both, and because the pattern of peaks and troughs in the daily loads matched the peaks and troughs of the measured loads a little better than models 1 and 2. It was noted above for nitrite-plus-nitrate nitrogen that the May 1999 – January 2000 plus January 2001 – September 2001 calibration data set appeared to give better load estimates than the May 1999 – January 2000 calibration data set. Model 4, calibrated with the May 1999 – January 2000 data, resulted in an average daily load that was similar to the result from the default model (model 2) calibrated with the longer period in the data set (table B3).

As was the case for the nitrogen species, Loadest2 also generated a warning message for suspended sediment indicating the model was overestimating maximum concentrations compared with observed maximum concentrations. The program was calibrated again with May 1999 – January 2000 concentration data and with specific regression models to improve the model's relation to measured concentrations while providing reasonable estimates of loads for the 1999-2000 period. The average loads predicted by the different models varied greatly, ranging from 426 to 662 tons per day for the 1999-2000 period, from 557 to 1,173 tons per day for water 1999, and from 153 to 477 tons per day for water year 2000 (table B4). The decision was to use the results from model 4 because its average of the relative percent differences between the absolute values of measured and predicted daily loads, the standard deviation of the daily loads, and the average of relative percent differences between measured and predicted concentrations were among the lowest of the model results (table B3). Although model 1 or 2 might have been selected on the basis of some of the values in table B3, the graph of predicted daily loads over time (fig. B2*D*) showed that model 4 predictions fit the measured loads fairly well, thus the results of model 4 were selected over those of the default and other models.

For total phosphorus and orthophosphate phosphorus loads in the Yakima River at Kiona, the results of the default regression models selected by Aikaike information criteria in Loadest2 were used for this report. Figure B3 show the relation between predicted loads and measured loads for total phosphorus and orthophosphate phosphorus, respectively. The average loads, standard deviations, percentiles of measured and predicted concentrations, and relative percent differences between measured and predicted loads are presented in table B5.

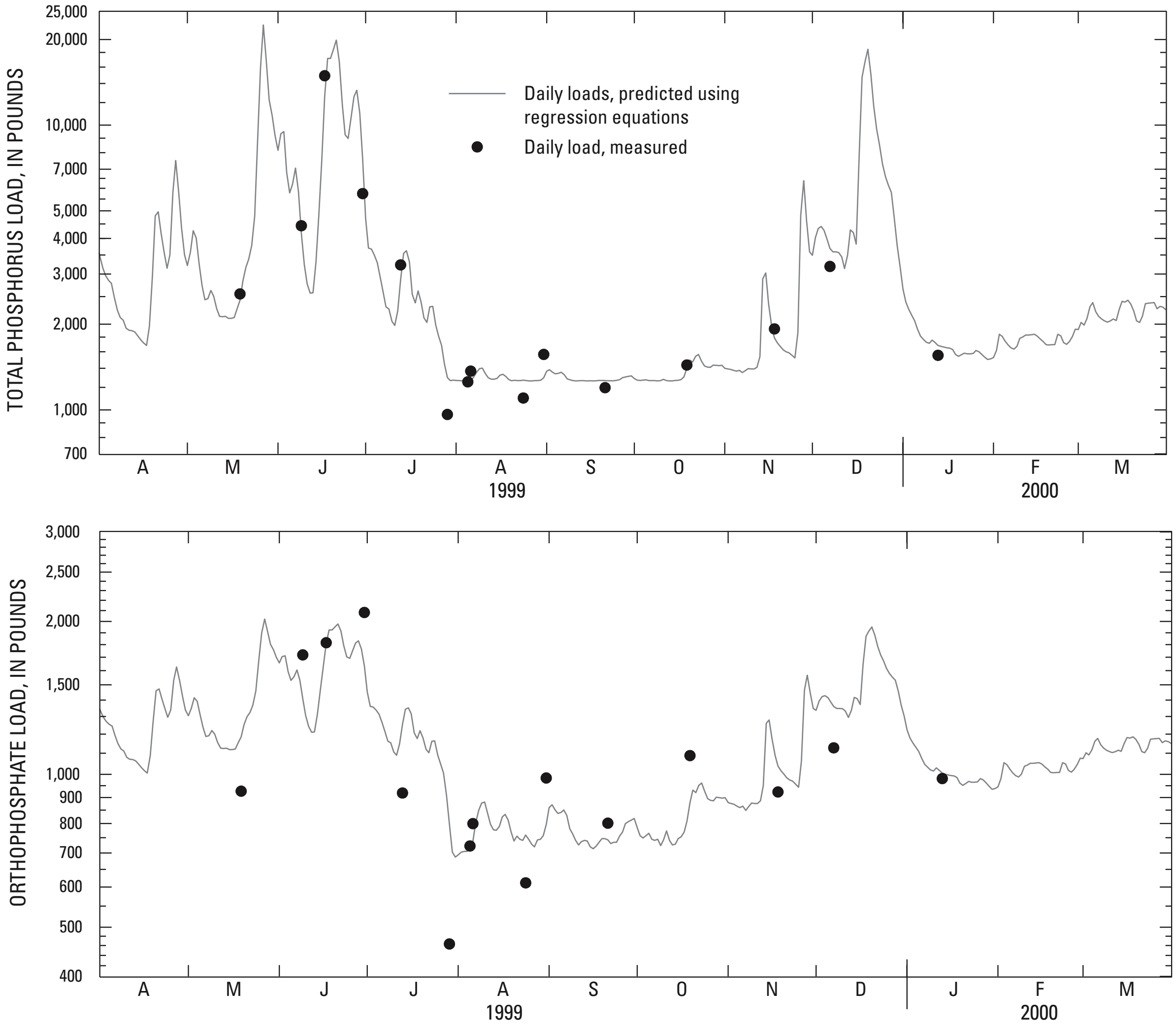


Figure B3. Predicted and measured daily loads of phosphorus for 1999-2000 water years, Yakima River at Kiona, Yakima River Basin, Washington.

Table B4. Estimates of average daily loads of suspended sediment and nutrients in the Yakima River at Kiona, Yakima River Basin, Washington for the period 1999–2000, water year 1999, and water year 2000 computed using discharge and concentration data from different calibration periods and different regression equations

[**Bold** indicates loads used for data interpretation in this report. Default models are the Loadest2 computer program selections using Aikaike information criteria. **Abbreviations:** ft^3/s, cubic feet per second; WY, water year]

Year	Annual mean discharge (ft^3/s)	Suspended sediment, tons per day								
		Calibration period								
		May 1999–January 2000					May 1999–Jan. 2000 plus Jan. 2001–Sept. 2001		Oct. 1974–Sept. 2001	May 1999–Jan. 2000 plus Jan. 2001–Aug. 2002
		Model 5 (default)	Model 1	Model 2	Model 3	Model 4	Model 4 (default)	Model 2	Model 8	Model 7
1999–2000	4,070	635	551	648	662	**426**	463	597	613	465
WY 1999	4,374	1,072	642	819	1,173	**557**	592	721	773	568
WY 2000	3,766	200	461	477	153	**295**	335	473	452	361

Year	Annual mean discharge (ft^3/s)	Total nitrogen, pounds per day							
		Calibration period							
		May 1999–January 2000				May 1999–Jan. 2000 plus Jan. 2001–Sept. 2001		Oct. 1974–Sept. 2001	May 1999–Jan. 2000 plus Jan. 2001–Aug. 2002
		Model 1 (default)	Model 2	Model 3	Model 4	Model 2 (default)	Model 8	Model 8	Model 7
1999–2000	4,070	**20,419**	20,261	20,522	19,964	21,039	21,573	23,179	23,008
WY 1999	4,374	**21,069**	20,903	19,954	20,647	21,783	23,412	24,263	24,711
WY 2000	3,766	**19,770**	19,621	21,088	19,283	20,296	19,740	22,097	21,310

Year	Annual mean discharge (ft^3/s)	Unfiltered ammonia-plus-organic nitrogen, pounds per day							
		Calibration period							
		May 1999–January 2000				May 1999–Jan. 2000 plus Jan. 2001–Sept. 2001		Oct. 1974–Sept. 2001	May 1999–Jan. 2000 plus Jan. 2001–Aug. 2002
		Model 3 (default)	Model 1	Model 2	Model 4	Model 4 (default)	Model 8	Model 6	Model 2
1999–2000	4,070	6,194	5,957	**5,808**	5,492	5,433	5,510	7,637	6,637
WY 1999	4,374	9,486	6,296	**6,192**	5,894	5,928	6,310	8,271	7,331
WY 2000	3,766	2,911	5,619	**5,425**	5,091	4,940	4,711	7,004	5,946

Table B4. Estimates of average daily loads of suspended sediment and nutrients in the Yakima River at Kiona, Yakima River Basin, Washington for the period 1999–2000, water year 1999, and water year 2000 computed using discharge and concentration data from different calibration periods and different regression equations—*Continued*

Year	Annual mean discharge (ft^3/s)	Nitrite-plus-nitrate nitrogen, pounds per day							
		Calibration period							
		May 1999–January 2000				May 1999–Jan. 2000 plus Jan. 2001–Sept. 2001		Oct. 1974–Sept. 2001	May 1999–Jan. 2000 plus Jan. 2001–Aug. 2002
		Model 4	Model 1	Model 2	Model 3 (default)	Model 2 (default)	Model 8	Model 6	Model 7
1999–2000	4,070	**14,398**	14,182	14,310	15,864	14,446	15,082	16,263	21,074
WY 1999	4,374	**14,654**	14,419	14,578	11,356	14,825	15,753	16,749	24,047
WY 2000	3,766	**14,143**	13,946	14,044	20,361	14,068	14,413	15,779	18,110

Year	Annual mean discharge (ft^3/s)	Total phosphorus, pounds per day				Orthophosphate, pounds per day			
		Calibration period							
		May 1999–Jan. 2000	May 1999–Jan. 2000 plus Jan. 2001–Sept. 2001	Oct. 1974–Sept. 2001	May 1999–Jan. 2000 plus Jan. 2001–Aug. 2002	May 1999–Jan. 2000	May 1999–Jan. 2000 plus Jan. 2001–Sept. 2001	Oct. 1974–Sept. 2001	May 1999–Jan. 2000 plus Jan. 2001–Aug. 2002
		Model 2 (default)	Model 2 (default)	Model 5	Model 2	Model 1 (default)	Model 1 (default)	Model 8	Model 1
1999–2000	4,070	**2,785**	2,808	2,556	3,075	1,065	1,097	1,131	1,223
WY 1999	4,374	**3,121**	3,100	2,802	3,444	1,109	1,150	1,189	1,275
WY 2000	3,766	**2,450**	2,520	2,311	2,707	1,021	1,050	1,073	1,171

Table B5. Suspended-sediment and nutrient loads transported during water years 1999–2000, standard deviations, differences between measured and predicted loads, regression equations, and concentration summary statistics for load estimates at Yakima River at Kiona, Washington

[Daily loads are in pounds; ln, natural logarithm; Q, streamflow in cubic feet per second; sin, sine; cos, cosine; dectime, time in fractional years; MLE, maximum likelihood estimate; dload, daily load in pounds. Total nitrogen is based on the sum of unfiltered ammonia-plus-organic and nitrite-plus-nitrate nitrogen concentrations in the calibration data set, which included data collected from May 1999 through January 2000.]

Constituent	Daily load for water years 1999 –2000, and (standard deviation)	Number of samples (number censored)	Average of the relative percent differences between the absolute values of the measured and predicted daily loads for the period 1999–2000	Relative percent difference between the average of the measured loads minus the average of the predicted loads for the period 1999–2000	MLE regression equation
Suspended sediment	850,000 (104,000)	16 (0)	22	5.9	$\ln(\text{dload}) = 4.8794 + 2.3744 \ln(Q) - 0.26501 \sin(\text{dectime}) - 0.56849 \cos(\text{dectime})$
Total nitrogen	20,000 (920)	16 (0)	14	0.6	$\ln(\text{dload}) = 9.821 + 0.42383 \ln(Q)$
Ammonia-plus-organic nitrogen	5,800 (560)	16 (0)	25	4.7	$\ln(\text{dload}) = 8.2734 + 0.42454 \ln(Q) + 0.63416 \ln(Q)^2$
Nitrite-plus-nitrate nitrogen	14,000 (860)	16 (0)	11	-.3	$\ln(\text{dload}) = 9.5066 + 0.30862 \ln(Q) - 0.12726 \sin(\text{dectime}) + 0.14316 \cos(\text{dectime})$
Total phosphorus	2,800 (140)	16 (0)	12	1.1	$\ln(\text{dload}) = 7.3134 + 0.76782 \ln(Q) + 0.81213 \ln(Q)^2$
Orthophosphate phosphorus	1,100 (68)	16 (0)	19	-1.1	$\ln(\text{dload}) = 6.8201 + 0.54726 \ln(Q)$

	Concentration summary statistics (milligrams per liter), water years 1999–2000						
	Minimum	25th percentile	Median	75th percentile	90th ercentile	95th percentile	Maximum
Suspended sediment							
Predicted	7	12	16	31	57	79	180
Measured	9	15	20	40	72	110	204
Total nitrogen							
Predicted	0.5	0.83	1.0	1.4	1.6	1.7	1.9
Measured	.50	.77	1.12	1.48	1.52	1.54	1.57
Ammonia-plus-organic nitrogen							
Predicted	.22	.23	.24	.34	.42	.48	.61
Measured	.12	.25	.28	.34	.42	.48	.49
Nitrite-plus-nitrate nitrogen							
Predicted	.26	.54	.73	1.1	1.3	1.3	1.5
Measured	.30	.49	.88	1.1	1.21	1.23	1.23
Total phosphorus							
Predicted	.091	.094	.11	.13	.16	.18	.33
Measured	.079	.099	.12	.13	.13	.17	.27
Orthophosphate phosphorus							
Predicted	.03	.045	.053	.067	.074	.077	.084
Measured	.028	.046	.074	.081	.088	.093	.127

APPENDIX C.—MASS-BALANCE COMPUTATIONS

Table C1. Mass-balance analyses for instantaneous streamflows and loads of total nitrogen and phosphorus in the reach of the Yakima River extending from river mile 103.7 to river mile 55, Yakima River Basin, Washington, August 1999 and July 1988

[Cumulative and unmeasured flows and loads in **bold** computed by Pogue and others (1999) do not always agree with computed values in this table because more mainstem sites were sampled in July 1988 than in August 1999, and residuals in the mass-balance computations were set to zero at each mainstem site sampled; **Abbreviations:** ft^3/s, cubic feet per second; lb/d, pounds per day; mg/L, milligrams per liter; nc, not computed because concentration would be a negative number; –, Except for data from Pogue and others (1999), no value is listed because cumulative flows and loading apply to inflows upstream from the downstream end of the reach on the Yakima River]

Site name	River mile	Measured streamflow (ft^3/s)	Cumulative flows (ft^3/s)	Measured concen-tration (mg/L)	Measured load (lb/d)	Cumulative loading to reach (lb/d)	Computed concen-tration (mg/L)
Total nitrogen (1999)							
Yakima River near Parker[1,2]	103.7	685	685	0.25	939	939	
Return from Sunnyside fish bypass[2]	103.6	40	725	.25	55	993	
Zillah WWTP	89.5	.3	725	20.8	34	1,027	
East Toppenish Drain	86.0	27.5	753	3.22	478	1,505	
Sub-Drain 35	83.2	62.5	815	2.53	853	2,358	
Granger Drain	82.8	62	877	2.35	786	3,144	
Granger WWTP	82.8	.4	878	22.2	48	3,192	
Marion Drain	82.6	66.8	945	2.72	980	4,172	
Toppenish Creek	80.4	117	1,062	2.52	1,591	5,763	
Yakima River at River Mile 72	72.0	1,270	–	1.03	7,057	–	0.84
Yakima River at River Mile 72	72.0	1,270	1,270	1.03	7,057	7,057	
Satus Creek at Satus	69.6	128	1,398	1.86	1,284	8,342	
South Drain near Satus	69.3	33.1	1,431	2.73	488	8,829	
Sulphur Creek Wasteway	61.0	260	1,691	2.54	3,563	12,392	
Yakima River at River Mile 55	55.0	2,050	–	1.41	15,594	–	1.12

Other statistics for river mile 103.7 to river mile 72	
Unmeasured flow (ft^3/s)	209
Unmeasured load (lb/d)	1,294
Unmeasured concentration (mg/L)	1.15
Total flow from tributaries (ft^3/s)	337
Flow from tributaries as a percentage of total	26.5
Total load from tributaries (lb/d)	4,769
Load from tributaries as a percentage of total	67.6
Mean concentration in tributaries (mg/L)	2.63

Other statistics for river mile 72 to river mile 55	
Unmeasured flow (ft^3/s)	359
Unmeasured load (lb/d)	3,202
Unmeasured concentration (mg/L)	1.65
Total flow from tributaries (ft^3/s)	421
Flow from tributaries as a percentage of total	20.5
Total load from tributaries (lb/d)	5,335
Load from tributaries as a percentage of total	34.2
Mean concentration in tributaries (mg/L)	2.35

Table C1. Mass-balance analyses for instantaneous streamflows and loads of total nitrogen and phosphorus in the reach of the Yakima River extending from river mile 103.7 to river mile 55, Yakima River Basin, Washington, August 1999 and July 1988—*Continued*

Site name	River mile	Measured streamflow (ft^3/s)	Cumulative flows (ft^3/s)	Measured concen-tration (mg/L)	Measured load (lb/d)	Cumulative loading to reach (lb/d)	Computed concen-tration (mg/L)
Total nitrogen (1988) (data from Pogue and others, 1999)							
Yakima River near Parker[1,2]	103.7	163	163	0.16	440	440	
Zillah WWTP	89.5	0.3	163	8.0	12	452	
East Toppenish Drain	86.0	30	193	4.5	730	1,182	
Sub-Drain 35	83.2	34	227	2.4	480	1,662	
Granger Drain	82.8	49	276	3.4	1,000	2,662	
Granger WWTP	82.8	.3	277	4.0	7	2,669	
Marion Drain	82.6	39	316	2.8	610	3,279	
Toppenish Creek	80.4	54	370	2.9	840	4,119	
Coulee Drain	77.0	28	398	2.1	320	4,439	
Yakima River at River Mile 72	72.0	513	**456**	1.5	4,100	**4,520**	1.60
Yakima River at River Mile 72	72.0	513	513	1.5	4,100	4,100	
Satus Creek at Satus	69.6	84	597	2.6	1,200	5,300	
South Drain near Satus	69.3	82	679	3.7	1,600	6,900	
DID No. 7	65.1	25	704	3.7	500	7,400	
Sulphur Creek Wasteway	61.0	151	855	3.8	2,900	10,300	
Mabton sewage plant	60.5	.9	856	3.1	15	10,315	
Satus Drain 303	60.2	60	916	2.3	740	11,055	
Yakima River at River Mile 55	55.0	972	**916**	1.9	10,000	**11,055**	2.11

Other statistics for river mile 103.7 to river mile 72		
Unmeasured flow (ft^3/s)	115	**57**
Unmeasured load (lb/d)	-339	**-420**
Unmeasured concentration (mg/L)	nc	
Total flow from tributaries (ft^3/s)	235	
Flow from tributaries as a percentage of total	45.7	
Total load from tributaries (lb/d)	3,999	
Load from tributaries as a percentage of total	97.5	
Mean concentration in tributaries (mg/L)	3.16	

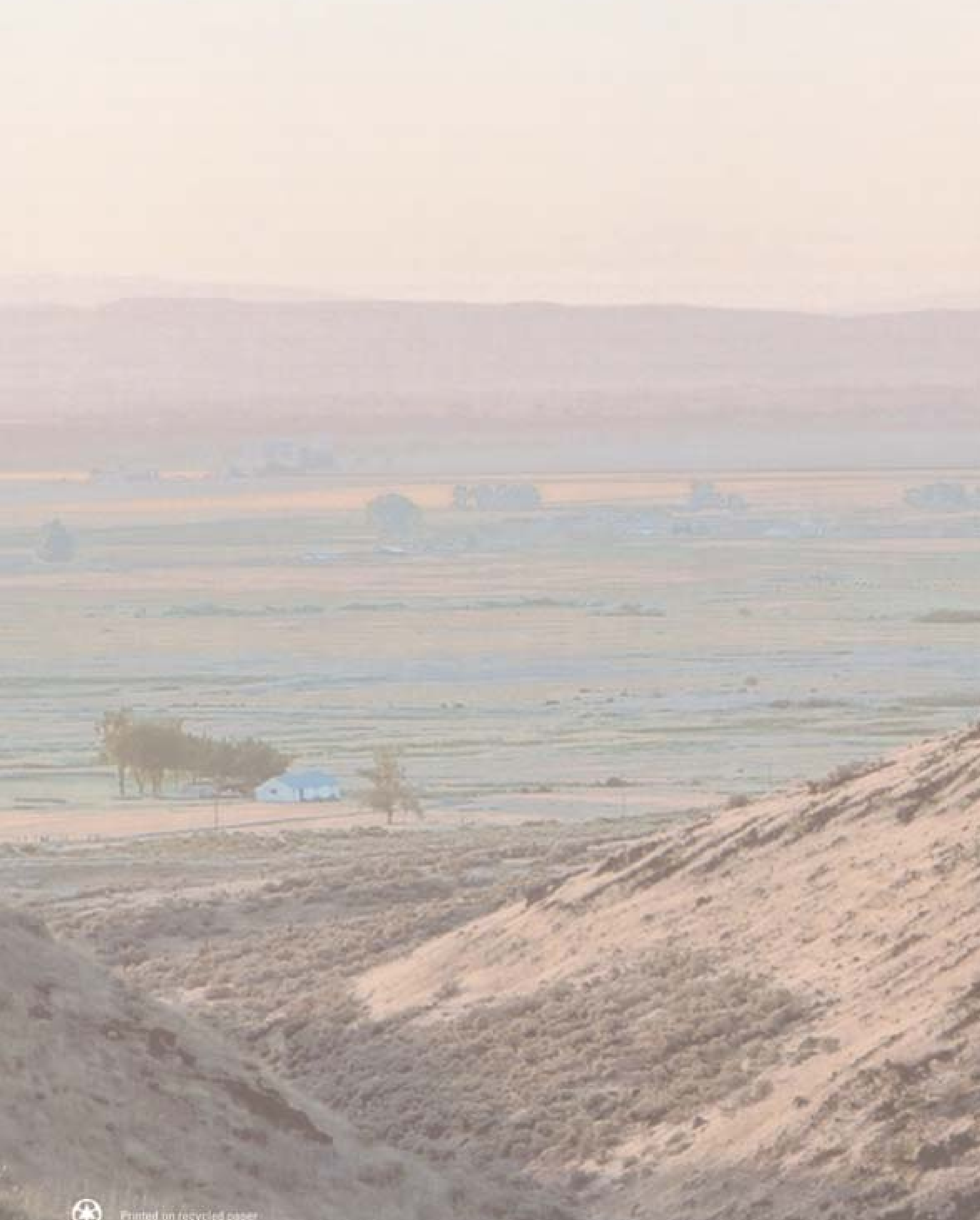
Other statistics for river mile 72 to river mile 55		
Unmeasured flow (ft^3/s)	56	**56**
Unmeasured load (lb/d)	-1,055	**-1,055**
Unmeasured concentration (mg/L)	nc	
Total flow from tributaries (ft^3/s)	403	
Flow from tributaries as a percentage of total	41.5	
Total load from tributaries (lb/d)	6,955	
Load from tributaries as a percentage of total	69.6	
Mean concentration in tributaries (mg/L)	3.20	

Table C1. Mass-balance analyses for instantaneous streamflows and loads of total nitrogen and phosphorus in the reach of the Yakima River extending from river mile 103.7 to river mile 55, Yakima River Basin, Washington, August 1999 and July 1988—*Continued*

Site name	River mile	Measured streamflow (ft^3/s)	Cumulative flows (ft^3/s)	Measured concen-tration (mg/L)	Measured load (lb/d)	Cumulative loading to reach (lb/d)	Computed concen-tration (mg/L)
Total phosphorus (1999)							
Yakima River near Parker[1,2]	103.7	685	685	0.05	188	188	
Return from Sunnyside fish bypass[2]	103.6	40	725	.05	11	199	
Zillah WWTP	89.5	0.3	725	5.03	8	208	
East Toppenish Drain	86.0	27.5	753	.19	27	235	
Sub-Drain 35	83.2	62.5	815	.17	56	291	
Granger Drain	82.8	62	877	.46	155	446	
Granger WWTP	82.8	.4	878	1.18	3	449	
Marion Drain	82.6	66.8	945	.12	41	490	
Toppenish Creek	80.4	117	1,062	.13	79	569	
Yakima River at River Mile 72	72.0	1,270	–	.06	439	–	0.08
Yakima River at River Mile 72	72.0	1,270	1,270	.06	439	439	
Satus Creek at Satus	69.6	128	1,398	.17	120	559	
South Drain near Satus	69.3	33.1	1,431	.22	39	598	
Sulphur Creek Wasteway	61.0	260	1,691	.21	295	893	
Yakima River at River Mile 55	55.0	2,050	–	.10	1,150	–	0.08

Other statistics for river mile 103.7 to river mile 72	
Unmeasured flow (ft^3/s)	209
Unmeasured load (lb/d)	-131
Unmeasured concentration (mg/L)	nc
Total flow from tributaries (ft^3/s)	337
Flow from tributaries as a percentage of total	26.5
Total load from tributaries (lb/d)	370
Load from tributaries as a percentage of total	84.3
Mean concentration in tributaries (mg/L)	0.20

Other statistics for river mile 72 to river mile 55	
Unmeasured flow (ft^3/s)	359
Unmeasured load (lb/d)	258
Unmeasured concentration (mg/L)	.13
Total flow from tributaries (ft^3/s)	421
Flow from tributaries as a percentage of total	20.5
Total load from tributaries (lb/d)	454
Load from tributaries as a percentage of total	39.5
Mean concentration in tributaries (mg/L)	.20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