# Surface-Water-Quality Assessment of the Yakima River Basin in Washington: Spatial and Temporal Distribution of Trace Elements in Water, Sediment, and Aquatic Biota, 1987–91

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By GREGORY J. FUHRER, DANIEL J. CAIN,
STUART W. McKENZIE, JOSEPH F. RINELLA,
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## *With a section on* GEOLOGY

By MARSHALL W. GANNETT

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# FOREWORD

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

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

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

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

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

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 59 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 59 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

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

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

Robert M. Hirsch

Robert M. Hirsch
Chief Hydrologist

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## CONVERSION FACTORS

| Multiply | By | To obtain |
|---|---|---|
| acre | 4,047 | square meter ($m^2$) |
| acre-foot (acre-ft) | 1,233 | cubic meter ($m^3$) |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |
| inch | 25.4 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| cubic yard ($yd^3$) | 0.7646 | cubic meter ($m^3$) |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |

Temperature in degrees Celsius (°C) as follows:

$$^{\circ}C = (^{\circ}F-32)/1.8$$

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

# Surface-Water-Quality Assessment of the Yakima River Basin in Washington: Spatial and Temporal Distribution of Trace Elements in Water, Sediment, and Aquatic Biota, 1987–91

*By* Gregory J. Fuhrer, Daniel J. Cain, Stuart W. McKenzie, Joseph F. Rinella,
J. Kent Crawford, Kenneth A. Skach, *and* Michelle I. Hornberger

*With a section on* Geology *by* Marshall W. Gannett

## Abstract

In 1986, the U.S. Geological Survey implemented a pilot program to test and refine concepts for a National Water Quality Assessment (NAWQA) Program. Washington State's Yakima River Basin was selected as one of the Nation's four surface-water pilot studies.

One of the objectives of the NAWQA Program, and the subject of this report, is to determine the occurrence and distribution of major and trace elements in sediment, water, and aquatic biota. Between 1987 and 1990, fine-grained (less than 62 micrometers in diameter) streambed sediment was collected from 448 sites in the Yakima River Basin. During 1-week periods in July and November 1987, trace elements were measured in filtered (0.45-micrometer pore size) water samples from 44 sites during steady-state flow conditions. Of the 44 sites, 7 were termed fixed sites and were sampled monthly and during some storms for the period 1987–90. These sites provide the coverage necessary to describe temporal variations in element concentrations and loads. Fixed sites were sampled for trace elements in streambed sediment, water (filtered-water samples and unfiltered-water samples), suspended sediment, and aquatic biota. Aquatic biota from 34 sites were sampled for trace elements during the period 1989–91. Aquatic biota include plant tissue (algae, curlyleaf pondweed, waterweed, and coontail), fish (rainbow trout, mountain whitefish, sculpin, brook trout, bridgelip sucker, largescale sucker, chiselmouth, carp, and cutthroat trout), clams (Asiatic), and aquatic insects (caddisflies, stoneflies, and mayflies).

The results of this study will provide multiple lines of evidence to:

- Define spatial and temporal variability for major and trace elements in several media;
- Identify sources and describe the transport and fate of trace elements;
- Evaluate the effects of trace elements on fish, benthic invertebrates, and algae.

The Yakima NAWQA data will be comparable with data collected at 58 other NAWQA basins throughout the United States so that the status of trace elements in the Nation's water can be addressed.

Most element enrichment in the Yakima River Basin results from natural geologic sources in the forested landscapes of the Kittitas and mid-Yakima Valley—primarily in the Cle Elum, Upper Naches, Teanaway and Tieton Subbasins. These areas are geologic sources of antimony, arsenic,

chromium, copper, mercury, nickel, selenium, and zinc. Concentrations of arsenic, chromium, and nickel in streambed sediment (as high as 45, 212, and 260 µg/g [micrograms per gram], respectively) are nearly 4 to 13 times higher than their respective median concentrations in streambed sediment of agricultural land-use areas in the lower Yakima Valley. As a result of geologic sources, several of these elements, including arsenic, chromium, and nickel, leave chemical signatures that are measurable in streambed sediment and suspended sediment of higher order streams, including the main stem. For example, the median concentration of chromium in streamed sediment in the Kittitas Valley (near the geologic source of chromium) is nearly twice that in the Yakima River at Kiona, located in the lower Yakima Valley. Some of the geologically derived elements, including chromium, nickel, and selenium, are measurable in aquatic biota of higher order streams. In the Teanaway Subbasin alone, concentrations of chromium and nickel in benthic insects are, respectively, 4 to 52 times and 43 to 102 times higher than the minimum concentration in the Yakima River Basin.

Distributions of element concentrations that increase in areas affected by human activities include arsenic, cadmium, copper, lead, mercury, selenium, and zinc. These element concentrations commonly are high in the streambed sediment of Wide Hollow Creek, which drains urbanized and lightly industrialized lowlands as well as agricultural land. In Wide Hollow Creek, concentrations of lead in sediment (63 µg/g) and benthic insects (5.6 µg/g), respectively, are more than twice that in streambed sediment from local geologic sources and 15 times higher than that in caddisflies from a reference site not affected directly by human activity. In addition to suspected urban sources, lead may result from past applications of lead arsenate. Concentrations of lead in soils of apple orchards in the Yakima River Basin are as much as 60 times higher than the median concentration of lead in streambed sediment from local geologic sources.

Suspended-arsenic concentrations in Sulphur Creek Wasteway, an agricultural drain, range from 4.9 to 20 µg/g and are the highest in the Yakima River Basin. Arsenic may result from past applications of lead arsenate—soils of apple orchards in the Yakima River Basin have as much as 36 times more arsenic than the median concentration in streambed sediment from local geologic sources. During the irrigation season, the June contributions of suspended arsenic from Sulphur Creek Wasteway (2 lb [pounds] per day) typically account for most of the suspended-arsenic load (measured 6 miles downstream) in the main stem. Between the Kittitas Valley and the mid-Yakima Valley, the annual suspended-arsenic loads during 1987–90 increased by as much as threefold. During the irrigation season, in particular, about 2.2 lb of suspended arsenic per day enter the mid-Yakima Valley over a 9.4-river-mile reach that receives irrigation return flow from Moxee Subbasin and Wide Hollow Subbasin. This arsenic load represents about one-half the irrigation-season load in the Yakima River above Ahtanum Creek at Union Gap.

Concentrations of arsenic in filtered-water samples from Sulphur Creek Wasteway and in the main stem of the lower Yakima Valley are high (exceed the 90th percentile [3 µg/L] for the Yakima River Basin) in comparison to fixed sites (less than 1 µg/L) in the Kittitas Valley. These high concentrations are in waters affected primarily by agricultural return flow. In addition to higher concentrations of arsenic in filtered-water samples from agriculturally affected parts of the Yakima River Basin, the load of arsenic in agricultural drains probably represents a large proportion of the arsenic load passing the Yakima River at Kiona, the terminus of the basin. For example, Sulphur Creek Wasteway has an annual streamflow representing only about 8 percent of the annual streamflow at the Kiona fixed site, yet accounts for nearly 20 percent of the dissolved-arsenic load at Kiona. Comparisons, between loads determined from filtered-water samples (an operational approximation of dissolved load) and loads determined from arsenic in suspended sediment, show that the annual dissolved-arsenic loads at fixed sites in the lower Yakima Valley are from four to nine times higher than their respective suspended loads.

Fish taxa provide the most comprehensive spatial coverage for arsenic, mercury, and selenium; however, no single fish taxon is widely distributed across the Yakima River Basin. The aquatic-insect taxon *Hydropsyche* spp. provides the most comprehensive spatial coverage of any single insect taxon. Concentrations of several elements, including cadmium, mercury, and selenium, in various taxa (except sculpin) were higher in the main stem of the lower Yakima Valley than in the Kittitas and mid-Yakima Valley. In mountain whitefish livers from the lower Yakima Valley, the concentrations of mercury (1.3 µg/g) and selenium (15 µg/g) were nearly twice that measured in mountain whitefish in the Kittitas Valley—similar patterns also were observed for largescale suckers. Compared with other studies of mercury in liver tissue of pike and mud fish, mercury concentrations in some mountain whitefish in the lower Yakima Valley are indicative of moderate enrichment. Sculpin were not sampled in the main stem; however, concentrations in some mid-Yakima Valley tributaries that drain the Northern Cascades were about 10 times higher (because of geologic sources of selenium) than in Satus Creek, a lower Yakima Valley tributary. Concentrations of selenium in sculpin in the Yakima River Basin (mean and 85th percentile values) also exceeded those for sculpin in the National Contaminant Biomonitoring Program.

## INTRODUCTION

One of the most difficult issues facing water managers today is protecting the Nation's water resources while maintaining viable industrial and agricultural activities. Over the last several decades, concern about the water quality of our Nation's waterways has intensified. Federal, State, and local governments, as well as the public in general, recognize the detrimental effects of major and especially trace elements that enter surface waters from point and nonpoint sources. When present in excessive concentrations, these elements may cause acute toxicity in the water column as well as accumulate in the tissues of aquatic organisms to toxic amounts, thereby altering the aquatic-community structure. Trace elements enter the aquatic environment from sources that include the weathering of rocks and human activities.

***Streambed sediment*** is derived primarily from the physical and chemical weathering of rocks at the Earth's surface. Initially, rock is transformed into an aggregate of loose material by physical weathering processes, such as frost. The freshly disaggregated rock surfaces are then subject to chemical-weathering processes when water is present. Chemical-weathering processes (hydration and hydrolysis, oxidation and reduction, and the action of carbon dioxide) enable some of the physically disaggregated rocks to dissolve in water. Additionally, other rocks may be altered chemically by reacting with ions present in water or may remain totally unaltered by the action of water. The physically, and sometimes chemically, disaggregated rocks ultimately are transported to surface water by the action of rain, ice, wind, and animals (including man). Once in surface water, streambed sediment is known as ***suspended sediment***. Trace-element concentrations in suspended sediment often are inversely related to grain size because they tend to sorb on sediment-particle surfaces (Horowitz, 1991; Forstner and Wittmann, 1979). Larger streamflows (often capable of suspending larger grain-sized sediment) normally carry lower concentrations of suspended trace elements; conversely, higher streamflows (normally capable of suspending only fine-grain-sized sediment) normally carry higher concentrations of suspended-trace elements.

Once in the aquatic environment, streambed sediment becomes an important sink, or accumulator, of potentially toxic trace elements like arsenic, cadmium, copper, mercury, and zinc that enter streams from point and nonpoint sources. Many of these elements can be remobilized from streambed sediment to overlying ***water***. Some of these trace elements are essential to ***aquatic biota***. At the cellular level, elements like copper and zinc chemically bond to protein molecules and catalyze enzymatic reactions; additionally, without these trace elements, organisms would fail to grow or complete their life cycles (Forstner and Wittmann, 1979). The same trace elements, however, can be toxic at the cellular level in aquatic biota when concentrations exceed those required for cellular metabolism and, additionally, can accumulate in aquatic biota and pass up the food chain. Thus, contaminants can disrupt the structure of the aquatic-biological community and through trophic transfers and biomagnification can pose a risk to consumers near the top of the food chain, including humans.

## Background

In 1986, Congress appropriated funds for the U.S. Geological Survey (USGS) to implement a pilot program to test and refine concepts for a National Water-Quality Assessment (NAWQA) Program (Hirsch and others, 1988). The Yakima River Basin was one of four surface-water pilot studies selected to refine NAWQA concepts (McKenzie and Rinella, 1987). The Yakima River Basin study included a planning phase in 1986, a data-collection phase from 1987 to 1990, and a report-writing phase that began in 1991. This report, one of several topical reports for the Yakima NAWQA study, presents the spatial and temporal distribution of major and trace elements in water, sediment, and aquatic biota.

The full-scale NAWQA Program, which entails operation of 60 combined surface-water and ground-water study units and covers about 60 to 70 percent of the Nation's water use, began operation in 1991 (Leahy and others, 1990). The NAWQA Program will provide results that are useful in understanding and managing water resources and will address national water-quality issues. Specifically, the goals of the NAWQA Program are to:

1. Provide a nationally consistent description of current water-quality conditions for a large part of the Nation's water resources;
2. Define long-term trends (or lack of trends) in water quality; and
3. Identify, describe, and explain, as possible, the major factors affecting observed water-quality conditions and trends.

The program is perennial and will involve a cyclic pattern of 3 years of active sampling followed by a period of low-level sampling. This cyclic pattern of sampling is sufficient to define long-term trends in water quality. The water-quality issues addressed in the program are broad, covering topics such as euthrophication, pesticides, major and trace elements,[1] fecal indicator bacteria, suspended sediment, temperature, and aquatic biota.

## Purpose and Scope

Most trace elements in the aquatic environment result from natural sources; however, some trace elements result from anthropogenic sources or a mixture of natural and anthropogenic sources. With traditional environmental studies, it is often difficult to separate these sources and to assess the effects on the aquatic environment. Similarly, with traditional studies, it is often difficult to relate elements in water and sediment media to land use or geology and even more difficult to relate elements in water and sediment media to element concentrations in aquatic biota. Determining activities and conditions that affect the distribution and bioaccumulation of trace elements, therefore, entails a basinwide sampling of lower and higher order[2] streams. The purpose of this report is to describe, to the extent possible:

(1) The occurrence and distribution of selected elements in water, sediment, and aquatic biota of the Yakima River Basin;

(2) The temporal variation for element concentrations in filtered water and in suspended sediment at selected sites;

(3) The suitability of surface water for preservation of aquatic life and protection of human health;

(4) The major natural and anthropogenic sources in the Yakima River Basin that affect observed water-quality conditions; and

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[1] Although definitions of the terms "major" and "trace" in reference to element concentration are not precise, substances typically occurring in concentrations of less than 1,000 parts per million (less than 0.1 percent) are considered trace elements (Forstner and Wittmann, 1979, p. 5). Elements typically occurring in concentrations of greater than 1,000 parts per million are considered major elements. In this report major elements are reported in concentration units of percent and minor elements are reported in concentration units of micrograms per gram.

[2] In this report, lower order streams are defined as first- or second-order tributaries and higher order streams are defined as third-order or larger tributaries–the largest being the main stem of the Yakima River. The smallest unbranched mapped (1:24,000 map scale) tributaries are first-order tributaries, streams receiving only first-order tributaries are second-order tributaries, larger streams receiving only first- and second-order tributaries are third-order, and so on (Horton, 1945).

(5) Implications of the assessment study with regard to future monitoring activities, assessment studies, and water management.

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| | |
|---|---|
| David W. Zimmer | Bureau of Reclamation |
| Don Schram | Bureau of Reclamation |
| Richard Albright | U.S. Environmental Protection Agency |
| Bill Garrigues | U.S. Forest Service |
| Terry W. Berkompas | Bureau of Indian Affairs |
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| Brent Renfrow | Washington State Department of Wildlife |
| Glen Patrick | Washington State Department of Health |
| Dr. L. Clint Duncan | Washington Water Research Center, Central Washington State University |
| Skip Steinmetz | Yakima County Health Department |
| Ronald L. Van Gundy | Yakima River Basin Association of Irrigation Districts |
| Ray L. Wondercheck | National Resources Conservation Service |
| Elaine Taylor | Yakima Valley Conference of Governments |
| Don Chaplin | County Extension Service |
| Mike Tobin | North Yakima Conservation District |
| Richard C. Bain, Jr. | Kittitas County Conservation District |

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## THE YAKIMA RIVER BASIN

The Yakima River flows 214.5 miles from the outlet of Keechelus Lake, in the central Washington Cascade Range, southeasterly to the Columbia River, draining an area of 6,155 $mi^2$ (square miles) (fig. 1) (Columbia Basin Inter-Agency Committee, 1964). The Yakima River Basin is one of the most intensively irrigated areas in the United States. The main stem and its largest tributary, the Naches River, have perennial streamflow with peak runoff occurring during peak snowmelt, usually in April and May. The Bureau of Reclamation's Yakima Project has seven irrigation divisions and provides water to irrigate almost one-half million acres. The project facilities include 6 storage dams, 416 miles of canals, 1,701 miles of laterals, 30 pumping plants, 145 miles of drains, 2 small power plants, and 74 miles of transmission lines (Bonneville Power Administration, 1985). Many of these waterways, most of which are natural streams, convey agricultural runoff and drainage, livestock wastes, and sewage-treatment-plant effluent to the main stem. Surface-water diversions account for about 60 percent of the mean annual streamflow from the basin. Return flows, downstream from the city of Yakima, contribute as much as 80 to 90 percent of the flow in the lower main stem during irrigation season. A schematic diagram of selected inflows and outflows

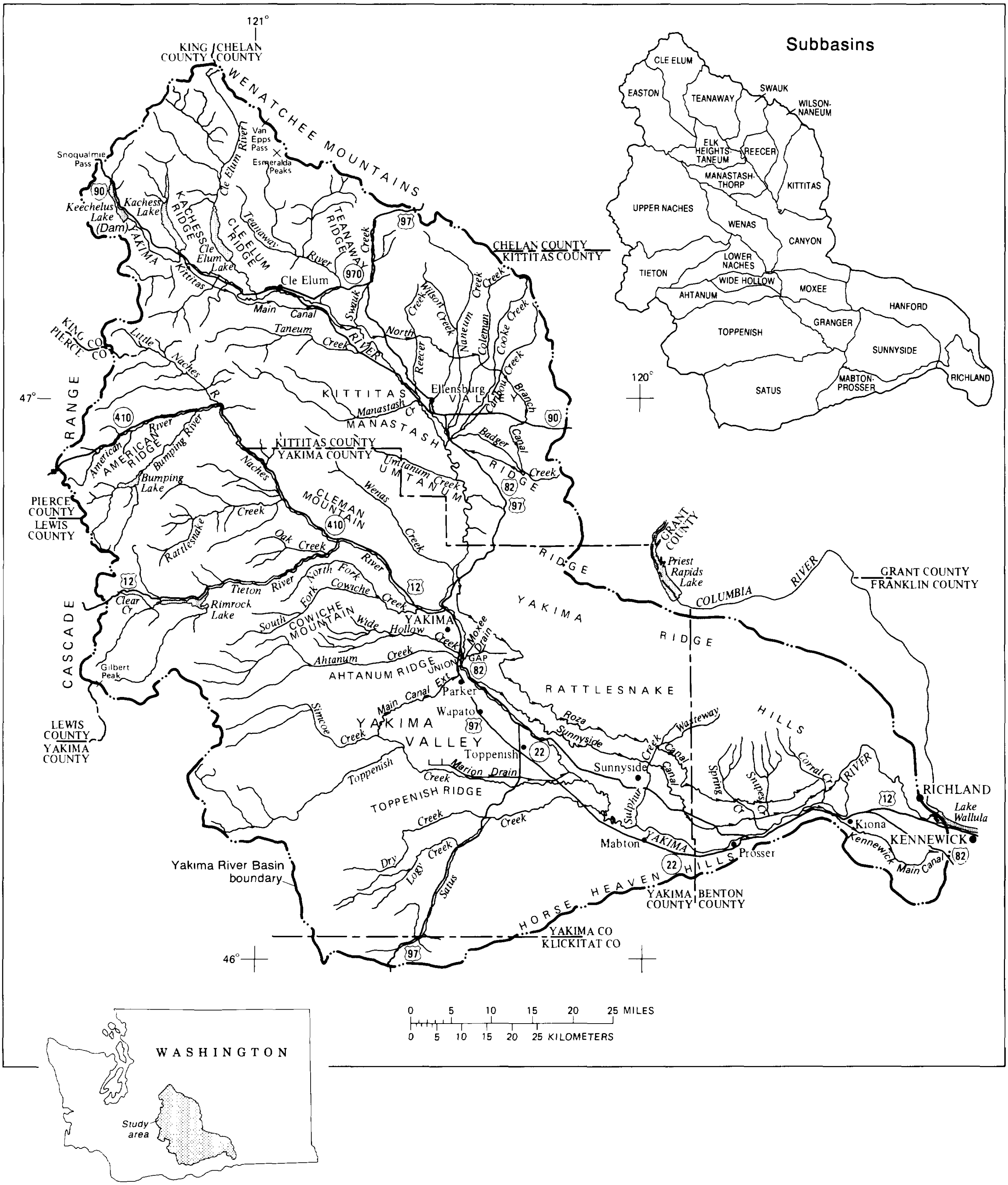

**Figure 1**. The Yakima River Basin, Washington.

is shown in figure 2. Many of these inflows carry agricultural return flow.

The Yakima River Basin contains a variety of landforms, including the high peaks and deep valleys of the Cascade Range, the broad valleys and basalt ridges of the Columbia River Plateau, and the lowlands. Altitude in the basin ranges from about 340 ft (feet) at the mouth of the Yakima River, to 8,184 ft in the headwaters located in the Cascade Range. Glaciation has carved deep valleys in the high mountains, and currently, erosion by streams and small glaciers continues on the steep gradients. Mean annual precipitation in the basin ranges from 140 inches per year in the mountains to less than 10 inches per year in Kennewick, near the mouth of the basin. The eastern part of the basin consists of basalt flows, which form ridges trending northwest-southeast with valleys between them, and is more arid than the western part that is forested and mountainous.

It is estimated that before 1880, anadromous fish runs were more than 500,000 annually in the Yakima River Basin. By 1905, however, construction of irrigation projects, including reservoirs, had affected fish habitat and fish migrations. By 1920, anadromous fish runs had declined to 12,000 per year and in the 1980s declined to less than 4,000 adults of all species (Bonneville Power Administration, 1988). Currently, the major factors considered to affect fisheries in the basin are loss of fish habitat, mortality of smolts as they migrate down the Yakima and Columbia Rivers to the ocean, fishing pressures on the Columbia River and in the ocean, and poor water-quality conditions.

## Stream Reaches

The Yakima River descends from a water-surface altitude of 2,449 ft at the foot of Keechelus Dam to 340 ft at its mouth, downstream from Horn Rapids Dam near Richland (fig. 3). The headwater of Keechelus Lake and other tributaries flowing to the lake range in altitude from about 2,500 ft to more than 6,000 ft on the eastern slopes of the Cascade Range. Because of physical characteristics, the Yakima River Basin can be divided into three distinctive river reaches (fig. 3). The upper reach drains the Kittitas Valley, is high gradient, and has an average streambed slope of 14 ft/mi (feet per mile) that extends 67.5 miles from the foot of Keechelus Dam to just upstream from Wilson Creek (river mile [RM] 147). In this reach, the river is shallow and the streambed is composed mostly of cobble and large gravel with some boulders, sand, and silt. Rocks are covered lightly with periphyton and slightly embedded in sediment.

The middle reach drains the mid-Yakima Valley and extends a distance of 39.5 miles from Wilson Creek to Union Gap (RM 107), also is high gradient, and has an average streambed slope of 11 ft/mi (fig. 3). Located on the Yakima River in the mid-Yakima Valley are the Roza (RM 127.9), Wapato (RM 106.6), and Sunnyside (RM 103.8) Dams that raise the hydraulic head of the river to divert water into irrigation canals. Upstream from the irrigation diversion dams, small stream segments of 1.0 RM or less are in backwater and accumulate fine-fraction sediment. Several waterways, including Wilson Creek and Moxee Drain, carry sediment-laden, irrigation return flow to the middle reach during the irrigation season (March 15 through October 15). Typical suspended-sediment concentrations during the irrigation season were about 100 mg/L (milligrams per liter) and 650 mg/L for Wilson Creek and Moxee Drain, respectively. Some of this sediment-laden water is, in turn, diverted into the Roza, Wapato, and Sunnyside irrigation canals. Sediment also is deposited in low-velocity backwaters of the middle reach. The fine-fraction sediment is transported farther down the main stem. Similar to the upper reach, the middle reach is shallow and the streambed is composed mostly of cobble and large gravel with some boulders, sand, and silt. In general, the rocks are covered lightly with periphyton and are free of rooted aquatic plants. Conversely, physical characteristics in reaches affected by backwaters of diversion dams are notably different. For example, the substrate in backwater of the Roza Dam is predominantly silt/clay with some organic matter and supports rooted aquatic plants.

The Naches River, a major tributary with 1,106 mi$^2$ of drainage area, flows into the mid-Yakima Valley at RM 116.3. The Naches River is a high-gradient stream with an average streambed slope of 36 ft/mi. The Naches River ranges in altitude from 2,560 ft at the confluence of the Little Naches and Bumping Rivers to 1,070 ft at its mouth (headwaters of the Naches River have water-surface altitudes as high as 6,000 ft). The river is shallow and the streambed is composed mostly of cobble and large gravel with some boulders, sand, and silt. Rocks are covered lightly to moderately with periphyton and are embedded slightly in sediment. The vegetative cover and thin soil mantle of the upper Naches Subbasin

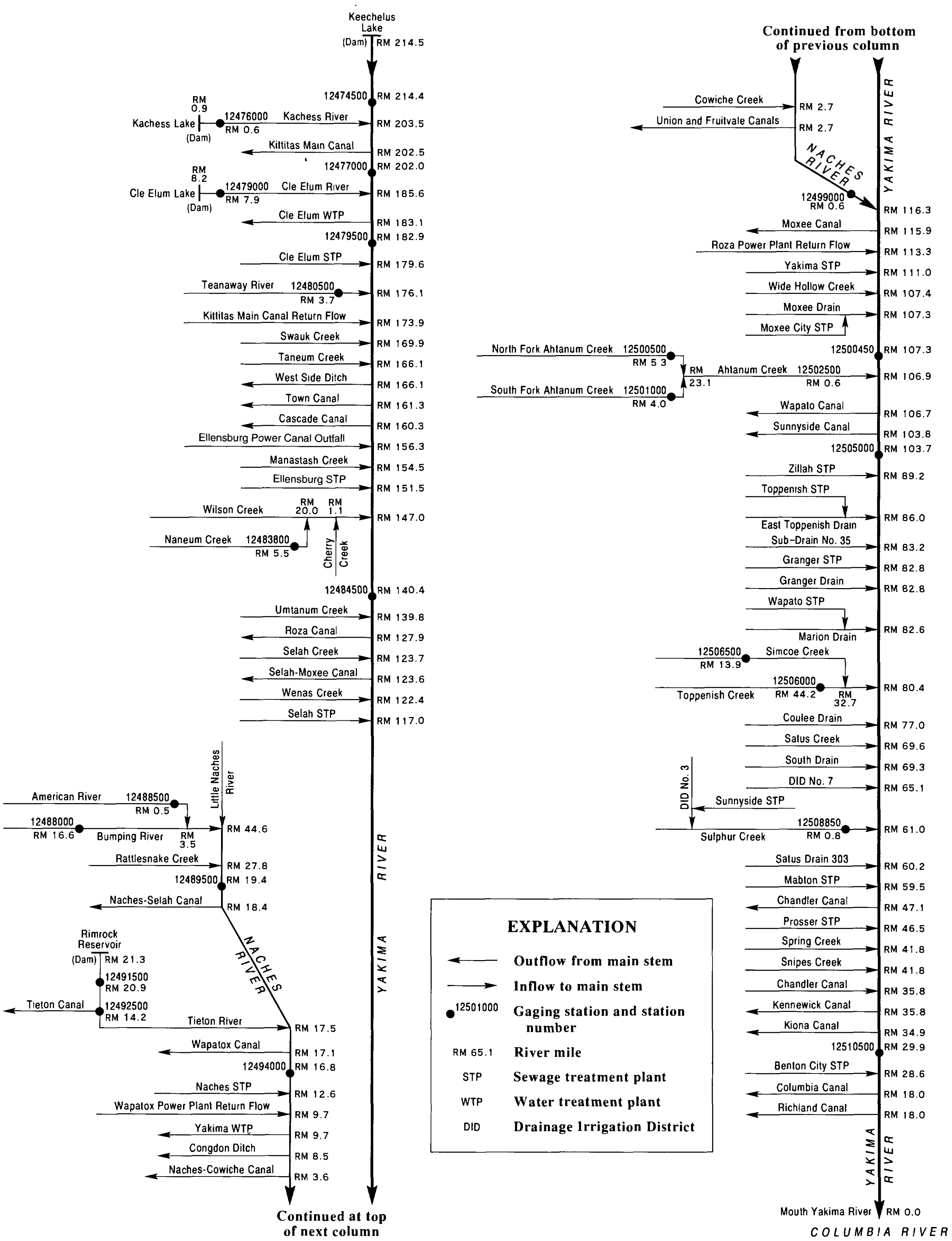

**Figure 2.** Schematic diagram showing relative positions of selected tributaries, diversion canals, return flows, and streamflow-gaging stations in the Yakima River Basin, Washington.

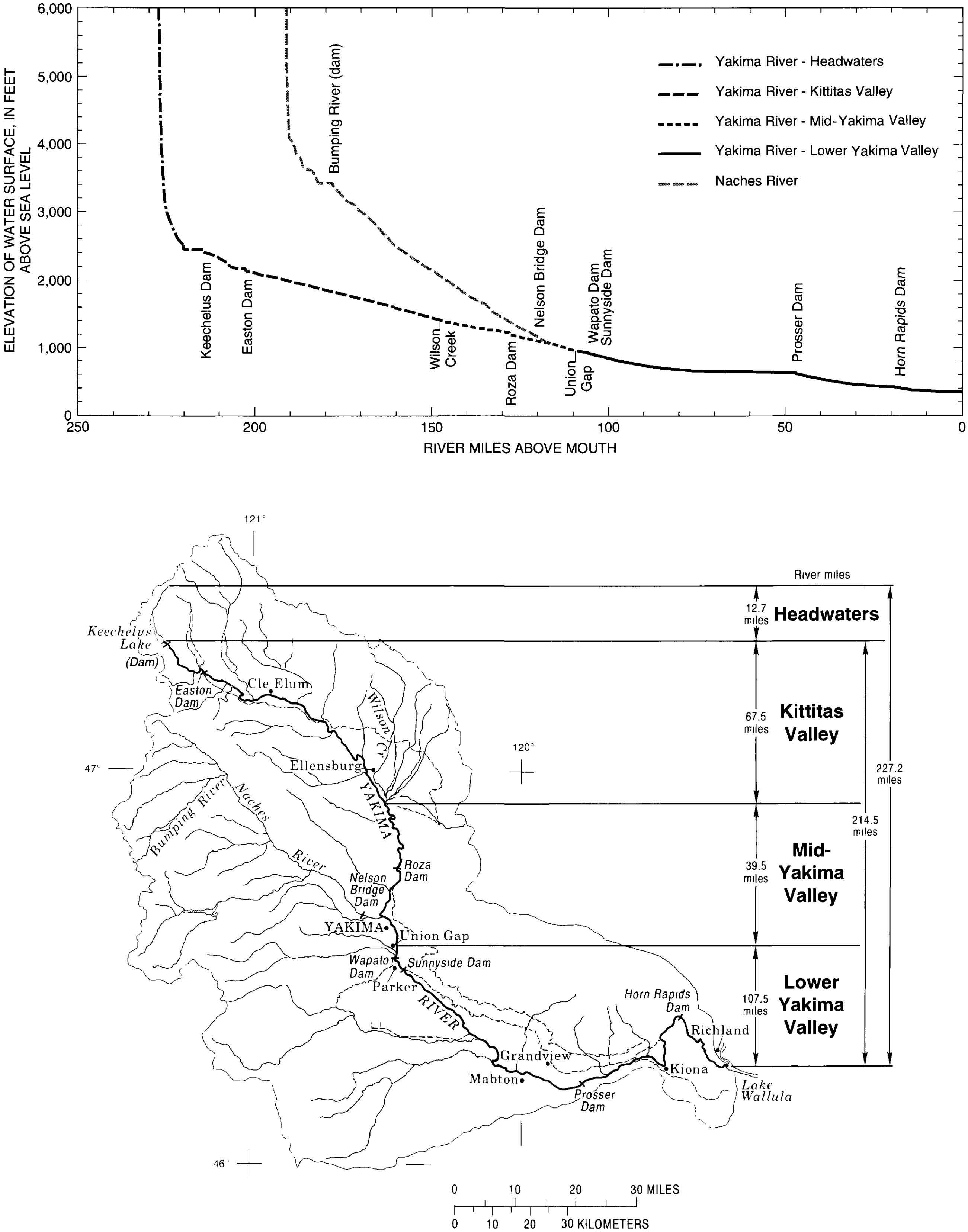

**Figure 3.** Elevation profile and distinctive hydrologic reaches of the Yakima River, Washington.

limit the amount of suspended sediment in the stream. Steep river gradients tend to keep most sediment suspended until the Naches River flows into the middle reach where velocities decrease in the backwaters of the Wapato and Sunnyside Diversion Dams.

The lower reach of the Yakima River drains the lower Yakima Valley and has an average streambed slope of 7 ft/mi and extends for 107.5 miles from the city of Union Gap to the mouth of the Yakima River (fig. 3). The streambed slope, streamflow, and average velocity are highly variable through this reach. During the irrigation season, streamflow in the main stem below the Wapato and Sunnyside Diversion Dams commonly is less than a few hundred cubic feet per second; streamflows remain low until irrigation water returns to the main stem by waterways between Parker (RM 104.6) and Mabton (RM 59.8). During the 1974–81 irrigation seasons, as much as 80 percent of the mean monthly irrigation return at Kiona was from tributaries carrying irrigation return flow between Parker and Kiona (Rinella and others, 1992). The upstream part of the lower reach of the Yakima River has a steep channel slope (12.8 ft/mi) which decreases midway through the reach (0.9 ft/mi) and results in a slow moving, meandering pool. The pool, located upstream from the Euclid Street Bridge (RM 55) near Grandview, is hydraulically characterized as a stilling basin behind a bedrock control. The pool is a depositional reach and contains predominantly silt/clay and some small gravel and organic matter. The substrate in the higher gradient sections, preceding and following the pool, is similar to that of the upper and middle reaches. Numerous rooted aquatic plants exist along the lower reach, especially in the vicinity of Horn Rapids Dam (RM 18.0).

## Geologic Overview

*By* Marshall W. Gannett

The Yakima River Basin comprises parts of the Columbia Plateau and the Cascade geologic provinces. The largest segment of the basin, including the entire southern and eastern parts, is in the Columbia Plateau, a province that consists primarily of basaltic lava flows with minor interbedded and overlying sediment. The western and northern margins of the basin are in the Cascade Range (fig. 1). The mountains in the basin consist of a complex assemblage of volcanic, sedimentary, metamorphic, and intrusive rocks.

Approximately two-thirds of the Yakima River Basin is in the Columbia Plateau province. In the Yakima River Basin, this province is dominated by lavas of the Columbia River Basalt Group, which include the Grande Ronde, Wanapum, and Saddle Mountain Basalts (Walsh and others, 1987). The basalt occurs as multiple flows, each ranging in thickness from 10 to more than 100 ft. Compressional forces in the Earth's crust during and after the emplacement of Columbia River Basalt Group lavas have warped and faulted the basalt into a series of east-northeast to east-southeast trending valleys and ridges. The ridges include the Horse Heaven Hills, the Rattlesnake Hills, and Toppenish, Ahtanum, Umtanum, Manastash, Naneum, and Yakima Ridges (fig. 1). Some of the lowlands between these basalt highlands have accumulated significant amounts of sediment. Major sediment accumulations, such as the Ellensburg Formation, are in structural lows of the Kittitas, Selah, Yakima, and Toppenish sedimentary basins according to Smith and others (1989).

Basalt flows of the Columbia River Basalt Group are overlain by, and locally interbedded with, sedimentary deposits. The major sedimentary unit in the Columbia Plateau province, in the Yakima River Basin, is the Ellensburg Formation, which consists chiefly of volcaniclastic material derived from the Cascade Range. Smith and others (1989) report that more than 1,000 ft of coarse-grained volcaniclastic sediment has accumulated over many parts of the Yakima River Basin.

A variety of unconsolidated surficial deposits of Quaternary age is present on the Columbia Plateau in the Yakima River Basin. These deposits include alluvial deposits along rivers and streams, alluvial terrace deposits, loess, and deposits resulting from catastrophic glacial outburst floods that inundated the lower part of the basin during the Pleistocene Epoch (Waitt, 1985). These catastrophic flood deposits are present up to an altitude of about 1,000 ft in parts of the basin (Waitt, 1985).

Approximately one-third of the Yakima River Basin is located in the Cascade Range geologic province. The Cascade Range province includes parts of the western and northern margins of the basin. The southern part of the Cascade Range in the basin, south of the Naches River, is dominated by Tertiary volcanic rocks, which include basalt and andesite flows, flow breccias, and related pyroclastic and volcaniclastic rocks (Walsh and others, 1987). Tertiary volcanic units are predominant in the middle part of the Tieton

River drainage, the upper part of the Rattlesnake Creek, most of the American River, Bumping River, and Crow Creek drainages. Older Jurassic to early Cretaceous marine sedimentary rocks are present in the Cascade Range south of the Naches River, most notably in the upper Tieton River drainage. These nonvolcanic rocks consist of sandstone and mudstone with lesser conglomerate (Walsh and others, 1987).

North of the Naches River, the Cascade Range province in the Yakima River Basin is dominated by Tertiary nonmarine sedimentary rocks, and pre-Tertiary metamorphic and intrusive rocks with small amounts of Tertiary volcanic rocks. Major sedimentary units in this area include the Eocene Roslyn and Swauk Formations.

The Roslyn Formation, which underlies a large part of the Teanaway River drainage, consists primarily of nonmarine sandstone with a smaller amount of conglomerate and thin coal seams (Tabor and others, 1982). The Swauk Formation, which is older than the Roslyn Formation, is located in the upper parts of the Teanaway River, Cle Elum River, and Swauk Creek drainages and consists primarily of nonmarine sandstone and a small amount of siltstone, shale, and conglomerate. The Swauk and Roslyn Formations are separated by the Teanaway Basalt, which consists primarily of basaltic flows, tuff, and breccia.

The upper parts of the south fork of Manastash Creek and the north and south forks of Taneum Creek drain areas where pre-Tertiary metamorphic rocks are found, including gneiss, schist, phyllite and amphibolite. These metamorphic rocks are surrounded and locally overlain by Tertiary volcanic rocks and nonmarine sedimentary rocks similar to the Swauk and Roslyn Formations.

In the far northern part of the Yakima River Basin, the uppermost sections of the Cle Elum River and the north fork of the Teanaway River drain an area underlain by ultramafic rocks adjacent to the Mount Stuart batholith. These ultramafic rocks include serpentinite, serpentinized peridotite, metaserpentinite, metaperidotite, diabase, and gabbro (Tabor and others, 1982).

Unconsolidated surficial deposits in the Cascade Range province in the Yakima River Basin include alluvium along rivers and streams, alluvial fans, landslides, and glacial drift and outwash.

## Land Use

Major land-use activities in the Yakima River Basin include growing and harvesting timber, grazing on nonirrigated land, intensively irrigated agriculture, and urbanization (fig. 4). Intense water use for agriculture and cities makes these land-use categories of primary importance to water-quality issues. Population in the Yakima River Basin was about 250,000 in 1990 (Elaine Taylor, Yakima Valley Conference of Governments, Yakima, Washington, written commun., October 1992).

The forested northern and western areas in the Yakima River Basin lie in the Wenatchee and Snoqualmie National Forests, in the eastern slope of the Cascade Range. These forest lands are used for recreation, wildlife habitat, grazing, and timber harvesting. About one-fourth of this area is wilderness land, which has been designated for nonmotorized recreation. Rangelands are used for cattle grazing, wildlife habitat, and military training (at the Yakima Firing Center, northeast of the city of Yakima).

## Previous Studies

Water-quality investigations in the Yakima River Basin historically have focused on specific issues and objectives rather than a river-basin assessment of water quality. However, data from previous studies did provide useful historical perspectives when compared with present-study data. Most streambed-sediment chemistry studies in the Yakima River Basin were mineral-resource investigations and mostly cover the mountainous regions in the northern and southwestern Yakima River Basin. The following studies are noteworthy: the Goat Rocks Wilderness area (Church and others, 1983), the Alpine Lakes Wilderness area (U.S. Geological Survey and U.S. Bureau of Mines, 1989), and the mineral-resource study of the headwaters of the Yakima and Naches Rivers (Moen, 1969).

The Alpine Lakes study (U.S. Geological Survey and U.S. Bureau of Mines, 1989), the largest of the three previous studies, included collection of 4,702 streambed-sediment and rock samples between 1971 and 1972. The Alpine Lakes report contains geology, mineral resources, geochemical data, and a detailed chronology of historical mining activities. Streambed-sediment samples were screened by semiquantitative-spectrographic analysis for

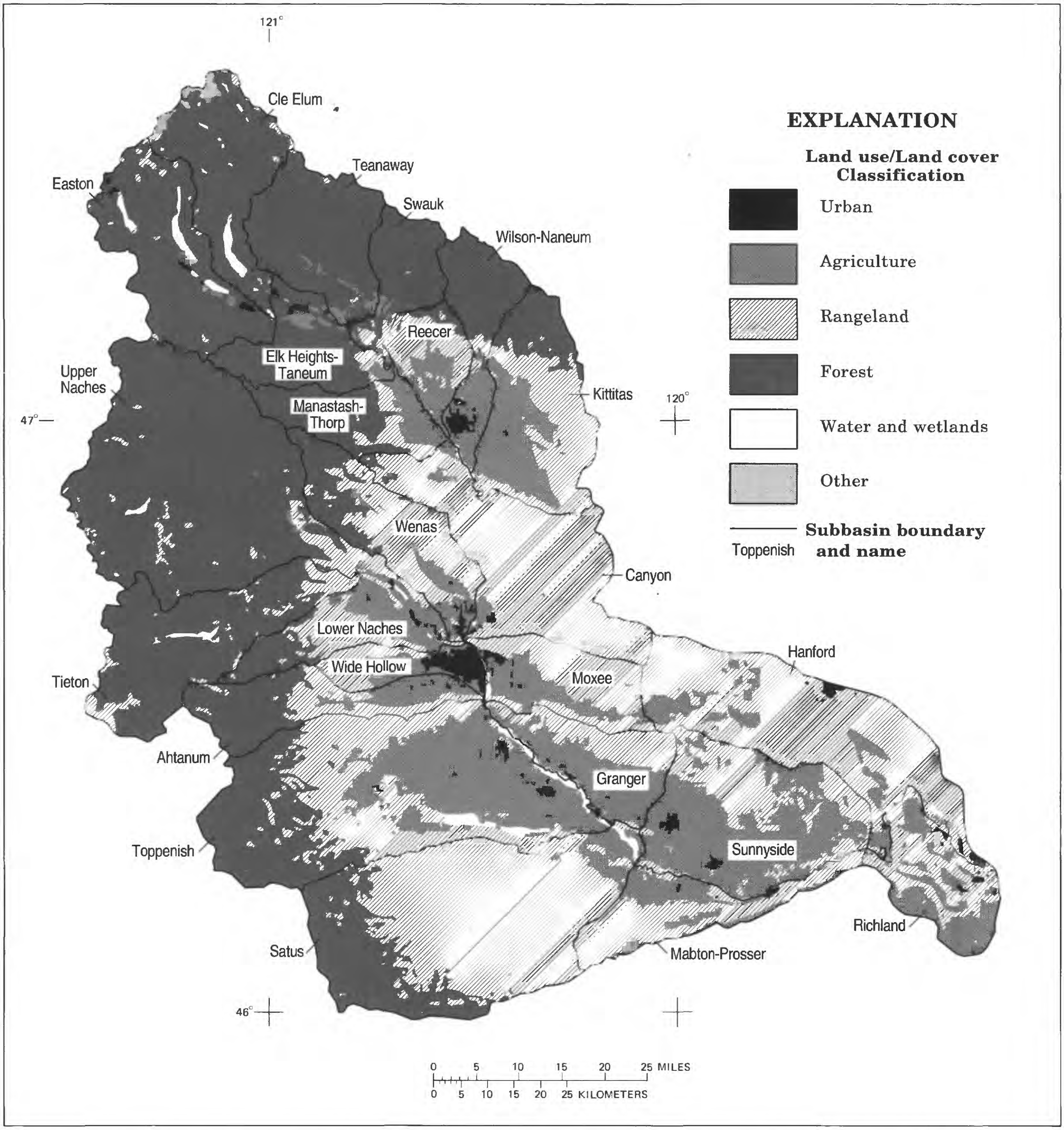

**Figure 4.** Land use and land cover by subbasin in the Yakima River Basin, Washington, 1981 (U.S. Geological Survey, 1986).

30 elements; anomalous data were further analyzed by atomic absorption spectrophotometry. Streambed sediment collected in the northeastern part of the Yakima River Basin is enriched in concentrations of copper and zinc—concentrations varied in proportion to the distance from the contact between the Mount Stuart batholith and local ultramafic rocks. Many of the anomalous data collected from the northwestern part of the basin—in the vicinity of Gold Creek—indicate the presence of hydrothermally altered and mineralized rock containing proportionally more lead and zinc and less copper. The second largest study of the headwaters of the Yakima and Naches Rivers (Moen, 1969) included collection and analysis of 182 streambed-sediment samples for copper, molybdenum, lead, and zinc, between 1965 and 1968. Fries and Ryder (in Rinella and others, 1992) interpreted the data from these headwater studies and concluded that concentrations of copper (206 µg/g [micrograms per gram] in Easton Subbasin), and zinc (330 µg/g in the Upper Naches Subbasin and 120 µg/g in the Tieton Subbasin) exceeded the 95-percent range shown for soils in the Western United States (R.C. Severson, U.S. Geological Survey, written commun., 1987, based on data in Shacklette and Boerngen, 1984). The Goat Rocks study (Church and others, 1983) included collection and analysis of 43 streambed-sediment samples for 31 elements (using a direct current arc emission spectrographic method) in 1981. Fries and Ryder (in Rinella and others, 1992) interpreted data for the Goats Rocks study and concluded that the 90th-percentile concentrations of copper (50 µg/g), vanadium (300 µg/g), and zinc (200 µg/g) in the Tieton Subbasin were anomalous.

Few studies of trace elements in filtered-water samples or in suspended sediment and water mixtures were made in the Yakima River Basin. For the most part, historical data were collected in the Yakima River at Kiona (RM 29) as part of the USGS and U.S. Environmental Protection Agency (USEPA) monitoring programs from 1966 to 1972. In 1973, samples were collected from the Yakima River above Ahtanum Creek at Union Gap (RM 107) and in 1974 from the Yakima River at Kiona (RM 29.9). Both sites were operated as part of the USGS National Stream Quality Accounting Network (NASQAN).

The Washington State Department of Ecology did a study in 1987 of low-flow conditions in Wide Hollow Creek, which flows into the Yakima River (RM 107.4). This creek receives urban runoff from the city of Yakima, as well as agricultural return flow. Water and streambed sediment were analyzed for trace metals and trace-organic compounds. Water-quality measurements also were made, and fish and macroinvertebrate communities were surveyed in order to relate the abundance and diversity of taxa to water-quality conditions. Fish abundance generally increased upstream, while macroinvertebrate distribution varied more with canopy shading than with water-quality conditions. Six trace elements, analyzed in unfiltered-water samples, were either below or only slightly above the lower limit of determination[3] (LLD). Streambed sediment was sampled at two sites and analyzed for 13 elements. The upstream site (RM 7.2) was subject to orchard and pasture effects, and the downstream site (RM 0.9) was subject to urban and livestock-pasturing activities. Arsenic, lead, mercury, and zinc concentrations at the upstream site were, respectively, 2.5 µg/g, 32 µg/g, 0.028 µg/g, and 92 µg/g. Concentrations of arsenic, lead, mercury, and zinc at the downstream sites were, respectively, 0.9 µg/g, 11 µg/g, 0.036 µg/g, and 132.5 µg/g (Kendra, 1988). The concentrations of arsenic and lead were higher in close proximity to orchard and pasture effects. Mercury and zinc concentrations were higher in close proximity to urban and livestock-pasturing activities.

Filtered-water samples[4] analyzed for iron, manganese, lead, and mercury equaled or exceeded USEPA National Primary and Secondary Drinking-Water Regulations at one or more sites in the Yakima River Basin, from water years 1953 through 1985; filtered concentrations of cadmium, chromium, copper, lead, mercury, silver, and zinc equaled or exceeded USEPA acute and (or) chronic standards established for the protection of freshwater-aquatic life at four or more sites (Rinella and others, 1992). Dissolved elements with the largest percentage of drinking-water exceedances (relative to the total number of determinations) were iron (8 percent), manganese (less than 1 percent), lead (3 percent), and mercury (less than

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[3] The limit of determination is three times the standard deviation of a blank water sample added to the average of the blank.

[4] The term "filtered water" is operationally defined as that portion of a water-suspended sediment sample that passes through a nominal 0.45-µm (micrometer) filter. Conversely, the term "unfiltered water" refers to a water sample that has not been filtered or centrifuged, nor in any way altered from the original matrix.

1 percent). Similarly, elements with the largest percentage of aquatic-life exceedances were lead (59 percent), mercury (41 percent), copper (24 percent), cadmium (11 percent), zinc (3 percent), chromium (1 percent), and silver (less than 1 percent). Whole-water and whole-water recoverable concentrations with the largest percentage of drinking-water exceedances (relative to the total number of determinations) are manganese (34 percent), iron (6 percent), and lead (2 percent). Similarly, elements with the largest percentages of acute and (or) chronic aquatic-life exceedances were lead (77 percent), mercury (50 percent), copper (46 percent), and nickel (less than 1 percent).

Few monitoring programs for trace elements in aquatic biota exist in the Yakima River Basin. Most programs emphasize the collection of fish tissue and cover only a small number of sites (Hopkins and others, 1985; Johnson and others, 1986; Lowe and others, 1985; Walsh and others, 1977; Schmitt and Brumbaugh, 1990). Washington State Department of Ecology did a study in the Yakima River Basin in 1985, targeting mercury in addition to trace-organic compounds. Fish, water, and streambed sediments were analyzed. The highest mercury concentrations in fish were detected in northern squawfish. The maximum concentrations were at Wymer (RM 134–136), and the concentrations were 0.33 µg/g for whole fish and 0.45 µg/g for fish muscle, in wet weight. Mercury concentrations at downstream sites tended to increase in other species of fish. Whole fish, excluding northern squawfish, had mercury concentrations ranging from 0.02 µg/g for mountain whitefish at Cle Elum (RM 179–181) to 0.05 µg/g for mixed suckers at Buena (RM 93–95). Fish muscle, excluding northern squawfish, had mercury concentrations, in wet weight, ranging from 0.03 µg/g for mountain whitefish at Wymer to 0.13 µg/g for largescale sucker at Kiona (Johnson and others, 1986).

Since 1978, the Washington State Department of Ecology has analyzed fish tissue at selected sites in Washington through the Basic Water Monitoring Program. In 1984, streambed-sediment sampling was initiated in addition to the fish sampling. Ten sites were sampled in 1984, two of which were on the Yakima River (below Moxee Drain at RM 107.6 and at Kiona at RM 29.9). Fish muscle was analyzed for pesticides and seven trace metals. Northern squawfish from the Yakima River below Moxee Drain had the highest concentration of mercury (0.78 µg/g, wet weight) measured during the 1984 sampling. Mountain whitefish at the same site had 0.64 µg/g, wet weight, of mercury (Hopkins and others, 1985). These concentrations exceeded the National Academy of Sciences/National Academy of Engineering (NAS/NAE) recommendation for the protection of selected species of fish and predatory aquatic organisms. The recommendation states that the concentration of total mercury should not exceed a total body burden of 0.5 µg/g, wet weight, in any aquatic organism (National Academy of Sciences/National Academy of Engineering, 1972, p. 173).

The U.S. Fish and Wildlife Service has participated in the National Contaminant Biomonitoring Program (before 1984, called the National Pesticide Monitoring Program) since 1967. In this program, samples of bottom-feeding and predator fish were taken at over 100 sites throughout the United States and analyzed for potentially toxic elements and selected organochlorine compounds. One of these sites is in the Yakima River Basin (Yakima River at Granger). From 1971 to 1973, concentrations of mercury in northern squawfish were below the U.S. Food and Drug Administration (FDA) guideline (1.0 µg/g, dry weight) for human consumption (Walsh and others, 1977). In 1978, a concentration of lead (1.4 µg/g, wet weight), which exceeded the 85th percentile value determined for various fish species in the United States, was measured in a sample of white crappie at Granger (Lowe and others, 1985). In 1980 and 1984, however, none of the samples collected at Granger contained concentrations of lead that exceeded 85th-percentile values, or concentrations of mercury that exceeded FDA guidelines (Lowe and others, 1985; and Schmitt and Brumbaugh, 1990). Different species were collected during different years, which might account for some of the variation reported among years (Schmitt and Brumbaugh, 1990). Additionally, some of the variation may have resulted from a change in the location of the sampling site (Don Kane, U.S. Fish and Wildlife Service, oral commun., 1991). Samples were collected in 1984–88 from a pond located near the main stem of the Yakima River at Granger. In 1978 and 1980, however, it is unknown whether or not the main stem or the pond was sampled. The pond was believed to have been connected hydrologically to the main stem by a culvert; however, based on a site inspection in 1992, no evidence of a culvert remained.

## APPROACH AND METHODS

Trace-element concentrations were determined in media from the Yakima River Basin (fig. 5). These media included ***streambed sediment, suspended sediment, water*** (filtered and unfiltered), and ***aquatic biota***. One or more of these media were measured at 57 sites in the Yakima River Basin, 1987–91 (table 1) for selected elements (table 2). Data pertaining to these media have been published for streambed sediment by Ryder and others (1992) and for sediment, water, and biota by Fuhrer, Fluter, and others (1994). To characterize temporal variations for trace-element concentrations and loads, trace-element data for suspended-sediment and water media were categorized according to season. The seasons defined for use in this report are ***snowmelt, irrigation*, and *nonirrigation***. The irrigation season (March 15 to October 15) and snowmelt season, however, are not mutually exclusive. Snowmelt generally is a major contributor to streamflow during April and May; consequently, the snowmelt portion of the irrigation season is considered separately. As a result, the snowmelt season is defined as April and May, the irrigation season as June through September, and the nonirrigation season as October through March.

Spatially, the most extensively sampled medium was streambed sediment. In 1987, as part of the Yakima NAWQA occurrence and distribution survey, streambed sediment was collected from 448 locations in the Yakima River Basin. These locations represented a variety of sampling sites that covered lower and higher order streams and included limited samplings of urban storm drains and agricultural soils. Results from this streambed-sediment study were published earlier (Fuhrer, McKenzie, and others, 1994). Many of the sites measured for trace elements measured in aquatic biota, water, and suspended sediment corresponded to streambed-sediment sites sampled as part of the occurrence and distribution survey in 1987. Additionally, some new streambed-sediment sites were sampled in 1989–90 to complement sites where trace elements were measured in aquatic biota. During 1987–90, one streambed-sediment sample was collected at each of the 32 sites at which an aquatic biota sample also was collected. Results from the 1987 occurrence and distribution survey are used in this report to describe the spatial distribution of trace elements in water, aquatic biota, and sediment from sites where aquatic biota were sampled.

Sampling frequency for filtered water varied for some sites. Forty-four sites were sampled at least once for filtered trace elements; a majority of these sites were sampled during synoptic surveys in July and (or) November 1987. Synoptic surveys were made over a short period of time (during steady-state streamflow conditions) and provided a broad spatial coverage for occurrence and distribution of trace-element concentrations in filtered water. Seven of the 44 sites also were sampled monthly and during hydrologic events (including snowmelt and winter rainstorms) for the period March 1987 to April 1990. These seven sites are referred to in this report as ***fixed sites*** 6, 19, 26, 32, 50, 52, and 56 (table 3 and fig. 5). The monthly and event-sampling frequency provides the temporal coverage necessary to describe seasonal variations for trace-element concentrations in filtered water.

Of the sites sampled, fixed sites were sampled with the greatest frequency. Generally, trace elements in all media were measured at these sites (fig. 5), with the exception of the Yakima River above Ahtanum Creek at Union Gap. (This site is not wadable; consequently, aquatic biota and streambed sediment samples were collected 2.6 miles downstream at the Yakima River at Parker.) Five of the seven fixed sites were on the main stem of the Yakima River; one site was located at the mouth of the Naches River—a major tributary; and the other site was located at the mouth of Sulphur Creek Wasteway—a major drain for carrying irrigation return flow and urban runoff (fig. 5). Fixed sites were sampled in a systematic downstream order to simulate the movement of surface water passing through the Yakima River Basin. Operation of fixed sites in the basin is described by Fuhrer, Fluter, and others (1994).

Sampling frequency for suspended sediment and filtered water was identical for the period March 1987 to April 1990. The seven fixed sites were sampled monthly and during hydrologic events, including snowmelt and winter rainstorms, and analyzed for major and trace elements. At the fixed sites, suspended sediment and water (filtered and unfiltered) were sampled simultaneously. The sampling frequency for unfiltered water, however, varied from that of the filtered portion and likewise, from that of the suspended sediment. Generally, unfiltered samples were collected quarterly during 1987 and not at all during 1988–90; however, some sites were sampled less frequently in 1987.

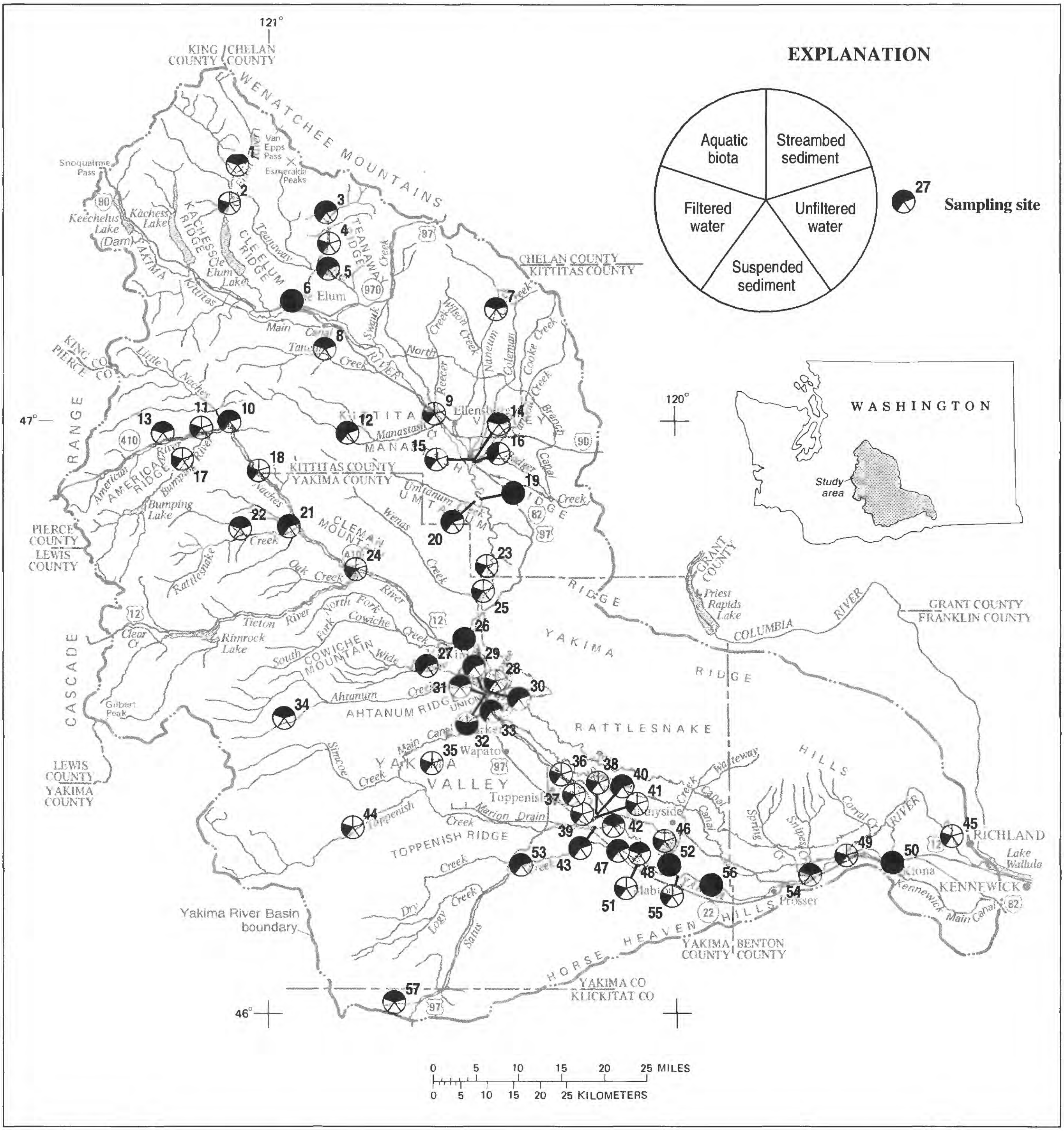

**Figure 5.** Sampling-site locations for major and trace elements in sediment, water, and aquatic biota, Yakima River Basin, Washington, 1987–91 (site reference numbers are shown on map and are listed in table 1; shaded areas of individual pie charts correspond to media that were sampled at the site).

**Table 1.** Sampling-site locations and media sampled for major and trace elements, Yakima River Basin, Washington, 1987–91

[S, streambed sediment; SS, suspended sediment; T, aquatic-biota tissue; F, filtered water; U, unfiltered water; RM, river mile; STP, sewage treatment plant; and DID, drainage irrigation district; --, not analyzed]

| | | | | | Media | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Sediment | | | Water | |
| Site reference number | Site name | Station number[1] | Latitude | Longitude | S | SS | T | F | U |
| 1 | Waptus River at mouth near Roslyn | 12478100 | 47°25′13″ | 121°05′15″ | X | -- | X | -- | -- |
| 2 | Cle Elum River above Cle Elum Lake near Roslyn | 12478300 | 47°21′19″ | 121°06′22″ | -- | -- | -- | X | -- |
| 3 | Jungle Creek near mouth near Cle Elum | 12479720 | 47°20′30″ | 120°51′59″ | X | -- | X | X | -- |
| 4 | North Fork Teanaway River below bridge at Dickey Creek Campground | 12479750 | 47°17′21″ | 120°51′30″ | -- | -- | X | -- | -- |
| 5 | Teanaway River below Forks near Cle Elum | 12480000 | 47°14′48″ | 120°51′36″ | X | X | X | -- | -- |
| 6 | Yakima River at Cle Elum | 12479500 | 47°11′35″ | 120°56′55″ | X | X | X | X | X |
| 7 | Naneum Creek below High Creek near Ellensburg | 12483750 | 47°10′55″ | 120°26′44″ | X | -- | X | -- | -- |
| 8 | Taneum Creek at Taneum Meadow near Thorp | 12481900 | 47°06′47″ | 120°52′01″ | X | -- | X | -- | -- |
| 9 | Yakima River at Thorp Highway bridge at Ellensburg | 12482800 | 47°00′20″ | 120°35′43″ | -- | -- | -- | X | -- |
| 10 | Little Naches River at mouth near Cliffdell | 12487200 | 46°59′20″ | 121°05′55″ | X | -- | X | X | -- |
| 11 | American River near Nile | 12488500 | 46°58′39″ | 121°10′05″ | -- | -- | -- | X | -- |
| 12 | South Fork Manastash Creek near Ellensburg | [2]12483190 | 46°58′18″ | 120°48′32″ | X | -- | X | X | -- |
| 13 | American River at Hell's Crossing near Nile | 12488250 | 46°58′04″ | 121°15′45″ | X | -- | X | -- | -- |
| 14 | Cherry Creek above Wipple Wasteway at Thrall | 12484440 | 46°55′44″ | 120°29′48″ | X | -- | X | -- | -- |
| 15 | Wilson Creek above Cherry Creek at Thrall | 12484100 | 46°55′35″ | 120°30′01″ | -- | -- | -- | X | -- |
| 16 | Cherry Creek at Thrall | 12484480 | 46°55′34″ | 120°29′51″ | -- | -- | X | X | -- |
| 17 | Bumping River at Soda Springs Walkway near Nile | 12488050 | 46°55′27″ | 121°12′50″ | -- | -- | -- | X | -- |
| 18 | Naches River at Cottonwood Campground near Cliffdell | 12489050 | 46°54′24″ | 121°01′33″ | -- | -- | -- | X | -- |
| 19 | Yakima River at Umtanum | 12484500 | 46°51′46″ | 120°28′44″ | X | X | X | X | X |
| 20 | Umtanum Creek near mouth at Umtanum | 12484550 | 46°51′27″ | 120°29′46″ | X | -- | X | X | -- |
| 21 | Rattlesnake Creek above Little Rattlesnake Creek near Nile | [3]12489150 | 46°48′50″ | 120°56′58″ | X | -- | X | X | -- |
| 22 | Rattlesnake Creek above North Fork Rattlesnake Creek near Nile | 12489100 | 46°48′34″ | 121°04′08″ | X | -- | X | -- | -- |

**Table 1.** Sampling-site locations and media sampled for major and trace elements, Yakima River Basin, Washington, 1987–91—Continued

[S, streambed sediment; SS, suspended sediment; T, aquatic-biota tissue; F, filtered water; U, unfiltered water; RM, river mile; STP, sewage treatment plant; and DID, drainage irrigation district; --, not analyzed]

| Site reference number | Site name | Station number[1] | Latitude | Longitude | Media | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Sediment | | | Water | |
| | | | | | S | SS | T | F | U |
| 23 | Yakima River above canal diversion at RM 128 at Roza Dam | 12484950 | 46°45′03″ | 120°27′52″ | -- | -- | -- | X | -- |
| 24 | Tieton River at mouth near Naches | 12493100 | 46°44′39″ | 120°47′06″ | -- | -- | -- | X | -- |
| 25 | Yakima River above Selah Creek at Pomona | 12485550 | 46°42′32″ | 120°28′25″ | -- | -- | -- | X | -- |
| 26 | Naches River near North Yakima | 12499000 | 46°37′42″ | 120°31′10″ | X | X | X | X | X |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | 12500437 | 46°34′56″ | 120°36′34″ | X | -- | X | X | -- |
| 28 | Tributary to Moxee Drain at Bell Road near Union Gap | 12500415 | 46°33′26″ | 120°26′32″ | -- | -- | -- | X | -- |
| 29 | Wide Hollow Creek at old STP at Union Gap | [4]12500442 | 46°32′35″ | 120°28′26″ | X | -- | X | X | -- |
| 30 | Moxee Drain at Thorp Road near Union Gap | 12500430 | 46°32′18″ | 120°27′19″ | X | -- | X | X | -- |
| 31 | Ahtanum Creek at Union Gap | 12502500 | 46°32′10″ | 120°28′20″ | X | -- | X | -- | -- |
| 32 | Yakima River above Ahtanum Creek at Union Gap | 12500450 | 46°32′04″ | 120°27′58″ | -- | X | -- | X | X |
| 33 | Yakima River at Parker | [5]12503950 | 46°30′22″ | 120°27′07″ | X | -- | X | X | -- |
| 34 | South Fork Ahtanum Creek above Conrad Ranch near Tampico | 12500900 | 46°29′32″ | 120°57′23″ | X | -- | X | -- | -- |
| 35 | Unnamed drain at Progressive Road near Harrah | 12507050 | 46°25′09″ | 120°35′45″ | -- | -- | -- | X | -- |
| 36 | Yakima River at RM 91 at Zillah | 12505320 | 46°24′07″ | 120°16′54″ | -- | -- | -- | X | -- |
| 37 | East Toppenish Drain at Wilson Road near Toppenish | 12505350 | 46°22′04″ | 120°15′00″ | -- | -- | -- | X | -- |
| 38 | Yakima River at Bridge Avenue at Granger | 12505440 | 46°20′16″ | 120°11′48″ | -- | -- | -- | X | -- |
| 39 | Sub 35 Drain at Parton Road near Granger | 12505410 | 46°20′11″ | 120°13′48″ | -- | -- | -- | X | -- |
| 40 | Granger Drain at mouth near Granger | 12505460 | 46°20′10″ | 120°11′38″ | X | -- | X | X | -- |
| 41 | Marion Drain at Indian Church Road at Granger | 12505510 | 46°19′52″ | 120°11′54″ | -- | -- | -- | X | -- |
| 42 | Yakima River below Toppenish Creek at RM 79.6 near Granger | 12507525 | 46°18′58″ | 120°09′13″ | X | -- | X | -- | -- |
| 43 | Toppenish Creek at Indian Church Road near Granger | 12507508 | 46°18′52″ | 120°11′53″ | X | -- | X | X | -- |
| 44 | Toppenish Creek near Fort Simcoe | 12506000 | 46°18′40″ | 120°47′13″ | -- | -- | -- | X | -- |

**Table 1.** Sampling-site locations and media sampled for major and trace elements, Yakima River Basin, Washington, 1987–91—Continued

[S, streambed sediment; SS, suspended sediment; T, aquatic-biota tissue; F, filtered water; U, unfiltered water; RM, river mile; STP, sewage treatment plant; and DID, drainage irrigation district; --, not analyzed]

| Site reference number | Site name | Station number[1] | Latitude | Longitude | Media | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Sediment | | | Water | |
| | | | | | S | SS | T | F | U |
| 45 | Yakima River at Van Geison Bridge near Richland | 12511800 | 46°17′50″ | 119°19′56″ | -- | -- | -- | X | -- |
| 46 | DID 3 Drain below STP at Midvale Road at Sunnyside | 12508838 | 46°17′28″ | 120°01′48″ | -- | -- | -- | X | -- |
| 47 | Satus Creek at Gage at Satus | 12508620 | 46°16′26″ | 120°08′32″ | X | -- | X | X | -- |
| 48 | Yakima River at RM 72 above Satus Creek near Sunnyside | 12507585 | 46°16′11″ | 120°05′30″ | X | -- | X | -- | -- |
| 49 | Yakima River above Chandler Pump at RM 35.9 near Whitstran | 12509900 | 46°15′58″ | 119°35′18″ | -- | -- | -- | X | -- |
| 50 | Yakima River at Kiona | 12510500 | 46°15′13″ | 119°28′37″ | X | X | X | X | X |
| 51 | Yakima River below Satus Creek at RM 68 near Satus | 12508625 | 46°15′06″ | 120°05′45″ | -- | -- | -- | X | -- |
| 52 | Sulphur Creek Wasteway near Sunnyside | 12508850 | 46°15′03″ | 120°01′07″ | X | X | X | X | X |
| 53 | Satus Creek below Dry Creek near Toppenish | 12508500 | 46°15′00″ | 120°22′40″ | X | -- | X | X | -- |
| 54 | Spring Creek at mouth at Whitstran | 12509710 | 46°14′00″ | 119°40′38″ | X | -- | X | -- | -- |
| 55 | Yakima River at Mabton | 12508990 | 46°13′53″ | 119°59′54″ | -- | -- | -- | X | -- |
| 56 | Yakima River at Euclid Bridge at RM 55 near Grandview | 12509050 | 46°13′01″ | 119°55′00″ | X | X | X | X | X |
| 57 | Satus Creek above Wilson-Charley Canyon near Toppenish | 12507594 | 46°01′00″ | 120°40′54″ | X | -- | X | -- | -- |

[1] This number can be used for computer retrieval of suspended-sediment, filtered-water, and unfiltered-water chemical data from either the U.S. Geological Survey's WATer data STOrage and REtrieval system (WATSTORE) or U.S. Environmental Protection Agency's STOrage and RETrieval system (STORET).

[2] For filtered-water data retrieval, use station number 12483200.

[3] For filtered-water data retrieval, use station number 12489300.

[4] For filtered-water data retrieval, use station number 12500445.

[5] For filtered-water data retrieval, use station number 12505000.

**Table 2.** Major and trace elements analyzed in aquatic biota, water, and sediment, Yakima River Basin, Washington, 1987–91

[--, not analyzed]

| Element analyzed | Aquatic biota | | | | Water | | Sediment | |
|---|---|---|---|---|---|---|---|---|
| | Insects | Fish | Clams | Plants | Filtered | Unfiltered | Streambed | Suspended |
| **Major Elements** | | | | | | | | |
| Aluminum | X | X | X | X | X | X | X | X |
| Calcium | -- | X | X | -- | -- | -- | X | X |
| Carbon, inorganic | -- | -- | -- | -- | -- | -- | X | -- |
| Carbon, organic | -- | -- | -- | -- | X | -- | -- | X |
| Carbon, total | -- | -- | -- | -- | -- | -- | X | -- |
| Iron | X | X | X | X | X | X | X | X |
| Magnesium | X | X | X | X | -- | -- | X | X |
| Phosphorus | -- | -- | -- | -- | -- | -- | X | X |
| Potassium | -- | -- | X | -- | -- | -- | X | X |
| Sodium | -- | -- | X | -- | -- | -- | X | X |
| Sulfur | -- | -- | -- | -- | -- | -- | X | -- |
| Titanium | X | X | X | -- | -- | -- | X | X |
| **Trace Elements** | | | | | | | | |
| Antimony | -- | -- | -- | -- | X | -- | X | X |
| Arsenic | X | X | X | X | X | -- | X | X |
| Barium | X | X | X | X | X | X | X | -- |
| Beryllium | X | X | X | X | X | X | X | X |
| Bismuth | -- | -- | -- | -- | -- | -- | X | -- |
| Boron | X | X | X | X | X | X | X | -- |
| Bromide | -- | -- | -- | -- | X | -- | -- | -- |
| Cadmium | X | X | X | X | X | X | X | X |
| Cerium | -- | -- | -- | -- | -- | -- | X | -- |
| Chromium | X | X | X | X | X | X | X | X |
| Cobalt | X | X | X | -- | X | -- | X | X |
| Copper | X | X | X | X | X | X | X | X |
| Cyanide | -- | -- | -- | -- | X | -- | -- | -- |
| Europium | -- | -- | -- | -- | -- | -- | X | -- |
| Gallium | -- | -- | -- | -- | -- | -- | X | -- |
| Gold | -- | -- | -- | -- | -- | -- | X | -- |
| Lanthanum | -- | -- | -- | -- | -- | -- | X | -- |
| Lead | X | X | X | X | X | X | X | X |
| Lithium | -- | -- | -- | -- | X | -- | X | -- |
| Manganese | X | X | X | X | X | X | X | X |
| Mercury | X | X | X | X | X | X | X | -- |
| Molybdenum | X | X | X | X | X | X | X | X |
| Neodymium | -- | -- | -- | -- | -- | -- | X | -- |
| Nickel | X | X | X | X | X | X | X | X |
| Niobium | -- | -- | -- | -- | -- | -- | X | -- |
| Scandium | -- | -- | -- | | -- | -- | X | -- |
| Selenium | X | X | X | X | X | -- | X | -- |
| Silver | X | X | X | X | X | X | X | X |
| Strontium | X | X | X | X | X | -- | X | -- |
| Thallium | X | X | X | X | -- | -- | -- | X |
| Thorium | -- | -- | -- | -- | -- | -- | X | -- |
| Tin | -- | -- | -- | -- | -- | -- | X | -- |
| Uranium | -- | -- | -- | -- | -- | -- | X | -- |
| Vanadium | X | X | X | X | X | -- | X | X |
| Ytterbium | -- | -- | -- | -- | -- | -- | X | -- |
| Yttrium | -- | -- | -- | -- | -- | -- | X | -- |
| Zinc | X | X | X | X | X | X | X | X |

**Table 3.** Types of samples analyzed for major and trace elements in the Yakima River Basin, Washington, 1987–91

[**OT**, sample was collected at the site at least one time; **M**, sample was collected at a fixed site once a month from March 1987 to April 1990; **RT**, rainbow trout (*Oncorhynchus mykiss*); **MW**, mountain whitefish (*Prosopium williamsoni*); **BT**, brook trout (*Salvelinus fontinalis*); **BS**, bridgelip sucker (*Catostomus columbianus*); **LS**, largescale sucker (*Catostomus macrocheilus*); **CM**, chiselmouth (*Acrocheilus alutaceus*); **CT**, cutthroat trout (*Oncorhynchus clarki*); **CP**, carp (*Cyprinus carpio*); **SN**, sculpin (*Cottus* spp.); **CF**, caddisflies (Trichoptera: Hydropsychidae); **SF**, stoneflies (Plecoptera: Perlidae; Perlodidae; Pteronarcidae); **MF**, mayflies (Ephemeroptera); **WP**, western pearlshell clam (Unionoida: Unionidae *Margaritifera falcata*); **AC**, Asiatic clam (Veneroida: Corbiculidae *Corbicula fluminea*); **AG**, algae (unidentified); **CL**, curlyleaf pondweed (*Potamogeton crispus*); **WW**, waterweed (*Elodea* sp.); **CO**, coontail (*Ceratophyllum demersum*); **Q**, sample was collected at the site approximately four times in a year and (or) during storm events; "--", not analyzed; **N.F.**, North Fork; **R**, River; **RM**, river mile; **MS**, Middle School; **STP**, sewage treatment plant; **DID**, drainage irrigation district]

| | | | | Aquatic-biota tissue[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sediment | | Fish | | | Insects | Clams | Plants | Water | |
| Site reference number | Site name | Streambed | Sus-pended | Liver | Whole fish | Muscle | Whole organism | Soft tissue | Stems and leaves | Filtered[2] | Unfiltered |
| 1 | Waptus River at mouth near Roslyn | OT | -- | RT | -- | -- | CF | -- | -- | -- | -- |
| 2 | Cle Elum River above Cle Elum Lake near Roslyn | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 3 | Jungle Creek near mouth near Cle Elum | OT | -- | RT | -- | -- | MF | -- | AG | OT | -- |
| 4 | N.F. Teanaway R below bridge at Dickey Creek Campground | -- | -- | -- | -- | -- | CF,SF | -- | -- | -- | -- |
| 5 | Teanaway River below Forks near Cle Elum | OT | -- | RT | -- | -- | -- | -- | -- | OT | -- |
| 6 | Yakima River at Cle Elum | OT | M | MW | SN | -- | CF,SF | -- | -- | M | Q |
| 7 | Naneum Creek below High Creek near Ellensburg | OT | -- | BT | SN | -- | CF,SF | -- | -- | -- | -- |
| 8 | Taneum Creek at Taneum Meadow near Thorp | OT | -- | RT | SN | RT | CF,SF | -- | -- | -- | -- |
| 9 | Yakima River at Thorp Highway bridge at Ellensburg | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 10 | Little Naches River at mouth near Cliffdell | OT | -- | -- | -- | -- | CF,SF | -- | -- | OT | -- |
| 11 | American River near Nile | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 12 | South Fork Manastash Creek near Ellensburg | OT | -- | RT | SN | -- | CF,SF | -- | -- | OT | -- |
| 13 | American River at Hell's Crossing near Nile | OT | -- | -- | RT,SN | -- | CF,SF | -- | -- | -- | -- |

**Table 3.** Types of samples analyzed for major and trace elements in the Yakima River Basin, Washington, 1987–91—Continued

| Site reference number | Site name | Sediment | | Aquatic-biota tissue[1] | | | | | | Water | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Fish | | | Insects | Clams | Plants | | |
| | | Streambed | Sus-pended | Liver | Whole fish | Muscle | Whole organism | Soft tissue | Stems and leaves | Filtered[2] | Unfiltered |
| 14 | Cherry Creek above Wipple Wasteway at Thrall | OT | -- | MW | -- | -- | CF | -- | -- | -- | -- |
| 15 | Wilson Creek above Cherry Creek at Thrall | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 16 | Cherry Creek at Thrall | -- | -- | BS | -- | -- | CF | -- | CL | OT | -- |
| 17 | Bumping River at Soda Springs Walkway near Nile | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 18 | Naches River at Cottonwood Campground near Cliffdell | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 19 | Yakima River at Umtanum | OT | M | MW,RT | -- | RT | CF,SF | WP | CL | M | Q |
| 20 | Umtanum Creek near mouth at Umtanum | OT | -- | RT | SN | -- | CF,SF | -- | -- | OT | -- |
| 21 | Rattlesnake Creek above Little Rattlesnake Creek near Nile | OT | -- | -- | -- | -- | CF,SF | -- | -- | OT | -- |
| 22 | Rattlesnake Creek above N.F. Rattlesnake Creek near Nile | OT | -- | RT | SN | RT | CF,SF | -- | -- | -- | -- |
| 23 | Yakima River above canal diversion at RM 128 at Roza Dam | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 24 | Tieton River at mouth near Naches | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 25 | Yakima River above Selah Creek at Pomona | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 26 | Naches River near North Yakima | OT | M | LS,MW | -- | -- | CF,SF | -- | -- | M | Q |
| 27 | Wide Hollow Creek at West Valley MS near Ahtanum | OT | -- | BS | -- | -- | CF | -- | -- | OT | -- |
| 28 | Tributary to Moxee Drain at Bell Road near Union Gap | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |

**Table 3.** Types of samples analyzed for major and trace elements in the Yakima River Basin, Washington, 1987–91—Continued

| | | | | Aquatic-biota tissue[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sediment | | Fish | | | Insects | Clams | Plants | Water | |
| Site reference number | Site name | Streambed | Sus-pended | Liver | Whole fish | Muscle | Whole organism | Soft tissue | Stems and leaves | Filtered[2] | Unfiltered |
| 29 | Wide Hollow Creek at old STP at Union Gap | OT | -- | CM,RT | -- | -- | CF | -- | CL,WW | OT | -- |
| 30 | Moxee Drain at Thorp Road near Union Gap | OT | -- | CM | -- | -- | -- | -- | -- | OT | -- |
| 31 | Ahtanum Creek at Union Gap | OT | -- | -- | SN | -- | CF | -- | -- | -- | -- |
| 32 | Yakima River above Ahtanum Creek at Union Gap | -- | M | -- | -- | -- | -- | -- | -- | M | Q |
| 33 | Yakima River at Parker | OT | -- | LS,CP, MW | -- | -- | CF | -- | CL | OT | -- |
| 34 | South Fork Ahtanum Creek above Conrad Ranch near Tampico | OT | -- | CT | SN | -- | CF,SF | -- | -- | -- | -- |
| 35 | Unnamed drain at Progressive Road near Harrah | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 36 | Yakima River at RM 91 at Zillah | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 37 | East Toppenish Drain at Wilson Road near Toppenish | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 38 | Yakima River at Bridge Avenue at Granger | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 39 | Sub 35 Drain at Parton Road near Granger | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 40 | Granger Drain at mouth near Granger | OT | -- | BS | -- | -- | CF | -- | -- | OT | -- |
| 41 | Marion Drain at Indian Church Road at Granger | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 42 | Yakima R below Toppenish Creek at RM 79.6 near Granger | OT | -- | LS,MW | -- | -- | CF | AC | -- | -- | -- |
| 43 | Toppenish Creek at Indian Church Road near Granger | OT | -- | LS | -- | -- | CF | -- | WW | OT | -- |

**Table 3.** Types of samples analyzed for major and trace elements in the Yakima River Basin, Washington, 1987–91—Continued

| Site reference number | Site name | Sediment | | Aquatic-biota tissue[1] | | | | | | Water | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Fish | | | Insects | Clams | Plants | | |
| | | Streambed | Sus-pended | Liver | Whole fish | Muscle | Whole organism | Soft tissue | Stems and leaves | Filtered[2] | Unfiltered |
| 44 | Toppenish Creek near Fort Simcoe | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 45 | Yakima River at Van Geison Bridge near Richland | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 46 | DID 3 Drain below STP at Midvale Road at Sunnyside | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 47 | Satus Creek at Gage at Satus | OT | -- | LS | SN | -- | CF | -- | WW,CL | OT | -- |
| 48 | Yakima River at RM 72 above Satus Creek near Sunnyside | OT | -- | LS,CP | -- | -- | -- | AC | CL | -- | -- |
| 49 | Yakima R above Chandler Pump at RM 35.9 near Whitstran | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 50 | Yakima River at Kiona | OT | M | MW,LS,CP | -- | LS,MW | CF | AC | CL,CO | M | Q |
| 51 | Yakima River below Satus Creek at RM 68 near Satus | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 52 | Sulphur Creek Wasteway near Sunnyside | OT | M | LS | -- | -- | CF | -- | -- | M | Q |
| 53 | Satus Creek below Dry Creek near Toppenish | OT | -- | -- | SN | -- | CF,SF | -- | -- | OT | -- |
| 54 | Spring Creek at mouth at Whitstran | OT | -- | LS | -- | -- | CF | AC | WW | -- | -- |
| 55 | Yakima River at Mabton | -- | -- | -- | -- | -- | -- | -- | -- | OT | -- |
| 56 | Yakima River at Euclid Bridge at RM 55 near Grandview | OT | M | LS | -- | -- | CF | AC | CL | M | Q |
| 57 | Satus Creek above Wilson-Charley Canyon near Toppenish | OT | -- | RT | SN | -- | CF,SF | -- | -- | -- | -- |

[1] Tissue samples were collected during one or more of the following time periods: May and October-November of 1989, October-November of 1990, and October of 1991.

[2] Elements analyzed varied with frequency of sampling. For example, only cadmium, copper, mercury, and lead were analyzed monthly. All other elements were analyzed once or twice in a given year.

Of the seven fixed sites, the Yakima River above Ahtanum Creek at Union Gap (site 32) and the Yakima River at Kiona (site 50) were sampled most frequently. Additionally, unfiltered samples had been collected previously at these sites as part of the USGS NASQAN program. Trace-element concentrations in unfiltered water were used to determine the suitability of surface water for supporting aquatic life, based on USEPA guidelines for freshwater aquatic life (U.S. Environmental Protection Agency, 1986, 1992c). These guidelines are based on a total recoverable method (trace elements removed by a mild-acid extraction of an unfiltered-water sample) in which complete digestion of all particulate matter is not achieved and the determination actually represents something less than 95 percent of the trace-element concentration being sought. This extraction method is similar to that used on unfiltered-water samples analyzed by the USGS National Water Quality Laboratory (Fuhrer, Fluter, and others, 1994). The analytical method for determining trace-element concentrations in suspended sediment is termed a total method (elements removed by a harsh-acid extraction of a suspended sediment sample) in which complete digestion is nearly achieved and the determination actually represents something greater than 95 percent of the trace-element concentration being sought (Fuhrer, Fluter, and others, 1994). Trace-element concentrations determined using the total-recoverable method for unfiltered-water samples will be compared to trace-element concentrations from the total method for suspended-sediment and filtered-water samples. If the sum of the trace-element concentrations from the suspended-sediment sample and the filtered-water sample were similar to the trace-element concentrations in unfiltered water, then the sum of the trace-element concentrations in filtered water and suspended sediment, for the period March 1987 to April 1990, were evaluated against USEPA guidelines for freshwater aquatic life.

Sampling frequency for the aquatic biota medium varied among sampling sites (table 4). A preliminary sampling for trace elements in the tissue of aquatic biota was made in May 1989 (sites 3, 19, 20, and 27) to test and refine collection and processing methods for aquatic biota. Aquatic biota were sampled at 34 sites from 1989 to 1990—seven sites were located on the main stem. The aquatic biota medium included analyses of plant tissues, such as algae (unidentified specimens), curlyleaf pondweed (*Potamogeton crispus*), waterweed (*Elodea* sp.), and coontail (*Ceratophyllum demersum*); fish tissues, such as rainbow trout (*Oncorhynchus mykiss*), mountain whitefish (*Prosopium williamsoni*), sculpin (*Cottus* spp.), brook trout (*Salvelinus fontinalis*), bridgelip sucker (*Catostomus columbianus*), largescale sucker (*Catostomus macrocheilus*), chiselmouth (*Acrocheilus alutaceus*), carp (*Cyprinus carpio*), and cutthroat trout (*Oncorhynchus clarki*), Asiatic clam (Veneroida: Corbiculidae *Corbicula fluminea*), western pearlshell (*margaritifera falcata*); and aquatic insects, such as caddisflies (*Arctopsyche* spp.) (*Cheumatopsyche* spp.) (*Parapsyche* spp.) (*Hydropsyche amblis*) (*Hydropsyche californica*) (*Hydropsyche cockerelli*) (*Hydropsyche occidentalis*), stoneflies (*Calineuria* spp.) (*Claassennia* spp.) (*Doroneuria* spp.) (*Hesperoperla* spp.) (*Isoperla* spp.) (*Megarcys* spp.) (*Perlinodes* spp.) (*Skwala* spp.) (*Pteronarcys* spp.), and mayflies (unidentified) (see table 3).

Streamflow was usually measured during each site visit for sites not equipped with continuous stage recorders. All fixed sites were equipped with stage recorders—stage was recorded every 30 minutes. Streamflow rating tables were developed and updated for fixed sites according to methods described by Buchanan and Somers (1969). At sites not equipped with stage recorders, either suspension- or wading-streamflow measurements were made according to methods described by Buchanan and Somers (1969).

Loads were determined for selected trace elements using the ESTIMATOR load computation model version 92.07 (Cohn and others, 1992). The ESTIMATOR model uses the minimum variance unbiased estimator for estimating constituent transport. Daily mean streamflow and trace-element concentrations for the period 1987–89 were used to calculate monthly and annual loads at the fixed sites in the Yakima River Basin. Equations used by ESTIMATOR for calculating specific constituent loads are found in the appendix.

### Water and Suspended Sediment

Water and suspended sediment were sampled using an equal-width-increment method, which requires a sample volume proportional to the amount of flow at each of several equally spaced verticals in the stream cross section (Edwards and Glysson, 1988). A minimum of 10 verticals was sampled in the stream

**Table 4.** Sampling frequency for major and trace elements in aquatic biota, Yakima River Basin, Washington, 1989–91
[X, aquatic biota sampled in the month and year indicated]

| Site reference number | Site name | May 1989 | November 1989 | November 1990 | October 1991 |
|---|---|---|---|---|---|
| 1 | Waptus River at mouth near Roslyn |  | X |  |  |
| 3 | Jungle Creek near mouth near Cle Elum | X |  |  |  |
| 4 | North Fork Teanaway River below bridge at Dickey Creek Campground |  |  | X |  |
| 5 | Teanaway River below Forks near Cle Elum |  | X |  |  |
| 6 | Yakima River at Cle Elum |  | X | X |  |
| 7 | Naneum Creek below High Creek near Ellensburg |  |  | X |  |
| 8 | Taneum Creek at Taneum Meadow near Thorp |  |  | X | X |
| 10 | Little Naches River at mouth near Cliffdell |  |  | X |  |
| 12 | South Fork Manastash Creek near Ellensburg |  |  | X |  |
| 13 | American River at Hell's Crossing near Nile |  | X | X |  |
| 14 | Cherry Creek above Wipple Wasteway at Thrall |  |  | X |  |
| 16 | Cherry Creek at Thrall |  | X | X |  |
| 19 | Yakima River at Umtanum | X | X | X | X |
| 20 | Umtanum Creek near mouth at Umtanum | X | X | X |  |
| 21 | Rattlesnake Creek above Little Rattlesnake Creek near Nile |  |  | X |  |
| 22 | Rattlesnake Creek above North Fork Rattlesnake Creek near Nile |  | X | X | X |
| 26 | Naches River near North Yakima |  |  | X |  |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | X |  | X |  |
| 29 | Wide Hollow Creek at old Sewage Treatment Plant at Union Gap |  | X | X |  |
| 30 | Moxee Drain at Thorp Road near Union Gap |  |  | X |  |
| 31 | Ahtanum Creek at Union Gap |  |  | X |  |
| 33 | Yakima River at Parker |  | X | X |  |
| 34 | South Fork Ahtanum Creek above Conrad Ranch near Tampico |  |  | X |  |
| 40 | Granger Drain at mouth near Granger |  | X | X |  |
| 42 | Yakima River below Toppenish Creek at river mile 79.6 near Granger |  |  | X |  |
| 43 | Toppenish Creek at Indian Church Road near Granger |  | X |  |  |
| 47 | Satus Creek at Gage at Satus |  | X | X |  |
| 48 | Yakima River at river mile 72 above Satus Creek near Sunnyside |  | X |  |  |
| 50 | Yakima River at Kiona |  | X | X | X |
| 52 | Sulphur Creek Wasteway near Sunnyside |  | X | X |  |
| 53 | Satus Creek below Dry Creek near Toppenish |  |  | X |  |
| 54 | Spring Creek at mouth at Whitstran |  | X | X |  |
| 56 | Yakima River at Euclid Bridge at river mile 55 near Grandview |  | X | X |  |
| 57 | Satus Creek above Wilson-Charley Canyon near Toppenish |  | X | X |  |

cross section. Additional verticals were sampled at sites where water in the cross section may not have been equally mixed because of nearby tributary inflow. Samples were collected using USGS depth-integrating samplers fitted with polyethylene, 3-liter bottles. The D-77 (depth-integrating sampler) is an epoxy-coated brass sampler that is operated by a cable and reel assembly; this sampler was used most of the time for sampling. The DH-81 (depth-integrating, hand-held sampler) was an optional sampler used when streamflow conditions permitted crossing the stream by wading.

Equipment used for trace-element sampling was washed in liquinox and rinsed in distilled deionized water. Sample containers and equipment, with the exception of depth-integrating samplers, were rinsed again in 10 percent (by volume) hydrochloric acid. The depth-integrating sampler was not rinsed because the water sample did not come into contact with the sampler body. The acid rinse was followed by several rinses with distilled deionized water. All equipment was thoroughly rinsed in native stream water prior to sample collection.

Analytical methods have become more sensitive to contamination because of decreases in the analytical limit of determination. Field-processing methods and sampling equipment were evaluated by the USGS Office of Water Quality to determine if they were a source of contamination to water samples analyzed at concentrations of parts per billion (micrograms per liter). Personnel from the Yakima NAWQA study participated in two field-processing and equipment blanks for cadmium, copper, lead, and zinc in filtered-water samples (Fuhrer, Fluter, and others, 1994). Cadmium, copper, lead, and zinc were among a listing of trace elements derived by the Office of Water Quality that pose a risk of contaminating water samples that are processed using certain water-quality samplers and processing techniques (D.A. Rickert, U.S. Geological Survey, written commun., 1991). Blanks (assayed distilled-deionized water) run on the type of sampler and processing equipment used to collect water samples at fixed sites contained concentrations of cadmium, copper, lead, and nickel that were lower than the analytical limit of determination for the Yakima study, and were similar to background concentrations found in the blank water prior to the test (Fuhrer, Fluter, and others, 1994). A second study was made by the Office of Water Quality (D.A. Rickert, U.S. Geological Survey, written commun., 1992) to determine the potential for trace-element contamination from a variety of surface-water-quality samplers including the D-77 (depth-integrating) sampler. The Office of Water Quality concluded that the D-77 sampler with a polyethylene sample bottle is suitable for trace-element sampling at the parts per billion level. Furthermore, specific cleaning techniques were recommended for sampling and processing equipment which include a detergent wash, water rinse, acid soak/rinse, and several distilled water rinses (D.A. Rickert, U.S. Geological Survey, written commun., 1992). Cleaning techniques similar to these were used on sampling equipment used at fixed-location sampling sites (Fuhrer, Fluter, and others, 1994).

Filtered and unfiltered-water samples were preserved according to methods described in Fishman and Friedman (1989) and shipped on ice from the field to the USGS National Water Quality Laboratory in Arvada, Colorado. The samples were analyzed for major and trace elements according to methods described by Fishman and Friedman. For fixed sites, a small suite of trace elements (cadmium, copper, and lead) was determined with an atomic absorption spectrometer in conjunction with a graphite furnace containing a graphite platform (AAGF). This method of analysis can detect low concentrations of trace elements that may adversely affect aquatic organisms. A larger suite of dissolved trace elements, which included aluminum, antimony, barium, beryllium, nickel, selenium, silver, and zinc, was determined simultaneously on a single sample by a direct-reading emission spectrometric method by using an induction-coupled argon plasma as an excitation source (ICP). This ICP method of analysis was used periodically for fixed sites during the first year of operation. Also, ICP was used during synoptic surveys in July and November 1987; however, this method was not ideally suited to evaluate element concentrations in filtered water against guidelines for the protection of freshwater aquatic life. Ambient concentrations for some elements (for example, cadmium, copper, lead, and zinc) with potential to adversely affect aquatic biota, were below the analytical limit of determination for the ICP. Method reporting levels, analytical method codes, and listings of trace-element suites are published in Fuhrer, Fluter, and others (1994).

## Streambed Sediment

Streambed sediment was collected from five to seven points in each cross section of the stream channel; sampling was confined to surficial sediment that is usually in the upper one-half inch of the streambed. All streambed-sediment samples were wet sieved through a 62-μm (micrometer) mesh polyethylene sieve, using a minimum amount of stream-site water.

Samples were analyzed for 48 constituents; see Ryder and others (1992) for analytic methods, limits of determination, and decomposition methods. The majority of elements were determined by inductively coupled plasma-atomic emission spectrometry (ICP-AES). Decompositions of the sediment samples for elements measured by atomic absorption spectroscopy (AAS) and ICP-AES are total digestions—more than 95 percent of the element is recovered during analysis. Total carbon was determined by combustion techniques. The decomposition used for boron and inorganic carbon are partial techniques. Quality assurance was addressed by including standard reference materials, random sample splits, and analytical sample splits (Sanzolone and Ryder, 1989; Fuhrer, McKenzie, and others, 1994, appendix A). Protocols used for sample handling procedures, sample preparation, analytical methods, instrument use, and laboratory procedures and quality control are described in Arbogast (1990).

## Aquatic Biota

Aquatic biota were collected over the period 1989–91. The 1990 data, however, are more comprehensive in the number of sites sampled and in using analytical methods with low or sensitive limits of determination. As a result, the 1990 data are used primarily to describe the spatial distribution of trace elements; data from other years also are used to complement the 1990 data.

For sites where duplicate and triplicate measurements of a single species of aquatic biota were made, the mean trace-element concentration value was used; these values also were used for constructing a statistical-summary table. In contrast, multiple species of *Hydropsyche* were combined and reported under the single name of caddisfly (*Hydropsyche* spp.). The caddisfly (*Hydropsyche* spp.) and Asiatic clam (*Corbicula fluminea*) tissue concentrations were normalized by calculating the logarithm of the trace-element concentrations, taking the mean of these values, and then calculating the antilogarithm of the aggregated data. Thus, in the statistical-summary table, each site is represented by a single trace-element concentration for each species analyzed. Because of the small number of stations summarized, only minimum, median, and maximum values were reported in the statistical-summary table for aquatic biota. The modified 1990 data were used to create maps of trace-element distribution using a geographical information system (GIS).

Several species of aquatic biota were collected in order to spatially depict the distribution of trace elements in the Yakima River Basin. In 1990, for example, the aquatic insect caddisfly (*Hydropsyche* spp.) provided the greatest coverage of a single taxon for spatially depicting trace-element concentrations. Arsenic, mercury, and selenium, however, were not analyzed in *Hydropsyche*. For these trace elements, analyses of fish liver provided the greatest spatial coverage where several different fish species were sampled because no single species was present at all sites. Conversely, Asiatic clams (*Corbicula fluminea*) were sampled only at five sites in the lower Yakima River Basin.

Chemical data for aquatic biota in the Yakima River Basin were compared to data from other basins for *Corbicula* sp. and caddisfly (*Hydropsyche* spp.). Several caveats exist when making comparisons between basins. Only general comparisons were possible because differences may exist in species collected, size and (or) age of individuals in the sample, the tissues analyzed (muscle, gills, whole body, and so forth), analytical methods, and the way data were reported. Data for fish liver and whole fish were considered separately, because liver tissue is a principal site for accumulation of many trace elements, and concentrations of trace elements in liver tissue are typically higher than in whole fish (Kaiser and others, 1979; Finley, 1985; Ogle and others, 1988). To make comparisons with other studies, data originally reported as wet-weight concentrations were converted to dry-weight concentrations; unless otherwise stated, wet-weight data were converted using an assumed percent-moisture value of 75 percent.

In 1989 and 1990–91, a U.S. Fish and Wildlife Service (USFWS) contract laboratory and USGS laboratories prepared and analyzed samples from the Yakima River Basin (Fuhrer, Fluter, and others, 1994). The trace elements analyzed among years are shown in table 5. In 1989 and 1990, benthic insect samples were not sorted, prior to chemical analysis, to the same

**Table 5.** Elements analyzed in whole fish, fish liver, fish muscle, clams, and aquatic insects, Yakima River Basin, Washington, 1989–91

| Sample | Number of sites | Year(s) collected | Elements analyzed |
|---|---|---|---|
| Whole fish (sculpin [*Cottus* spp.] only) | 13 | 1990 | Arsenic, mercury, and selenium. |
| Fish liver (multiple species) | 29 | 1989–90 | See footnotes [1] and [2]. |
| Fish muscle (multiple species) | 4 | 1991 | Mercury |
| Clams (*Corbicula fluminea* and *Margaritifera falcata*) | 6 | 1989–90 | See footnotes [1] and [2]. |
| Aquatic insects (multiple species) | 31 | 1989–90 | See footnotes [1] and [2].<br>Arsenic, mercury, and selenium not determined in 1990. |

[1] 1989: silver, aluminium, arsenic, boron, barium, beryllium, cadmium, chromium, copper, iron, mercury, magnesium, manganese, molybdenum, nickel, lead, selenium, strontium, titanium, vanadium, and zinc.

[2] 1990: silver, arsenic, calcium, cadmium, cobalt, chromium, copper, iron, mercury, magnesium, manganese, molybdenum, nickel, lead, selenium, titanium, vanadium, and zinc.

taxonomic level. In other studies, differences in the taxonomic composition of samples have been shown to affect comparisons of element concentrations between years (Cain and others, 1992) and may be a factor in the Yakima River Basin. Also, differences in analytical methods of laboratories resulted in different analytical limits of determination. Differences in sample preparation or analysis between years are explained in greater detail in subsequent sections, as relevant to results of this study. Approach and methods, analytical methods, limits of determination, and quality-assurance data have been described by Fuhrer, Fluter, and others (1994) as well as trace-element data for the different media covered in this report.

Elemental analyses of tissue from aquatic biota are a widely accepted approach to assess temporal (year to year) and spatial variations in environmental contaminants (Phillips, 1980); this approach has been incorporated into the NAWQA program (Crawford and Luoma, 1993). Additionally, multiple species were sampled to provide the spatial coverage necessary for the Yakima River Basin. In this manner, complementary data from other species may aid in describing spatial variations in environmental contaminants (Moore and others, 1991; Cain and others, 1992). Data from streambed sediment, suspended sediment, and water media also were examined to help identify natural and anthropogenic sources contributing to the spatial distribution of trace elements in aquatic biota. Ancillary data were collected for some species as correlative measures of bioaccumulation. Age, size, sex, and the presence of abnormalities, for example, were recorded as ancillary data for fish. These data, however, were of limited use. Because a limited number of species of fish existed at many sites, acquiring 10 individual livers for each composite sample sometimes required collection of a wide range of ages and sizes of fish.

Polar substances, such as cadmium, copper, lead, and zinc, concentrate in the livers of fish but are regulated to small concentrations in muscle (Crawford and Luoma, 1993). For this reason, fish liver was selected as the target organ for the Yakima River Basin assessment of trace elements. Obtaining liver samples from a single species that was pervasive over the basin was problematic. Only sculpin were found in numbers suitable for a basinwide survey; however, sculpin were not collected from the main stem. Sculpin were analyzed for arsenic, mercury, and selenium. Whole bodies were analyzed instead of the liver because sculpin are small. Therefore, comparing absolute concentrations of trace elements between fish liver (from other species) and whole sculpin should be made with caution. In 1991, fish muscle was analyzed for mercury (sites 8, 19, 22, and 50 [table 5]) to determine the risk to human health from consumption of local game fish.

## COMPARISON OF TRACE-ELEMENT CONCENTRATIONS IN STREAMBED SEDIMENT, WATER, AND FISH MUSCLE TO WATER-QUALITY GUIDELINES

Bioavailability and toxicity vary with the form of a trace element (Jenne and Luoma, 1977). Aquatic organisms that feed on detritus are exposed to trace elements in solution and from the ingestion of sediment (Luoma, 1989). Trace elements associated with sediment generally are believed to be less bioavailable than trace elements dissolved in water (U.S. Environmental Protection Agency, 1992a). The toxicity to aquatic organisms from trace elements associated with sediment, however, is not necessarily zero. The concentration of total metals in sediment often are orders of magnitude higher than in water; small geochemical changes in the chemistry of sediment can affect solution chemistry greatly, and thus enhance bioavailability (Luoma, 1989). For example, trace elements associated with suspended sediment may dissolve in the chemical environment of the gill or the gut of an aquatic organism (U.S. Environmental Protection Agency, 1992a; Luoma, 1983).

### Streambed Sediment

As of 1993, the Washington State Department of Ecology and USEPA Region X did not have sediment-quality guidelines. However, the Water Resources Branch of the Ontario Ministry of the Environment, Canada, developed Provincial Sediment Quality Guidelines (Persaud and others, 1993). These guidelines are compared with trace-element concentrations in streambed sediment of the Yakima River Basin.

The Provincial Sediment Quality Guidelines for trace elements are based on two levels of toxic effects. The first level, termed the lowest effect level, represents trace-element concentrations that can be tolerated by a majority of benthic organisms and that are comparable to the low effect levels determined through a review of sediment-toxicity bioassays by the National Oceanic and Atmospheric Administration (Persaud and others, 1993). The second level, termed the severe effect level, represents trace-element concentrations at which "pronounced disturbances of the sediment-dwelling community can be expected" and has been deemed a concentration that would be detrimental to the majority of benthic species (Persaud and others, 1993).

The lowest effect level and the severe effect level were derived from a survey of trace-element concentrations in bulk sediment in addition to a survey of in-situ benthic abundance. Because concentrations of trace elements in the Yakima River Basin were determined from sediment finer than 62 μm in diameter (rather than bulk sediment) and because the 62-μm size fraction tends to have higher element concentrations than bulk sediment, element concentrations in the Yakima River Basin may in some instances exceed the Provincial Sediment Quality Guidelines, solely due to differences in the quantity of fine-grain-sized sediment. Consequently, instances where trace-element concentrations in the Yakima River Basin that exceed Provincial Sediment Quality Guidelines should be used only as an indication of potential sediment-quality concerns. The Provincial Sediment Quality Guidelines are derived from a large number of data sets—each data set represents a minimum of 10 sites where at least 10 species of interest reside. In addition, the sum total of the data sets is assumed to represent a complete range of trace-element concentrations for benthic species of interest. The 90th-percentile concentration is determined for the trace-element concentrations in each data set. These concentrations were then pooled and plotted as a frequency distribution. The concentration corresponding to the 5th percentile of the frequency distribution was termed the "lowest effect level" and, similarly, the concentration corresponding to the 95th percentile of the frequency distribution was termed the "severe effect level." Application of the Provincial Sediment Quality guidelines was limited, however, because the guidelines were not based on a toxicological response and do not directly infer a cause and effect relation between the trace-element content of streambed sediment and the uptake of trace elements by aquatic organisms.

Streambed sediment was compared with the Provincial Sediment Quality Guidelines at 32 locations in the Yakima River Basin (table 6). Trace-element concentrations at a number of sites exceeded the severe effect level. Trace elements that exceeded the severe-effect level with the greatest frequency were: iron > manganese > chromium > nickel > arsenic. Concentrations of cadmium, copper, lead, mercury, and zinc did not exceed the severe effect level at any of the sites. Numerous sites had trace-element concentrations that exceeded the lowest effect level but did not exceed the severe effect level.

### Water

Trace-element concentrations in filtered- and unfiltered-water samples collected from the Yakima River Basin, 1987–90, are screened against

(1) USEPA ambient water-quality criteria for the protection of aquatic life and human health (U.S. Environmental Protection Agency, 1986 and 1992c),

**Table 6.** Summary of major- and trace-element concentrations in streambed sediment that exceeded Provincial Sediment-Quality Guidelines, Yakima River Basin, Washington, 1987–90

[The Provincial Sediment-Quality Guidelines were developed by the Water Resources Branch of the Ontario Ministry of the Environment, Canada, for use in evaluating sediments throughout the province of Ontario (Persaud and others, 1993); the guidelines define two levels of toxic effects which are based on protecting benthic organisms from the chronic, long-term effects of selected elements; these levels are: (1) lowest effect level and (2) severe effect level; a lowest effect level is a level of contamination that can be tolerated by a majority of benthic organisms, and a severe effect level is a level of contamination that would be detrimental to a majority of benthic species; note, some sites have been sampled in duplicate or triplicate as part of the quality-assurance program that has been described along with results by Fuhrer and others (1994); for replicate sites, only the mean element concentration is reported here; percentages were calculated using all measurements (censored and detected) for all sites sampled; concentrations are provided in units of micrograms per gram (μg/g) except for iron, which is reported in units of percent; RM, river mile]

| Site reference number | Site name | Streambed-sediment concentration | Samples exceeding guidelines | |
|---|---|---|---|---|
| | | | Lowest effect level | Severe effect level |
| **Arsenic, guideline: lowest effect level: 6 μg/g; severe effect level: 33 μg/g** | | | | |
| 1 | Waptus River at mouth near Roslyn | 45 | X | X |
| 3 | Jungle Creek near mouth near Cle Elum | 29 | X | |
| 6 | Yakima River at Cle Elum | 7.9 | X | |
| 13 | American River at Hell's Crossing near Nile | 13 | X | |
| 21 | Rattlesnake Creek above Little Rattlesnake Creek near Nile | 7.8 | X | |
| 22 | Rattlesnake Creek above North Fork Rattlesnake Creek near Nile | 9.5 | X | |
| 56 | Yakima River at Euclid Bridge at RM 55 near Grandview | 6.6 | X | |
| Percentage of samples that exceeded guidelines | | | 22 | 3 |
| **Cadmium, guideline: lowest effect level: 0.6 mg/g; severe effect level: 10 μg/g** | | | | |
| 13 | American River at Hell's Crossing near Nile | .8 | X | |
| Percentage of samples that exceeded guidelines | | | 3 | 0 |
| **Chromium, guideline: lowest effect level: 26 μg/g; severe effect level: 110 μg/g** | | | | |
| 1 | Waptus River at mouth near Roslyn | 61 | X | |
| 3 | Jungle Creek near mouth near Cle Elum | 93 | X | |
| 5 | Teanaway River below Forks near Cle Elum | 210 | X | X |
| 6 | Yakima River at Cle Elum | 210 | X | X |
| 7 | Naneum Creek below High Creek near Ellensburg | 58 | X | |
| 8 | Taneum Creek at Taneum Meadow near Thorp | 170 | X | X |
| 10 | Little Naches River at mouth near Cliffdell | 50 | X | |
| 12 | South Fork Manastash Creek near Ellensburg | 130 | X | X |
| 14 | Cherry Creek above Wipple Wasteway at Thrall | 52 | X | |
| 19 | Yakima River at Umtanum | 64 | X | |
| 20 | Umtanum Creek near mouth at Umtanum | 50 | X | |
| 21 | Rattlesnake Creek above Little Rattlesnake Creek near Nile | 49 | X | |
| 22 | Rattlesnake Creek above North Fork Rattlesnake Creek near Nile | 62 | X | |
| 26 | Naches River near North Yakima | 90 | X | |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | 42 | X | |
| 29 | Wide Hollow Creek at old STP at Union Gap | 67 | X | |

**Table 6.** Summary of major- and trace-element concentrations in streambed sediment that exceeded Provincial Sediment-Quality Guidelines, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Streambed-sediment concentration | Samples exceeding guidelines: Lowest effect level | Samples exceeding guidelines: Severe effect level |
|---|---|---|---|---|
| **Chromium, guideline: lowest effect level: 26 µg/g; severe effect level: 110 µg/g—Continued** | | | | |
| 30 | Moxee Drain at Thorp Road near Union Gap | 64 | X | |
| 31 | Ahtanum Creek at Union Gap | 56 | X | |
| 33 | Yakima River at Parker | 64 | X | |
| 34 | South Fork Ahtanum Creek above Conrad Ranch near Tampico | 33 | X | |
| 40 | Granger Drain at mouth near Granger | 60 | X | |
| 42 | Yakima River below Toppenish Creek at RM 79.6 near Granger | 73 | X | |
| 43 | Toppenish Creek at Indian Church Road near Granger | 75 | X | |
| 47 | Satus Creek at gage at Satus | 54 | X | |
| 48 | Yakima River at RM 72 above Satus Creek near Sunnyside | 64 | X | |
| 50 | Yakima River at Kiona | 61 | X | |
| 52 | Sulphur Creek Wasteway near Sunnyside | 80 | X | |
| 53 | Satus Creek below Dry Creek near Toppenish | 48 | X | |
| 54 | Spring Creek at mouth at Whitstran | 62 | X | |
| 56 | Yakima River at Euclid Bridge at RM 55 near Grandview | 56 | X | |
| 57 | Satus Creek above Wilson-Charley Canyon near Toppenish | 53 | X | |
| | Percentage of samples that exceeded guidelines | | 97 | 12 |
| **Copper, guideline: lowest effect level: 16 µg/g; severe effect level: 110 µg/g** | | | | |
| 1 | Waptus River at mouth near Roslyn | 20 | X | |
| 3 | Jungle Creek near mouth near Cle Elum | 36 | X | |
| 5 | Teanaway River below Forks near Cle Elum | 32 | X | |
| 6 | Yakima River at Cle Elum | 43 | X | |
| 7 | Naneum Creek below High Creek near Ellensburg | 24 | X | |
| 8 | Taneum Creek at Taneum Meadow near Thorp | 47 | X | |
| 10 | Little Naches River at mouth near Cliffdell | 48 | X | |
| 12 | South Fork Manastash Creek near Ellensburg | 44 | X | |
| 13 | American River at Hell's Crossing near Nile | 79 | X | |
| 14 | Cherry Creek above Wipple Wasteway at Thrall | 22 | X | |
| 19 | Yakima River at Umtanum | 28 | X | |
| 20 | Umtanum Creek near mouth at Umtanum | 30 | X | |
| 21 | Rattlesnake Creek above Little Rattlesnake Creek near Nile | 39 | X | |
| 22 | Rattlesnake Creek above North Fork Rattlesnake Creek near Nile | 43 | X | |
| 26 | Naches River near North Yakima | 61 | X | |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | 93 | X | |
| 29 | Wide Hollow Creek at old STP at Union Gap | 42 | X | |
| 30 | Moxee Drain at Thorp Road near Union Gap | 25 | X | |
| 31 | Ahtanum Creek at Union Gap | 25 | X | |

**Table 6.** Summary of major- and trace-element concentrations in streambed sediment that exceeded Provincial Sediment-Quality Guidelines, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Streambed-sediment concentration | Samples exceeding guidelines | |
|---|---|---|---|---|
| | | | Lowest effect level | Severe effect level |
| **Copper, guideline: lowest effect level: 16 µg/g; severe effect level: 110 µg/g—Continued** | | | | |
| 33 | Yakima River at Parker | 29 | X | |
| 34 | South Fork Ahtanum Creek above Conrad Ranch near Tampico | 29 | X | |
| 40 | Granger Drain at mouth near Granger | 21 | X | |
| 42 | Yakima River below Toppenish Creek at RM 79.6 near Granger | 31 | X | |
| 43 | Toppenish Creek at Indian Church Road near Granger | 32 | X | |
| 47 | Satus Creek at gage at Satus | 29 | X | |
| 48 | Yakima River at RM 72 above Satus Creek near Sunnyside | 31 | X | |
| 50 | Yakima River at Kiona | 29 | X | |
| 52 | Sulphur Creek Wasteway near Sunnyside | 26 | X | |
| 53 | Satus Creek below Dry Creek near Toppenish | 32 | X | |
| 54 | Spring Creek at mouth at Whitstran | 17 | X | |
| 56 | Yakima River at Euclid Bridge at RM 55 near Grandview | 27 | X | |
| 57 | Satus Creek above Wilson-Charley Canyon near Toppenish | 25 | X | |
| Percentage of samples that exceeded guidelines | | | 100 | 0 |
| **Iron, guideline: lowest effect level: 2 percent; severe effect level: 4 percent** | | | | |
| 1 | Waptus River at mouth near Roslyn | 3.9 | X | |
| 3 | Jungle Creek near mouth near Cle Elum | 6.0 | X | X |
| 5 | Teanaway River below Forks near Cle Elum | 5.5 | X | X |
| 6 | Yakima River at Cle Elum | 5.1 | X | X |
| 7 | Naneum Creek below High Creek near Ellensburg | 4.9 | X | X |
| 8 | Taneum Creek at Taneum Meadow near Thorp | 5.0 | X | X |
| 10 | Little Naches River at mouth near Cliffdell | 6.0 | X | X |
| 12 | South Fork Manastash Creek near Ellensburg | 6.3 | X | X |
| 13 | American River at Hell's Crossing near Nile | 4.9 | X | X |
| 14 | Cherry Creek above Wipple Wasteway at Thrall | 4.2 | X | X |
| 19 | Yakima River at Umtanum | 4.3 | X | X |
| 20 | Umtanum Creek near mouth at Umtanum | 6.7 | X | X |
| 21 | Rattlesnake Creek above Little Rattlesnake Creek near Nile | 5.6 | X | X |
| 22 | Rattlesnake Creek above North Fork Rattlesnake Creek near Nile | 5.2 | X | X |
| 26 | Naches River near North Yakima | 4.9 | X | X |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | 4.5 | X | X |
| 29 | Wide Hollow Creek at old STP at Union Gap | 5.2 | X | X |
| 30 | Moxee Drain at Thorp Road near Union Gap | 4.3 | X | X |
| 31 | Ahtanum Creek at Union Gap | 5.7 | X | X |
| 33 | Yakima River at Parker | 4.6 | X | X |

**Table 6.** Summary of major- and trace-element concentrations in streambed sediment that exceeded Provincial Sediment-Quality Guidelines, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Streambed-sediment concentration | Samples exceeding guidelines<br>Lowest effect level | Samples exceeding guidelines<br>Severe effect level |
|---|---|---|---|---|
| **Iron, guideline: lowest effect level: 2 percent; severe effect level: 4 percent—Continued** | | | | |
| 34 | South Fork Ahtanum Creek above Conrad Ranch near Tampico | 6.9 | X | X |
| 40 | Granger Drain at mouth near Granger | 5.5 | X | X |
| 42 | Yakima River below Toppenish Creek at RM 79.6 near Granger | 5.1 | X | X |
| 43 | Toppenish Creek at Indian Church Road near Granger | 5.1 | X | X |
| 47 | Satus Creek at gage at Satus | 5.9 | X | X |
| 48 | Yakima River at RM 72 above Satus Creek near Sunnyside | 4.9 | X | X |
| 50 | Yakima River at Kiona | 5.1 | X | X |
| 52 | Sulphur Creek Wasteway near Sunnyside | 5.1 | X | X |
| 53 | Satus Creek below Dry Creek near Toppenish | 5.2 | X | X |
| 54 | Spring Creek at mouth at Whitstran | 5.5 | X | X |
| 56 | Yakima River at Euclid Bridge at RM 55 near Grandview | 5.0 | X | X |
| 57 | Satus Creek above Wilson-Charley Canyon near Toppenish | 7.3 | X | X |
| Percentage of samples that exceeded guidelines | | | 100 | 97 |
| **Lead, guideline: lowest effect level: 31 µg/g; severe effect level: 250 µg/g** | | | | |
| 26 | Naches River near North Yakima | 36 | X | |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | 63 | X | |
| 29 | Wide Hollow Creek at old STP at Union Gap | 48 | X | |
| Percentage of samples that exceeded guidelines | | | 9 | 0 |
| **Manganese, guideline: lowest effect level: 460 µg/g; severe effect level: 1,100 µg/g** | | | | |
| 1 | Waptus River at mouth near Roslyn | 1,400 | X | X |
| 3 | Jungle Creek near mouth near Cle Elum near Cle Elum | 910 | X | |
| 5 | Teanaway River below Forks near Cle Elum near Cle Elum | 1,100 | X | X |
| 6 | Yakima River at Cle Elum | 1,100 | X | X |
| 7 | Naneum Creek below High Creek near Ellensburg | 1,000 | X | |
| 8 | Taneum Creek at Taneum Meadow near Thorp | 820 | X | |
| 10 | Little Naches River at mouth near Cliffdell | 1,400 | X | X |
| 12 | South Fork Manastash Creek near Ellensburg | 1,100 | X | X |
| 13 | American River at Hell's Crossing near Nile | 1,100 | X | X |
| 14 | Cherry Creek above Wipple Wasteway at Thrall | 830 | X | |
| 19 | Yakima River at Umtanum | 1,700 | X | X |
| 20 | Umtanum Creek near mouth at Umtanum | 1,100 | X | X |
| 21 | Rattlesnake Creek above Little Rattlesnake Creek near Nile | 1,000 | X | |
| 22 | Rattlesnake Creek above North Fork Rattlesnake Creek near Nile | 1,200 | X | X |
| 26 | Naches River near North Yakima | 1,100 | X | X |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | 550 | X | |
| 29 | Wide Hollow Creek at old STP at Union Gap | 770 | X | |

**Table 6.** Summary of major- and trace-element concentrations in streambed sediment that exceeded Provincial Sediment-Quality Guidelines, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Streambed-sediment concentration | Samples exceeding guidelines<br>Lowest effect level | Samples exceeding guidelines<br>Severe effect level |
|---|---|---|---|---|
| **Manganese, guideline: lowest effect level: 460 μg/g; severe effect level: 1,100 μg/g—Continued** | | | | |
| 30 | Moxee Drain at Thorp Road near Union Gap | 740 | X | |
| 31 | Ahtanum Creek at Union Gap | 960 | X | |
| 33 | Yakima River at Parker | 780 | X | |
| 34 | South Fork Ahtanum Creek above Conrad Ranch near Tampico | 1,500 | X | X |
| 40 | Granger Drain at mouth near Granger | 1,000 | X | |
| 42 | Yakima River below Toppenish Creek at RM 79.6 near Granger | 750 | X | |
| 43 | Toppenish Creek at Indian Church Road near Granger | 960 | X | |
| 47 | Satus Creek at gage at Satus | 1,100 | X | X |
| 48 | Yakima River at RM 72 above Satus Creek near Sunnyside | 1,000 | X | |
| 50 | Yakima River at Kiona | 1,500 | X | X |
| 52 | Sulphur Creek Wasteway near Sunnyside | 990 | X | |
| 53 | Satus Creek below Dry Creek near Toppenish | 820 | X | |
| 54 | Spring Creek at mouth at Whitstran | 930 | X | |
| 56 | Yakima River at Euclid Bridge at RM 55 near Grandview | 1,000 | X | |
| 57 | Satus Creek above Wilson-Charley Canyon near Toppenish | 1,400 | X | X |
| Percentage of samples that exceeded guidelines | | | 100 | 44 |
| **Mercury, guideline: lowest effect level: 0.2 μg/g; severe effect level: 2 μg/g** | | | | |
| 3 | Jungle Creek near mouth near Cle Elum | .56 | X | |
| 5 | Teanaway River below Forks near Cle Elum | .20 | X | |
| 8 | Taneum Creek at Taneum Meadow near Thorp | .40 | X | |
| 21 | Rattlesnake Creek above Little Rattlesnake Creek near Nile | .24 | X | |
| 26 | Naches River near North Yakima | .27 | X | |
| 29 | Wide Hollow Creek at old STP at Union Gap | .26 | X | |
| 33 | Yakima River at Parker | .26 | X | |
| Percentage of samples that exceeded guidelines | | | 22 | 0 |
| **Nickel, guideline: lowest effect level: 16 μg/g; severe effect level: 75 μg/g** | | | | |
| 1 | Waptus River at mouth near Roslyn | 29 | X | |
| 3 | Jungle Creek near mouth near Cle Elum | 43 | X | |
| 5 | Teanaway River below Forks near Cle Elum | 260 | X | X |
| 6 | Yakima River at Cle Elum | 150 | X | X |
| 7 | Naneum Creek below High Creek near Ellensburg | 22 | X | |
| 8 | Taneum Creek at Taneum Meadow near Thorp | 78 | X | X |
| 10 | Little Naches River at mouth near Cliffdell | 20 | X | |
| 12 | South Fork Manastash Creek near Ellensburg | 61 | X | |
| 14 | Cherry Creek above Wipple Wasteway at Thrall | 21 | X | |
| 19 | Yakima River at Umtanum | 48 | X | |

**Table 6.** Summary of major- and trace-element concentrations in streambed sediment that exceeded Provincial Sediment-Quality Guidelines, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Streambed-sediment concentration | Samples exceeding guidelines | |
|---|---|---|---|---|
| | | | Lowest effect level | Severe effect level |
| **Nickel, guideline: lowest effect level: 16 μg/g; severe effect level: 75 μg/g—Continued** | | | | |
| 20 | Umtanum Creek near mouth at Umtanum at Umtanum | 19 | X | |
| 21 | Rattlesnake Creek above Little Rattlesnake Creek near Nile | 16 | X | |
| 22 | Rattlesnake Creek above North Fork Rattlesnake Creek near Nile | 27 | X | |
| 26 | Naches River near North Yakima | 43 | X | |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | 19 | X | |
| 29 | Wide Hollow Creek at old STP at Union Gap | 28 | X | |
| 30 | Moxee Drain at Thorp Road near Union Gap | 22 | X | |
| 31 | Ahtanum Creek at Union Gap | 19 | X | |
| 33 | Yakima River at Parker | 36 | X | |
| 40 | Granger Drain at mouth near Granger | 20 | X | |
| 42 | Yakima River below Toppenish Creek at RM 79.6 near Granger | 35 | X | |
| 43 | Toppenish Creek at Indian Church Road near Granger | 31 | X | |
| 47 | Satus Creek at gage at Satus | 25 | X | |
| 48 | Yakima River at RM 72 above Satus Creek near Sunnyside | 36 | X | |
| 50 | Yakima River at Kiona | 30 | X | |
| 52 | Sulphur Creek Wasteway near Sunnyside | 37 | X | |
| 53 | Satus Creek below Dry Creek near Toppenish | 24 | X | |
| 54 | Spring Creek at mouth at Whitstran | 22 | X | |
| 56 | Yakima River at Euclid Bridge at RM 55 near Grandview | 27 | X | |
| 57 | Satus Creek above Wilson-Charley Canyon near Toppenish | 23 | X | |
| Percentage of samples that exceeded guidelines | | | 94 | 9 |
| **Zinc, guideline: lowest effect level: 120 μg/g; severe effect level: 820 μg/g** | | | | |
| 3 | Jungle Creek near mouth near Cle Elum | 150 | X | |
| 13 | American River at Hell's Crossing near Nile | 210 | X | |
| 26 | Naches River near North Yakima | 120 | X | |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | 170 | X | |
| 29 | Wide Hollow Creek at old STP at Union Gap | 210 | X | |
| 34 | South Fork Ahtanum Creek above Conrad Ranch near Tampico | 120 | X | |
| 57 | Satus Creek above Wilson-Charley Canyon near Toppenish | 160 | X | |
| Percentage of samples that exceeded guidelines | | | 22 | 0 |

(2) USEPA primary and secondary drinking-water regulations (U.S. Environmental Protection Agency, 1992b), and

(3) USEPA drinking-water human-health advisories (U.S. Environmental Protection Agency, 1992b).

All USEPA ambient water-quality criteria are nonenforceable guidelines that may provide the basis for State standards (Nowell and Resek, 1994) and are designed to protect human health and aquatic organisms from deleterious element concentrations. Ambient water-quality data in the Yakima River Basin was screened in order to identify trace-element concentrations that may require study by State and local health agencies. State and local health agencies are responsible for issuing advice or formal advisories to protect the health of their constituents.

The primary drinking-water regulations have been established for contaminants that are known to be present in public-water systems and which may affect human health adversely; secondary drinking-water regulations are nonenforceable guidelines, based on aesthetics, for contaminants that can affect the odor or appearance of drinking water adversely (Nowell and Resek, 1994). Health advisories provide nonregulatory levels of contaminants in drinking water which would result in no known or anticipated health effects.

## Ambient Stream Water

### Aquatic Life

According to USEPA's interim guidance on aquatic-life criteria for metals (U.S. Environmental Protection Agency, 1992a, p. 4), the toxicity tests that form the basis for USEPA ambient water-quality criteria for the protection of aquatic life were generally done in water "lower in metal-binding particulate matter and dissolved organic carbon than most ambient waters[. Therefore], these toxicity tests may overstate the ambient toxicity of nonbiomagnified metals that interact with particulate matter or dissolved organic matter." Trace elements used for the toxicity tests by USEPA were analyzed from an unfiltered-water sample using a total-recoverable method of analysis. This type of analysis for ambient water, with metal-binding phases, may extract trace elements from the particulate or carbon phases and, consequently, overstate ambient toxicity. Presently, USEPA provides guidance on the use of two new methods that may be used to implement aquatic-life criteria without overstating ambient toxicity (U.S. Environmental Protection Agency, 1992c). The new methods can be used to adjust the numeric value of the criteria in proportion to the quantity of the metal-binding phases in the ambient water. These methods may increase the numeric value of the aquatic-life criteria (making it less stringent). The simplest and most conservative method, however, is to use the total-recoverable method for filtered- and unfiltered-water samples and to compare such measurements to USEPA criteria.

Although USEPA's ambient water-quality criteria are based on analyses of unfiltered-water samples, the trace-element concentrations in filtered-water samples analyzed for this report were usually high enough to equal or exceed the criteria. Consequently, USEPA's ambient water-quality criteria are used as screening values for the protection of aquatic organisms. For many trace elements, including cadmium, chromium, lead, nickel, silver, and zinc, aquatic toxicity is related to the hardness of the water—toxicity increases (the screening value decreases) as hardness decreases. For example, as water hardness ranges from 50 to 200 mg/L as calcium carbonate, lead toxicity to aquatic organisms ranges from 1.3 to 7.7 μg/L (micrograms per liter) (U.S. Environmental Protection Agency, 1986). For trace elements with toxicity that varies with water hardness, the ambient-water hardness at the time of sample collection was used to derive the appropriate screening value. Both acute (1-hour average concentrations) and chronic (4-day average concentrations) trace-element criteria for aquatic life are used to evaluate waters in the Yakima River Basin; however, trace-element concentrations in the basin are from discrete measurements, rather than multiple measurements to derive 1-hour or 4-day average concentrations.

Concentrations of cadmium, copper, lead, mercury, silver, and zinc in filtered-water samples exceeded the screening value (based on USEPA's ambient water-quality criteria for the protection of aquatic organisms) at two or more sites. Additionally, concentrations of cadmium, mercury, and zinc at several sites exceeded acute or chronic screening values for the protection of aquatic life (table 7). Sites with zinc exceedances include those receiving irrigation return flow, such as East Toppenish Drain at Wilson Road near Toppenish (site 37), as well as those in mountainous areas, such as Bumping River at Soda Springs Walkway near Nile (site 17). Acute and chronic exceedances of copper exist in the Yakima River at Cle Elum (site 6) and the Yakima River at Umtanum (site 19). These exceedances, although infrequent, happen during periods of winter-storm

**Table 7.** Summary of trace-element concentrations in filtered-water samples that exceeded screening values derived from water-quality guidelines, Yakima River Basin, Washington, 1987–90

[The term "filtered water" is an operational definition referring to the chemical analysis of that portion of a water-suspended sediment sample that passes through a nominal 0.45-micrometer filter; element concentrations of antimony, barium, beryllium, boron, chromium, cyanide, iron, nickel, and selenium met: (1) U.S. Environmental Protection Agency (1986, 1992c) ambient water-quality criteria or State Standards (Washington State Administrative Code (1992) for the protection of aquatic life and human health, and (2) U.S. Environmental Protection Agency (1992b) drinking-water guidelines. Only detectable concentrations were evaluated against water-quality guidelines; percentages were calculated using all measurements (censored and detected) for all sites sampled. To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate during a single site visit, only one element concentration per visit was evaluated. For reference purposes, the aquatic-life guidelines listed below are based on a hardness of 50 milligrams per liter (mg/L) as calcium carbonate; for evaluation of detected concentrations for aquatic life, the ambient hardness was used to calculate screening values. The listed acute and chronic criteria for arsenic and mercury and the chronic criteria for silver do not vary with water hardness; µg/L, micrograms per liter; *, waterway not required to meet drinking-water guidelines; --, no current guideline exists; DID, drainage irrigation district; STP, sewage treatment plant]

| Site reference number | Site name | Total number of samples | Number of samples that exceeded screening values | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Ambient water-quality criteria | | | | Drinking-water guidelines | |
| | | | Aquatic life[1] | | Human health[2] | | | |
| | | | Acute[5] | Chronic[6] | Aquatic organisms and water[7] | Aquatic organisms only[8] | Regulations[3] | Human-health advisories[4] |
| **Arsenic:**<br>Ambient water-quality criteria:<br>Aquatic life:<br>Acute: 1-hour average 360 µg/L once in 3 years<br>Chronic: 4-day average 190 µg/L once in 3 years<br>Human health:<br>Consumption of aquatic organisms and water: 0.18 µg/L<br>Consumption of aquatic organisms only: 1.4 µg/L<br>Note: Human-health guidelines are based on a slope factor ($q_1^*$) of 1.75 (milligrams per kilogram per day)$^{-1}$, a bioconcentration factor of 44 liters per kilogram, a lifetime risk of cancer equivalent to 1 in 100,000, a human consumption rate of fish equal to 6.5 grams per day (about one 6-ounce fillet per month—the national average), a human consumption rate of water equal to 2 liters per day, a human-body weight of 70 kilograms (154 pounds), and a life expectancy of 70 years.[9]<br>Drinking water:<br>Regulation: 50.0 µg/L (Maximum Contaminant Level)<br>Human-health advisory: 0.2 µg/L Risk-specific dose (RSD)<br>Note: Human-health advisory is based on a slope factor ($q_1^*$) of 1.75 (milligrams per kilogram per day)$^{-1}$, a lifetime risk of cancer equivalent to 1 in 100,000, a human consumption rate of water equal to 2 liters per day, a human-body weight of 70 kilograms (154 pounds), and a life expectancy of 70 years.[10]<br>Note: Because the limit of determination for arsenic (1 µg/L) exceeds the human-health criterion for consumption of aquatic organisms and water (0.18 µg/L) and the human-health advisory for drinking water (0.2 µg/L), censored data (concentrations reported as less than 1 µg/L) were not counted as exceeding these screening values. | | | | | | | | |
| 3 | Jungle Creek near mouth near Cle Elum | 1 | 0 | 0 | 1 | 1 | 0 | 1 |
| 26 | Naches River near North Yakima | 15 | 0 | 0 | 1 | 0 | 0 | 1 |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| 32 | Yakima River above Ahtanum Creek at Union Gap | 23 | 0 | 0 | 4 | 0 | 0 | 4 |
| 50 | Yakima River at Kiona | 25 | 0 | 0 | 20 | 15 | 0 | 20 |
| 52 | Sulphur Creek Wasteway near Sunnyside | 15 | 0 | 0 | 15 | 15 | * | * |
| 56 | Yakima River at Euclid Bridge at river mile 55 near Grandview | 14 | 0 | 0 | 11 | 6 | 0 | 11 |
| | Percentage of samples that exceeded screening values | | 0 | 0 | 43 | 30 | 0 | 31 |

**Table 7.** Summary of trace-element concentrations in filtered-water samples that exceeded screening values derived from water-quality guidelines, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Total number of samples | Number of samples that exceeded screening values | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Ambient water-quality criteria | | | | Drinking-water guidelines | |
| | | | Aquatic life[1] | | Human health[2] | | | |
| | | | Acute[5] | Chronic[6] | Aquatic organisms and water[7] | Aquatic organisms only[8] | Regulations[3] | Human-health advisories[4] |
| **Cadmium:**<br>Ambient water-quality criteria:<br>Aquatic life:<br>Acute: 1-hour average 1.8 µg/L once in 3 years<br>Chronic: 4-day average 0.66 µg/L once in 3 years<br>Drinking water:<br>Regulation: 5 µg/L (Maximum Contaminant Level) | | | | | | | | |
| 6 | Yakima River at Cle Elum | 42 | 0 | 6 | -- | -- | 0 | -- |
| 9 | Yakima River at Thorp Highway Bridge at Ellensburg | 3 | 0 | 1 | -- | -- | 0 | -- |
| 19 | Yakima River at Umtanum | 40 | 0 | 4 | -- | -- | 0 | -- |
| 23 | Yakima River above canal diversion at river mile 128 at Roza Dam | 1 | 0 | 1 | -- | -- | 0 | -- |
| 26 | Naches River near North Yakima | 38 | 1 | 1 | -- | -- | 0 | -- |
| 43 | Toppenish Creek at Indian Church Road near Granger | 2 | 0 | 1 | -- | -- | 0 | -- |
| | Percentage of samples that exceeded screening values | | 0.3 | 4 | -- | -- | 0 | -- |
| **Copper**:<br>Ambient water-quality criteria:<br>Aquatic life:<br>Acute: 1-hour average 9.2 µg/L once in 3 years<br>Chronic: 4-day average 6.5 µg/L once in 3 years<br>Drinking water:<br>Regulation: 1,300 µg/L (Maximum Contaminant Level Goal) | | | | | | | | |
| 9 | Yakima River at Cle Elum | 42 | 4 | 4 | -- | -- | 0 | -- |
| 16 | Yakima River at Umtanum | 39 | 1 | 2 | -- | -- | 0 | -- |
| | Percentage of samples that exceeded screening values | | 2 | 2 | -- | -- | 0 | -- |

**Table 7.** Summary of trace-element concentrations in filtered-water samples that exceeded screening values derived from water-quality guidelines, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Total number of samples | Number of samples that exceeded screening values | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Ambient water-quality criteria | | | | Drinking-water guidelines | |
| | | | Aquatic life[1] | | Human health[2] | | Regulations[3] | Human-health advisories[4] |
| | | | Acute[5] | Chronic[6] | Aquatic organisms and water[7] | Aquatic organisms only[8] | | |
| **Lead**:<br>Ambient water-quality criteria:<br>Aquatic life:<br>Acute: 1-hour average 34 µg/L once in 3 years<br>Chronic: 4-day average 1.3 µg/L once in 3 years<br>Drinking water:<br>Regulation: 0 µg/L (Maximum Contaminant Level Goal)<br>Note: Because the limit of determination for lead (0.5 µg/L) exceeds the drinking-water regulation (0 µg/L), censored data (concentrations reported as less than 0.5 µg/L) were not counted as drinking-water exceedances. | | | | | | | | |
| 19 | Yakima River at Umtanum | 39 | 0 | 1 | -- | -- | 0 | -- |
| 26 | Naches River near North Yakima | 37 | 0 | 0 | -- | -- | 4 | -- |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | 1 | 0 | 0 | -- | -- | 1 | -- |
| 32 | Yakima River above Ahtanum Creek at Union Gap | 41 | 0 | 0 | -- | -- | 2 | -- |
| 36 | Yakima River at river mile 91 at Zillah | 1 | 0 | 1 | -- | -- | 1 | -- |
| 50 | Yakima River at Kiona | 39 | 0 | 1 | -- | -- | 6 | -- |
| 56 | Yakima River at Euclid Bridge at river mile 55 near Grandview | 38 | 0 | 1 | -- | -- | 2 | -- |
| | Percentage of samples that exceeded screening values | | 0 | 1 | -- | -- | 6 | -- |
| **Manganese**:<br>Drinking water:<br>Regulation: 200 µg/L (Maximum Contaminant Level Goal) | | | | | | | | |
| 35 | Unnamed drain at Progressive Road near Harrah | 1 | -- | -- | -- | -- | 1 | -- |
| | Percentage of samples that exceeded screening values | | -- | -- | -- | -- | 1 | -- |

**Table 7.** Summary of trace-element concentrations in filtered-water samples that exceeded screening values derived from water-quality guidelines, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Total number of samples | Number of samples that exceeded screening values | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Ambient water-quality criteria | | | | Drinking-water guidelines | |
| | | | Aquatic life[1] | | Human health[2] | | | |
| | | | Acute[5] | Chronic[6] | Aquatic organisms and water[7] | Aquatic organisms only[8] | Regulations[3] | Human-health advisories[4] |
| **Mercury**:<br>Ambient water-quality criteria:<br>Aquatic life:<br>Acute: 1-hour average 2.4 µg/L<br>Chronic: 4-day average 0.012 µg/L<br>Human health:<br>Consumption of aquatic organisms and water: 0.14 µg/L<br>Consumption of aquatic organisms only: 0.15 µg/L<br>Note: Human-health guidelines are based on a reference dose (RfD) of 6 × $10^{-5}$ milligrams per kilogram per day, a bioconcentration factor of 5,500 liters per kilogram, a human consumption rate of fish equal to 6.5 grams per day (about one 6-ounce fillet per month—the national average), a human consumption rate of water equal to 2 liters per day, a human-body weight of 70 kilograms (154 pounds), and a life expectancy of 70 years.[11]<br>Drinking water:<br>Regulation: 2 µg/L (Maximum Contaminant Level)<br>Human-health advisory: 0.4 µg/L Lifetime health advisory (relative-source contribution from drinking water is assumed to be 20 percent)<br>Note: Human-health advisory is based on a reference dose (RfD) of 6 × $10^{-5}$ milligrams per kilogram per day, a human consumption rate of water equal to 2 liters per day, a human-body weight of 70 kilograms (154 pounds), and a life expectancy of 70 years.[12]<br>Note: Because the limit of determination for mercury (0.1 µg/L) exceeds the chronic criterion (0.012 µg/L), censored data (concentrations reported as less than 0.1 µg/L) were not counted as exceeding the chronic-mercury screening value. | | | | | | | | |
| 6 | Yakima River at Cle Elum | 42 | 0 | 2 | 2 | 2 | 0 | 1 |
| 19 | Yakima River at Umtanum | 40 | 0 | 3 | 3 | 3 | 0 | 1 |
| 26 | Naches River near North Yakima | 38 | 0 | 1 | 1 | 1 | 0 | 0 |
| 32 | Yakima River above Ahtanum Creek at Union Gap | 42 | 0 | 2 | 2 | 2 | 0 | 0 |
| 50 | Yakima River at Kiona | 43 | 0 | 3 | 2 | 2 | 0 | 0 |
| 52 | Sulphur Creek Wasteway near Sunnyside | 41 | 0 | 2 | 1 | 1 | * | * |
| 56 | Yakima River at Euclid Bridge at river mile 55 near Grandview | 37 | 0 | 1 | 0 | 0 | 0 | 0 |
| | Percentage of samples that exceeded screening values | | 0 | 5 | 4 | 4 | 0 | 1 |

**Table 7.** Summary of trace-element concentrations in filtered-water samples that exceeded screening values derived from water-quality guidelines, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Total number of samples | Number of samples that exceeded screening values | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Ambient water-quality criteria | | | | Drinking-water guidelines | |
| | | | Aquatic life[1] | | Human health[2] | | | |
| | | | Acute[5] | Chronic[6] | Aquatic organisms and water[7] | Aquatic organisms only[8] | Regulations[3] | Human-health advisories[4] |
| **Silver**:<br>Ambient water-quality criteria:<br>Aquatic life:<br>Acute: 1.2 µg/L at any time<br>Chronic: 0.12 µg/L at any time<br>Drinking water:<br>Regulation: 100 µg/L (Secondary Maximum Contaminant Level)<br>Note: Because the limit of determination for silver (1 µg/L) exceeds the chronic criterion (0.12 µg/L), censored data (concentrations reported as less than 1 µg/L) were not counted as exceeding the chronic-silver screening value. | | | | | | | | |
| 9 | Yakima River at Thorp Highway Bridge at Ellensburg | 2 | 1 | 1 | -- | -- | 0 | -- |
| 12 | South Fork Manastash Creek near Ellensburg | 1 | 1 | 1 | -- | -- | 0 | -- |
| 19 | Yakima River at Umtanum | 6 | 1 | 2 | -- | -- | 0 | -- |
| 26 | Naches River near North Yakima | 3 | 2 | 2 | -- | -- | 0 | -- |
| 32 | Yakima River above Ahtanum Creek at Union Gap | 17 | 1 | 2 | -- | -- | 0 | -- |
| 36 | Yakima River at river mile 91 at Zillah | 2 | 1 | 1 | -- | -- | 0 | -- |
| 43 | Toppenish Creek at Indian Church Road near Granger | 2 | 0 | 1 | -- | -- | 0 | -- |
| 46 | DID 3 Drain below STP at Midvale Road at Sunnyside | 1 | 0 | 1 | -- | -- | 0 | -- |
| 50 | Yakima River at Kiona | 16 | 0 | 1 | -- | -- | 0 | -- |
| 52 | Sulphur Creek Wasteway near Sunnyside | 7 | 0 | 2 | -- | -- | * | * |
| 56 | Yakima River at Euclid Bridge at river mile 55 near Grandview | 4 | 0 | 1 | -- | -- | 0 | -- |
| | Percentage of samples that exceeded screening values | | 7 | 15 | -- | -- | 0 | -- |

**Table 7.** Summary of trace-element concentrations in filtered-water samples that exceeded screening values derived from water-quality guidelines, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Total number of samples | Number of samples that exceeded screening values | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Ambient water-quality criteria | | | | Drinking-water guidelines | |
| | | | Aquatic life[1] | | Human health[2] | | | |
| | | | Acute[5] | Chronic[6] | Aquatic organisms and water[7] | Aquatic organisms only[8] | Regulations[3] | Human-health advisories[4] |
| **Zinc**:<br>Ambient water-quality criteria:<br>Aquatic life:<br>Acute: 1-hour average 65 µg/L once in 3 years<br>Chronic: 4-day average 59 µg/L once in 3 years<br>Drinking water:<br>Regulation: 5,000 µg/L (Secondary Maximum Contaminant Level) | | | | | | | | |
| 13 | American River at Hell's Crossing near Nile | 2 | 1 | 1 | -- | -- | 0 | -- |
| 17 | Bumping River at Soda Springs Walkway near Nile | 1 | 1 | 1 | -- | -- | 0 | -- |
| 23 | Yakima River above canal diversion at river mile 128 at Roza Dam | 1 | 1 | 1 | -- | -- | 0 | -- |
| 30 | Moxee Drain at Thorp Road near Union Gap | 2 | 1 | 1 | -- | -- | 0 | -- |
| 37 | East Toppenish Drain at Wilson Road near Toppenish | 2 | 1 | 1 | -- | -- | 0 | -- |
| 55 | Yakima River at Mabton | 1 | 1 | 1 | -- | -- | 0 | -- |
| Percentage of samples that exceeded screening values | | | 6 | 6 | -- | -- | 0 | -- |

[1] U.S. Environmental Protection Agency (1986, 1992c).

[2] U.S. Environmental Protection Agency (1992c).

[3] U.S. Environmental Protection Agency (1992b).

[4] U.S. Environmental Protection Agency (1992b), Nowell and Resek (1994).

[5] Element concentrations were obtained by instantaneous measurements rather than 1-hour averages.

[6] Element concentrations were obtained by instantaneous measurements rather than 3-day averages.

[7] Assumes that 100 percent of exposure to the element is from consumption of contaminated water and contaminated aquatic organisms.

[8] Assumes that 100 percent of exposure to the element is from consumption of contaminated water.

[9] U.S. Environmental Protection Agency (1992c, 1992d).

[10] U.S. Environmental Protection Agency (1992c, 1992d).

[11] U.S. Environmental Protection Agency (1992c, 1992d).

[12] U.S. Environmental Protection Agency (1992c, 1992d).

runoff. Similar to copper, the number of chronic, aquatic-life exceedances of cadmium and mercury are few in number. Unlike copper, however, exceedances of cadmium and mercury do not appear to be associated with any particular season or streamflow condition.

Some of the above aquatic-life exceedances are related to hydrologic conditions or events. For example, concentrations of cadmium generally exceed the chronic aquatic-life criterion during periods of winter warming, in spring during snowmelt, and during storms. Of the seven fixed sites, exceedances are found principally in the Kittitas Valley at the Yakima River at Cle Elum and at the Yakima River at Umtanum. The exceedances, in part, are related to hardness, which generally is low in waters of the Kittitas Valley. Hardness in the Kittitas Valley is less than 50 mg/L as calcium carbonate and is noteworthy because aquatic-life screening values for cadmium decrease as hardness decreases. Consequently, concentrations of cadmium in the Kittitas Valley are more likely to exceed screening values for the protection of aquatic life than are cadmium concentrations in the mid- and lower Yakima Valley. Cadmium also was detected in the Kittitas Valley during synoptic samplings in July 1987–88—chronic aquatic-life exceedances at these times were measured in the main stem near Ellensburg (site 9) and in the main stem above Roza Dam (site 23).

Concentrations of cadmium, chromium, copper, iron, lead, mercury, and silver in unfiltered-water samples exceeded the screening value (based on USEPA's ambient water-quality criteria for the protection of aquatic organisms) at two or more fixed sites (table 8). In addition, concentrations of chromium and copper exceeded both acute and chronic screening values at several sites. The aquatic-life screening values for chromium vary depending on valency; for example, assuming a water hardness of 50 mg/L as calcium carbonate, the criteria for hexavalent (+ 6) and trivalent (+ 3) chromium range from 11 µg/L to 120 µg/L, respectively. Because chromium was analyzed as the sum of the trivalent and hexavalent species, the chromium data—as a conservative measure—were evaluated against the more stringent hexavalent chromium criterion. The screening values for the protection of aquatic life from copper were exceeded during spring and summer at the following fixed stations: Yakima River at Cle Elum (site 6), Yakima River at Umtanum (site 19), Yakima River above Ahtanum Creek at Union Gap (site 32), and Sulphur Creek Wasteway near Sunnyside (site 52). The seasonality of these exceedances coincides with those measured from 1953–85 (Rinella and others, 1992). The 1953–85 exceedances of copper, in part, were attributed to the use, past and present, of copper sulphate—a herbicide used by some irrigation districts to control nuisance-aquatic growths in irrigation canals (Lee Henderson, Kittitas Reclamation District, oral commun., 1989).

In this study, relatively few determinations of unfiltered-water samples were made using the ***total-recoverable*** method of analysis—the method of analysis used by the USEPA to derive aquatic-life criteria. Instead, element concentrations often are measured directly on suspended sediment using a ***total*** method of analysis, and on dissolved trace elements in filtered-water samples. To estimate a total-recoverable measurement in unfiltered-water samples (for the purpose of making comparisons with USEPA guidelines), trace-element concentrations on suspended sediment are added to concentrations in filtered-water samples.[5] The resultant values, termed ***calculated-total concentrations***, are regressed, in turn, against the relatively small number of trace-element concentrations derived using the total-recoverable method on unfiltered-water samples. There were nine unfiltered-water samples analyzed for iron and manganese. Only iron and manganese had an adequate number of uncensored data (detectable-trace-element concentrations) for making the regressions. The resulting prediction equation[6] is used to convert the calculated-total concentrations to ***estimated total-recoverable concentrations***, which are then compared against screening values as an aid in understanding water-quality concerns. The estimated total-recoverable concentrations of iron exceeded screening values for ambient water quality (1,000 µg/L) at most fixed sites (table 9). Nearly one-third of the estimated iron concentrations for the Yakima River above Ahtanum Creek at Union Gap and for the Yakima River at Kiona exceeded the screening value for aquatic organisms.

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[5] Element concentrations in suspended sediment (in micrograms per gram) were converted to volumetric concentrations (in micrograms per liter) and added to the dissolved element concentration to obtain an estimate of the trace-element concentration in an unfiltered-water sample.

[6] The regression equation for iron yielded an R-squared value of 0.87 and a prediction equation, $y = 517+0.58x$ ($y$ = estimated total-recoverable iron concentration; $x$ = calculated total-iron concentration).

**Table 8.** Summary of trace-element concentrations in unfiltered-water samples that exceeded screening values derived from water-quality guidelines, Yakima River Basin, Washington, 1987–90

[The term "unfiltered water" refers to the chemical analysis of a water sample that has not been filtered or centrifuged, nor in any way, altered from the original matrix; element concentrations of barium, beryllium, boron, nickel, and zinc met: (1) U.S. Environmental Protection Agency (1986, 1992c) ambient water-quality criteria or State Standards (Washington State Administrative Code, 1992) for the protection of aquatic life and human health, and (2) U.S. Environmental Protection Agency (1992b) drinking-water guidelines. Only detectable concentrations were evaluated against water-quality guidelines; percentages were calculated using all measurements (censored and detected) for all sites sampled. To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate during a single site visit, only one element concentration per visit was evaluated; for reference purposes, the aquatic-life guidelines listed below are based on a hardness of 50 milligrams per liter (mg/L) as calcium carbonate. For evaluation of detected concentrations for aquatic life, the ambient hardness was used to calculate screening values. The listed acute and chronic criteria for chromium and mercury and the chronic criteria for silver do not vary with water hardness; µg/L, micrograms per liter; *, waterway not required to meet drinking-water guidelines; --, no current guideline exists]

| Site reference number | Site name | Total number of samples | Number of samples that exceeded screening values | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Ambient water-quality criteria | | | | Drinking-water guidelines | |
| | | | Aquatic life[1] | | Human health[2] | | | |
| | | | Acute[5] | Chronic[6] | Aquatic organisms and water[7] | Aquatic organisms only[8] | Regulations[3] | Human-health advisories[4] |
| **Cadmium:**<br>Ambient water-quality criteria:<br>Aquatic life:<br>Acute: 1-hour average 1.8 µg/L once in 3 years<br>Chronic: 4-day average 0.66 µg/L once in 3 years<br>Drinking water:<br>Regulation: 5 µg/L (Maximum Contaminant Level)<br>Note: Because the limit of determination for cadmium (1 µg/L) exceeds the chronic criterion (0.66 µg/L), censored data (concentrations reported as less than1 µg/L) were not counted as exceeding the chronic-cadmium screening value. | | | | | | | | |
| 6 | Yakima River at Cle Elum | 3 | 0 | 1 | -- | -- | 0 | -- |
| 32 | Yakima River above Ahtanum Creek at Union Gap | 4 | 0 | 1 | -- | -- | 0 | -- |
| | Percentage of samples that exceeded screening values | | 0 | 11 | -- | -- | 0 | -- |
| **Chromium:**<br>Ambient water-quality criteria:<br>Aquatic life:<br>Acute: 1-hour average 16 µg/L once in 3 years<br>Chronic: 4-day average 11 µg/L once in 3 years<br>Drinking water:<br>Regulation: 100 µg/L (Maximum Contaminant Level) | | | | | | | | |
| 6 | Yakima River at Cle Elum | 3 | 0 | 1 | -- | -- | 0 | 0 |
| 19 | Yakima River at Umtanum | 3 | 1 | 1 | -- | -- | 0 | 0 |
| 50 | Yakima River at Kiona | 3 | 1 | 1 | -- | -- | 0 | 0 |
| 52 | Sulphur Creek Wasteway near Sunnyside | 2 | 1 | 2 | -- | -- | * | * |
| | Percentage of samples that exceeded screening values | | 17 | 28 | -- | -- | 0 | 0 |

**Table 8.** Summary of trace-element concentrations in unfiltered-water samples that exceeded screening values derived from water-quality guidelines, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Total number of samples | Number of samples that exceeded screening values | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Ambient water-quality criteria | | | | Drinking-water guidelines | |
| | | | Aquatic life[1] | | Human health[2] | | Regulations[3] | Human-health advisories[4] |
| | | | Acute[5] | Chronic[6] | Aquatic organisms and water[7] | Aquatic organisms only[8] | | |
| **Copper**:<br>Ambient water-quality criteria:<br>Aquatic life:<br>Acute: 1-hour average 9.2 µg/L once in 3 years<br>Chronic: 4-day average 6.5 µg/L once in 3 years<br>Drinking water:<br>Regulation: 1,300 µg/L (Maximum Contaminant Level Goal)<br>Note: Because the limit of determination for copper (10 µg/L) exceeds the acute (9.2 µg/L) and chronic (6.5 µg/L) criteria, censored data (concentrations reported as less than 10 µg/L) were not counted as exceeding acute- or chronic-copper screening values. | | | | | | | | |
| 6 | Yakima River at Cle Elum | 3 | 1 | 1 | -- | -- | 0 | -- |
| 19 | Yakima River at Umtanum | 3 | 1 | 1 | -- | -- | 0 | -- |
| 32 | Yakima River above Ahtanum Creek at Union Gap | 4 | 2 | 2 | -- | -- | 0 | -- |
| 50 | Yakima River at Kiona | 3 | 1 | 1 | -- | -- | 0 | -- |
| 52 | Sulphur Creek Wasteway near Sunnyside | 2 | 1 | 1 | -- | -- | * | * |
| 56 | Yakima River at Euclid Bridge at river mile 55 near Grandview | 2 | 1 | 1 | -- | -- | 0 | -- |
| Percentage of samples that exceeded screening values | | | 39 | 39 | -- | -- | 0 | -- |
| **Iron:**<br>Ambient water-quality criteria:<br>Aquatic life:<br>Chronic: 1,000 µg/L<br>Drinking water:<br>Regulation: 300 µg/L (Secondary Maximum Contaminant Level) | | | | | | | | |
| 6 | Yakima River at Cle Elum | 3 | -- | 1 | -- | -- | 2 | -- |
| 19 | Yakima River at Umtanum | 3 | -- | 2 | -- | -- | 3 | -- |
| 26 | Naches River near North Yakima | 1 | -- | 0 | -- | -- | 1 | -- |
| 32 | Yakima River above Ahtanum Creek at Union Gap | 4 | -- | 2 | -- | -- | 4 | -- |
| 50 | Yakima River at Kiona | 3 | -- | 3 | -- | -- | 3 | -- |
| 52 | Sulphur Creek Wasteway near Sunnyside | 1 | -- | 1 | -- | -- | * | * |
| 56 | Yakima River at Euclid Bridge at river mile 55 near Grandview | 2 | -- | 2 | -- | -- | 2 | -- |
| Percentage of samples that exceeded screening values | | | -- | 65 | -- | -- | 94 | -- |

**Table 8.** Summary of trace-element concentrations in unfiltered-water samples that exceeded screening values derived from water-quality guidelines, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Total number of samples | Number of samples that exceeded screening values | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Ambient water-quality criteria | | | | Drinking-water guidelines | |
| | | | Aquatic life[1] | | Human health[2] | | Regulations[3] | Human-health advisories[4] |
| | | | Acute[5] | Chronic[6] | Aquatic organisms and water[7] | Aquatic organisms only[8] | | |
| **Lead**:<br>Ambient water-quality criteria:<br>Aquatic life:<br>Acute: 1-hour average 34 µg/L once in 3 years<br>Chronic: 4-day average 1.3 µg/L once in 3 years<br>Drinking water:<br>Regulation: 0 µg/L (Maximum Contaminant Level Goal)<br>Note: Because the limit of determination for lead (5 µg/L) exceeds the chronic criterion (1.3 µg/L) and the drinking-water regulation (0 µg/L), censored data (concentrations reported as less than 5 µg/L) were not counted as exceeding these guidelines. | | | | | | | | |
| 6 | Yakima River at Cle Elum | 3 | 0 | 1 | -- | -- | 1 | -- |
| 19 | Yakima River at Umtanum | 3 | 0 | 2 | -- | -- | 2 | -- |
| 32 | Yakima River above Ahtanum Creek at Union Gap | 4 | 0 | 1 | -- | -- | 1 | -- |
| 50 | Yakima River at Kiona | 3 | 0 | 1 | -- | -- | 1 | -- |
| 56 | Yakima River at Euclid Bridge at river mile 55 near Grandview | 2 | 0 | 1 | -- | -- | 1 | -- |
| | Percentage of samples that exceeded screening values | | 0 | 33 | -- | -- | 33 | -- |
| **Manganese**:<br>Drinking water:<br>Regulation: 200 µg/L (Maximum Contaminant Level Goal) | | | | | | | | |
| 56 | Yakima River at Euclid Bridge at river mile 55 near Grandview | 2 | -- | -- | -- | -- | 1 | -- |
| | Percentage of samples that exceeded screening values | | -- | -- | -- | -- | 6 | -- |

**Table 8.** Summary of trace-element concentrations in unfiltered-water samples that exceeded screening values derived from water-quality guidelines, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Total number of samples | Number of samples that exceeded screening values | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Ambient water-quality criteria | | | | Drinking-water guidelines | |
| | | | Aquatic life[1] | | Human health[2] | | | |
| | | | Acute[5] | Chronic[6] | Aquatic organisms and water[7] | Aquatic organisms only[8] | Regulations[3] | Human-health advisories[4] |
| **Mercury**:<br>Ambient water-quality criteria:<br>Aquatic life:<br>Acute: 1-hour average 2.4 µg/L<br>Chronic: 4-day average 0.012 µg/L<br>Human health:<br>Consumption of aquatic organisms and water: 0.14 µg/L<br>Consumption of aquatic organisms only: 0.15 µg/L<br>Note: Human-health guidelines are based on a reference dose (RfD) of $6 \times 10^{-5}$ milligrams per kilogram per day, a bioconcentration factor of 5,500 liters per kilogram, a human consumption rate of fish equal to 6.5 grams per day (about one 6-ounce fillet per month—the national average), a human consumption rate of water equal to 2 liters per day, a human-body weight of 70 kilograms (154 pounds), and a life expectancy of 70 years.[9]<br>Drinking water:<br>Regulation: 2 µg/L (Maximum Contaminant Level)<br>Human-health advisory: 0.4 µg/L Lifetime health advisory (relative-source contribution from drinking water is assumed to be 20 percent)<br>Note: Human-health advisory is based on a reference dose (RfD) of $6 \times 10^{-5}$ milligrams per kilogram per day, a human consumption rate of water equal to 2 liters per day, a human-body weight of 70 kilograms (154 pounds), and a life expectancy of 70 years.[10]<br>Note: Because the limit of determination for mercury (0.1 µg/L) exceeds the chronic criterion (0.012 µg/L), censored data (concentrations reported as less than 0.1 µg/L) were not counted as exceeding the chronic-mercury screening value. | | | | | | | | |
| 6 | Yakima River at Cle Elum | 3 | 0 | 1 | 0 | 0 | 0 | 0 |
| 19 | Yakima River at Umtanum | 3 | 0 | 2 | 2 | 2 | 0 | 0 |
| 26 | Naches River near North Yakima | 1 | 0 | 1 | 1 | 1 | 0 | 1 |
| 32 | Yakima River above Ahtanum Creek at Union Gap | 4 | 0 | 1 | 0 | 0 | 0 | 0 |
| 50 | Yakima River at Kiona | 3 | 0 | 1 | 1 | 1 | 0 | 0 |
| 52 | Sulphur Creek Wasteway near Sunnyside | 2 | 0 | 1 | 0 | 0 | * | * |
| 56 | Yakima River at Euclid Bridge at river mile 55 near Grandview | 2 | 0 | 1 | 1 | 1 | 0 | 0 |
| Percentage of samples that exceeded screening values | | | 0 | 44 | 28 | 28 | 0 | 6 |

**Table 8.** Summary of trace-element concentrations in unfiltered-water samples that exceeded screening values derived from water-quality guidelines, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Total number of samples | Number of samples that exceeded screening values | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Ambient water-quality criteria | | | | Drinking-water guidelines | |
| | | | Aquatic life[1] | | Human health[2] | | | |
| | | | Acute[5] | Chronic[6] | Aquatic organisms and water[7] | Aquatic organisms only[8] | Regulations[3] | Human-health advisories[4] |
| **Silver**: | | | | | | | | |
| Ambient water-quality criteria: | | | | | | | | |
| Aquatic life: | | | | | | | | |
| Acute: 1.2 µg/L at any time | | | | | | | | |
| Chronic: 0.12 µg/L at any time | | | | | | | | |
| Drinking water: | | | | | | | | |
| Regulation: 100 µg/L (Secondary Maximum Contaminant Level) | | | | | | | | |
| Note: Because the limit of determination for silver (1 µg/L) exceeds the chronic criterion (0.12 µg/L), censored data (concentrations reported as less than 1 µg/L) were not counted as exceeding the chronic-silver screening value. | | | | | | | | |
| 19 | Yakima River at Umtanum | 3 | 0 | 1 | -- | -- | 0 | -- |
| 32 | Yakima River above Ahtanum Creek at Union Gap | 4 | 1 | 1 | -- | -- | 0 | -- |
| 52 | Sulphur Creek Wasteway near Sunnyside | 2 | 1 | 1 | -- | -- | * | * |
| Percentage of samples that exceeded screening values | | | 7 | 15 | -- | -- | 0 | -- |

[1] U.S. Environmental Protection Agency (1986, 1992c).

[2] U.S. Environmental Protection Agency (1992c).

[3] U.S. Environmental Protection Agency (1992b)

[4] U.S. Environmental Protection Agency (1992b); Nowell and Resek (1994).

[5] Element concentrations were obtained by instantaneous measurements rather than 1-hour averages.

[6] Element concentrations were obtained by instantaneous measurements rather than 3-day averages.

[7] Assumes that 100 percent of exposure to the element is from consumption of contaminated water and contaminated aquatic organisms.

[8] Assumes that 100 percent of exposure to the element is from consumption of contaminated water.

[9] U.S. Environmental Protection Agency (1992c, 1992d).

[10] U.S. Environmental Protection Agency (1992c, 1992d).

**Table 9.** Summary of estimated total-recoverable iron and manganese concentrations in unfiltered-water samples that exceeded screening values derived from water-quality guidelines, Yakima River Basin, Washington, 1987–90

[The term "unfiltered water" refers to the chemical analysis of a water sample that has not been filtered or centrifuged, nor in any way altered from the original matrix. Estimated total-recoverable concentrations of iron and manganese were derived using prediction equations generated from a least-squares regression made between the measured total-recoverable concentration in unfiltered water and the calculated-total concentrations. Estimated concentrations were evaluated against (1) U.S. Environmental Protection Agency (USEPA) (1986, 1992c) ambient water-quality criteria for the protection of aquatic life, and (2) USEPA (1992b) drinking-water guidelines; µg/L, micrograms per liter; *, waterway not required to meet drinking-water guidelines; --, no current guideline exists]

| Site reference number | Site name | Number of estimated total-recoverable concentrations | Number of samples that exceeded screening values | |
|---|---|---|---|---|
| | | | Aquatic life: Chronic | Drinking-water regulations |
| **Iron**:<br>Ambient water-quality criteria:<br>Aquatic life:<br>Chronic: 1,000 µg/L<br>Drinking water:<br>Regulation: 300 µg/L (Secondary Maximum Contaminant Level) | | | | |
| 6 | Yakima River at Cle Elum | 1 | 1 | 1 |
| 19 | Yakima River at Umtanum | 3 | 2 | 2 |
| 32 | Yakima River above Ahtanum Creek at Union Gap | 12 | 3 | 10 |
| 50 | Yakima River at Kiona | 15 | 5 | 14 |
| 52 | Sulphur Creek Wasteway near Sunnyside | 6 | 5 | * |
| 56 | Yakima River at Euclid Bridge at river mile 55 near Grandview | 4 | 1 | 4 |
| Percentage of estimated concentrations that exceeded screening values | | | 41 | 90 |
| **Manganese:**<br>Drinking water:<br>Regulation: 200 µg/L (Maximum Contaminant Level Goal) | | | | |
| 6 | Yakima River at Cle Elum | 1 | -- | 0 |
| 19 | Yakima River at Umtanum | 4 | -- | 0 |
| 32 | Yakima River above Ahtanum Creek at Union Gap | 12 | -- | 1 |
| 50 | Yakima River at Kiona | 15 | -- | 0 |
| 52 | Sulphur Creek Wasteway near Sunnyside | 6 | -- | * |
| 56 | Yakima River at Euclid Bridge at river mile 55 near Grandview | 4 | -- | 0 |
| Percentage of estimated concentrations that exceeded screening values | | | -- | 2 |

### Human Health

The ambient stream-water criteria for the protection of human health (table 7) consist of ambient concentrations which, for noncarcinogens, prevent adverse health effects in humans and represent various levels of incremental cancer risk for suspected or proven carcinogens. The human-health criteria are designed to indicate human exposure to a contaminant from (1) ingestion of water and aquatic organisms, and (2) ingestion of aquatic organisms (U.S. Environmental Protection Agency, 1992c). In the former, 100 percent of the exposure to humans is assumed to be from consumption of water containing a specified-contaminant concentration and aquatic organisms that have biologically concentrated a contaminant from ambient stream water according to an assumed biological concentration factor (Nowell and Resek, 1994; U.S. Environmental Protection Agency, 1992c). In the latter, 100 percent of the exposure to humans is assumed to be from consumption of aquatic organisms that have biologically concentrated a contaminant from water on the basis of a bioconcentration factor. Equations for deriving ambient-contaminant concentrations for the protection of human health are given in Nowell and Resek (1994). The following discussion is focused principally on arsenic (a carcinogen) and mercury (a noncarcinogen); concentrations of each exceeded screening values for human health.

For carcinogens, the human-health criteria are derived from a two-part evaluation in which the trace element is assigned a weight of evidence classification and a slope factor. The weight of evidence classification is the likelihood that a trace element is a human carcinogen. Arsenic, which is measured in filtered-water samples in the Yakima River Basin, has a "Group A" weight-of-evidence classification—a human carcinogen (U.S. Environmental Protection Agency, 1989). The slope factor is generally a plausible upper-bound estimate (95-percent confidence limit) of a human developing cancer as a result of a lifetime (70 years) of exposure to a particular level of a potential carcinogen. Slope factors are derived from mathematical models that are used on available data sets. These models extrapolate from carcinogenic responses observed at high doses in experimental animals to responses expected in humans from lower exposure levels in the environment. If the extrapolation model selected is USEPA's linearized-multistage model (as in the case of arsenic) then the resultant slope factor is known as $q_1$* (U.S. Environmental Protection Agency, 1989).

For example, the slope factor or $q_1$* for arsenic is a 1.75 risk per milligram contaminant per kilograms body weight per day $(mg/kg/d)^{-1}$ (U.S. Environmental Protection Agency, 1992c). For carcinogens, the derivation of human-health criteria for ambient stream water is contingent on several additional assumptions which include:

Risk Level (RL) = an assigned level of maximum-acceptable individual-lifetime risk. Screening values for human health are based on a RL = $10^{-5}$which is a level of risk not to exceed one excess case of cancer per 100,000 individuals exposed over a 70-year lifetime (U.S. Environmental Protection Agency, 1993).

Consumption Rate (CR) = Mean daily consumption rate, in kilograms per day (kg/d), of the species of interest by the general population or subpopulation of concern averaged over a 70-year lifetime. Screening values for human health were derived using a CR of 0.0065 kg/d—an estimate of the average fish and shellfish consumption by the general United States population (U.S. Environmental Protection Agency, 1993). The value is approximately one 6-oz (ounce) fillet of fish per month. In addition, screening concentrations which include a measure of chemical uptake from the consumption of water (for example, USEPA's health advisories for drinking water), or from the consumption of water and fish, use a CR of 2 liters of water per day—an estimate of the average water consumption by the general United States population.

Body Weight (BW) = Mean body weight, in kilograms, of a standard adult within the general population or subpopulation of concern. Screening values for human health were derived using a BW of 70 kg (about 154 pounds, the average weight of the general United States population).

Biological Concentration Factor = the ratio of the contaminant concentration in an aquatic organism, in milligrams per kilograms, to the contaminant concentration in the surrounding water, in milligrams per liter, and is reported in units of liters per kilogram. A weighted-average biological concentration factor (BCF), adjusted to the average percent lipids in fish and shellfish (3 percent), is used by USEPA in deriving human-health guidelines (U.S. Environmental Protection Agency, 1992c).

Concentrations of arsenic in ambient stream water (filtered-water samples) in the Yakima River Basin exceeded the screening value (based on USEPA's ambient stream-water-quality criteria) for consumption of aquatic organisms and water (0.18 μg/L) at seven sites, and overall, exceeded the screening value in 43 percent of the samples (table 7). Additionally, arsenic concentrations in ambient stream water did not meet the screening value for consumption of aquatic organisms (1.4 μg/L) at four sites, and overall, exceeded the screening values in 30 percent of the samples (table 7). Exceedances of arsenic were found predominantly in the lower Yakima Valley. The screening value for arsenic is based only on the inorganic form (U.S. Environmental Protection Agency, 1992e). The arsenic determination in the Yakima River Basin study, however, is based on the organic and inorganic forms of arsenic. As a conservative assumption for screening, arsenic is assumed to reside in ambient water in the pentavalent and (or) trivalent forms—the former being most likely in surface water (Eisler, 1988, p. 8). Methylated forms of arsenic also reside in surface water; their exact proportions, however, are not known (Hem, 1989, p. 144). Methylated forms are significantly less toxic than inorganic forms of arsenic (U.S. Environmental Protection Agency, 1993, p. III–56; U.S. Environmental Protection Agency, 1992e).

For noncarcinogens, the screening values are based on a Reference Dose (RfD) which represents a daily exposure (with uncertainty spanning perhaps an order of magnitude or more) to the human population (including sensitive subpopulations) that is probably without appreciable risk of causing deleterious effects during a 70-year lifetime (U.S. Environmental Protection Agency, 1992d). Addi tionally, the assumptions listed for BW, CR, and BCF are used in determining screening values for human health. Screening values are derived from USEPA ambient water-quality criteria for human health (U.S. Environmental Protection Agency, 1992c).

For the purpose of calculating screening values for mercury (a noncarcinogen), USEPA recommends that the RfD for methylmercury be lowered from 0.0003 mg/kg/d to $6.0 \times 10^{-5}$ mg/kg/d (U.S. Environmental Protection Agency, 1992d). The lowering of the RfD is based on evidence that human fetuses, and possibly pregnant women, are at increased risk of adverse neurological effects from exposure to methylmercury (U.S. Environmental Protection Agency, 1992d).

Under the usual conditions of temperature and pressure, mercury in surface water exists in inorganic forms, which include the liquid ($Hg^0$) and the ionic ($Hg_2^+$ and $Hg^{2+}$) states. In addition, inorganic forms in sediment and water can be methylated to highly soluble and toxic methylmercury (Moore, 1991). The analytical technique used in the Yakima River Basin study for measuring mercury in ambient stream water is defined as a total- (inorganic plus organic) mercury analysis. For screening purposes, total-mercury concentrations are compared to the screening values for human health. Using total-mercury concentrations for comparison to screening values is conservative, because 100 percent of the mercury that accumulates in fish tissue (based on a BCF) is assumed to be in the toxic methylmercury form. It is this methylated form of mercury that is highly toxic to humans (U.S. Environmental Protection Agency, 1992d).

Concentrations of filtered mercury in ambient stream water in the Yakima River Basin exceeded the human-health screening value for consumption of aquatic organisms and water (0.14 μg/L) at six of the seven fixed sites, and overall, exceeded the screening value in 4 percent of the samples. Because the criterion for consumption of aquatic organisms is similar (0.15 μg/L) to the human-health screening value, the frequency and occurrence of exceedances for consumption of aquatic organisms is identical to that for consumption of aquatic organisms and water (table 7).

Concentrations of mercury in unfiltered-ambient water in the Yakima River Basin exceeded the human-health screening value for consumption of aquatic organisms and water at four of the seven fixed sites—exceedances are identical for consumption of aquatic organisms (table 8). Using mercury concentrations from unfiltered-water samples for comparison to screening values is not conservative, and exceedances should be interpreted accordingly.

### Drinking Water

Trace-element concentrations determined from filtered- and unfiltered-water samples were screened by making comparisons with USEPA drinking-water regulations (U.S. Environmental Protection Agency, 1992c) and USEPA advisories for human health (U.S. Environmental Protection Agency, 1992b).

The water samples from the Yakima River Basin that were compared to drinking-water guidelines represent untreated water (ambient stream water rather than finished or treated water available for distribution to community-water supplies). The principal sites for diverting stream water to water-treatment plants for the cities of Cle Elum and Yakima, respectively, are located on the Yakima River (RM 183) and on the Naches River (RM 18.4). The Yakima River at Cle Elum (RM 183) was the only sampling site adjacent to a water-treatment-plant intake. Although nearly all sites sampled in this study were not sources for domestic-water supplies, water-quality exceedances were important because many of these sites reside in streams classified by the State of Washington as AA- or A-type waters. Classifications AA and A require that water "shall markedly and uniformly exceed requirements for all uses," which include domestic-water supplies (Washington State Administrative Code, 1992). It is important to note, however, that "although a surface water in Washington State may be designated as a potential domestic-water source," in Chapter 173–201 in the Washington State Administrative Code (1992), "approval for such use must first be obtained from the Washington State Department of Health following an evaluation of the water quality" (Harriet Ammann, Denise Laflamme, and Glen Patrick, Washington State Department of Health, written commun., 1993). Thus, trace-element concentrations that exceed screening values (drinking-water regulations) in filtered and unfiltered stream-water samples are not an indication that human health is directly at risk.

#### Regulations

The types of primary and secondary drinking-water regulations set forth by USEPA include Maximum Contaminant Levels (MCLs), Maximum Contaminant Level Goals (MCLGs), and Secondary Maximum Contaminant Levels (SMCLs) (U.S. Environmental Protection Agency, 1991). The MCLs represent achievable levels of drinking-water quality that take into consideration health effects, treatment feasibility, and aesthetic considerations. The MCLGs are nonenforceable health goals that are not expected to cause any adverse human-health effects over a lifetime of exposure and include a margin of safety. The SMCLs are unenforceable guidelines regarding the taste, odor, color, and certain other, nonaesthetic effects of drinking water.

Concentrations of lead in filtered-water samples did not meet the screening value (based on the MCLG for drinking water) at six sites, and overall, exceeded the screening value in 6 percent of the samples (table 7). In the Yakima River at Kiona, a fixed site, lead was detected in 6 of 40 determinations for 1987–90—the MCLG for lead is 0 µg/L. Kiona had the largest number of detectable lead concentrations; the next largest concentrations of lead were detected in the Naches River near North Yakima, also a fixed site, which had detectable lead in 4 of 37 determinations. Manganese did not meet the MCLG at site 35, a drain that receives agricultural runoff at Progressive Road near Harrah. Analysis of historical water-quality data (1953–85) in the Yakima River Basin shows that drinking-water exceedances for lead and manganese represent about 2 percent of the total number of historical determinations (Rinella and others, 1992). During the July 1987 synoptic sampling, a concentration of 30 µg/L of lead was detected by ICP in the Yakima River at RM 91 at Zillah; however, during a followup sampling in November 1987, lead was below the analytical limit of determination. The high lead concentration in July 1987 corresponds to anomalous concentrations of chromium and zinc and probably indicates the inadvertent use of a brass sampler.

Concentrations of iron in unfiltered-water samples did not meet the screening value (based on the SMCL for drinking water) at six of the fixed sites and, overall, exceeded the SMCL in 94 percent of the samples (table 8). However, because the corresponding iron concentrations in filtered-water samples met the SMCL, the exceedances in unfiltered water probably resulted from iron associated with sediment. Additionally, iron associated with sediment probably would be removed in the water-treatment process. The percentage of estimated total-recoverable concentrations that did not meet the SMCL for iron (table 9) was similar to that for iron in unfiltered-water samples. Again, however, the exceedances probably resulted from iron associated with sediment. The concentration of suspended sediment associated with iron exceedances ranged from 19 to 212 mg/L; however, concentrations associated with nonexceedances were less than or equal to 16 mg/L. The concentration of manganese in an unfiltered-water sample collected in the Yakima River at Euclid Bridge at RM 55 near Grandview (table 8) did not meet the MCLG (200 µg/L). Of 42 estimated total-recoverable manganese concentrations,[7] only one value exceeded the MCLG (table 9). This value was determined from a sample collected in November 1987 at the Yakima River above Ahtanum Creek at Union Gap, which contained high concentrations of suspended sediment (137 mg/L) and suspended manganese (2,930 µg/g).

### Health Advisories

Concentrations of trace elements in filtered- and unfiltered-water samples are screened for human-health effects by making comparisons to human-health advisories for drinking water (U.S. Environmental Protection Agency, 1992b). For the carcinogen arsenic, the human-health advisory listed in table 7 is a risk specific dose (RSD) associated with a specified RL and is calculated from the $q_1$* for arsenic (Nowell and Resek, 1994). For the noncarcinogen mercury, the human-health advisory listed in table 7 is a lifetime-health advisory which is equal to 20 percent of the drinking water equivalent level (Nowell and Resek, 1994). Unlike the ambient water-quality criteria, however, health advisories are based only on the consumption of domestic water. In the Yakima River Basin study, ambient stream water is used to screen for health effects. Additionally, the aforementioned assumptions for BW, CR (2 liters of water per day), and RL ($10^{-5}$) are applicable to screening values for health advisories.

Concentrations of arsenic in ambient stream water (filtered-water samples) in the Yakima River Basin exceeded the screening value (USEPA's RSD of 0.2 µg/L) for consumption of domestic drinking water at six sites and overall exceeded the screening value in 31 percent of the samples (table 7). The largest number of exceedances were in the lower Yakima Valley. For example, 20 of 25 ambient stream-water samples collected from the Yakima River at Kiona from 1987 to 1990 exceeded the screening value. Although all 15 arsenic determinations at Sulphur Creek Wasteway near Sunnyside would have exceeded the screening value, these determinations were omitted from table 7 because Sulphur Creek is designated Class B in the Washington State Administrative Code (1992). Class B waterways are not required to meet water-quality guidelines for domestic water supplies. The arsenic concentrations in Sulphur Creek (especially during base-flow conditions), however, may be indicative of arsenic concentrations in shallow domestic groundwater supplies in the Sulphur Creek drainage.

Concentrations of mercury in ambient stream water (filtered-water samples) rarely exceeded the screening value (USEPA's lifetime-health advisory of 0.4 µg/L). The two exceedances measured were in the Kittitas Valley—one from the Yakima River at Cle Elum and the other from the Yakima River at Umtanum (table 7). These exceedances, however, represent only 1 percent of all the samples.

## Fish Muscle

Fish muscle was analyzed for mercury for various fish taxa collected from four sites in 1991 (table 10). Sites sampled in 1991 generally coincided with mercury anomalies in fish livers from samplings in 1989–90 (Fuhrer, Fluter, and others, 1994). The median mercury concentration in fish muscle and for each fish species from each site (table 10) was screened against mercury concentrations in fish that are of potential public-health concern. According to the USEPA, "exceedance of screening values should be taken as an indication that more intensive site-specific monitoring and (or) evaluation of human-health risk should be done" (U.S. Environmental Protection Agency, 1992d). State and local health agencies are responsible for issuing advice and (or) formal advisories to protect the health of their constituents.

The screening values for mercury in fish muscle are calculated from a dose-response variable which, for noncarcinogens such as mercury, is the *RfD*. Additionally, the assumptions listed above for *BW* and *CR* also are applicable. Screening values are determined for noncarcinogens by the following equation:

$$SV_n = \frac{RfD \times BW}{CR} ,$$

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[7] The regression for manganese yielded an R-squared value of 0.78 and a prediction equation, y = 20.4+0.74 x (y = estimated total-recoverable manganese concentration; x = calculated total-manganese concentration).

**Table 10.** Concentrations of mercury in muscle of rainbow trout, largescale sucker, and mountain whitefish, Yakima River Basin, Washington, October 29–31, 1991

[Concentrations are reported in micrograms per gram (μg/g), dry weight; sample species: rainbow trout (*Oncorhynchus mykiss*), largescale sucker (*Catostomus macrocheilus*), and mountain whitefish (*Prosopium williamsoni*)]

| Site reference number | Site name | Species sampled | Concentrations |
|---|---|---|---|
| 8 | Taneum Creek at Taneum Meadow near Thorp | Rainbow trout | 0.32 |
| | | | .20 |
| | | | .20 |
| | | | .25 |
| | | | .25 |
| 19 | Yakima River at Umtanum | Rainbow trout | .30 |
| 22 | Rattlesnake Creek above North Fork Rattlesnake Creek near Nile | Rainbow trout | .18 |
| | | | .17 |
| | | | .21 |
| | | | .20 |
| | | | .17 |
| 50 | Yakima River at Kiona | Largescale sucker | .41 |
| | | | .84 |
| | | | 1.05 |
| | | | .89 |
| | | | 1.56 |
| | | | .98 |
| | | | 1.00 |
| | | Mountain whitefish | .23 |
| | | | .38 |
| | | | .58 |
| | | | .29 |
| | | | .31 |
| | | | .25 |
| | | | .28 |

where $SV_n$ is the screening value for a noncarcinogen in units of milligrams per kilogram and BW and CR are defined earlier. Recognizing that screening levels change as CR and (or) BW vary, screening levels are calculated for standard adults, children, recreational fishermen, and subsistence fishermen (table 11). The USEPA applies an uncertainty factor of 1,000 to the RfD as a safeguard to account for uncertainty in projecting human-health effects over a 70-year lifetime from animal studies of less than a lifetime duration (Moore, 1991, p. 205). In addition to applying an uncertainty factor, the USEPA also has lowered the RfD to $6.0 \times 10^{-5}$ for screening purposes as a conservative measure to prevent adverse neurological effects from exposure to methylmercury (U.S. Environmental Protection Agency, 1992c).

Muscle samples collected from rainbow trout and mountain whitefish at four sites in the Yakima River Basin contained mercury concentrations that were below the screening-value standards for adults (table 11). The standard-adult screening value is based on the consumption of about one 6-ounce fillet per month for a 70-kg adult over a 70-year lifetime. Mercury concentrations in fish muscle of largescale sucker collected in the Yakima River at Kiona, however, exceeded the USEPA screening value (0.65 μg/g) for standard adults. Because some

**Table 11.** Concentrations of mercury in fish muscle relative to U.S. Environmental Protection Agency screening values, Yakima River Basin, Washington, October 29–31, 1991

[Shaded areas represent instances where median mercury concentrations in fish muscle exceeded the screening values determined by the U.S. Environmental Protection Agency (USEPA) [1992d]. Screening values are based on a reference dose (RfD) for mercury of 0.00006 milligram per kilogram per day (mg/kg/d). The reference dose is defined as the preferred toxicity value set by USEPA for evaluating noncarcinogenic effects resulting from exposure of the human population to the specified element (U.S. Environmental Protection Agency, 1989). Human consumption rates of fish are equal to (1) 6.5 grams per day (g/day), about one 6-ounce fillet per month—the national average, (2) 30 g/day, about five 6-ounce fillets per month—the 50th percentile for recreational fishermen, and (3) 140 g/day, about 25 6-ounce fillets per month—the 90th percentile for recreational fishermen (for example, subsistence fishermen); a body weight of 12 kilograms (26 pounds) is assumed for children of 3 years and younger; a body weight of 70 kilograms (154 pounds) is assumed for standard adults. Sample species: rainbow trout (*Oncorhynchus mykiss*), largescale sucker (*Catostomus macrocheilus*), mountain whitefish (*Prosopium williamsoni*); kg, kilogram; µg/g, micrograms per gram]

| Site reference number | Site name | Species sampled | Subpopulation | Consumption rate (g/day) | Body weight (kg) | Mercury<br>Screening value (µg/g) | Mercury<br>Median concentration[1] (µg/g) |
|---|---|---|---|---|---|---|---|
| 8 | Taneum Creek at Taneum Meadow near Thorp | Rainbow trout | Children | 6.5 | 12 | 0.11 | 0.25 |
| | | | Standard adults | 6.5 | 70 | .65 | .25 |
| | | | Recreational fishermen | 30 | 70 | .14 | .25 |
| | | | Subsistence fishermen | 140 | 70 | .03 | .25 |
| 19 | Yakima River at Umtanum | Rainbow trout | Children | 6.5 | 12 | .11 | .30 |
| | | | Standard adults | 6.5 | 70 | .65 | .30 |
| | | | Recreational fishermen | 30 | 70 | .14 | .30 |
| | | | Subsistence fishermen | 140 | 70 | .03 | .30 |
| 22 | Rattlesnake Creek above North Fork Rattlesnake Creek near Nile | Rainbow trout | Children | 6.5 | 12 | .11 | .18 |
| | | | Standard adults | 6.5 | 70 | .65 | .18 |
| | | | Recreational fishermen | 30 | 70 | .14 | .18 |
| | | | Subsistence fishermen | 140 | 70 | .03 | .18 |
| 50 | Yakima River at Kiona | Largescale sucker | Children | 6.5 | 12 | .11 | .98 |
| | | | Standard adults | 6.5 | 70 | .65 | .98 |
| | | | Recreational fishermen | 30 | 70 | .14 | .98 |
| | | | Subsistence fishermen | 140 | 70 | .03 | .98 |
| | | Mountain whitefish | Children | 6.5 | 12 | .11 | .29 |
| | | | Standard adults | 6.5 | 70 | .65 | .29 |
| | | | Recreational fishermen | 30 | 70 | .14 | .29 |
| | | | Subsistence fishermen | 140 | 70 | .03 | .29 |

[1] Median mercury concentrations for fish muscle from the Yakima River Basin; see table 10 for individual values.

individuals consume different quantities of fish and differ in body weight, USEPA screening values are calculated for subpopulations that include children, recreational fishermen, and subsistence fishermen in addition to standard adults (table 11). The concentration of mercury in fish muscle consumed by children eating an average of one 6-ounce fillet per month exceeded the screening value (0.11 µg/g) for all species sampled and at all sites sampled. Similarly, screening values of 0.14 and 0.03 µg/g were exceeded, respectively, by recreational fishermen (consumers of an average of about five 6-ounce fillets per month) and subsistence fishermen (consumers of an average of about 25 6-ounce fillets per month) for all fish species sampled and at all sites sampled.

The screening values derived for mercury are based on the assumption that mercury resides in or has been converted to methylmercury in fish muscle that is consumed by humans. Total mercury, rather than methylmercury, was measured in the Yakima River Basin study in accordance with the USEPA recommendation that total mercury be determined and the conservation assumption be made that all mercury is present as methylmercury. This approach has been deemed the most protective of human health because methylmercury is the most toxic mercury form for humans, and also because methylmercury is the most common form measured in fish muscle (U.S. Environmental Protection Agency, 1992d).

## SPATIAL AND TEMPORAL DISTRIBUTION OF TRACE ELEMENTS IN THE AQUATIC ENVIRONMENT

The spatial distribution of trace elements in sediment, water, and aquatic organisms in the Yakima River Basin is governed by factors which include: natural weathering and erosion of rocks and soils of the Cascade Range; decomposition of plant and animal matter; atmospheric deposition affected by natural events (ash fallout from the volcanic eruption of Mount St. Helens); human activities (combustion of fossil fuels and air emissions from industrial processes); transportation; municipal and industrial wastewater; urban stormwater runoff; paints; fertilizers; and pesticides. Data for trace-element concentrations (including some major elements) and organic carbon in streambed sediment, suspended sediment, filtered water, and aquatic organisms were collated and statistically summarized as percentiles (tables 12, 13, 14, and 15).

### Antimony

Concentrations of antimony in streambed sediment at the 32 biological-sampling sites ranged from 0.2 to 1.4 µg/g (table 12) and are within the range of concentration (0.1 to 1.5 µg/g) reported by Parker (1967) for igneous and sedimentary rock on the Earth's surface. The median concentration (0.4 µg/g) of antimony at the biological sites is slightly smaller than that determined from analysis of fine-fraction streambed sediment in other river basins of the United States (table 34, at back of report). The concentration maximum (1.4 µg/g) for the biological sampling sites, found in streambed sediment at the Naches River near north Yakima (site 26), probably is related to a geologic source. The headwaters of the Naches River contained large concentrations of antimony. For example, 3.0 µg/g of antimony was found in streambed sediment, formed from Miocene and older volcanic rock, in the American River (Fuhrer, McKenzie, and others, 1994). Although antimony has a variety of industrial sources (Sittig, 1981) and would be expected at enriched levels at the mouths of urban and industrialized tributaries to the main stem, few cases of antimony enrichment were found in the Yakima River Basin during the occurrence and distribution survey (Fuhrer, McKenzie, and others, 1994); additionally, antimony enrichment was attributed to geologic sources.

Concentrations of antimony in suspended sediment at the seven fixed sites ranged from 0.5 to 3.1 µg/g (table 13). The highest concentrations were in the Yakima River at Cle Elum (site 6). Here, the median (0.8 µg/g) and maximum (3.1 µg/g) concentration exceeded concentrations measured at the other fixed sites in the Yakima River Basin (fig. 6 and table 35 at back of report). Large concentrations of antimony are not unprecedented in streambed sediment in the Cle Elum River drainage. Of the 407 sites sampled for antimony in streambed sediment during the occurrence and distribution survey (Fuhrer, McKenzie, and others, 1994), the maximum concentration (4.8 µg/g) is in the Cle Elum River drainage—an area in which the U.S. Geological Survey (1989) reported the presence of pyrite (iron sulfide), galena (lead sulfate), and sphalerite (zinc-iron sulfide), all known sources of antimony (Levinson, 1980).

Concentrations of suspended antimony as high as 2.6, 3.1, and 2.3 µg/g were measured in May 1989, January 1990, and February 1990, respectively, in the Yakima River at Cle Elum. The highest concentration

**Table 12.** Summary of major- and trace-element concentrations in streambed sediment, Yakima River Basin, Washington, 1987–91

[To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate at a site, only one element concentration per site was statistically summarized. Concentrations of major elements are given as percentages. Concentrations of trace elements are in units of micrograms per gram (μg/g), dry weight. Data statistically summarized in this table are from Fuhrer and others (1994). Element names and percentile concentrations shown in bold print are U.S. Environmental Protection Agency (1992c) Priority Pollutants; <, less than]

| Element | Number of sites | Minimum value | Value at indicated percentile | | | | | | Maximum value |
|---|---|---|---|---|---|---|---|---|---|
| | | | 10 | 25 | 50 | 75 | 90 | 95 | |
| | | | | Major Elements | | | | | |
| Aluminum | 32 | 5.8 | 6.3 | 6.8 | 7.1 | 7.6 | 8.0 | 8.2 | 8.2 |
| Calcium | 32 | .8 | 1.8 | 2.1 | 2.5 | 2.9 | 3.0 | 3.1 | 3.2 |
| Carbon, inorganic | 32 | <.01 | <.01 | <.01 | <.01 | <.01 | .1 | .1 | .1 |
| Carbon, total | 32 | .4 | .7 | 1.5 | 2.3 | 4.0 | 5.7 | 7.5 | 9.2 |
| Iron | 32 | 3.9 | 4.3 | 4.9 | 5.1 | 5.7 | 6.6 | 7.1 | 7.3 |
| | | | | | | | | | |
| Magnesium | 32 | .7 | .9 | 1.2 | 1.3 | 1.4 | 1.8 | 2.3 | 2.6 |
| Phosphorus | 32 | .1 | .1 | .1 | .1 | .1 | .1 | .2 | .2 |
| Potassium | 32 | .7 | .8 | .9 | 1.0 | 1.3 | 1.4 | 1.4 | 1.5 |
| Sodium | 32 | 1.1 | 1.2 | 1.4 | 1.6 | 1.7 | 1.9 | 2.0 | 2.0 |
| Sulfur | 32 | <.05 | <.05 | <.05 | <.05 | .1 | 1.2 | 3.3 | 5.3 |
| | | | | | | | | | |
| Titanium | 32 | .3 | .6 | .6 | .7 | .8 | 1.0 | 1.0 | 1.1 |
| | | | | Trace Elements | | | | | |
| **Antimony**[1] | 17 | .2 | .3 | .3 | .4 | .6 | .9 | 1.4 | 1.4 |
| **Arsenic** | 32 | 1.1 | 1.5 | 2.4 | 3.7 | 5.7 | 12 | 35 | 45 |
| Barium | 32 | 380 | 393 | 447 | 480 | 530 | 563 | 584 | 590 |
| **Beryllium** | 32 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 3 |
| Bismuth | 32 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| | | | | | | | | | |
| Boron | 16 | .4 | .4 | .5 | .8 | 1.4 | 3.6 | 4.0 | 4.0 |
| **Cadmium**[2] | 27 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 |
| **Cadmium**[3] | 5 | .2 | .2 | .2 | .2 | .2 | .5 | .6 | .8 |
| Cerium | 32 | 35 | 37 | 39 | 45 | 56 | 74 | 91 | 94 |
| **Chromium** | 32 | 21 | 44 | 53 | 62 | 79 | 170 | 210 | 210 |
| | | | | | | | | | |

**Table 12.** Summary of major- and trace-element concentrations in streambed sediment, Yakima River Basin, Washington, 1987–91—Continued

| Element | Number of sites | Minimum value | Value at indicated percentile |  |  |  |  |  | Maximum value |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  | 10 | 25 | 50 | 75 | 90 | 95 |  |
| Trace Elements |  |  |  |  |  |  |  |  |  |
| Cobalt | 32 | 14 | 16 | 19 | 20 | 23 | 30 | 32 | 33 |
| **Copper** | **32** | **17** | **21** | **25** | **30** | **42** | **70** | **94** | **96** |
| Europium | 32 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | 2 |
| Gallium | 32 | 15 | 15 | 17 | 18 | 19 | 20 | 20 | 21 |
| Gold | 32 | <8 | <8 | <8 | <8 | <8 | <8 | <8 | <8 |
|  |  |  |  |  |  |  |  |  |  |
| Lanthanum | 32 | 18 | 20 | 22 | 24 | 29 | 38 | 48 | 51 |
| **Lead** | **32** | **9** | **11** | **12** | **14** | **17** | **32** | **49** | **63** |
| Lithium | 32 | 17 | 19 | 21 | 24 | 28 | 35 | 45 | 45 |
| Manganese | 32 | 550 | 760 | 860 | 1,000 | 1,200 | 1,500 | 1,600 | 1,700 |
| **Mercury** | **32** | **<.02** | **<.02** | **<.02** | **.1** | **.2** | **.3** | **.5** | **.6** |
|  |  |  |  |  |  |  |  |  |  |
| Molybdenum | 32 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | 2 |
| Neodymium | 32 | 19 | 21 | 23 | 26 | 30 | 35 | 45 | 45 |
| **Nickel** | **32** | **9** | **17** | **20** | **27** | **37** | **82** | **190** | **260** |
| Niobium | 32 | <4 | <4 | 5 | 8 | 9 | 10 | 13 | 15 |
| Scandium | 32 | 13 | 15 | 18 | 20 | 21 | 25 | 27 | 29 |
|  |  |  |  |  |  |  |  |  |  |
| **Selenium** | **23** | **<.4** | **<.4** | **<.4** | **.4** | **.7** | **.9** | **1.0** | **1.0** |
| Silver | 32 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | 3 |
| Strontium | 32 | 140 | 210 | 230 | 260 | 290 | 310 | 340 | 350 |
| Thorium | 32 | <4 | 4 | 5 | 6 | 7 | 10 | 12 | 15 |
| Tin | 32 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
|  |  |  |  |  |  |  |  |  |  |
| Uranium[4] | 24 | <.05 | .1 | .7 | 1.1 | 1.4 | 1.9 | 3.0 | 3.3 |
| Vanadium | 32 | 84 | 113 | 130 | 140 | 180 | 220 | 230 | 24 |
| Ytterbium | 32 | 2 | 2 | 2 | 3 | 3 | 3 | 4 | 4 |
| Yttrium | 32 | 19 | 19 | 21 | 23 | 26 | 29 | 35 | 380 |
| **Zinc** | **32** | **77** | **84** | **95** | **100** | **110** | **170** | **200** | **210** |

[1] For antimony, two limits of determination (LD) exist (0.1 µg/g and 0.7 µg/g). "Less than" values for the higher LD of 0.7 µg/g were not statistically summarized.

[2] Analyzed by inductively coupled plasma-atomic emission spectroscopy (ICP-AES); limit of determination = 2.0 µg/g.

[3] Analyzed by ICP-AES with organometallic-halide extraction; limit of determination = 0.05 µg/g.

[4] For uranium, two different methods of determination were used with different LDs (0.05 µg/g and 100 µg/g). "Less than" values for the higher LD of 100 µg/g were not statistically summarized.

**Table 13.** Summary of major- and trace-element concentrations in suspended sediment, Yakima River Basin, Washington, 1987–90

[Data statistically summarized in this table are from sites 6, 19, 26, 32, 50, 52, and 56 (see table 1). To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate at a site, only one element concentration per visit was statistically summarized. Concentrations of major elements are given as percentages, except suspended organic carbon, which is in milligrams per liter (mg/L). Concentrations of trace elements are in units of micrograms per gram (µg/g). Element names and percentile concentrations shown in bold print are U.S. Environmental Protection Agency (1992c) Priority Pollutants; <, less than]

| Element | Number of samples | Minimum value | Value at indicated percentile | | | | | | Maximum value |
|---|---|---|---|---|---|---|---|---|---|
| | | | 10 | 25 | 50 | 75 | 90 | 95 | |
| Major Elements | | | | | | | | | |
| Aluminum | 211 | 4.6 | 6.3 | 6.6 | 6.9 | 7.3 | 7.7 | 8.3 | 9.7 |
| Calcium | 211 | 1.2 | 1.8 | 2.0 | 2.2 | 2.5 | 2.9 | 3.0 | 3.5 |
| Carbon, suspended organic | 203 | <.1 | .2 | .4 | .6 | 1.3 | 2.5 | 2.9 | 4.9 |
| Iron | 211 | 3.8 | 4.7 | 4.9 | 5.2 | 5.5 | 5.7 | 5.9 | 8.1 |
| Magnesium | 210 | .8 | 1.1 | 1.2 | 1.4 | 1.4 | 1.6 | 1.7 | 2.4 |
| Phosphorus | 211 | .10 | .13 | .14 | .16 | .18 | .21 | .24 | 1.2 |
| Potassium | 211 | .70 | .90 | 1.0 | 1.2 | 1.4 | 1.6 | 1.6 | 2.4 |
| Sodium | 211 | .8 | 1.0 | 1.2 | 1.3 | 1.4 | 1.6 | 1.7 | 2.4 |
| Titanium | 211 | .4 | .5 | .5 | .6 | .6 | .7 | .7 | .8 |
| Trace Elements | | | | | | | | | |
| **Antimony** | **211** | **.3** | **.5** | **.5** | **.6** | **.7** | **.8** | **.9** | **3.1** |
| **Arsenic** | **211** | **2.8** | **4.7** | **5.4** | **6.6** | **8.2** | **11** | **14** | **20** |
| **Beryllium** | **211** | **<2** | **<2** | **<2** | **<2** | **<2** | **2** | **2** | **3** |
| **Cadmium** | **211** | **<.1** | **.2** | **.3** | **.5** | **.7** | **1.4** | **1.7** | **32.6** |
| **Chromium** | **184** | **28** | **46** | **55** | **60** | **83** | **110** | **120** | **160** |
| Cobalt | 211 | 13 | 18 | 19 | 21 | 22 | 24 | 25 | 31 |
| **Copper** | **211** | **21** | **33** | **39** | **44** | **55** | **74** | **96** | **680** |
| **Lead** | **211** | **6** | **12** | **15** | **19** | **24** | **27** | **30** | **410** |
| Manganese | 211 | 910 | 1,200 | 1,400 | 1,900 | 2,900 | 3,500 | 4,000 | 6,300 |
| Molybdenum | 211 | <.1 | <.1 | .6 | .6 | .8 | 1.1 | 1.4 | 3.0 |
| **Nickel** | **184** | **12** | **22** | **29** | **37** | **55** | **82** | **105** | **170** |
| Silver | 211 | <.1 | .2 | .2 | .4 | .5 | .9 | 1.3 | 7.7 |
| **Thallium** | **211** | **.1** | **.2** | **.3** | **.4** | **0.4** | **.5** | **.5** | **.6** |
| Vanadium | 211 | 101 | 121 | 131 | 142 | 149 | 160 | 166 | 193 |
| **Zinc** | **184** | **88.0** | **112** | **123** | **142** | **172** | **202** | **231** | **521** |

**Table 14.** Summary of major- and trace-element concentrations in filtered-water samples, Yakima River Basin, Washington, 1987–90

[The term "filtered water" is an operational definition referring to the chemical analysis of that portion of a water-suspended sediment sample that passes through a nominal 0.45-micrometer filter. To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate, only one element concentration per visit was statistically summarized. Data statistically summarized in this table are from sites 6, 19, 26, 32, 50, 52, and 56 (see table 1). All concentrations listed below are in micrograms per liter (μg/L), except organic carbon, hardness, and bromide, which are given in milligrams per liter (mg/L). Element names and percentile concentrations shown in bold print are U.S. Environmental Protection Agency (1992c) Priority Pollutants. For cadmium, chromium, copper, and lead, only samples analyzed by atomic absorption spectroscopy with graphite furnace (AAGF) were statistically summarized; <, less than]

| Element | Number of samples | Minimum value | Value at indicated percentile | | | | | | Maximum value |
|---|---|---|---|---|---|---|---|---|---|
| | | | 10 | 25 | 50 | 75 | 90 | 95 | |
| | | | Major Elements | | | | | | |
| Aluminum | 27 | <10 | <10 | <10 | 10 | 20 | 50 | 150 | 210 |
| Carbon, organic | 275 | .4 | 1.2 | 1.5 | 2.0 | 2.6 | 3.5 | 4.4 | 8.0 |
| Hardness | 292 | 18 | 25 | 34 | 54 | 95 | 120 | 250 | 270 |
| Iron | 36 | 8 | 13 | 18 | 28 | 39 | 57 | 101 | 250 |
| | | | Trace Elements | | | | | | |
| **Antimony** | **18** | **<1** | **<1** | **<1** | **<1** | **<1** | **<1** | **1** | **1** |
| **Arsenic** | **106** | **<1** | **<1** | **<1** | **<1** | **2** | **3** | **7** | **9** |
| Barium | 36 | <2 | 3 | 6 | 10 | 26 | 40 | 74 | 79 |
| **Beryllium** | **36** | **<.5** | **<.5** | **<.5** | **<.5** | **<.5** | **<.5** | **<.5** | **<.5** |
| Boron | 23 | <10 | <10 | 10 | 20 | 20 | 40 | 40 | 40 |
| | | | | | | | | | |
| Bromide | 19 | <.01 | <.01 | <.01 | <.01 | <.01 | .02 | .08 | .08 |
| **Cadmium** | **279** | **<.2** | **<.2** | **<.2** | **<.2** | **<.2** | **.3** | **.5** | **2.2** |
| **Chromium** | **26** | **<.5** | **<.5** | **<.5** | **<.5** | **.6** | **1.0** | **1.1** | **1.1** |
| Cobalt | 36 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| **Copper** | **280** | **<.5** | **<.5** | **.6** | **.9** | **1.3** | **1.9** | **3.0** | **20** |
| | | | | | | | | | |
| **Lead** | **279** | **<.5** | **<.5** | **<.5** | **<.5** | **<.5** | **<.5** | **.6** | **1.9** |
| Lithium | 36 | <4 | <4 | <4 | <4 | <4 | 5 | 8 | 16 |
| Manganese | 36 | <1 | 2 | 3 | 7 | 16 | 40 | 87 | 110 |
| **Mercury** | **283** | **<.1** | **<.1** | **<.1** | **<.1** | **<.1** | **<.1** | **.1** | **.6** |
| Molybdenum | 36 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| | | | | | | | | | |
| **Nickel** | **36** | **<10** | **<10** | **<10** | **<10** | **<10** | **<10** | **<10** | **<10** |
| **Selenium** | **22** | **<1** | **<1** | **<1** | **<1** | **<1** | **<1** | **2** | **2** |
| Silver | 36 | <1 | <1 | <1 | <1 | <1 | 1 | 2 | 2 |
| Strontium | 36 | 21 | 30 | 46 | 68 | 130 | 160 | 330 | 330 |
| Vanadium | 36 | <6 | <6 | <6 | <6 | 8 | 10 | 21 | 22 |
| | | | | | | | | | |
| **Zinc** | **36** | **<3** | **<3** | **<3** | **5** | **12** | **18** | **29** | **30** |

**Table 15.** Summary of selected trace-element concentrations in aquatic biota, Yakima River Basin, Washington, 1989–91

[To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate at a site, the mean trace-element concentration of each site was statistically summarized. Concentrations are reported in units of micrograms per gram (µg/g), dry weight; livers from bridgelip sucker, carp, largescale sucker, mountain whitefish, and rainbow trout were analyzed from composites of usually 10 samples; whole bodies of sculpin, caddisflies, and stoneflies were analyzed from composites of usually 10 fish and 50 or more insects; soft parts of the Asiatic clam were analyzed from composites of usually 20 samples; curlyleaf-pondweed and waterweed samples consisted of a minimum of 5 grams of mass; only 1990 data are summarized for largescale suckers, *Arctopsyche* spp., *Hydropsyche* spp., and lead in Asiatic clams; Asiatic clams were of the order Veneroida and family Corbiculidae; organism taxa are listed as follows: common name (*Genus species*); <, less than]

| Sample | Number of sites | Minimum | Median | Maximum |
|---|---|---|---|---|
| **Arsenic** | | | | |
| Bridgelip sucker (*Catostomus columbianus*) | 3 | 0.20 | 0.85 | 1.2 |
| Largescale sucker (*Catostomus macrocheilus*) | 6 | .10 | .30 | .50 |
| Mountain whitefish (*Prosopium williamsoni*) | 7 | <.30 | <.30 | .40 |
| Sculpin (*Cottus* spp.) | 12 | <.10 | .15 | .37 |
| Asiatic clam (*Corbicula fluminea*) | 5 | 3.6 | 4.1 | 5.2 |
| Curlyleaf pondweed (*Potamogeton crispus*) | 8 | .48 | .79 | 1.5 |
| Waterweed (*Elodea* sp.) | 4 | 1.0 | 1.6 | 2.6 |
| **Cadmium** | | | | |
| Carp (*Cyprinus carpio*) | 3 | .46 | .79 | 2.5 |
| Largescale sucker (*Catostomus macrocheilus*) | 6 | .03 | .35 | .43 |
| Mountain whitefish (*Prosopium williamsoni*) | 7 | <.20 | <.20 | 1.2 |
| Rainbow trout (*Oncorhynchus mykiss*) | 10 | <.40 | <.40 | 1.0 |
| Asiatic clam (*Corbicula fluminea*) | 5 | <.20 | .24 | .38 |
| Caddisfly (*Arctopsyche* sp.) | 12 | <.41 | <.41 | .43 |
| Caddisfly (*Cheumatopsyche* spp.) | 4 | <.19 | <.19 | .19 |
| Caddisfly (*Hydropsyche* spp.) | 24 | <.18 | <.18 | .25 |
| Stonefly (*Calineuria* spp.) | 6 | <.14 | <.14 | .45 |
| Stonefly (*Claassenia* sp.) | 7 | <.15 | .16 | .40 |
| Stonefly (*Doroneuria* spp.) | 5 | <.15 | <.15 | .50 |
| Stonefly (*Hesperoperla* sp.) | 10 | <.12 | <.12 | .33 |

**Table 15.** Summary of selected trace-element concentrations in aquatic biota, Yakima River Basin, Washington, 1989–91—Continued

| Sample | Number of sites | Minimum | Median | Maximum |
|---|---|---|---|---|
| **Cadmium—Continued** | | | | |
| Stonefly (*Megarcys* spp.) | 3 | .18 | .24 | .36 |
| Stonefly (*Perlinodes* spp.) | 3 | .12 | .17 | .25 |
| Stonefly (*Pteronarcys* spp.) | 8 | <.41 | <.41 | <.41 |
| Stonefly (*Skwala* spp.) | 9 | <.23 | <.23 | .23 |
| Curlyleaf pondweed (*Potamogeton crispus*) | 8 | <.80 | <.80 | .91 |
| **Chromium** | | | | |
| Largescale sucker (*Catostomus macrocheilus*) | 6 | .50 | .59 | .78 |
| Mountain whitefish (*Prosopium williamsoni*) | 7 | <1.0 | <1.0 | 1.0 |
| Rainbow trout (*Oncorhynchus mykiss*) | 10 | <4.0 | <4.0 | <4.0 |
| Asiatic clam (*Corbicula fluminea*) | 5 | 1.0 | 1.4 | 2.0 |
| Caddisfly (*Arctopsyche* sp.) | 12 | .71 | 1.6 | 10 |
| Caddisfly (*Cheumatopsyche* spp.) | 4 | 2.3 | 4.3 | 5.9 |
| Caddisfly (*Hydropsyche* spp.) | 24 | .66 | 2.4 | 3.8 |
| Stonefly (*Calineuria* spp.) | 6 | <.11 | 1.1 | 3.9 |
| Stonefly (*Claassenia* sp.) | 7 | .49 | 1.4 | 2.2 |
| Stonefly (*Doroneuria* spp.) | 5 | .95 | 1.3 | 2.6 |
| Stonefly (*Hesperoperla* sp.) | 10 | .61 | 1.3 | 2.4 |
| Stonefly (*Megarcys* spp.) | 3 | .44 | 2.2 | 5.2 |
| Stonefly (*Perlinodes* spp.) | 3 | 2.2 | 3.0 | 34 |
| Stonefly (*Pteronarcys* spp.) | 8 | .58 | 1.2 | 3.3 |
| Stonefly (*Skwala* spp.) | 9 | .31 | 1.8 | 16 |
| Curlyleaf pondweed (*Potamogeton crispus*) | 8 | 2.0 | 3.0 | 4.0 |
| Waterweed (*Elodea* sp.) | 4 | 3.8 | 6.4 | 8.3 |

**Table 15.** Summary of selected trace-element concentrations in aquatic biota, Yakima River Basin, Washington, 1989–91—Continued

| Sample | Number of sites | Minimum | Median | Maximum |
|---|---|---|---|---|
| **Cobalt** | | | | |
| Largescale sucker<br>(*Catostomus macrocheilus*) | 6 | 0.12 | 0.31 | 0.50 |
| Mountain whitefish<br>(*Prosopium williamsoni*) | 6 | .38 | .46 | .84 |
| Rainbow trout<br>(*Oncorhynchus mykiss*) | 5 | .18 | .32 | .46 |
| Asiatic clam<br>(*Corbicula fluminea*) | 4 | .50 | .58 | 1.1 |
| Caddisfly<br>(*Arctopsyche* sp.) | 12 | .71 | 1.1 | 5.0 |
| Caddisfly<br>(*Cheumatopsyche* spp.) | 4 | 1.8 | 2.5 | 5.7 |
| Caddisfly<br>(*Hydropsyche* spp.) | 24 | .75 | 2.7 | 9.1 |
| Stonefly<br>(*Calineuria* spp.) | 6 | .37 | .68 | .86 |
| Stonefly<br>(*Claassenia* sp.) | 7 | .39 | .57 | 1.0 |
| Stonefly<br>(*Doroneuria* spp.) | 5 | .20 | .49 | 1.7 |
| Stonefly<br>(*Hesperoperla* sp.) | 10 | .25 | .43 | 1.8 |
| Stonefly<br>(*Megarcys* spp.) | 3 | .58 | .88 | .97 |
| Stonefly<br>(*Perlinodes* spp.) | 3 | 1.8 | 2.2 | 5.7 |
| Stonefly<br>(*Pteronarcys* spp.) | 8 | .74 | .82 | 4.3 |
| Stonefly<br>(*Skwala* spp.) | 9 | .89 | 1.6 | 3.0 |
| **Copper** | | | | |
| Bridgelip sucker<br>(*Catostomus columbianus*) | 3 | 7.7 | 14 | 19 |
| Carp<br>(*Cyprinus carpio*) | 3 | 28 | 55 | 100 |
| Largescale sucker<br>(*Catostomus macrocheilus*) | 6 | 23 | 26 | 32 |
| Mountain whitefish<br>(*Prosopium williamsoni*) | 7 | 5.6 | 6.4 | 11 |
| Rainbow trout<br>(*Oncorhynchus mykiss*) | 10 | 18 | 91 | 480 |
| Asiatic clam<br>(*Corbicula fluminea*) | 5 | 25 | 28 | 34 |

**Table 15.** Summary of selected trace-element concentrations in aquatic biota, Yakima River Basin, Washington, 1989–91—Continued

| Sample | Number of sites | Minimum | Median | Maximum |
|---|---|---|---|---|
| **Copper—Continued** | | | | |
| Caddisfly<br>(*Arctopsyche* sp.) | 12 | 5.9 | 9.8 | 15 |
| Caddisfly<br>(*Cheumatopsyche* spp.) | 4 | 6.5 | 12 | 19 |
| Caddisfly<br>(*Hydropsyche* spp.) | 24 | 9.2 | 13 | 21 |
| Stonefly<br>(*Calineuria* spp.) | 6 | 18 | 22 | 24 |
| Stonefly<br>(*Claassenia* sp.) | 7 | 27 | 32 | 38 |
| Stonefly<br>(*Doroneuria* spp.) | 5 | 25 | 30 | 38 |
| Stonefly<br>(*Hesperoperla* sp.) | 10 | 18 | 24 | 28 |
| Stonefly<br>(*Megarcys* spp.) | 3 | 11 | 26 | 36 |
| Stonefly<br>(*Perlinodes* spp.) | 3 | 14 | 15 | 22 |
| Stonefly<br>(*Pteronarcys* spp.) | 8 | 8.0 | 21 | 32 |
| Stonefly<br>(*Skwala* spp.) | 9 | 14 | 19 | 26 |
| Curlyleaf pondweed<br>(*Potamogeton crispus*) | 8 | 9.2 | 11 | 22 |
| Waterweed<br>(*Elodea* sp.) | 4 | 13 | 19 | 65 |
| **Lead** | | | | |
| Largescale sucker<br>(*Catostomus macrocheilus*) | 6 | <.12 | .18 | .29 |
| Mountain whitefish<br>(*Prosopium williamsoni*) | 7 | <4.0 | <4.0 | <4.0 |
| Asiatic clam<br>(*Corbicula fluminea*) | 4 | .18 | .31 | .40 |
| Caddisfly<br>(*Arctopsyche* sp.) | 12 | <2.1 | <2.1 | 24 |
| Caddisfly<br>(*Cheumatopsyche* spp.) | 4 | 1.3 | 2.1 | 3.2 |
| Caddisfly<br>(*Hydropsyche* spp.) | 24 | <.96 | 1.1 | 5.6 |
| Stonefly<br>(*Claassenia* sp.) | 7 | <.68 | <.68 | 1.8 |

**Table 15.** Summary of selected trace-element concentrations in aquatic biota, Yakima River Basin, Washington, 1989–91—Continued

| Sample | Number of sites | Minimum | Median | Maximum |
|---|---|---|---|---|
| **Lead—Continued** | | | | |
| Stonefly<br>(*Doroneuria* spp.) | 5 | <0.59 | <0.59 | 0.65 |
| Stonefly<br>(*Hesperoperla* sp.) | 10 | <.65 | <.65 | .92 |
| Stonefly<br>(*Perlinodes* spp.) | 3 | 1.8 | 2.8 | 3.3 |
| Stonefly<br>(*Pteronarcys* spp.) | 8 | <2.1 | <2.1 | <2.1 |
| Stonefly<br>(*Skwala* spp.) | 9 | <.80 | <.80 | 2.8 |
| **Mercury** | | | | |
| Bridgelip sucker<br>(*Catostomus columbianus*) | 3 | .05 | .06 | .06 |
| Carp<br>(*Cyprinus carpio*) | 3 | .30 | .38 | .42 |
| Largescale sucker<br>(*Catostomus macrocheilus*) | 6 | .05 | .32 | .47 |
| Mountain whitefish<br>(*Prosopium williamsoni*) | 7 | .40 | .81 | 1.3 |
| Rainbow trout<br>(*Oncorhynchus mykiss*) | 10 | .12 | .26 | .35 |
| Sculpin<br>(*Cottus* spp.) | 12 | .09 | .19 | .31 |
| Asiatic clam<br>(*Corbicula fluminea*) | 5 | .10 | .16 | .17 |
| Curlyleaf pondweed<br>(*Potamogeton crispus*) | 8 | .03 | .05 | .06 |
| Waterweed<br>(*Elodea* sp.) | 4 | .06 | .07 | .09 |
| **Nickel** | | | | |
| Asiatic clam<br>(*Corbicula fluminea*) | 5 | <2.0 | <2.0 | <2.0 |
| Caddisfly<br>(*Arctopsyche* sp.) | 12 | <1.0 | <1.0 | 42 |
| Caddisfly<br>(*Cheumatopsyche* spp.) | 4 | 1.5 | 5.1 | 7.3 |
| Caddisfly<br>(*Hydropsyche* spp.) | 24 | .58 | 2.4 | 5.5 |
| Stonefly<br>(*Calineuria* spp.) | 6 | .28 | .48 | 6.9 |
| Stonefly<br>(*Claassenia* sp.) | 7 | <.38 | <.38 | 6.4 |
| Stonefly<br>(*Doroneuria* spp.) | 5 | <.15 | 1.4 | 1.6 |
| Stonefly<br>(*Hesperoperla* sp.) | 10 | <.26 | .43 | 7.1 |

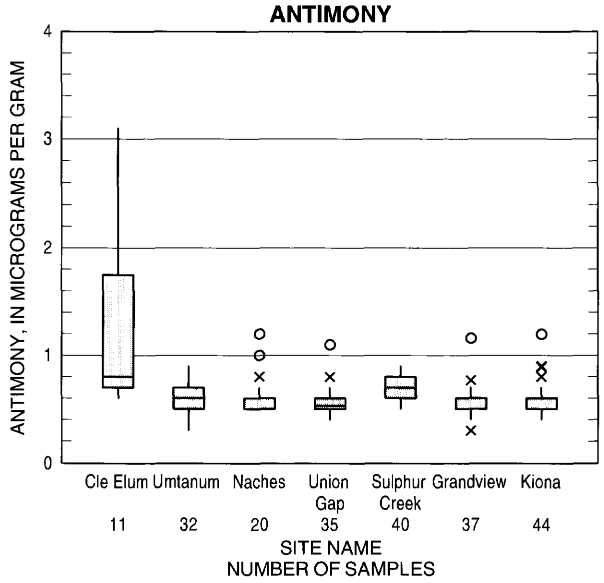
**Table 15.** Summary of selected trace-element concentrations in aquatic biota, Yakima River Basin, Washington, 1989–91—Continued

| Sample | Number of sites | Minimum | Median | Maximum |
|---|---|---|---|---|
| **Nickel—Continued** | | | | |
| Stonefly<br>(*Megarcys* spp.) | 3 | 0.26 | 2.0 | 2.4 |
| Stonefly<br>(*Perlinodes* spp.) | 3 | 2.2 | 2.3 | 76 |
| Stonefly<br>(*Pteronarcys* spp.) | 8 | .74 | 1.2 | 7.5 |
| Stonefly<br>(*Skwala* spp.) | 9 | .38 | .86 | 34 |
| Curlyleaf pondweed<br>(*Potamogeton crispus*) | 8 | 3.0 | 5.8 | 20 |
| Waterweed<br>(*Elodea* sp.) | 4 | 8.5 | 14 | 23 |
| **Selenium** | | | | |
| Bridgelip sucker<br>(*Catostomus columbianus*) | 3 | 1.9 | 2.0 | 5.2 |
| Carp<br>(*Cyprinus carpio*) | 3 | 2.2 | 3.8 | 4.2 |
| Largescale sucker<br>(*Catostomus macrocheilus*) | 6 | 1.9 | 3.5 | 4.8 |
| Mountain whitefish<br>(*Prosopium williamsoni*) | 7 | 4.2 | 5.0 | 13 |
| Rainbow trout<br>(*Oncorhynchus mykiss*) | 10 | 2.2 | 7.0 | 31 |
| Sculpin<br>(*Cottus* spp.) | 12 | .20 | 1.6 | 5.4 |
| Asiatic clam<br>(*Corbicula fluminea*) | 5 | 2.1 | 2.4 | 3.0 |
| Curlyleaf pondweed<br>(*Potamogeton crispus*) | 8 | .20 | .36 | .70 |
| Waterweed<br>(*Elodea* sp.) | 4 | .30 | .59 | 1.2 |
| **Silver** | | | | |
| Carp<br>(*Cyprinus carpio*) | 3 | .24 | .45 | 3.0 |
| Largescale sucker<br>(*Catostomus macrocheilus*) | 6 | .06 | .10 | .14 |
| Mountain whitefish<br>(*Prosopium williamsoni*) | 7 | <2.0 | <2.0 | <2.0 |
| Rainbow trout<br>(*Oncorhynchus mykiss*) | 10 | <7.0 | <7.0 | 20 |
| Stonefly<br>(*Calineuria* spp.) | 6 | <.09 | .13 | .21 |
| Stonefly<br>(*Claassenia* sp.) | 7 | .13 | .15 | .30 |
| Stonefly<br>(*Doroneuria* spp.) | 5 | <.07 | .12 | .30 |
| Stonefly<br>(*Hesperoperla* sp.) | 10 | <.08 | .08 | .22 |

**Table 15.** Summary of selected trace-element concentrations in aquatic biota, Yakima River Basin, Washington, 1989–91—Continued

| Sample | Number of sites | Minimum | Median | Maximum |
|---|---|---|---|---|
| **Zinc** | | | | |
| Bridgelip sucker<br>(*Catostomus columbianus*) | 3 | 55 | 56 | 94 |
| Carp<br>(*Cyprinus carpio*) | 3 | 160 | 634 | 890 |
| Largescale sucker<br>(*Catostomus macrocheilus*) | 6 | 60 | 81 | 102 |
| Mountain whitefish<br>(*Prosopium williamsoni*) | 7 | 57 | 72 | 79 |
| Rainbow trout<br>(*Oncorhynchus mykiss*) | 10 | 75 | 99 | 226 |
| Asiatic clam<br>(*Corbicula fluminea*) | 5 | 96 | 108 | 452 |
| Caddisfly<br>(*Arctopsyche* sp.) | 12 | 96 | 141 | 192 |
| Caddisfly<br>(*Cheumatopsyche* spp.) | 4 | 81 | 96 | 102 |
| Caddisfly<br>(*Hydropsyche* spp.) | 24 | 67 | 105 | 152 |
| Stonefly<br>(*Calineuria* spp.) | 6 | 142 | 196 | 251 |
| Stonefly<br>(*Claassenia* sp.) | 7 | 174 | 218 | 352 |
| Stonefly<br>(*Doroneuria* spp.) | 5 | 216 | 231 | 254 |
| Stonefly<br>(*Hesperoperla* sp.) | 10 | 276 | 372 | 450 |
| Stonefly<br>(*Megarcys* spp.) | 3 | 127 | 256 | 271 |
| Stonefly<br>(*Perlinodes* spp.) | 3 | 84 | 106 | 141 |
| Stonefly<br>(*Pteronarcys* spp.) | 8 | 114 | 128 | 150 |
| Stonefly<br>(*Skwala* spp.) | 9 | 102 | 138 | 314 |
| Curlyleaf pondweed<br>(*Potamogeton crispus*) | 8 | 50 | 76 | 187 |
| Waterweed<br>(*Elodea* sp.) | 4 | 44 | 130 | 239 |

(3.1 μg/g) of antimony corresponds to a major storm (January 9–12, 1990) in which U.S. Geological Survey personnel, during sampling at the Yakima River at Cle Elum, reported rain falling on 5 to 8 inches of snow. Two samplings were made during this major storm. The first sampling was at the onset of the storm (January 9, 1990) when streamflow (1,450 cubic feet per second [$ft^3/s$]) was rapidly rising, and the suspended-sediment concentration (12 mg/L) was twice the median concentration measured during the 1987–90 period of study at Cle Elum. The second sampling was at the peak of the storm (January 10, 1990) when streamflow was 3,130 $ft^3/s$, and the suspended-sediment concentration (130 mg/L) was the maximum concentration at Cle Elum for the period of study 1987–90. The concentration of antimony decreases from 3.1 μg/g at the onset of the storm to 0.6 μg/g at the peak of the storm (fig. 7). Similarly, the fraction of fine-grain-sized suspended sediment (the percentage of suspended sediment finer than 0.062 μm in diameter) decreased from about 90 percent at the onset of the storm to less than 50 percent at the peak of the storm. Even when the storm concentrations of antimony are normalized to the percentage of fine-grain-sized sediment, grain size alone does not account for the increase in antimony concentration at the onset of the storm event. The variability of antimony concentrations during the January storm probably indicates a change in the source of suspended sediment and the distribution of fine-grain-sized suspended sediment.



EXPLANATION

**Interquartile range equals the value of the 75th percentile minus the value of the 25th percentile.**

○ More than 3 times the interquartile range from the 75th-percentile value

× 1.5 to 3 times the interquartile range from the 75th-percentile value

Less than 1.5 times the interquartile range from the 75th-percentile value

75th-percentile value

Median value

25th-percentile value

Less than 1.5 times the interquartile range from the 25th-percentile value

× 1.5 to 3 times the interquartile range from the 25th-percentile value

**Figure 6**. Distribution of antimony concentrations in suspended sediment at fixed sites in the Yakima River Basin, Washington, 1987–90 ("Cle Elum" represents Yakima River at Cle Elum; "Umtanum" represents Yakima River at Umtanum; "Naches" represents Naches River near North Yakima; "Union Gap" represents Yakima River above Ahtanum Creek at Union Gap; "Sulphur Creek" represents Sulphur Creek Wasteway near Sunnyside; "Grandview" represents Yakima River at Euclid Bridge at river mile 55 near Grandview; and "Kiona" represents Yakima River at Kiona).

Because streambed sediment in the Cle Elum River drainage is enriched in antimony (Fuhrer, McKenzie, and others, 1994), storms may be a source of measurable suspended antimony in the Yakima River at Cle Elum. It is doubtful that all suspended sediment, transported from the reach upstream from Cle Elum Lake, enters the Yakima River at Cle Elum. At times, Cle Elum Lake may act as a sieve, by passing small-grain-sized suspended sediment and trapping larger sediment particles. Contributions of suspended sediment, from areas less enriched than the Cle Elum River drainage, would dilute the concentration of suspended antimony in the Yakima River at Cle Elum. One possible source of less-enriched antimony is Crystal Creek (formerly Roslyn Creek) which flows into the main stem 0.15 mile upstream from the Yakima River at Cle Elum sampling site. Crystal Creek receives urban runoff from the towns of Cle Elum and Roslyn, in addition to runoff from numerous open-pit coal mines that are located east of Roslyn. During the January storm, Crystal Creek was creating a turbidity plume which, during the rising limb of the storm, obscured the shallow river bottom near the left bank of the main stem at Cle Elum. The Crystal Creek drainage, which is located in the nonmarine rock geologic unit, contains concentrations of antimony (0.5 μg/g and 0.8 μg/g) in streambed sediment that were small in comparison to the large concentration (4.8 μg/g) in streambed sediment in the Cle Elum

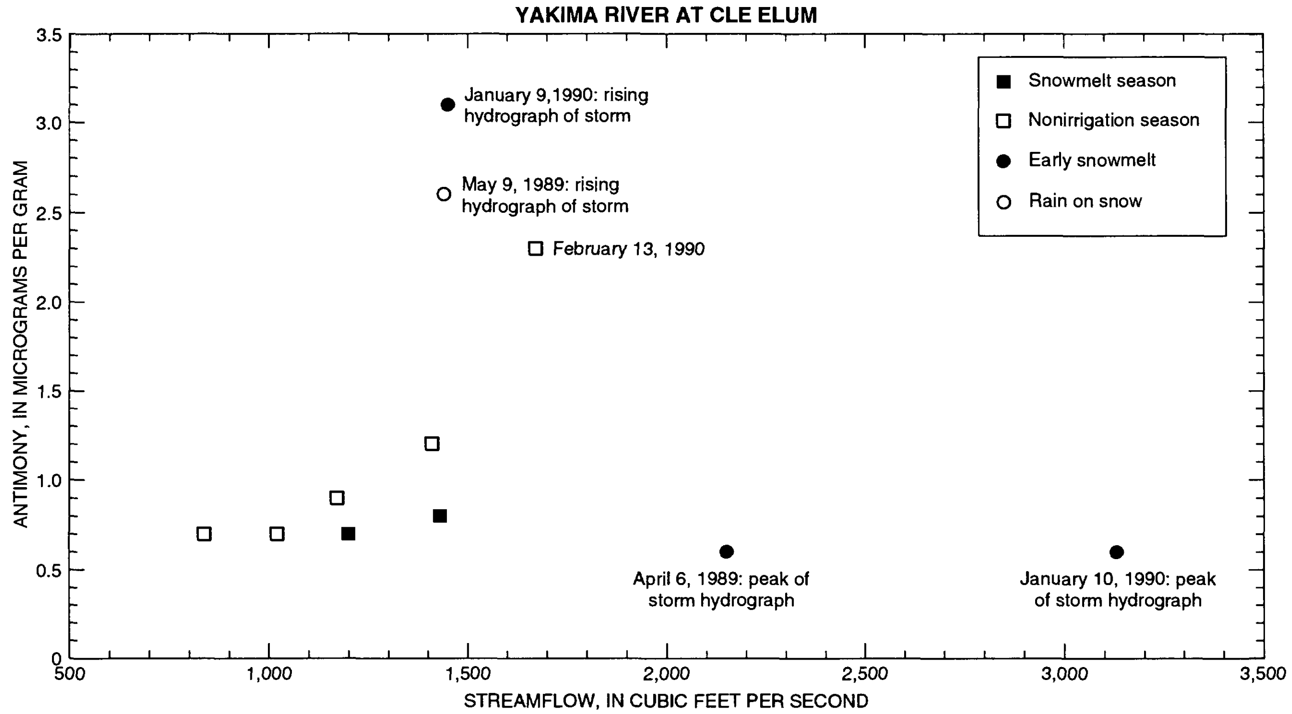


**Figure 7.** Streamflow and antimony concentrations in suspended sediment for selected time periods for the Yakima River at Cle Elum, Yakima River Basin, Washington, 1988–90 (snowmelt season occurs April through May; nonirrigation season occurs October through March).

River drainage (Ryder and others, 1992). During large storms, therefore, Crystal Creek may be diluting the concentration of suspended antimony at Cle Elum because of Crystal Creek's close proximity to the Yakima River at Cle Elum sampling site.

The peak of a rain-on-snow storm at the Yakima River at Cle Elum was sampled on April 6, 1989. Similar to the January 1990 storm, streamflow near the peak of the storm was large (2,150 $ft^3/s$) and the concentration of suspended sediment also was large (85 mg/L). Similar to the sample collected near the peak of the storm in January 1990, the concentration of antimony near the peak of the April 1989 storm was only 0.6 μg/g (fig. 7). These two storm samplings, in addition to a third storm-event sampling (May 9, 1989), indicated that concentrations of suspended antimony are diluted during large storms, presumably by less-enriched concentrations of antimony from drainages such as Crystal Creek. What remains unclear, however, is the transport potential of antimony to the main stem from sources in the Cle Elum River Drainage.

On the basis of a limited number of filtered-water determinations at fixed sites, antimony was measured in the Yakima River at Umtanum and in the Yakima River above Ahtanum Creek at Union Gap at the limit of determination (1 μg/L) in 2 of 22 samples. Although antimony was detected at the limit of determination (1 μg/L), antimony concentrations were high in comparison to background concentrations in natural water. Antimony measured at the Umtanum and Union Gap sites were 10 times greater than background concentrations in other basins that are minimally affected by human activities (0.1 μg/L; Forstner and Wittmann, 1979) (table 36 at back of report).

## Arsenic and Lead

Concentrations of arsenic in streambed sediment at the 32 biological sampling sites ranged from 1.1 to 45 μg/g (table 12). Concentrations of arsenic as high as 45 μg/g and 29 μg/g were measured in streambed sediment of the Waptus River at mouth near Roslyn (site 1) and Jungle Creek near mouth (site 3), respectively, which are probably from geologic sources. Streambed sediment in the Waptus River drainage in the Wenatchee Mountains is formed from pre-Tertiary metamorphic and intrusive rocks of the Cascade Range geologic province. Streambed sediment concentrations of arsenic as large as 31 μg/g in this pre-Tertiary rock geologic unit were reported by

Fuhrer, McKenzie, and others (1994) and were attributed to the presence of arsenopyrite. Streambed sediment in the Jungle Creek drainage is formed from nonmarine sedimentary rock of the Cascade Range geologic province. Concentrations of arsenic as high as 21 µg/g were reported in streambed sediment of the nonmarine rock geologic unit (Fuhrer, McKenzie, and others, 1994) which contains hydrothermally altered volcanic and granitic rock with concentrations of arsenic as large as 7,000 µg/g (Simmons and others, 1983; Gualtieri and Simmons, 1989).

Concentrations of arsenic in main-stem tributaries are as much as 16 times larger than concentrations in the main stem. The largest difference in arsenic concentration was between the Waptus River at mouth near Roslyn (site 1, 45 µg/g) and the Yakima River at Umtanum (site 19, 2.8 µg/g) located 6.6 miles downstream from irrigation return flows entering the main stem from the Kittitas Valley (fig. 8). Arsenic-depleted sediment within the Kittitas Valley was probably the source of the measurably lower arsenic concentrations in the Yakima River at Umtanum (Fuhrer, McKenzie, and others, 1994). Concentrations of arsenic as high as 13.0 µg/g and 9.8 µg/g were measured in the American River at Hell's Crossing and in Rattlesnake Creek above North Fork Rattlesnake Creek, respectively. Both streams are tributaries to the Naches River, and the presence of arsenic in these streams probably was the result of geologic sources. Although arsenic concentrations at the mouths of many streams carrying irrigation return flow to the main stem are lower than in streams affected by geologic sources, some streams that receive irrigation return flow show evidence of arsenic enrichment. For example, arsenic concentrations increased more than fourfold in a downstream direction in Satus Creek. Arsenic concentrations increased from 1.3 to 2.8 to 5.8 µg/g at Satus Creek sites upstream from Wilson-Charley Canyon (site 57), downstream from Dry Creek (site 53), and at Gage at Satus (site 47), respectively.

Potential sources of arsenic in agricultural land-use areas include the historical application of pesticides containing lead arsenate. In eastern Washington, beginning in 1908, lead-arsenate formulations

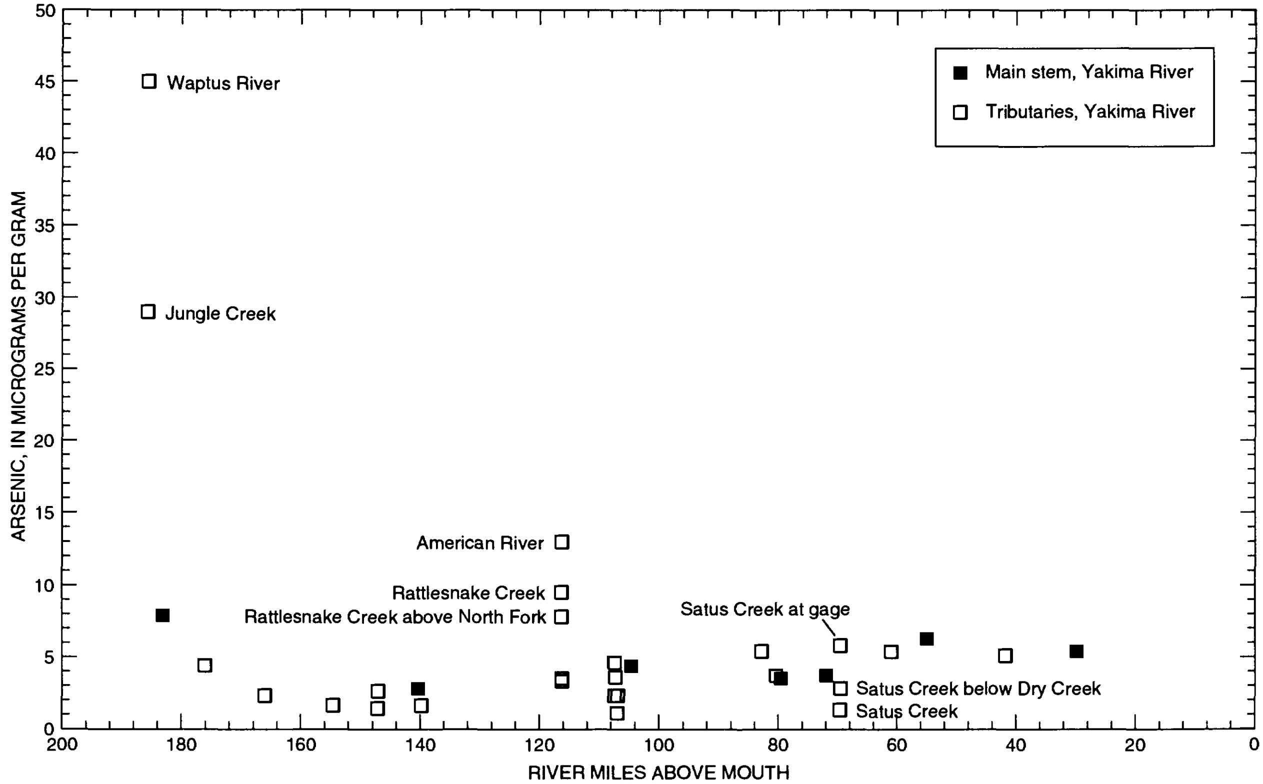


**Figure 8.** Arsenic concentrations in streambed sediment of the main stem and tributaries, Yakima River Basin, Washington, 1987–90 ("Waptus River" represents Waptus River at mouth near Roslyn; "Jungle Creek" represents Jungle Creek near mouth near Cle Elum; "Rattlesnake Creek above North Fork" represents Rattlesnake Creek above North Fork Rattlesnake Creek near Nile; "Rattlesnake Creek" represents Rattlesnake Creek above Little Rattlesnake Creek near Nile; "American River" represents American River at Hell's Crossing near Nile; "Satus Creek at gage" represents Satus Creek at gage at Satus; "Satus Creek below Dry Creek" represents Satus Creek below Dry Creek near Toppenish; and "Satus Creek" represents Satus Creek above Wilson-Charley Canyon near Toppenish).

were applied to control codling moth in apples. This practice continued until the introduction of dichlorodiphenyltrichloroethane (DDT) in 1947. Significant amounts of this pesticide have been applied and detected in the basin's agricultural soils; arsenic concentrations as large as 140 µg/g were detected in a former Yakima River Basin apple orchard (Fuhrer, McKenzie, and others, 1994). Using available land-use information, which does not separate agricultural land into orchard and non-orchard categories, and a spatially large sampling of Yakima River Basin streambed sediment, Fuhrer, McKenzie, and others (1994) have shown that lands classified as agricultural had significantly larger ($\rho \leq 0.05$) arsenic concentrations than lands classified as nonagricultural fig. 9). The enrichment of arsenic occurred in agricultural land-use areas residing in the Quaternary deposits and loess geologic unit and the nonmarine sedimentary rock geologic unit—geologic hosts to many of the basin's apple orchards. The enrichment of arsenic in agricultural areas may result from a legacy of pesticide use.

Concentrations of lead in streambed sediment of the Yakima River Basin ranged from 9.0 to 63.0 µg/g (table 12) and slightly exceed the 5.2 to 55 µg/g range of concentration that encompasses 95 percent of Western United States soils (R.C. Severson, U.S. Geological Survey, written commun.,1987, based on data in Shacklette and Boerngen, 1984). The median concentration of lead at the biological sampling sites (14 µg/g) is nearly one-half that in fine-fraction streambed sediment in the highly urbanized upper Illinois River Basin (table 34, at back of report). Lead concentrations as large as 63 µg/g, 56 µg/g, and 36 µg/g, however, were measured in Wide Hollow Creek at West Valley Middle School near Ahtanum (site 27), Wide Hollow Creek at old Sewage Treatment Plant at Union Gap (site 29), and Naches River near North Yakima (site 26), respectively.

Lead in Wide Hollow Creek Subbasin probably results from urbanization, agricultural practices, and light industrial sources rather than from geologic sources. Geologic sources of lead in Wide Hollow Creek Subbasin are few and consist of the Quaternary deposits and loess geologic unit, which contains a median lead concentration of only 14 µg/g (Fuhrer, McKenzie, and others, 1994). The 56-µg/g concentration of lead at Wide Hollow Creek at the old Sewage Treatment Plant—located near the mouth of Wide Hollow Creek—is not unexpected considering that Wide Hollow Creek drains the urban area of Union Gap and that the median concentration of lead in sediment from urban drains of the Yakima River Basin is 71 µg/g (Fuhrer, McKenzie, and others, 1994). What is unexpected, however, is the 63 µg/g lead at the upstream site, Wide Hollow Creek at West Valley Middle School near Ahtanum, which is farther removed from the urban effects of Union Gap. In addition to urban sources, sources of lead enrichment in Wide Hollow Creek probably result from the legacy of lead-arsenate usage for control of codling moth in apple orchards. The application of lead arsenate, from 1908 to 1947, in eastern Washington increased from 50 lb (pounds) of lead and 18 lb of arsenic to 192 lb of

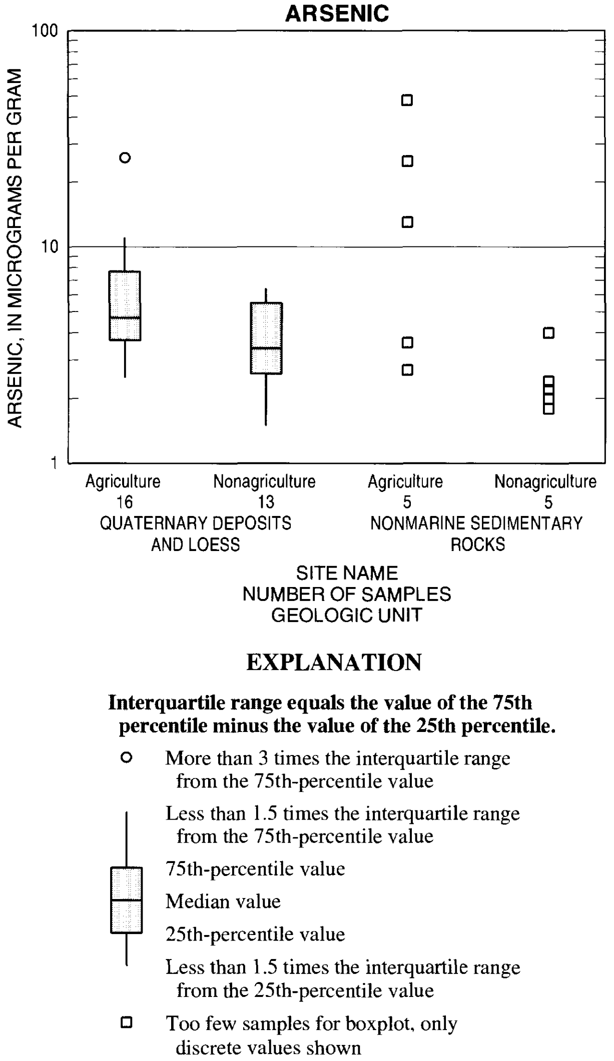


**Figure 9.** Comparison of arsenic concentrations between agricultural and nonagricultural land uses for streambed sediment of lower order streams in the Quaternary deposits and loess geologic unit and in the nonmarine sedimentary rocks geologic unit, Yakima River Basin, Washington, 1987.

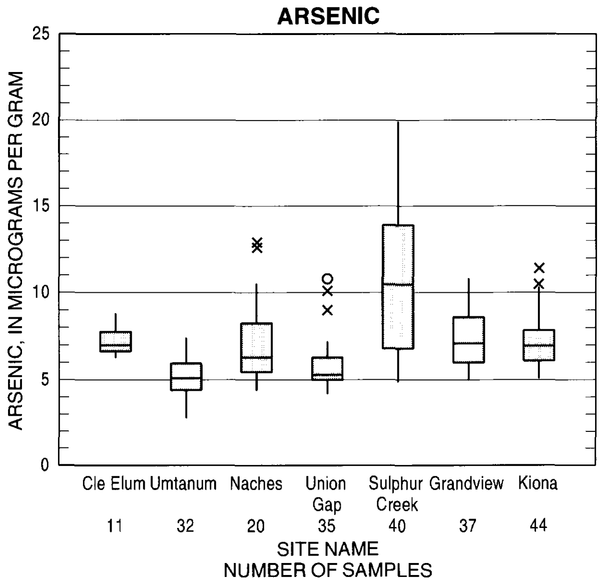
lead and 71 lb of arsenic per acre (Peryea, 1989). A considerable reservoir of lead and arsenic may exist in the Yakima River Basin considering that 3,000 acres of apple orchards existed (primarily in the middle and lower basin) prior to 1955 (U.S. Department of Agriculture, 1986). Concentrations of lead in soils of former apple orchards, located in an adjacent subbasin, were as large as 890 µg/g—a concentration approximately 60 times that associated with geologic sources in the Ahtanum Subbasin (Fuhrer, McKenzie, and others, 1994). Lead also was reported in streambed sediment of Wide Hollow Creek in an earlier study by Washington State Department of Ecology (see Previous Studies section of this report).

Concentrations of suspended arsenic at the seven fixed sites ranged from 2.8 to 20 µg/g (table 13). Arsenic was enriched slightly (median 7.0 µg/g) in the Yakima River at Cle Elum and notably (median 10 µg/g) in Sulphur Creek Wasteway near Sunnyside (fig. 10; table 35, at back of report). The highest concentrations of arsenic were detected in the lower Yakima Valley where median arsenic concentrations ranged from 7.0 to 10 µg/g.

Concentrations of suspended arsenic in the Yakima River at Cle Elum ranged from 6.3 µg/g to 8.8 µg/g. Although these concentrations of arsenic were not high in comparison to Sulphur Creek Wasteway near Sunnyside, these concentrations probably are indicative of an upstream source of enrichment. Similar to antimony, arsenic enrichment from geologic sources is not uncommon in the Cle Elum Subbasin. As discussed previously, high arsenic concentrations are present in streambed sediment and rock in the pre-Tertiary and metamorphic rock geologic unit which contains arsenopyrite (Gualtieri and Simmons, 1989; Fuhrer, McKenzie, and others, 1994).

During storms, higher arsenic concentrations were detected preceding the storm's peak than at the peak. During the peak of the January 9, 1990, storm at Cle Elum (rain-on-snow), the suspended arsenic concentration was 6.3 µg/g; preceding the storm's peak, however, the suspended arsenic concentration was 7.6 µg/g. This variation, although low in comparison to antimony, represents approximately one-half the range of concentrations measured over the 1987–90 monthly sampling period for Cle Elum.

The highest concentrations of suspended arsenic were detected in Sulphur Creek Wasteway near Sunnyside (site 52). The median concentration was 10 µg/g (exceeding those of other fixed sites) and overall, arsenic concentrations ranged from 4.9 µg/g to 20 µg/g. Concentrations of suspended arsenic in Sulphur Creek Wasteway also varied seasonally to a greater extent than at the other fixed sites; the interquartile range for suspended arsenic in Sulphur Creek Wasteway was 7.4 µg/g in comparison to just 1.9 µg/g in the Yakima River at Kiona (site 50). Differences in the interquartile ranges among sampling sites probably were related to the size of the waterway and to the principal water use in the drainage. Sulphur Creek Wasteway, located in the Sunnyside Subbasin, is different from other fixed sites because it is a major con-



**EXPLANATION**

**Interquartile range equals the value of the 75th percentile minus the value of the 25th percentile.**

o More than 3 times the interquartile range from the 75th-percentile value

× 1.5 to 3 times the interquartile range from the 75th-percentile value

Less than 1.5 times the interquartile range from the 75th-percentile value

75th-percentile value

Median value

25th-percentile value

Less than 1.5 times the interquartile range from the 25th-percentile value

**Figure 10.** Distribution of arsenic concentrations in suspended sediment at fixed sites in the Yakima River Basin, Washington, 1987–90 ("Cle Elum" represents Yakima River at Cle Elum; "Umtanum" represents Yakima River at Umtanum; "Naches" represents Naches River near North Yakima; "Union Gap" represents Yakima River above Ahtanum Creek at Union Gap; "Sulphur Creek" represents Sulphur Creek Wasteway near Sunnyside; "Grandview" represents Yakima River at Euclid Bridge at river mile 55 near Grandview; and "Kiona" represents Yakima River at Kiona).

veyance of agricultural return flow, as well as a spillway for excess canal water during the irrigation season. Large variations in constituent concentrations, similar to those measured for arsenic, may not be unusual in Sulphur Creek Wasteway or in other waterways that principally receive irrigation return flow. Conversely, sites located along the main stem or on larger tributaries probably receive adequate dilution to dampen large fluxes in constituent concentrations from smaller waterways carrying agricultural return flow to the main stem.

During the irrigation season, concentrations of suspended arsenic in Sulphur Creek Wasteway near Sunnyside are significantly lower ($\rho \leq 0.001$) than during the nonirrigation season (fig. 11).These concentrations also are in close agreement with arsenic concentrations measured in streambed sediment (finer than 62 μm, in diameter) of Sunnyside Subbasin (Fuhrer, McKenzie, and others, 1994). The median concentration of suspended arsenic during the irrigation season was 7.0 μg/g, and the median arsenic concentration of streambed sediment was 8.2 μg/g. The similarity between suspended- and streambed-sediment concentrations of arsenic, in addition to high concentrations of suspended sediment during the irrigation season, indicate the significance of agricultural soil erosion as a dampening mechanism which, during the irrigation season, limits concentrations of suspended arsenic in Sulphur Creek (fig. 11).

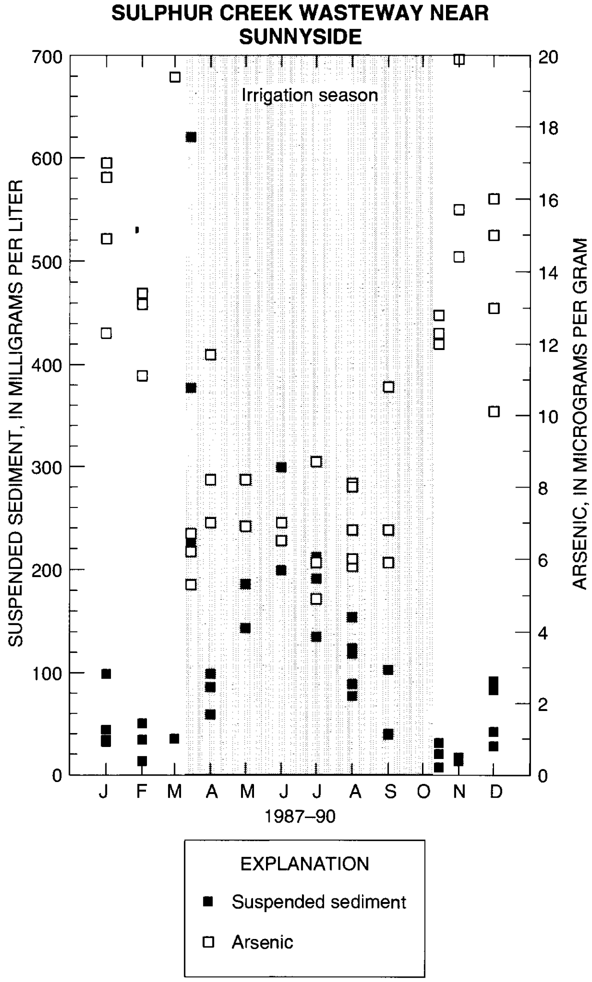


**Figure 11.** Concentrations of suspended sediment and arsenic in suspended sediment at Sulphur Creek Wasteway near Sunnyside, Yakima River Basin, Washington, 1987–90 (shaded area represents the irrigation season).

Conversely, during the nonirrigation season, the median concentration of suspended arsenic is 13.9 μg/g at Sulphur Creek Wasteway near Sunnyside. The higher concentrations of suspended arsenic during the nonirrigation season coincide with increases in the percentage of fine-grained suspended sediment and increases in the concentration of suspended-organic carbon (fig. 12). As a result, the higher arsenic concentrations probably are not from new or different sources, but rather from a change in the distribution of fine-grain-sized sediment and organic carbon content.

Differences in the concentrations of suspended arsenic between the irrigation and the nonirrigation seasons probably result from variations in the quantity of fine-grained suspended sediment and suspended organic carbon. Finer grain-sized sediment contains larger element concentrations because of the increase in sediment surface area; larger grain-sized sediments, however, have comparatively small surface areas and low element concentrations (Horowitz, 1991, p. 32). The variations in suspended arsenic concentrations in Sulphur Creek Wasteway have a distinct pattern which is statistically ($\rho \leq 0.001$) correlated to the percentage of suspended sediment finer than 62 μm, in diameter (fig.13). A similar relation and significant correlation exists between suspended-arsenic concentrations and suspended-organic carbon (fig.13). Thus, the concentrations of suspended arsenic in Sulphur Creek Wasteway increased in proportion to the quantity of fine-grained suspended sediment and organic carbon.

High concentrations of suspended arsenic in Sulphur Creek Wasteway near Sunnyside may be a legacy of lead-arsenate formulations applied to apple orchards in the Sunnyside Subbasin. In addition to the Sunnyside Subbasin, other agricultural subbasins (although not measured in this study) also may be sources of suspended arsenic. Present day applications

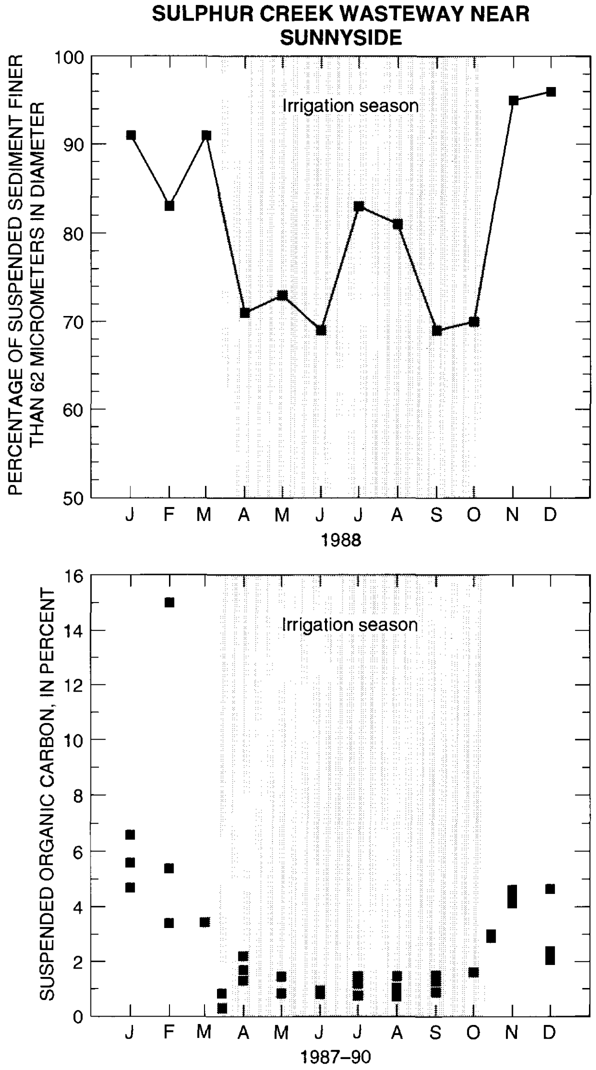


**Figure 12.** Distribution of suspended sediment finer than 62 micrometers in diameter and suspended organic carbon concentrations at Sulphur Creek Wasteway near Sunnyside, Yakima River Basin, Washington, 1987–90 (shaded area represents the irrigation season).

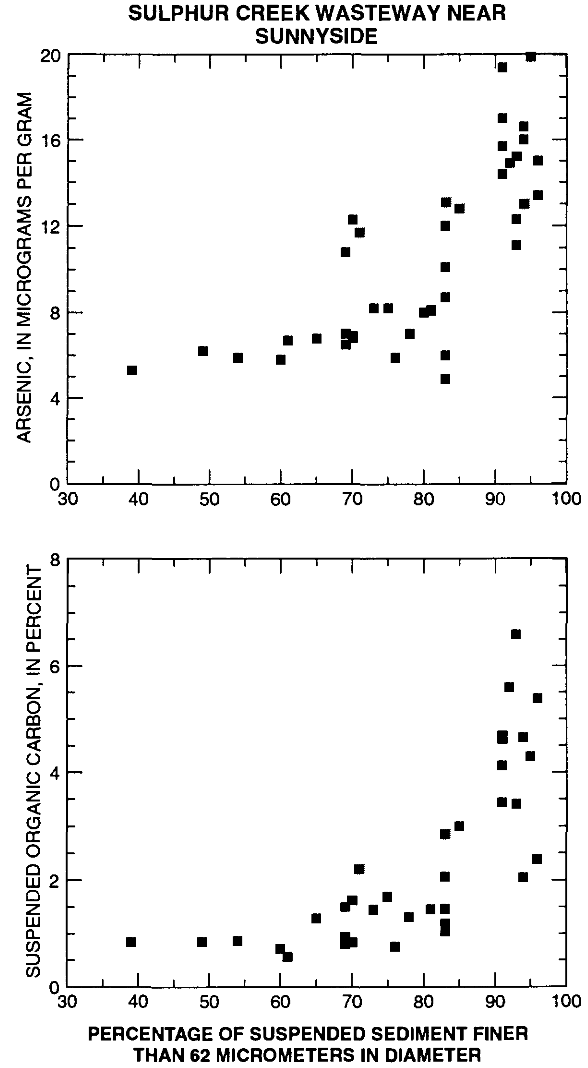


**Figure 13.** Percentage of suspended sediment finer than 62 micrometers in diameter and the concentration of arsenic in suspended sediment and the concentration of suspended organic carbon at Sulphur Creek Wasteway near Sunnyside, Yakima River Basin, Washington, 1987–90.

of phosphate fertilizer may leach arsenic from soils to shallow ground water (Peryea, 1989). Arsenic, therefore, may not occur only in streambed sediment from the erosion of soil treated with lead arsenate, but arsenic also may be discharged to waterways (in dissolved form) from shallow ground water. Once dissolved, arsenic subsequently can attach to streambed sediment by adsorption or coprecipitation reactions with hydrous iron oxides (Hem, 1989, p. 144).

The significant contribution of Sulphur Creek Wasteway to the suspended-arsenic load in the main stem is perhaps more important than the relation that exists in Sulphur Creek Wasteway between suspended-arsenic concentrations and the physical and chemical measurements described earlier. During the irrigation season, Sulphur Creek had a suspended-arsenic load two-thirds that of the Yakima River at Kiona (table 16) but accounted for less than 20 percent of the streamflow at Kiona. The suspended-arsenic loads in Sulphur Creek also vary seasonally (fig. 14). In 1989, for example, the irrigation-season load of arsenic (1.5 pounds per day) was nearly 4 times higher than the nonirrigation season load (0.4 pound per day). This increase was not caused directly by high concentrations of suspended arsenic, but rather by agricultural soil erosion that results in high suspended-

**Table 16.** Estimated arsenic loads in suspended sediment at selected fixed sites, Yakima River Basin, Washington, 1987–90

[Loads reported as pounds per day; load estimates are based on calibration data collected from March 1987 to March 1990; --, insufficient data. Bold lines represent the irrigation season, and lightly shaded cells represent the snowmelt portion of the irrigation season; nonirrigation season, October through March]

| Year | January | February | March | April | May | June | July | August | September | October | November | December | Daily mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Yakima River at Umtanum** | | | | | | | | | | | | | |
| 1987 | 0.2 | 0.4 | 2 | 2 | 1 | 2 | 2 | 2 | 0.4 | 0.1 | 0.1 | 0.2 | 1.0 |
| 1988 | .1 | .5 | .6 | 2 | .9 | 1 | 3 | 3 | 1 | .2 | .4 | .6 | 1.1 |
| 1989 | .8 | .6 | .8 | 4 | 3 | 2 | 3 | 3 | .9 | .4 | .6 | .7 | 1.7 |
| 1990 | 1 | 2 | 2 | 5 | 3 | 5 | 3 | 3 | .8 | -- | -- | -- | -- |
| **Naches River near North Yakima** | | | | | | | | | | | | | |
| 1987 | -- | -- | 1 | 2 | 9 | .5 | .1 | <.05 | .5 | .3 | <.05 | .2 | -- |
| 1988 | .1 | .2 | .3 | 2 | 2 | 1 | .2 | .1 | 1 | .6 | .2 | .3 | .7 |
| 1989 | .3 | .1 | .4 | 4 | 3 | 2 | .1 | .1 | 1 | .3 | .1 | .6 | 1.0 |
| 1990 | 2 | .9 | .9 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Yakima River above Ahtanum Creek at Union Gap** | | | | | | | | | | | | | |
| 1987 | 1 | 2 | 5 | 5 | 8 | 4 | 4 | 4 | 2 | 1 | .4 | 1 | 3.2 |
| 1988 | .7 | 2 | 2 | 6 | 4 | 4 | 4 | 5 | 3 | 2 | 2 | 2 | 3.0 |
| 1989 | 2 | 2 | 3 | 10 | 8 | 6 | 5 | 4 | 3 | 2 | 2 | 2 | 4.1 |
| 1990 | 3 | 3 | 4 | 10 | 7 | 11 | 5 | 5 | 5 | 4 | -- | -- | -- |
| **Sulphur Creek Wasteway near Sunnyside** | | | | | | | | | | | | | |
| 1987 | -- | -- | 1 | 3 | 3 | 2 | 2 | .9 | .6 | .3 | .1 | .2 | -- |
| 1988 | .2 | .3 | 2 | 2 | 2 | 2 | 1 | .9 | .9 | .4 | .1 | .1 | 1.0 |
| 1989 | .2 | .2 | 1 | 4 | 4 | 2 | 2 | 1 | 1 | .6 | .2 | .2 | 1.4 |
| 1990 | .2 | .2 | 2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Yakima River at Euclid Bridge at river mile 55 near Grandview** | | | | | | | | | | | | | |
| 1987 | -- | -- | 7 | 6 | 10 | 2 | 2 | 2 | 1 | 1 | .9 | 2 | -- |
| 1988 | 1 | 2 | 2 | 6 | 4 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2.5 |
| 1989 | 2 | 2 | 5 | 16 | 11 | 4 | 2 | 2 | 2 | 2 | 3 | 3 | 4.5 |
| 1990 | 4 | 4 | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Yakima River at Kiona** | | | | | | | | | | | | | |
| 1987 | .5 | 1 | 12 | 4 | 18 | 1 | 1 | 1 | .7 | 1 | .5 | 1 | 3.5 |
| 1988 | .5 | 1 | .9 | 8 | 4 | 3 | 1 | 1 | 2 | 1 | 2 | 1 | 2.2 |
| 1989 | .9 | .7 | 3 | 30 | 17 | 3 | 2 | 2 | 2 | 2 | 3 | 2 | 5.6 |
| 1990 | 4 | 2 | 3 | 18 | 9 | 50 | 2 | 8 | 3 | -- | -- | -- | -- |

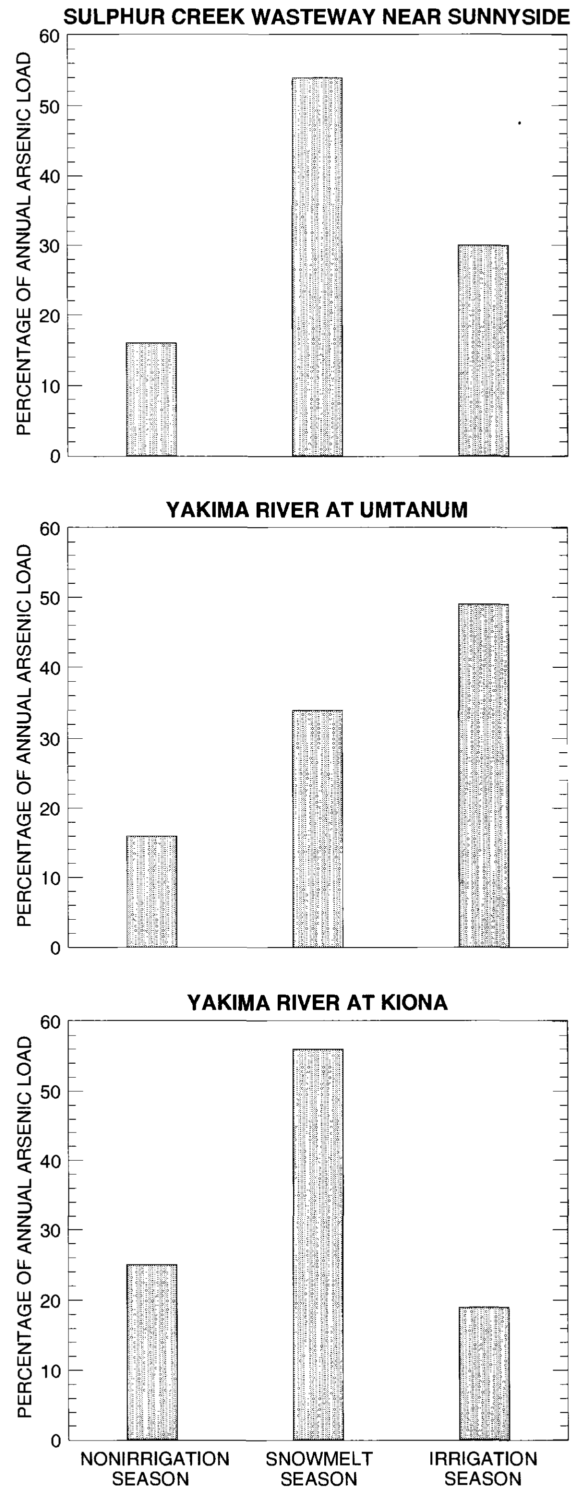


**Figure 14.** Percentages of the annual load of arsenic in suspended sediment for selected time periods at Sulphur Creek Wasteway near Sunnyside, the Yakima River at Umtanum, and the Yakima River at Kiona, Yakima River Basin, Washington, 1989 (nonirrigation season is October through March; snowmelt season is April through May; irrigation season is June through September).

sediment concentrations in Sulphur Creek Wasteway. As noted earlier, the concentration of arsenic in suspended sediment during the irrigation season was not large relative to that measured in streambed sediment of the Sunnyside Subbasin. Concentrations of suspended sediment were high; however, during the 1989 irrigation season, the average suspended-sediment concentration (162 mg/L) in Sulphur Creek was about 4 times higher than that measured during the nonirrigation season. Thus, large concentrations of suspended sediment, and not of suspended arsenic, result in high irrigation-season loads of suspended arsenic in Sulphur Creek. Farm practices that tend to reduce erosion also will reduce the suspended-arsenic load of Sulphur Creek Wasteway to the main stem.

The irrigation-season load of arsenic for the Yakima River at Umtanum, like Sulphur Creek Wasteway near Sunnyside, also is larger than the nonirrigation season load. In 1989, the irrigation- season load of arsenic (2.2 pounds per day) was more than three times the nonirrigation season load. The large irrigation-season load probably results from agricultural soil erosion in the Kittitas Valley rather than from an increase in the concentration of suspended arsenic at Umtanum. In July 1988, Wilson Creek (RM 147) was discharging 83 mg/L of suspended sediment to the main stem upstream from Umtanum (Embrey, 1992). Several other irrigation drains also discharge to the main stem, upstream from the Umtanum site (Bureau of Reclamation and U.S. Soil Conservation Service, 1974); although not sampled in this study, these irrigation drains also may contribute to the suspended-arsenic load at Umtanum.

The dominant season for transport of suspended arsenic at most sites, however, is snowmelt. At Kiona, for example, the quantity of arsenic transported during the snowmelt season of 1989 (about 1,400 pounds) was 5 times larger than that transported during the irrigation season, and the load of arsenic during the snowmelt season (24 pounds per day) is more than 10 times larger than the irrigation-season load. Additionally, more than one-half the 1989 annual load of suspended arsenic at Kiona was transported during the snowmelt season (fig. 14). Similar transport patterns were measured for the Yakima River at Euclid Bridge at RM 55 near Grandview and at the Naches River near North Yakima. For the Yakima River at Umtanum, however, the 1989 irrigation-season load was only 1.3 times larger than the snowmelt-season load. The smaller load of snowmelt at Umtanum indicates the capture of snowmelt runoff by irrigation-storage reservoirs in the Kittitas Valley. During the irrigation season, water released from reservoirs in the Kittitas Valley is routed down the main stem and, at various points, diverted for irrigation. The steep channel slope (14 ft/mi) and high streamflow in the main-stem portion of the Kittitas Valley provide the high velocity streamflows for transporting suspended arsenic.

Annual loads of suspended arsenic increase as much as threefold between the Yakima River at Umtanum and the Yakima River above Ahtanum Creek at Union Gap, but loads were similar between the Union Gap site and the Yakima River at Euclid Bridge at RM 55 near Grandview and between the Grandview site and the Yakima River at Kiona (table 16). The similarity in load between the Union Gap site and the Grandview site should not be interpreted as meaning that Sulphur Creek's load contribution to the main stem is negligible. Instead, during the irrigation season, most of the suspended-arsenic load, as well as streamflow, is diverted into irrigation canals downstream of the Union Gap site. As a result of these diversions, about 80 percent of the streamflow in the main stem of the lower Yakima Valley is from tributaries that carry agricultural return flow (Rinella and others, 1992), and suspended-arsenic loads measured at the Grandview site principally represent suspended arsenic returned to the main stem from agricultural drains.

The annual loads of suspended arsenic for most sites were larger in 1989 than in 1987–88. These differences were attributed to increased streamflows during 1989 rather than an increase in the concentration of suspended arsenic. For example, the annual average streamflow in 1989 for the Kiona site was 20 percent more in 1989 than in 1988.

In the Yakima River, between the Umtanum and Union Gap sites, the sources of arsenic that exist in Wide Hollow Subbasin, and possibly Moxee Subbasin may account for the increase in suspended-arsenic load between the Umtanum and Union Gap sites. Lead-arsenate formulations of pesticide were applied in these areas to control codling moths in apples from 1908 to 1947. To determine contributions in the reach of the main stem affected by Wide Hollow Subbasin and Moxee Subbasin during 1989, the sum of the loads for the Naches River near North Yakima and the Yakima River at Umtanum was subtracted from the load for the Yakima River above Ahtanum Creek at Union Gap. A small correction was applied to the Umtanum loads to account for the load diverted around Union Gap, through Roza Canal, during the irrigation season. During the 1989 irrigation season, approximately 2.2 lb of suspended arsenic per day enter the main stem over the 9.4-mile reach that includes discharges from the Wide Hollow and Moxee Subbasins; this suspended arsenic represents about one-half the irrigation-season load of arsenic at the Union Gap site.

The suspended arsenic load was estimated for Moxee Drain, the major irrigation return flow in this reach, to determine if the irrigation season load of 2.2 lb of suspended arsenic per day is a reasonable estimate for the reach of main stem affected by Wide Hollow and Moxee Subbasins. This estimate was made by using the arsenic concentration of streambed sediment instead of the suspended-arsenic concentration, because suspended-arsenic concentrations were not measured. For example, by using the Moxee Drain concentration of suspended sediment (597 mg/L) and discharge (76 $ft^3/s$) measurements from July 28, 1988 (Embrey, 1992), and a streambed-sediment concentration of arsenic (3.6 μg/g) (Moxee Drain at Thorp Road; Fuhrer, McKenzie, and others, 1994), the estimated instantaneous load of suspended arsenic was nearly 1 lb per day. Irrigation season contributions of suspended arsenic from waterways such as Moxee Drain easily could account for the observed increase in load over this reach. Additionally, because the concentration of suspended sediment is high and the concentration of suspended arsenic was low, the load estimated for Moxee Drain was affected more by suspended sediment than by the suspended-arsenic concentration.

Arsenic concentrations in filtered-water samples ranged from less than 1 to 9 μg/L at the seven fixed sites (table 14). The largest concentrations were in the lower Yakima Valley (fig. 15 and table 37 at back of report). Arsenic concentrations exceeding 3 μg/L, the 90th percentile for the Yakima River Basin, were found in Sulphur Creek Wasteway near Sunnyside, the Yakima River at Euclid Bridge at RM 55 near Grandview, and the Yakima River at Kiona—the three most downstream sites in the lower Yakima Valley. Arsenic concentrations in the Yakima River at Cle Elum, the Yakima River at Umtanum, and the Yakima River above Ahtanum Creek at Union Gap generally are below the limit of determination for arsenic (1.0 μg/L).

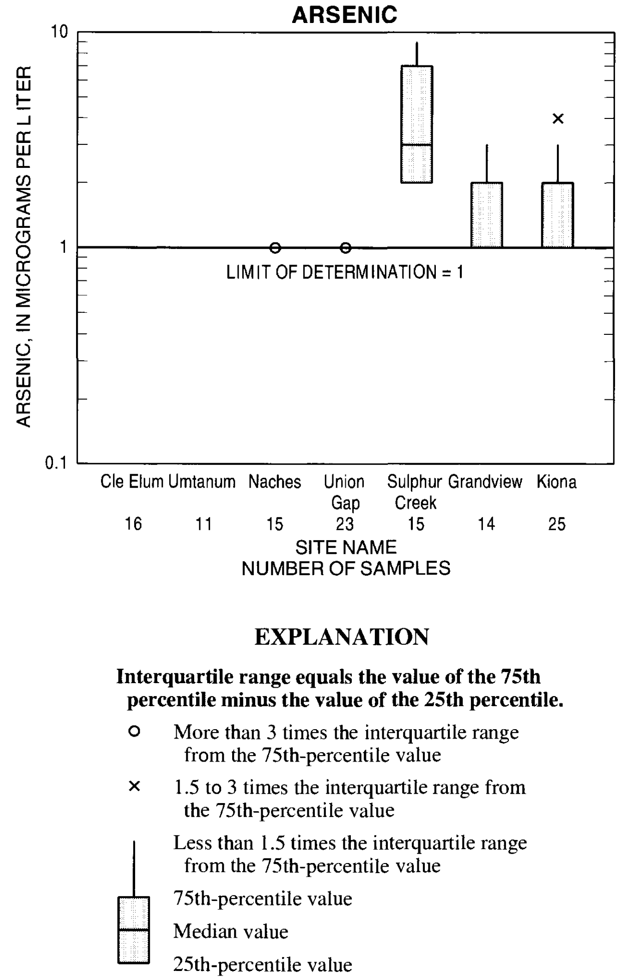


**Figure 15.** Distribution of arsenic concentrations in filtered-water samples at fixed sites, Yakima River Basin, Washington, 1987–90 ("Cle Elum" represents Yakima River at Cle Elum; "Umtanum" represents Yakima River at Umtanum; "Naches" represents Naches River near North Yakima; "Union Gap" represents Yakima River above Ahtanum Creek at Union Gap; "Sulphur Creek" represents Sulphur Creek Wasteway near Sunnyside; "Grandview" represents Yakima River at Euclid Bridge at river mile 55 near Grandview; and "Kiona" represents Yakima River at Kiona).

The concentrations of arsenic during the irrigation season, at the Sulphur Creek site, are lower than during the nonirrigation season (fig. 16). In contrast, concentrations of arsenic during the irrigation season at the Grandview and Kiona sites generally were higher than during the nonirrigation season. The lower arsenic concentrations at the Sulphur Creek site are probably the result of dilution from excess canal water spilled into Sulphur Creek from Roza Canal and by irrigation return flow in the Sunnyside Subbasin. Although arsenic concentrations in Roza Canal were not measured directly, concentrations should be similar to those measured during the irrigation season in

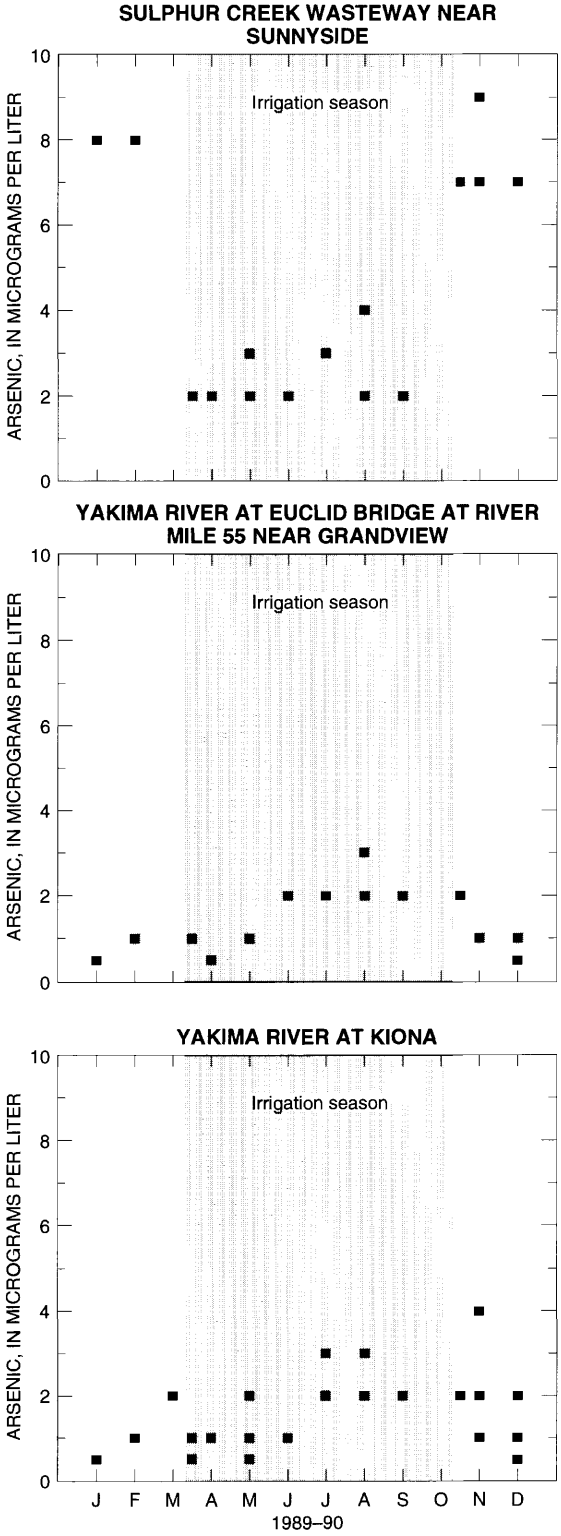


**Figure 16.** Arsenic concentrations in filtered-water samples at Sulphur Creek Wasteway near Sunnyside, the Yakima River at Euclid Bridge at river mile 55 near Grandview, and the Yakima River at Kiona, Yakima River Basin, Washington, 1987–90 (shaded area represents the irrigation season; "less than" values are graphically represented as one-half their value).

the Yakima River at Umtanum (RM 140.4). The Umtanum site is located 12.5 miles upstream from the Roza Canal diversion. Monthly arsenic concentrations at Umtanum were low (less than 1 µg/L) for the period April 1989 to March 1990) and probably accounted for the dilution of arsenic in Sulphur Creek Wasteway. Sunnyside Subbasin also receives water from Sunnyside Canal. Again, arsenic concentrations were not measured directly in the canal, but were similar to concentrations in the main stem at the Union Gap site. The Union Gap site is located 3.4 miles upstream from the diversion to Sunnyside Canal and has monthly arsenic concentrations generally below the method reporting level.

Although arsenic concentrations at the Sulphur Creek site were low during the irrigation season, concentrations generally were similar to higher arsenic concentrations measured at the Grandview and Kiona sites (fig. 16). These increases in arsenic concentrations during the irrigation season at the Grandview and Kiona sites coincide with decreased streamflows (fig. 17) in the main stem and probably result from dilution processes—higher concentrations of arsenic generally were associated with decreased streamflows and conversely, lower concentrations of arsenic generally were associated with increased streamflows. Arsenic concentrations in Sulphur Creek Wasteway, and possibly in other tributaries that carry irrigation return flow (although not measured in this study), are important sources of arsenic in the main stem. The effect of these sources of arsenic is especially important during the irrigation season, because most of the streamflow in the main stem of the lower Yakima Valley is irrigation return flow (Rinella and others, 1992).

Intersite comparisons of arsenic loads were hampered in the Kittitas Valley because a majority of the arsenic determinations were below the method reporting level. In the lower Yakima Valley, however, detectable arsenic was measured; thus, quantifiable loads were calculated and are reported in table 17. In Sulphur Creek Wasteway near Sunnyside, for example, the monthly arsenic loads ranged from 3 to 4 pounds per day in 1989 and were similar between the irrigation and nonirrigation seasons. The large variation in arsenic concentrations between the irrigation and the nonirrigation seasons, as well as the small intrasite variability for arsenic loads, indicates that Sulphur Creek Wasteway is a constant year-round source of arsenic to the main stem. Agricultural lands historically treated with lead-arsenate formulations and present-day applications of phosphate fertilizers may

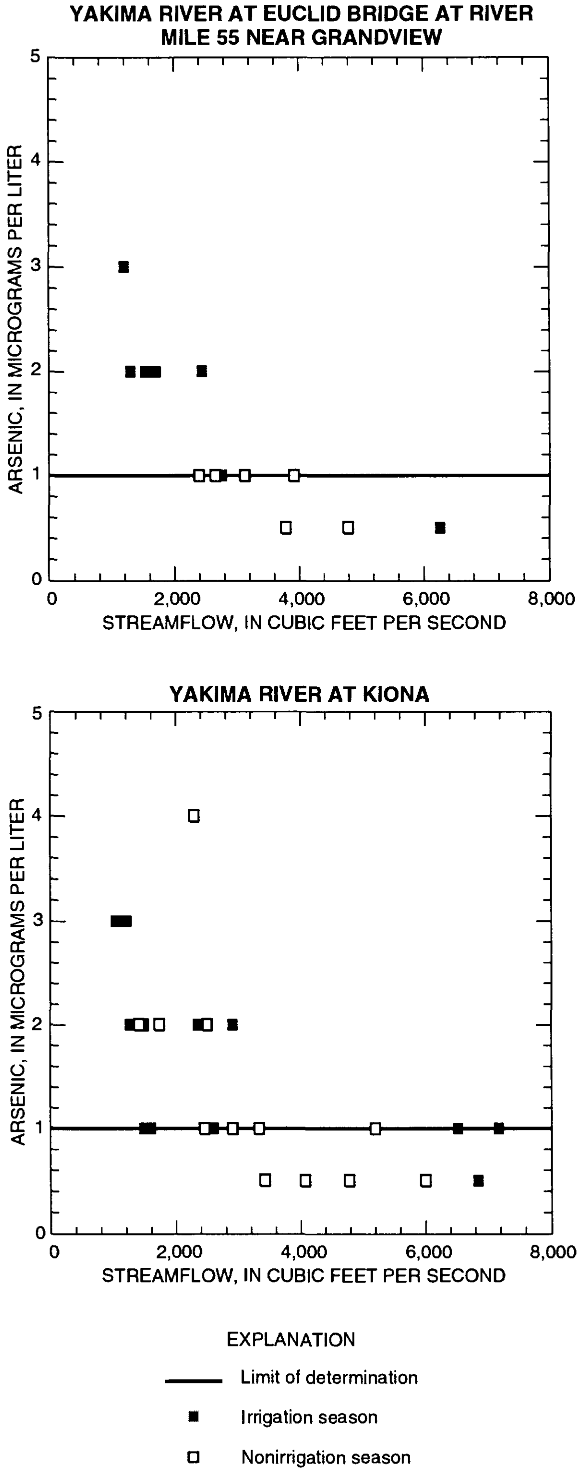


**Figure 17.** Arsenic concentrations in filtered-water samples and streamflow for selected time periods at the Yakima River at Euclid Bridge at river mile 55 near Grandview and the Yakima River at Kiona, Yakima River Basin, Washington, 1989–90 (concentrations lower than the limit of determination [1.0 microgram per liter] are shown as 0.5 microgram per liter; irrigation season is June through September; nonirrigation season is October through March).

**Table 17.** Estimated arsenic loads in filtered-water samples at selected fixed sites, Yakima River Basin, Washington, 1989–90

[The term "filtered water" is an operational definition referring to the chemical analysis of that portion of a water-suspended sediment sample that passes through a nominal 0.45-micrometer filter. Loads reported as pounds per day; load values are based on calibration data collected from April 1989 to March 1990; --, insufficient data. Lightly shaded and darkly shaded cells, respectively, represent the snowmelt portion and the nonsnowmelt portion of the irrigation season; unshaded cells represent the nonirrigation season]

| Year | January | February | March | April | May | June | July | August | September | October | November | December | Daily mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sulphur Creek Wasteway near Sunnyside** | | | | | | | | | | | | | |
| 1989 | 2.9 | 3.0 | 3.2 | 3.8 | 3.8 | 3.6 | 3.6 | 3.7 | 3.7 | 3.4 | 3.0 | 3.0 | 3.4 |
| 1990 | 3.0 | 2.9 | 3.2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Yakima River at Euclid Bridge at river mile 55 near Grandview** | | | | | | | | | | | | | |
| 1989 | 17.2 | 17.0 | 17.5 | 18.1 | 17.7 | 17.0 | 16.5 | 16.5 | 16.6 | 16.7 | 17.3 | 17.3 | 17.1 |
| 1990 | 17.5 | 17.6 | 17.7 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Yakima River at Kiona** | | | | | | | | | | | | | |
| 1989 | 19.6 | 18.8 | 21.2 | 25.4 | 21.9 | 17.8 | 15.8 | 16.1 | 16.7 | 18.0 | 19.8 | 20.4 | 19.3 |
| 1990 | 21.4 | 21.2 | 21.5 | 24.4 | 21.1 | 24.2 | 16.1 | 17.8 | 17.8 | -- | -- | -- | -- |

be a source of arsenic to shallow ground water and to surface water.

Arsenic in Sulphur Creek Wasteway also represents a large proportion of the load in the main stem at the Grandview site. In 1989, the Sulphur Creek site (located about 5 miles upstream from the Grandview site) accounted for approximately 20 percent of the annual arsenic load at Grandview but accounted for only about 8 percent of the streamflow—ratios were similar at the Kiona site. In addition, during the nonirrigation season, the Sulphur Creek site accounts for approximately 18 percent of the annual load of arsenic at the Grandview site but accounts for less than 3 percent of the streamflow. The consistency among monthly arsenic loads and the intrasite variability for streamflow and arsenic concentrations confirmed that arsenic is diluted in Sulphur Creek Wasteway during the irrigation season. The consistency among monthly arsenic loads at the Grandview and Kiona sites also indicates that arsenic is discharged to the main stem at a relatively constant rate.

Arsenic in dissolved form (water sample filtered through a nominal 0.45-μm-pore-size filter) comprises the major transport phase in the lower Yakima Valley (fig. 18). For the Sulphur Creek, Grandview, and Kiona sites, the irrigation- and nonirrigation-season loads of arsenic in dissolved forms are from 4 to 9 times higher than the respective suspended loads. Conversely, during the snowmelt season, arsenic is transported in near-equal proportions in both forms. Increases in suspended-sediment concentration, rather than increases in suspended-arsenic concentrations (mass/mass), however, are responsible for the increase in suspended-arsenic load. For example, the suspended-sediment concentration was nearly 8 times the median suspended-sediment concentration during the 1989 snowmelt season at the Kiona site; although, concentrations of suspended arsenic remained unchanged.

Arsenic concentrations in aquatic biota generally were low throughout the Yakima River Basin; however, a few sites in the lower Yakima Valley had relatively high concentrations (table 18). In curlyleaf pondweed, arsenic concentrations ranged from 0.48 to 1.5 μg/g (table 15) and concentrations in the main stem of the lower Yakima Valley were 3 times higher than in the main stem of the Kittitas Valley. Enrichment of arsenic in aquatic vegetation in the lower Yakima Valley also coincides with the high concentrations of arsenic in filtered water described previously. Concentrations of arsenic from 0.1 to 0.4 μg/g were typical in whole sculpins and in fish liver (table 15). Slightly higher concentrations were observed in livers of bridgelip sucker from Granger Drain at mouth near Granger (0.8 µg/g) and in carp from the Yakima River at Kiona (0.7 µg/g). In 1990, arsenic concentrations in Asiatic clams varied little (3.6 to 4.6 µg/g) among sites. In 1989, arsenic concentrations in caddisflies from Granger Drain site (5.4 µg/g) and from Sulphur Creek Wasteway near Sunnyside (4.1 µg/g) exceeded the 85th-percentile concentration for the basin.

Arsenic concentrations in fish in the Yakima River Basin were low in relation to concentrations measured in other basins. Concentrations in whole sculpin generally were less than the mean arsenic concentration in freshwater fish collected for the National Contaminant Biomonitoring Program between 1976 and 1984 (table 38, at back of report).

Arsenic concentrations in sculpin from the Yakima River Basin also were similar to background concentrations for bluegills and common carp in the San Joaquin River Basin in California (approximately 0.18 to 0.42 µg/g for bluegills and 0.26 to 1.68 µg/g for common carp, as calculated from original wet-weight data) (Saiki and May, 1988). Sampling sites for sculpin, however, are not representative of the entire Yakima River Basin. Sculpin were not collected from the main stem, and samplings in tributaries containing agricultural runoff were limited to Satus Creek at gage at Satus and Ahtanum Creek at Union Gap.

Arsenic concentrations in Asiatic clams from the four main-stem sites in the lower Yakima Valley and from Spring Creek at mouth near Whitstran were compared to concentrations reported for uncontaminated or minimally contaminated aquatic environments (table 39, at back of report). Arsenic concentrations in Asiatic clams of the Yakima River Basin were an order of magnitude higher than concentrations reported in the Apalachicola River in Florida (Elder and Mattraw, 1984); arsenic concentrations were at least 3 times higher than in the Sacramento River Basin in California (McCleneghan and others, 1981), but were similar to arsenic concentrations in Asiatic clams in the San Joaquin River in California, which are considered to be affected by minor anthropogenic sources (Johns and Luoma, 1990; Leland and Scudder, 1990). However, Asiatic clams of the Yakima River Basin had lower arsenic concentrations than the 8 to 13 µg/g measured in Asiatic clams of the upper San Joaquin River in California that are affected by arsenic in agricultural drainage water (Leland and Scudder, 1990).

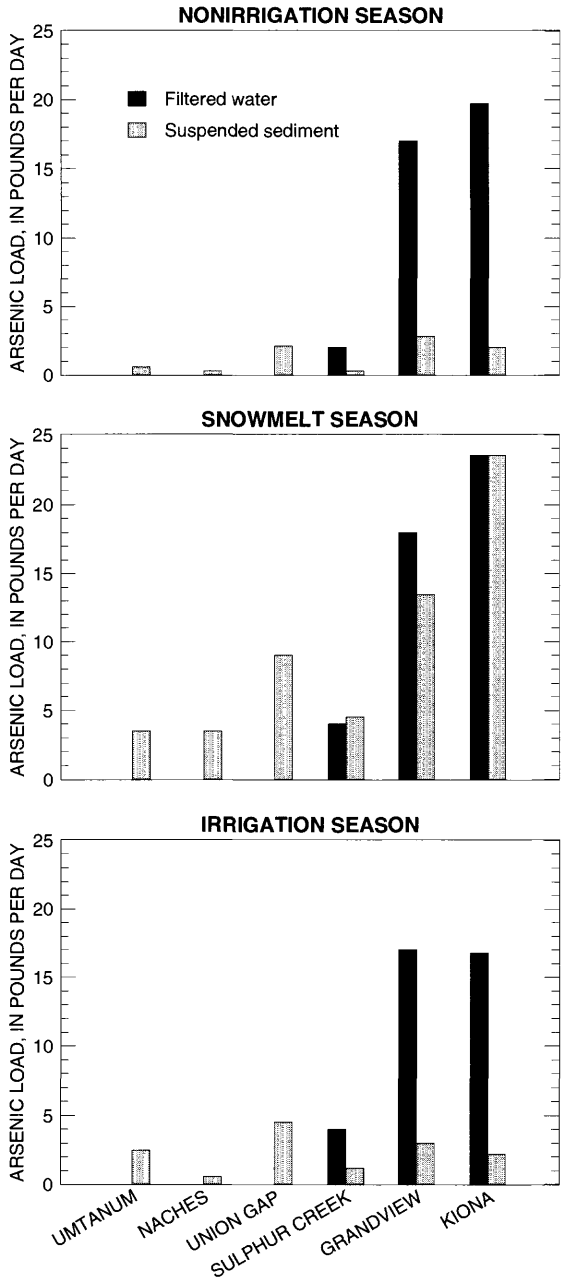


**Figure 18.** Arsenic loads in filtered-water samples and in suspended-sediment samples for selected time periods at fixed sites, Yakima River Basin, Washington, 1989 (the term "filtered water" represents the portion of a water sample passing through a nominal 0.45-micrometer-pore-size filter; nonirrigation season is October through March; snowmelt season is April through May; irrigation season is June through September; "Umtanum" represents Yakima River at Umtanum; "Naches" represents Naches River near North Yakima; "Union Gap" represents Yakima River above Ahtanum Creek at Union Gap; "Sulphur Creek" represents Sulphur Creek Wasteway near Sunnyside; "Grandview" represents Yakima River at Euclid Bridge at river mile 55 near Grandview; and "Kiona" represents Yakima River at Kiona).

**Table 18.** Comparison of low and high arsenic concentrations in water, sediment, and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91

[For filtered water and suspended sediment, the low- and high-concentration assignments are based on a percentile distribution of the 50th-percentile values (median) for each fixed site. For streambed sediment and aquatic biota, the low and high concentration assignments are based on a percentile distribution of the mean concentrations for each fixed site. High concentrations (denoted with an "H" in the table) represent that portion of the distribution which is greater than or equal to the 75th-percentile value. Low concentrations (denoted with an "L" in the table) represent that portion of the distribution which is less than or equal to the 25th-percentile value. Concentrations greater than 25th, but less than 75th-percentile value are denoted with an "*" in the table. The term "filtered water" is an operational definition referring to the chemical analysis of that portion of a water-suspended sediment sample that passes through a nominal 0.45-micrometer filter. Only 1990 data are summarized for largescale sucker livers; sample species: largescale sucker (*Catostomus macrocheilus)* mountain whitefish (*Prosopium willliamsoni*), sculpin (*Cottus spp.*), Asiatic clam (Veneroida: Corbiculidae *Corbicula fluminea*), and curlyleaf pondweed (*Potamogeton crispus*). Data statistically summarized for fixed sites are from monthly and selected hydrologic-event samplings from the Yakima River at Cle Elum, Yakima River at Umtanum, Naches River near North Yakima, Yakima River above Ahtanum Creek at Union Gap, Sulphur Creek Wasteway near Sunnyside, Yakima River at Euclid Bridge at river mile 55 near Grandview, and Yakima River at Kiona for the period 1987–90. To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate at a site, only one element concentration per visit was statistically summarized; --, no data]

| Site reference number | Site name | Filtered water | Sediment | | Aquatic biota | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Fish | | | | |
| | | | Streambed | Suspended | Largescale sucker | Mountain whitefish | Sculpin | Asiatic clam | Curlyleaf pondweed |
| 1 | Waptus River at mouth near Roslyn | -- | H | -- | * | -- | -- | -- | -- |
| 3 | Jungle Creek near mouth near Cle Elum | -- | H | -- | -- | -- | -- | -- | -- |
| 5 | Teanaway River below Forks near Cle Elum | -- | * | -- | -- | -- | -- | -- | -- |
| 6 | Yakima River at Cle Elum | L | H | * | -- | L | * | -- | -- |
| 7 | Naneum Creek below High Creek near Ellensburg | -- | L | -- | -- | -- | L | -- | -- |
| 8 | Taneum Creek at Taneum Meadow near Thorp | -- | L | -- | -- | -- | L | -- | -- |
| 10 | Little Naches River at mouth near Cliffdell | -- | * | -- | -- | -- | -- | -- | -- |
| 12 | South Fork Manastash Creek near Ellensburg | -- | L | -- | -- | -- | L | -- | -- |
| 13 | American River at Hell's Crossing near Nile | -- | H | -- | -- | -- | H | -- | -- |
| 14 | Cherry Creek above Wipple Wasteway at Thrall | -- | * | -- | -- | * | -- | -- | L |
| 19 | Yakima River at Umtanum | L | * | L | -- | L | -- | -- | L |
| 20 | Umtanum Creek near mouth at Umtanum | -- | L | -- | -- | -- | L | -- | -- |
| 21 | Rattlesnake Creek above Little Rattlesnake Creek near Nile | -- | H | -- | -- | -- | -- | -- | -- |
| 22 | Rattlesnake Creek above North Fork Rattlesnake Creek near Nile | -- | H | -- | -- | -- | H | -- | -- |
| 26 | Naches River near North Yakima | L | * | * | -- | * | -- | -- | -- |

**Table 18.** Comparison of low and high arsenic concentrations in water, sediment, and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91—Continued

| Site reference number | Site name | Filtered water | Sediment | | Aquatic biota | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Fish | | | | |
| | | | Streambed | Suspended | Largescale sucker | Mountain whitefish | Sculpin | Asiatic clam | Curlyleaf pondweed |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | -- | * | -- | -- | -- | -- | -- | -- |
| 29 | Wide Hollow Creek at old Sewage Treatment Plant at Union Gap | -- | * | -- | -- | -- | -- | -- | H |
| 30 | Moxee Drain at Thorp Road near Union Gap | -- | * | -- | -- | -- | -- | -- | -- |
| 31 | Ahtanum Creek at Union Gap | -- | L | -- | -- | -- | H | -- | -- |
| 32 | Yakima River above Ahtanum Creek at Union Gap | L | -- | L | -- | -- | -- | -- | -- |
| 33 | Yakima River at Parker | -- | * | -- | L | H | -- | -- | * |
| 34 | South Fork Ahtanum Creek above Conrad Ranch near Tampico | -- | L | -- | -- | -- | L | -- | -- |
| 40 | Granger Drain at mouth near Granger | -- | * | -- | -- | -- | -- | -- | -- |
| 42 | Yakima River below Toppenish Creek at river mile 79.6 near Granger | -- | * | -- | H | H | -- | * | -- |
| 43 | Toppenish Creek at Indian Church Road near Granger | -- | * | -- | -- | -- | -- | -- | -- |
| 47 | Satus Creek at gage at Satus | -- | H | -- | * | -- | H | -- | * |
| 48 | Yakima River at river mile 72 above Satus Creek near Sunnyside | -- | * | -- | -- | -- | -- | * | * |
| 50 | Yakima River at Kiona | H | * | * | * | * | -- | * | * |
| 52 | Sulphur Creek Wasteway near Sunnyside | H | * | H | -- | -- | -- | -- | -- |
| 53 | Satus Creek below Dry Creek near Toppenish | -- | * | -- | -- | -- | H | -- | -- |
| 54 | Spring Creek at mouth at Whitstran | -- | * | -- | -- | -- | -- | L | -- |
| 56 | Yakima River at Euclid Bridge at river mile 55 near Grandview | H | H | H | L | -- | -- | H | H |
| 57 | Satus Creek above Wilson-Charley Canyon near Toppenish | -- | L | -- | -- | -- | H | -- | -- |

Median concentrations of lead in suspended sediment ranged from 15 µg/g to 24 µg/g at the seven fixed sites (table 13); the lowest and highest median values of lead, respectively, were in the Yakima River at Umtanum and in Sulphur Creek Wasteway near Sunnyside (fig. 19; and table 35, at back of report). The low concentrations of suspended lead at Cle Elum, Umtanum, and Naches indicate the lack of a significant geologic source of lead and contrast sharply with enrichment measured at these same sites for suspended elements such as arsenic, chromium, and nickel—all of which have geologic sources. Furthermore, the lack of a significant geologic source is consistent with the distribution of lead in streambed sediment of the Yakima River Basin (Fuhrer, McKenzie, and others, 1994). For example, the 90th-percentile concentration of lead in streambed sediment from 272 first- or second-order streams in the basin was only 23 µg/g. A few small and isolated geologic sources of lead were found in streambed sediment of first- and second-order streams in the Naches Subbasin; however, no evidence of enrichment was found in corresponding higher order streams (Fuhrer, McKenzie, and others, 1994), indicating that measurable quantities of lead were not being transported as suspended sediment and then later redeposited in streambed sediment of higher order streams.

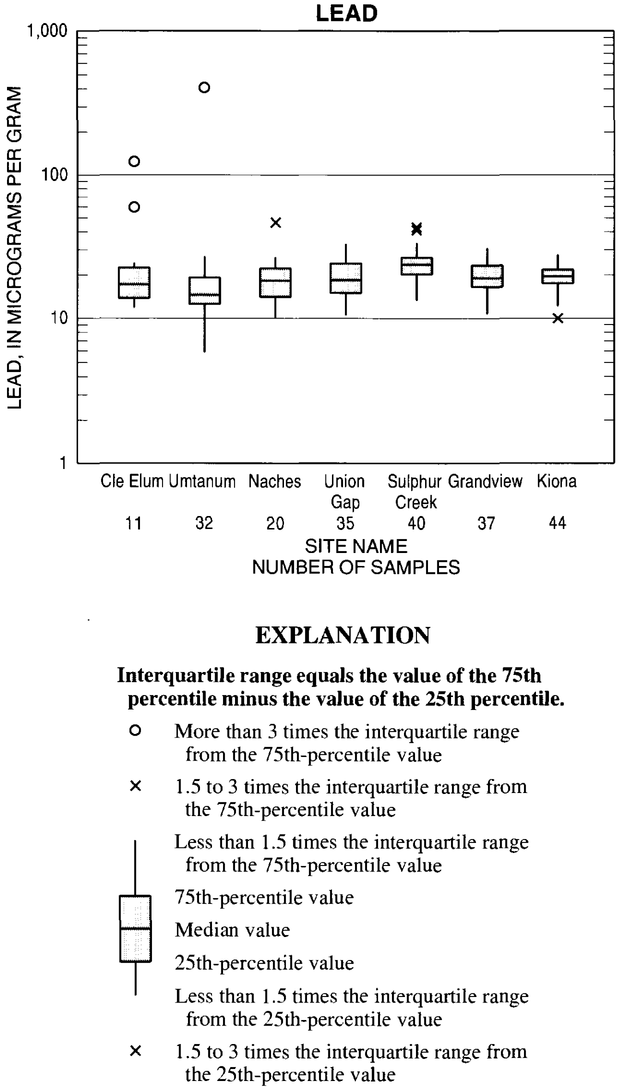


**Figure 19.** Distribution of lead concentrations in suspended sediment at fixed sites, Yakima River Basin, Washington, 1987–90 ("Cle Elum" represents Yakima River at Cle Elum; "Umtanum" represents Yakima River at Umtanum; "Naches" represents Naches River near North Yakima; "Union Gap" represents Yakima River above Ahtanum Creek at Union Gap; "Sulphur Creek" represents Sulphur Creek Wasteway near Sunnyside; "Grandview" represents Yakima River at Euclid Bridge at river mile 55 near Grandview; and "Kiona" represents Yakima River at Kiona).

A few anomalous concentrations of suspended lead were measured in the Yakima River at Cle Elum and in the Yakima River at Umtanum (fig. 19). At the Cle Elum site, concentrations of suspended lead as high as 120 µg/g and 60 µg/g were measured during the rising limb of a May 9, 1989, snowmelt and a January 9–12, 1990, rainstorm or snowstorm, respectively. During the January storm, 60 µg/g of lead was measured on the rising limb, but concentration decreased to just 6 µg/g at the peak of the storm. The Cle Elum site, located 0.15 mile downstream from Crystal Creek, receives urban runoff from the towns of Roslyn and Cle Elum and runoff from numerous open-pit coal mines east of Roslyn. During the storm, Crystal Creek created a turbidity plume which, during the rising limb of the storm, obscured the shallow river bottom in the main stem at the Cle Elum site. The Crystal Creek drainage, located in the nonmarine rocks geologic unit, contains concentrations of lead in streambed sediment (13 µg/g, 14 µg/g, and 18 µg/g; Fuhrer, McKenzie, and others, 1994) that were low when compared to the 60 µg/g of suspended lead measured during the rising limb of the storm. Considering the close proximity of the Cle Elum site to outfall from Crystal Creek and the lack of measurable enrichment for lead in streambed sediment, the high concentration of suspended lead on the rising limb of the storm may have resulted from local urban runoff.

The probable effect of urban runoff on suspended-lead concentrations is confirmed by computing ratios of lead:arsenic. Arsenic was selected because upstream from the Cle Elum site in the Kittitas Valley, the predominant source of arsenic is geologic formations. Variations in lead relative to arsenic may be indicative of urban runoff. For the May snowmelt and January storms, the ratios of lead:arsenic were 15 and 8, respectively. Generally, the lead:arsenic ratios ranged from 2.2 to 2.6 for streambed sediment eroded from geologic units in the Kittitas Valley (based on median lead and arsenic concentrations shown in table 10 in Fuhrer, McKenzie, and others, 1994). These ratios are similar to lead:arsenic ratios measured in suspended-sediment samples. Lead concentrations during the May snowmelt and January storms, however, were approximately 3 to 6 times higher than expected, indicating that a small anthropogenic source of lead exists in close proximity to the Cle Elum site.

In addition to urban runoff, agricultural areas that historically were treated with pesticides containing lead arsenate possibly may be sources of suspended lead. The median concentration of suspended lead in Sulphur Creek Wasteway near Sunnyside, for example, was higher than that measured at the other fixed sites (fig. 19). Lead concentrations at the Sulphur Creek site, however, did not vary seasonally to the extent measured for arsenic and were generally in agreement with lead concentrations found in streambed sediment (17 to 21 μg/g) in the Sulphur Creek drainage (Ryder and others, 1992). The lack of seasonal variability for lead may result from geochemical associations that retard the movement of lead to shallow ground water and subsequently to Sulphur Creek, during the nonirrigation season. The application of phosphate fertilizer tends to form insoluble lead-phosphate compounds (Peryea, 1989). In soils of agricultural areas historically treated with pesticides containing lead arsenate, lead was found to accumulate below the immediate soil surface (30 to 60 cm [centimeters]), but not to the deeper soil depths (50 to 120 cm) noted for arsenic (Peryea, 1989). Lead may be trapped effectively between subsurface ground water and the immediate soil surface. The immobile nature of lead may explain the absence of lead anomalies in suspended sediment and in filtered-water samples during the nonirrigation season, when subsurface ground-water contributions dominate Sulphur Creek streamflow.

Lead in filtered-water samples, determined by atomic-absorption spectrometry with graphite furnace (AAGF), ranged from less than 0.5 to 1.9 μg/L at the seven fixed sites (table 14). Most lead determinations (approximately 94 percent of the 279 measurements made by AAGF), however, were below the limit of determination (0.5 μg/L). Detectable lead concentrations were distributed evenly among most sampling sites. The Cle Elum site, however, had no detectable concentrations of lead. With one exception, spatial and temporal patterns generally were absent among sites. A few days after the close of the irrigation season on October 15, 1989, detectable concentrations of lead were measured at the Naches site (0.7 μg/L), the Union Gap site (0.8 μg/L), and the Sulphur Creek site (0.9 μg/L). All sites had experienced sharp decreases in streamflow over the preceding days due to the close of the irrigation season. None of these lead concentrations, however, exceeded water-quality criteria, regulations, or standards. Additionally, only a small number of the 279 lead determinations for 1987–90 exceeded water-quality guidelines (table 7).

Because the quantity of rainfall in the lower Yakima Valley is small (less than 10 inches annually), storms would be expected to contain detectable lead if urban runoff was a significant source. On the basis of the absence of lead enrichment, in general, and storm-related enrichment, in particular, urban sources of lead are probably limited over much of the Yakima River Basin.

The maximum lead concentrations in fish liver, Asiatic clams (*Corbicula fluminea*), and caddisflies (*Hydropsyche* spp.) were 0.29, 0.40, and 5.6 μg/g, respectively (table 15). For *Hydropsyche* spp., the highest lead concentrations were measured in Wide Hollow Creek site (fig. 20). Lead in rainbow trout liver from the Wide Hollow Creek was below the limit of determination (less than 0.19 μg/g). The apparent disparity in these results may be attributed to the tendency of lead to decrease in concentration in higher trophic-level consumers, such as fish (Luoma, 1986). Lead also was moderately elevated in *Hydropsyche* spp. in Ahtanum Creek (3.0 μg/g), Sulphur Creek (2.6 μg/g), and Spring Creek (2.6 μg/g). The Ahtanum site, which is located near the mouth of Ahtanum Creek, receives irrigation return flow and some urban runoff. The Ahtanum site has lead concentrations in *Hydropsyche* spp. that are more than 5 times higher than at the upstream site (South Fork Ahtanum Creek above Conrad Ranch near Tampico) which does not receive irrigation return flow and is removed from urban effects. A substantial lead concentration (24 μg/g) was measured in *Arctopsyche* sp. in Naneum Creek; however, other insect taxa collected from this site were not similarly enriched (Fuhrer, Fluter, and others, 1994).

Most samples collected in 1989 had lead concentrations below the limit of determination. Lead was detected in 1989 only in caddisflies from Wide Hollow Creek at old Sewage Treatment Plant at Union Gap (8.0 and 9.0 µg/g) and in Granger Drain at mouth near Granger (5.0 µg/g) and in Sulphur Creek Wasteway near Sunnyside (5.0 µg/g).

Compared with concentrations reported for benthic insects from other systems (Cain and others, 1992; Lynch and others, 1988), lead appears to be slightly enriched at Wide Hollow Creek, Ahtanum Creek, and possibly Naneum Creek. Most tissue samples, however, had little or no lead enrichment, which is consistent with the geology as well as lead concentrations in streambed sediment (table 19; and table 40, at back of report). Concentrations of lead in aquatic plants were below limits of determination, except for Wide Hollow Creek at old Sewage Treatment Plant at Union Gap where a lead concentration of 7.0 µg/g was measured in waterweed (Fuhrer, Fluter, and others, 1994). As described earlier, Wide Hollow Creek also had the largest concentrations of lead among the biological sampling sites in the Yakima River Basin.

Lead concentrations were comparatively low in fish livers from the Yakima River Basin (0.09 to 0.31 µg/g). For comparison, five fish species from two rivers that receive agricultural and some urban runoff had lead concentrations ranging from 0.12 to 0.44 µg/g (calculated from original wet-weight data; Barak and Mason, 1990). Mean lead concentrations in the liver of bream (*Abramis brama*) and in pike perch (*Stizostedion lucioperca*) from Lake Balaton, a popular recreational, mildly contaminated lake in Hungary, were 12.9 µg/g and 3.10 µg/g (Salanki and others, 1982). The 85th-percentile lead concentration for fish livers sampled in California's Toxic Substances Monitoring Program was approximately 0.4 µg/g (calculated from original wet-weight data; Rasmussen, 1992).

Primarily on the basis of samplings from main-stem sites, lead does not appear to be enriched in Asiatic clams. Concentrations in the Yakima River Basin were at least 4 times lower than from an area of the San Joaquin River in California that is not subject to urban and industrial inputs (Luoma and others, 1990), but concentrations were somewhat higher than concentrations in the Apalachicola River in Florida (Elder and Mattraw, 1984; table 39, at back of report).

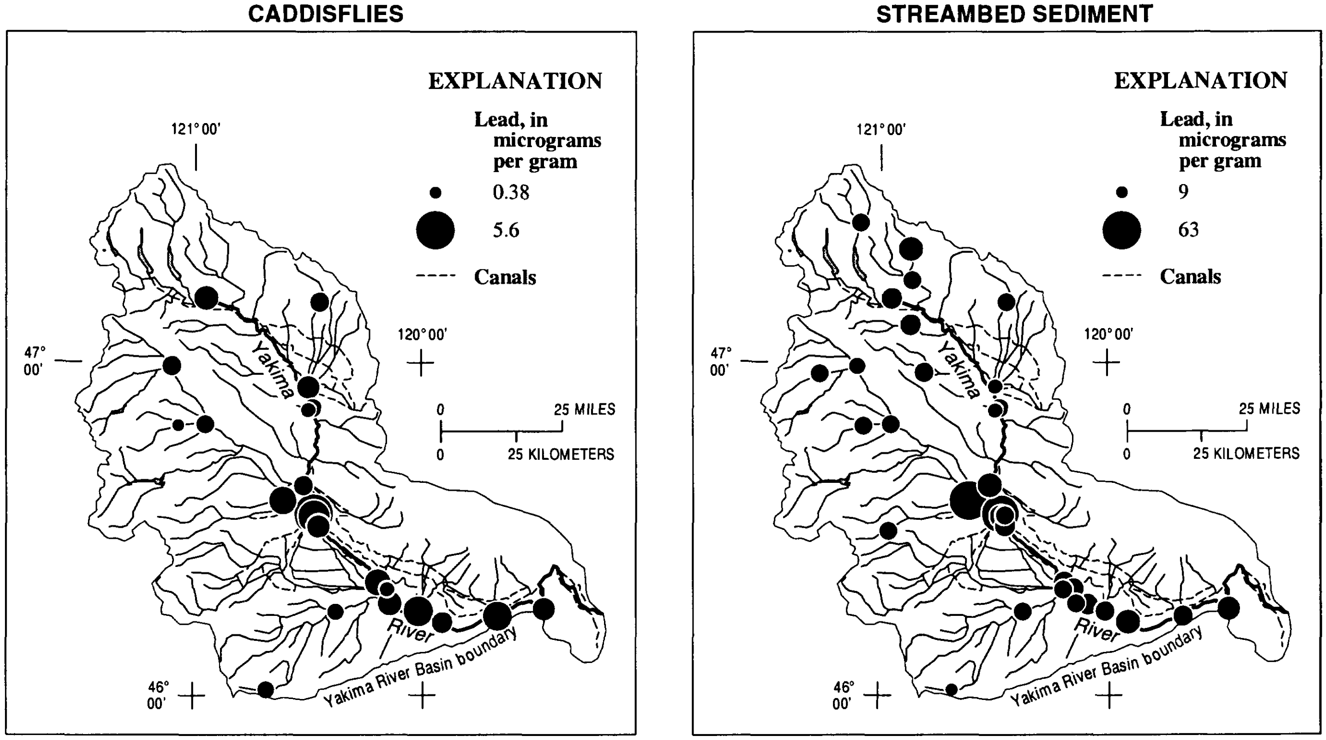


**Figure 20.** Distribution of lead concentrations in caddisflies and streambed sediment, Yakima River Basin, Washington, 1987–90 (element concentrations are reported in units of micrograms per gram [µg/g], dry weight; symbol sizes are proportional to element concentrations; the largest and smallest symbols, respectively, represent the high and low concentration end members; only 1990 data are graphically represented for caddisflies; sample species: caddisflies [Trichoptera: Hydropsychidae *Hydropsyche* spp]).

**Table 19.** Comparison of low and high lead concentrations in sediment and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91

[For filtered water and suspended sediment, the low and high concentration assignments are based on a percentile distribution of the 50th-percentile values (median) for each fixed site; for streambed sediment and aquatic biota, the low and high concentration assignments are based on a percentile distribution of the mean concentrations for each fixed site. High concentrations (denoted with an "H" in the table) represent that portion of the distribution which is greater than or equal to the 75th-percentile value. Low concentrations (denoted with an "L" in the table) represent that portion of the distribution which is less than or equal to the 25th-percentile value. Concentrations greater than 25th, but less than 75th-percentile value are denoted with an "*" in the table. The term "filtered water" is an operational definition referring to the chemical analysis of that portion of a water-suspended sediment sample that passes through a nominal 0.45-micrometer filter; only 1990 data are summarized for largescale sucker livers; sample species: largescale sucker (*Catostomus macrocheilus*), caddisfly (*Hydropsyche* spp.), and Asiatic clam (Veneroida: Corbiculidae *Corbicula fluminea*). Data statistically summarized for fixed sites are from monthly and selected hydrologic-event samplings from the Yakima River at Cle Elum, Yakima River at Umtanum, Naches River near North Yakima, Yakima River above Ahtanum Creek at Union Gap, Sulphur Creek Wasteway near Sunnyside, Yakima River at Euclid Bridge at river mile 55 near Grandview, and Yakima River at Kiona for the period 1987–90. To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate at a site, only one element concentration per visit was statistically summarized; --, no data]

| Site reference number | Site name | Sediment | | Aquatic biota | | |
|---|---|---|---|---|---|---|
| | | Streambed | Suspended | Largescale sucker liver | Caddisfly | Asiatic clam |
| 1 | Waptus River at mouth near Roslyn | * | -- | -- | -- | -- |
| 3 | Jungle Creek near mouth near Cle Elum | H | -- | -- | -- | -- |
| 5 | Teanaway River below Forks near Cle Elum | L | -- | -- | -- | -- |
| 6 | Yakima River at Cle Elum | * | L | -- | * | -- |
| 7 | Naneum Creek below High Creek near Ellensburg | L | -- | -- | * | -- |
| 8 | Taneum Creek at Taneum Meadow near Thorp | * | -- | -- | -- | -- |
| 10 | Little Naches River at mouth near Cliffdell | L | -- | -- | * | -- |
| 12 | South Fork Manastash Creek near Ellensburg | * | -- | -- | -- | -- |
| 13 | American River at Hell's Crossing near Nile | * | -- | -- | -- | -- |
| 14 | Cherry Creek above Wipple Wasteway at Thrall | L | -- | -- | * | -- |
| 16 | Cherry Creek at Thrall | -- | -- | -- | * | -- |
| 19 | Yakima River at Umtanum | * | L | -- | * | -- |
| 20 | Umtanum Creek near mouth at Umtanum | L | -- | -- | L | -- |
| 21 | Rattlesnake Creek above Little Rattlesnake Creek near Nile | L | -- | -- | * | -- |
| 22 | Rattlesnake Creek above North Fork Rattlesnake Creek near Nile | * | -- | -- | L | -- |
| 26 | Naches River near North Yakima | H | * | H | * | -- |

**Table 19.** Comparison of low and high lead concentrations in sediment and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91—Continued

| Site reference number | Site name | Sediment | | Aquatic biota | | |
|---|---|---|---|---|---|---|
| | | Streambed | Suspended | Largescale sucker liver | Caddisfly | Asiatic clam |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | H | -- | -- | H | -- |
| 29 | Wide Hollow Creek at old Sewage Treatment Plant at Union Gap | H | -- | -- | H | -- |
| 30 | Moxee Drain at Thorp Road near Union Gap | * | -- | -- | -- | -- |
| 31 | Ahtanum Creek at Union Gap | * | -- | -- | H | -- |
| 32 | Yakima River above Ahtanum Creek at Union Gap | -- | * | -- | -- | -- |
| 33 | Yakima River at Parker | * | -- | L | * | -- |
| 34 | South Fork Ahtanum Creek above Conrad Ranch near Tampico | L | -- | -- | * | -- |
| 40 | Granger Drain at mouth near Granger | * | -- | -- | H | -- |
| 42 | Yakima River below Toppenish Creek at river mile 79.6 near Granger | * | -- | * | L | H |
| 43 | Toppenish Creek at Indian Church Road near Granger | * | -- | -- | -- | -- |
| 47 | Satus Creek at gage at Satus | L | -- | * | * | -- |
| 48 | Yakima River at river mile 72 above Satus Creek near Sunnyside | * | -- | -- | -- | -- |
| 50 | Yakima River at Kiona | H | H | * | * | L |
| 52 | Sulphur Creek Wasteway near Sunnyside | * | H | -- | H | -- |
| 53 | Satus Creek below Dry Creek near Toppenish | * | -- | -- | L | -- |
| 54 | Spring Creek at mouth at Whitstran | * | -- | -- | H | * |
| 56 | Yakima River at Euclid Bridge at river mile 55 near Grandview | H | * | H | * | * |
| 57 | Satus Creek above Wilson-Charley Canyon near Toppenish | L | -- | -- | * | -- |

## Barium

Concentrations of barium in streambed sediment of the Yakima River Basin ranged from 380 to 590 µg/g (table 12) and were well within the 200- to 1,700-µg/g range of concentration, which characterizes 95 percent of Western United States soils (R.C. Severson, U.S. Geological Survey, written commun., 1987, based on data in Shacklette and Boerngen, 1984). Concentrations of barium increase down the main stem from a minimum of 470 µg/g (site 19) at the Yakima River at Umtanum to a maximum of 540 µg/g (site 54) at the Yakima River at Grandview (fig. 21), and barium concentrations are notably higher at the mouths of several tributaries that carry agricultural return flow to the main stem. For example, concentrations of 510 µg/g, 560 µg/g, and 590 µg/g (the concentration maximum) were measured at Cherry Creek above Wipple at Thrall (site 14), Moxee Drain at Thorp Road near Union Gap (site 30), and Sulphur Creek Wasteway near Sunnyside (site 52), respectively—all sites that carry agricultural return flow to the main stem. The increased barium concentration in streambed sediment of agricultural drains and streambed sediment of the lower main stem probably results from the precipitation of barium as barite (barium sulfate). According to Hem (1989), barium solubility in water is limited by the solubility of barite. When the concentrations of dissolved barium and sulfate become large enough to exceed the solubility product for barite, the concentrations are precipitated to streambed sediment as barite. A common agricultural source of sulfate in the Yakima River Basin is the application of zinc sulfate to promote and retain the blossoms on fruit trees (Robert Wample, University of Washington, Prosser Experimental Station, oral commun., 1991). The solubility of barite is probably exceeded in many of the basin's agricultural waters as a result of various soil amendments that contain sulphate. The large concentration of barium in Waptus River streambed sediment is attributed to nonmarine sedimentary rock of the Swauk Formation which contains barium and potassium aluminosilicate minerals (Tabor and others, 1982).

Barium concentrations in filtered-water samples ranged from less than 2 to 79 µg/L at the seven fixed

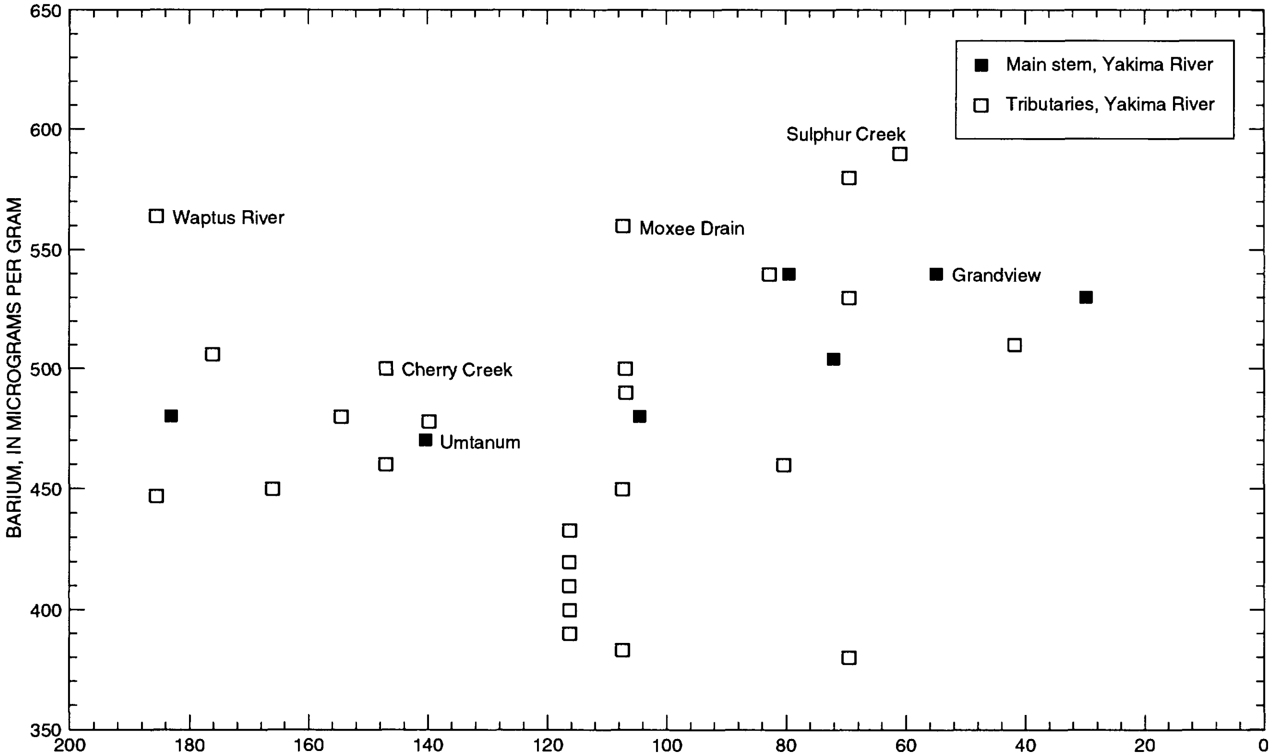


**Figure 21.** Barium concentrations in streambed sediment of the main stem and tributaries, Yakima River Basin, Washington, 1987 ("Waptus River" represents Waptus River at mouth near Roslyn; "Cherry Creek" represents Cherry Creek above Wipple Wasteway at Thrall; "Umtanum" represents Yakima River at Umtanum; "Moxee Drain" represents Moxee Drain at Thorp Road near Union Gap; "Sulphur Creek" represents Sulphur Creek Wasteway near Sunnyside; and "Grandview" represents Yakima River at Euclid Bridge at river mile 55 near Grandview).

sites (table 14). The highest concentrations were in the lower Yakima Valley (table 37, at back of report). Barium concentrations exceeding 39 µg/L, the 90th percentile for the Yakima River Basin, were detected in Sulphur Creek Wasteway near Sunnyside and in the Yakima River at Kiona. The highest concentrations, however, were from Sulphur Creek Wasteway and coincide with high barium concentrations in streambed sediment.

## Cadmium

Most of the cadmium determinations were made using inductively coupled plasma-atomic emission spectrometry (ICP-AES), which had an analytical limit of determination of 2 µg/g. Cadmium concentrations were below the limit of determination for the 27 samples analyzed by using ICP-AES. Five of 32 determinations, however, were made by using an organometallic halide extraction prior to ICP-AES that had a method reporting level of 0.05 µg/g (Arbogast, 1990). Concentrations of cadmium, determined by using the latter analytical method, ranged from 0.2 to 0.8 µg/g. The largest concentration of cadmium (0.8 µg/g) was from streambed sediment in the American River at Hell's Crossing near Nile (site 13) and was well above the average crustal abundance for basalt, which composes most of the Yakima River Basin (0.19 µg/g) (Parker, 1967). Additionally, the concentration of cadmium at the American River site also exceeded that from the anthropogenically affected main stem of the Willamette River at Portland, Oregon (Fuhrer, 1989).

Concentrations of suspended cadmium at the seven fixed sites ranged from less than 0.1 µg/g to 33 µg/g (table 13). Cadmium enrichment was found at the Yakima River at Cle Elum in the Kittitas Valley, the Naches River near North Yakima in the mid-Yakima Valley at Naches, and at the Yakima River at Euclid Bridge at RM 55 near Grandview and the Yakima River at Kiona in the lower Yakima Valley (fig. 22 and table 35, at back of report). The highest median concentration (0.8 µg/g), however, was from the Kittitas Valley at the Cle Elum site.

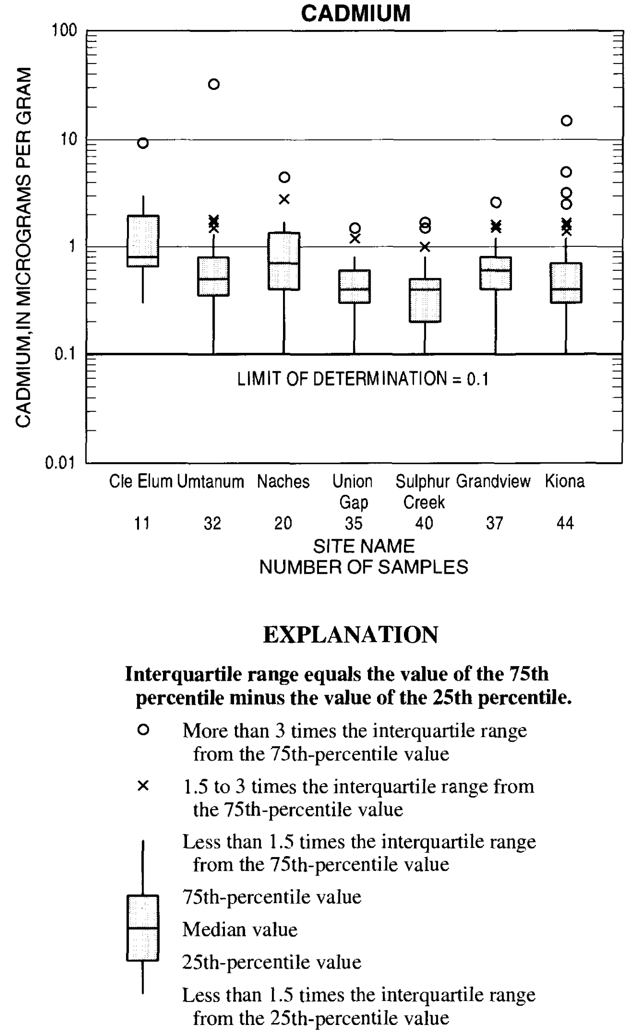


**Figure 22.** Distribution of cadmium concentrations in suspended sediment at fixed sites, Yakima River Basin, Washington, 1987–90 ("Cle Elum" represents Yakima River at Cle Elum; "Umtanum" represents Yakima River at Umtanum; "Naches" represents Naches River near North Yakima; "Union Gap" represents Yakima River above Ahtanum Creek at Union Gap; "Sulphur Creek" represents Sulphur Creek Wasteway near Sunnyside; "Grandview" represents Yakima River at Euclid Bridge at river mile 55 near Grandview; and "Kiona" represents Yakima River at Kiona).

Concentrations of suspended cadmium in the Yakima River at Cle Elum ranged from 0.3 to 9.3 µg/g. Based on limited data, suspended-cadmium concentrations were higher during storms (rising limb of the storm hydrograph) and during late snowmelt. In the late snowmelt season, during mid-April and May, cadmium concentrations increased by a factor of four, but suspended-sediment concentrations decreased from 85 to 5 mg/L. A similar pattern resulted during a January 9–10, 1990, storm. Relative to the preceding month's (December) sampling, suspended-cadmium concentrations during the rising limb of the January 9, 1990, storm increased to 1.0 µg/g—2 times that of the December sampling; the suspended-sediment concentration increased to 12 mg/L—4 times that of the December sampling. The following day (January 10, 1990), during the storm's peak, the suspended cadmium concentration decreased to 0.3 µg/g—a threefold decrease in relation to the rising limb of the storm—but the suspended-sediment concentration increased from 12 mg/L to 130 mg/L. During storms and snowmelt, suspended-cadmium concentrations at Cle Elum decreased as suspended-sediment concentration increased.

Crystal Creek created a turbidity plume of suspended sediment that obscured the shallow river bottom in the Yakima River at Cle Elum during the January 10, 1990, storm. The lower suspended-cadmium concentration during the storm's peak, noted earlier at the Cle Elum site, coincided with the presence of the turbidity plume of suspended sediment from Crystal Creek and indicates that suspended-cadmium concentrations were diluted from mixing with incoming sediment from Crystal Creek. This hypothesis is possible especially if cadmium concentrations in the Crystal Creek drainage are low. The lower limit of determination of cadmium for the sites sampled in the Crystal Creek drainage, as part of the occurrence and distribution survey (Fuhrer, Fluter, and others, 1994), was too high to conclude that Crystal Creek sediment potentially could dilute suspended-cadmium concentrations at the Cle Elum site.

Suspended-cadmium concentrations in the Naches River near North Yakima may reflect the presence of cadmium in streambed sediment of the Upper Naches Subbasin. A cadmium concentration of 0.8 µg/g was measured in streambed sediment of the American River at Hell's Crossing near Nile (site 13) located in the Upper Naches Subbasin. This cadmium concentration was 4 times higher than the average crustal abundance of cadmium in basalt and was similar to the median suspended-cadmium concentration (0.7 µg/g) at site 13 in the Naches Subbasin. Suspended-cadmium concentrations at the Naches site probably originate from geologic sources in the Upper Naches and Tieton Subbasins. Most of the cadmium determinations for streambed sediment, however, had an analytical limit of determination (2.0 µg/g) that exceeded concentrations typical in basalt rock. As a result, cadmium concentrations at many sites were below the limit of determination and could not be used for making comparisons with suspended-cadmium concentrations or for locating geologic sources of cadmium.

The highest cadmium concentrations in the Naches River near North Yakima (site 26) generally were detected during the nonirrigation season (November through March), when suspended-sediment concentrations were small (less than 10 mg/L) and the proportion of fine-grain-sized sediment was large (greater than 85 percent) (fig. 23). During the irrigation and snowmelt seasons at Naches River (site 26), the highest suspended-cadmium concentrations coincide with periods of increased streamflow (fig. 23). During the irrigation season at Naches, streamflow was augmented by withdrawing water from Rimrock Reservoir and Bumping Reservoir. Irrigation-season releases from these reservoirs probably assist in the transport of cadmium that originates from sources in the Upper Naches Subbasin.

As noted earlier, the Kittitas Valley had concentrations of suspended cadmium that generally exceeded concentrations measured at other fixed sites. The annual load of cadmium in the Kittitas Valley, however, is similar to that measured in the mid-Yakima Valley at the Yakima River above Ahtanum Creek at Union Gap, the lower Yakima Valley at the Yakima River at Euclid Bridge at RM 55 near Grandview, and the Yakima River at Kiona (table 20). Although annual loads of cadmium generally are similar for these main-stem sites, the proportions of the annual load transported during the snowmelt, irrigation, and nonirrigation seasons vary; moreover, snowmelt loads generally exceed loads during the irrigation season and the nonirrigation season (fig. 24). At the Kiona site, nearly 68 percent of the 1989 annual cadmium load was transported during the snowmelt season—this load is nearly 6 times the quantity of cadmium transported during the irrigation season. Similarly, at the Naches River near North Yakima more than 70 percent of the 1989 annual cadmium load was transported during the snowmelt season—this load is 4 times the quantity of cadmium transported during the irrigation season. During the snowmelt season, the higher cadmium loads at the Naches site are the result of suspended-sediment concentrations that are 3 to 4 times larger than during the irrigation season.

In filtered-water samples, cadmium concentrations, determined by AAGF, ranged from less than 0.2 to 2.2 µg/L at the seven fixed sites (table 14). Among fixed sites, the highest number of detections of cadmium were in the Yakima River at Cle Elum and in the Yakima River at Umtanum—cadmium was detected at least 25 percent of the time at both sites

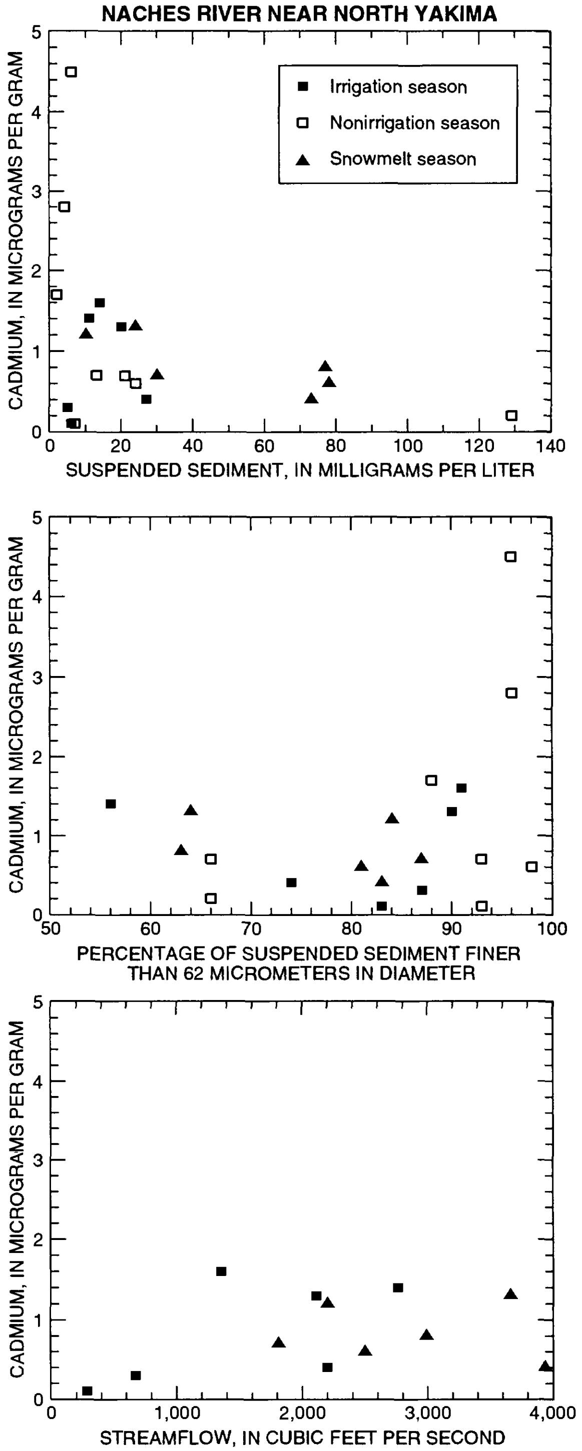


**Figure 23.** Cadmium concentrations in suspended sediment and suspended-sediment concentrations, percentage of suspended sediment finer than 62 micrometers in diameter, and streamflow in the Naches River near North Yakima, Yakima River Basin, Washington, 1987–90 (irrigation season is June through September; nonirrigation season is October through March; and snowmelt season is April through May).

(table 37, at back of report). Conversely, in the mid- and lower Yakima Valley at least 75 percent of the determinations for cadmium were below the limit of determination (0.2 µg/L). The higher concentrations of cadmium in filtered-water samples in the Kittitas Valley also coincide with cadmium enrichment in suspended sediment. Cadmium concentrations in suspended sediment are higher at Cle Elum during snowmelt and storms. Comparisons between cadmium concentration in filtered-water samples in the Yakima River Basin and cadmium concentrations in other studies (table 36, at back of report) are hampered by a large amount of censored data.

Cadmium concentrations, which exceeded the limit of determination by at least a factor of two, were selected as conservative measures of detectable cadmium in order to illustrate temporal and spatial patterns (table 21). These patterns indicate that sources of cadmium generally are not anthropogenic, but these patterns are related to periods of snowmelt and to storms in the Kittitas Valley. Cadmium was detected during periods of snowmelt at the Cle Elum, Umtanum, Naches, and Union Gap sites in concentrations that ranged from 0.4 to 0.5 µg/L in April 1987 and at the same sites in 1988 at lower concentrations. In November 1988, fixed sites were visited during an early November winter warming period (early snowmelt); and cadmium concentrations ranging from 0.2 to 2.2 µg/L were measured at the Cle Elum, Umtanum, Naches, Union Gap, and Kiona sites. Similar patterns also were detected during storms and during the irrigation season in June. The cadmium concentration (2.2 µg/L) at the Naches site exceeded that of other sites by an order of magnitude.

During November 1988, the increase in cadmium concentration at the Naches site, in part, may have resulted from construction of a walking path/green way along the left bank, upstream and downstream from the Naches site. Fill material was placed into and alongside the right bank of the Naches River as a foundation for an asphalt pathway. Although in this instance the cadmium concentration probably was affected to a larger degree by the construction activity than by snowmelt, the snowmelt conditions probably enhanced the cadmium concentration. The effect of snowmelt conditions on cadmium concentrations was noted during an earlier sampling, prior to construction activity. In December 1987—again, during a period of winter warming and subsequent snowmelt runoff—dissolved cadmium (0.3 µg/L) was detected at the Naches site on the rising limb of the

**Table 20.** Estimated cadmium loads in suspended sediment at selected-fixed sites, Yakima River Basin, Washington, 1987–90

[Loads reported as pounds per day; load estimates are based on calibration data collected from March 1987 to March 1990; --, indicates insufficient data. Bold lines represent the irrigation season, and lightly shaded cells represent the snowmelt portion of the irrigation season; nonirrigation season, October through March; <, less than]

| Year | January | February | March | April | May | June | July | August | September | October | November | December | Daily mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Yakima River at Umtanum** | | | | | | | | | | | | | |
| 1987 | <0.05 | 0.1 | 0.5 | 0.4 | 0.3 | 0.4 | 0.3 | 0.2 | <0.05 | <0.05 | <0.05 | <0.05 | 0.2 |
| 1988 | <.05 | .1 | .2 | .5 | .2 | .2 | .3 | .2 | .1 | <.05 | <.05 | .1 | .2 |
| 1989 | .1 | .1 | .2 | 1 | .6 | .4 | .3 | .2 | .1 | <.05 | <.05 | .1 | .3 |
| 1990 | .2 | .3 | .4 | 1 | .6 | .7 | .3 | .2 | .1 | -- | -- | -- | -- |
| **Naches River near North Yakima** | | | | | | | | | | | | | |
| 1987 | -- | -- | .2 | .4 | 1 | .1 | <.05 | <.05 | <.05 | <.05 | <.05 | <.05 | -- |
| 1988 | <.05 | <.05 | .1 | .4 | .3 | .1 | <.05 | <.05 | .1 | <.05 | <.05 | <.05 | .1 |
| 1989 | <.05 | <.05 | .1 | .7 | .5 | .2 | <.05 | <.05 | .1 | <.05 | <.05 | .1 | .1 |
| 1990 | .3 | .2 | .2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Yakima River above Ahtanum Creek at Union Gap** | | | | | | | | | | | | | |
| 1987 | .2 | .4 | .8 | .7 | .9 | .3 | .2 | .2 | .1 | .1 | .1 | .1 | .3 |
| 1988 | .2 | .4 | .3 | .7 | .5 | .3 | .2 | .2 | .1 | .1 | .2 | .2 | .3 |
| 1989 | .3 | .4 | .5 | 1 | .7 | .4 | .2 | .2 | .1 | .1 | .1 | .2 | .4 |
| 1990 | .4 | .5 | .7 | 1 | .7 | .6 | .3 | .2 | .2 | -- | -- | -- | -- |
| **Sulphur Creek Wasteway near Sunnyside** | | | | | | | | | | | | | |
| 1987 | -- | -- | <.05 | .1 | .1 | .1 | .1 | <.05 | <.05 | <.05 | <.05 | <.05 | -- |
| 1988 | <.05 | <.05 | .1 | .1 | .1 | .1 | <.05 | <.05 | <.05 | <.05 | <.05 | <.05 | <.05 |
| 1989 | <.05 | <.05 | <.05 | .1 | .2 | .1 | .1 | <.05 | <.05 | <.05 | <.05 | <.05 | <.05 |
| 1990 | <.05 | <.05 | .1 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Yakima River at Euclid Bridge at river mile 55 near Grandview** | | | | | | | | | | | | | |
| 1987 | -- | -- | .6 | .6 | .6 | .2 | .2 | .1 | .1 | .1 | .1 | .2 | -- |
| 1988 | .3 | .4 | .4 | .6 | .4 | .3 | .1 | .1 | .1 | .1 | .2 | .2 | .3 |
| 1989 | .4 | .4 | .6 | 1 | .7 | .3 | .2 | .1 | .1 | .1 | .2 | .3 | .4 |
| 1990 | .5 | .6 | .7 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Yakima River at Kiona** | | | | | | | | | | | | | |
| 1987 | .1 | .1 | 1 | .4 | 1 | .1 | .1 | <.05 | <.05 | <.05 | <.05 | .1 | .2 |
| 1988 | .1 | .1 | .1 | .7 | .3 | .2 | .1 | .1 | .1 | .1 | .1 | .1 | .2 |
| 1989 | .1 | .1 | .4 | 2 | 1 | .2 | .1 | .1 | .1 | .1 | .1 | .1 | .4 |
| 1990 | .3 | .3 | .3 | 1 | .7 | 2 | .1 | .2 | .1 | -- | -- | -- | -- |

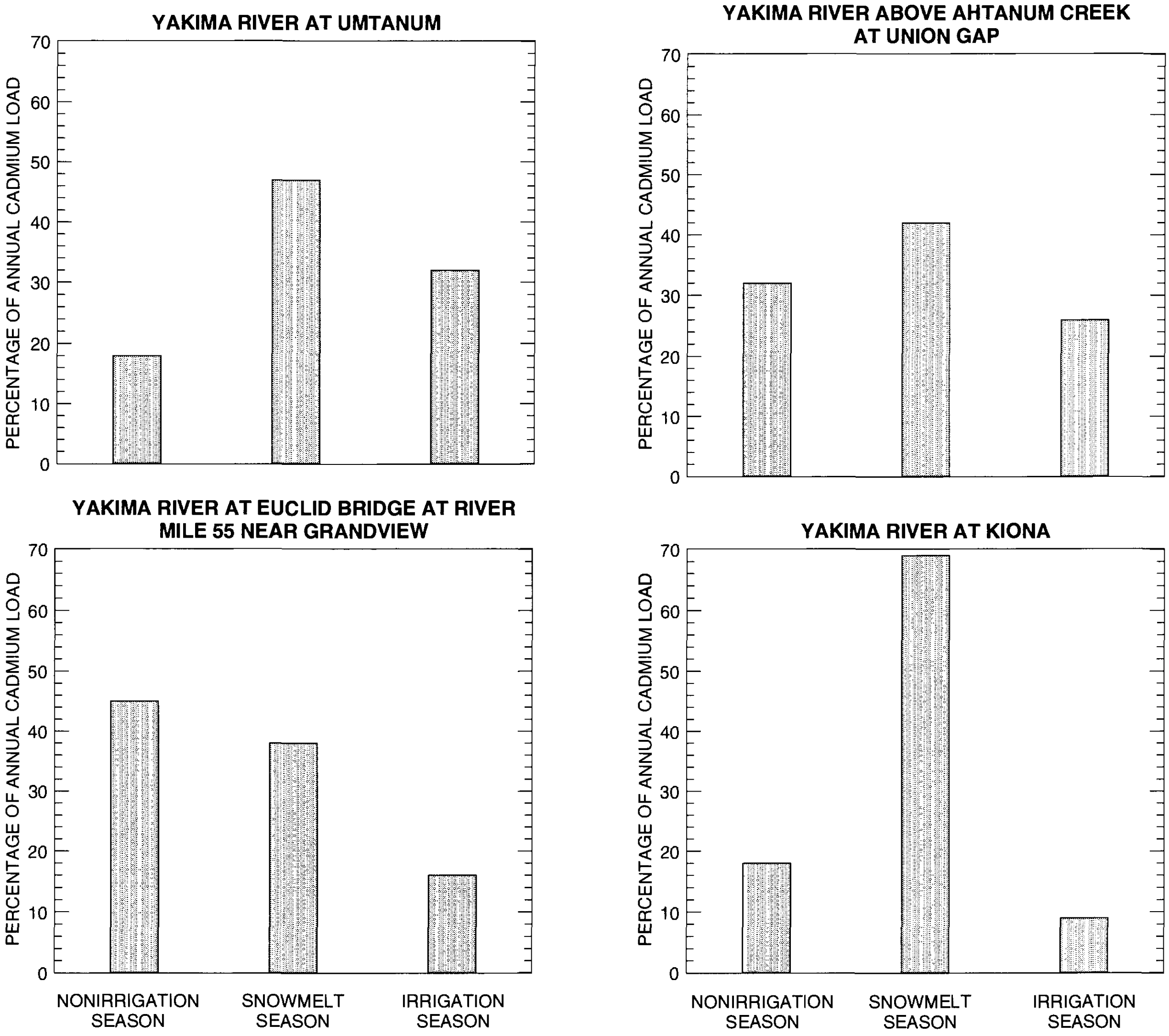


**Figure 24.** Percentages of the annual load of cadmium in suspended sediment for the Yakima River at Umtanum, the Yakima River above Ahtanum Creek at Union Gap, the Yakima River at Euclid Bridge at river mile 55 near Grandview, and the Yakima River at Kiona, Yakima River Basin, Washington, 1989 (nonirrigation season is October through March; snowmelt season is April through May; irrigation season is June through September).

streamflow hydrograph. This time, however, the concentration was similar to streamflow enhanced by snowmelt at other fixed sites.

Load computations for cadmium were hampered at mid- and lower Yakima Valley sites by large amounts of censored data (element concentrations lower than the limit of determination). Consequently, load estimates were made only for the Cle Elum and Umtanum sites—sites with the most uncensored data. In 1988 and 1989, the annual load of cadmium between the Cle Elum and Umtanum sites increased twofold (table 22), and the annual streamflow increased by a factor of about 1.5. The increase in load was primarily because of increases in streamflow and, to a lesser extent, increases in cadmium concentrations between sites.

A large proportion of the annual cadmium load is transported during the irrigation season. At the Cle Elum and Umtanum sites in 1989, for example, the irrigation season accounted for 63 and 53 percent, respectively, of the annual load. The importance of the irrigation season, in relation to the annual load of cadmium, is directly related to streamflow, because storage reservoirs are used to augment streamflow in the Kittitas Valley during the irrigation season. At the Cle Elum and Umtanum sites in 1989, the irrigation season accounted for 61 and 49 percent, respectively, of the annual streamflow. At these sites, smaller

**Table 21.** Frequency of occurrence of cadmium concentrations equaling or exceeding 0.2 microgram per liter in filtered-water samples at fixed sites, Yakima River Basin, Washington, 1987–89

[The term "filtered water" is an operational definition referring to the chemical analysis of that portion of a water-suspended sediment sample that passes through a nominal 0.45-micrometer filter; ref. no., reference number; --, no data; blank cells in table, cadmium concentrations less than 0.2 microgram per liter; shaded cells represent months in which the total number of occurrences of cadmium concentrations that equaled or exceeded 0.2 μg/L is greater than or equal to seven; •, one cadmium concentration equaled or exceeded 0.2 microgram per liter (μg/L); ••, two cadmium concentrations equaled or exceeded 0.2 microgram per liter; Cle Elum, Yakima River at Cle Elum; Umtanum, Yakima River at Umtanum; Naches, Naches River near North Yakima; Union Gap, Yakima River above Ahtanum Creek at Union Gap; Sulphur Creek, Sulphur Creek Wasteway near Sunnyside; Grandview, Yakima River at Euclid Bridge at river mile 55 near Grandview; Kiona, Yakima River at Kiona]

| Year | Site ref. no. | Site name | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1987 | 6 | Cle Elum | -- | -- | -- | • | | • | • | • | | | | |
| 1987 | 19 | Umtanum | -- | -- | -- | • | • | • | | | • | | | |
| 1987 | 26 | Naches | -- | -- | -- | • | | • | | | | | | • |
| 1987 | 32 | Union Gap | -- | -- | -- | • | • | • | | | | | | |
| 1987 | 50 | Kiona | -- | -- | -- | | | • | | | | | • | |
| 1987 | 52 | Sulphur Creek | -- | -- | -- | • | | • | | | | | | |
| 1987 | 56 | Grandview | -- | -- | -- | | | • | | | • | | | • |
| Subtotal | | | -- | -- | -- | 5 | 2 | 7 | 1 | 1 | 2 | 0 | 1 | 2 |
| 1988 | 6 | Cle Elum | • | | | •• | • | • | | • | • | | • | • |
| 1988 | 19 | Umtanum | | | •• | • | | • | | | • | • | • | • |
| 1988 | 26 | Naches | | | | • | | | | • | | | • | |
| 1988 | 32 | Union Gap | | | | • | | | | | | | • | |
| 1988 | 50 | Kiona | • | | • | | | | | | | | • | • |
| 1988 | 52 | Sulphur Creek | •• | | | | | • | | | | | | |
| 1988 | 56 | Grandview | • | | | | | | | | | | | |
| Subtotal | | | 5 | 0 | 3 | 5 | 1 | 3 | 1 | 2 | 2 | 1 | 5 | 3 |
| 1989 | 6 | Cle Elum | • | | • | | • | | | | | | • | |
| 1989 | 19 | Umtanum | • | | • | | | | | • | | • | • | |
| 1989 | 26 | Naches | | | | | | | | | | | | |
| 1989 | 32 | Union Gap | | | | | | | | | | | | |
| 1989 | 50 | Kiona | | | | | | | | | | | | |
| 1989 | 52 | Sulphur Creek | | | • | | | | | | | | | |
| 1989 | 56 | Grandview | | | | | | | | | | | | |
| Subtotal | | | 2 | 0 | 3 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 2 | 0 |
| Total | | | 7 | 0 | 6 | 10 | 4 | 10 | 2 | 4 | 4 | 2 | 8 | 5 |

proportions of the annual cadmium load (17 and 28 percent, respectively) were transported during the snowmelt season in 1989. The smaller proportion of the load transported during the snowmelt season also is directly related to streamflow. During the 1989 snowmelt season, the Cle Elum and Umtanum sites accounted for only 19 and 31 percent, respectively, of the annual streamflow.

Based on comparisons between dissolved (water sample filtered through a nominal 0.45-µm-pore-size filter) and suspended forms of cadmium, the dissolved form is the major transport phase in the Yakima River at Umtanum (fig. 25). Dissolved loads exceeded suspended loads by more than an order of magnitude during the irrigation season and the nonirrigation season.

Cadmium concentrations in fish livers and Asiatic clams generally were less than 0.5 µg/g (table 15). Maximum concentrations in mountain whitefish (1.4 µg/g), largescale sucker (0.43 µg/g), and carp (2.5 µg/g) were measured in the lower Yakima Valley in the Yakima River below Toppenish Creek at RM 79.6 near Granger and in the Yakima River at Kiona. In 1989, cadmium concentrations were below the limit of determination in most fish samples; however, detectable concentrations were measured in several samples in the lower Yakima Valley portion of the main stem. For example, the cadmium concentration in mountain whitefish was 1.1 µg/g in the Yakima River at Kiona, and the concentration in largescale sucker was 0.6 µg/g in Sulphur Creek Wasteway near Sunnyside and 0.45 µg/g in the Yakima River at Kiona.

In aquatic plants, variations in cadmium concentrations are generally small. When measured, high concentrations do exist in waterways that carry irrigation return flow and (or) urban runoff. Cadmium concentrations as high as 3.3 µg/g were measured in waterweed in Spring Creek at mouth at Whitstran as well as concentrations as high as 0.9 µg/g in curlyleaf pondweed in Cherry Creek at Thrall (Fuhrer, Fluter, and others, 1994). Cadmium in plant tissue at the latter site and the detection of cadmium in filtered-water samples in the Yakima River at Umtanum (located just downstream from Cherry Creek) indicates that a source(s) of cadmium exists in the Kittitas Valley.

Cadmium concentrations in benthic insects do not exceed 0.25 µg/g (table 15). Several areas of cadmium enrichment, however, are evident in the

**Table 22.** Estimated cadmium loads in filtered-water samples at selected fixed sites, Yakima River Basin, Washington, 1987–90

[The term "filtered water" is an operational definition referring to the chemical analysis of that portion of a water-suspended sediment sample that passes through a nominal 0.45-micrometer filter. Loads reported as pounds per day; load values are based on calibration data collected from March 1987 to March 1990; --, indicates insufficient data. Lightly shaded and darkly shaded cells, respectively, represent the snowmelt portion and the nonsnowmelt portion of the irrigation season; unshaded cells represent the nonirrigation season]

| Year | January | February | March | April | May | June | July | August | September | October | November | December | Daily mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Yakima River at Cle Elum** | | | | | | | | | | | | | |
| 1987 | -- | -- | 0.8 | 0.9 | 1 | 2 | 3 | 3 | 0.7 | 0.3 | 0.2 | 0.3 | -- |
| 1988 | 0.3 | 0.5 | .6 | .9 | .7 | 1 | 3 | 3 | 1 | .4 | .6 | .6 | 1.0 |
| 1989 | .7 | .5 | .4 | 1 | 2 | 2 | 4 | 3 | 1 | .4 | .7 | .7 | 1.4 |
| 1990 | .8 | .9 | .8 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Yakima River at Umtanum** | | | | | | | | | | | | | |
| 1987 | .5 | .8 | 2 | 2 | 3 | 4 | 5 | 5 | 1 | .4 | .3 | .5 | 2.0 |
| 1988 | .3 | 1 | 1 | 3 | 2 | 3 | 5 | 6 | 2 | .7 | 1 | 1 | 2.2 |
| 1989 | 1 | 1 | 1 | 5 | 4 | 4 | 6 | 5 | 2 | 1 | 1 | 1 | 2.7 |
| 1990 | 1 | 2 | 2 | 6 | 5 | 7 | 6 | 6 | 2 | -- | -- | -- | -- |

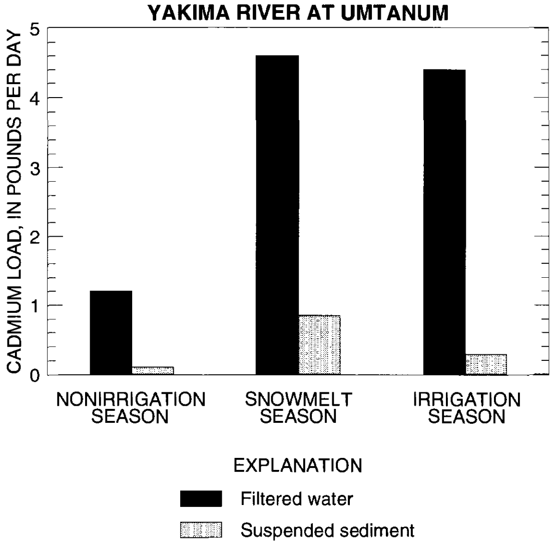


**Figure 25.** Cadmium loads in filtered-water samples and in suspended-sediment samples for selected time periods at the Yakima River at Umtanum, Yakima River Basin, Washington, 1989 (the term "filtered water" represents the portion of a water sample passing through a nominal 0.45-micrometer pore-size filter; nonirrigation season is October through March; snowmelt season is April through May; irrigation season is June through September).

mid-Yakima Valley and in the Kittitas Valley at the Cle Elum site (fig. 26). Cadmium concentrations as high as 0.25 μg/g were measured in *Hydropsyche* spp. in Rattlesnake Creek above Little Rattlesnake Creek near Nile and in Rattlesnake Creek above North Fork Rattlesnake Creek near Nile. In relation to other sites in the Yakima River Basin, cadmium concentrations also were high in six other insect taxa in Rattlesnake Creek. Additionally, of the two locations on Rattlesnake Creek, concentrations were higher at the more upstream station (Rattlesnake Creek above North Fork Rattlesnake Creek near Nile) in four of the five taxa common to both locations (Fuhrer, Fluter, and others, 1994). Cadmium (1 μg/g) also was detected in the liver of rainbow trout from this site in 1989. These data indicate that an upstream source of cadmium is present in Rattlesnake Creek.

The median concentration of cadmium (0.2 μg/g) in *Hydropsyche* spp. at the Cle Elum site, although not as large as cadmium concentrations in caddisflies in Rattlesnake Creek, is twice that determined from the 23 sites sampled in 1990. The high concentration in caddisflies at Cle Elum also coincides with concentrations of cadmium in filtered water that were among the highest in the Yakima River Basin.

In 1989, rainbow trout sampled from the Waptus River at mouth near Roslyn had a cadmium concentration of 1.1 μg/g, but rainbow trout sampled in the Jungle Creek near mouth near Cle Elum had a cadmium concentration of only 0.4 μg/g. In the American River, the cadmium concentration in a predaceous stonefly (*Doroneuria* spp.) was 3 to 16 times higher than concentrations in this taxon from any other location in the Yakima River Basin. High concentrations of cadmium in the stonefly also coincided with the maximum concentration of cadmium in streambed sediment (0.8 μg/g) for the biological sampling sites. However, cadmium enrichment in streambed sediment and stoneflies did not correspond to cadmium enrichment in the liver of rainbow trout or whole body sculpin—both were below the limit of determination (0.2 μg/g).

Cadmium concentrations in most biological samples from the Yakima River Basin indicate natural background concentrations and were similar to concentrations reported by Lynch and others (1988) and Cain and others (1992) for uncontaminated streams (table 40, at back of report).

Cadmium, found in the liver of rainbow and brook trout sampled from the Yakima River Basin in 1990, was near the mean concentration (0.18 μg/g) found in the livers of cutthroat trout from an uncontaminated stream (Moore and others, 1991). Concentrations of cadmium (1.0 μg/g) in rainbow trout from Rattlesnake Creek and the Waptus River at mouth near Roslyn were elevated relative to other sites in the Yakima River Basin and coincided with higher concentrations of cadmium in suspended-sediment and filtered- water samples, but these concentrations were not exceedingly high when compared to concentrations observed in trout and other freshwater fish in California's Toxic Substances Monitoring Program (Rasmussen, 1992; McClenegham and others, 1981). Cadmium found in the livers of other species of fish in the Yakima River Basin rarely exceeded 0.5 μg/g. For comparison, mean cadmium concentrations in northern pike and white sucker from a "control" lake were 0.4 and 0.9 μg/g, respectively (McFarlane and Franzin, 1980). Mean concentrations of cadmium, ranging from 0.12 to 0.92 μg/g (calculated from original wet-weight data; Barak and Mason, 1990), were found in liver from five species of fish: dace (*Leueiscus leueiscus*), chub (*Leueiscus cephalus*), tench (*Tinca tinca*), perch (*Perca fluviatilis*), and pike (*Esox lucius*). The species of fish were collected from two rivers in England. Cadmium in the livers of mountain whitefish and carp

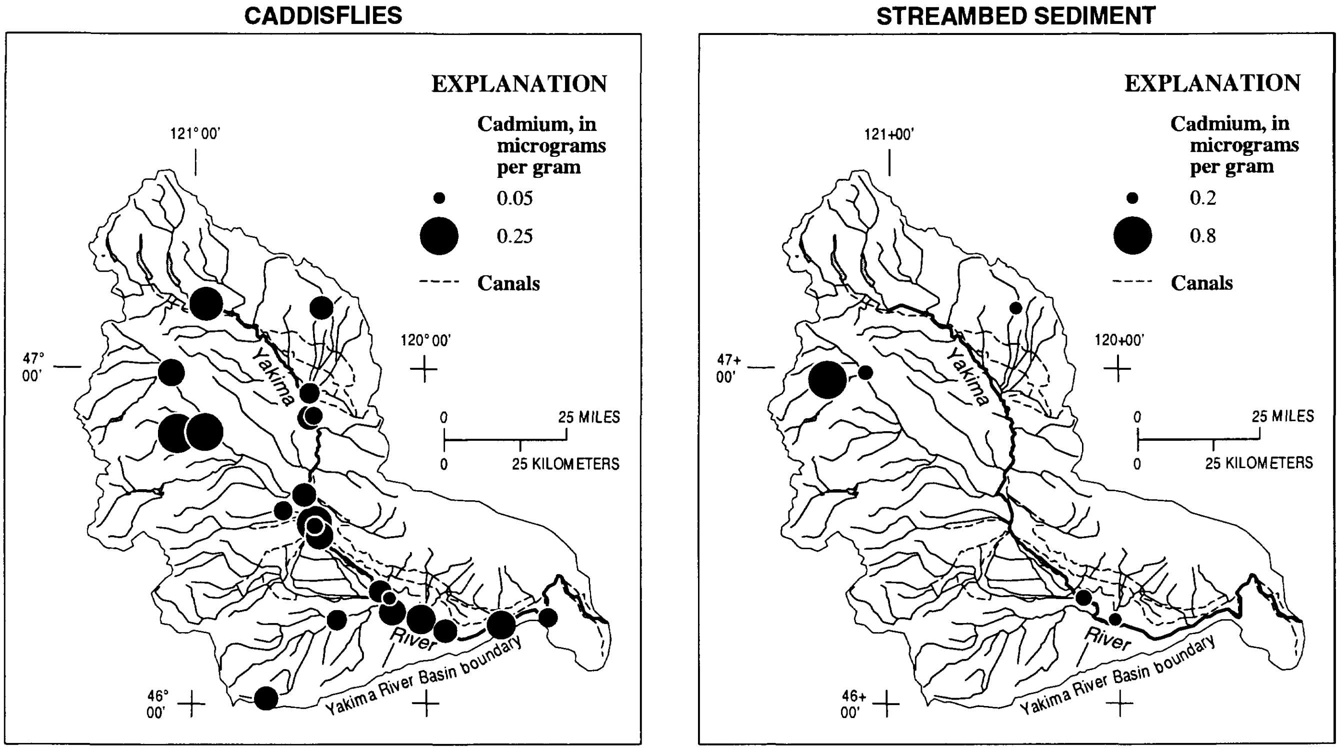


**Figure 26.** Distribution of cadmium concentrations in caddisflies and streambed sediment, Yakima River Basin, Washington, 1987–90 (element concentrations are reported in units of micrograms per gram [µg/g], dry weight; symbol sizes are proportional to element concentrations; the largest and smallest symbols, respectively, represent the high and low concentration end members; only 1990 data are graphically represented for caddisflies; sample species: caddisflies [Trichoptera: Hydropsychidae *Hydropsyche* spp.]).

(1.43 and 2.55 µg/g, respectively) collected in the Yakima River at Kiona were slightly higher than concentrations noted *in* Barak and Mason (1990), possibly indicating an increase in bioavailable cadmium at the Kiona site. Some of these concentrations exceed and others are near the 85th percentile concentrations reported in California's Toxic Substances Monitoring Program (Rasmussen, 1992). Cadmium concentrations in Asiatic clams in the Yakima River Basin were indicative of an uncontaminated system. In the San Joaquin River in California, for example, the concentrations of cadmium found in Asiatic clams (*Corbicula fluminea*) from an area receiving minimal inputs of cadmium were less than 1 µg/g (table 39, at back of report; Leland and Scudder, 1990; Luoma and others, 1990).

## Chromium and Nickel

Concentrations of chromium in streambed sediment of the Yakima River Basin ranged from 21 to 212 µg/g (table 12) and slightly exceeded the 8.5 to 200 µg/g range of concentration that characterizes 95 percent of Western United States soils (R.C. Severson, U.S. Geological Survey, written commun., 1987, based on data in Shacklette and Boerngen, 1984). The distribution of chromium concentrations at the biological sites generally exceeded those determined from analysis of fine-fraction streambed sediment in other river basins of the United States (table 34, at back of report).

Concentrations of nickel in streambed sediment of the Yakima River Basin ranged from 9.0 to 260 µg/g (table 12); several sites had concentrations in excess of the 3.4 to 66 µg/g range of concentration that characterizes 95 percent of Western United States soils (R.C. Severson, U.S. Geological Survey, written commun., 1987, based on data in Shacklette and Boerngen, 1984). Chromium concentrations as high as 212 and 210 µg/g were detected in the Teanaway River below Forks near Cle Elum (site 5) and the Yakima River at Cle Elum (site 6), respectively. Similarly, nickel concentrations as high as 262 and 150 µg/g were detected at these same sites, respectively.

Geologic sources of chromium exist in the Wenatchee Mountains where the pre-Tertiary metamorphic and intrusive rocks geologic unit contains the mineral chromite (Fuhrer, McKenzie, and others, 1994; Tabor and others, 1982; Gualtieri and Simmons, 1989; and Simmons and others, 1983). Fuhrer, McKenzie, and others (1994) reported that concentrations of chromium affected by the mineral chromite, in streambed sediment of the pre-Tertiary rocks geologic unit, ranged from 1,200 to 1,700 µg/g. Another natural source of chromium and nickel in the northern part of the Yakima River Basin is a 1.5-mile segment of the Cle Elum River between Big Boulder Creek and Camp Creek (upstream from Cle Elum Lake and in the pre-Tertiary rock geologic unit) which contains outcrops of nickel-chromium-bearing ferruginous laterite (a highly weathered, iron-rich subsoil) (Lucas, 1975). The enrichment of chromium and nickel at the Yakima River at Cle Elum probably can be attributed to the presence of chromite and ferruginous laterite. Chromium and nickel enrichment along the geologic contact between the pre-Tertiary rocks geologic unit and the nonmarine sedimentary rocks geologic unit (Lucas, 1975) probably is responsible for the enrichment at the Teanaway River below Forks near Cle Elum. Enrichment of chromium and nickel in streambed sediment of the pre-Tertiary rocks and the nonmarine sedimentary rocks geologic units has been described in detail by Fuhrer, McKenzie, and others (1994).

In addition to chromium and nickel enrichment in some of the northern tributaries of the Yakima River Basin, the upper reach of the main stem has similar but somewhat attenuated enrichment. The attenuation or concentration decrease along the main stem is attributed to sediment dilution—a decrease in element concentration by the mixing of enriched streambed sediment from (in this instance) a geologic source with less enriched sediment from another geologic source. For example, figure 27 shows enrichment of chromium in streambed sediment of the Cle Elum River (620 µg/g) and in streambed sediment of the North Fork of the Teanaway River (212 µg/g); in addition, chromium was enriched along the main stem at the Yakima River at Cle Elum (210 µg/g) and again downstream at the Yakima River at Evergreen Farm (160 µg/g). The concentration (64 µg/g) of chromium at the Yakima River at Umtanum decreases sharply in comparison to upstream main-stem concentrations. The decrease in chromium concentration was attributed to dilution caused by sediment entering the main stem from Wilson Creek, located a short distance upstream from the Yakima River at Umtanum. Sediment entering the main stem from Wilson Creek was formed from chromium-depleted Quaternary deposits and loess and Quaternary flood deposits and contained only 84 and 54 µg/g of chromium, respectively (Fuhrer, McKenzie, and others, 1994). The similar behavior of nickel and chromium was expected because of the relation between nickel and chromium in streambed sediment that originates from the pre-Tertiary metamorphic and intrusive rocks geologic unit.

Concentrations of chromium in suspended sediment at the seven fixed sites ranged from 28 to 160 µg/g (table 13 and fig. 28). The largest temporal variation for suspended chromium was measured in the Yakima River at Umtanum—the interquartile range for chromium was 37 µg/g (table 35, at back of report). In contrast, the smallest temporal variation for suspended chromium was found in Sulphur Creek Wasteway near Sunnyside, where the interquartile range was more than 6 times smaller than Umtanum. Interquartile ranges also were small for sites in the lower Yakima Valley. The large difference between the distribution of chromium concentrations for the Yakima River at Cle Elum and the Naches River near North Yakima is attributed to geology. The Cle Elum Subbasin has geologic sources of chromium, as high as 1,700 µg/g in streambed sediment, whereas the Naches River Basin does not contain a significant geologic source of chromium (Fuhrer, McKenzie, and others, 1994).

The large temporal variation in chromium concentrations for the Yakima River at Umtanum was indicative of a change in the source of chromium, as well as sediment dilution from chromium-poor sediment in agricultural lands in the Kittitas Valley. Large concentrations of suspended chromium were measured during the nonirrigation season as well as during the early and mid-irrigation season at the Umtanum site. However, the concentrations of suspended chromium decreased sharply in the late irrigation season, during September and October (fig. 29), which coincides with the curtailment of reservoir releases upstream from the Umtanum site, including those from Cle Elum Lake. The lowering of streamflow in the Kittitas Valley is a water-management strategy designed to enhance salmon productivity by forcing spawning salmon to make redds in portions of the streambed that will be covered by water following the irrigation season. Numerous streambed-sediment samples collected in the Kittitas Valley indicate that the Cle Elum River drainage was a probable source of chromium to the main stem; furthermore, suspended-chromium samples from the Yakima River at Cle Elum (although sparse and collected only during the

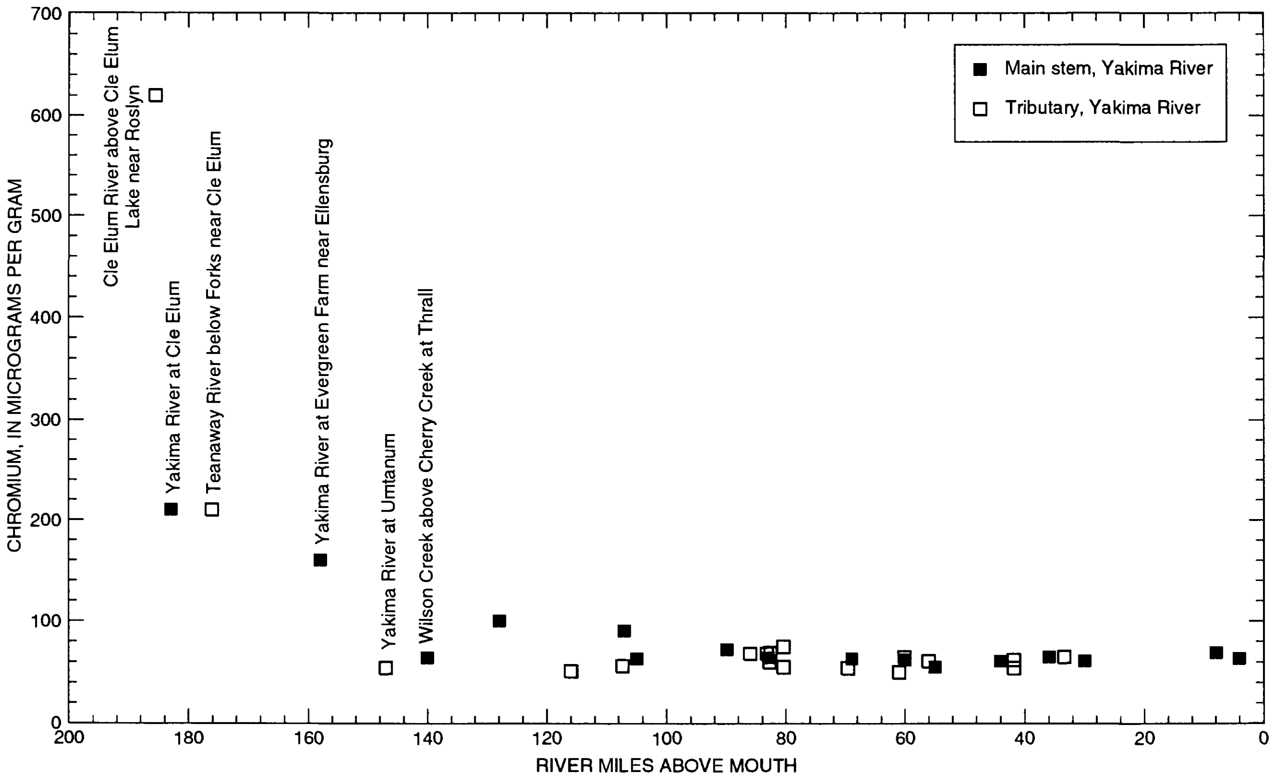
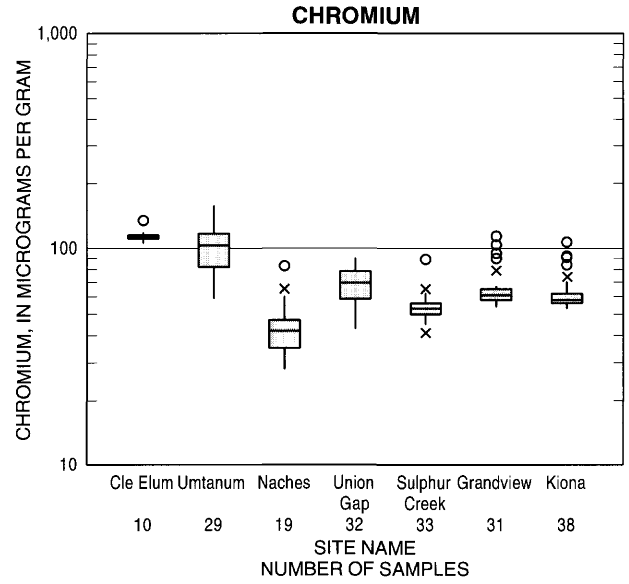


**Figure 27.** Chromium concentrations in streambed sediment of the main stem and tributaries, Yakima River Basin, Washington, 1987.

nonirrigation season) were similar in concentration to those from the Umtanum site and indicated that the Cle Elum River drainage is a probable source of chromium to the main stem. Conversely, streambed samples collected in agricultural land-use areas of the Kittitas Valley indicate that streambed sediment entering the main stem from the Kittitas Valley (especially during the irrigation season) could decrease the suspended-chromium concentrations in the main stem (Fuhrer, McKenzie, and others, 1994). Decreases in the Cle Elum River drainage's contribution of chromium to the main stem, as well as concurrent increases in the proportion of chromium-depleted sediment from agricultural areas in Kittitas Valley, are possible causes for sharp declines in suspended-chromium concentrations.

Effects from the curtailment of reservoir releases and the diluting effect of incoming sediment also are measurable in the Yakima River above Ahtanum Creek at Union Gap. Although not as pronounced, concentrations of suspended chromium at Union Gap generally decrease during September and October each year, when reservoir releases from the upper Yakima Valley are curtailed. These decreases probably result from reductions of suspended sediment, enriched in chromium, from the Cle Elum River drainage during September and October, as well as the diluting effect of incoming suspended sediment, depleted in chromium, from tributaries such as Wilson Creek, Selah Creek, Moxee Drain, Wide Hollow Creek, and the Naches River.

As the distance between sites on the main stem and the sources of chromium in the Kittitas Valley increase, concentrations of suspended chromium decrease, especially during rain-on-snow events. Samples from the Yakima River above Ahtanum Creek at Union Gap following rain or snow storms—two in 1989 and one in 1990 (fig. 30)—had lower concentrations of chromium compared to monthly samples. Lower chromium concentrations at the Union Gap site were attributed to streambed sediment that was formed in the Columbia River Basalt Group Rocks geologic unit. The median streambed-sediment concentration (40 μg/g; Fuhrer, McKenzie, and others, 1994) in this unit is low, and during rain-on-snow storms, erosion from this unit probably reduces the suspended-



**EXPLANATION**

**Interquartile range equals the value of the 75th percentile minus the value of the 25th percentile.**

○ More than 3 times the interquartile range from the 75th-percentile value

× 1.5 to 3 times the interquartile range from the 75th-percentile value

Less than 1.5 times the interquartile range from the 75th-percentile value

75th-percentile value

Median value

25th-percentile value

Less than 1.5 times the interquartile range from the 25th-percentile value

× 1.5 to 3 times the interquartile range from the 25th-percentile value

**Figure 28.** Distribution of chromium concentrations in suspended sediment at fixed sites, Yakima River Basin, Washington, 1987–90 ("Cle Elum" represents Yakima River at Cle Elum; "Umtanum" represents Yakima River at Umtanum; "Naches" represents Naches River near North Yakima; "Union Gap" represents Yakima River above Ahtanum Creek at Union Gap; "Sulphur Creek" represents Sulphur Creek Wasteway near Sunnyside; "Grandview" represents Yakima River at Euclid Bridge at river mile 55 near Grandview; and "Kiona" represents Yakima River at Kiona).

chromium concentrations at the Union Gap site. During one of the storms (May 10, 1989), suspended-chromium concentrations were measured in two small tributaries (Squaw and Burbank Creeks) located upstream from the Union Gap site. These tributaries were formed in the Columbia River Basalt Group Rocks geologic unit and, as expected, the suspended-chromium concentrations in these tributaries (40 and 38 µg/g, respectively) are nearly identical to that in streambed sediment from the Columbia River Basalt Group Rocks geologic unit. The low concentrations of chromium in Squaw and Burbank Creeks probably are indicative of concentrations in other mid-Yakima Valley tributaries that, when combined, result in lower chromium concentrations during event sampling at the Union Gap site.

During some storms, intrasite variations in suspended-chromium concentrations differed between storm peaks and the periods before and after storms. During a December 5, 1989, rain-on-snow storm (hydrologically affecting all main-stem sites), chromium concentrations in the Yakima River at Umtanum were higher near the peak of the storm than concentrations from monthly samples before and after the storm (fig. 29). Conversely, during the same storm, chromium concentrations in the Yakima River above Ahtanum Creek at Union Gap were lower near the storm's peak than concentrations from monthly samples preceding and following the storm (fig. 30). Whether chromium concentrations increase or decrease near the peak of the storm probably is related to the magnitude of the chromium source and the proximity of that source to the sampling site. Chromium concentrations measured near the storm's peak at the Umtanum site probably increased because of the close proximity between the site and sources of chromium in the Cle Elum and Teanaway drainages in the Kittitas Valley. During the same storm, chromium concentrations probably decreased near the peak of the storm at the Union Gap site because chromium-rich sediment from the Kittitas Valley mixed with chromium-poor sediment that entered the main stem from the Columbia River Basalt Group Rocks geologic unit in the mid-Yakima Valley.

Chromium concentrations in filtered-water samples ranged from less than 0.5 to 1.1 µg/L at the seven fixed sites (table 14). Chromium measurements were limited temporally and numerically among fixed sites; 26 measurements were made quarterly, primarily in 1987. The highest chromium concentrations were measured in the Yakima River at Cle Elum and at Kiona (1.1 and 1.0 µg/L, respectively; table 37, at back of report). The median chromium concentration among fixed sites (less than 0.5 µg/L) coincides with the background concentration of chromium in inland water and is low in comparison to the median chromium concentration measured from the National Stream Quality Accounting Network of the USGS (table 36, at back of report).

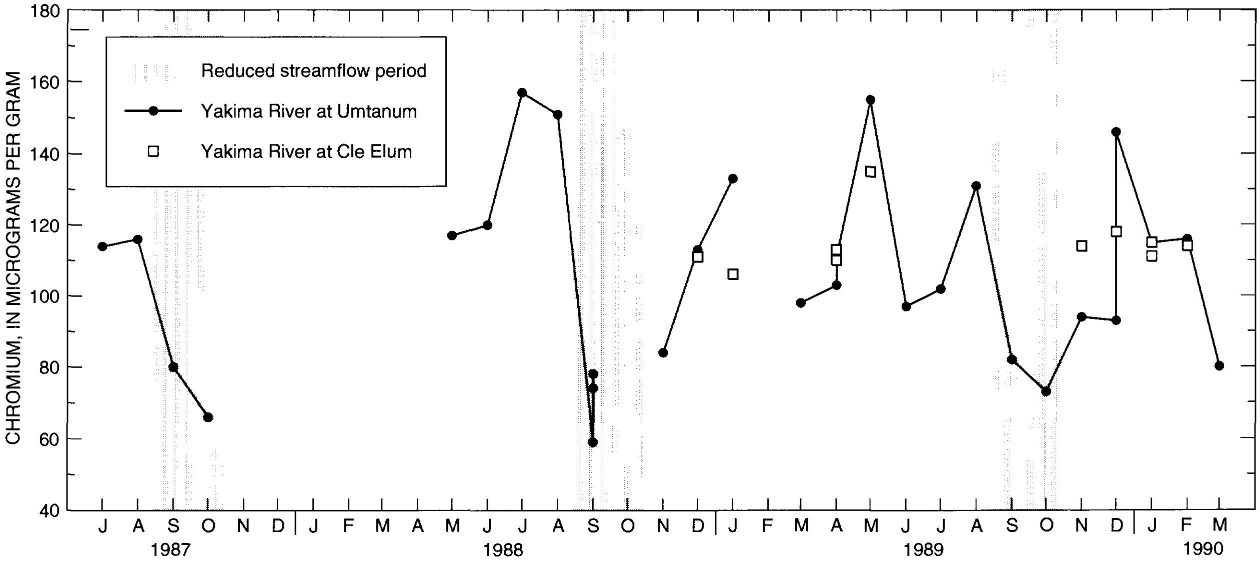


**Figure 29.** Chromium concentrations in suspended sediment at the Yakima River at Umtanum and the Yakima River at Cle Elum, Yakima River Basin, Washington, 1987–90 (shaded area represents the period of time when streamflow is reduced from reservoirs upstream from the Yakima River at Cle Elum).

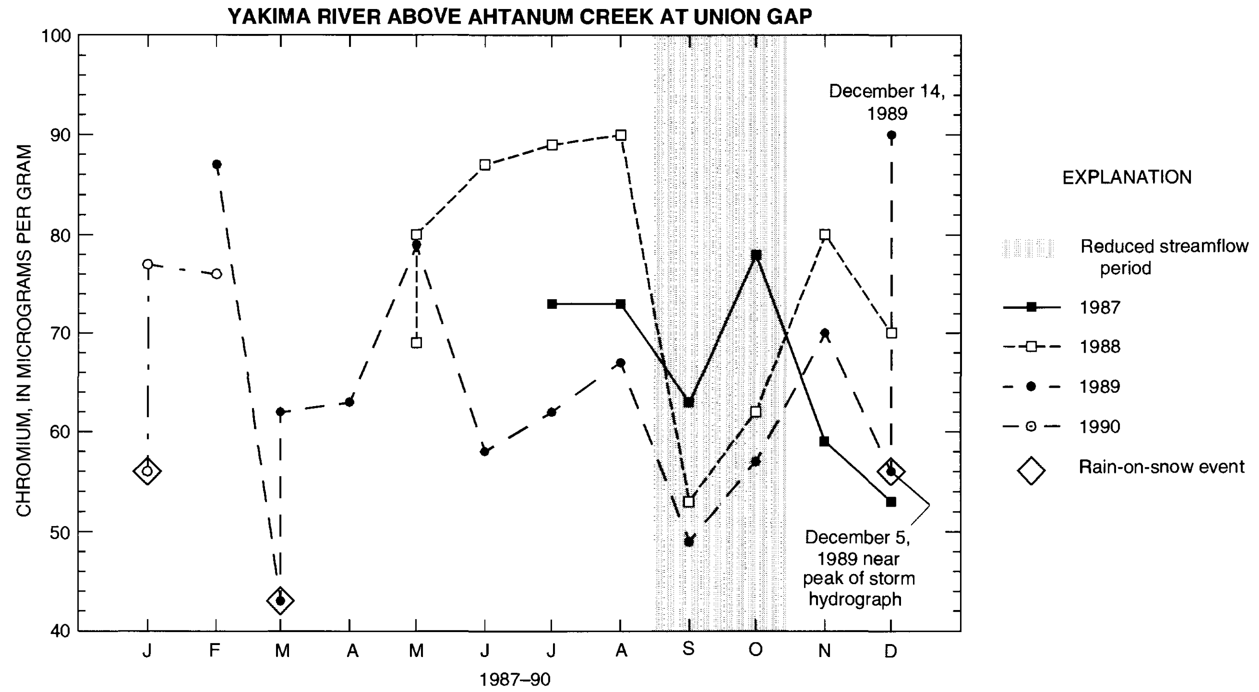


**Figure 30.** Chromium concentrations in suspended sediment at the Yakima River above Ahtanum Creek at Union Gap, Yakima River Basin, Washington, 1987–90 (shaded area represents the period of time when streamflow is reduced from reservoirs upstream from the Yakima River at Cle Elum).

Median concentrations of nickel in suspended sediment ranged from 17 to 89 µg/g at the fixed sites (table 13) and the lowest and highest median values, respectively, were in the Naches River near North Yakima and Yakima River at Umtanum (fig. 31; and table 35, at back of report). Similar to chromium, the largest temporal variation in suspended nickel was measured in the Yakima River at Umtanum, where the interquartile range for suspended nickel was 31 µg/g. Concentrations of nickel also were variable in the Yakima River at Union Gap, where the interquartile range was 18 µg/g. The concentrations and temporal variability for suspended nickel were reduced greatly in the lower Yakima Valley.

The concentrations of suspended nickel in the Yakima River at Umtanum and the Yakima River at Cle Elum indicate geologic sources of nickel. Nickel- and chromium-enriched deposits exist for a distance of approximately 20 miles between the geologic contacts of the pre-Tertiary rocks and the nonmarine sedimentary rocks geologic unit (Lucas, 1975). Additionally, streambed sediment in the headwaters of the Cle Elum and Teanaway Rivers, respectively, contained nickel concentrations as high as 1,800 and 1,900 µg/g, respectively (Fuhrer, McKenzie, and others, 1994). Although sources of nickel exist in the Cle Elum and Teanaway River drainages, higher concentrations of nickel were measured in the main stem at the Umtanum site than at the Cle Elum site, because higher concentrations of suspended nickel reached the main stem from the unregulated Teanaway River than from the Cle Elum River. The Teanaway River flows into the main stem (RM 176.1) downstream from the Yakima River at Cle Elum (RM 183.1) and upstream from the Yakima River at Umtanum (RM 140.4). Wilson Creek also flows into the main stem (RM 147), upstream from the Yakima River at Umtanum, but Wilson Creek is an unlikely source of suspended nickel because the median concentration of nickel in nine streambed-sediment samples from the alluvial sediment of the Kittitas Valley was 21 µg/g (Fuhrer, McKenzie, and others, 1994). This concentration is only one-third the median concentration of nickel detected in streambed sediment in the headwaters of the Teanaway and Cle Elum Rivers.

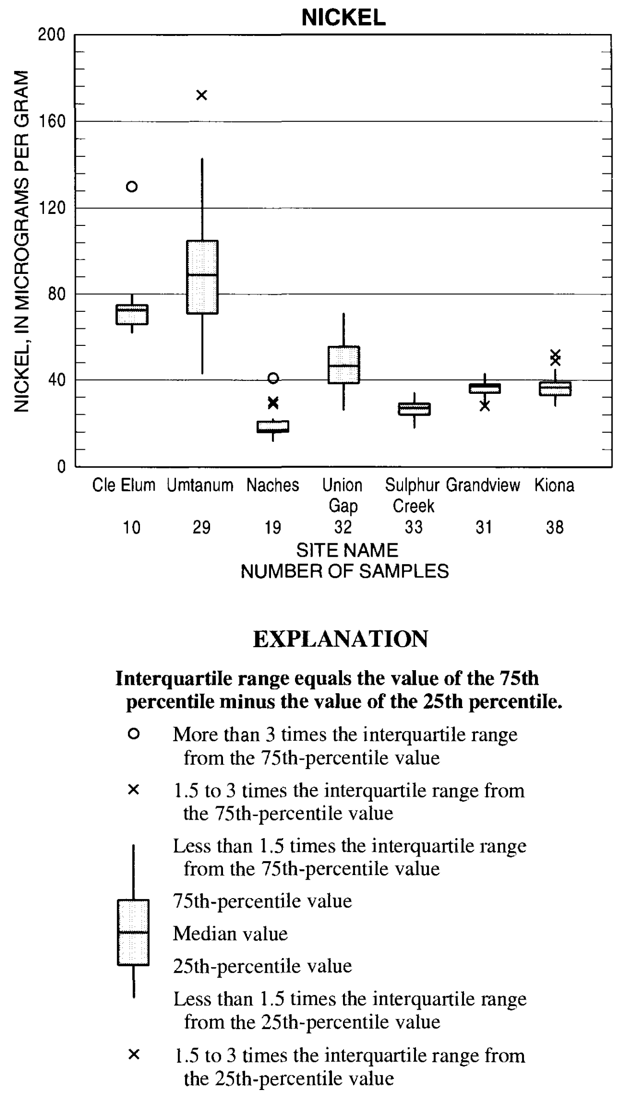


**Figure 31.** Distribution of nickel concentrations in suspended sediment at fixed sites, Yakima River Basin, Washington, 1987–90 ("Cle Elum" represents Yakima River at Cle Elum; "Umtanum" represents Yakima River at Umtanum; "Naches" represents Naches River near North Yakima; "Union Gap" represents Yakima River above Ahtanum Creek at Union Gap; "Sulphur Creek" represents Sulphur Creek Wasteway near Sunnyside; "Grandview" represents Yakima River at Euclid Bridge at river mile 55 near Grandview; and "Kiona" represents Yakima River at Kiona).

The potential contribution of suspended sediment from the Teanaway River to suspended-nickel concentrations in the Yakima River at Umtanum was evident during storms. During a January 29–31, 1989, storm, the daily mean streamflow increased from 505 to 1,290 $ft^3/s$ at the Yakima River at Cle Elum, from 202 to 931 $ft^3/s$ at the Teanaway River below Forks near Cle Elum, and from 891 to 2,610 $ft^3/s$ for the Yakima River at Umtanum. Near the peak of the storm on January 31, 1989, the Teanaway River accounted for 70 percent of the observed increase in streamflow between the Yakima River at Cle Elum and the Yakima River at Umtanum. The concentrations of suspended nickel near the peak of the storm increased from 66 µg/g at the Cle Elum site to 120 µg/g at the Umtanum site. In the future, the Teanaway River, the Yakima River at Cle Elum, and the Yakima River at Umtanum should be sampled during storm events to measure the concentration and load of suspended nickel in the Teanaway River.

During storms, suspended-nickel concentrations are related inversely to the distance between the geologic source and the sampling site. The Yakima River at Cle Elum is affected by nickel and chromium in serpentinized peridotite, an ultramafic rock (Fuhrer, McKenzie, and others, 1994). During a December 5, 1989, rain-on-snow storm, the nickel concentration nearly doubled at the Cle Elum site near the peak of the storm (fig. 32) but decreased at the Union Gap site.

Except for storms, the temporal variability for concentrations of nickel at the Union Gap site was similar to the Umtanum site. Nickel concentrations between sites differ; however, at the Umtanum site, nickel concentrations consistently exceeded those at the Union Gap site. The lower concentrations at the Union Gap site (RM 107.2) probably resulted from the mixing of nickel-depleted sediment, from tributaries like the Naches River (RM 116.3) and waterways that carry irrigation return flow such as Moxee Drain (RM 107.6), with nickel-enriched sediment from the Kittitas Valley. Concentrations of suspended nickel abruptly decreased in September and October 1987-89, after the curtailment of reservoir releases in the Kittitas Valley (fig. 32). Similar decreases, measured for suspended chromium, were expected because of existing chromium and nickel in ultramafic rock in the Kittitas Valley (Fuhrer, McKenzie, and others, 1994). Suspended-nickel concentrations at the Umtanum site also increase statistically ($\rho \leq 0.001$) in proportion to the concentration of suspended chromium (fig. 33). This is consistent with the streambed-sediment chemistry (Fuhrer, McKenzie, and others, 1994) and geologic sources (Tabor and others, 1982; Gualtieri and Simmons, 1989) in the Kittitas Valley.

Chromium concentrations in fish and Asiatic clams typically were less than 2 µg/g (table 15) and varied little among sites in the lower Yakima Valley and in tributaries in the mid-Yakima Valley (Fuhrer, Fluter, and others, 1994). Chromium concentrations in insects generally were lowest in Rattlesnake Creek and in Umtanum Creek near the mouth at Umtanum (table 23). Chromium enrichment, however, was measured in aquatic insects in the North Fork Teanaway River (site 4). Depending on insect species, concentrations of chromium in the North Fork Teanaway River were 4 to 52 times higher (concentrations ranged from 2.2 to 33.4 µg/g) than the minimum concentrations measured in the Yakima River Basin. Additionally, among the fish collected in 1989, the highest chromium concentration (2.0 µg/g) was in fish collected

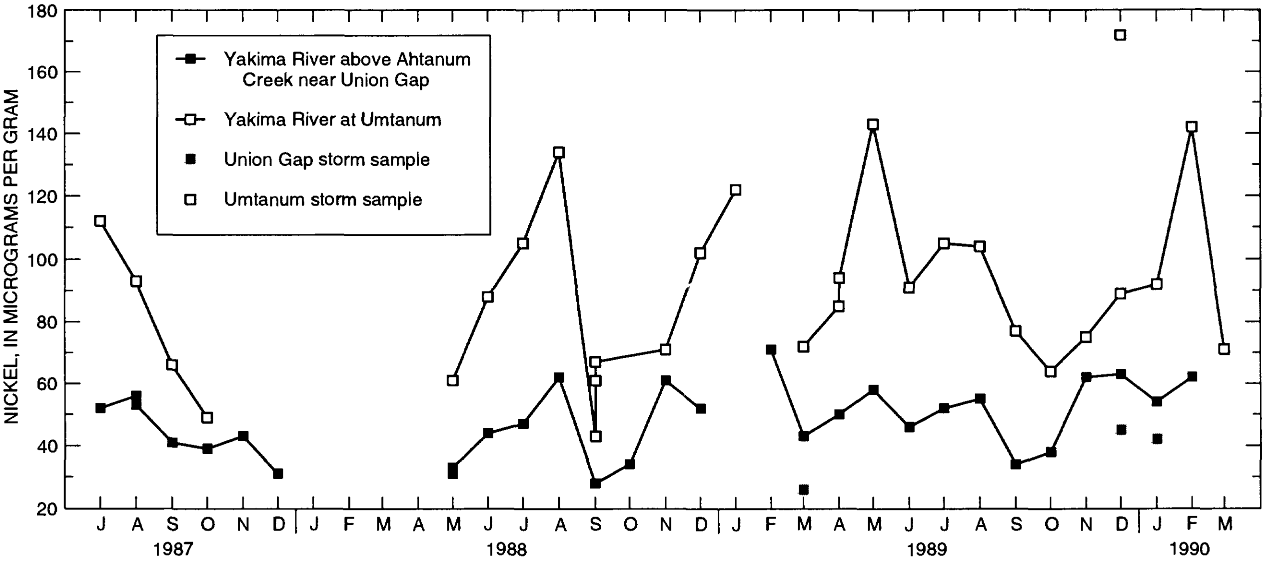
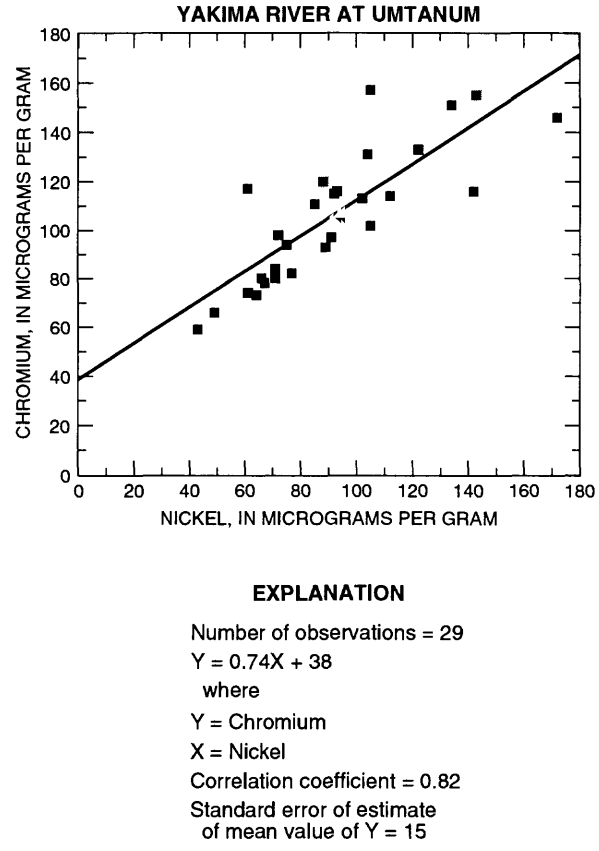


**Figure 32.** Nickel concentrations in suspended sediment at the Yakima River above Ahtanum Creek at Union Gap and at the Yakima River at Umtanum, Yakima River Basin, Washington, 1987–90 ("Union Gap" represents Yakima River above Ahtanum Creek at Union Gap and "Umtanum" represents Yakima River at Umtanum).

from the Teanaway River below Forks near Cle Elum. Fish were not collected at the North Fork Teanaway (site 4).

Concentrations of chromium in most biological samples from the Yakima River Basin were within ranges observed in uncontaminated basins. However, relatively high concentrations were detected in benthic insects in the North Fork Teanaway River. The maximum concentration of chromium observed in benthic insects (33 µg/g in a stonefly [*Perlinoides* sp.]) was measured at the North Fork Teanaway River and exceeded concentrations in uncontaminated systems reported in other studies (table 40, at back of report).

Concentrations of chromium in Asiatic clams were low because of the large distance between geologic sources of chromium in the Kittitas Valley and the sites sampled for Asiatic clams in the lower Yakima Valley. Chromium concentrations in Asiatic clams from the Yakima River were generally less than 2 µg/g and were similar to concentrations reported for uncontaminated areas of the San Joaquin River in California (Luoma and others, 1990; table 39, at back of report). By comparison, chromium concentrations of 4 to 15 µg/g were detected in Asiatic clams in areas of the San Francisco Bay estuary that are known to have inputs of chromium from industrial sources (Luoma and others, 1990). The chromium concentration in rainbow trout liver, collected in 1989 from the Teanaway River below Forks near Cle Elum, also exceeded that for fish sampled in California's Toxic Substances Monitoring Program (Rasmussen, 1992).



Number of observations = 29
Y = 0.74X + 38
where
Y = Chromium
X = Nickel
Correlation coefficient = 0.82
Standard error of estimate of mean value of Y = 15

**Figure 33.** Chromium and nickel concentrations in suspended sediment at the Yakima River at Umtanum, Yakima River Basin, Washington, 1987–90.

The maximum concentration of nickel that was detected in rainbow trout liver did not exceed 0.36 µg/g (Fuhrer, Fluter, and others, 1994). Nickel concentrations in Asiatic clams generally were higher than in fish, and concentrations were similar among sites (table 24). Nickel concentrations in fish samples also were similar among sites.

The maximum nickel concentration in benthic insects was from the North Fork Teanaway River below bridge at Dickey Creek Campground (site 4). Nickel concentrations from insect taxa collected at site 4 were 43 to 102 times greater (concentrations ranged from 6.4 to 76 µg/g) than insect taxa collected from other sites (Fuhrer, Fluter, and others, 1994). The caddisflies *(Hydropsyche* spp.) were not abundant enough at site 4 to sample. Additionally, levels of nickel enrichment for insects at site 4 were greater than any other element examined. Fish from site 4 were not sampled in 1990, and the limit of determination for rainbow trout liver collected in 1989 was too high to determine if trout livers were similarly enriched at site 4 (Fuhrer, Fluter, and others, 1994).

The presence of nickel in the Teanaway Subbasin also was evident in benthic insects in the main stem of the Yakima River. The caddisflies (*Hydropsyche* spp.) collected at the Umtanum site represented the maximum concentration (5.5 µg/g) for the Yakima River Basin and also coincide with the highest concentrations of suspended nickel in the basin. Collectively, high concentrations of nickel in caddisflies and suspended sediment underscores the importance of the Teanaway Subbasin as a source of nickel to the main stem. Nickel concentrations in caddisflies generally remained high in the main stem of the mid-Yakima and lower Yakima Valley instead of decreasing with distance from the Teanaway Subbasin (fig. 34). This enrichment may result from secondary contributions of nickel from tributaries in the mid-Yakima and lower Yakima Valley. Insects sampled at the mouths of some tributaries (including Cherry Creek, Ahtanum Creek, Spring Creek, Sulphur Creek, and Granger Drain)

**Table 23.** Comparison of low and high chromium concentrations in water, sediment, and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91

[For filtered water and suspended sediment, the low and high concentration assignments are based on a percentile distribution of the 50th-percentile values (median) for each fixed site. For streambed sediment and aquatic biota, the low and high concentration assignments are based on a percentile distribution of the mean concentrations for each fixed site. High concentrations (denoted with an "H" in the table) represent that portion of the distribution which is greater than or equal to the 75th-percentile value. Low concentrations (denoted with an "L" in the table) represent that portion of the distribution which is less than or equal to the 25th-percentile value. Concentrations greater than 25th, but less than 75th-percentile value are denoted with an "*" in the table. The term "filtered water" is an operational definition referring to the chemical analysis of that portion of a water-suspended sediment sample that passes through a nominal 0.45-micrometer filter. Only 1990 data are summarized for largescale-sucker livers and caddisflies; sample species: largescale sucker (*Catostomus macrocheilus*), caddisfly (*Hydropsyche* spp.), stonefly (*Hesperoperla* sp.), Asiatic clam (Veneroida: Corbiculidae *Corbicula fluminea*), and curlyleaf pondweed (*Potamogeton crispus*). Data statistically summarized for fixed sites are from monthly and selected hydrologic-event samplings from the Yakima River at Cle Elum, Yakima River at Umtanum, Naches River near North Yakima, Yakima River above Ahtanum Creek at Union Gap, Sulphur Creek Wasteway near Sunnyside, Yakima River at Euclid Bridge at river mile 55 near Grandview, and Yakima River at Kiona for the period 1987–90. To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate at a site, only one element concentration per visit was statistically summarized; --, no data]

| Site reference number | Site name | Filtered water | Sediment | | Aquatic biota | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Insects | | | |
| | | | Streambed | Suspended | Largescale sucker liver | Caddisfly | Stonefly | Asiatic clam | Curlyleaf pondweed |
| 1 | Waptus River at mouth near Roslyn | -- | * | -- | -- | -- | -- | -- | -- |
| 3 | Jungle Creek near mouth near Cle Elum | -- | H | -- | -- | -- | -- | -- | -- |
| 4 | North Fork Teanaway River below bridge at Dickey Creek Campground | -- | -- | -- | -- | -- | H | -- | -- |
| 5 | Teanaway River below Forks near Cle Elum | -- | H | -- | -- | -- | -- | -- | -- |
| 6 | Yakima River at Cle Elum | H | H | H | -- | * | * | -- | -- |
| 7 | Naneum Creek below High Creek near Ellensburg | -- | * | -- | -- | * | * | -- | -- |
| 8 | Taneum Creek at Taneum Meadow near Thorp | -- | H | -- | -- | -- | * | -- | -- |
| 10 | Little Naches River at mouth near Cliffdell | -- | L | -- | -- | * | -- | -- | -- |
| 12 | South Fork Manastash Creek near Ellensburg | -- | H | -- | -- | -- | * | -- | -- |
| 13 | American River at Hell's Crossing near Nile | -- | L | -- | -- | -- | -- | -- | -- |
| 14 | Cherry Creek above Wipple Wasteway at Thrall | -- | L | -- | -- | * | -- | -- | -- |
| 16 | Cherry Creek at Thrall | -- | -- | -- | -- | H | -- | -- | H |
| 19 | Yakima River at Umtanum | L | * | H | -- | H | H | -- | H |
| 20 | Umtanum Creek near mouth at Umtanum | -- | L | -- | -- | L | -- | -- | -- |
| 21 | Rattlesnake Creek above Little Rattlesnake Creek near Nile | -- | L | -- | -- | L | L | -- | -- |
| 22 | Rattlesnake Creek above North Fork Rattlesnake Creek near Nile | -- | * | -- | -- | L | L | -- | -- |

**Table 23**. Comparison of low and high chromium concentrations in water, sediment, and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91—Continued

| Site reference number | Site name | Filtered water | Sediment | | Aquatic biota | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Insects | | | |
| | | | Streambed | Suspended | Largescale sucker liver | Caddisfly | Stonefly | Asiatic clam | Curlyleaf pondweed |
| 26 | Naches River near North Yakima | * | H | L | * | L | -- | -- | -- |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | -- | L | -- | -- | L | -- | -- | -- |
| 29 | Wide Hollow Creek at old Sewage Treatment Plant at Union Gap | -- | * | -- | -- | * | -- | -- | * |
| 30 | Moxee Drain at Thorp Road near Union Gap | -- | * | -- | -- | -- | -- | -- | -- |
| 31 | Ahtanum Creek at Union Gap | -- | * | -- | -- | * | -- | -- | -- |
| 32 | Yakima River above Ahtanum Creek at Union Gap | L | -- | * | -- | -- | -- | -- | -- |
| 33 | Yakima River at Parker | -- | * | -- | H | * | -- | -- | * |
| 34 | South Fork Ahtanum Creek above Conrad Ranch near Tampico | -- | L | -- | -- | * | * | -- | -- |
| 40 | Granger Drain at mouth near Granger | -- | * | -- | -- | H | -- | -- | -- |
| 42 | Yakima River below Toppenish Creek at river mile 79.6 near Granger | -- | * | -- | * | * | -- | * | -- |
| 43 | Toppenish Creek at Indian Church Road near Granger | -- | * | -- | -- | -- | -- | -- | -- |
| 47 | Satus Creek at gage at Satus | -- | * | -- | L | H | -- | -- | L |
| 48 | Yakima River at river mile 72 above Satus Creek near Sunnyside | -- | * | -- | -- | -- | -- | L | L |
| 50 | Yakima River at Kiona | H | * | * | * | * | -- | * | * |
| 52 | Sulphur Creek Wasteway near Sunnyside | * | H | L | -- | H | -- | -- | - |
| 53 | Satus Creek below Dry Creek near Toppenish | -- | * | -- | -- | L | -- | -- | -- |
| 54 | Spring Creek at mouth at Whitstran | -- | * | -- | -- | H | -- | * | -- |
| 56 | Yakima River at Euclid Bridge at river mile 55 near Grandview | * | * | * | * | * | -- | H | * |
| 57 | Satus Creek above Wilson-Charley Canyon near Toppenish | -- | * | -- | -- | * | * | -- | -- |

**Table 24.** Comparison of low and high nickel concentrations in sediment and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91

[For filtered water and suspended sediment, the low and high concentration assignments are based on a percentile distribution of the 50th-percentile values (median) for each fixed site; For streambed sediment and aquatic biota, the low and high concentration assignments are based on a percentile distribution of the mean concentrations for each fixed site. High concentrations (denoted with an "H" in the table) represent that portion of the distribution which is greater than or equal to the 75th-percentile value. Low concentrations (denoted with an "L" in the table) represent that portion of the distribution which is less than or equal to the 25th-percentile value. Concentrations greater than 25th, but less than 75th-percentile value are denoted with an "*" in the table. The term "filtered water" is an operational definition referring to the chemical analysis of that portion of a water-suspended sediment sample that passes through a nominal 0.45-micrometer filter. Only 1990 data are summarized for largescale-sucker livers and caddisflies; sample species: largescale sucker (*Catostomus macrocheilus*), caddisfly (*Hydropsyche* spp.), stonefly (*Hesperoperla* sp.), Asiatic clam (Veneroida: Corbiculidae *Corbicula fluminea*), and curlyleaf pondweed (*Potamogeton crispus*). Data statistically summarized for fixed sites are from monthly and selected hydrologic-event samplings from the Yakima River at Cle Elum, Yakima River at Umtanum, Naches River near North Yakima, Yakima River above Ahtanum Creek at Union Gap, Sulphur Creek Wasteway near Sunnyside, Yakima River at Euclid Bridge at river mile 55 near Grandview, and Yakima River at Kiona for the period 1987–90. To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate at a site, only one element concentration per visit was statistically summarized; --, no data]

| Site reference number | Site name | Sediment | | Aquatic biota | | | |
|---|---|---|---|---|---|---|---|
| | | Streambed | Suspended | Largescale sucker liver | Insects | | Curlyleaf pondweed |
| | | | | | Caddisfly | Stonefly | |
| 1 | Waptus River at mouth near Roslyn | * | -- | -- | -- | -- | -- |
| 3 | Jungle Creek near mouth near Cle Elum | H | -- | -- | -- | -- | -- |
| 4 | North Fork Teanaway River below bridge at Dickey Creek Campground | -- | -- | -- | -- | H | -- |
| 5 | Teanaway River below Forks near Cle Elum | H | -- | -- | -- | -- | -- |
| 6 | Yakima River at Cle Elum | H | H | -- | * | H | -- |
| 7 | Naneum Creek below High Creek near Ellensburg | * | -- | -- | L | * | -- |
| 8 | Taneum Creek at Taneum Meadow near Thorp | H | -- | -- | -- | * | -- |
| 10 | Little Naches River at mouth near Cliffdell | L | -- | -- | L | -- | -- |
| 12 | South Fork Manastash Creek near Ellensburg | H | -- | -- | - | * | -- |
| 13 | American River at Hell's Crossing near Nile | L | -- | -- | -- | -- | -- |
| 14 | Cherry Creek above Wipple Wasteway at Thrall | * | -- | -- | * | -- | - |
| 16 | Cherry Creek at Thrall | -- | -- | -- | * | -- | * |
| 19 | Yakima River at Umtanum | H | H | -- | H | * | H |
| 20 | Umtanum Creek near mouth at Umtanum | L | -- | -- | L | -- | -- |
| 21 | Rattlesnake Creek above Little Rattlesnake Creek near Nile | L | -- | -- | L | * | -- |
| 22 | Rattlesnake Creek above North Fork Rattlesnake Creek near Nile | * | -- | -- | L | L | -- |

**Table 24.** Comparison of low and high nickel concentrations in sediment and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91—Continued

| Site reference number | Site name | Sediment | | Aquatic biota | | | |
|---|---|---|---|---|---|---|---|
| | | | | Largescale sucker liver | Insects | | Curlyleaf pondweed |
| | | Streambed | Suspended | | Caddisfly | Stonefly | |
| 26 | Naches River near North Yakima | * | L | L | * | -- | -- |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | L | -- | -- | * | -- | -- |
| 29 | Wide Hollow Creek at old Sewage Treatment Plant at Union Gap | * | -- | -- | * | -- | L |
| 30 | Moxee Drain at Thorp Road near Union Gap | * | -- | -- | -- | -- | -- |
| 31 | Ahtanum Creek at Union Gap | L | -- | -- | H | -- | -- |
| 32 | Yakima River above Ahtanum Creek at Union Gap | -- | * | -- | -- | -- | -- |
| 33 | Yakima River at Parker | * | -- | H | * | -- | * |
| 34 | South Fork Ahtanum Creek above Conrad Ranch near Tampico | L | -- | -- | L | * | -- |
| 40 | Granger Drain at mouth near Granger | L | -- | -- | H | -- | -- |
| 42 | Yakima River below Toppenish Creek at river mile 79.6 near Granger | * | -- | * | * | -- | -- |
| 43 | Toppenish Creek at Indian Church Road near Granger | * | -- | -- | -- | -- | -- |
| 47 | Satus Creek at gage at Satus | * | -- | L | H | -- | L |
| 48 | Yakima River at river mile 72 above Satus Creek near Sunnyside | * | -- | -- | -- | -- | * |
| 50 | Yakima River at Kiona | * | * | L | * | -- | H |
| 52 | Sulphur Creek Wasteway near Sunnyside | H | L | -- | H | -- | -- |
| 53 | Satus Creek below Dry Creek near Toppenish | * | -- | -- | * | -- | -- |
| 54 | Spring Creek at mouth at Whitstran | * | -- | -- | H | -- | -- |
| 56 | Yakima River at Euclid Bridge at river mile 55 near Grandview | * | * | L | * | -- | * |
| 57 | Satus Creek above Wilson-Charley Canyon near Toppenish | * | - | -- | L | * | -- |

were enriched moderately with nickel when compared to tributaries at higher elevations in the western part of the Yakima River Basin. For example, the nickel concentration (3.3 µg/g) in caddisflies (*Hydropsyche* spp.) collected near the mouth of Ahtanum Creek, which receives irrigation return flow and some urban runoff, was more than 4 times higher than at the upstream site (South Fork Ahtanum Creek above Conrad Ranch near Tampico), which does not receive irrigation return flow and is removed from urban effects. The presence of nickel in these lower Yakima Valley tributaries may indicate why nickel concentrations did not decrease down the main stem, as might be expected, if the Kittitas Valley is the sole source of nickel.

Few data are available on nickel in benthic insects; however, concentrations of nickel in several taxa in the North Fork Teanaway River greatly exceeded concentrations reported by Lynch and others (1988) for combined insect samples collected upstream from a molybdenum mine (table 40, at back of report).

Nickel concentrations in Asiatic clams (*Corbicula* sp.) in the Yakima River were consistent with concentrations reported by Leland and Scudder (1990) for the San Joaquin River in California (table 39, at back of report). The consistently low concentrations of nickel in the Yakima River and the San Joaquin River may be indicative of natural concentrations for Asiatic clams. Nickel in fish liver sampled from the Yakima River Basin was within the 85th-percentile concentration for fish sampled in California's Toxic Substances Monitoring Program (Rasmussen, 1992).

## Cobalt

Cobalt concentrations in fish and Asiatic clams were generally less than 1 µg/g, and concentrations of cobalt in benthic insects were higher and more variable in the Yakima River Basin (table 15). The highest concentrations in benthic insects were in the South Fork of Ahtanum Creek (site 34) and in Ahtanum Creek at Union Gap (site 31). At these sites, concen-

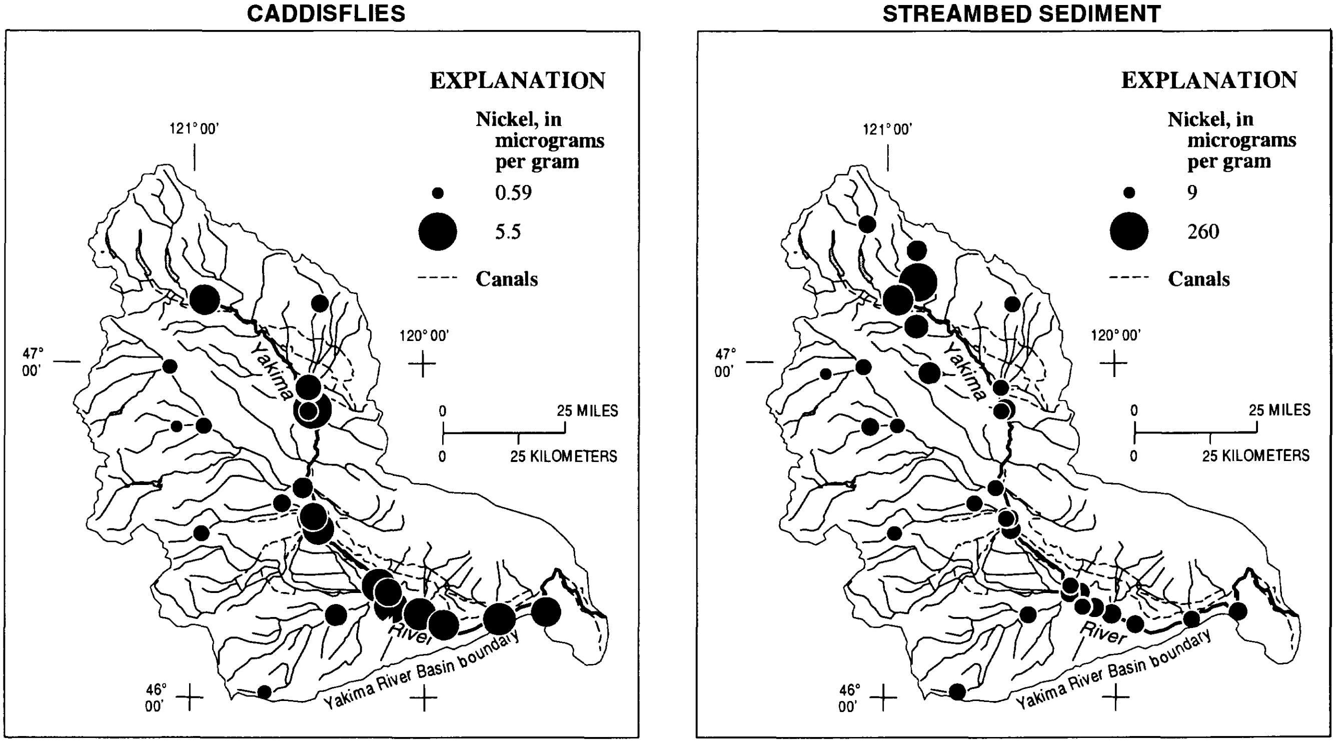


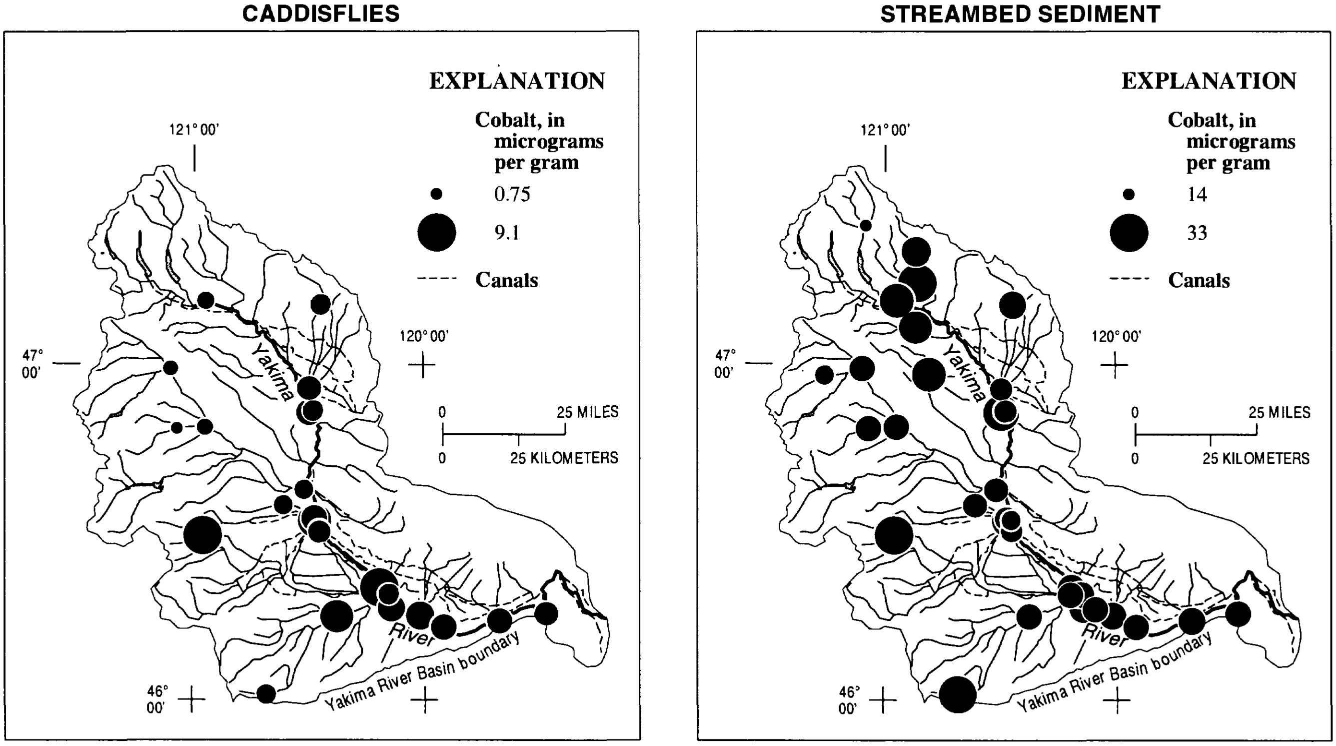
**Figure 34.** Nickel concentrations in caddisflies and streambed sediment, Yakima River Basin, Washington, 1987–90 (element concentrations are reported in units of micrograms per gram [µg/g], dry weight; symbol sizes are proportional to element concentrations; the largest and smallest symbols, respectively, represent the high and low concentration end members; only 1990 data are graphically represented for caddisflies; sample species: caddisflies [Trichoptera: Hydropsychidae *Hydropsyche* spp.]).

trations in caddisflies (*Hydropsyche* spp.) were 9.1 and 6.2 µg/g, respectively, and approximately 6 to 9 times higher than the lowest cobalt concentration in the Yakima River Basin (fig. 35). Comparative data for fish are not available for these sites 31 and 34, but cobalt in streambed sediment at site 34 was the maximum concentration among biological sampling sites. Cobalt concentrations at site 34 in benthic insects were as much as 3 to 6 times higher than mean concentrations reported for uncontaminated streams (Elwood and others, 1976; Smock, 1983; table 40, at back of report), indicating some benthic insects in the Yakima River Basin have been enriched from geologic sources of cobalt.

Maximum concentrations of cobalt also were observed in other taxa (for example, caddisflies [*Arctopsyche* sp.] and stoneflies [*Doroneuria* sp., *Pteronarcys* sp., and *Hesperoperla* sp.]) at either the South Fork of Ahtanum Creek or Ahtanum Creek (Fuhrer, Fluter, and others, 1994). High concentrations of cobalt also were measured in caddisflies (*Hydropsyche* spp.) in Satus Creek below Dry Creek, Granger Drain at mouth near Granger, and Sulphur Creek Wasteway near Sunnyside. In the main stem of the Yakima River, however, concentrations in insects, fish and Asiatic clams (*Corbicula* sp.) were consistent and relatively low among sites. Inputs of cobalt from some of the enriched tributaries in the basin are apparently diluted by other tributaries carrying lower cobalt concentrations.

## Copper

Concentrations of copper in Yakima River Basin streambed sediment ranged from 17 to 96 µg/g (table 12) and slightly exceeded the 4.9 to 90 µg/g range of concentration, which encompasses 95 percent of Western United States soils (R.C. Severson, U.S. Geological Survey, written commun., 1987, based on data in Shacklette and Boerngen, 1984). Concentrations of copper as high as 93 µg/g were detected in streambed sediment of the Naches River near North Yakima (site 26) and Wide Hollow Creek


CADDISFLIES

STREAMBED SEDIMENT

**Figure 35.** Cobalt concentrations in caddisflies and streambed sediment, Yakima River Basin, Washington, 1987-90 (element concentrations are reported in units of micrograms per gram [µg/g], dry weight; symbol sizes are proportional to element concentrations; the largest and smallest symbols, respectively, represent the high and low concentration end members; only 1990 data are graphically represented for caddisflies; sample species: caddisflies [Trichoptera: Hydropsychidae *Hydropsyche* spp.]).

at West Valley Middle School near Ahtanum (site 27). The 93 μg/g of copper measured near West Valley Middle School was more than twice the concentration in Wide Hollow Creek (near the mouth) at the old Sewage Treatment Plant and probably is the result of light urbanization and industrialization. The median concentration of copper at the biological sampling sites (20 μg/g) was as much as two times that found in fine-fraction sediment from other river basins in the United States, but the concentration was similar to that in fine-fraction sediment from randomly sampled lower order streams in the Yakima River Basin (table 34, at back of report).

Another source of suspended copper in the Yakima River Basin was from the use of highly insoluble, copper-bearing fungicides such as copper hydroxide and copper oxychloride (Dennis Johnson, Washington State University, Prosser Experimental Station, oral commun., 1992). These chemicals are registered for a broad array of uses, including applications on alfalfa, grapes, and peaches (Poplyk, 1989). Although copper has a number of agricultural uses in the basin and is known to readily associate with clay and organic matter in streambed sediment, copper concentrations in streambed sediment of the main stem—as previously mentioned—are within the expected 95th-percentile range of copper concentrations found in soils of the Western United States. However, there does appear to be a geologic source of copper within the Naches River drainage (fig. 36). In addition to enrichment at the Naches River site, other sites including American River at Hell's Crossing near Nile (site 13), Little Naches River at mouth near Cliffdell (site 10), Rattlesnake Creek above North Fork Rattlesnake Creek near Nile (site 22), and Rattlesnake Creek above Little Rattlesnake Creek near Nile (site 21)—all of which flow to the Naches River—have copper concentrations as high as 79, 48, 43, and 39 μg/g, respectively. Geologic sources of copper exist in the basin; for example, copper enrichment as high as 150 μg/g was reported in streambed sediment of a tributary to Rattlesnake Creek (Fuhrer, McKenzie, and others, 1994). Areas with reported copper enrichment also contained anomalous concentrations of arsenic and zinc; these areas of copper enrichment have been described by Simmons and others (1983) as andesitic tuff and breccia of the Ohanapecosh Formation.

Median concentrations of copper in suspended sediment ranged from 40 to 60 μg/g at the seven fixed sites and maximum concentrations were as high as 680 μg/g in the Yakima River at Kiona (table 13). The largest variations of copper concentrations were from Sulphur Creek Wasteway near Sunnyside—the interquartile range for suspended copper was 32 μg/g.

Concentrations of suspended copper in Sulphur Creek Wasteway during the nonirrigation season generally were lower than concentrations measured during the irrigation season (fig. 37).

Concentrations of suspended copper were significantly correlated ($\rho = 0.0001$) to the percentage of suspended sediment finer than 62 μm in diameter and also were significantly correlated negatively ($\rho = 0.0001$) to the concentration of suspended sediment. Thus, high concentrations of suspended copper, associated with an increasing percentage of fine-grain-sized suspended sediment, were typical of conditions during the nonirrigation season. Conversely, the lower concentrations of suspended copper, associated with coarse-grain-sized suspended sediment and high concentrations of suspended sediment in Sulphur Creek Wasteway, were typical of the irrigation season. As expected, the concentrations of suspended copper during the irrigation season are similar to the median concentrations of copper (21 μg/g) measured in streambed sediment of the Sunnyside Subbasin by Fuhrer, McKenzie, and others (1994).

In most cases, the concentrations of suspended copper in Sulphur Creek Wasteway were enhanced by increasing quantities of fine-grain-sized suspended sediment. This is typical of sediment dilution (the mixing of copper-rich, fine-grain-sized suspended sediment with large quantities of copper-poor, coarse-grain-sized suspended sediment) rather than changes in the source of copper between the irrigation and the nonirrigation season. However, two suspended-copper concentrations were in excess of concentrations expected based on relations to particle size and were considered anomalous (fig. 38). These anomalies may be typical of extreme temporal variability that is a characteristic of drainages receiving trace elements from multiple sources, including agricultural runoff, urban runoff, and sewage-treatment plant effluent.

A concentration of 190 μg/g of suspended copper was measured on June 21, 1988, during the irrigation season at Sulphur Creek Wasteway near Sunnyside. This copper concentration was higher than expected based on the relation between copper and fine-grain-sized suspended sediment. The concentration of suspended lead measured in the same sample had a near maximum (for Sulphur Creek Wasteway) of 41 μg/g—similar enrichment existed for cadmium. High concentrations of copper, lead, and cadmium

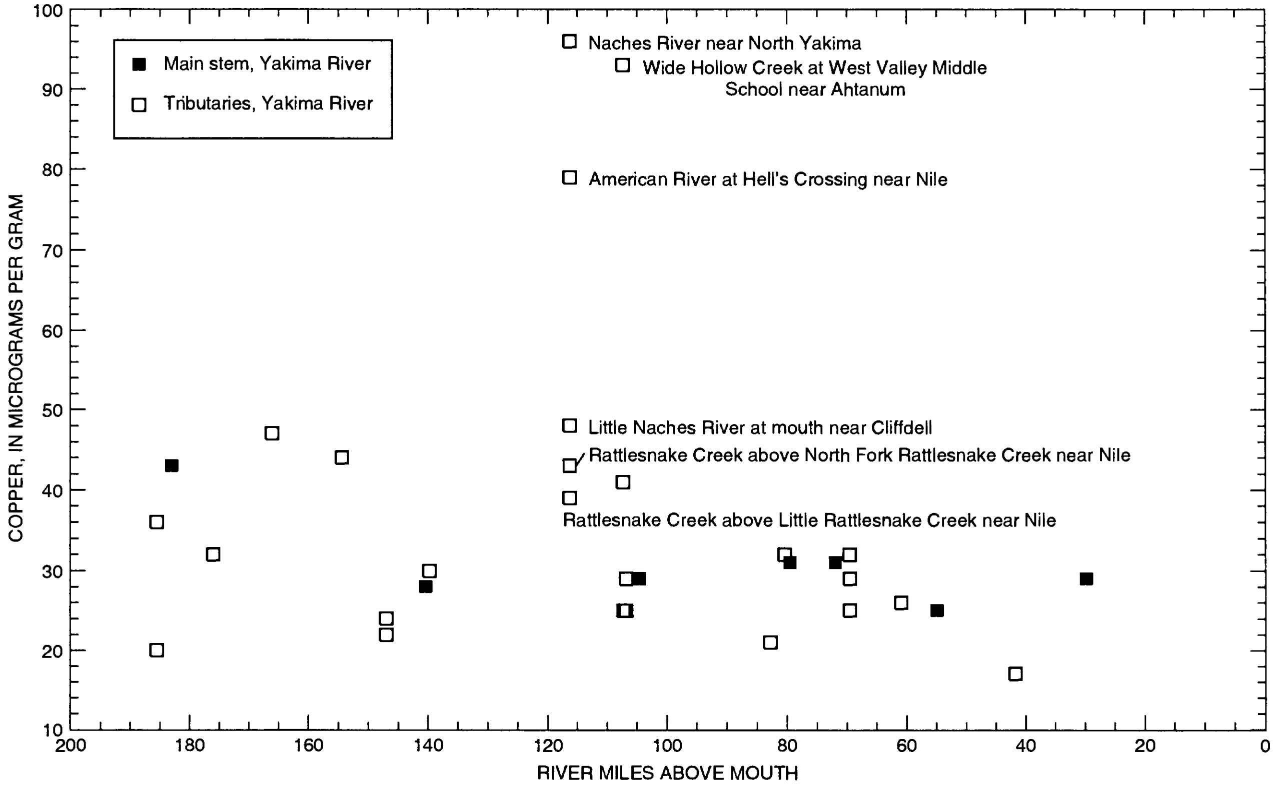


**Figure 36.** Copper concentrations in streambed sediment of the main stem and tributaries, Yakima River Basin, Washington, 1987.

may be indicative of sampling during a period of effluent discharge from the Sunnyside Sewage Treatment Plant or urban runoff from the city of Sunnyside. Although no data exist to characterize the trace-element composition of Sunnyside Sewage Treatment Plant effluent, data available for the city of Yakima's sewage treatment plant indicate that unfiltered-water samples of copper in treated effluent ranged from 8 to 30 µg/L (J. Schnebly, City of Yakima Wastewater Treatment Plant, written commun., 1990). Assuming the latter concentration also, at times, exists in Sunnyside Sewage Treatment Plant effluent and using the suspended-sediment concentration for the June 21 sampling at the Sulphur Creek site, effluent from only the sewage-treatment plant could account for more than one-half the 190 µg/g of suspended copper measured at the Sulphur Creek site. Statistically significant correlations exist between the concentration of suspended copper in Sulphur Creek Wasteway and arsenic ($\rho \leq 0.001$), cadmium ($\rho \leq 0.001$), lead ($\rho \leq 0.001$), and silver ($\rho \leq 0.001$). These elements commonly are associated with sewage-treatment-plant effluent; additionally, these trace elements are

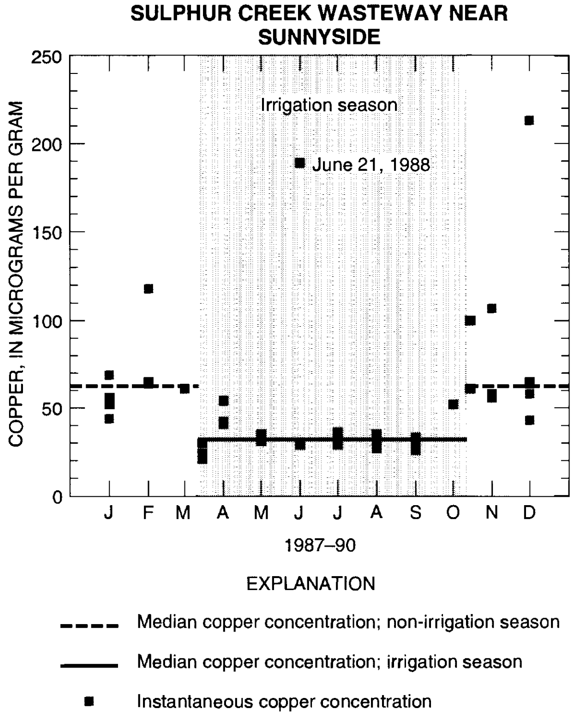


**Figure 37.** Copper concentrations in suspended sediment at Sulphur Creek Wasteway near Sunnyside, Yakima River Basin, Washington, 1987–90 (shaded area represents the irrigation season).

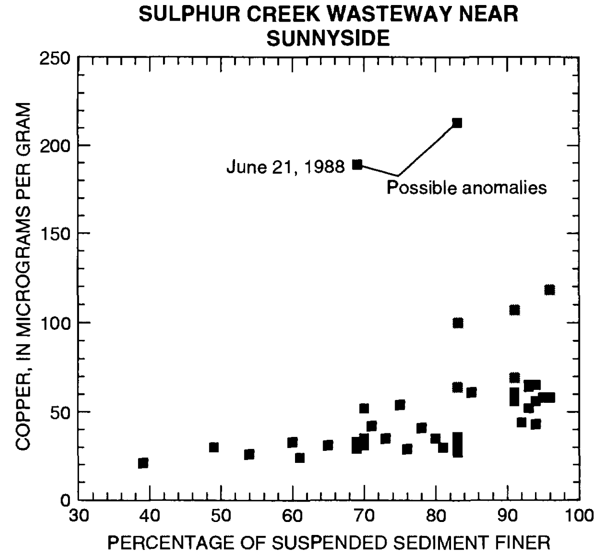


**Figure 38.** Copper concentrations in suspended sediment and the percentage of suspended sediment finer than 62 micrometers in diameter at Sulphur Creek Wasteway near Sunnyside, Yakima River Basin, Washington, 1987–90.

attributed to corrosion of pipes in urban water-supply networks (Forstner and Wittman, 1979, p. 44).

Suspended-copper loads in Sulphur Creek Wasteway near Sunnyside, unlike suspended-copper concentrations, are larger during the irrigation season than during the nonirrigation season. In 1989 for example, the irrigation-season load of copper at the Sulphur Creek site was 3 times higher than the non-irrigation season load (table 25). Suspended-copper loads also were high at the Sulphur Creek site during the snowmelt season; however, a proportion of the snowmelt load results from the overflow of water from Roza Canal to Sulphur Creek Wasteway rather than from only agricultural runoff. The quantity of water spilled is ungaged; consequently, the associated load cannot be accurately determined.

Annual loads of suspended copper were variable among main-stem sites and, without exception, suspended-copper loads were higher in 1989 than in 1988 (table 25) because annual-average streamflow for the Yakima River at Kiona in 1989 was 20 percent higher than in 1988. Between the Yakima River at Umtanum and the Yakima River above Ahtanum Creek at Union Gap, annual loads of suspended copper increased more than twofold. Loads decreased between Union Gap and Grandview, probably as a result of irrigation-season diversions to Wapato and Sunnyside Canals. Loads increased from Grandview to Kiona and again, the largest increase was measured in 1989.

The suspended-copper load doubled between the Umtanum site and the Union Gap site principally from contributions of copper over a 9.1-mile reach that extends from below the Naches River to the Yakima River above Ahtanum Creek at Union Gap as well as from the Naches River (the largest tributary in the Yakima River Basin). Over this 9.1-mile reach, sources of copper exist in Wide Hollow and the Moxee Subbasins. Copper-bearing fungicides are used in both subbasins (J.F. Rinella, unpub. data, 1996); additionally, urban runoff and effluent from the city of Yakima's sewage-treatment plant are potential sources of copper over this reach. In 1989, the Naches River accounted for about one-fourth of the annual load of copper measured at the Union Gap site; the 9.1-mile reach,[8] however, accounted for nearly one-half the annual load measured at the Union Gap site. During the irrigation season and the nonirrigation season, the loads over the 9.1-mile reach were similar (11 pounds per day and 12 pounds per day, respectively).

For the Naches River near North Yakima, the Yakima River at Euclid Bridge at RM 55 near Grandview, and the Yakima River at Kiona, most of the annual-suspended-copper load was transported during the snowmelt season (table 25). In 1989, more than one-half the annual copper load for the Naches, Grandview, and Kiona sites was transported during the snowmelt season. In the Yakima River at Umtanum, however, flow augmentation (by storage reservoirs in the Kittitas Valley) probably affects the irrigation-season load. In 1989, more than one-half the suspended-copper load at the Umtanum site was transported during the irrigation season.

Copper was determined in filtered-water samples by atomic-absorption spectrometry with graphite furnace and ranged in concentration from less than 0.5 to 20 µg/L at the fixed sites (table 14). Copper concentrations, determined by induction-coupled argon plasma at the 45 synoptic sites in July and November 1987, were all below the limit of determination (10 µg/L). The highest concentrations of copper, typically, were measured in the Kittitas Valley. The distribution of copper concentrations for the Yakima River at Umtanum for example, exceeded those of the other fixed sites (fig. 39; and table 37, at back of report). Additionally, 25 percent of

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[8] The load for the reach was determined by subtracting the sum of the loads at the Naches and Umtanum sites from the load at the Union Gap site; a correction was applied to the Umtanum-site load to account for streamflow diverted around the Union Gap site (by way of Roza Canal) during the irrigation season.

**Table 25.** Estimated copper loads in suspended sediment at selected fixed sites, Yakima River Basin, Washington, 1987–90

[Loads reported as pounds per day; load values are based on calibration data collected from March 1987 to March 1990; --, insufficient data. Bold lines represent the irrigation season, and lightly shaded cells represent the snowmelt portion of the irrigation season; nonirrigation season, October through March]

| Year | January | February | March | April | May | June | July | August | September | October | November | December | Daily mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Yakima River at Umtanum** | | | | | | | | | | | | | |
| 1987 | 2 | 3 | 12 | 12 | 14 | 23 | 28 | 27 | 5 | 1 | 1 | 2 | 10.8 |
| 1988 | 1 | 4 | 5 | 15 | 9 | 15 | 29 | 34 | 12 | 2 | 4 | 5 | 11.2 |
| 1989 | 5 | 4 | 6 | 28 | 25 | 24 | 35 | 30 | 10 | 5 | 5 | 5 | 15.2 |
| 1990 | 7 | 9 | 11 | 34 | 26 | 42 | 33 | 36 | 9 | -- | -- | -- | -- |
| **Naches River near North Yakima** | | | | | | | | | | | | | |
| 1987 | -- | -- | 5 | 16 | 65 | 6 | 1 | .3 | 5 | 2 | .2 | .8 | -- |
| 1988 | .4 | .9 | 2 | 17 | 21 | 12 | 2 | 1 | 10 | 4 | 1 | 1 | 6.0 |
| 1989 | 1 | .5 | 2 | 27 | 28 | 19 | 1 | .8 | 9 | 2 | .7 | 2 | 7.8 |
| 1990 | 9 | 4 | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Yakima River above Ahtanum Creek at Union Gap** | | | | | | | | | | | | | |
| 1987 | 10 | 15 | 43 | 42 | 70 | 40 | 36 | 33 | 22 | 12 | 5 | 11 | 28.2 |
| 1988 | 8 | 15 | 15 | 49 | 40 | 40 | 39 | 41 | 30 | 15 | 17 | 18 | 27.2 |
| 1989 | 19 | 16 | 25 | 82 | 70 | 54 | 41 | 36 | 28 | 15 | 17 | 20 | 35.2 |
| 1990 | 28 | 28 | 34 | 85 | 64 | 94 | 44 | 46 | 33 | -- | -- | -- | -- |
| **Sulphur Creek Wasteway near Sunnyside** | | | | | | | | | | | | | |
| 1987 | -- | -- | 5 | 14 | 15 | 12 | 9 | 5 | 3 | 1 | .7 | .8 | -- |
| 1988 | 1 | 2 | 7 | 12 | 14 | 14 | 7 | 5 | 4 | 2 | .8 | .8 | 6.0 |
| 1989 | 1 | 2 | 5 | 18 | 21 | 14 | 9 | 7 | 5 | 2 | .8 | .8 | 7.2 |
| 1990 | 1 | 1 | 6 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Yakima River at Euclid Bridge at river mile 55 near Grandview** | | | | | | | | | | | | | |
| 1987 | -- | -- | 60 | 36 | 97 | 12 | 9 | 7 | 6 | 8 | 4 | 11 | -- |
| 1988 | 6 | 11 | 10 | 46 | 23 | 18 | 8 | 10 | 11 | 13 | 19 | 11 | 15.6 |
| 1989 | 11 | 8 | 31 | 163 | 100 | 27 | 13 | 13 | 12 | 12 | 21 | 18 | 34.3 |
| 1990 | 32 | 28 | 32 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Yakima River at Kiona** | | | | | | | | | | | | | |
| 1987 | 3 | 7 | 85 | 31 | 137 | 12 | 10 | 8 | 5 | 7 | 3 | 10 | 26.5 |
| 1988 | 3 | 7 | 6 | 59 | 30 | 24 | 9 | 11 | 13 | 10 | 15 | 8 | 16.2 |
| 1989 | 6 | 4 | 23 | 226 | 130 | 25 | 12 | 14 | 12 | 14 | 18 | 15 | 41.6 |
| 1990 | 28 | 16 | 20 | 135 | 72 | 396 | 14 | 62 | 23 | -- | -- | -- | -- |

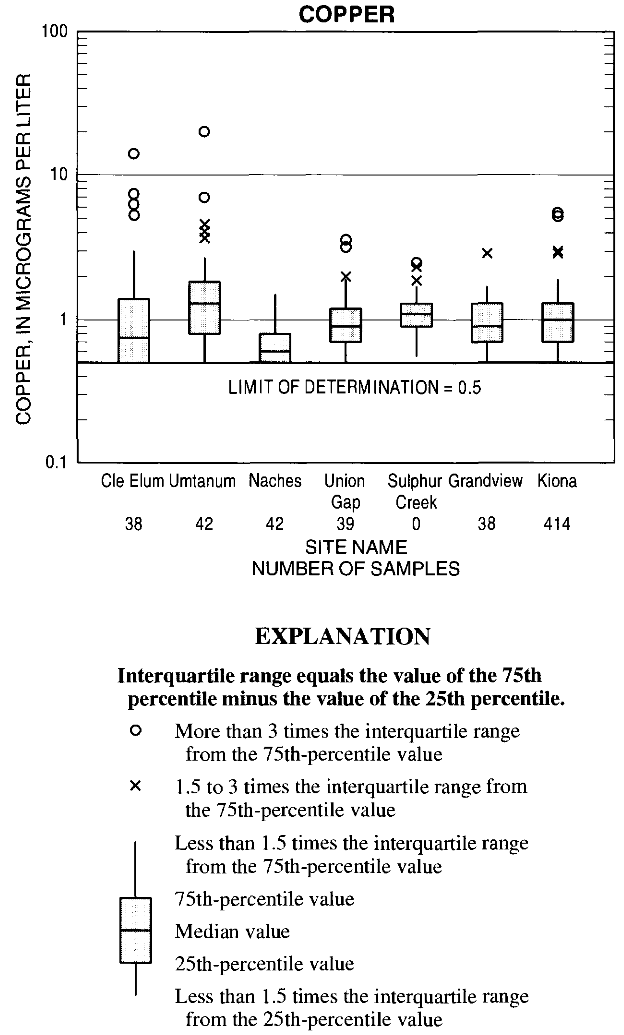


**Figure 39.** Distribution of copper concentrations in filtered-water samples at fixed sites, Yakima River Basin, Washington, 1987–90 ("Cle Elum" represents Yakima River at Cle Elum; "Umtanum" represents Yakima River at Umtanum; "Naches" represents Naches River near North Yakima; "Union Gap" represents Yakima River above Ahtanum Creek at Union Gap; "Sulphur Creek" represents Sulphur Creek Wasteway near Sunnyside; "Grandview" represents Yakima River at Euclid Bridge at river mile 55 near Grandview; and "Kiona" represents Yakima River at Kiona).

the copper concentrations at the Umtanum site exceeded background concentrations in inland waters (table 36, at back of report). Although other fixed sites are in close proximity to urban sources, none of these sites had percentile values of copper similar or as high as the Umtanum site. For example, although the Yakima River above Ahtanum Creek at Union Gap is located downstream from the city of Yakima, the 75th-percentile value for copper at this site (0.9 µg/L) is smaller than the median copper value for the Umtanum site (1.3 µg/L).

The two highest copper concentrations, 20 µg/L on October 12, 1989 and 7.4 µg/L on November 15, 1989, were measured in the Yakima River at Umtanum —these copper concentrations exceeded the acute and chronic criterion, respectively, derived for the protection of freshwater aquatic life (table 7). Additionally, these two concentrations of copper were measured after the curtailment of streamflow, which usually occurs during mid-September, from reservoirs in the Kittitas Valley. Mean monthly streamflows at the Umtanum site for October and November 1989 were about 1,000 $ft^3/s$ and represented about 25 percent of mean monthly streamflows measured during the 1989 irrigation season. The anomalous 7.4 µg/L of copper at the Umtanum site coincided with a copper concentration of 14 µg/L measured the previous day (November 14, 1989) in the Yakima River at Cle Elum. The copper concentration (14 µg/L) at the Cle Elum site was the maximum value for the period 1987–89. During storms, the copper-bearing pre-Tertiary metamorphic and intrusive rocks geologic unit in the Cle Elum Subbasin (Fuhrer, McKenzie, and others, 1994) may be a potential source of dissolved copper to the main stem. The Cle Elum and the Umtanum sites were sampled in a 10-day interval in which streamflow increased more than threefold. The anomalies at both sites were probably the result of an early winter storm that affected the Kittitas Valley.

The anomalous 20 µg/L of copper at the Umtanum site did not coincide with a storm event and probably resulted from a local anthropogenic source. The upstream concentration of copper the previous day (October 11, 1989) at the Cle Elum site was low (0.6 µg/L) and was not indicative of a geologic source that might have affected the Umtanum site. High concentrations of copper during the post-irrigation season probably resulted from smaller streamflow in the main stem and, consequently, less dilution water for copper entering the main stem from anthropogenic sources. The Umtanum site is located 6.3 miles downstream from Wilson Creek, which carries irrigation return flow and urban runoff from the Kittitas Valley to the main stem. During 1989, only 5 pounds per day of copper was applied to crops in the Kittitas Irrigation District (Rinella and others, 1992). This application rate is small when compared to the approximately 440 pounds per day applied to crops in the mid- and lower Yakima Valley. Urban sources of copper, measurable at Umtanum, may include the city of Ellensburg's street runoff that flows into Wilson Creek, but probably does not include significant quantities of effluent from Ellensburg's Sewage Treatment Plant. The copper in Ellensburg's Sewage Treatment Plant effluent is small (3 µg/L; Reif, 1989) and streamflow from the plant accounts for less than one-half of one percent of the streamflow at the Umtanum site during October and November 1989. Concentrations of copper and lead, in streambed sediment affected by urban runoff, were as large as 65 µg/g and 130 µg/g in Wilson Creek (Fuhrer, McKenzie, and others, 1994). In an oxygen-depleted environment, streambed sediment becomes anaerobic, and dissolved copper may increase greatly in the sediment pore water (Forstner and Whittman, 1979). Oftentimes, the concentration of copper in pore water of sediment is greater than that predicted on the basis of copper's solubility product with sulfide complexes; such behavior is attributed to the formation of humic-copper complexes (Forstner and Wittmann, 1979, p. 252–253; Moore, 1991, p. 109–139). In July 1987, dissolved oxygen in stream water at the Wilson Creek site was depleted to 72 percent of saturation. Releases of pore water from Wilson Creek streambed sediment may be a potential source of copper to the main stem during periods of low streamflow.

The distribution of copper concentrations at the Cle Elum site was similar to that for the Umtanum site. Higher concentrations generally were associated with winter storms—storm concentrations of copper at Cle Elum were as large as 14 µg/L (fig. 40). Additionally, copper concentrations in four of the five sampled storms exceeded acute and chronic criteria established for the protection of freshwater aquatic life (table 7). Although flow augmentation from reservoirs in the Kittitas Valley produces streamflow that varies from approximately 1,000 ft$^3$/s to 3,500 ft$^3$/s, associated copper concentrations only varied slightly and generally were low from April through September.

The spatial coverage for dissolved copper in the Kittitas Valley was inadequate to separate geologic sources of copper from anthropogenic sources. Storm sampling, however, suggests that urban runoff also may be a potential source of copper at the Cle Elum site. This site was sampled on January 9 and 10, 1990, during a storm; samples were collected on the rising limb and near the peak of the storm hydrograph, and concentrations of copper were measured as 5.3 µg/L and 3.0 µg/L, respectively (fig. 41). A similar pattern was measured during the same storm for suspended-copper concentrations—concentrations on the rising limb and near the peak of the storm were 67 and 47 µg/g, respectively. The Cle Elum site, located 0.15 mile downstream from Crystal Creek, receives urban runoff from the towns of Roslyn and Cle Elum, sewage-treatment-plant effluent from the town of Roslyn, and runoff from numerous open-pit coal mines east of Roslyn. During the storm, Crystal Creek created a turbidity plume which, during the rising limb of the storm, obscured the shallow river bottom in the main stem at the Cle Elum site. Streambed sediment in the Crystal Creek drainage probably is not a geologic source of copper because the average concentration of 33 µg/g of copper in streambed sediment (Fuhrer, McKenzie, and others, 1994) was low in comparison to storm concentrations of suspended copper at the Cle Elum site. Considering the close proximity of the Cle Elum site to the inflow of Crystal Creek and the apparent absence of a large geological source of copper in the Crystal Creek drainage, urban runoff may be a source of copper measurable in filtered-water samples at the Cle Elum site.

Annual loads of dissolved copper generally were consistent among main-stem sites. The largest difference in loads of dissolved copper was measured

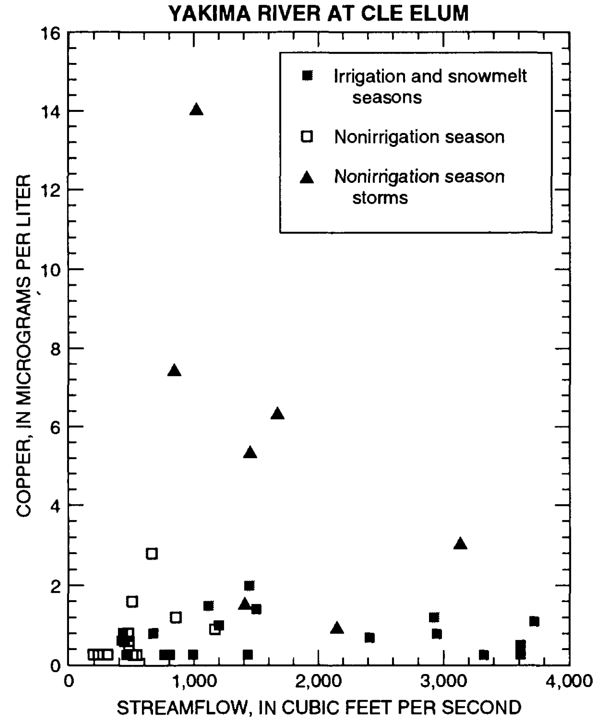


**Figure 40.** Relation between copper concentrations in filtered-water samples and streamflow for selected time periods at the Yakima River at Cle Elum, Yakima River Basin, Washington, 1987–90 (irrigation season is June through September; snowmelt season is April through May; nonirrigation season is October through March).

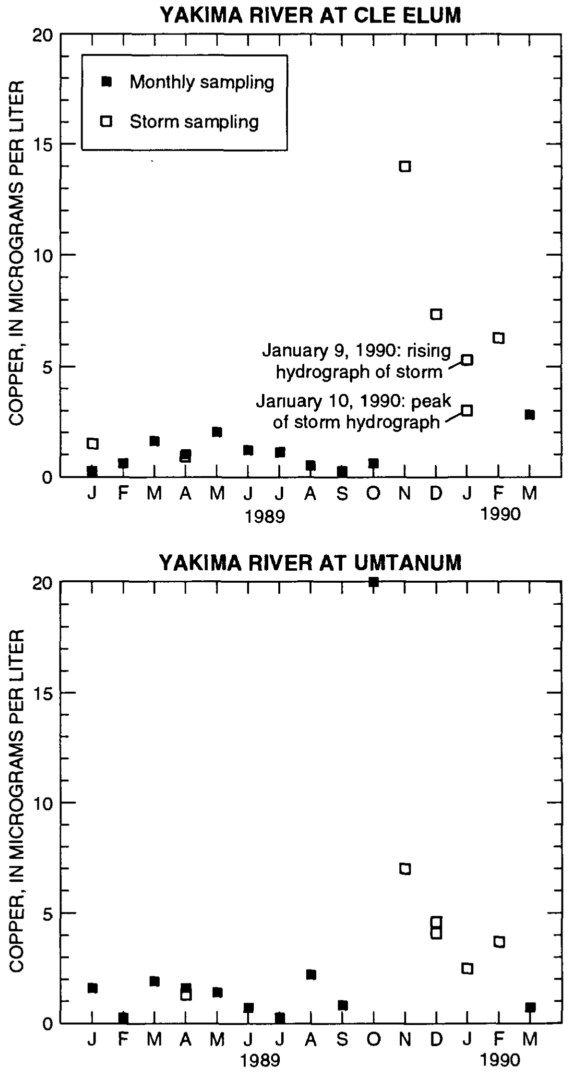


**Figure 41.** Copper concentrations in filtered-water samples for the Yakima River at Cle Elum and the Yakima River at Umtanum, Yakima River Basin, Washington, 1989–90.

between the Yakima River at Cle Elum and the Yakima River at Umtanum, where loads increased about twofold (table 26). Increases between these sites were not confined to any particular hydrologic season and were uniformly distributed during the snowmelt, irrigation, and nonirrigation seasons. Within 3.5 miles downstream from the Union Gap site, more than 80 percent of the copper load is diverted into the Wapato and Sunnyside Canals during the irrigation season. Consequently, the irrigation-season load at the Grandview and Kiona sites is affected by irrigation return flow downstream from Parker.

Copper-based pesticides are applied on an annual basis in the lower Yakima Valley. During 1989, an estimated average of 460 pounds per day of copper in pesticide formulations was applied to the Yakima River Basin; major crops that received pesticide applications were hops, cherries, and pears (J.F. Rinella, unpub. data, 1996). Although 330 pounds per day (75 percent of the total copper in pesticide formulations) was applied to the lower Yakima Valley, no appreciable increase in copper load or copper concentration was noted during the irrigation season at the Grandview and Kiona sites. For example, during the 4-month irrigation season in 1989, the copper load at the Grandview site was only 1,281 pounds, which accounted for only 25 percent of the annual load. Similarly, no appreciable increase in suspended-copper load was noted earlier during the irrigation season at either of these sites. In fact, the total load of copper (in filtered water and suspended sediment) in the Yakima River at Kiona in 1989 represented only 13 percent of that applied to the basin in pesticide formulations.

The increase in copper concentration attributable to pesticide application was estimated for the agricultural soils of the Moxee Subbasin. The estimate was made to determine if pesticide applications were large enough to be measurable in streambed sediment of Moxee Drain. Based on an application rate for Moxee Subbasin of 88 pounds of copper per day and an agricultural land-use area of 40 $mi^2$ (J.F. Rinella, unpub. data, 1996), soil concentrations were calculated for pesticide-application periods of 10, 20, and 30 years. To determine the volume of soils potentially affected by pesticide applications, a till depth of 1 foot was assumed. Furthermore, as a conservative estimate, 100 percent of the copper in the pesticide formulation was assumed to be sorbed to soil. The concentrations of copper in agricultural soils of the Moxee Subbasin after 10, 20, and 30 years of pesticide application would be expected to be 1.7, 3.5, and 5.2 µg/g, respectively. By the time soils are eroded from agricultural fields and mixed with streambed sediment that contains copper at background concentrations, the effects attributable to pesticide applications probably are not measurable in streambed sediment. Similar findings were true for other agriculturally affected subbasins such as Ahtanum and Wide Hollow. These results indicate that copper in pesticide formulations is not likely to accumulate in significant quantities in streambed sediment nor will pesticide formulations represent a significant source or flux of copper leaving the Yakima River Basin.

The Cle Elum, Umtanum, and Union Gap sites have irrigation-season copper loads that account for a

**Table 26.** Estimated copper loads in filtered-water samples at fixed sites, Yakima River Basin, Washington, 1987–90

[The term "filtered water" is an operational definition referring to the chemical analysis of that portion of a water-suspended sediment sample that passes through a nominal 0.45-micrometer filter; loads reported as pounds per day. Load values are based on calibration data collected from March 1987 to March 1990; --, insufficient data. Bold lines represent the irrigation season, and lightly shaded cells represent the snowmelt portion of the irrigation season; nonirrigation season, October through March]

| Year | January | February | March | April | May | June | July | August | September | October | November | December | Daily mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Yakima River at Cle Elum** | | | | | | | | | | | | | |
| 1987 | -- | -- | 5 | 4 | 4 | 13 | 22 | 29 | 4 | 1 | 0.8 | 2 | -- |
| 1988 | 1 | 3 | 3 | 4 | 1 | 5 | 21 | 33 | 9 | 2 | 5 | 7 | 7.8 |
| 1989 | 8 | 4 | 1 | 8 | 11 | 13 | 28 | 29 | 8 | 2 | 9 | 9 | 10.8 |
| 1990 | 12 | 11 | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Yakima River at Umtanum** | | | | | | | | | | | | | |
| 1987 | 5 | 6 | 16 | 12 | 12 | 20 | 28 | 36 | 10 | 3 | 3 | 6 | 13.1 |
| 1988 | 3 | 7 | 7 | 14 | 8 | 13 | 29 | 46 | 21 | 7 | 12 | 13 | 15.0 |
| 1989 | 13 | 9 | 8 | 28 | 21 | 21 | 36 | 41 | 19 | 12 | 15 | 15 | 19.8 |
| 1990 | 17 | 17 | 14 | 33 | 22 | 36 | 34 | 48 | 13 | -- | -- | -- | -- |
| **Naches River near North Yakima** | | | | | | | | | | | | | |
| 1987 | -- | -- | 4 | 7 | 17 | 5 | 2 | 1 | 4 | 2 | 1 | 1 | -- |
| 1988 | 1 | 2 | 2 | 8 | 9 | 7 | 2 | 2 | 6 | 3 | 2 | 2 | 3.8 |
| 1989 | 2 | 1 | 3 | 10 | 11 | 8 | 2 | 2 | 6 | 2 | 1 | 3 | 4.2 |
| 1990 | 5 | 4 | 4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Yakima River above Ahtanum Creek at Union Gap** | | | | | | | | | | | | | |
| 1987 | 7 | 9 | 20 | 20 | 29 | 18 | 16 | 14 | 10 | 6 | 4 | 6 | 13.3 |
| 1988 | 5 | 9 | 10 | 22 | 19 | 18 | 17 | 16 | 12 | 8 | 8 | 9 | 12.8 |
| 1989 | 10 | 10 | 14 | 32 | 29 | 23 | 18 | 15 | 12 | 8 | 8 | 10 | 15.8 |
| 1990 | 13 | 14 | 17 | 34 | 27 | 34 | 19 | 18 | 13 | -- | -- | -- | -- |
| **Sulphur Creek Wasteway near Sunnyside** | | | | | | | | | | | | | |
| 1987 | -- | -- | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | .4 | .4 | -- |
| 1988 | .4 | .4 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 1 | .5 | .4 | 1.0 |
| 1989 | .4 | .4 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | .5 | .4 | 1.3 |
| 1990 | .5 | .4 | 1 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Yakima River at Euclid Bridge at river mile 55 near Grandview** | | | | | | | | | | | | | |
| 1987 | -- | -- | 14 | 15 | 17 | 9 | 8 | 8 | 8 | 9 | 8 | 11 | -- |
| 1988 | 11 | 13 | 12 | 15 | 12 | 10 | 8 | 8 | 9 | 10 | 13 | 12 | 11.1 |
| 1989 | 13 | 12 | 16 | 23 | 18 | 12 | 9 | 9 | 10 | 10 | 14 | 14 | 13.3 |
| 1990 | 16 | 16 | 17 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Yakima River at Kiona** | | | | | | | | | | | | | |
| 1987 | 14 | 18 | 33 | 20 | 24 | 10 | 8 | 8 | 8 | 10 | 10 | 15 | 14.8 |
| 1988 | 13 | 17 | 14 | 22 | 15 | 12 | 8 | 9 | 11 | 12 | 16 | 16 | 13.8 |
| 1989 | 17 | 15 | 22 | 37 | 24 | 13 | 9 | 10 | 10 | 13 | 17 | 19 | 17.2 |
| 1990 | 23 | 22 | 22 | 33 | 21 | 32 | 10 | 13 | 12 | -- | -- | -- | -- |

large proportion of their respective annual loads and that are large compared to snowmelt-season and nonirrigation-season loads (fig. 42). In 1989, for example, the irrigation season accounted for about 59 percent of the annual copper load and about 56 percent of the annual streamflow at the Cle Elum site. The similarity between the percentages of load and streamflow was expected because copper concentrations only varied slightly with streamflow (with the exception of storms) and, as stated above, generally were low from April through September (irrigation and snowmelt seasons; fig. 40). Conversely, the Grandview and Kiona sites had irrigation-season copper loads that accounted for smaller proportions of their respective annual loads and that, furthermore, were small in comparison to snowmelt-season and nonirrigation season loads (fig. 42). At the Grandview site in 1989, the irrigation season accounted for about 25 percent of the annual copper load and about 22 percent of the annual streamflow; again, as with the Cle Elum site, similarity existed between the percentages of load and streamflow. Because copper concentrations varied only slightly with streamflow, variations in streamflow greatly affected seasonal copper loads. Therefore, copper loads generally are controlled by flow regulation; loads in the main stem increase in the Kittitas Valley as a result of reservoir releases during the irrigation season and decrease in the lower Yakima Valley as a result of streamflow diversions to irrigation canals.

Copper can be transported in dissolved and suspended forms. The suspended form, however, is the major transport mechanism for copper at the Union Gap, Sulphur Creek, Naches, Grandview, and Kiona sites (fig. 43). The dominance of the suspended load is most notable during the snowmelt season and least notable during the nonirrigation season. The largest difference between dissolved and suspended forms of copper for different hydrologic seasons was at Kiona. The snowmelt suspended load (average monthly load for April and May 1989) of 178 pounds of copper per day was nearly 6 times larger than the respective dissolved copper load.

Copper concentrations in aquatic biota generally were less than 35 μg/g except for rainbow trout liver, carp liver, and some species of stonefly (table 40, at back of report). Differences in copper concentrations among different taxa might reflect species-specific differences in metal accumulation, a common phenomenon. For example, trout tend to accumulate more copper when compared to other fish (Rasmussen, 1992). Among sites, copper concentrations varied less than 2 times in most taxa. For example, in the caddisfly (*Hydropsyche* spp.), concentrations ranged from 10 to 15 μg/g at 20 of the 24 sites where caddisflies were collected in 1990 (fig. 44). The results indicate that biologically available copper is distributed uniformly over much of the Yakima River Basin.

Two sites, however, consistently had high copper concentrations in biological samples. Wide Hollow Creek at the old Sewage Treatment Plant at Union Gap had maximum copper concentrations in caddisflies (*Hydropsyche* spp.) of 48 μg/g in 1989 and 21 μg/g in 1990; 480 μg/g in 1990 in rainbow trout liver (trout were not collected at this site in 1989); and curlyleaf pondweed, an aquatic plant. The copper concentration in trout in Wide Hollow Creek was more than an order of magnitude greater than in rainbow trout of the same size in Taneum Creek at Taneum Meadow near Thorp (a site unaffected by agricultural or urban activity). Wide Hollow Creek drains agricultural land and also receives urban runoff from the city of Yakima. Relatively high concentrations of copper (290 μg/g in 1990 and 130 μg/g in 1989) also were measured in trout livers collected from the Yakima River at Umtanum, a site which receives urban runoff from the city of Ellensburg and has episodically high copper concentrations in filtered-water samples, as previously mentioned. The greater variation in copper concentration in rainbow trout livers may indicate differences in the capacity of individual trout to accumulate copper, as well as site-related differences in copper concentrations among samples (Vidal, 1978).

Concentrations of copper in curlyleaf pondweed ranged from 9.2 to 22 μg/g (table 15). Concentrations of copper in pondweed in Cherry Creek at Thrall (22 μg/g) and in Wide Hollow Creek at the old Sewage Treatment Plant at Union Gap (21 μg/g) were among the highest concentrations in the Yakima River Basin (Fuhrer, Fluter, and others, 1994). The water weed (*Elodea* sp.) in Spring Creek at mouth at Whitstran had the highest copper concentration among all aquatic plants. The Spring Creek site carries agricultural return flow to the main stem.

Enrichment of copper in Wide Hollow Creek is measurable in all media sampled. In addition to enrichment in aquatic biota, copper concentrations also were high in filtered water and streambed sediment (suspended sediment was not measured) (table 27). The concentrations of copper in filtered water from Wide Hollow Creek near West Valley High School (site 27) and in Wide Hollow Creek at the old Sewage Treatment Plant (site 29) were, respectively,

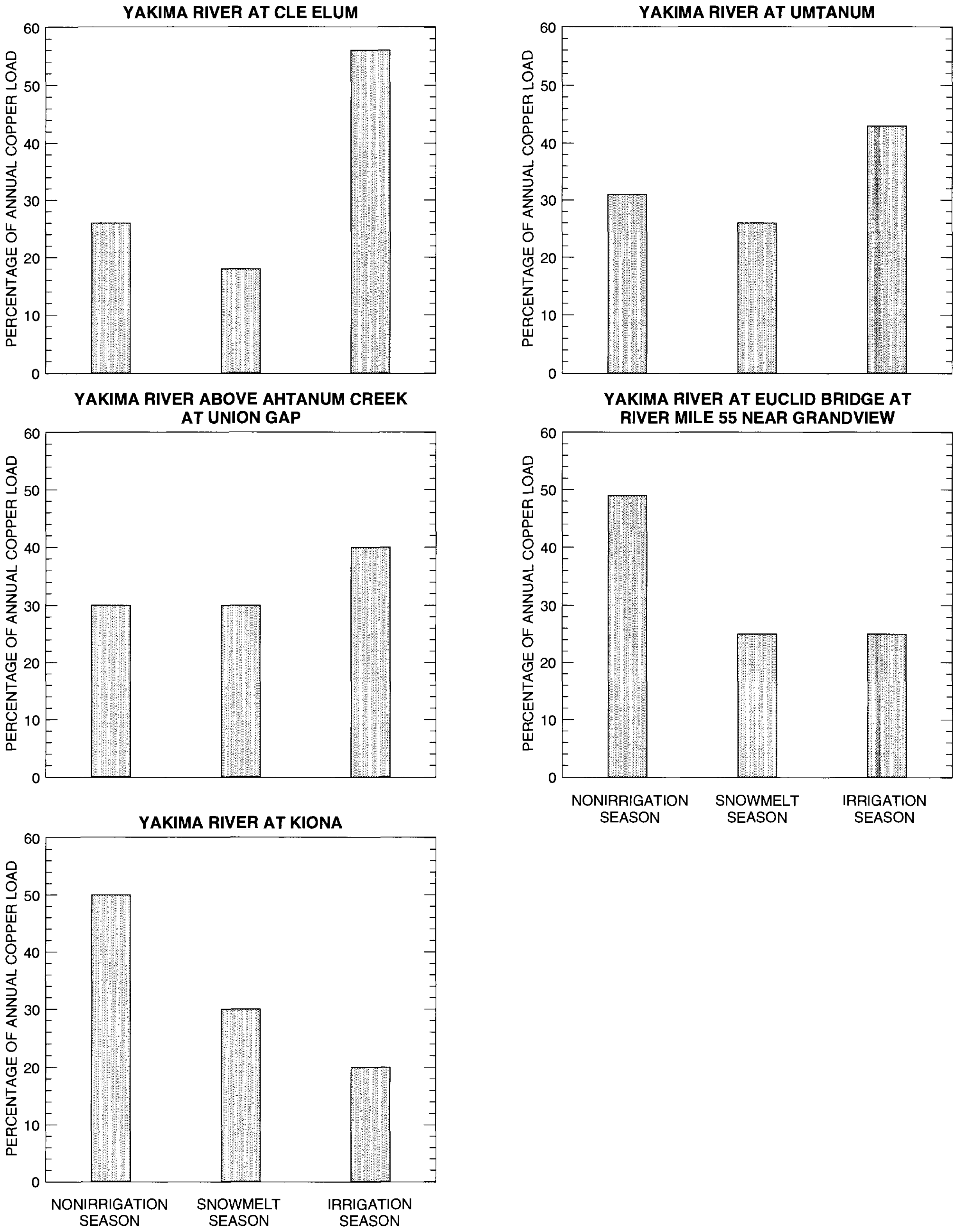


**Figure 42.** Percentages of the annual load of copper in filtered-water samples for selected time periods at selected fixed sites, Yakima River Basin, Washington, 1989 (nonirrigation season is October through March; snowmelt season is April through May; irrigation season is June through September).

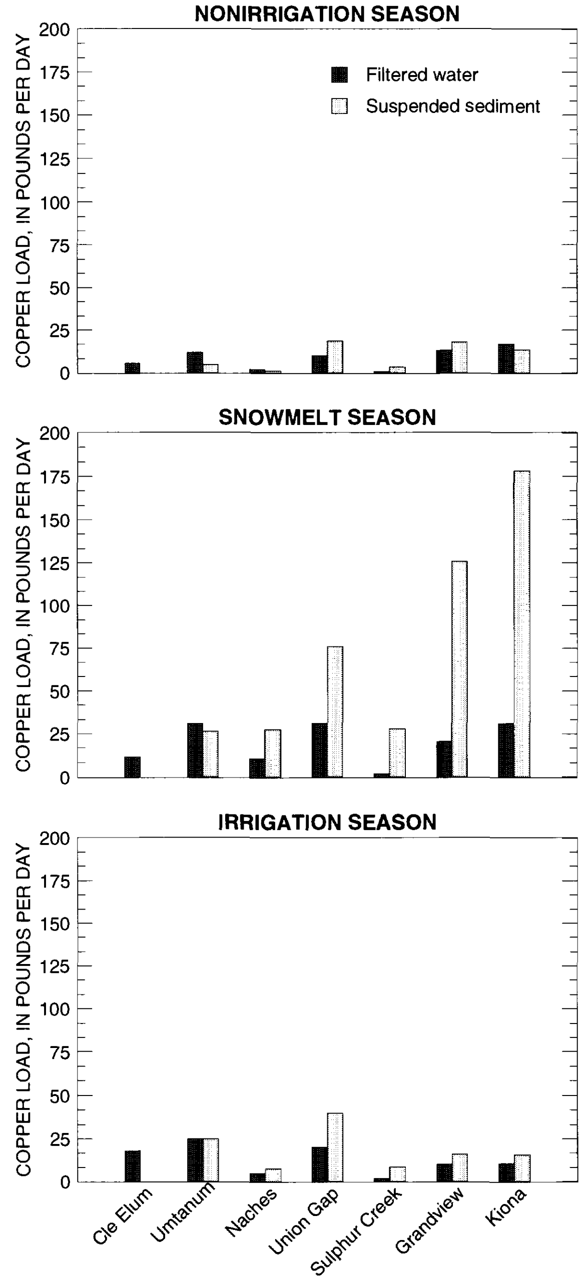
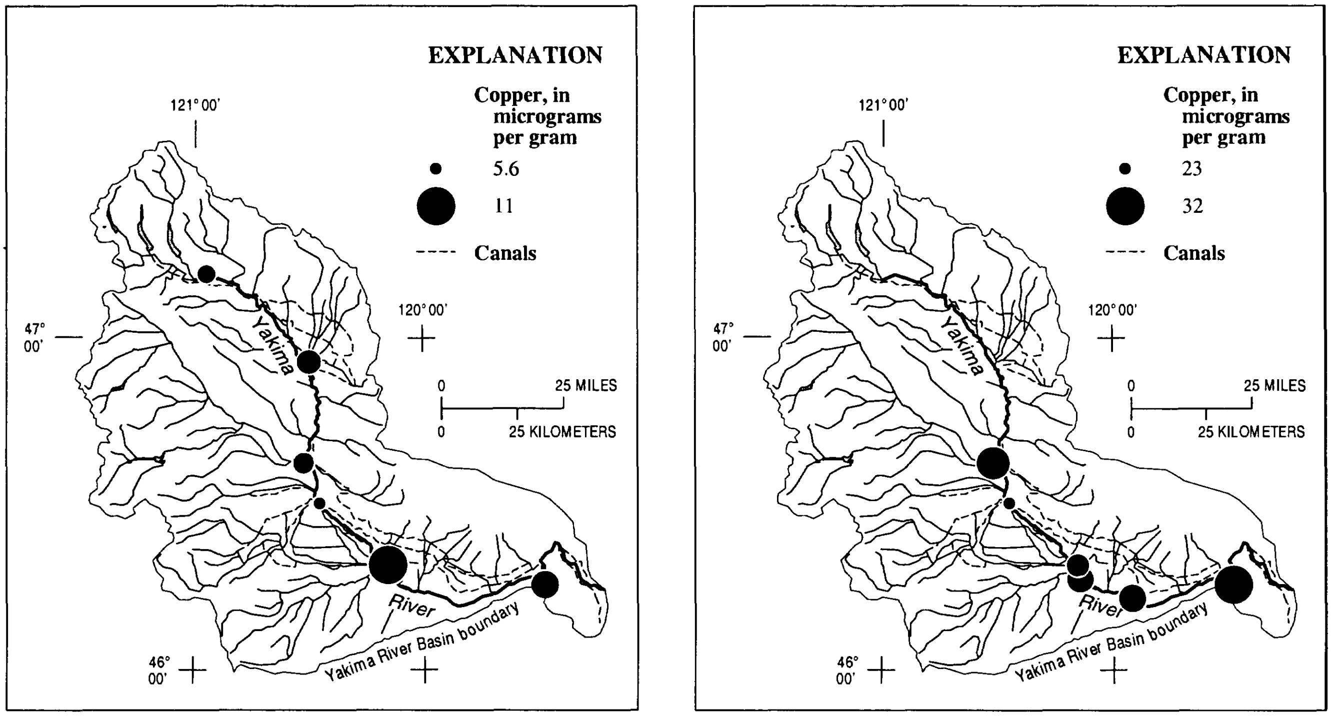


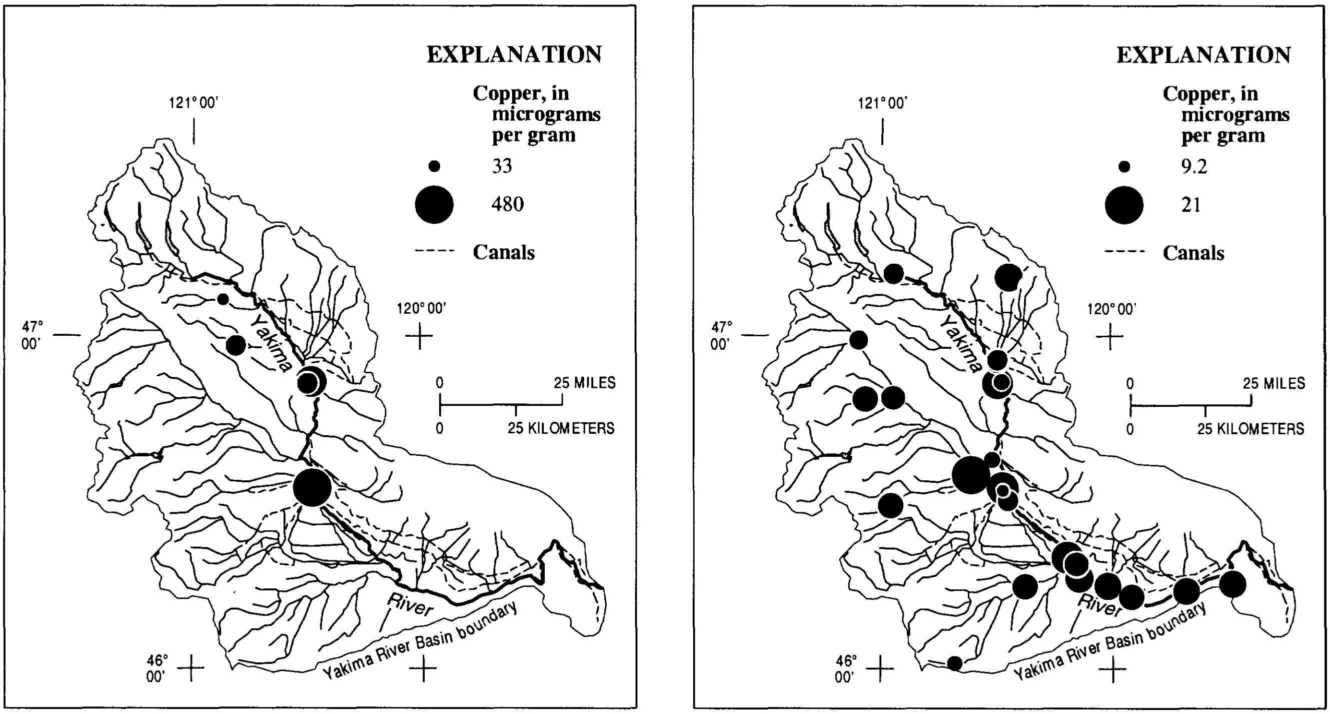
**Figure 43.** Copper loads in filtered-water samples and in suspended-sediment samples for selected time periods at fixed sites, Yakima River Basin, Washington, 1989 (the term "filtered water" represents the portion of a water sample passing through a nominal 0.45-micrometer-pore-size filter; nonirrigation season is October through March; snowmelt season is April through May; irrigation season is June through September; "Cle Elum" represents Yakima River at Cle Elum; "Umtanum" represents Yakima River at Umtanum; "Naches" represents Naches River near North Yakima; "Union Gap" represents Yakima River above Ahtanum Creek at Union Gap; "Sulphur Creek" represents Sulphur Creek Wasteway near Sunnyside; "Grandview" represents Yakima River at Euclid Bridge at river mile 55 near Grandview; and "Kiona" represents Yakima River at Kiona).

5.0 μg/L and 1.4 μg/L and exceeded the 75th-percentile value (1.3 μg/L) for copper determinations at fixed sites during 1987–90. Concentrations of copper in streambed sediment at these sites were, respectively, 93 μg/g and 42 μg/g, and equaled or exceeded the 75th percentile for streambed sediment collected from biological sampling sites in the Yakima River Basin. Additionally, concentrations of copper in all media sampled were larger at the West Valley High School site than at the mouth of Wide Hollow Creek (old Sewage Treatment Plant site). Water and streambed sediment near the mouth of Wide Hollow Creek may have been affected by the mixing of copper-poor sediment from the Yakima River with copper-rich sediment from Wide Hollow Subbasin.

The patterns of copper enrichment in water and fish in the Yakima River at Umtanum (site 19) are similar to those measured in Wide Hollow Creek; however, the relative concentrations are not as high. The copper concentration in rainbow trout liver, for example, is 290 μg/g in the Yakima River at Umtanum and 480 μg/g in Wide Hollow at old Sewage Treatment Plant at Union Gap. Both concentrations, however, were larger than the median concentration (100 μg/g) for rainbow trout liver. The Umtanum site is located 6.6 miles downstream from Wilson Creek, which is affected by anthropogenic activities in the Kittitas, Wilson-Naneum, and Swauk Subbasins. The city of Ellensburg is located in the Wilson-Naneum Subbasin. Streambed-sediment concentrations of copper, although high (65 μg/g) in the city of Ellensburg's urban stormwater drain site, were attenuated near the mouth of Wilson Creek. Sediment affected by urban runoff was mixed, near the mouth of Wilson Creek, with copper-poor sediment in agricultural return flow; furthermore, after entering the main stem, sediment concentrations of copper were again attenuated downstream. Comparisons between copper detected in rainbow trout collected from the Yakima River at Umtanum and from the Umtanum Creek near mouth at Umtanum (site 20) indicate the presence of an upstream source of copper. Samples collected in the fall of 1989 and 1990 indicated that copper concentrations in liver tissue of rainbow trout from the Yakima River at Umtanum were approximately 2.5 times higher than concentrations from Umtanum Creek near the mouth at Umtanum. Umtanum Creek is located immediately downstream from the Yakima River at Umtanum; Umtanum Creek's drainage is isolated from copper anomalies (excluding atmospheric deposition) in the Kittitas Valley. High concentrations of


MOUNTAIN WHITEFISH LIVERS

LARGESCALE SUCKER LIVERS


RAINBOW TROUT LIVERS

CADDISFLIES

**Figure 44.** Distribution of copper concentrations in mountain whitefish livers, largescale sucker livers, rainbow trout livers, caddisflies, and streambed sediment, Yakima River Basin, Washington, 1987–90 (element concentrations are reported in units of micrograms per gram [μg/g], dry weight; symbol sizes are proportional to element concentrations; the largest and smallest symbols, respectively, represent the high and low concentration end members; only 1990 data are graphically represented for mountain whitefish, largescale sucker, rainbow trout, and caddisflies; sample species: mountain whitefish [*Prosopium williamsoni*], largescale sucker [*Catostomus macrocheilus*], rainbow trout [*Oncorhynchus mykiss*], and caddisflies [Trichoptera: Hydropsychidae *Hydropsyche* spp.]).

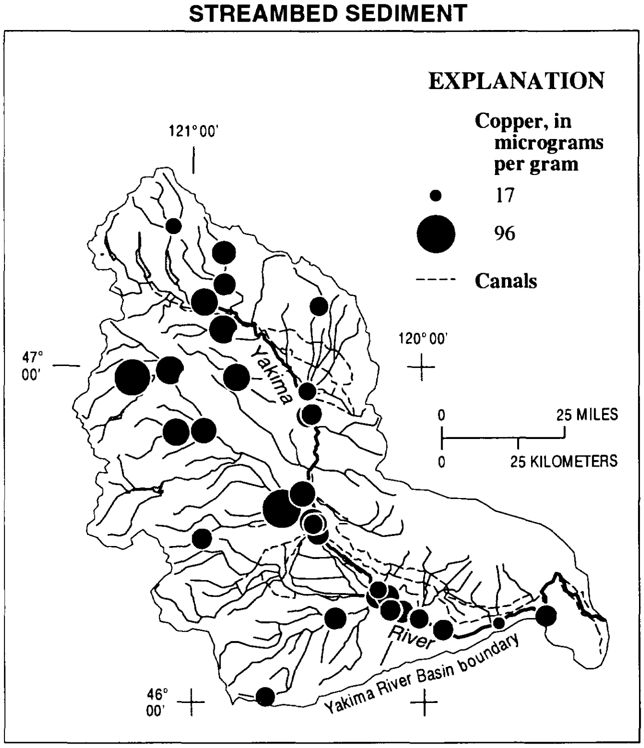

STREAMBED SEDIMENT

**Figure 44.** Distribution of copper concentrations in mountain whitefish livers, largescale sucker livers, rainbow trout livers, caddisflies, and streambed sediment, Yakima River Basin, Washington, 1987–90—Continued.

copper in rainbow trout may result from dissolved forms of copper in the Yakima River at Umtanum. Dissolved forms of copper are absorbed readily through the gills of fish—rainbow trout in particular. Accordingly, guidelines for protecting fish in low hardness waters are in units of tenths of a microgram per liter (Moore, 1991, p. 119). The highest copper concentrations (20 and 7.4 µg/L) in filtered-water samples were measured at Umtanum in the fall, a period characterized by low streamflows after the irrigation season. During this period, the Yakima River at Umtanum is susceptible to episodic increases in concentrations of copper in filtered water. Among sites, other factors, such as differences in fish length may affect the distribution of copper in rainbow trout, however.

Overall, copper concentrations in most biological samples from the Yakima River Basin were comparatively low and appear indicative of background concentrations. The enrichment of copper in Wide Hollow Creek and the Yakima River at Umtanum is modest when compared to other river basins. For example, the maximum concentrations in benthic insects in the Yakima River Basin in 1990 generally were lower than the mean concentrations reported for aquatic insects from uncontaminated streams and rivers (table 40, at back of report) [Cain and others, 1992; Gower and Darlington, 1990; Lynch and others, 1988; Miller and others, 1992]. The variation in copper concentration shown in table 40 indicates differences in concentrations among sites and differences in copper accumulation among different species. More direct comparisons can be made with caddisflies *(Hydropsyche* spp.*)*. Cain and others (1992) reported that the mean and standard deviation for copper concentrations in caddisflies *(Hydropsyche* spp.) from reference streams in Montana were 18 ± 0.4 µg/g. The Montana reference mean is comparable to concentrations of copper in caddisflies *(Hydropsyche* spp.) at all sites in the Yakima River Basin except for the 1989 insect sample (48 µg/g) from Wide Hollow Creek. Concentrations of copper in Wide Hollow Creek, although high relative to caddisflies *(Hydropsyche* spp.*)* in the Yakima River Basin were similar to those found in aquatic insects in the least contaminated reaches of the Clark Fork in Montana (Axtmann and others, 1991; Cain and others, 1992).

Concentrations of copper in fish liver in the Yakima River Basin also were not particularly high. All fish-liver samples in the basin had copper concentrations that were lower than the 85th-percentile concentrations in salmonid and nonsalmonid fish liver sampled in California's Toxic Substances Monitoring Program (Rasmussen, 1992). In California's program, copper concentrations in salmonid and nonsalmonids, respectively, were 680 and 52 µg/g (calculated from original wet-weight data; Rasmussen, 1992). The concentrations of copper in rainbow trout in Wide Hollow Creek (480 µg/g) and the Yakima River at Umtanum (290 µg/g) were intermediate compared to the 55 to 941 µg/g in the liver of rainbow trout from California rivers (calculated from original wet-weight data or percent-moisture data when available) (McCleneghan and others, 1981). The highest concentration reported by McCleneghan in rainbow trout liver (941 µg/g) is from a reach of the Sacramento River reportedly affected by acid mine wastes. Moore and others (1991) reported a much lower concentration (15 µg/g) in cutthroat trout livers from an uncontaminated stream, a concentration comparable to that found in the only sample of cutthroat trout collected in the Yakima River Basin (7.2 µg/g in the South Fork of Ahtanum Creek above Conrad Ranch near Tampico).

No evidence of copper contamination was found in Asiatic clams in the Yakima River (table 39, at back

**Table 27.** Comparison of low and high copper concentrations in water, sediment, and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91

[For filtered water and suspended sediment, the low and high concentration assignments are based on a percentile distribution of the 50th-percentile values (median) for each fixed site; For streambed sediment and aquatic biota, the low and high concentration assignments are based on a percentile distribution of the mean concentrations for each fixed site. High concentrations (denoted with an "H" in the table) represent that portion of the distribution which is greater than or equal to the 75th-percentile value. Low concentrations (denoted with an "L" in the table) represent that portion of the distribution which is less than or equal to the 25th-percentile value. Concentrations greater than 25th, but less than 75th-percentile value are denoted with an "*" in the table. The term "filtered water" is an operational definition referring to the chemical analysis of that portion of a water-suspended sediment sample that passes through a nominal 0.45-micrometer filter. Only 1990 data are summarized for largescale sucker livers and caddisflies; sample species: largescale sucker (*Catostomus macrocheilus*), rainbow trout (*Oncorhynchus mykiss*), caddisfly (*Hydropsyche* spp.), stonefly (*Hesperoperla* sp.), Asiatic clam (Veneroida: Corbiculidae *Corbicula fluminea*), and curlyleaf pondweed (*Potamogeton crispus*). Data statistically summarized for fixed sites are from monthly and selected hydrologic-event samplings from the Yakima River at Cle Elum, Yakima River at Umtanum, Naches River near North Yakima, Yakima River above Ahtanum Creek at Union Gap, Sulphur Creek Wasteway near Sunnyside, Yakima River at Euclid Bridge at river mile 55 near Grandview, and Yakima River at Kiona for the period 1987–90. To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate at a site, only one element concentration per visit was statistically summarized; --, no data; NF, North Fork; SF, South Fork; Cr, Creek; RM, river mile]

| Site reference number | Site name | Filtered water | Sediment | | Aquatic biota | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Fish livers | | | Insects | | Asiatic clam | Curlyleaf pondweed |
| | | | Streambed | Suspended | Largescale sucker | Mountain whitefish | Rainbow trout | Caddisfly | Stonefly | | |
| 1 | Waptus River at mouth near Roslyn | -- | L | -- | -- | -- | * | -- | -- | -- | -- |
| 3 | Jungle Creek near mouth near Cle Elum | -- | * | -- | -- | -- | L | -- | -- | -- | -- |
| 4 | NF Teanaway River below bridge at Dickey Creek Campground | -- | -- | -- | -- | -- | -- | -- | H | -- | -- |
| 5 | Teanaway River below Forks near Cle Elum | -- | * | -- | -- | -- | * | -- | -- | -- | -- |
| 6 | Yakima River at Cle Elum | L | H | H | -- | * | -- | * | H | -- | -- |
| 7 | Naneum Creek below High Creek near Ellensburg | -- | L | -- | -- | -- | -- | H | * | -- | -- |
| 8 | Taneum Creek at Taneum Meadow near Thorp | -- | H | -- | -- | -- | L | -- | * | -- | -- |
| 10 | Little Naches River at mouth near Cliffdell | -- | H | -- | -- | -- | -- | L | -- | -- | -- |
| 12 | SF Manastash Creek near Ellensburg | -- | H | -- | -- | -- | * | -- | * | -- | -- |
| 13 | American River at Hell's Crossing near Nile | -- | H | -- | -- | -- | -- | -- | -- | -- | -- |

**Table 27.** Comparison of low and high copper concentrations in water, sediment, and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91—Continued

| Site reference number | Site name | Filtered water | Sediment | | Aquatic biota | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Fish livers | | | Insects | | Asiatic clam | Curlyleaf pondweed |
| | | | Streambed | Suspended | Largescale sucker | Mountain whitefish | Rainbow trout | Caddisfly | Stonefly | | |
| 14 | Cherry Creek above Wipple Wasteway at Thrall | -- | -- | -- | -- | * | -- | * | -- | -- | -- |
| 16 | Cherry Creek at Thrall | -- | L | -- | -- | -- | -- | * | -- | -- | H |
| 19 | Yakima River at Umtanum | H | * | L | -- | L | H | L | * | -- | L |
| 20 | Umtanum Creek near mouth at Umtanum | -- | * | -- | -- | -- | * | H | -- | -- | -- |
| 21 | Rattlesnake Creek above Little Rattlesnake Creek near Nile | -- | * | -- | -- | -- | -- | * | * | -- | -- |
| 22 | Rattlesnake Creek above NF Rattlesnake Creek near Nile | -- | H | -- | -- | -- | * | * | * | -- | -- |
| 26 | Naches River near North Yakima | L | H | * | * | * | -- | L | -- | -- | - |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | -- | H | -- | -- | -- | -- | H | -- | -- | -- |
| 29 | Wide Hollow Creek at old Sewage Treatment Plant at Union Gap | -- | H | -- | -- | -- | H | H | -- | -- | H |
| 30 | Moxee Drain at Thorp Road near Union Gap | -- | L | -- | -- | -- | -- | -- | -- | -- | -- |
| 31 | Ahtanum Creek at Union Gap | -- | L | -- | -- | -- | -- | L | -- | -- | -- |
| 32 | Yakima River above Ahtanum Creek at Union Gap | * | -- | H | -- | -- | -- | -- | -- | -- | -- |
| 33 | Yakima River at Parker | -- | * | -- | L | L | -- | * | -- | -- | L |
| 34 | South Fork Ahtanum Creek above Conrad Ranch near Tampico | -- | * | -- | -- | -- | -- | * | L | -- | -- |

**Table 27.** Comparison of low and high copper concentrations in water, sediment, and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91—Continued

| Site reference number | Site name | Filtered water | Sediment | | Aquatic biota | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Fish livers | | | Insects | | | |
| | | | Streambed | Suspended | Largescale sucker | Mountain whitefish | Rainbow trout | Caddisfly | Stonefly | Asiatic clam | Curlyleaf pondweed |
| 40 | Granger Drain at mouth near Granger | -- | L | -- | -- | -- | -- | H | -- | -- | -- |
| 42 | Yakima River below Toppenish Creek at RM 79.6 near Granger | -- | * | -- | * | H | -- | * | -- | * | -- |
| 43 | Toppenish Creek at Indian Church Road near Granger | -- | * | -- | -- | -- | -- | -- | - | -- | -- |
| 47 | Satus Creek at gage at Satus | -- | * | -- | * | -- | -- | H | -- | -- | * |
| 48 | Yakima River at RM 72 above Satus Creek near Sunnyside | -- | * | -- | -- | -- | -- | -- | -- | * | * |
| 50 | Yakima River at Kiona | * | * | L | H | H | -- | H | -- | L | H |
| 52 | Sulphur Creek Wasteway near Sunnyside | H | * | * | -- | -- | -- | * | -- | -- | -- |
| 53 | Satus Creek below Dry Creek near Toppenish | -- | * | -- | -- | -- | -- | * | -- | -- | -- |
| 54 | Spring Creek at mouth at Whitstran | -- | L | -- | -- | -- | -- | * | -- | * | -- |
| 56 | Yakima River at Euclid Bridge at RM 55 near Grandview | * | * | L | * | -- | -- | * | -- | H | * |
| 57 | Satus Creek above Wilson-Charley Canyon near Toppenish | -- | L | -- | -- | -- | * | L | L | -- | -- |

of report). In other studies of uncontaminated areas, copper concentrations in Asiatic clams ranged from 20 to 40 μg/g (Luoma and others, 1990; Leland and Scudder, 1990). For comparison, copper concentrations in clams from contaminated areas were as high as 200 μg/g (Luoma and others, 1990).

## Mercury

Concentrations of mercury in streambed sediment of the Yakima River Basin ranged from less than 0.2 to 0.6 μg/g (table 12). Approximately 10 percent of the sites had mercury concentrations that exceeded the baseline value (0.3 μg/g) for Yakima River streambed sediment reported by Fuhrer, McKenzie, and others (1994). Similarly, about 10 percent of the sites sampled had mercury concentrations that exceeded the 0.008 to 0.25 μg/g range of concentration which characterizes 95 percent of Western United States soils (R.C. Severson, U.S. Geological Survey, written commun., 1987, based on data in Shacklette and Boerngen, 1984). The median concentration of mercury at the biological sampling sites (0.1 μg/g) also exceeded those determined from analysis of fine-fraction streambed sediment in other river basins of the United States (table 34, at back of report). Concentrations of mercury as high as 0.56 μg/g, 0.40 μg/g, and 0.30 μg/g were detected in streambed sediment of Jungle Creek near mouth near Cle Elum (site 3), Taneum Creek at Taneum Meadow near Thorp (site 8), and the Naches River near North Yakima (site 26), respectively.

Mercury enrichment at Jungle Creek near mouth near Cle Elum, a tributary to the North Fork of the Teanaway River, probably was from geologic sources. Streambed sediment in lower order streams of the north, middle, and west forks of the Teanaway River are enriched similarly (Ryder and others, 1992) and indicate base-metal enrichment in sediment derived from the nonmarine sedimentary rocks geologic unit, which includes the Swauk and Roslyn Formations, and the Miocene and older volcanic rocks geologic unit, which includes the Teanaway Basalt (Fuhrer, McKenzie, and others, 1994).

Similar to Jungle Creek, mercury in sediment at Taneum Creek near Taneum Meadow probably originates from geologic sources. Upstream, concentrations of mercury in the fine-grain-sized sediment in lower order streams of the Taneum Creek drainage were as high as 0.24 μg/g (Ryder and others, 1992). Mercury in the Naches River near North Yakima probably resulted from geologic sources present in sediment formed from the Miocene and older volcanic rocks, Tertiary granitic and intermediate intrusive rocks, and marine sedimentary rocks (Fuhrer, McKenzie, and others, 1994). The concentration of mercury in the Naches River near North Yakima probably comes from lower order streams of the Naches River that are affected by geologic sources of mercury (Fuhrer, McKenzie, and others, 1994).

Based on three independent samplings, streambed sediment in Wide Hollow Creek contained an average of 0.26 μg/g mercury. Mercury in Wide Hollow Creek at the old Sewage Treatment Plant at Union Gap (site 29) is probably from an anthropogenic source. Wide Hollow Creek drains urbanized and industrialized lowlands in the vicinity of the city of Yakima. Wide Hollow Creek lacks geologic sources of mercury that are known to exist in streambed sediment derived from geologic sources because its drainage is confined to the mercury-poor Quaternary deposits and loess geologic unit (Fuhrer, McKenzie, and others, 1994).

Mercury concentrations in most fish samples were less than 0.5 μg/g (table 15). Higher concentrations of mercury were detected in mountain whitefish. For a given species, higher concentrations of mercury were measured in the Yakima River and in the Naches River near North Yakima (site 26) than in tributaries (table 28). For example, concentrations of mercury in mountain whitefish ranged from 0.7 to 1.3 μg/g at sites in the main stem and in the Naches River, compared to only 0.4 μg/g at Cherry Creek above Wipple Wasteway at Thrall (fig. 45).

Similar to mountain whitefish, concentrations of mercury in the livers of largescale suckers were higher at sites in the Yakima River (0.3 to 0.47 μg/g) and at the Naches River near North Yakima (0.14 μg/g, site 26) than, for example, from the Satus Creek at gage at Satus (0.05 μg/g, site 47). However, between species, concentrations of mercury were smaller in livers of largescale suckers than in livers of mountain whitefish (table 15 and fig. 45). Concentrations of mercury in largescale sucker also were lower statistically ($\rho \leq 0.0001$) than in mountain whitefish.

Mercury concentrations, during the 1990 sampling of rainbow trout liver from the Yakima River at Umtanum (0.27 μg/g), were similar to those in Wide Hollow Creek at the old Sewage Treatment Plant at Union Gap, in Taneum Creek at Taneum Meadow near Union Gap, and in Umtanum Creek near mouth at Umtanum (0.33 to 0.38 μg/g) (fig. 45).

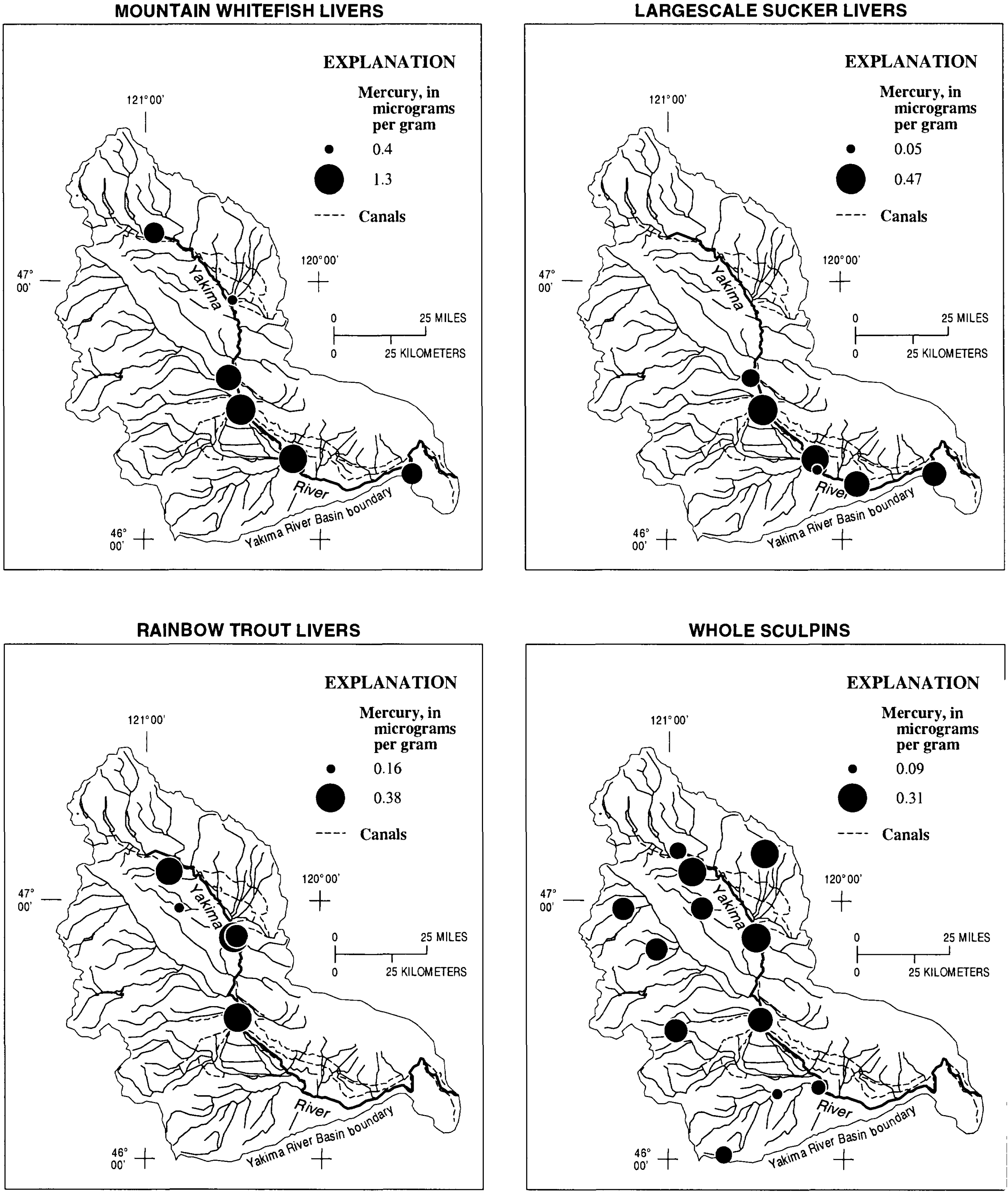
**Table 28.** Comparison of low and high mercury concentrations in streambed sediment and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91

[For filtered water and suspended sediment, the low and high concentration assignments are based on a percentile distribution of the 50th-percentile values (median) for each fixed site; For streambed sediment and aquatic biota, the low and high concentration assignments are based on a percentile distribution of the mean concentrations for each fixed site. High concentrations (denoted with an "H" in the table) represent that portion of the distribution which is greater than or equal to the 75th-percentile value. Low concentrations (denoted with an "L" in the table) represent that portion of the distribution which is less than or equal to the 25th-percentile value. Concentrations greater than 25th, but less than 75th-percentile value are denoted with an "*" in the table. Only 1990 data are summarized for largescale sucker livers; sample species: largescale sucker (*Catostomus macrocheilus*), mountain whitefish (*Prosopium williamsoni*), rainbow trout (*Oncorhynchus mykiss*), sculpin (*Cottus* spp.), Asiatic clam (Veneroida: Corbiculidae *Corbicula fluminea*), and curlyleaf pondweed (*Potamogeton crispus*). Data statistically summarized for fixed sites are from monthly and selected hydrologic-event samplings from the Yakima River at Cle Elum, Yakima River at Umtanum, Naches River near North Yakima, Sulphur Creek Wasteway near Sunnyside, Yakima River at Euclid Bridge at river mile 55 near Grandview, and Yakima River at Kiona for the period 1987–90. To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate at a site, only one element concentration per visit was statistically summarized; --, no data]

| Site reference number | Site name | Streambed sediment | Aquatic biota | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Fish | | | | Asiatic clam | Curlyleaf pondweed |
| | | | Largescale sucker | Mountain whitefish | Rainbow trout | Sculpin | | |
| 1 | Waptus River at mouth near Roslyn | * | -- | -- | * | -- | -- | -- |
| 3 | Jungle Creek near mouth near Cle Elum | H | -- | -- | H | -- | -- | -- |
| 5 | Teanaway River below Forks near Cle Elum | H | -- | -- | L | -- | -- | -- |
| 6 | Yakima River at Cle Elum | * | -- | * | -- | L | -- | -- |
| 7 | Naneum Creek below High Creek near Ellensburg | * | -- | -- | -- | H | -- | -- |
| 8 | Taneum Creek at Taneum Meadow near Thorp | H | -- | -- | H | H | -- | -- |
| 10 | Little Naches River at mouth near Cliffdell | * | -- | -- | -- | -- | -- | -- |
| 12 | South Fork Manastash Creek near Ellensburg | * | -- | -- | L | * | -- | -- |
| 13 | American River at Hell's Crossing near Nile | * | -- | -- | -- | * | -- | -- |
| 16 | Cherry Creek at Thrall | * | -- | L | -- | -- | -- | * |
| 19 | Yakima River at Umtanum | * | -- | L | * | -- | -- | L |
| 20 | Umtanum Creek near mouth at Umtanum | L | -- | -- | * | H | -- | -- |
| 21 | Rattlesnake Creek above Little Rattlesnake Creek near Nile | H | -- | -- | L | -- | -- | -- |
| 22 | Rattlesnake Creek above North Fork Rattlesnake Creek near Nile | * | -- | -- | -- | * | -- | -- |
| 26 | Naches River near North Yakima | H | * | * | -- | -- | -- | -- |
| | | | | | | | | |

**Table 28.** Comparison of low and high mercury concentrations in streambed sediment and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91—Continued

| Site reference number | Site name | Streambed sediment | Aquatic biota | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Fish | | | | | |
| | | | Largescale sucker | Mountain whitefish | Rainbow trout | Sculpin | Asiatic clam | Curlyleaf pondweed |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | * | -- | -- | -- | -- | -- | -- |
| 29 | Wide Hollow Creek at old Sewage Treatment Plant at Union Gap | H | -- | -- | H | -- | -- | H |
| 30 | Moxee Drain at Thorp Road near Union Gap | L | -- | -- | -- | -- | -- | -- |
| 31 | Ahtanum Creek at Union Gap | * | -- | -- | -- | * | -- | -- |
| 33 | Yakima River at Parker | H | H | H | -- | -- | -- | * |
| 34 | South Fork Ahtanum Creek above Conrad Ranch near Tampico | * | -- | -- | -- | * | -- | -- |
| 40 | Granger Drain at mouth near Granger | L | -- | -- | -- | -- | -- | -- |
| 42 | Yakima River below Toppenish Creek at river mile 79.6 near Granger | * | * | H | -- | -- | H | -- |
| 43 | Toppenish Creek at Indian Church Road near Granger | * | -- | -- | -- | -- | -- | -- |
| 47 | Satus Creek at gage at Satus | * | L | -- | -- | L | -- | L |
| 48 | Yakima River at river mile 72 above Satus Creek near Sunnyside | * | -- | -- | -- | -- | * | H |
| 50 | Yakima River at Kiona | * | * | * | -- | -- | L | * |
| 52 | Sulphur Creek Wasteway near Sunnyside | L | -- | -- | -- | -- | -- | -- |
| 53 | Satus Creek below Dry Creek near Toppenish | L | -- | -- | -- | L | -- | -- |
| 54 | Spring Creek at mouth at Whitstran | L | -- | -- | -- | -- | H | -- |
| 56 | Yakima River at Euclid Bridge at river mile 55 near Grandview | * | * | -- | -- | -- | H | L |
| 57 | Satus Creek above Wilson-Charley Canyon near Toppenish | * | -- | -- | * | L | -- | -- |

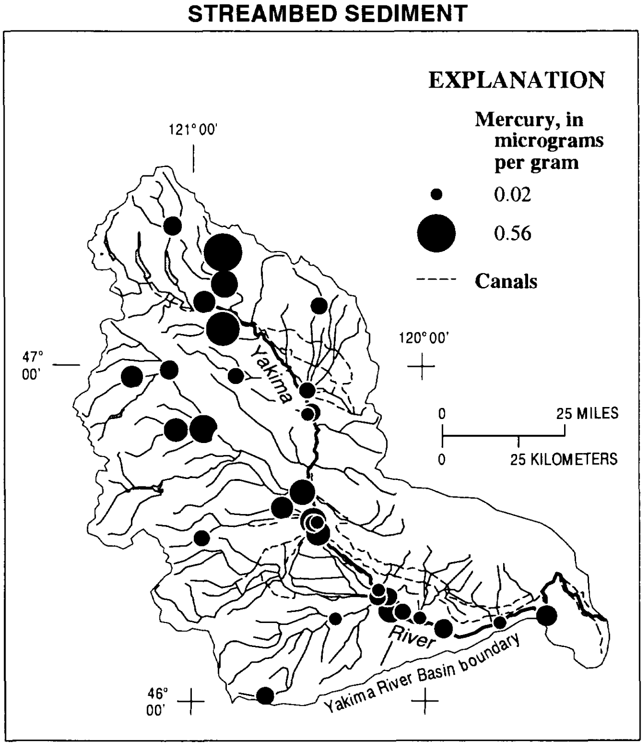

MOUNTAIN WHITEFISH LIVERS

LARGESCALE SUCKER LIVERS

RAINBOW TROUT LIVERS

WHOLE SCULPINS

**Figure 45.** Distribution of mercury concentrations in mountain whitefish livers, largescale sucker livers, rainbow trout livers, whole sculpins, and streambed sediment, Yakima River Basin, Washington, 1987–90 (element concentrations are reported in units of micrograms per gram [μg/g], dry weight; symbol sizes are proportional to element concentrations; the largest and smallest symbols, respectively, represent the high and low concentration end members; only 1990 data are graphically represented for mountain whitefish, largescale sucker, rainbow trout, and sculpins; sample species: mountain whitefish [*Prosopium williamsoni*], largescale sucker [*Catostomus macrocheilus*], rainbow trout [*Oncorhynchus mykiss*], and sculpin [*Cottus* spp.]).



STREAMBED SEDIMENT

**Figure 45.** Distribution of mercury concentrations in mountain whitefish livers, largescale sucker livers, rainbow trout livers, whole sculpins, and streambed sediment, Yakima River Basin, Washington, 1987–90—Continued.

Lower concentrations of mercury were detected in trout from the South Fork of Manastash Creek (0.16 μg/g). Mercury concentrations in whole sculpin from lower-order tributaries ranged from 0.09 to 0.31 μg/g. The highest concentrations of mercury existed in Naneum Creek below High Creek near Ellensburg (site 7), in Umtanum Creek near mouth at Umtanum (site 20), and in Taneum Creek at Tanum Meadow near Thorp (site 8); the latter sites also coincided with higher mercury concentrations in rainbow trout.

The distribution of mercury concentrations in samples collected in 1989 generally was consistent with that in 1990. The highest concentrations of mercury are in the liver of mountain whitefish in the Yakima River at Cle Elum (0.91 μg/g). Lower concentrations of mercury existed downstream in the Yakima River at Umtanum (0.6 μg/g) and in the Yakima River at Kiona (0.58 μg/g). Mercury concentrations in largescale sucker and rainbow trout were comparatively low (less than 0.4 μg/g). The highest concentrations of mercury in rainbow trout were detected in the Kittitas Valley in Jungle Creek near mouth near Cle Elum (0.32 μg/g) and in the Waptus River at mouth near Roslyn (0.27 μg/g)—these sites were not resampled in 1990. The mercury concentrations in rainbow trout liver at the Jungle Creek site, however, corresponded to the concentration maximum (0.56 μg/g) for mercury in streambed sediment at the biological sampling sites. Caddisflies analyzed for mercury in 1989 had concentrations of less than 0.2 μg/g. Additionally, concentrations of mercury among all sites only varied by a factor of 3 (0.05 to 0.16 μg/g) with the highest concentrations at Rattlesnake Creek (0.16 μg/g) and Toppenish Creek (0.10 μg/g). A slight downstream concentration gradient was apparent in samples from the main stem. Concentrations of mercury were highest at the Cle Elum and Umtanum sites (0.090 and 0.080 μg/g, respectively) and lower in the Yakima River at Parker, the Yakima River at Euclid Bridge at RM 55 near Grandview, and at Kiona (0.066 to 0.070 μg/g).

The lower concentrations of mercury, in mountain whitefish from Cherry Creek (0.4 μg/g) and in largescale suckers from Satus Creek (0.05 μg/g), may result when fish are physically smaller (fig. 46). Intersite variations in size, however, do not account for all the concentration variability. Variations in mercury concentrations among larger fish from other sites were relatively high; additionally, no significant correlation among all sites existed between fish length and mercury concentration. Thus, site differences were not simply a function of fish size (age). For mountain whitefish, the variations in mercury content among sites were perhaps best explained by considering the quantity of mercury and total-organic carbon in streambed sediment. Mercury in streambed sediment has an affinity for sorption to organic material (Forstner and Wittmann, 1979, p. 222). The quantity of mercury relative to organic material has been shown to affect the bioavailability of mercury to Asiatic clams (Langston, 1982). Mercury concentrations in streambed sediment in the Yakima River Basin were normalized to the concentrations of total-organic carbon (ratio of mercury in micrograms per gram to total-organic carbon in micrograms per gram) and compared to mercury concentrations in fish liver. The normalized value for the mouth of the Naches River near North Yakima is 0.75 and was exceeded only at the Parker site (0.84), where a mercury concentration of 1.3 μg/g (the maximum concentration for biological sites) was measured in the liver of mountain whitefish. The ratio of mercury in mountain whitefish liver to total-organic carbon is significantly correlated ($\rho$ <0.05) to mercury accumulation in the liver of mountain whitefish in the Yakima River Basin (fig. 47). The same relation, however, does not exist for mercury in rainbow trout liver (fig. 47), possibly because of differences in lipid content between species and from differences in age between species. Mountain whitefish from main-stem sites generally were larger physically (and presumably older) than the smaller (presumably younger) rainbow trout from tributary sites (Fuhrer, Fluter, and others, 1994).

Mercury concentrations in whole sculpin from tributaries to the Yakima River were below 0.31 μg/g, which also is below the mean mercury concentration for whole fish collected for the National Contaminant Biomonitoring Program (0.4 μg/g, calculated from original wet-weight data) in 1984 (table 38, at back of report; Schmitt and Brumbaugh, 1990). Mercury concentrations determined as part of the National Contaminant Biomonitoring Program are generally from near the mouths of large rivers and are more likely to be affected by human activities than are headwater tributaries in many of the streams in the Yakima River Basin. In general, concentrations of mercury greater than 0.5 μg/g appear to be indicative of contamination (Saiki and May, 1988).

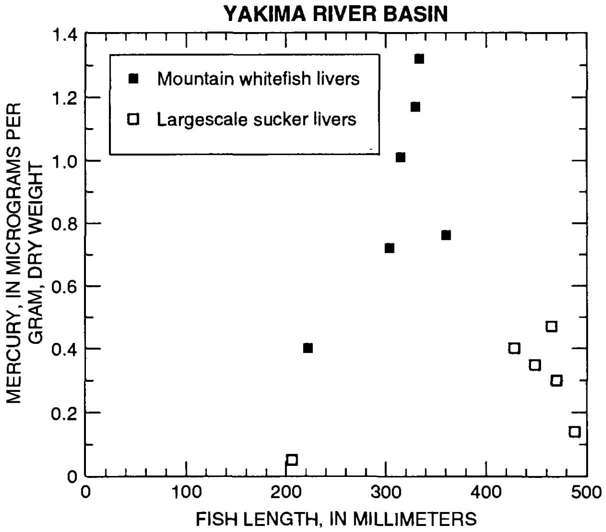


**Figure 46.** Relation between fish length and mercury concentrations of mountain whitefish livers and largescale sucker livers, Yakima River Basin, Washington, 1990 (sample species: mountain whitefish [*Prosopium williamsoni*] and largescale sucker [*Catostomus macrocheilus*]).

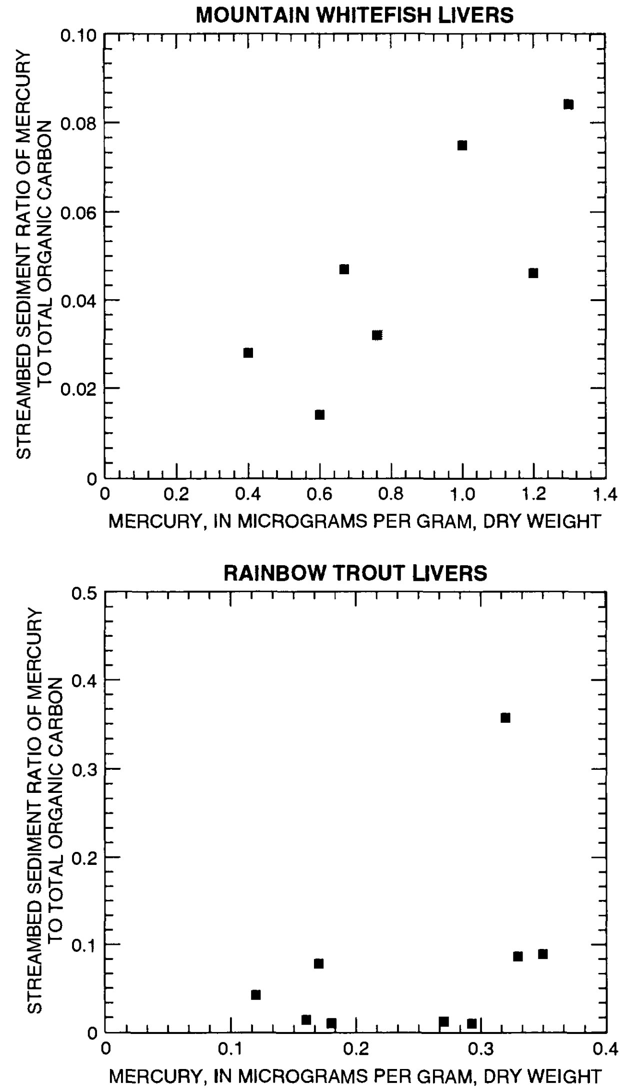


**Figure 47.** Mercury in mountain whitefish livers and rainbow trout livers compared to mercury in streambed sediment normalized to total organic carbon, Yakima River Basin, Washington, 1989–90 (sample species: mountain whitefish [*Prosopium williamsoni*] and rainbow trout [*Oncorhynchus mykiss*]).

Mercury concentrations in fish liver have been reported in several studies. Concentrations in uncontaminated tissue appear to be less than 0.5 μg/g. For example, the livers of four species of fish, including whitefish (*Coregonus lavaretus*) from an uncontaminated lake in Finland, had mercury concentrations that ranged from 0.03 to 0.48 μg/g (Lodenius and others, 1982). Mean mercury concentrations in five species from two rivers ranged from 0.16 to 0.64 μg/g (calculated from original wet-weight data in Barak and Mason, 1990). Mean mercury concentrations in bream

(*Abramis brama*) and in pike perch (*Stizostedion lucioperca*) from Lake Balaton in western Hungary (determined to be mildly contaminated) were 0.3 µg/g and 0.35 µg/g, respectively (Salanki and others, 1982). In contrast, Koli and others (1977) reported that mercury concentrations in the livers of contaminated pike and mudfish were 0.94 µg/g and 0.83 µg/g, respectively, whereas concentrations of mercury in muscle tissue were higher than 0.5 µg/g. Compared with these studies, mercury concentrations (0.7 to 1.3 µg/g) in livers of mountain whitefish in the Yakima River Basin were moderately enriched. Concentrations of mercury in mountain whitefish collected from the mouth of the Naches River also were enriched (1.0 µg/g); however, mountain whitefish may have moved freely between the Yakima and Naches Rivers. Concentrations of mercury in other species of fish collected with mountain whitefish (for example, largescale sucker and carp) were relatively low (typically less than 0.5 µg/g). However, distribution patterns of mercury in largescale sucker were consistent with those of mountain whitefish; both species indicated enrichment in the Yakima River. Fish collected in the Yakima River at Bridge Avenue at Granger for the National Contaminant Biomonitoring Program, for the period 1978–79, also showed evidence of mercury enrichment (Lowe and others, 1985).

In contrast to fish, Asiatic clam (*Corbicula fluminea)* collected in the Yakima River did not show mercury enrichment. Concentrations of mercury varied between 0.10 and 0.17 µg/g among stations in the Yakima River and were similar to concentrations observed in uncontaminated systems (Johns and others, 1988; Leland and Scudder, 1990) (table 39, at back of report).

Mercury concentrations in aquatic plants in the Yakima River Basin were relatively uniform. In curlyleaf pondweed for example, concentrations of mercury ranged from 0.03 to 0.06 µg/g among sites (Fuhrer, Fluter, and others, 1994). The uptake of mercury by aquatic plants has been described as extremely rapid and efficient (Moore, 1991). In another study, moss *(Fontinalis squamosa)* in a rural river that received acid mine drainage contained mercury in concentrations ranging from 0.12 to 0.48 µg/g (Moore, 1991, p. 200). The absence of appreciable mercury concentrations in aquatic plants sampled at sites in the Yakima River Basin indicates that concentrations of mercury in dissolved and solid forms are relatively low.

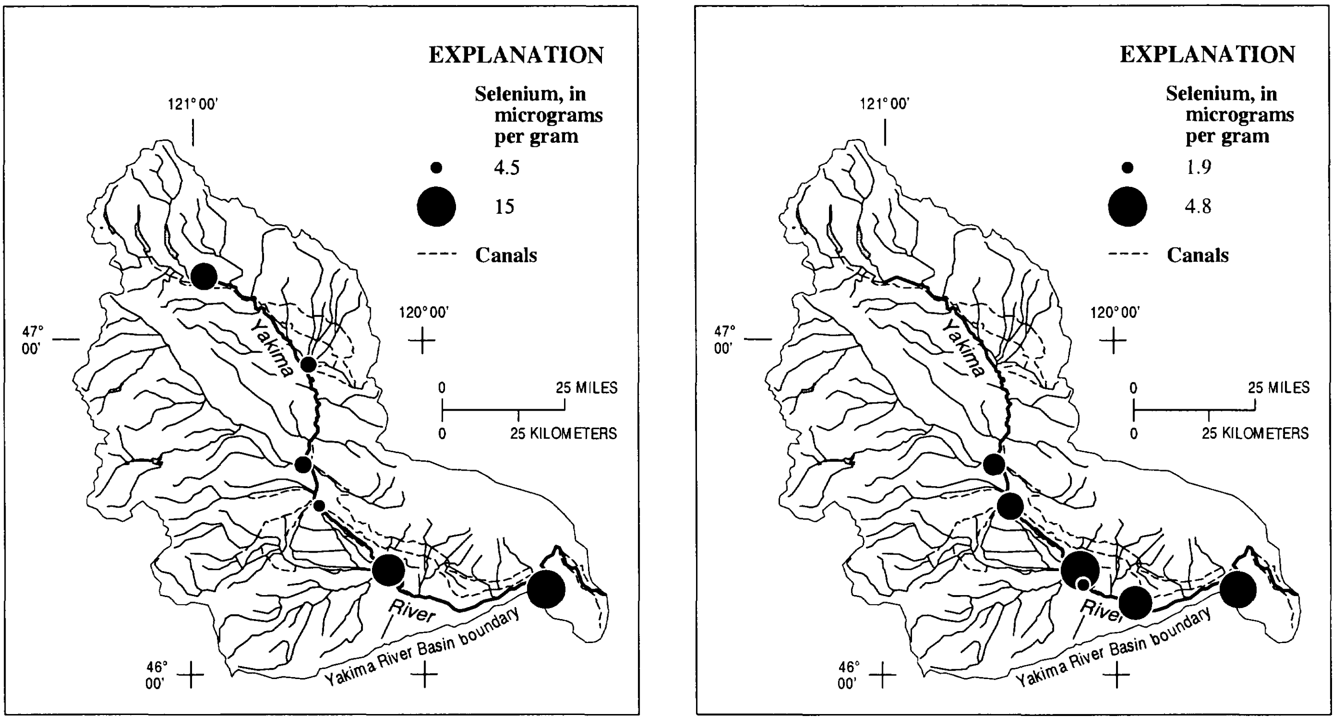
## Selenium

Concentrations of selenium in Yakima River streambed sediment ranged from less than 0.4 to 1.0 µg/g (table 12). Approximately 25 percent of the sites had selenium concentrations that exceeded the baseline value (0.7 µg/g) for Yakima River streambed sediment as reported by Fuhrer, McKenzie, and others (1994). None of the sites had selenium concentrations that exceeded the 0.04 to 1.4 µg/g range of concentration, which encompasses 95 percent of Western United States soils (R.C. Severson, U.S. Geological Survey, written commun., 1987, based on data in Shacklette and Boerngen, 1984). Concentrations of selenium as high as 1.0, 0.9, 0.9, 0.8, and 0.7 µg/g were measured in streambed sediment of Rattlesnake Creek above North Fork Rattlesnake Creek near Nile (site 22), in Naneum Creek below High Creek near Ellensburg (site 7), in Taneum Creek at Taneum Meadow near Thorp (site 8), in Waptus River at mouth near Rosyln (site 1), and in American River at Hell's Crossing near Nile (site 13), respectively.

Selenium in Rattlesnake Creek above North Fork Rattlesnake Creek near Nile (site 22) is probably associated with streambed sediment formed from the marine sedimentary rocks geologic unit. Streambed sediment was sampled by Fuhrer, McKenzie, and others (1994) from three lower order tributaries of Rattlesnake Creek, upstream from site 22. Although selenium was not measured, large concentrations of arsenic and copper measured at these sites were indicative of selenium enrichment—selenium is known to have strong geochemical associations with arsenic and copper (Levinson, 1980; Rankama and Sahama, 1950). The presence of selenium at the remaining sites probably is due to geological sources; drainages are forested and selenium inputs from human activities are expected to be negligible.

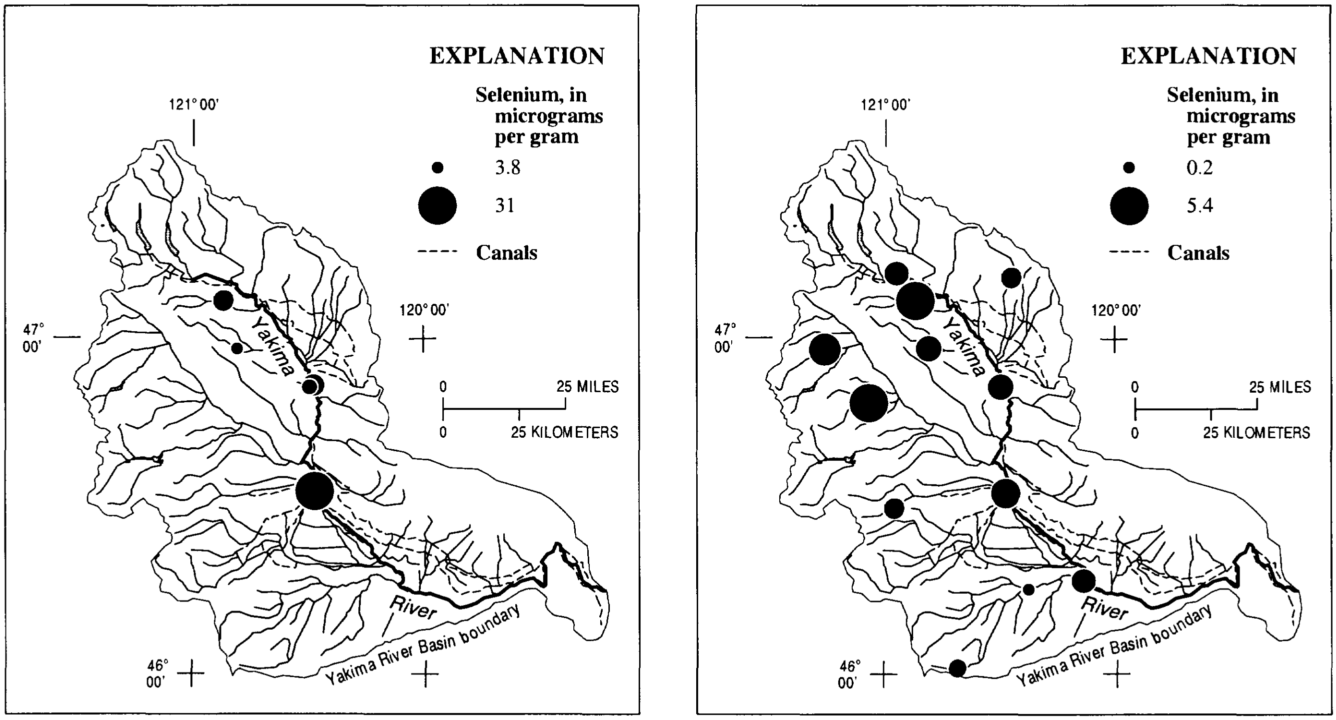
In the Yakima River Basin, several higher order tributaries including Rattlesnake Creek, the American River, Ahtanum Creek, and Wide Hollow Creek had high selenium concentrations in fish (fig. 48). Selenium concentrations also were high at some sites in the lower Yakima River Basin, particularly in the main stem.

The selenium concentrations in the whole sculpin, collected from 12 sites in the Yakima River Basin in 1990, ranged more than an order of magnitude (table 15). The lowest concentrations of selenium were from two sites in the upper portion of Satus Creek (above Wilson-Charley Canyon near Toppenish



MOUNTAIN WHITEFISH LIVERS

LARGESCALE SUCKER LIVERS



RAINBOW TROUT LIVERS

WHOLE SCULPINS

**Figure 48.** Distribution of selenium concentrations in mountain whitefish livers, largescale sucker livers, rainbow trout livers, whole sculpins, and streambed sediment, Yakima River Basin, Washington, 1987–90 (element concentrations are reported in units of micrograms per gram [µg/g], dry weight; symbol sizes are proportional to element concentrations; the largest and smallest symbols, respectively, represent the high and low concentration end members; only 1990 data are summarized for mountain whitefish, largescale sucker, rainbow trout, and sculpins; sample species: mountain whitefish [*Prosopium williamsoni*], largescale sucker [*Catostomus macrocheilus*], rainbow trout [*Oncorhynchus mykiss*], and sculpin [*Cottus* spp.]).

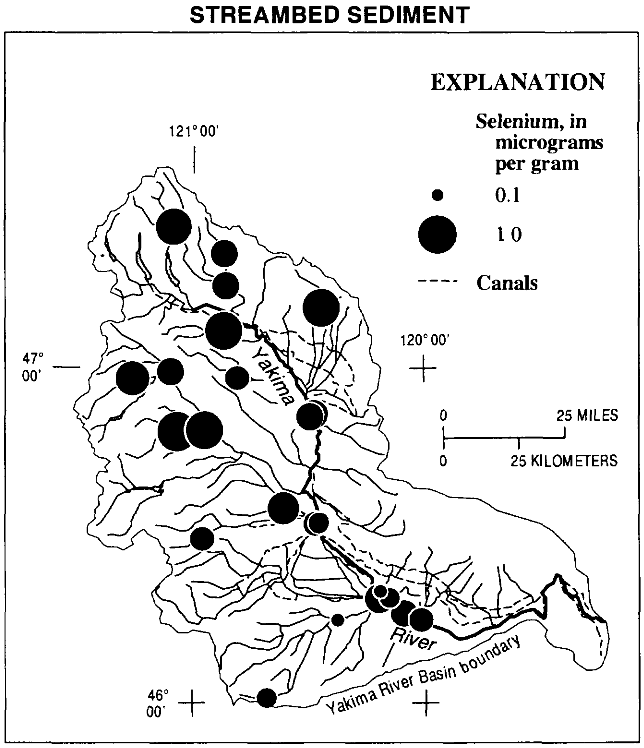


**Figure 48.** Distribution of selenium concentrations in mountain whitefish livers, largescale sucker livers, rainbow trout livers, whole sculpins, and streambed sediment, Yakima River Basin, Washington, 1987–90—Continued.

[0.5 µg/g] and below Dry Creek near Toppenish [0.2 µg/g]). The highest concentrations of selenium were from Rattlesnake Creek above North Fork Rattlesnake Creek near Nile (5.5 µg/g, site 2) and in Taneum Creek. near Taneum Meadow (5.4 µg/g, site 8). The concentrations of selenium in whole sculpin in Rattlesnake and Taneum Creeks were approximately 3 times higher than the median for the basin. Selenium in sculpin from the Rattlesnake and Taneum Creek sites also coincided with high concentrations of selenium in streambed sediment. Concentrations of selenium in streambed sediment from these two sites were approximately 2.5 times higher than the median for the basin. Concentrations of selenium in sculpin in the American River were intermediate (3.2 µg/g); however, concentrations of selenium in sculpin at most of the other sites ranged from 1 to 3 µg/g.

Other whole sculpin data indicated that selenium concentrations are higher at sites located near the mouths of creeks that carry irrigation return flow than at sites located above agricultural activity. For example, 2.6 µg/g of selenium was measured in whole sculpin from Ahtanum Creek at Union Gap site. This site is located near the mouth of Ahtanum Creek and receives irrigation return flow from the Ahtanum Subbasin. Upstream from agricultural activity on Ahtanum Creek, concentrations of selenium in sculpin were only 1.0 µg/g (fig. 49). Similar concentration gradients also existed in the Satus Creek drainage; Satus Creek at gage is located near the mouth and receives irrigation return flow (fig. 49).

Selenium concentrations in the livers of mountain whitefish ranged from 4.2 to 15 µg/g (table 15 and fig. 48). In 1990, concentrations of selenium in mountain whitefish liver from Cherry Creek at Thrall and other Kittitas and mid-Yakima Valley sites ranged from 4.5 to 8.2 µg/g; higher concentrations, however, were detected in the lower Yakima Valley. A similar pattern of selenium concentrations was observed in livers of largescale suckers, although, concentrations of selenium were lower than in livers of mountain whitefish (table 15). Concentrations of selenium in largescale suckers from the Naches River near North Yakima and Satus Creek at Gage at Satus were approximately 2 µg/g. Concentrations of selenium in the Yakima River ranged from 2.9 to 4.8 µg/g. The highest selenium concentration measured in liver tissue, 31 µg/g, was from one sample of rainbow trout liver collected from Wide Hollow Creek at the old Sewage Treatment Plant at Union Gap. The concentration of selenium in this sample was about 4 to 8 times higher than the concentration in rainbow trout from other sites (fig. 48).

At the American River at Hell's Crossing near Nile (site 13), selenium concentrations in sculpin seem to decrease with fish length (fig. 50). At other sites, the relation between fish size and selenium concentration was not evident because the average length of fish in composite samples was relatively uniform (for example, see Rattlesnake Creek in fig. 50). Size-related effects are of secondary importance when comparing selenium concentrations in fish from Rattlesnake Creek to other sites. Selenium concentrations were high in Rattlesnake Creek regardless of whether site comparisons were made with mean-site concentrations or concentrations in fish of similar size. In addition, among all sites, significant correlation did not exist between fish length and selenium concentration. In other studies, Saiki (1987) reported no correlation between selenium concentrations in whole fish and fish size. Similarly, selenium in northern pike muscle also was unrelated to size (Speyer, 1980)In fish collected from Lake Erie, however, a significant positive correlation was observed between size and selenium concentration in yellow perch at one station, but not in this species from other sites or in other species of fish (Adams and Johnson, 1977).

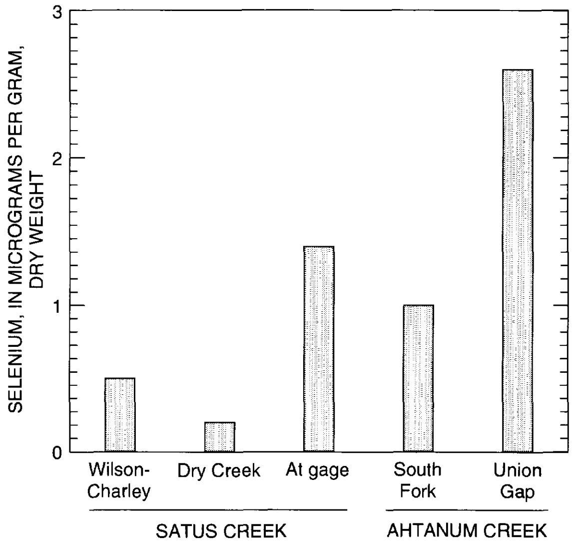


**Figure 49.** Selenium concentrations in whole sculpins at sites in Satus Creek and Ahtanum Creek, Yakima River Basin, Washington, 1990 (samples species: sculpin [*Cottus* spp.]; "Wilson-Charley" represents Satus Creek above Wilson-Charley Canyon near Toppenish; "Dry Creek" represents Satus Creek below Dry Creek near Toppenish; "at gage" represents Satus Creek at gage at Satus; "South Fork" represents South Fork Ahtanum Creek near Tampico; "Union Gap" represents Ahtanum Creek at Union Gap).

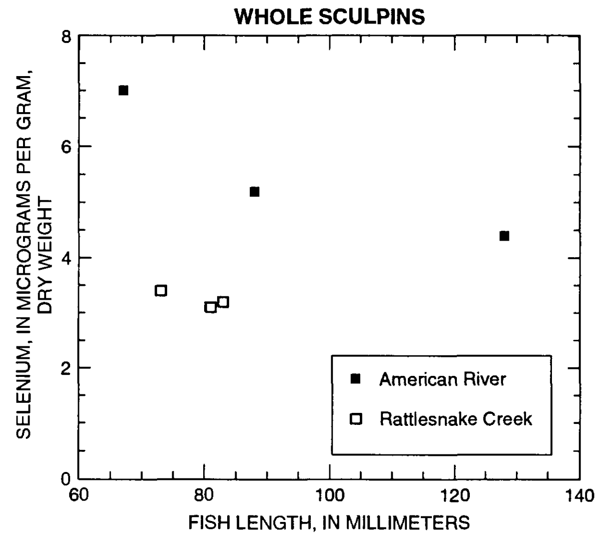


**Figure 50**. Relation between fish length and selenium concentrations of whole sculpins from the American River at Hell's Crossing near Nile and Rattlesnake Creek above North Fork Rattlesnake Creek near Nile, Yakima River Basin, Washington, 1990 (sample species: sculpin [*Cottus* spp.]; "American River" represents American River at Hell's Crossing near Nile and "Rattlesnake Creek" represents Rattlesnake Creek above North Fork Rattlesnake Creek near Nile).

Comparison of selenium concentrations in whole sculpin from the Yakima River Basin to existing data for whole fish indicates that the American River, Rattlesnake Creek, and Taneum Creek sites in the Yakima River Basin are moderately enriched in selenium. At these sites, selenium concentrations in whole sculpin exceeded 3 µg/g; for comparison, the mean and 85th-percentile selenium concentrations in whole fish collected for the National Contaminant Biomonitoring Program were 1.7 and 2.9 µg/g, respectively, as calculated from original wet-weight data (Schmitt and Brumbaugh, 1990) (table 38, at back of report). Selenium concentrations in juvenile striped bass, collected from the San Francisco Bay Estuary which receives low to moderate inputs of selenium, were 1 to 2 µg/g (Saiki and Palawski, 1990). In contrast, selenium concentrations in striped bass, from sites in the San Joaquin River system which receive inputs of selenium in irrigation return flow, ranged from 2.7 to 6.9 µg/g (Saiki and Palawski, 1990). Also in the San Joaquin River in California, mean selenium concentrations in bluegill and common carp were lowest (0.647 to 1.41 and 0.988 to 1.50 µg/g, respectively) in tributaries and main-stem sites that do not receive irrigation return flow, and, conversely, were highest (1.36 to 2.9 and 1.67 to 4.30 µg/g, respectively) in tributaries and main-stem sites affected by irrigation return flow (Saiki and May, 1988). In uncontaminated lakes in the Atchafalaya River Basin in Louisiana, selenium concentrations in whole bodies of seven fish species ranged from about 0.4 to 2.0 ug/g (calculated from original wet-weight data) (Winger and Andreasen, 1985).

Comparison of selenium concentrations in livers of whitefish and largescale sucker from the lower Yakima Valley of the Yakima River Basin to existing data (Wiener and others, 1984; Rassmussen, 1992; and Sorensen and Bauer, 1984) indicates that selenium concentrations in the basin are representative of background concentrations that generally ranged from 2 to 3 µg/g. At sites in the lower Yakima Valley, selenium concentrations in whitefish and largescale sucker livers ranged from 1.9 to 15 µg/g; for comparison, the 85th-percentile selenium concentration in whole fish collected in California's Toxic Substances Monitoring Program was 13.8 µg/g (calculated from original wet-weight data) (Rassmussen, 1992). Selenium concentrations in common carp from sites in the upper Mississippi River ranged from 2.2 to 5.3 µg/g (Wiener and others, 1984). The mean selenium concentration in combined liver and pancreas of sunfish from a reference lake was 7.2 µg/g, and in contaminated lakes, selenium concentrations in combined liver and pancreas of sunfish ranged from 33.6 to 89.2 µg/g. The concentration of selenium measured in rainbow trout liver in 1990 from Wide Hollow Creek at the old Sewage Treatment Plant at Union Gap (31 µg/g) clearly exceeded concentrations measured in fish liver from uncontaminated rivers. However, the selenium concentration (0.40 µg/g) in curlyleaf pondweed from Wide Hollow Creek was not high relative to other pondweed samples in the Yakima River Basin—selenium was not measured in streambed sediment and aquatic insects (table 29). Before concluding that the Wide Hollow drainage (which receives irrigation return flow) is affected by selenium, the high selenium concentration in rainbow trout liver should be confirmed; additionally, selenium should be measured in streambed sediment and filtered water to collectively determine the presence and (or) degree of selenium enrichment. Of the largescale suckers collected in 1989, Sulphur Creek Wasteway (which receives large quantities of irrigation return flow) had the maximum concentration of selenium in liver (4.8 µg/g) (fig. 48). Although few filtered-water samples collected in the basin were analyzed for selenium, two of the three samples collected from the Sulphur Creek site had detectable selenium concentrations (1 and 2 µg/L). Again, as in the Wide Hollow Creek drainage, some evidence of selenium was present in aquatic biota; however, additional data are needed to determine to what degree selenium is present in Sulphur Creek Wasteway. Although not unusually high compared to other studies, the concentration of selenium (11 µg/g) in the liver of rainbow trout collected from Rattlesnake Creek in 1989 was the maximum concentration measured in fish liver for 1989. This concentration of selenium also coincided with the relatively high selenium concentration in whole sculpin and streambed sediment (described earlier) in Rattlesnake Creek—selenium was not measured in aquatic plants, insects, and suspended sediment from Rattlesnake Creek. Collectively, streambed sediment and aquatic biota data corroborated the moderate selenium enrichment in Rattlesnake Creek that probably originates from natural geologic sources present in the marine sedimentary rocks geologic unit (Fuhrer, McKenzie, and others, 1994). High concentrations of selenium have been measured in fish chronically exposed to high concentrations of selenium from natural sources (Kaiser and others, 1979).

Selenium concentrations ranged from 2 to 3 µg/g in Asiatic clams in the Yakima River Basin and were indicative of background concentrations. For example, selenium concentrations ranged from 1 to 3 µg/g in uncontaminated reaches of the San Joaquin and Sacramento Rivers in California (Johns and others, 1988; Leland and Scudder, 1990) (table 39, at back of report). In reaches of the San Joaquin River that are affected by irrigation return flow, selenium concentrations ranged from 2.5 to 5.13 µg/g (Leland and Scudder, 1990).

## Silver

Median concentrations of silver in suspended sediment ranged from 0.2 to 0.5 µg/g at the fixed sites. The lowest and highest median values of silver were from the Yakima River at Umtanum and the Yakima River above Ahtanum Creek at Union Gap (table 13 and fig. 51; table 35, at back of report). With the exception of the Union Gap site and Sulphur Creek Wasteway near Sunnyside, interquartile ranges for silver concentrations at most sites were small and indicated little or no temporal variation. The variation in the concentration of suspended silver at these latter two sites may result from their close proximity to point sources.

The Union Gap site is located less than 4 miles downstream from the discharge point for the city of Yakima's sewage-treatment plant. In 1989, the city of Yakima's sewage-treatment plant had a monthly average discharge of 12.8 Mgal/d (million gallons per day) or about 20 $ft^3/s$ (Chris Waurvich, city of Yakima Wastewater Treatment Plant, written commun., 1990). The Sulphur Creek site is located immediately downstream from the discharge point for the city of Sunnyside's sewage treatment plant. Over the period 1987–89, the Sunnyside plant had a monthly average discharge of 1.3 Mgal/d or about 2 $ft^3/s$ (Washington State Department of Ecology, National Pollutant Discharge Elimination System Waste Discharge Permit, 1990). Metallic wastes (dissolved and suspended), passing through municipal waste-treatment plants, may be a source of trace elements (including silver) to streambed sediment (Forstner and Wittmann, 1979).

The concentrations of suspended silver at both the Union Gap site and the Sulphur Creek site were high during the nonirrigation season and low during the irrigation season (fig. 52). Geologic sources are unlikely to affect the distribution of suspended-silver

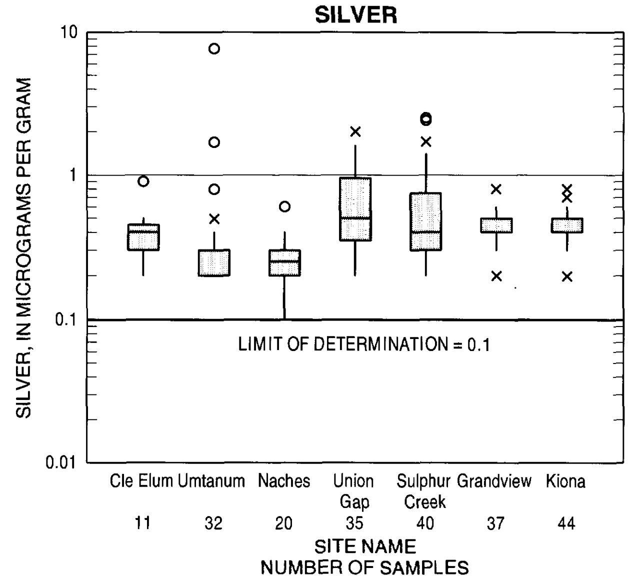
**Table 29.** Comparison of low and high selenium concentrations in streambed sediment and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91

[For filtered water and suspended sediment, the low and high concentration assignments are based on a percentile distribution of the 50th-percentile values (median) for each fixed site; For streambed sediment and aquatic biota, the low and high concentration assignments are based on a percentile distribution of the mean concentrations for each fixed site. High concentrations (denoted with an "H" in the table) represent that portion of the distribution which is greater than or equal to the 75th-percentile value. Low concentrations (denoted with an "L" in the table) represent that portion of the distribution which is less than or equal to the 25th-percentile value. Concentrations greater than 25th, but less than 75th-percentile value are denoted with an "*" in the table. The term "filtered water" is an operational definition referring to the chemical analysis of that portion of a water-suspended sediment sample that passes through a nominal 0.45-micrometer filter. Only 1990 data are summarized for largescale sucker livers and caddisflies; sample species: largescale sucker (*Catostomus macrocheilus*), mountain whitefish (*Prosopium williamsoni*), rainbow trout (*Oncorhynchus mykiss*), sculpin (*Cottus* spp.), Asiatic clam (Veneroida: Corbiculidae *Corbicula fluminea*), and curlyleaf pondweed (*Potamogeton crispus*). Data statistically summarized for fixed sites are from monthly and selected hydrologic-event samplings from the Yakima River at Cle Elum, Yakima River at Umtanum, Naches River near North Yakima, Sulphur Creek Wasteway near Sunnyside, Yakima River at Euclid Bridge at river mile 55 near Grandview, and Yakima River at Kiona for the period 1987–90. To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate at a site, only one element concentration per visit was statistically summarized; --, no data]

| Site reference number | Site name | Streambed sediment | Aquatic biota | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Fish | | | | | |
| | | | Largescale sucker | Mountain whitefish | Rainbow trout | Sculpin | Asiatic clam | Curlyleaf pondweed |
| 1 | Waptus River at mouth near Roslyn | H | -- | -- | H | -- | -- | -- |
| 3 | Jungle Creek near mouth near Cle Elum | L | -- | -- | -- | -- | -- | -- |
| 5 | Teanaway River below Forks near Cle Elum | * | -- | -- | * | - | -- | -- |
| 6 | Yakima River at Cle Elum | -- | -- | * | -- | * | -- | -- |
| 7 | Naneum Creek below High Creek near Ellensburg | H | -- | -- | -- | L | -- | -- |
| 8 | Taneum Creek at Taneum Meadow near Thorp | H | -- | -- | * | H | -- | -- |
| 10 | Little Naches River at mouth near Cliffdell | * | -- | -- | | -- | -- | -- |
| 12 | South Fork Manastash Creek near Ellensburg | L | -- | -- | L | * | -- | -- |
| 13 | American River at Hell's Crossing near Nile | H | -- | -- | -- | H | - | -- |
| 14 | Cherry Creek above Wipple Wasteway at Thrall | -- | -- | * | -- | -- | -- | -- |
| 16 | Cherry Creek at Thrall | -- | -- | | -- | -- | -- | L |
| 19 | Yakima River at Umtanum | * | -- | L | * | -- | -- | L |
| 20 | Umtanum Creek near mouth at Umtanum | L | -- | -- | * | * | -- | -- |
| 21 | Rattlesnake Creek above Little Rattlesnake Creek near Nile | H | -- | -- | -- | -- | -- | -- |

**Table 29.** Comparison of low and high selenium concentrations in streambed sediment and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91—Continued

| Site reference number | Site name | Streambed sediment | Aquatic biota | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Fish | | | | Asiatic clam | Curlyleaf pondweed |
| | | | Largescale sucker | Mountain whitefish | Rainbow trout | Sculpin | | |
| 22 | Rattlesnake Creek above North Fork Rattlesnake Creek near Nile | H | -- | -- | * | H | -- | -- |
| 26 | Naches River near North Yakima | -- | * | * | -- | -- | -- | -- |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | * | -- | -- | -- | -- | -- | -- |
| 29 | Wide Hollow Creek at old Sewage Treatment Plant at Union Gap | -- | -- | -- | H | -- | -- | H |
| 30 | Moxee Drain at Thorp Road near Union Gap | L | -- | -- | -- | - | -- | -- |
| 31 | Ahtanum Creek at Union Gap | L | -- | -- | -- | * | -- | -- |
| 33 | Yakima River at Parker | -- | * | L | -- | -- | -- | * |
| 34 | South Fork Ahtanum Creek above Conrad Ranch near Tampico | L | -- | -- | -- | * | -- | -- |
| 40 | Granger Drain at mouth near Granger | L | -- | -- | -- | -- | -- | -- |
| 42 | Yakima River below Toppenish Creek at river mile 79.6 near Granger | L | H | H | -- | -- | H | -- |
| 43 | Toppenish Creek at Indian Church Road near Granger | * | -- | -- | -- | -- | -- | -- |
| 47 | Satus Creek at gage at Satus | -- | L | -- | -- | * | -- | * |
| 48 | Yakima River at river mile 72 above Satus Creek near Sunnyside | * | -- | -- | -- | -- | * | L |
| 50 | Yakima River at Kiona | -- | * | H | -- | -- | L | H |
| 52 | Sulphur Creek Wasteway near Sunnyside | L | -- | -- | -- | -- | -- | -- |
| 53 | Satus Creek below Dry Creek near Toppenish | L | -- | -- | -- | L | -- | -- |
| 54 | Spring Creek at mouth at Whitstran | -- | -- | -- | -- | -- | * | -- |
| 56 | Yakima River at Euclid Bridge at river mile 55 near Grandview | -- | * | -- | -- | -- | L | * |
| 57 | Satus Creek above Wilson-Charley Canyon near Toppenish | L | -- | -- | L | L | -- | -- |



EXPLANATION

**Interquartile range equals the value of the 75th percentile minus the value of the 25th percentile.**

- ○ More than 3 times the interquartile range from the 75th-percentile value
- × 1.5 to 3 times the interquartile range from the 75th-percentile value
- Less than 1.5 times the interquartile range from the 75th-percentile value
- 75th-percentile value
- Median value
- 25th-percentile value
- Less than 1.5 times the interquartile range from the 25th-percentile value
- × 1.5 to 3 times the interquartile range from the 25th-percentile value

**Figure 51.** Distribution of silver concentrations in suspended sediment at fixed sites, Yakima River Basin, Washington, 1987–90 ("Cle Elum" represents Yakima River at Cle Elum; "Umtanum" represents Yakima River at Umtanum; "Naches" represents Naches River near North Yakima; "Union Gap" represents Yakima River above Ahtanum Creek at Union Gap; "Sulphur Creek" represents Sulphur Creek Wasteway near Sunnyside; "Grandview" represents Yakima River at Euclid Bridge at river mile 55 near Grandview; and "Kiona" represents Yakima River at Kiona).

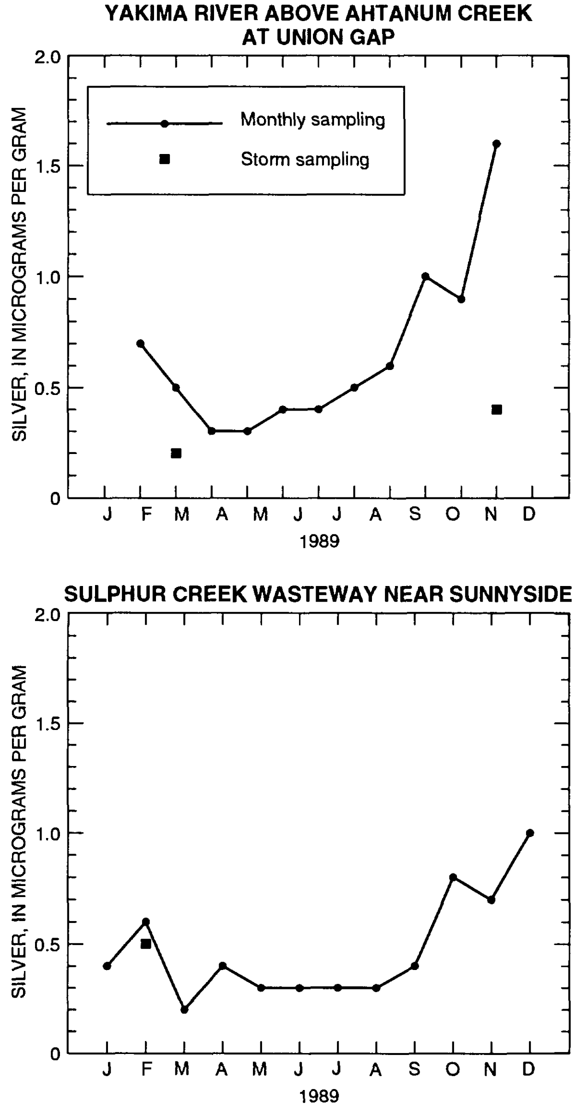


**Figure 52.** Silver concentrations in suspended sediment at the Yakima River above Ahtanum Creek at Union Gap and at Sulphur Creek Wasteway near Sunnyside, Yakima River Basin, Washington, 1989 ("Union Gap" represents Yakima River above Ahtanum Creek at Union Gap and "Sulphur Creek" represents Sulphur Creek Wasteway near Sunnyside).

concentrations at the Union Gap site, because of low suspended-silver concentrations in the Kittitas Valley and in the Naches Subbasin. Similarly, streambed sediment, originating from Quaternary deposits and loess geologic unit in the Sunnyside Subbasin, are an unlikely source of suspended silver for Sulphur Creek. Instead, the distribution of silver at both sites probably results from the concentration and particle size of the suspended sediment mixing with effluent from point sources. During the irrigation season, for example, the concentration of suspended sediment at the Sulphur Creek site is substantially higher than during the non-irrigation season and, conversely, the quantity of fine-grain-sized, suspended sediment during the irrigation season is smaller than during the non-irrigation season (fig. 53). These factors are consistent with the concept of sediment dilution—the mixing of fine-grain-sized, trace-element-enriched, suspended sediment with coarse-grain-sized, trace-element

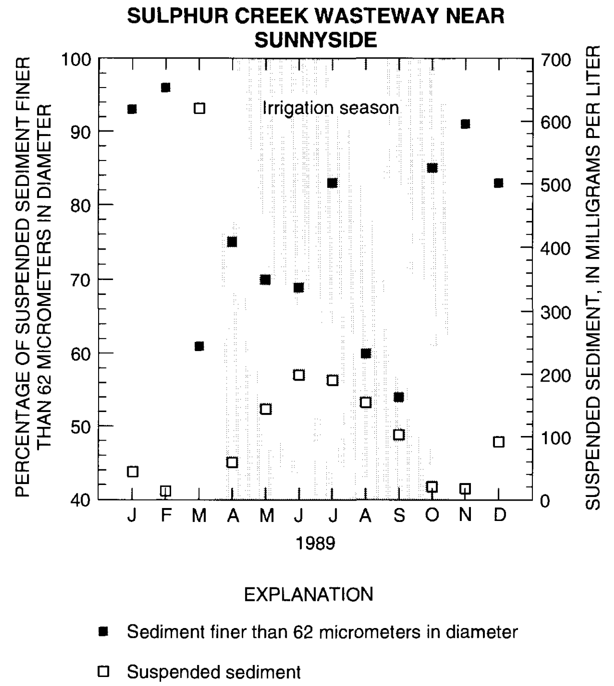


**Figure 53.** Suspended-sediment concentrations and the percentage of suspended sediment finer than 62 micrometers in diameter at Sulphur Creek Wasteway near Sunnyside, Yakima River Basin, Washington, 1989 (shaded area represents the irrigation season).

depleted, suspended sediment. At the Sulphur Creek site, the irrigation-season decrease in suspended-silver concentration probably resulted from the diluting effect of coarse-grain-sized, agricultural soils eroded to Sulphur Creek Wasteway. Conversely, during the nonirrigation season, the fine-grain-sized sediment was probably enriched in silver from point-source effluent because of the absence of recently eroded agricultural soils.

For the Sulphur Creek Wasteway drainage, comparisons between the concentrations of suspended silver during the irrigation season and silver in streambed sediment were not possible because the limits of determination were lower in suspended sediment (0.1 μg/g) than in streambed sediment (2 μg/g).

## Zinc

Concentrations of zinc in streambed sediment in the Yakima River Basin ranged from 77 to 210 μg/g (table 12) and slightly exceeded the 17 to 180 μg/g range of concentration which characterizes 95 percent of Western United States soils (R.C. Severson, U.S. Geological Survey, written commun., 1987, based on data in Shacklette and Boerngen, 1984). The median concentrations of zinc at the biological sites (100 μg/g) also exceeded those determined from analysis of fine-fraction streambed sediment in other river basins of the United States (table 34, at back of report). Concentrations of zinc increased slightly down the main stem and in contrast were notably enriched in several tributaries (fig. 54). Concentrations of zinc as high as 210, 200, and 174 μg/g were detected in streambed sediment of the American River at Hell's Crossing near Nile (site 13), in Wide Hollow Creek at the old Sewage Treatment Plant at Union Gap (site 29), and in Wide Hollow Creek at West Valley Middle School near Ahtanum (site 27). The enrichment of zinc, measured in samples from the American River, is probably of a geologic nature. Simmons and others (1983, p. 49) noted concentrations of zinc as high as 500 μg/g in streambed sediment of Mesatchee Creek. This upstream tributary to the American River was described as a zone of contact between andesitic rocks of the Ohanapecosh Formation and a granitic pluton. Conversely, the enrichment of zinc in Wide Hollow Creek drainage is not predominantly from a geologic source; rather, it is probably the result of agricultural practices and urbanization. Geologic sources of zinc in Wide Hollow Creek Subbasin are small and confined to the Quaternary deposits and the loess geologic unit that contain a median zinc concentration of 88 μg/g (Fuhrer, McKenzie, and others, 1994).

The enrichment of zinc in Wide Hollow Creek at the old Sewage Treatment Plant—located near the mouth of Wide Hollow Creek—was expected because Wide Hollow Creek drains the urban area of Union Gap and because the median concentration of zinc in urban drains of the Yakima River Basin is 210 μg/g (Fuhrer, McKenzie, and others, 1994). However, the 174 μg/g of zinc at the upstream site, Wide Hollow Creek at West Valley High School, was not anticipated because the site is farther removed from the higher density, urban effects of the Union Gap area. Most of the Wide Hollow Creek drainage above the West Valley High School site is used to support orchards. Agricultural practices associated with orchard crops may represent a nonpoint source of zinc to streambed sediment. According to a census of pesticide use in the Yakima River Basin for 1989, the zinc-based pesticide Ziram (zinc dimethyldithiocarbamate) was applied to orchards in quantities that ranged from 4.7 to 8 pounds of zinc per acre per year (J.F. Rinella, unpub. data, 1996). Based on these applications, the quantity of

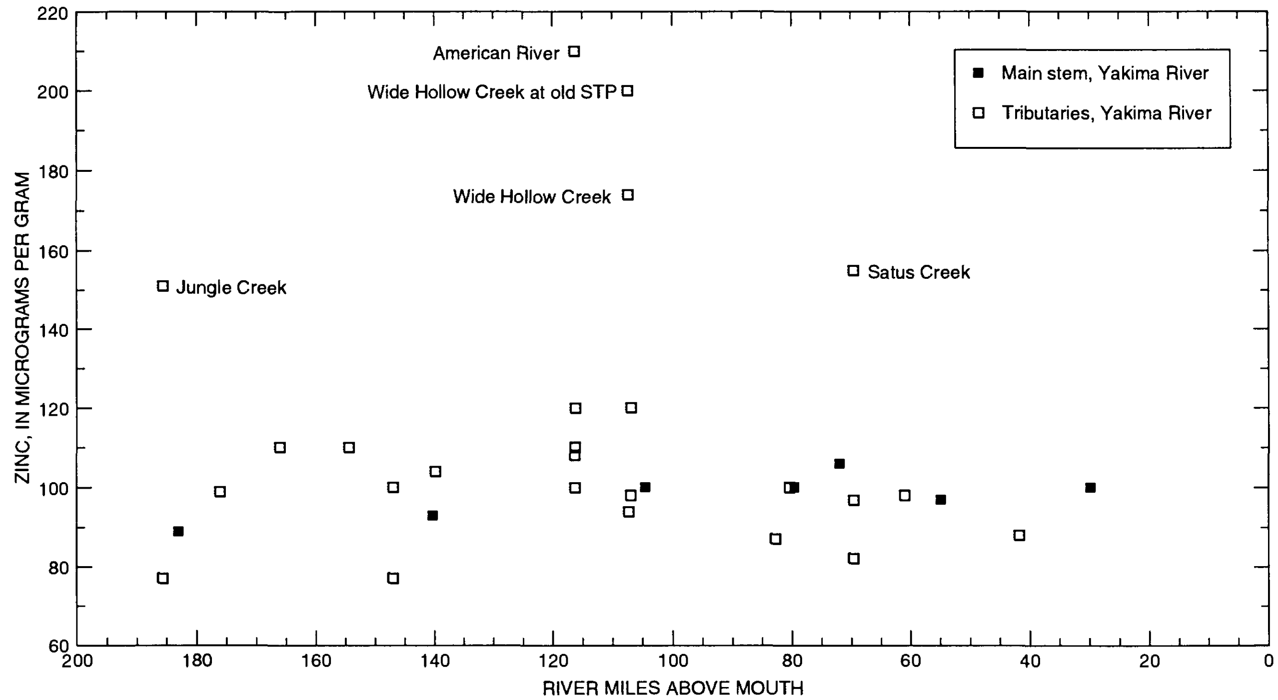


**Figure 54.** Zinc concentrations in streambed sediment of the main stem and tributaries, Yakima River Basin, Washington, 1987 ("American River" represents American River at Hell's Crossing near Nile; "Wide Hollow Creek at old STP" represents Wide Hollow Creek at old Sewage Treatment Plant at Union Gap; "Wide Hollow Creek" represents Wide Hollow Creek at West Valley Middle School near Ahtanum; "Jungle Creek" represents Jungle Creek near mouth near Cle Elum; and "Satus Creek" represents Satus Creek above Wilson-Charley Canyon near Toppenish).

elemental zinc ranged from 0.8 to 1.3 pounds per acre per year. In the mid-Yakima Valley alone, as much as 3,000 pounds of zinc was applied to apple, pear, and peach orchards in 1989. Soils of several former apple orchards in the Ahtanum Subbasin—the subbasin containing the Wide Hollow Creek drainage—contained concentrations of zinc as high as 150 μg/g, and streambed sediment within the same drainage contained concentrations of zinc as high as 180 μg/g (Fuhrer, McKenzie, and others, 1994). It was noted that the concentration of zinc was only 73 μg/g in a nearby agricultural plot used to grow peas. This concentration of zinc is understandably low (Ziram is not used on peas) compared to the former apple-orchard sites and agrees closely with the median concentration of zinc in the geologic units that form the soils and streambed sediments of the Ahtanum Creek Subbasin (Fuhrer, McKenzie, and others, 1994).

Median concentrations of zinc in suspended sediment ranged from 120 to 190 μg/g at the fixed sites, and the lowest and highest median values, respectively, were found in the Naches River near North Yakima and the Yakima River at Cle Elum (table 13, fig. 55).

Sources of suspended zinc in the Yakima River at Cle Elum probably originate from the pre-Tertiary metamorphic and intrusive rocks and Miocene and older volcanic rocks geologic units in the northern part of the Kittitas Valley (Fuhrer, McKenzie, and others, 1994). Additionally, sources of zinc at the Cle Elum site probably are identical to geologic sources of antimony, arsenic, chromium, and nickel in the Kittitas Valley. Streambed-sediment samples, collected from lower order streams in the pre-Tertiary rocks geologic unit of the Cle Elum River drainage and in the drainage upstream from Little Kachess Lake (both in the Kittitas Valley), contained zinc concentrations as high as 180 and 160 μg/g, respectively (Fuhrer, McKenzie, and others, 1994). Neighboring sites in the same drainage and geologic unit had zinc concentrations that were lower than 71 μg/g (Fuhrer, McKenzie, and others, 1994). The large interquartile range for suspended-sediment concentrations of zinc at the Cle Elum site probably results from the large spatial variability of zinc concentrations in streambed sediment in the pre-Tertiary metamorphic and intrusive rocks geologic unit of the Kittitas Valley (Fuhrer, McKenzie, and others, 1994).

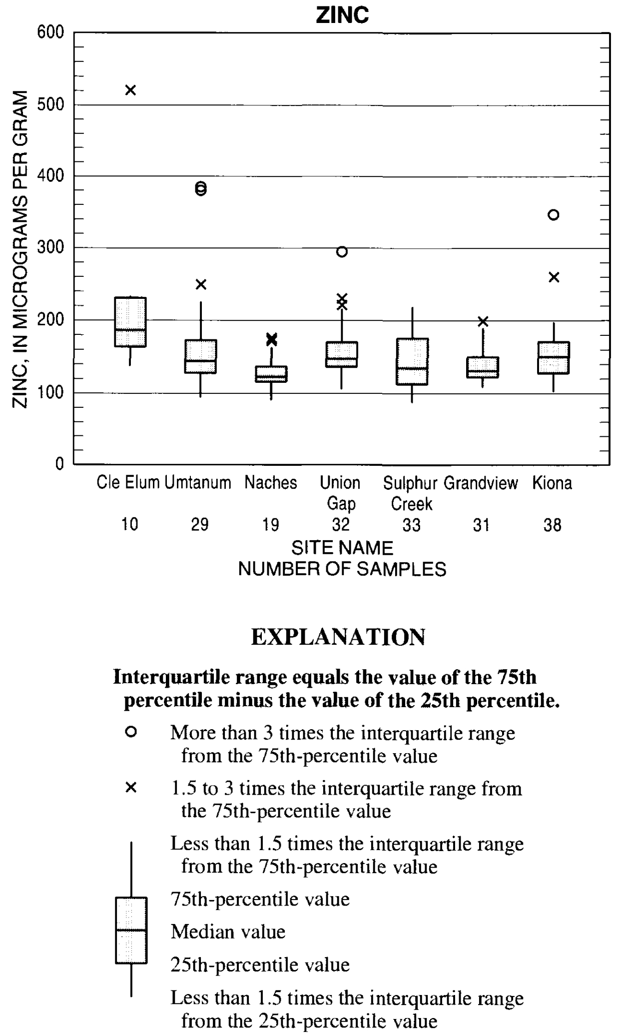


**Figure 55**. Distribution of zinc concentrations in suspended sediment at fixed sites, Yakima River Basin, Washington, 1987–90 ("Cle Elum" represents Yakima River at Cle Elum; "Umtanum" represents Yakima River at Umtanum; "Naches" represents Naches River near North Yakima; "Union Gap" represents Yakima River above Ahtanum Creek at Union Gap; "Sulphur Creek" represents Sulphur Creek Wasteway near Sunnyside; "Grandview" represents Yakima River at Euclid Bridge at river mile 55 near Grandview; and "Kiona" represents Yakima River at Kiona).

Although geologic sources of zinc exist in the Kittitas Valley, fluctuations in suspended-zinc concentrations during storms at the Yakima River at Umtanum indicate that these sources are relatively small in comparison to sources for chromium and nickel. Unlike the increase in concentration for chromium and nickel at the Umtanum site near the peak of a December 5, 1989, rain-on-snow storm, the concentration of suspended zinc (160 μg/g) measured near the storm's peak was lower than that measured after the storm (230 μg/g) on December 13, 1989 (fig. 56). The pattern was the same during an April 6, 1989, storm at the Umtanum site; the zinc concentration measured near the storm's peak was lower than that measured after the storm (180 μg/g) on April 12, 1989. The zinc concentration measured after this storm was similar to that measured the preceding and following month. During the December 5, 1989, storm at Umtanum, similar patterns of decreasing element concentrations for cadmium, copper, and lead were measured near the peak of the storm.

With the exception of zinc concentrations in Asiatic clams in Spring Creek (452 μg/g) and in carp in the Yakima River at Kiona (634 μg/g), zinc concentrations in biota had little variation among sites (table 15 and table 30). Such observations are common and may indicate metabolic regulation of zinc, an essential element (Bryan 1984; O'Grady and Abdullah, 1985; Luoma and others, 1990; Krantzberg and Stokes, 1989; Nugegoda and Rainbow, 1989; Timmermans and others, 1992).

Zinc concentrations in most taxa from the Yakima River Basin appear typical of a zinc-poor system (table 39, at back of report) [Moore and others, 1991; Salanki and others, 1982; Luoma and others, 1990]. However, in Spring Creek, the mean concentration in Asiatic clams (452 μg/g) was more than twice that observed either at other sites sampled in this study or in the San Francisco Bay/Delta (Luoma and others, 1990). Zinc concentrations also were high in carp (634 μg/g) from the Yakima River at Kiona. Although in another study, carp seemed to accumulate zinc to higher concentrations than other fish (Lowe and others, 1985), the concentrations measured in carp at Kiona were more than five times the 85th-percentile concentration for all freshwater fish samples in California's Toxic Substances Monitoring Program (Rassmussen, 1992). Thus, some sites in the lower Yakima Valley seem to be enriched in zinc.

The concentrations of zinc ranged from 50 to 187 μg/g in curlyleaf pondweed and from 44 to 239 μg/g in the waterweed (table 15). The maximum concentrations in both species of aquatic plants were from Wide Hollow Creek at the old Sewage Treatment Plant at Union Gap. High concentrations of zinc (201 μg/g) also were detected in waterweed in Spring Creek at mouth at Whitstran and corresponded with similar enrichment in Asiatic clams, as previously mentioned. High concentrations of zinc in aquatic plants at the Wide Hollow Creek site coincided with the high concentrations of zinc measured in streambed sediment, as previously mentioned, and collectively indicated that Wide Hollow Creek is affected by anthropogenic sources of zinc.

**Table 30.** Comparison of low and high zinc concentrations in water, sediment, and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91

[For filtered water and suspended sediment, the low and high concentration assignments are based on a percentile distribution of the 50th-percentile values (median) for each fixed site; For streambed sediment and aquatic biota, the low and high concentration assignments are based on a percentile distribution of the mean concentrations for each fixed site. High concentrations (denoted with an "H" in the table) represent that portion of the distribution which is greater than or equal to the 75th-percentile value. Low concentrations (denoted with an "L" in the table) represent that portion of the distribution which is less than or equal to the 25th-percentile value. Concentrations greater than 25th, but less than 75th-percentile value are denoted with an "*" in the table. The term "filtered water" is an operational definition referring to the chemical analysis of that portion of a water-suspended sediment sample that passes through a nominal 0.45-micrometer filter. Only 1990 data are summarized for largescale sucker livers and caddisflies; sample species: largescale sucker (*Catostomus macrocheilus*), mountain whitefish (*Prosopium williamsoni*), rainbow trout (*Oncorhynchus mykiss*), caddisfly (*Hydropsyche* spp.), stonefly (*Hesperoperla* sp.), Asiatic clam (Veneroida: Corbiculidae *Corbicula fluminea*), and curlyleaf pondweed (*Potamogeton crispus*); NF, North Fork; SF, South Fork; Cr = Creek; RM = river mile. Data statistically summarized for fixed sites are from monthly and selected hydrologic-event samplings from the Yakima River at Cle Elum, Yakima River at Umtanum, Naches River near North Yakima, Ahtanum Creek at Union Gap, Sulphur Creek Wasteway near Sunnyside, Yakima River at Euclid Bridge at river mile 55 near Grandview, and Yakima River at Kiona for the period 1987–90. To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate at a site, only one element concentration per visit was statistically summarized; --, no data]

| Site reference number | Site name | Filtered water | Sediment | | Aquatic biota | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Fish livers | | | Insects | | | |
| | | | Streambed | Suspended | Largescale sucker | Mountain whitefish | Rainbow trout | Caddisfly | Stonefly | Asiatic clam | Curlyleaf pondweed |
| 1 | Waptus River at mouth near Roslyn | -- | L | -- | -- | -- | H | -- | -- | -- | -- |
| 3 | Jungle Creek near mouth near Cle Elum | -- | H | -- | -- | -- | * | -- | -- | -- | -- |
| 4 | NF Teanaway River below bridge at Dickey Creek Campground | -- | -- | -- | -- | -- | -- | -- | L | -- | -- |
| 5 | Teanaway River below Forks near Cle Elum | -- | * | -- | -- | -- | H | -- | -- | -- | -- |
| 6 | Yakima River at Cle Elum | H | L | H | -- | * | -- | L | * | -- | -- |
| 7 | Naneum Creek below High Creek near Ellensburg | -- | * | -- | -- | -- | -- | H | H | -- | -- |
| 8 | Taneum Creek at Taneum Meadow near Thorp | -- | H | -- | -- | -- | L | -- | L | -- | -- |
| 10 | Little Naches River at mouth near Cliffdell | -- | * | -- | -- | -- | -- | H | -- | -- | -- |
| 12 | SF Manastash Cr near Ellensburg | -- | H | -- | -- | -- | L | -- | H | -- | -- |
| 13 | American River at Hell's Crossing near Nile | -- | H | -- | -- | -- | -- | -- | -- | -- | -- |

**Table 30.** Comparison of low and high zinc concentrations in water, sediment, and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91—Continued

| Site reference number | Site name | Filtered water | Sediment | | Aquatic biota | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Fish livers | | | Insects | | Asiatic clam | Curlyleaf pondweed |
| | | | Streambed | Suspended | Largescale sucker | Mountain whitefish | Rainbow trout | Caddisfly | Stonefly | | |
| 14 | Cherry Creek above Wipple Wasteway at Thrall | -- | L | -- | -- | H | -- | * | -- | -- | -- |
| 16 | Cherry Creek at Thrall | -- | -- | -- | -- | -- | -- | * | -- | -- | * |
| 19 | Yakima River at Umtanum | * | L | * | -- | H | * | L | -- | -- | L |
| 20 | Umtanum Creek near mouth at Umtanum | -- | * | -- | -- | -- | * | * | * | -- | -- |
| 21 | Rattlesnake Creek above Little Rattlesnake Creek near Nile | -- | H | -- | -- | -- | -- | * | * | -- | -- |
| 22 | Rattlesnake Creek above North Fork Rattlesnake Creek near Nile | -- | H | -- | -- | -- | * | L | * | -- | -- |
| 26 | Naches River near North Yakima | L | H | L | H | L | -- | * | -- | -- | -- |
| 27 | Wide Hollow Creek at West Valley Middle School near Ahtanum | -- | H | -- | -- | -- | -- | * | -- | -- | -- |
| 29 | Wide Hollow Creek at old Sewage Treatment Plant at Union Gap | -- | H | -- | -- | -- | * | H | -- | -- | H |
| 30 | Moxee Drain at Thorp Road near Union Gap | -- | L | -- | -- | -- | -- | -- | -- | -- | -- |
| 31 | Ahtanum Creek at Union Gap | -- | * | -- | -- | -- | -- | * | -- | -- | -- |
| 32 | Yakima River above Ahtanum Creek at Union Gap | * | -- | H | -- | -- | -- | -- | -- | -- | -- |
| 33 | Yakima River at Parker | -- | * | -- | * | L | -- | * | -- | -- | * |
| 34 | South Fork Ahtanum Creek above Conrad Ranch near Tampico | -- | H | -- | -- | -- | -- | H | * | -- | -- |
| 40 | Granger Drain at mouth near Granger | -- | L | -- | -- | -- | -- | * | -- | -- | -- |

**Table 30.** Comparison of low and high zinc concentrations in water, sediment, and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91—Continued

| Site reference number | Site name | Filtered water | Sediment | | Aquatic biota | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Fish livers | | | Insects | | Asiatic clam | Curlyleaf pondweed |
| | | | Streambed | Suspended | Largescale sucker | Mountain whitefish | Rainbow trout | Caddisfly | Stonefly | | |
| 42 | Yakima River below Toppenish Creek at RM 79.6 near Granger | -- | * | -- | * | H | -- | L | -- | * | -- |
| 43 | Toppenish Creek at Indian Church Road near Granger | -- | * | -- | -- | -- | -- | -- | -- | -- | -- |
| 47 | Satus Creek at gage at Satus | -- | * | -- | L | -- | -- | * | -- | -- | L |
| 48 | Yakima River at RM 72 above Satus Creek near Sunnyside | -- | H | -- | -- | -- | -- | -- | -- | * | * |
| 50 | Yakima River at Kiona | L | * | H | * | -- | -- | L | -- | * | H |
| 52 | Sulphur Creek Wasteway near Sunnyside | * | * | * | -- | -- | -- | * | -- | -- | -- |
| 53 | Satus Creek below Dry Creek near Toppenish | -- | L | -- | -- | -- | -- | H | -- | -- | -- |
| 54 | Spring Creek at mouth at Whitstran | -- | L | -- | -- | -- | -- | * | -- | H | -- |
| 56 | Yakima River at Euclid Bridge at RM 55 near Grandview | H | * | L | * | * | -- | L | -- | L | L |
| 57 | Satus Creek above Wilson-Charley Canyon near Toppenish | -- | H | -- | -- | -- | * | H | * | -- | -- |

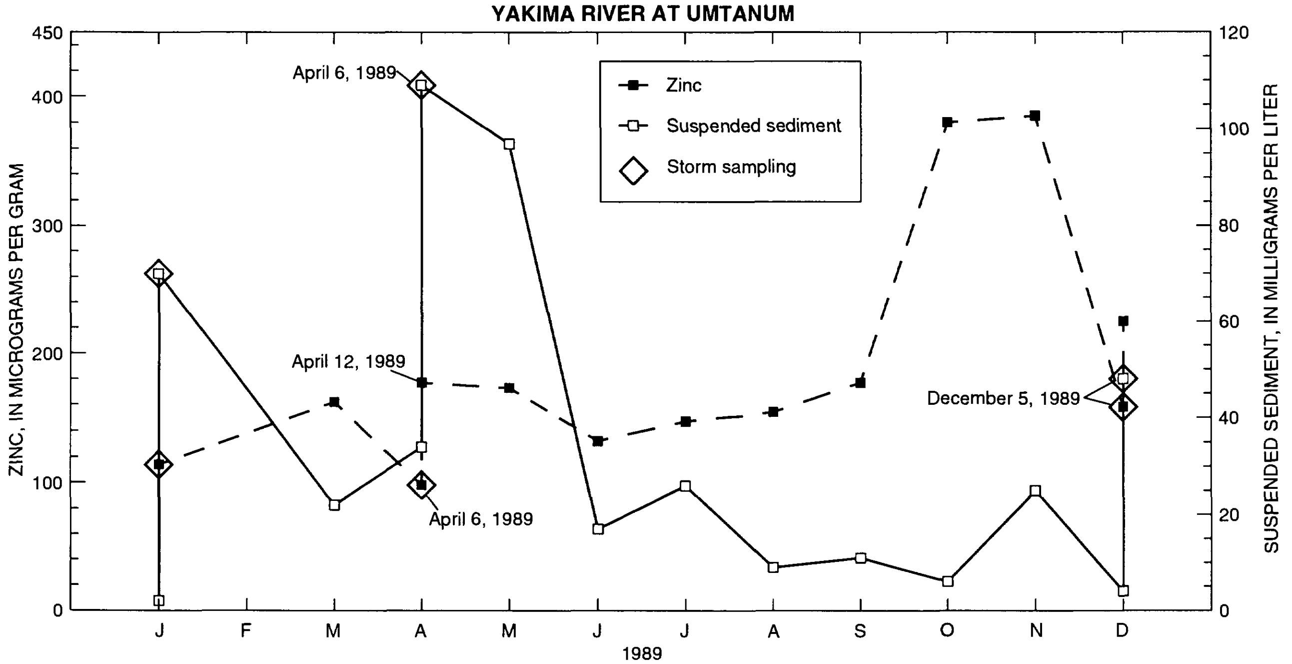


**Figure 56.** Zinc concentrations in suspended sediment and suspended-sediment concentrations at the Yakima River at Umtanum, Yakima River Basin, Washington, 1989.

## TEMPORAL VARIATIONS IN ELEMENT CONCENTRATIONS FOR AQUATIC BIOTA SAMPLED AT SITES IN COMMON IN 1989 AND 1990

The aquatic insect order *Trichoptera* (caddisfly) was sampled in 1989 and 1990. Among biological samples, this taxon had the greatest number of sites in common for 1989 and 1990 and, therefore, provided the best basinwide assessment of intrasite differences in element concentrations. Element concentrations in the *Trichoptera* were consistently higher in 1989 than in 1990 (table 31), possibly because of (1) differences between laboratory processing methods, (2) differences in bioaccumulation among *Trichoptera* species included in samples collected in 1989 and 1990, and (3) differences in bioaccumulation (exposure) between 1989 and 1990.

**Table 31.** Comparison of selected element concentrations in caddisflies sampled at sites in common in 1989 and 1990, Yakima River Basin, Washington

[To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate at a site, the mean element concentration of each site was statistically summarized; only detectable concentrations were statistically summarized; concentrations are reported in units of micrograms per gram, dry weight; identifications of caddisflies collected in 1989 were verified only to order (Trichoptera); samples for 1990 are Trichoptera: Hydropsychidae *Hydropsyche* spp.]

| Element | Number of sites | 1989 | | | 1990 | | |
|---|---|---|---|---|---|---|---|
| | | Minimum | Median | Maximum | Minimum | Median | Maximum |
| Chromium | 13 | 2.0 | 6.6 | 11 | 0.66 | 2.9 | 4.0 |
| Copper | 14 | 14 | 20 | 48 | 9.8 | 14 | 21 |
| Iron | 14 | 2,060 | 5,700 | 13,400 | 1,020 | 2,490 | 5,030 |
| Lead | 4 | 5.0 | 6.8 | 10 | .81 | 2.3 | 5.6 |
| Nickel | 12 | 2.0 | 7.2 | 24 | .93 | 3.2 | 5.7 |
| Zinc | 14 | 83 | 118 | 260 | 67 | 95 | 148 |

In 1989 and in 1990–91, respectively, the USFWS and the USGS laboratories prepared and analyzed samples from the Yakima River Basin (Fuhrer, Fluter, and others, 1994). One aspect of laboratory processing that may have contributed to intrasite variability is the difference in the degree that benthic insects were taxonomically sorted between 1989 and 1990. In 1990, benthic insect samples were sorted to genus or species prior to chemical analysis. This level of taxonomic separation was not performed on samples collected in 1989; instead, samples were sorted to the order *Trichoptera* (caddisfly). In other studies, differences in the taxonomic composition of samples have been shown to affect comparisons of element concentrations between years (Cain and others, 1992) and may be a factor contributing to intrasite variability in the Yakima River Basin.

Asiatic clam samples from the Yakima River indicated little change in elemental exposure between 1989 and 1990. For example, element concentrations in Asiatic clams from the Yakima River at Euclid Bridge at RM 55 near Grandview and the Yakima River at Kiona were similar between years (table 32). For most elements, the concentrations in the livers of rainbow trout, mountain whitefish, and largescale suckers also were similar between years (table 33). However, differences for cadmium and mercury in largescale suckers were measured between years. The minimum concentrations for cadmium and mercury were 13 times and 4 times higher, respectively, in 1989 than in 1990. These differences in concentrations may be related to differences in the sizes of largescale suckers collected between 1989 and 1990. The minimum concentrations of cadmium and mercury were measured in fish from Satus Creek in 1990. The mean length of these fish was 206 cm. The fish collected at the Satus Creek site in 1989, however, were larger (mean length 413 cm) and also had higher cadmium concentrations (0.4 µg/g). Little difference in either cadmium or mercury concentrations was noted between years at the other sites in the basin where similar sized fish could be compared. Copper concentrations in rainbow trout in the Yakima River at the mouth of Umtanum Creek differed two to threefold between 1989 and 1990 (table 33). These differences did not seem to be related to size—between 1989 and 1990, the average length of fish at the Yakima River at Umtanum varied from only 248 to 293 cm. Analyses of these samples indicate copper exposures in this reach of the river increased between 1989 and 1990, although differences between years also could reflect interlaboratory variability.

**Table 32.** Comparison of selected element concentrations in Asiatic clams sampled at sites in common in 1989 and 1990, Yakima River Basin, Washington

[To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate at a site, the mean element concentration of each site was statistically summarized; concentrations are reported in units of micrograms per gram, dry weight; **Grandview**, Yakima River at Euclid Bridge at river mile 55 near Grandview (site 56); **Kiona**, Yakima River at Kiona (site 50); sample species: Asiatic clam (Veneroida: Corbiculidae *Corbicula fluminea*); <, less than]

| Element | Grandview | | Kiona | |
|---|---|---|---|---|
| | 1989 | 1990 | 1989 | 1990 |
| Arsenic | 5.8 | 4.6 | 3.9 | 4.2 |
| Cadmium | .30 | .34 | .20 | .28 |
| Chromium | 2.0 | 2.0 | 2.5 | 1.2 |
| Copper | 33 | 35 | 23 | 27 |
| Lead | <4.0 | .33 | <4.0 | .18 |
| Mercury | .15 | .16 | .10 | .10 |
| Nickel | <2.0 | .93 | 2.0 | 1.2 |
| Selenium | 2.3 | 2.0 | 1.8 | 2.6 |
| Zinc | 93 | 99 | 106 | 98 |

**Table 33.** Comparison of selected element concentrations in fish livers sampled at sites in common in 1989 and 1990, Yakima River Basin, Washington

[To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate at a site, the mean-element concentration of each site was statistically summarized; concentrations are reported in units of micrograms per gram, dry weight; **Parker**, Yakima River at Parker (site 33); **Satus Creek**, Satus Creek at gage at Satus (site 47); **Kiona**, Yakima River at Kiona (site 50); **Cle Elum,** Yakima River at Cle Elum (site 6); **Umtanum Creek**, Umtanum Creek near mouth at Umtanum (site 20); **Yakima River**, Yakima River at Umtanum (site 19); --, not determined; sample species: largescale sucker (*Catostomus macrocheilus*), mountain whitefish (*Prosopium williamsoni*), and rainbow trout (*Oncorhynchus mykiss*); <, less than]

| | Largescale sucker | | | | | | Mountain whitefish | | | | Rainbow trout | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Parker | | Satus Creek | | Kiona | | Cle Elum | | Kiona | | Umtanum Creek | | Yakima River | |
| Element | 1989 | 1990 | 1989 | 1990 | 1989 | 1990 | 1989 | 1990 | 1989 | 1990 | 1989 | 1990 | 1989 | 1990 |
| Arsenic | <0.20 | 0.20 | <0.20 | 0.30 | 0.27 | 0.30 | <0.20 | 0.10 | <0.20 | 0.20 | <0.2 | <0.50 | 0.20 | <0.50 |
| Cadmium | <.20 | .32 | .40 | .03 | .47 | .43 | <.20 | .13 | 1.1 | 1.4 | <.30 | .23 | <.20 | .10 |
| Chromium | <1.0 | .78 | <1.0 | .50 | <1.0 | .59 | < 1.0 | 1.0 | <1.0 | .64 | <1.0 | .84 | <1.0 | .75 |
| Copper | 11 | 23 | 27 | 26 | 21 | 32 | 6.1 | 6.0 | 9.6 | 7.7 | 59 | 100 | 130 | 290 |
| Lead | <4.0 | .15 | <4.0 | .17 | <4.0 | .17 | .91 | .72 | .58 | .76 | -- | -- | -- | -- |
| Mercury | .21 | .47 | .27 | .05 | .28 | .30 | < 2.0 | .18 | <2.0 | <.06 | .25 | .38 | .22 | .27 |
| Selenium | 2.6 | 2.9 | 3.3 | 1.9 | 3.7 | 4.5 | <4.0 | .22 | <4.0 | .31 | -- | -- | -- | -- |
| Zinc | 86 | 100 | 120 | 60 | 84 | 85 | 9.5 | 8.2 | 11 | 15 | 101 | 81 | 109 | 80 |

## SUMMARY AND CONCLUSIONS

The Yakima River Basin is one of four surface-water pilot project areas selected to test and refine concepts for implementing a National Water Quality Assessment Program. As part of the pilot project, major and trace elements were determined from several media that included streambed sediment, suspended sediment, water (filtered-water samples and unfiltered-water samples), and aquatic biota. Spatially, the most extensively sampled medium was streambed sediment; 448 sites were sampled in 1987 to determine the occurrence and spatial distribution of potentially toxic major and trace elements (Fuhrer, McKenzie, and others, 1994). Thirty-two of the sites that had been sampled for streambed sediment in 1987 were sampled for aquatic biota in 1989–91. Seven of these sites, termed fixed-sampling sites, were sampled for suspended sediment and other water media (monthly and during several hydrologic events) for the period 1987–90. Trace elements were measured in filtered-water samples at least once at 44 sites; most of these sites were sampled over a period of 1 to 2 weeks (synoptic samplings) in July and (or) November 1987. Trace elements generally were measured quarterly in unfiltered-water samples during 1987 at fixed-sampling sites.

This report describes the occurrence and distribution of potentially toxic trace elements in sediment, water, and aquatic biota. More specifically, this report provides information about:

1. Variations in element concentrations and loads attributable to different hydrologic conditions, including the irrigation season, nonirrigation season, snowmelt season, and storms;
2. Suitability of surface water for the protection of aquatic life and human health based on State and Federal water-quality criteria, guidelines, and regulations;
3. Major natural and human factors in the Yakima River Basin that affect observed water-quality conditions; and
4. Patterns of element enrichment that are common among sediment, water, and aquatic biota media.

***Comparison of trace-element concentrations in water and fish muscle to water-quality guidelines***—Trace-element concentrations in filtered- and unfiltered-water samples were screened against U.S. Environmental Protection Agency (USEPA) ambient water-quality criteria for the protection of aquatic life and human health, drinking-water regulations, and drinking-water human-health advisories. Although all USEPA ambient water-quality criteria are nonenforceable guidelines, the guidelines were used to screen ambient water-quality data in the Yakima River Basin in order to identify element concentrations that may require study by State and local health agencies. Concentrations of cadmium, chromium, copper, iron, lead, mercury, silver, and zinc in filtered and (or) unfiltered water exceeded the screening value (based on USEPA's ambient water-quality criteria for the protection of aquatic organisms) at two or more sites in the Yakima River Basin. Zinc concentrations in filtered water exceeded acute and chronic criteria for aquatic life at several sites, including those receiving irrigation return flow and those located in mountainous areas. Copper exceedances occurred during winter-storm runoff periods, and coincided with seasonal historical patterns of copper exceedances attributed, in part, to the use, past and present, of copper sulfate (a herbicide).

The USEPA ambient water-quality criteria for the protection of human health are designed to indicate exposure of humans to a contaminant because of (1) consumption of water and aquatic organisms or (2) consumption of aquatic organisms only. Concentrations of arsenic (a carcinogen) exceeded the human-health screening value for consumption of aquatic organisms and water in 47 percent of the filtered-water samples and exceeded the screening value for consumption of only aquatic organisms in 30 percent of the samples. Exceedances of arsenic were measured predominantly in the lower Yakima Valley. Concentrations of mercury (a noncarcinogen) in filtered-water samples exceeded the human-health screening values for consumption of aquatic organisms and water and consumption of only aquatic organisms in 4 percent of the samples.

Trace-element concentrations, determined from filtered- and unfiltered-water samples, were screened by making comparisons with USEPA drinking-water regulations and USEPA advisories for human health. Because filtered and unfiltered stream-water samples represent untreated water, element concentrations which exceeded screening values (based on drinking-water regulations) do not indicate that human health is directly at risk. Concentrations of iron in unfiltered-water samples did not meet the screening value in 94 percent of the samples. In filtered-water samples, iron concentrations, however, did meet the screening value; therefore, the exceedances in unfiltered water probably resulted from iron associated with sediment that probably would be removed in a water-treatment process.

Unlike the ambient water-quality criteria for human health, drinking-water health advisories are based only on the consumption of domestic water. In the present study, however, ambient stream water was used to screen for health effects. Concentrations of arsenic (a carcinogen) in filtered-water samples exceeded the screening value in 31 percent of the samples. The largest number of exceedances of arsenic was from the lower Yakima Valley. Concentrations of mercury (a noncarcinogen) in filtered-water samples rarely exceeded the screening value.

Fish muscle, analyzed for mercury for various fish taxa, was collected from four sites in the Yakima River Basin in 1991. The median mercury concentration in fish muscle from each site and for each fish species was screened against mercury concentrations in fish that were of potential public-health concern. Muscle samples collected from rainbow trout and mountain whitefish from the four sites contained mercury concentrations that were below the screening value for standard adults (consumers of an average of about one 6-ounce fillet per month). Screening values also were calculated for children, recreational fishermen, and subsistence fishermen. The concentration of mercury in fish muscle, consumed by children who ate an average of one 6-ounce fillet per month, exceeded the screening value for children for all species of fish sampled and at all sites sampled. Similarly, screening values for recreational fishermen (consumers of about five 6-ounce fillets per month) and subsistence fishermen (consumers of about 25 6-ounce fillets per month) are exceeded for all species of fish sampled and at all sites sampled.

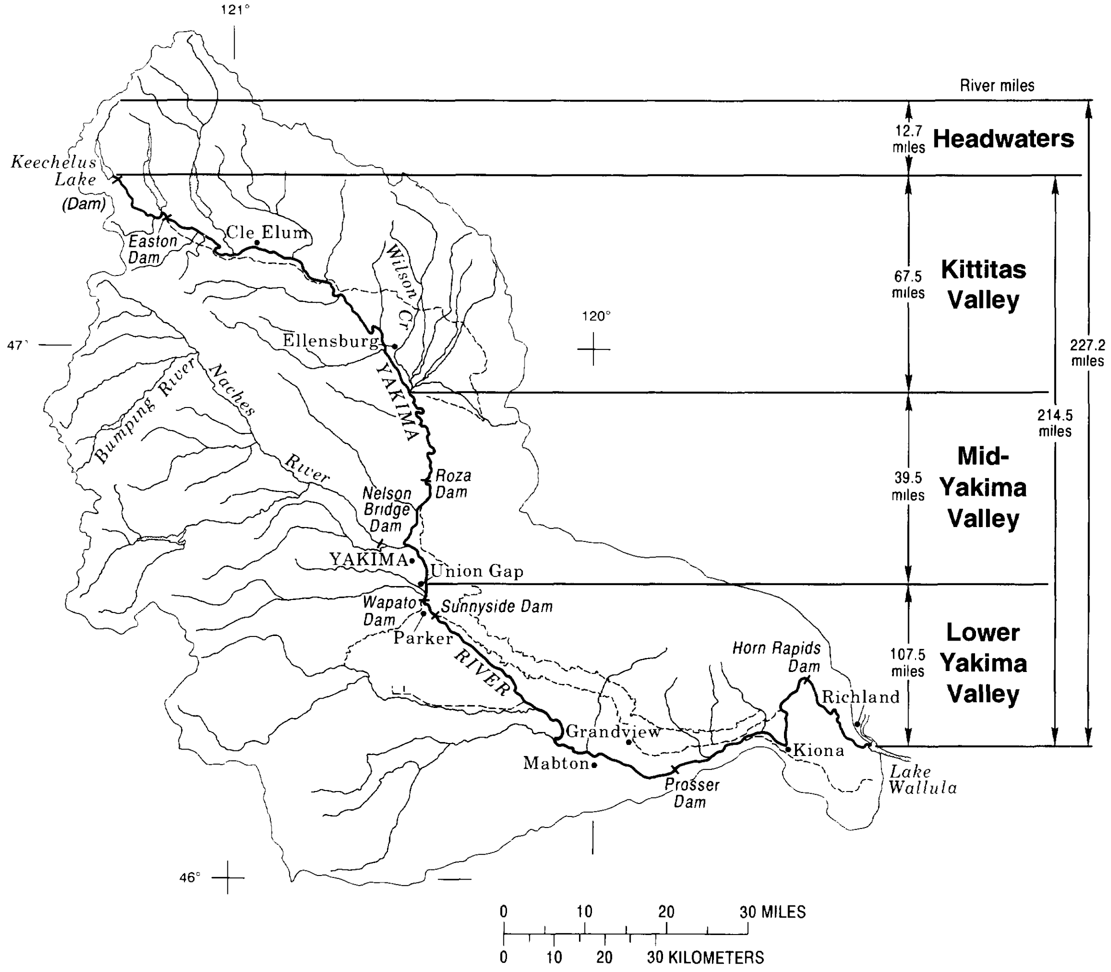
***Distribution of elements in sediment, water, and aquatic biota***—Most element enrichment results from natural geologic sources in the forested landscapes of the Kittitas and mid-Yakima Valley, primarily in the Cle Elum, Upper Naches, Teanaway, and Tieton Subbasins (see table below and figure on p. 154). These areas might be classified as "pristine" by the casual observer yet they are geologic sources of

| Element | Dominant Source | | |
|---|---|---|---|
| | Geology | Agriculture | Urban and light industry |
| Arsenic | Kittitas Valley | Mid-Yakima Valley and lower Yakima Valley | |
| Chromium | Kittitas Valley | | |
| Copper | Mid-Yakima Valley | **Mid-Yakima Valley** | |
| Lead | | **Mid-Yakima Valley and lower Yakima Valley** | |
| Mercury | Kittitas Valley and Mid-Yakima Valley | | |
| Nickel | Kittitas Valley | | |
| Selenium | Mid-Yakima Valley | | |
| Zinc | Mid-Yakima Valley | Mid-Yakima Valley | |

antimony, arsenic, chromium, copper, mercury, nickel, selenium, and zinc. As an example, arsenic, chromium, and nickel concentrations in streambed sediment (as high as 45, 212, and 260 μg/g, respectively) were nearly 4 to as much as 13 times higher than their respective median concentrations in streambed sediment of agricultural land-use areas in the lower Yakima Valley. As a result of geologic sources, several of these elements, including arsenic, chromium, and nickel, leave chemical signatures that were measurable in streambed sediment and suspended sediment of higher order streams, including the main stem. In addition to streambed sediment and suspended sediment, some of the geologically derived elements, including chromium, nickel, and selenium, were measurable in aquatic biota of higher order streams. Only the Teanaway Subbasin was a qualified source of chromium and nickel to sediment and aquatic biota. In the Teanaway Subbasin, chromium and nickel concentrations in benthic insects were, respectively, 4 to 52 times and 43 to 102 times higher than concentrations in insect taxa collected from other sites in the Yakima River Basin. Enrichment of chromium and nickel from the Teanaway Subbasin also affected sediment and biota, although to a lesser extent, in the Yakima River at Umtanum. The median concentration of nickel in suspended sediment at the Umtanum site was more than twice that in the Yakima River at Kiona.

Streambed sediment, formed from the Quaternary deposits and loess geologic unit, comprises a majority of the agricultural farmland in the Yakima River Basin and helps control the downstream effects of geologically derived trace elements. Concentrations of several elements, including arsenic, chromium, and nickel, result from geologic sources and were attenuated by mixing with element-poor streambed sediment from agricultural lands. For example, concentrations of arsenic in the Yakima River at Cle Elum were high as a result of geologic sources in the Cle Elum Subbasin; however, farther downstream at the Yakima River at Umtanum, a site that receives sediment from agricultural land-use areas, arsenic concentrations were 16 times lower than those found in close proximity to geologic sources. Lower arsenic concentrations at Umtanum result from streambed sediment that enters the main stem from agricultural land located in the Quaternary deposits and loess geologic unit in the Kittitas Valley.

In some parts of the Yakima River Basin, human activities (such as farming) can decrease some trace-element concentrations; in other parts, human activities can increase element concentrations. Trace-element distributions of cadmium, copper, lead, mercury, selenium, and zinc increase in areas affected by human activities. Concentrations of the aforementioned elements frequently were highest in the Wide Hollow Subbasin, which drains urbanized and lightly industrialized lowland, as well as agricultural land in the upper reaches of Wide Hollow Subbasin. Concentrations of lead in streambed sediment of Wide Hollow Creek, for example, were more than twice that expected in streambed sediment from geologic sources in Wide Hollow Subbasin and also exceeded the 5.2 to 55 μg/g range of concentrations, which characterizes 95 percent of Western United States soils. In addition to urban runoff, past applications of lead arsenate in apple orchards, including applications in the upper reaches of Wide Hollow Subbasin, may be a source of lead. Benthic insects seemed to be sensitive to lead in Wide Hollow Creek. Lead concentrations in caddisflies (*Hydropsyche* spp.) in Wide Hollow Creek not only represented the basin maximum, but also were 15 times higher than concentrations in caddisflies from Umtanum Creek—a reference site not affected directly by human activities. Although lead concentrations were high in caddisflies in Wide Hollow Creek, caddisflies were only slightly enriched compared to



Distinctive hydrologic reaches of the Yakima River, Washington.

insects in other systems; lead concentrations were not high in fish. Among liver samples from the basin's different fish taxa, the concentration of selenium in rainbow trout from Wide Hollow Creek (31 μg/g) was 4 to 8 times higher than concentrations of selenium in rainbow trout from other sites in the basin. In Wide Hollow Creek, cadmium concentrations in *Hydropsyche californica*, a caddisfly species, increased threefold from the upstream site (0.07 μg/g) to the downstream site. This increase probably resulted from larger proportions of urban area at the downstream site.

In streambed sediment of the Kittitas Valley, human activities have been shown, in some instances, to affect arsenic concentrations that result from geologic sources. In filtered water, suspended sediment, and aquatic biota of the mid- and lower Yakima Valley, however, human activities can increase arsenic concentrations in addition to arsenic loads. As with lead, sources of arsenic in the mid-Yakima and lower Yakima Valley included lead-arsenate pesticides that have been applied historically to apple orchards. Consequently, agricultural drains seemed to be good indicators of past arsenic use. Suspended-arsenic concentrations in Sulphur Creek Wasteway, an agricultural drain, were the highest in the basin; these arsenic concentrations ranged from 4.9 to 20 μg/g. The annual suspended-arsenic loads during 1987–90 between the Kittitas Valley and the mid-Yakima Valley increased as much as threefold. During the irrigation season, in particular, about 2.2 pounds of suspended arsenic per day entered the mid-Yakima Valley over a 9.4-mile reach that receives irrigation return flow from Moxee Subbasin and Wide Hollow Subbasin. This arsenic load represents about one-half the irrigation-season load in the Yakima River above Ahtanum Creek at Union Gap. Irrigation drains probably are large contributors over this reach—Moxee Drain is estimated to contribute nearly 1 pound of suspended arsenic per day. During the irrigation season in the lower Yakima Valley, the June contributions of suspended arsenic (2 pounds per day) from Sulphur Creek Wasteway typically account for most of the suspended-arsenic load in the Yakima River at Euclid Bridge at RM 55 near

Grandview—located 6 miles downstream from Sulphur Creek Wasteway.

Concentrations of arsenic in filtered-water samples in Sulphur Creek Wasteway and in the main stem of the lower Yakima Valley were high (exceeded the 90th percentile (3 µg/L) for the Yakima River Basin) in comparison to fixed sites (less than 1 µg/L) in the Kittitas Valley. These high concentrations were found in waters affected primarily by agricultural return flow. In addition to higher concentrations of arsenic in filtered-water samples from agriculturally affected portions of the basin, the load of arsenic in agricultural drains probably represents a large proportion of the arsenic load passing the Yakima River at Kiona, the terminus of the basin. Sulphur Creek Wasteway, for example, has an annual streamflow representing only about 8 percent of the annual streamflow at the Kiona fixed site, yet accounts for nearly 20 percent of the filtered-arsenic load at Kiona. Comparisons, between loads determined from filtered-water samples (an operational approximation of dissolved load) and loads determined from arsenic in suspended sediment, showed that most of the arsenic load in the basin is in dissolved form. For example, the annual dissolved-arsenic loads in the lower Yakima Valley at Sulphur Creek Wasteway, Grandview, and Kiona sites were from 4 to 9 times higher than their respective suspended loads.

Arsenic also was present in aquatic biota in the Yakima River Basin. In curlyleaf pondweed, an aquatic plant, concentrations ranged from 0.48 to 1.5 µg/g and were 3 times higher in the main stem of the lower Yakima Valley than in the main stem of the Kittitas Valley. Concentrations of arsenic in caddisflies, collected from agricultural drains in 1989 in the lower Yakima Valley, were as large as 5.4 µg/g and exceeded the 85th-percentile concentration for the basin. Asiatic clams were collected only from the lower Yakima Valley, and arsenic concentrations (3.6 to 4.6 µg/g) varied little among sites. Compared to other studies, however, arsenic concentrations in Asiatic clams of the lower Yakima Valley were as much as an order of magnitude greater than in clams in uncontaminated or minimally contaminated environments.

Fish taxa provided the most comprehensive spatial coverage for arsenic, mercury, and selenium; however, no single fish taxon was distributed widely across the Yakima River Basin. The aquatic insect taxon *Hydropsyche* spp. (caddisfly) provides the most comprehensive spatial coverage of any single insect taxon. Concentrations of several trace elements, including cadmium, mercury, and selenium, in various taxa were higher in the main stem of the lower Yakima Valley than in the Kittitas and mid-Yakima Valley. In mountain whitefish livers from the lower Yakima Valley, the concentration of mercury in the Yakima River at Parker (1.3 µg/g) and of selenium in the Yakima River at Kiona (15 µg/g) was nearly twice that measured in mountain whitefish in the Kittitas Valley at the Cle Elum site. Similar patterns also were observed for largescale suckers. Compared to other studies of mercury in liver tissue of pike and mudfish, mercury concentrations in some mountain whitefish in the lower Yakima Valley were indicative of moderate enrichment. The concentration of selenium in sculpin (5.5 µg/g) in the northeastern Cascade Range was about 10 times higher than in Satus Creek, a lower Yakima Valley tributary. Concentrations of selenium in sculpin in the Yakima River Basin (mean and 85th-percentile values) also exceeded those for sculpin in the National Contaminant Biomonitoring Program. Because no single fish species is pervasive throughout the Yakima River Basin, mountain whitefish were good indicators of selenium enrichment in the lower Yakima Valley (where they reside), and sculpin are good indicators of selenium enrichment at sites in close proximity to geologic sources in the northeastern Cascade Range.

***Implications for water-resource monitoring and regulation***—Trace elements that should be considered as part of future water-resource monitoring in the Yakima River Basin include arsenic, cadmium, chromium, copper, lead, nickel, mercury, selenium, and zinc. Some of these trace elements in streams (for example, chromium) are primarily from geologic sources; some (for example, lead) are primarily from anthropogenic sources; and others (for example, arsenic, copper, and zinc) are from both sources. Thus, because sources of trace elements may vary, monitoring-design strategies may need to vary among subbasin(s).

The presence of anomalous concentrations of arsenic, lead, and zinc in streambed sediment of agricultural lands and soils in the mid-Yakima and lower Yakima Valley indicates that agricultural practices are a source of arsenic, lead, and zinc to streambed sediment—particularly, agricultural practices that tend to facilitate soil loss or erosion. Additionally, the presence of arsenic in filtered-water samples from Sulphur Creek Wasteway near Sunnyside (the only agricultural drain sampled) indicates that other agricultural drains may be sources of arsenic to the lower Yakima Valley. Similarly, the presence of arsenic in Sulphur Creek

Wasteway, especially the presence of higher arsenic concentrations during the nonirrigation season, indicates that shallow ground water in areas of intense irrigation, although not measured, also may be affected by arsenic.

The screening of ambient water-quality data in the Yakima River Basin was done in order to assist State and local health agencies in the identification of element concentrations that may require further study. Concentrations of arsenic in ambient stream water in the lower Yakima Valley frequently exceeded the screening values based on USEPA's ambient stream-water-quality criteria and USEPA human-health advisories for drinking water. These exceedances primarily are associated with waterways affected by irrigation return flow and may be indicative of shallow ground-water quality in some agricultural areas or subbasins.

Concentrations of mercury in fish muscle also frequently exceeded screening values based on USEPA's guidance document for assessing chemical contaminant data for use in fish advisories. Depending on the quantity of fish consumed by individuals, the concentration of mercury in fish muscle exceeded the screening value for standard adults, children, recreational fishermen, and subsistence fishermen. Relative to future monitoring activities, the measurement of mercury in streambed sediment was not a sensitive indicator of mercury uptake by biota in the lower Yakima Valley; rather, fish-liver and fish-muscle samples were the preferred sample media.

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# SUPPLEMENTAL DATA TABLES

**Table 34.** Comparison of selected element concentrations in streambed-sediment samples of the Yakima River Basin to streambed-sediment samples in the lower Kansas River Basin, upper Illinois River Basin, and the Kentucky River Basin

[Concentrations are in micrograms per gram, dry weight, except for iron, which is in percent. Sample collection, processing, and analytical protocols are identical among river basins (Sanzolone and Ryder, 1989). Statistical summaries are based on sampling sites selected randomly using a Universal-Transverse-Mercator, square-grid-sampling procedure. Biological-sampling sites in the Yakima River Basin, however, were not selected randomly; lower order streams are defined as first- or second-order tributaries, with the smallest unbranched-mapped (1:24,000 map scale) tributaries classified as first-order tributaries and streams receiving only first-order tributaries classified as second-order tributaries (Horton, 1945); --, no data; <, less than]

| | Lower Kansas[1] | | | Upper Illinois[2] | | | Kentucky[3] | | | Yakima | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lower order stream sites | | | | | | | | | Biological sites[4] | | | Lower order stream sites[5] | | |
| | Percentiles | | | Percentiles | | | Percentiles | | | Percentiles | | | Percentiles | | |
| **Element** | **10th** | **50th** | **90th** | **10th** | **50th** | **90th** | **10th** | **50th** | **90th** | **10th** | **50th** | **90th** | **10th** | **50th** | **90th** |
| Antimony | 0.5 | 0.7 | 1.0 | 0.4 | 0.7 | 1.1 | 0.3 | 0.5 | 1.0 | 0.3 | 0.4 | 0.9 | 0.2 | 0.4 | 0.7 |
| Arsenic | 4.5 | 6.4 | 11 | 5.4 | 9.3 | 21 | 4.7 | 6.7 | 13 | 1.5 | 3.7 | 11.9 | 1.5 | 3.6 | 10 |
| Beryllium | 1 | 2 | 2 | <1 | 2 | 2 | 1 | 2 | 3 | 1 | 1 | 2 | 1 | 1 | 2 |
| Cadmium | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | .18 | .18 | .50 | <2 | <2 | <2 |
| Chromium | 38 | 45 | 57 | 41 | 56 | 74 | 42 | 62 | 86 | 44 | 62 | 167 | 31 | 52 | 110 |
| | | | | | | | | | | | | | | | |
| Cobalt | 8 | 11 | 21 | 9 | 13 | 20 | 13 | 20 | 32 | 16 | 20 | 30 | 14 | 20 | 31 |
| Copper | 12 | 15 | 19 | 17 | 23 | 35 | 12 | 20 | 32 | 21 | 30 | 70 | 20 | 27 | 43 |
| Iron | 1.8 | 2.2 | 2.8 | 2.2 | 2.9 | 4.1 | 2.5 | 3.5 | 4.7 | 4.3 | 5.1 | 6.6 | 3.8 | 5.0 | 7.0 |
| Lead | 17 | 20 | 29 | 19 | 27 | 53 | 19 | 27 | 42 | 11 | 14 | 32 | 9 | 13 | 22 |
| Manganese | 330 | 550 | 1,400 | 520 | 680 | 1,400 | 680 | 1,300 | 3,400 | 759 | 1,015 | 1,470 | 640 | 940 | 1,400 |
| | | | | | | | | | | | | | | | |
| Mercury | <.02 | <.02 | .04 | .02 | .04 | .12 | <.02 | .04 | .06 | <.02 | .1 | .3 | <.02 | <.02 | .10 |
| Nickel | 14 | 18 | 29 | 17 | 26 | 35 | 18 | 30 | 49 | 17 | 27 | 82 | 13 | 20 | 48 |
| Selenium | -- | -- | -- | .4 | .7 | 1.3 | -- | -- | -- | <.4 | .4 | .9 | <.1 | .4 | 1 |
| Silver | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | < 2 | <2 | <2 |
| Zinc | 44 | 56 | 79 | 67 | 100 | 240 | 56 | 91 | 150 | 84 | 100 | 168 | 70 | 91 | 130 |

[1] Tanner and others, 1990.

[2] Colman and Sanzolone, 1991.

[3] Ryder and others, 1993.

[4] Fuhrer, Fluter, and others, 1994.

[5] Ryder and others, 1992.

**Table 35.** Distribution of major- and trace-element concentrations in suspended sediment at fixed sites, Yakima River Basin, Washington, 1987–90

[To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate at a site, only one element concentration per visit was statistically summarized. Concentrations of major elements are reported as percentages, except suspended organic carbon, which is reported as milligrams per liter; concentrations of trace elements are reported as micrograms per gram, dry weight; element names shown in bold print are U.S. Environmental Protection Agency (1992c) Priority Pollutants; Cle Elum, Yakima River at Cle Elum; Umtanum, Yakima River at Umtanum; Naches, Naches River near North Yakima; Union Gap, Yakima River above Ahtanum Creek at Union Gap; Sulphur Creek, Sulphur Creek Wasteway near Sunnyside; Grandview, Yakima River at Euclid Bridge at river mile 55 near Grandview; Kiona, Yakima River at Kiona; <, less than]

| Site reference number | Site name | Number of samples | Minimum value | Value at indicated percentile | | | | | | Maximum value |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 10 | 25 | 50 | 75 | 90 | 95 | |
| MAJOR ELEMENTS | | | | | | | | | | |
| Aluminum | | | | | | | | | | |
| 6 | Cle Elum | 11 | 7.5 | 7.6 | 8.3 | 8.5 | 9.0 | 9.1 | 9.2 | 9.2 |
| 19 | Umtanum | 32 | 5.8 | 5.8 | 6.4 | 6.9 | 7.4 | 7.8 | 8.7 | 9.7 |
| 26 | Naches | 20 | 5.2 | 5.4 | 6.4 | 7.5 | 7.8 | 8.0 | 8.6 | 8.7 |
| 32 | Union Gap | 35 | 4.6 | 6.1 | 6.5 | 7.0 | 7.3 | 7.6 | 7.7 | 8.0 |
| 50 | Kiona | 44 | 6.3 | 6.4 | 6.5 | 6.8 | 7.0 | 7.3 | 7.4 | 7.4 |
| 52 | Sulphur Creek | 40 | 5.6 | 6.3 | 6.6 | 7.0 | 7.2 | 7.4 | 7.6 | 7.6 |
| 56 | Grandview | 37 | 6.3 | 6.5 | 6.7 | 6.9 | 7.0 | 7.2 | 7.4 | 7.5 |
| Calcium | | | | | | | | | | |
| 6 | Cle Elum | 11 | 1.2 | 1.3 | 1.6 | 1.8 | 1.9 | 2.0 | 2.0 | 2.0 |
| 19 | Umtanum | 32 | 1.5 | 1.6 | 1.7 | 1.9 | 2.0 | 2.0 | 2.4 | 2.9 |
| 26 | Naches | 20 | 1.4 | 1.8 | 1.9 | 2.3 | 2.5 | 2.8 | 2.9 | 2.9 |
| 32 | Union Gap | 35 | 1.3 | 1.7 | 1.9 | 2.0 | 2.2 | 2.5 | 2.5 | 2.6 |
| 50 | Kiona | 44 | 1.9 | 2.0 | 2.1 | 2.2 | 2.2 | 2.3 | 2.3 | 2.4 |
| 52 | Sulphur Creek | 40 | 2.3 | 2.5 | 2.7 | 2.9 | 3.0 | 3.1 | 3.5 | 3.5 |
| 56 | Grandview | 37 | 2.1 | 2.2 | 2.2 | 2.2 | 2.3 | 2.4 | 2.5 | 2.5 |
| Carbon, suspended organic | | | | | | | | | | |
| 6 | Cle Elum | 15 | <.1 | <.1 | .1 | .3 | .5 | 1.1 | 1.9 | 1.9 |
| 19 | Umtanum | 31 | .1 | .2 | .3 | .4 | .6 | 1.2 | 1.8 | 1.9 |
| 26 | Naches | 22 | .2 | .2 | .3 | .4 | 1.2 | 2.7 | 4.1 | 4.3 |
| 32 | Union Gap | 32 | <.1 | .1 | .3 | .6 | 1.0 | 3.1 | 4.8 | 4.9 |
| 50 | Kiona | 40 | .1 | .2 | .4 | .6 | 1.3 | 2.4 | 2.7 | 2.8 |
| 52 | Sulphur Creek | 36 | .2 | .6 | .7 | 1.3 | 1.9 | 3.0 | 3.6 | 3.9 |
| 56 | Grandview | 34 | .4 | .4 | .6 | .7 | 1.0 | 2.1 | 3.1 | 3.6 |
| Iron | | | | | | | | | | |
| 6 | Cle Elum | 11 | 4.0 | 4.1 | 5.1 | 5.4 | 5.8 | 5.9 | 5.9 | 5.9 |
| 19 | Umtanum | 32 | 4.3 | 4.5 | 4.7 | 4.9 | 5.4 | 5.7 | 5.9 | 6.3 |
| 26 | Naches | 20 | 3.8 | 4.2 | 4.8 | 5.0 | 5.3 | 5.6 | 5.8 | 5.8 |
| 32 | Union Gap | 35 | 3.9 | 4.5 | 4.8 | 5.0 | 5.2 | 5.4 | 5.6 | 6.4 |
| 50 | Kiona | 44 | 4.9 | 5.1 | 5.2 | 5.4 | 5.6 | 5.9 | 6.2 | 8.1 |
| 52 | Sulphur Creek | 40 | 4.6 | 4.7 | 4.8 | 5.2 | 5.4 | 5.6 | 5.7 | 5.9 |
| 56 | Grandview | 37 | 4.9 | 5.1 | 5.3 | 5.5 | 5.7 | 6.0 | 6.4 | 7.5 |

**Table 35.** Distribution of major- and trace-element concentrations in suspended sediment at fixed sites, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Number of samples | Minimum value | Value at indicated percentile | | | | | | Maximum value |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 10 | 25 | 50 | 75 | 90 | 95 | |
| Magnesium | | | | | | | | | | |
| 6 | Cle Elum | 11 | 1.1 | 1.2 | 1.7 | 1.8 | 1.9 | 1.9 | 1.9 | 1.9 |
| 19 | Umtanum | 32 | 1.1 | 1.2 | 1.3 | 1.5 | 1.6 | 1.9 | 2.2 | 2.4 |
| 26 | Naches | 20 | .8 | .9 | .9 | 1.0 | 1.2 | 1.3 | 1.5 | 1.5 |
| 32 | Union Gap | 34 | 1.0 | 1.1 | 1.2 | 1.2 | 1.3 | 1.4 | 1.4 | 1.4 |
| 50 | Kiona | 44 | 1.2 | 1.2 | 1.3 | 1.3 | 1.4 | 1.4 | 1.4 | 1.4 |
| 52 | Sulphur Creek | 40 | 1.3 | 1.3 | 1.4 | 1.4 | 1.5 | 1.5 | 1.5 | 1.6 |
| 56 | Grandview | 37 | 1.2 | 1.3 | 1.3 | 1.4 | 1.4 | 1.5 | 1.5 | 1.5 |
| Phosphorus | | | | | | | | | | |
| 6 | Cle Elum | 11 | .14 | .14 | .14 | .15 | .15 | .16 | .16 | .16 |
| 19 | Umtanum | 32 | .11 | .11 | .13 | .15 | .16 | .19 | .20 | .21 |
| 26 | Naches | 20 | .10 | .11 | .12 | .13 | .15 | .20 | .22 | .22 |
| 32 | Union Gap | 35 | .12 | .13 | .14 | .15 | .19 | .22 | .32 | .34 |
| 50 | Kiona | 44 | .14 | .15 | .16 | .18 | .20 | .22 | .23 | 1.2 |
| 52 | Sulphur Creek | 39 | .11 | .12 | .13 | .16 | .22 | .27 | .29 | .33 |
| 56 | Grandview | 37 | .14 | .15 | .16 | .17 | .18 | .20 | .20 | .21 |
| Potassium | | | | | | | | | | |
| 6 | Cle Elum | 11 | .90 | .92 | 1.1 | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 |
| 19 | Umtanum | 32 | .70 | .89 | .90 | .98 | 1.0 | 1.1 | 1.3 | 1.4 |
| 26 | Naches | 20 | .70 | .73 | .82 | .97 | 1.1 | 1.3 | 1.5 | 1.6 |
| 32 | Union Gap | 35 | .73 | .81 | .90 | 1.0 | 1.2 | 1.3 | 1.3 | 1.4 |
| 50 | Kiona | 44 | 1.1 | 1.1 | 1.2 | 1.3 | 1.3 | 1.4 | 1.4 | 1.5 |
| 52 | Sulphur Creek | 40 | 1.3 | 1.4 | 1.5 | 1.6 | 1.6 | 1.7 | 1.7 | 2.4 |
| 56 | Grandview | 37 | 1.1 | 1.2 | 1.2 | 1.3 | 1.4 | 1.4 | 1.5 | 1.5 |
| Sodium | | | | | | | | | | |
| 6 | Cle Elum | 11 | 1.0 | 1.0 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.6 |
| 19 | Umtanum | 32 | .8 | 1.0 | 1.1 | .13 | 1.4 | 1.6 | 2.0 | 2.4 |
| 26 | Naches | 20 | .9 | .9 | 1.1 | 1.3 | 1.5 | 1.7 | 1.8 | 1.8 |
| 32 | Union Gap | 35 | .8 | 1.0 | 1.1 | 1.3 | 1.5 | 1.7 | 1.7 | 1.8 |
| 50 | Kiona | 44 | 1.0 | 1.1 | 1.2 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 |
| 52 | Sulphur Creek | 40 | .9 | 1.0 | 1.2 | 1.4 | 1.6 | 1.7 | 1.8 | 1.8 |
| 56 | Grandview | 37 | 1.0 | 1.1 | 1.2 | 1.3 | 1.4 | 1.4 | 1.6 | 1.6 |

**Table 35**. Distribution of major- and trace-element concentrations in suspended sediment at fixed sites, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Number of samples | Minimum value | Value at indicated percentile | | | | | | Maximum value |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 10 | 25 | 50 | 75 | 90 | 95 | |
| | | | | Titanium | | | | | | |
| 6 | Cle Elum | 11 | 0.50 | 0.52 | 0.60 | 0.66 | 0.71 | 0.76 | 0.76 | 0.76 |
| 19 | Umtanum | 32 | .45 | .48 | .51 | .54 | .58 | .61 | .71 | .83 |
| 26 | Naches | 20 | .41 | .46 | .48 | .55 | .60 | .64 | .65 | .65 |
| 32 | Union Gap | 35 | .37 | .48 | .51 | .54 | .58 | .63 | .67 | .67 |
| 50 | Kiona | 44 | .57 | .58 | .59 | .61 | .63 | .68 | .71 | .74 |
| 52 | Sulphur Creek | 40 | .54 | .61 | .62 | .64 | .65 | .68 | .71 | .71 |
| 56 | Grandview | 37 | .58 | .60 | .61 | .63 | .68 | .73 | .76 | .79 |
| | | | | **TRACE ELEMENTS**<br>Antimony | | | | | | |
| 6 | Cle Elum | 11 | .6 | .6 | .7 | .8 | 2.3 | 3.0 | 3.1 | 3.1 |
| 19 | Umtanum | 32 | .3 | .4 | .5 | .6 | .7 | .8 | .8 | .9 |
| 26 | Naches | 20 | .5 | .5 | .5 | .6 | .6 | 1.0 | 1.2 | 1.2 |
| 32 | Union Gap | 35 | .4 | .5 | .5 | .5 | .6 | .7 | .9 | 1.1 |
| 50 | Kiona | 44 | .4 | .5 | .5 | .6 | .6 | .8 | .9 | 1.2 |
| 52 | Sulphur Creek | 40 | .5 | .6 | .6 | .7 | .8 | .8 | .9 | .9 |
| 56 | Grandview | 37 | .3 | .4 | .5 | .6 | .6 | .7 | .8 | 1.2 |
| | | | | **Arsenic** | | | | | | |
| 6 | Cle Elum | 11 | 6.3 | 6.3 | 6.6 | 7.0 | 7.9 | 8.7 | 8.8 | 8.8 |
| 19 | Umtanum | 32 | 2.8 | 3.9 | 4.4 | 5.1 | 6.0 | 6.3 | 7.1 | 7.4 |
| 26 | Naches | 20 | 4.4 | 4.7 | 5.4 | 6.3 | 8.5 | 12 | 13 | 13 |
| 32 | Union Gap | 35 | 4.2 | 4.4 | 5.0 | 5.3 | 6.4 | 7.9 | 10 | 11 |
| 50 | Kiona | 44 | 5.1 | 5.4 | 6.0 | 7.0 | 7.9 | 9.6 | 10 | 11 |
| 52 | Sulphur Creek | 40 | 4.9 | 5.9 | 6.8 | 10 | 14 | 16 | 19 | 20 |
| 56 | Grandview | 37 | 5.0 | 5.2 | 6.0 | 7.1 | 8.7 | 9.3 | 9.9 | 11 |
| | | | | **Beryllium** | | | | | | |
| 6 | Cle Elum | 11 | <2 | <2 | <2 | <2 | <2 | <2 | 2 | 2 |
| 19 | Umtanum | 32 | <2 | <2 | <2 | <2 | <2 | <2 | 2 | 2 |
| 26 | Naches | 20 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 |
| 32 | Union Gap | 35 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | 2 |
| 50 | Kiona | 44 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | 2 |
| 52 | Sulphur Creek | 40 | <2 | <2 | <2 | 2 | 2 | 2 | 2 | 3 |
| 56 | Grandview | 37 | <2 | <2 | <2 | <2 | <2 | 2 | 2 | 2 |

**Table 35.** Distribution of major- and trace-element concentrations in suspended sediment at fixed sites, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Number of samples | Minimum value | Value at indicated percentile | | | | | | Maximum value |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 10 | 25 | 50 | 75 | 90 | 95 | |
| **Cadmium** | | | | | | | | | | |
| 6 | Cle Elum | 11 | 0.3 | 0.3 | 0.6 | 0.8 | 2.6 | 8.0 | 9.3 | 9.3 |
| 19 | Umtanum | 32 | <.1 | 2 | 3 | .5 | .8 | 1.7 | 3 | 33 |
| 26 | Naches | 20 | .1 | .1 | .4 | .7 | 1.4 | 2.7 | 4.4 | 4.5 |
| 32 | Union Gap | 35 | .1 | 2 | 3 | .4 | .6 | 1.0 | 1.3 | 1.5 |
| 50 | Kiona | 44 | <.1 | 2 | 3 | .4 | .7 | 2.1 | 4.6 | 15 |
| 52 | Sulphur Creek | 40 | <.1 | 2 | 2 | .4 | .5 | .8 | 1.5 | 1.7 |
| 56 | Grandview | 37 | <.1 | 2 | .4 | .6 | .8 | 1.3 | 1.7 | 2.6 |
| **Chromium** | | | | | | | | | | |
| 6 | Cle Elum | 10 | 110 | 110 | 110 | 110 | 120 | 130 | 140 | 140 |
| 19 | Umtanum | 29 | 59 | 73 | 81 | 100 | 120 | 150 | 160 | 160 |
| 26 | Naches | 19 | 28 | 30 | 35 | 42 | 48 | 65 | 83 | 83 |
| 32 | Union Gap | 32 | 43 | 53 | 58 | 70 | 79 | 88 | 90 | 90 |
| 50 | Kiona | 38 | 53 | 55 | 56 | 58 | 62 | 85 | 93 | 110 |
| 52 | Sulphur Creek | 33 | 41 | 46 | 50 | 53 | 56 | 61 | 72 | 89 |
| 56 | Grandview | 31 | 54 | 56 | 58 | 61 | 66 | 94 | 110 | 110 |
| Cobalt | | | | | | | | | | |
| 6 | Cle Elum | 11 | 20 | 20 | 23 | 25 | 26 | 28 | 28 | 28 |
| 19 | Umtanum | 32 | 16 | 19 | 20 | 22 | 25 | 26 | 28 | 28 |
| 26 | Naches | 20 | 13 | 15 | 17 | 18 | 20 | 22 | 23 | 23 |
| 32 | Union Gap | 35 | 16 | 18 | 18 | 19 | 21 | 22 | 23 | 25 |
| 50 | Kiona | 44 | 18 | 18 | 20 | 20 | 22 | 23 | 25 | 31 |
| 52 | Sulphur Creek | 40 | 17 | 18 | 19 | 21 | 22 | 23 | 24 | 25 |
| 56 | Grandview | 37 | 19 | 19 | 20 | 21 | 22 | 23 | 24 | 28 |
| **Copper** | | | | | | | | | | |
| 6 | Cle Elum | 11 | 47 | 47 | 54 | 60 | 67 | 70 | 70 | 70 |
| 19 | Umtanum | 32 | 31 | 34 | 39 | 43 | 54 | 61 | 67 | 73 |
| 26 | Naches | 20 | 26 | 28 | 40 | 46 | 54 | 75 | 78 | 78 |
| 32 | Union Gap | 35 | 33 | 40 | 42 | 49 | 65 | 93 | 120 | 150 |
| 50 | Kiona | 44 | 32 | 38 | 39 | 43 | 53 | 120 | 440 | 680 |
| 52 | Sulphur Creek | 40 | 21 | 27 | 31 | 44 | 63 | 110 | 80 | 210 |
| 56 | Grandview | 37 | 29 | 32 | 37 | 40 | 44 | 52 | 56 | 74 |

**Table 35.** Distribution of major- and trace-element concentrations in suspended sediment at fixed sites, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Number of samples | Minimum value | Value at indicated percentile | | | | | | Maximum value |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 10 | 25 | 50 | 75 | 90 | 95 | |
| | | | | **Lead** | | | | | | |
| 6 | Cle Elum | 11 | 12 | 12 | 12 | 17 | 24 | 110 | 120 | 120 |
| 19 | Umtanum | 32 | 6 | 10 | 12 | 15 | 20 | 26 | 160 | 410 |
| 26 | Naches | 20 | 10 | 11 | 14 | 18 | 23 | 26 | 45 | 46 |
| 32 | Union Gap | 35 | 11 | 12 | 15 | 18 | 25 | 29 | 31 | 33 |
| 50 | Kiona | 44 | 10 | 15 | 17 | 20 | 22 | 24 | 25 | 28 |
| 52 | Sulphur Creek | 40 | 13 | 17 | 20 | 24 | 26 | 28 | 41 | 43 |
| 56 | Grandview | 37 | 11 | 14 | 16 | 19 | 24 | 26 | 29 | 31 |
| | | | | Manganese | | | | | | |
| 6 | Cle Elum | 11 | 1,400 | 1,400 | 1,500 | 1,600 | 2,000 | 2,500 | 2,600 | 2,600 |
| 19 | Umtanum | 32 | 1,100 | 1,200 | 1,400 | 1,700 | 2,200 | 2,600 | 3,200 | 3,700 |
| 26 | Naches | 20 | 1,200 | 1,300 | 1,300 | 1,500 | 2,100 | 3,300 | 3,600 | 3,600 |
| 32 | Union Gap | 35 | 1,100 | 1,200 | 1,300 | 1,600 | 2,300 | 2,900 | 3,000 | 3,100 |
| 50 | Kiona | 44 | 1,200 | 1,600 | 1,700 | 2,600 | 3,100 | 3,900 | 4,100 | 4,600 |
| 52 | Sulphur Creek | 40 | 910 | 950 | 1,000 | 1,500 | 2,800 | 4,100 | 5,200 | 5,400 |
| 56 | Grandview | 37 | 1,200 | 1,400 | 2,000 | 2,900 | 3,300 | 4000 | 4,500 | 6,300 |
| | | | | Molybdenum | | | | | | |
| 6 | Cle Elum | 11 | <.1 | .2 | .7 | .7 | .9 | 1.2 | 1.3 | 1.3 |
| 19 | Umtanum | 32 | <.1 | .2 | .5 | .6 | .6 | .7 | .8 | .9 |
| 26 | Naches | 20 | <.1 | .6 | .7 | .8 | 1.0 | 1.1 | 1.2 | 1.2 |
| 32 | Union Gap | 35 | <.1 | .3 | .6 | .7 | .8 | 1.2 | 1.6 | 3.0 |
| 50 | Kiona | 44 | <.1 | <.1 | .6 | .6 | .7 | .8 | .8 | 1.0 |
| 52 | Sulphur Creek | 40 | <.1 | <.1 | .6 | .7 | 1.3 | 1.7 | 1.7 | 2.0 |
| 56 | Grandview | 37 | <.1 | <.1 | <.1 | .6 | .8 | .8 | 1.0 | 1.8 |
| | | | | **Nickel** | | | | | | |
| 6 | Cle Elum | 10 | 62 | 62 | 66 | 72 | 76 | 120 | 130 | 130 |
| 19 | Umtanum | 29 | 43 | 61 | 69 | 89 | 100 | 140 | 160 | 170 |
| 26 | Naches | 19 | 12 | 14 | 16 | 17 | 21 | 30 | 41 | 41 |
| 32 | Union Gap | 32 | 26 | 31 | 38 | 46 | 56 | 62 | 66 | 71 |
| 50 | Kiona | 38 | 28 | 30 | 33 | 36 | 39 | 44 | 49 | 52 |
| 52 | Sulphur Creek | 33 | 18 | 23 | 24 | 27 | 30 | 33 | 33 | 34 |
| 56 | Grandview | 31 | 28 | 29 | 34 | 37 | 38 | 41 | 42 | 43 |

**Table 35.** Distribution of major- and trace-element concentrations in suspended sediment at fixed sites, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Number of samples | Minimum value | Value at indicated percentile | | | | | | Maximum value |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 10 | 25 | 50 | 75 | 90 | 95 | |
| **Silver** | | | | | | | | | | |
| 6 | Cle Elum | 11 | 0.2 | 0.2 | 0.3 | 0.4 | 0.5 | 0.8 | 0.9 | 0.9 |
| 19 | Umtanum | 32 | .2 | .2 | .2 | .2 | .3 | .7 | 3.8 | 7.7 |
| 26 | Naches | 20 | <.1 | .1 | .2 | .2 | .3 | .4 | .6 | .6 |
| 32 | Union Gap | 35 | .2 | .3 | .3 | .5 | 1.0 | 1.4 | 1.7 | 2.0 |
| 50 | Kiona | 44 | .2 | .3 | .4 | .4 | .5 | .6 | .8 | .8 |
| 52 | Sulphur Creek | 40 | .2 | .2 | .3 | .4 | .8 | 1.4 | 2.4 | 2.5 |
| 56 | Grandview | 37 | .2 | .2 | .4 | .4 | .5 | .6 | .6 | .8 |
| **Thallium** | | | | | | | | | | |
| 6 | Cle Elum | 11 | .3 | .3 | .3 | .3 | .4 | .5 | .5 | .5 |
| 19 | Umtanum | 32 | .2 | .2 | .2 | .3 | .3 | .3 | .4 | .4 |
| 26 | Naches | 20 | .2 | .2 | .2 | .3 | .4 | .4 | .5 | .5 |
| 32 | Union Gap | 35 | .1 | .2 | .3 | .3 | .4 | .4 | .4 | .4 |
| 50 | Kiona | 44 | .2 | .3 | .3 | .4 | .4 | .4 | .5 | .5 |
| 52 | Sulphur Creek | 40 | .3 | .4 | .4 | .4 | .5 | .5 | .6 | .6 |
| 56 | Grandview | 37 | .3 | .3 | .3 | .4 | .4 | .5 | .5 | .6 |
| Vanadium | | | | | | | | | | |
| 6 | Cle Elum | 11 | 120 | 120 | 140 | 160 | 170 | 170 | 170 | 170 |
| 19 | Umtanum | 32 | 110 | 120 | 120 | 130 | 140 | 150 | 160 | 170 |
| 26 | Naches | 20 | 110 | 110 | 120 | 130 | 140 | 160 | 170 | 170 |
| 32 | Union Gap | 35 | 100 | 120 | 120 | 130 | 140 | 140 | 150 | 150 |
| 50 | Kiona | 44 | 130 | 130 | 140 | 140 | 140 | 150 | 160 | 190 |
| 52 | Sulphur Creek | 40 | 140 | 140 | 140 | 150 | 160 | 170 | 170 | 170 |
| 56 | Grandview | 37 | 130 | 140 | 140 | 150 | 150 | 160 | 180 | 190 |
| **Zinc** | | | | | | | | | | |
| 6 | Cle Elum | 10 | 140 | 140 | 160 | 190 | 230 | 490 | 520 | 520 |
| 19 | Umtanum | 29 | 95 | 98 | 130 | 140 | 180 | 250 | 380 | 380 |
| 26 | Naches | 19 | 91 | 110 | 120 | 120 | 140 | 170 | 180 | 180 |
| 32 | Union Gap | 32 | 110 | 120 | 140 | 150 | 170 | 220 | 250 | 300 |
| 50 | Kiona | 38 | 100 | 120 | 130 | 150 | 170 | 180 | 260 | 350 |
| 52 | Sulphur Creek | 33 | 88 | 97 | 110 | 140 | 180 | 200 | 210 | 220 |
| 56 | Grandview | 31 | 110 | 110 | 120 | 130 | 150 | 180 | 190 | 200 |

**Table 35.** Distribution of major- and trace-element concentrations in suspended sediment at fixed sites, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Number of samples | Minimum value | Value at indicated percentile | | | | | | Maximum value |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 10 | 25 | 50 | 75 | 90 | 95 | |
| | | | | | | | | | | |
| **OTHER MEASUREMENTS**<br>**Discharge, in cubic feet per second** | | | | | | | | | | |
| 6 | Cle Elum | 17 | 442 | 626 | 1,100 | 1,440 | 2,550 | 3,610 | 3,610 | 3,610 |
| 19 | Umtanum | 35 | 454 | 907 | 1,230 | 1,910 | 3,450 | 3,850 | 4,290 | 5,600 |
| 26 | Naches | 23 | 285 | 453 | 680 | 1,470 | 2,500 | 3,830 | 4,720 | 4,910 |
| 32 | Union Gap | 36 | 678 | 1,320 | 1,870 | 2,980 | 3,580 | 7,280 | 8,920 | 8,940 |
| 50 | Kiona | 44 | 1,040 | 1,200 | 1,480 | 2,325 | 3,300 | 5,095 | 6,360 | 7,170 |
| 52 | Sulphur Creek | 40 | 57 | 66 | 73 | 205 | 255 | 348 | 384 | 422 |
| 56 | Grandview | 37 | 1,100 | 1,230 | 1,500 | 2,270 | 2,940 | 4,380 | 4,800 | 4,940 |
| **Surface area, in square meters per gram** | | | | | | | | | | |
| 6 | Cle Elum | 16 | 6.40 | 7.04 | 8.72 | 11.1 | 13.2 | 19.8 | 26.5 | 26.5 |
| 19 | Umtanum | 34 | 4.32 | 9.90 | 13.7 | 17.2 | 20.9 | 32.7 | 34.0 | 35.1 |
| 26 | Naches | 23 | 5.82 | 10.1 | 12.1 | 18.9 | 24.3 | 31.2 | 32.3 | 32.4 |
| 32 | Union Gap | 35 | 8.14 | 13.0 | 15.3 | 17.6 | 22.8 | 27.5 | 32.5 | 48.5 |
| 50 | Kiona | 44 | 13.6 | 15.3 | 17.7 | 21.6 | 27.0 | 36.0 | 40.7 | 63.7 |
| 52 | Sulphur Creek | 40 | 5.09 | 6.84 | 9.58 | 14.3 | 19.8 | 23.4 | 25.4 | 32.1 |
| 56 | Grandview | 37 | 1.11 | 13.8 | 17.4 | 23.5 | 28.7 | 34.2 | 39.3 | 57.0 |
| **Streambed sediment finer than 62 micrograms, in percent** | | | | | | | | | | |
| 6 | Cle Elum | 17 | 45 | 47 | 71 | 91 | 95 | 99 | 100 | 100 |
| 19 | Umtanum | 34 | 34 | 62 | 76 | 84 | 89 | 95 | 96 | 96 |
| 26 | Naches | 23 | 56 | 63 | 74 | 87 | 92 | 96 | 98 | 98 |
| 32 | Union Gap | 34 | 27 | 64 | 82 | 90 | 93 | 96 | 96 | 98 |
| 50 | Kiona | 39 | 60 | 86 | 90 | 93 | 95 | 97 | 97 | 99 |
| 52 | Sulphur Creek | 40 | 39 | 60 | 70 | 83 | 92 | 94 | 96 | 96 |
| 56 | Grandview | 37 | 19 | 68 | 90 | 94 | 95 | 97 | 98 | 99 |
| **Suspended sediment, in milligrams per liter** | | | | | | | | | | |
| 6 | Cle Elum | 17 | 2 | 2 | 3 | 6 | 20 | 94 | 130 | 130 |
| 19 | Umtanum | 34 | 2 | 3 | 6 | 17 | 28 | 88 | 110 | 110 |
| 26 | Naches | 23 | 2 | 3 | 5 | 13 | 27 | 78 | 120 | 130 |
| 32 | Union Gap | 36 | 4 | 7 | 12 | 18 | 43 | 140 | 300 | 1,100 |
| 50 | Kiona | 42 | 4 | 8 | 15 | 25 | 47 | 120 | 150 | 190 |
| 52 | Sulphur Creek | 40 | 7 | 13 | 32 | 80 | 142 | 220 | 370 | 620 |
| 56 | Grandview | 37 | 7 | 10 | 16 | 25 | 40 | 130 | 220 | 350 |

**Table 36.** Comparison of selected element concentrations in filtered-water samples from surface waters of the Yakima River Basin to surface waters in the United States

[Concentrations are in micrograms per liter; NASQAN, National Stream Quality Accounting Network based on data from 300 sites; --, no data; <, less than]

| Element | Background concentrations, inland water[1] | United States streams[2] | NASQAN 1974–81[3] | | | Yakima River Basin (water years 1953–85)[4] | | | | | Yakima River Basin (water years 1987–90)[5] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Percentiles | | | Number of samples | Percentiles | | | | Number of samples | Percentiles | | | |
| | | | 25th | 50th | 75th | | 25th | 50th | 75th | 90th | | 25th | 50th | 75th | 90th |
| Aluminum | <30 | -- | -- | --- | -- | 127 | 10 | 20 | 50 | 90 | 48 | <10 | 10 | 20 | 40 |
| Antimony | .1 | -- | -- | --- | -- | 24 | 0 | 0 | 0 | 0 | 22 | <1 | <1 | <1 | <1 |
| Arsenic | 2 | <10 | <1 | 1 | 3 | 218 | <5 | <5 | 5 | 5 | 119 | <1 | <1 | 2 | 3 |
| Beryllium | .01 | <.3 | -- | -- | -- | 69 | <.5 | <1 | <1 | <1 | 58 | <.5 | <.5 | <.5 | <.5 |
| Cadmium | .07 | 1 | <2 | <2 | <2 | 133 | <1 | <1 | <1 | 2 | 279 | <.2 | <.2 | <.2 | .3 |
| | | | | | | | | | | | | | | | |
| Chromium | .5 | 5.8 | 9 | 10 | 10 | 387 | 0 | 0 | 10 | 10 | 26 | <.5 | <.5 | .6 | 1.0 |
| Cobalt | .05 | <1 | --- | --- | -- | 132 | <3 | <3 | <3 | <3 | 58 | <3 | <3 | <3 | <3 |
| Copper | 1.8 | -- | -- | -- | -- | 491 | 2 | 3 | 10 | 20 | 280 | .6 | .9 | 1.3 | 1.9 |
| Iron | <30 | -- | 36 | 63 | 157 | 180 | 30 | 48 | 100 | 200 | 58 | 18 | 28 | 40 | 56 |
| Lead | .2 | -- | 3 | 4 | 6 | 372 | <2 | 4 | 10 | 18 | 279 | <.5 | <.5 | <.5 | <.5 |
| | | | | | | | | | | | | | | | |
| Manganese | <5 | -- | 11 | 24 | 51 | 165 | <10 | 10 | 20 | 30 | 58 | 4 | 10 | 16 | 33 |
| Mercury | .01 | (6) | .2 | .2 | .3 | 167 | <.1 | <.1 | .2 | .5 | 283 | <.1 | <.1 | <.1 | <.1 |
| Nickel | .3 | 10 | -- | -- | -- | 139 | 1 | 1 | 2 | 4 | <10 | <10 | <10 | <10 | <10 |
| Selenium | .1 | .2 | <1 | <1 | 1 | 133 | 0 | 0 | <1 | <1 | 44 | <1 | <1 | <1 | <1 |
| Silver | .3 | .3 | -- | -- | -- | 121 | <1 | <1 | 1 | 1 | 58 | <1 | <1 | <1 | 1 |
| | | | | | | | | | | | | | | | |
| Zinc | 10 | 20 | 12 | 15 | 21 | 465 | <3 | 11 | 20 | 50 | 58 | <3 | 4 | 8 | 18 |

[1] Minimally contaminated inland waters (Forstner and Wittmann, 1979).

[2] Hem, 1989.

[3] Percentiles are calculated from site-mean concentrations (Smith and others, 1987).

[4] Rinella and others, 1992.

[5] Fuhrer, Fluter, and others, 1994.

[6] Mercury concentrations rarely exceed a few tenths of a microgram per liter (Hem, 1989).

**Table 37.** Distribution of major- and trace-element concentrations in filtered-water samples at fixed sites, Yakima River Basin, Washington, 1987–90

[To avoid statistical bias that may be associated with constituents analyzed in duplicate or triplicate at a site, only one element concentration per visit was statistically summarized; all concentrations listed below are in micrograms per liter except bromide, organic carbon, and hardness, which are given in milligrams per liter; element names shown in bold print are U.S. Environmental Protection Agency (1992c) Priority Pollutants; for cadmium, copper, and lead, only samples analyzed by atomic absorption spectroscopy with graphite furnace were statistically summarized below; <, less than; Cle Elum, Yakima River at Cle Elum; Umtanum, Yakima River at Umtanum; Naches, Naches River near North Yakima; Union Gap, Yakima River above Ahtanum Creek at Union Gap; Sulphur Creek, Sulphur Creek Wasteway near Sunnyside; Grandview, Yakima River at Euclid Bridge at river mile 55 near Grandview; Kiona, Yakima River at Kiona]

| Site reference number | Site name | Number of samples | Minimum value | Value at indicated percentile | | | | | | Maximum value |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 10 | 25 | 50 | 75 | 90 | 95 | |
| **MAJOR ELEMENTS**<br>Aluminum | | | | | | | | | | |
| 6 | Cle Elum | 1 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 19 | Umtanum | 2 | 20 | 20 | 20 | 120 | 210 | 210 | 210 | 210 |
| 26 | Naches | 3 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| 32 | Union Gap | 17 | <10 | <10 | <10 | 20 | 30 | 60 | 60 | 60 |
| 50 | Kiona | 15 | <10 | <10 | <10 | <10 | 20 | 40 | 50 | 50 |
| 52 | Sulphur Creek | 6 | <10 | <10 | <10 | <10 | <10 | 20 | 20 | 20 |
| 56 | Grandview | 4 | <10 | <10 | <10 | <10 | 20 | 20 | 20 | 20 |
| **Carbon, Organic** | | | | | | | | | | |
| 6 | Cle Elum | 38 | .80 | .90 | 1.2 | 1.3 | 1.7 | 2.2 | 2.6 | 2.8 |
| 19 | Umtanum | 40 | .40 | 1.2 | 1.6 | 2.0 | 2.4 | 3.3 | 3.7 | 4.5 |
| 26 | Naches | 38 | .60 | 1.0 | 1.2 | 1.4 | 2.2 | 3.1 | 3.4 | 4.3 |
| 32 | Union Gap | 38 | .80 | 1.3 | 1.6 | 2.0 | 2.7 | 3.2 | 4.1 | 5.8 |
| 50 | Kiona | 41 | 1.1 | 1.3 | 1.9 | 2.3 | 2.8 | 3.6 | 6.5 | 7.5 |
| 52 | Sulphur Creek | 43 | 1.5 | 1.8 | 2.2 | 2.7 | 3.6 | 4.7 | 5.5 | 8.0 |
| 56 | Grandview | 37 | 1.0 | 1.2 | 1.6 | 2.0 | 2.6 | 4.4 | 5.7 | 6.4 |
| **Hardness** | | | | | | | | | | |
| 6 | Cle Elum | 41 | 20 | 21 | 22 | 26 | 28 | 32 | 35 | 36 |
| 19 | Umtanum | 40 | 33 | 35 | 41 | 46 | 57 | 65 | 68 | 70 |
| 26 | Naches | 39 | 18 | 21 | 28 | 32 | 37 | 46 | 48 | 57 |
| 32 | Union Gap | 43 | 28 | 33 | 37 | 44 | 55 | 66 | 79 | 87 |
| 50 | Kiona | 43 | 43 | 53 | 72 | 96 | 110 | 120 | 130 | 140 |
| 52 | Sulphur Creek | 46 | 70 | 86 | 98 | 130 | 260 | 260 | 270 | 270 |
| 56 | Grandview | 40 | 49 | 60 | 69 | 89 | 100 | 110 | 110 | 120 |

**Table 37.** Distribution of major- and trace-element concentrations in filtered-water samples at fixed sites, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Number of samples | Minimum value | Value at indicated percentile | | | | | | Maximum value |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 10 | 25 | 50 | 75 | 90 | 95 | |
| | | | | **Iron** | | | | | | |
| 6 | Cle Elum | 5 | 8 | 8 | 9 | 13 | 36 | 44 | 44 | 44 |
| 19 | Umtanum | 6 | 19 | 19 | 20 | 23 | 100 | 250 | 250 | 250 |
| 26 | Naches | 3 | 13 | 13 | 13 | 18 | 35 | 35 | 35 | 35 |
| 32 | Union Gap | 17 | 5 | 20 | 28 | 36 | 54 | 67 | 67 | 67 |
| 50 | Kiona | 16 | 8 | 12 | 16 | 24 | 36 | 48 | 53 | 53 |
| 52 | Sulphur Creek | 7 | 16 | 16 | 18 | 22 | 30 | 33 | 33 | 33 |
| 56 | Grandview | 4 | 20 | 20 | 21 | 27 | 64 | 75 | 75 | 75 |
| | | | | **TRACE ELEMENTS**<br>Antimony | | | | | | |
| 6 | Cle Elum | 4 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| 19 | Umtanum | 3 | <1 | <1 | <1 | <1 | 1 | 1 | 1 | 1 |
| 26 | Naches | 2 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| 32 | Union Gap | 4 | <1 | <1 | <1 | <1 | <1 | 1 | 1 | 1 |
| 50 | Kiona | 4 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| 52 | Sulphur Creek | 3 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| 56 | Grandview | 2 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| | | | | **Arsenic** | | | | | | |
| 6 | Cle Elum | 16 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| 19 | Umtanum | 11 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| 26 | Naches | 15 | <1 | <1 | <1 | <1 | <1 | <1 | 1 | 1 |
| 32 | Union Gap | 23 | <1 | <1 | <1 | <1 | <1 | <1 | 1 | 1 |
| 50 | Kiona | 25 | <1 | <1 | 1 | 1 | 2 | 3 | 4 | 4 |
| 52 | Sulphur Creek | 15 | 2 | 2 | 2 | 3 | 7 | 8 | 9 | 9 |
| 56 | Grandview | 14 | <1 | <1 | <1 | 1 | 2 | 2 | 3 | 3 |
| | | | | **Barium** | | | | | | |
| 6 | Cle Elum | 5 | 2 | 2 | 2 | 3 | 4 | 4 | 4 | 4 |
| 19 | Umtanum | 6 | 7 | 7 | 8 | 10 | 14 | 16 | 16 | 16 |
| 26 | Naches | 3 | <2 | <2 | <2 | 4 | 6 | 6 | 6 | 6 |
| 32 | Union Gap | 17 | 5 | 6 | 8 | 9 | 13 | 27 | 53 | 53 |
| 50 | Kiona | 16 | 7 | 9 | 17 | 20 | 26 | 32 | 40 | 40 |
| 52 | Sulphur Creek | 7 | 29 | 29 | 36 | 39 | 73 | 79 | 79 | 79 |
| 56 | Grandview | 4 | 11 | 11 | 14 | 24 | 26 | 27 | 27 | 27 |

**Table 37**. Distribution of major- and trace-element concentrations in filtered-water samples at fixed sites, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Number of samples | Minimum value | Value at indicated percentile | | | | | | Maximum value |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 10 | 25 | 50 | 75 | 90 | 95 | |
| **Beryllium** | | | | | | | | | | |
| 6 | Cle Elum | 5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 |
| 19 | Umtanum | 6 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 |
| 26 | Naches | 3 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 |
| 32 | Union Gap | 17 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 |
| 50 | Kiona | 16 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 |
| 52 | Sulphur Creek | 7 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 |
| 56 | Grandview | 4 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 |
| **Boron** | | | | | | | | | | |
| 6 | Cle Elum | 1 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| 19 | Umtanum | 2 | 10 | 10 | 10 | 20 | 20 | 20 | 20 | 20 |
| 26 | Naches | 3 | 10 | 10 | 10 | 10 | 20 | 20 | 20 | 20 |
| 32 | Union Gap | 5 | <10 | <10 | <10 | <10 | 20 | 20 | 20 | 20 |
| 50 | Kiona | 3 | 20 | 20 | 20 | 20 | 30 | 30 | 30 | 30 |
| 52 | Sulphur Creek | 6 | 20 | 20 | 20 | 20 | 40 | 40 | 40 | 40 |
| 56 | Grandview | 3 | 10 | 10 | 10 | 20 | 20 | 20 | 20 | 20 |
| **Bromide** | | | | | | | | | | |
| 6 | Cle Elum | 3 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 |
| 19 | Umtanum | 3 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 |
| 26 | Naches | 2 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 |
| 32 | Union Gap | 3 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 |
| 50 | Kiona | 3 | <.01 | <.01 | <.01 | <.01 | .02 | .02 | .02 | .02 |
| 52 | Sulphur Creek | 3 | <.01 | <.01 | <.01 | .02 | .08 | .08 | .08 | .08 |
| 56 | Grandview | 2 | <.01 | <.01 | <.01 | .01 | .02 | .02 | .02 | .02 |
| **Cadmium** | | | | | | | | | | |
| 6 | Cle Elum | 42 | <.2 | <.2 | <.2 | <.2 | .2 | .4 | .7 | 1.5 |
| 19 | Umtanum | 40 | <.2 | <.2 | <.2 | <.2 | .3 | 1.0 | 1.2 | 2.1 |
| 26 | Naches | 38 | <.2 | <.2 | <.2 | <.2 | <.2 | .3 | .4 | 2.2 |
| 32 | Union Gap | 40 | <.2 | <.2 | <.2 | <.2 | <.2 | .2 | .2 | .5 |
| 50 | Kiona | 38 | <.2 | <.2 | <.2 | <.2 | <.2 | .2 | .2 | .6 |
| 52 | Sulphur Creek | 43 | <.2 | <.2 | <.2 | <.2 | <.2 | .3 | .6 | .6 |
| 56 | Grandview | 38 | <.2 | <.2 | <.2 | <.2 | <.2 | .2 | .4 | 1.0 |

**Table 37.** Distribution of major- and trace-element concentrations in filtered-water samples at fixed sites, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Number of samples | Minimum value | Value at indicated percentile | | | | | | Maximum value |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 10 | 25 | 50 | 75 | 90 | 95 | |
| **Chromium** | | | | | | | | | | |
| 6 | Cle Elum | 3 | <.5 | <.5 | <.5 | <.5 | 1.1 | 1.1 | 1.1 | 1.1 |
| 19 | Umtanum | 4 | <.5 | <.5 | <.5 | <.5 | .5 | .6 | .6 | .6 |
| 26 | Naches | 2 | <.5 | <.5 | <.5 | <.5 | .7 | .7 | .7 | .7 |
| 32 | Union Gap | 4 | <.5 | <.5 | <.5 | <.5 | .5 | .6 | .6 | .6 |
| 50 | Kiona | 6 | <.5 | <.5 | <.5 | <.5 | 1.0 | 1.0 | 1.0 | 1.0 |
| 52 | Sulphur Creek | 4 | <.5 | <.5 | <.5 | <.5 | .7 | .8 | .8 | .8 |
| 56 | Grandview | 3 | <.5 | <.5 | <.5 | <.5 | .6 | .6 | .6 | .6 |
| Cobalt | | | | | | | | | | |
| 6 | Cle Elum | 5 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 19 | Umtanum | 6 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 26 | Naches | 3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 32 | Union Gap | 17 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 50 | Kiona | 16 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 52 | Sulphur Creek | 7 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 56 | Grandview | 4 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| **Copper** | | | | | | | | | | |
| 6 | Cle Elum | 42 | <.5 | <.5 | <.5 | .8 | 1.4 | 4.6 | 7.2 | 14 |
| 19 | Umtanum | 39 | <.5 | .5 | .8 | 1.3 | 1.9 | 4.1 | 7.0 | 20 |
| 26 | Naches | 38 | <.5 | <.5 | <.5 | .6 | .8 | 1.0 | 1.4 | 1.5 |
| 32 | Union Gap | 41 | <.5 | <.5 | .6 | .9 | 1.2 | 1.9 | 3.1 | 3.6 |
| 50 | Kiona | 40 | <.5 | <.5 | .7 | 1.0 | 1.3 | 2.8 | 5.1 | 5.5 |
| 52 | Sulphur Creek | 42 | <.5 | .7 | .9 | 1.1 | 1.3 | 1.7 | 2.3 | 2.5 |
| 56 | Grandview | 38 | <.5 | <.5 | .7 | .9 | 1.3 | 1.5 | 1.8 | 2.9 |
| **Lead** | | | | | | | | | | |
| 6 | Cle Elum | 42 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 |
| 19 | Umtanum | 39 | <.5 | <.5 | <.5 | <.5 | <.5 | .6 | .9 | 1.8 |
| 26 | Naches | 37 | <.5 | <.5 | <.5 | <.5 | <.5 | .6 | .7 | .7 |
| 32 | Union Gap | 41 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | .8 |
| 50 | Kiona | 39 | <.5 | <.5 | <.5 | <.5 | <.5 | .6 | .7 | .8 |
| 52 | Sulphur Creek | 43 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | 1.0 | 1.2 |
| 56 | Grandview | 38 | <.5 | <.5 | <.5 | <.5 | <.5 | .6 | 1.1 | 1.9 |

**Table 37.** Distribution of major- and trace-element concentrations in filtered-water samples at fixed sites, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Number of samples | Minimum value | Value at indicated percentile | | | | | | Maximum value |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 10 | 25 | 50 | 75 | 90 | 95 | |
| | | | | **Lithium** | | | | | | |
| 6 | Cle Elum | 5 | <4 | <4 | <4 | <4 | 4 | 5 | 5 | 5 |
| 19 | Umtanum | 6 | <4 | <4 | <4 | <4 | 6 | 16 | 16 | 16 |
| 26 | Naches | 3 | <4 | <4 | <4 | <4 | <4 | <4 | <4 | <4 |
| 32 | Union Gap | 17 | <4 | <4 | <4 | <4 | <4 | <4 | <4 | <4 |
| 50 | Kiona | 16 | <4 | <4 | <4 | <4 | <4 | 4 | 5 | 5 |
| 52 | Sulphur Creek | 7 | <4 | <4 | <4 | <4 | 8 | 9 | 9 | 9 |
| 56 | Grandview | 4 | <4 | <4 | <4 | <4 | <4 | <4 | <4 | <4 |
| | | | | Manganese | | | | | | |
| 6 | Cle Elum | 5 | 2 | 2 | 2 | 2 | 5 | 7 | 7 | 7 |
| 19 | Umtanum | 6 | 4 | 4 | 4 | 6 | 17 | 21 | 21 | 21 |
| 26 | Naches | 3 | 2 | 2 | 2 | 3 | 4 | 4 | 4 | 4 |
| 32 | Union Gap | 17 | 6 | 7 | 8 | 10 | 14 | 21 | 31 | 31 |
| 50 | Kiona | 16 | <1 | 2 | 2 | 10 | 12 | 24 | 34 | 34 |
| 52 | Sulphur Creek | 7 | 13 | 13 | 13 | 18 | 86 | 110 | 110 | 110 |
| 56 | Grandview | 4 | 10 | 10 | 16 | 36 | 49 | 53 | 53 | 53 |
| | | | | **Mercury** | | | | | | |
| 6 | Cle Elum | 42 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | .2 | .6 |
| 19 | Umtanum | 40 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | .2 | .6 |
| 26 | Naches | 38 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | .2 |
| 32 | Union Gap | 42 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | .2 | .2 |
| 50 | Kiona | 43 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | .2 | .3 |
| 52 | Sulphur Creek | 41 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | .1 | .3 |
| 56 | Grandview | 37 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | .1 |
| | | | | Molybdenum | | | | | | |
| 6 | Cle Elum | 5 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| 19 | Umtanum | 6 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| 26 | Naches | 3 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| 32 | Union Gap | 17 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| 50 | Kiona | 16 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| 52 | Sulphur Creek | 7 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| 56 | Grandview | 4 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |

**Table 37.** Distribution of major- and trace-element concentrations in filtered-water samples at fixed sites, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Number of samples | Minimum value | Value at indicated percentile | | | | | | Maximum value |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 10 | 25 | 50 | 75 | 90 | 95 | |
| Nickel | | | | | | | | | | |
| 6 | Cle Elum | 5 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| 19 | Umtanum | 6 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| 26 | Naches | 3 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| 32 | Union Gap | 17 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| 50 | Kiona | 16 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| 52 | Sulphur Creek | 7 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| 56 | Grandview | 4 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| Selenium | | | | | | | | | | |
| 6 | Cle Elum | 4 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| 19 | Umtanum | 3 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| 26 | Naches | 2 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| 32 | Union Gap | 15 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| 50 | Kiona | 15 | <1 | <1 | <1 | <1 | <1 | <1 | 1 | 1 |
| 52 | Sulphur Creek | 3 | <1 | <1 | <1 | 1 | 2 | 2 | 2 | 2 |
| 56 | Grandview | 2 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Silver | | | | | | | | | | |
| 6 | Cle Elum | 5 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| 19 | Umtanum | 6 | <1 | <1 | <1 | <1 | 1 | 1 | 1 | 1 |
| 26 | Naches | 3 | <1 | <1 | <1 | 2 | 2 | 2 | 2 | 2 |
| 32 | Union Gap | 17 | <1 | <1 | <1 | <1 | <1 | 1 | 1 | 1 |
| 50 | Kiona | 16 | <1 | <1 | <1 | <1 | <1 | <1 | 1 | 1 |
| 52 | Sulphur Creek | 7 | <1 | <1 | <1 | <1 | 1 | 1 | 1 | 1 |
| 56 | Grandview | 4 | <1 | <1 | <1 | <1 | 2 | 2 | 2 | 2 |
| Strontium | | | | | | | | | | |
| 6 | Cle Elum | 5 | 23 | 23 | 26 | 30 | 36 | 41 | 41 | 41 |
| 19 | Umtanum | 6 | 42 | 42 | 45 | 60 | 70 | 74 | 74 | 74 |
| 26 | Naches | 3 | 21 | 21 | 21 | 53 | 65 | 65 | 65 | 65 |
| 32 | Union Gap | 17 | 31 | 34 | 44 | 50 | 65 | 92 | 96 | 96 |
| 50 | Kiona | 16 | 49 | 65 | 84 | 110 | 140 | 150 | 150 | 150 |
| 52 | Sulphur Creek | 7 | 110 | 110 | 140 | 150 | 330 | 330 | 330 | 330 |
| 56 | Grandview | 4 | 71 | 71 | 86 | 130 | 140 | 140 | 140 | 140 |

**Table 37.** Distribution of major- and trace-element concentrations in filtered-water samples at fixed sites, Yakima River Basin, Washington, 1987–90—Continued

| Site reference number | Site name | Number of samples | Minimum value | Value at indicated percentile | | | | | | Maximum value |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 10 | 25 | 50 | 75 | 90 | 95 | |
| | | | | **Vanadium** | | | | | | |
| 6 | Cle Elum | 5 | <6 | <6 | <6 | <6 | <6 | <6 | <6 | <6 |
| 19 | Umtanum | 6 | <6 | <6 | <6 | <6 | <6 | <6 | <6 | <6 |
| 26 | Naches | 3 | <6 | <6 | <6 | <6 | <6 | <6 | <6 | <6 |
| 32 | Union Gap | 17 | <6 | <6 | <6 | <6 | <6 | <6 | <6 | <6 |
| 50 | Kiona | 16 | <6 | <6 | <6 | <6 | 10 | 10 | 10 | 10 |
| 52 | Sulphur Creek | 7 | 10 | 10 | 10 | 10 | 20 | 20 | 20 | 20 |
| 56 | Grandview | 4 | <6 | <6 | <6 | 10 | 10 | 10 | 10 | 10 |
| | | | | **Zinc** | | | | | | |
| 6 | Cle Elum | 5 | 4 | 4 | 6 | 10 | 18 | 19 | 19 | 19 |
| 19 | Umtanum | 6 | <3 | <3 | <3 | 4 | 9 | 12 | 12 | 12 |
| 26 | Naches | 3 | <3 | <3 | <3 | <3 | 18 | 18 | 18 | 18 |
| 32 | Union Gap | 17 | <3 | <3 | <3 | 5 | 8 | 32 | 40 | 40 |
| 50 | Kiona | 16 | <3 | <3 | <3 | <3 | 7 | 11 | 12 | 12 |
| 52 | Sulphur Creek | 7 | <3 | <3 | <3 | 4 | 5 | 9 | 9 | 9 |
| 56 | Grandview | 4 | <3 | <3 | <3 | 10 | 26 | 29 | 29 | 29 |

**Table 38.** Comparison of arsenic, mercury, and selenium concentrations in freshwater fish collected in 1984 for the National Contaminant Biomonitoring Program to concentrations in whole-body sculpin collected from the Yakima River Basin, Washington, 1990

[NCBP, National Contaminant Biomonitoring Program (Schmitt and Brumbaugh, 1990); concentrations are reported as micrograms per gram, dry weight; concentrations were converted to dry weight assuming a moisture content of 75 percent; statistics for the Yakima River Basin are based on site means in 1990, not individual sample concentrations; arsenic concentrations below the limit of determination were statistically summarized as one-half their value; sample species: sculpin (*Cottus* spp.);<, less than]

| Element | Yakima River Basin | | | | NCBP | | |
|---|---|---|---|---|---|---|---|
| | Minimum | Mean | 85th percentile | Maximum | Mean | 85th percentile | Maximum |
| Arsenic | <0.10 | 0.16 | 0.31 | 0.45 | 0.56 | 4.3 | 6.0 |
| Mercury | .09 | 20 | .19 | .31 | .40 | .68 | 1.4 |
| Selenium | .20 | 2.1 | 5.3 | 5.4 | 1.7 | 2.9 | 9.2 |

**Table 39.** Comparison of selected trace-element concentrations in *Corbicula* species collected from uncontaminated or minimally contaminated aquatic environments in other basins to Asiatic clams collected from the Yakima River Basin, Washington, 1990

[Statistics for the Yakima River Basin are based on site means for 1990 data, not individual sample concentrations; concentrations are reported in micrograms per gram, dry weight; reference basins are: (1) Apalachicola River (Elder and Mattraw, 1984), (2) San Francisco Bay and Sacramento/San Joaquin River Delta (Johns and Luoma, 1990), (3) San Francisco Bay, Sacramento-San Joaquin Delta, and selected tributaries (Johns and others, 1988), (4) San Joaquin River (Leland and others, 1988), (5) San Joaquin River (Leland and Scudder, 1990), (6) Suisun Bay/Delta in San Francisco Bay (Luoma and others, 1990), (7) selected river basins in the State of California (McCleneghan and others, 1981); data cited from McCleneghan and others (1981) were converted from fresh-weight concentrations using the reported values for percent moisture; Yakima River Basin sample species: Asiatic clam (Veneroidae: Corbiculidae *Corbicula fluminea*)]

| | **Yakima River Basin** | | | **Other basins** | |
|---|---|---|---|---|---|
| **Element** | **Minimum** | **Median** | **Maximum** | **Site mean** | **Reference basin** |
| Arsenic | 3.6 | 4.2 | 4.6 | <0.1–0.36 | 1 |
| | | | | 6.9–7.2 | 2 |
| | | | | 5.3–7.7 | 4 |
| | | | | 0.2–1.4 | 6 |
| Cadmium | .23 | .31 | .39 | <0.1–0.25 | 1 |
| | | | | 0.24–0.48 | 4 |
| | | | | <1 | 5 |
| Chromium | 1.2 | 1.3 | 2.1 | <0.1–2.0 | 1 |
| | | | | <2 | 5 |
| | | | | 0.8 | 6 |
| Copper | 25 | 29 | 35 | 1.0–13 | 1 |
| | | | | 16–66 | 4 |
| | | | | 20–40 | 5 |
| | | | | 48 | 3, 6 |
| Lead | .18 | .31 | .40 | <0.1–0.2 | 1 |
| | | | | 1.6 | 5 |
| Mercury | .10 | .16 | .17 | 0.086–0.184 | 3 |
| | | | | 0.11–0.13 | 4 |
| Nickel | .88 | 1.1 | 1.3 | 0.75–1.35 | 4 |
| Selenium | 2.0 | 2.6 | 3.0 | 2.8–3.1 | 3 |
| | | | | 1.26–2.02 | 4 |
| Zinc | 98 | 107 | 452 | 2.1–26 | 1 |
| | | | | 120–177 | 5 |
| | | | | 167 | 6 |

**Table 40.** Comparison of selected trace-element concentrations in benthic insects collected from uncontaminated or minimally contaminated aquatic environments in other basins to benthic insects collected from the Yakima River Basin, Washington, 1990

[Statistics for the Yakima River Basin are based on site means for 1990 data, not individual-sample concentrations; concentrations are reported in micrograms per gram, dry weight; N, number of taxa measured at all sites; reference basins are: (1) cobble-bottom rivers and streams (Cain and others, 1992) (2) spring-fed stream (Elwood and others, 1976), (3) mine-drainage streams (Gower and Darlington, 1990), (4) Red River, New Mexico (Lynch and others, 1988), (5) metal-contaminated sites (Miller and others, 1992), and (6) Uncontaminated streams (Smock, 1983)]

| Element | Yakima River Basin | | | | Other basins | |
|---|---|---|---|---|---|---|
| | N | Minimum | Median | Maximum | Site mean | Reference basin |
| Cadmium | 87 | 0.11 | 0.12 | 0.58 | 0.1–0.2 | 1 |
| | | | | | 1.9 | 4 |
| Chromium | 92 | .31 | 1.7 | 33 | 14.2 | 2 |
| | | | | | 4.9 | 4 |
| | | | | | 7.4 | 6 |
| Cobalt | 94 | .20 | 1.0 | 9.1 | 2.9 | 2 |
| | | | | | 6.2 | 6 |
| Copper | 94 | 5.6 | 16 | 39 | 11–34 | 1 |
| | | | | | 29 | 3 |
| | | | | | 43 | 4 |
| | | | | | 57–99 | 5 |
| Lead | 85 | .06 | .73 | 24 | 0.1–1.8 | 1 |
| | | | | | 0.5 | 4 |
| Nickel | 90 | .12 | 1.2 | 77 | 7.1 | 4 |
| Zinc | 94 | 67 | 138 | 450 | 11–34 | 1 |
| | | | | | 29 | 3 |
| | | | | | 43 | 4 |
| | | | | | 57–99 | 5 |

# APPENDIX

# APPENDIX

Equations for calculating estimated loads for arsenic, cadmium, and copper at fixed sites in the Yakima River Basin, Washington, 1987–90

**[Equations derived using model in Cohn and others (1992); ln, natural logarithm; L, load, in grams per day; Q, flow, in cubic feet per second; T, time, in decimal years; sin, sine; cos, cosine]**

| Element | Sample medium | Equation |
|---|---|---|
| Yakima River at Cle Elum | | |
| Cadmium | Filtered water | $\ln(L) = 0.9544\ln(Q) - 0.8720$ |
| Copper | Filtered water | $\ln(L) = 1.7504\ln(Q) - 0.1496\sin(2\pi T) + 0.9285\cos(2\pi T) - 4.547$ |
| Yakima River at Umtanum | | |
| Arsenic | Suspended sediment | $\ln(L) = 1.8952\ln(Q) + 0.2113\sin(2\pi T) + 0.3696\cos(2\pi T) - 8.252$ |
| Cadmium | Suspended sediment | $\ln(L) = 1.5532\ln(Q) + 0.9503\sin(2\pi T) + 0.2455\cos(2\pi T) - 7.558$ |
| Cadmium | Filtered water | $\ln(L) = 1.3087\ln(Q) - 3.532$ |
| Copper | Suspended sediment | $\ln(L) = 1.5635\ln(Q) - 3.554$ |
| Copper | Filtered water | $\ln(L) = 1.5360\ln(Q) - 0.3383\sin(2\pi T) + 0.5223\cos(2\pi T) - 2.866$ |
| Naches River near North Yakima | | |
| Arsenic | Suspended sediment | $\ln(L) = 2.3185\ln(Q) + 0.0774\sin(2\pi T) + 0.6033\cos(2\pi T) - 10.916$ |
| Cadmium | Suspended sediment | $\ln(L) = 2.1101\ln(Q) + 0.7819\sin(2\pi T) + 0.7520\cos(2\pi T) - 11.819$ |
| Copper | Suspended sediment | $\ln(L) = 2.1312\ln(Q) - 7.709$ |
| Copper | Filtered water | $\ln(L) = 1.1817\ln(Q) - 0.8732$ |
| Yakima River above Ahtanum Creek at Union Gap | | |
| Arsenic | Suspended sediment | $\ln(L) = 1.4355\ln(Q) - 11.73$ |
| Cadmium | Suspended sediment | $\ln(L) = 0.9314\ln(Q) + 0.6929\sin(2\pi T) + 0.2841\cos(2\pi T) - 2.923$ |
| Cadmium | Filtered water | $\ln(L) = 1.6426\ln(Q) - 7.203$ |
| Copper | Suspended sediment | $\ln(L) = 1.3215\ln(Q) - 1.346$ |
| Copper | Filtered water | $\ln(L) = 0.9334\ln(Q) + 0.1263\sin(2\pi T) - 0.0300\cos(2\pi T) + 1.276$ |
| Yakima River at Euclid Bridge at river mile 55 near Grandview | | |
| Arsenic | Suspended sediment | $1n(L) = 2.099\ln(Q) - 0.3149\sin(2\pi T) - 0.6459\cos(2\pi T) - 9.219$ |
| Arsenic | Filtered water | $\ln(L) = 0.0884\ln(Q) + 8.258$ |
| Cadmium | Suspended sediment | $1n(L) = 1.4354\ln(Q) + 0.3762\sin(2\pi T) - 0.3698\cos(2\pi T) - 6.577$ |
| Copper | Suspended sediment | $\ln(L) = 2.4962\ln(Q) - 0.2799\sin(2\pi T) - 0.6514\cos(2\pi T) - 10.474$ |
| Copper | Filtered water | $\ln(L) = 0.7494\ln(Q) + 2.737$ |
| Yakima River at Kiona | | |
| Arsenic | Filtered water | $\ln(L) = 0.5026\ln(Q) + 5.039$ |
| Cadmium | Suspended sediment | $\ln(L) = 2.4629\ln(Q) + 0.1347\sin(2\pi T) - 0.7258\cos(2\pi T) - 14.994$ |
| Copper | Suspended sediment | $\ln(L) = 2.9597 \ln(Q) - 0.5866\sin(2\pi T) - 1.1695\cos(2\pi T) - 14.160$ |
| Sulphur Creek Wasteway near Sunnyside | | |
| Arsenic | Suspended sediment | $\ln(L) = 1.4907\ln(Q) + 0.5104\sin(2\pi T) - 0.1757\cos(2\pi T) - 2.004$ |
| Arsenic | Filtered water | $\ln(L) = 0.1476\ln(Q) + 6.5755$ |
| Cadmium | Suspended sediment | $\ln(L) = 1.0724\ln(Q) + 0.6953\sin(2\pi T) - 0.4716\cos(2\pi T) - 3.166$ |
| Copper | Suspended sediment | $\ln(L) = 1.0648\ln(Q) + 0.6039\sin(2\pi T) - 0.5476\cos(2\pi T) + 1.751$ |
| Copper | Filtered water | $\ln(L) = 0.9674\ln(Q) + 1.118$ |

## GLOSSARY OF SELECTED TERMS

**alluvium**. A deposit of clay, silt, sand, gravel, mud, or similar unconsolidated detrital material formed by flowing water.

**amphibolite**. A crystalloblastic (metamorphic) rock consisting mainly of amphibole and plagioclase with little or no quartz.

**anadromous**. Migrating from the sea up a river to spawn.

**andesite**. A dark-colored, fine-grained volcanic rock composed essentially of plagioclase feldspar, resembling trachyte in appearance; the extrusive equivalent of diorite.

**anthropogenic**. Pertaining to, or resulting from, human activities.

**arsenopyrite**. A tin-white or silver-white to steel-gray orthorhombic mineral: FeAsS; it constitutes the principal ore of arsenic.

**asphalt**. A dark brown to black viscous liquid or low-melting solid bitumen formed in oil-bearing rocks by the evaporation of the volatiles.

**basalt**. The dark, dense igneous rock of a lava flow or minor intrusion, composed essentially of labradorite and pyroxene and often displaying a columnar structure.

**batholith**. A large body of igneous rock, bounded by irregular, cross-cutting surfaces or fault planes, and believed to have crystallized at a considerable depth below the Earth's surface.

**benthic**. Pertaining to the aggregate of organisms living on or at the bottom of a body of water.

**bioavailability**. The extent and rate at which a compound is taken up by an organism.

**breccia**. A coarse-grained, clastic rock composed of large, angular, and broken rock fragments that are cemented together in a fine-grained matrix and that can be of any composition, origin, or mode of accumulation; the consolidated equivalent of rubble.

**Cretaceous**. The final period of the Mesozoic era (after the Jurassic and before the Tertiary period of the Cenzoic era), thought to have covered the span of time between 136 and 65 million years ago; also, the corresponding system of rocks.

**deleterious**. Injurious to health.

**diabase**. An intrusive rock whose main components are labradorite and pyroxene and which is characterized by ophitic texture.

**elutriation**. A process in which streambed sediment is mixed with stream water, and after a settling period, the liquid portion is removed, filtered, and chemically analyzed.

**Eocene**. An epoch of the lower Tertiary period, after the Paleocene and before the Oligocene; also, the corresponding worldwide series of rocks.

**eutrophication**. The process by which a body of water becomes enriched in dissolved nutrients (such as nitrogen and phosphorus) that stimulate the growth of aquatic plant life, often resulting in reduced or depleted dissolved oxygen.

**first-order tributary**. Smallest unbranched mapped (1:24,000 map scale) tributaries.

**filtered water**. An operational definition referring to the chemical analysis of that portion of a water-suspended sediment sample that passes through a nominal 0.45-micrometer (μm) filter.

**fluvial**. Of or pertaining to a river or rivers.

**gabbro**. A group of dark-colored, basic, intrusive igneous rocks composed principally of ferromagnesium minerals and calcium-rich plagioclase feldspar; the approximate intrusive equivalent of basalt.

**galena (lead sulfate)**. A bluish-gray to lead-gray mineral: PbS; almost always contains silver; the most important ore of lead.

**gneiss**. A metamorphic rock, generally made up of bands that differ in color and composition, some bands being rich in feldspar and quartz, others rich in hornblende or mica. Varieties are distinguished by texture, characteristic minerals, or general composition and/or origins.

**granitic rock**. A term loosely applied to any light-colored, coarse-grained plutonic rock containing quartz as an essential component, along with feldspar and mafic minerals.

**higher order stream.** Third-order or larger tributary.

**hydrograph**. A graph showing stage, flow, velocity, or other characteristics of water with respect to time.

**intrusive rock**. An igneous rock mass that has been forced by magmatic activity, while molten or plastic, into fissures or other openings or between layers of other rocks.

**irrigation season**. An operational period defined as June through September for the Yakima River Basin.

**Jurassic**. The second period of the Mesozoic era (after the Triassic and before the Cretaceous), thought to have covered the span of time between 195–190 and 136 million years ago; also, the corresponding system of rocks.

**Kittitas Valley**. The part of the Yakima River Basin that extends 67.5 river miles from the foot of Keechelus Dam to just upstream from Wilson Creek (fig. 3).

**loess**. A widespread, homogeneous, commonly non-stratified, porous, friable, unconsolidated but slightly coherent, usually highly calcareous, fine-grained, blanket deposit of marl or loam, consisting predominantly of silt with subordinate grain sizes ranging from clay to fine sand.

**lower limit of determination (LLD)**. An operational limit determined as three times the standard deviation of the blank sample added to the average of the blank.

**lower limit of quantitation (LLQ)**. An operational limit determined as 10 times the standard deviation of the blank sample added to the average of the blank; a value that has a high probability of being the actual concentration.

**lower order stream.** First- or second-order tributary.

**lower Yakima Valley.** The part of the Yakima River Basin that extends 107.5 river miles from the city of Union Gap to the mouth of the Yakima River (fig. 3).

**metamorphic rock.** Any rock derived from pre-existing rocks by mineralogical, chemical, and structural changes in response to marked changes in temperature, pressure, shearing stress, and chemical environment.

**mid-Yakima Valley.** That part of the Yakima River Basin that extends a distance of 39.5 river miles from Wilson Creek to the city of Union Gap (fig. 3).

**Miocene.** An epoch of the upper Tertiary period, after the Oligocene and before the Pliocene; also, the corresponding worldwide series of rocks.

**nonirrigation season.** An operational period defined as October through March for the Yakima River Basin.

**peridotite.** A general term for a coarse-grained plutonic rock composed chiefly of olivine with or without other mafic minerals and containing little or no feldspar.

**periphyton.** Micro-organisms that adhere to rocks, plants, and other surfaces on the bottom of lakes and streams.

**phyllite.** A metamorphic rock in which clay minerals have recrystallized into microscopic micas, giving the rock a silky sheen.

**Pleistocene.** An epoch of the Quaternary period, after the Pliocene of the Tertiary and before the Holocene; also, the corresponding worldwide series of rocks.

**predaceous.** Predatory, rapacious.

**pyrite (iron sulfide).** A common pale-bronze or brass-yellow isometric mineral: $FeS_2$; an important ore of sulfur.

**pyroclastic.** Pertaining to clastic rock material formed by volcanic explosion or aerial expulsion from a volcanic vent; also, pertaining to rock texture of explosive origin.

**redd.** The spawning area or nest of trout or salmon.

**reference dose (RfD).** An estimate of the daily exposure of a noncarcinogen to the human population that is likely to be without appreciable risk of deleterious health effects during a lifetime of 70 years.

**schist.** A metamorphic rock characterized by coarse-grained minerals oriented approximately parallel.

**second-order tributary.** Stream receiving only first-order tributaries.

**sedimentary rock.** A rock resulting from the consolidation of loose sediment that has accumulated in layers.

**serpentinite.** A rock consisting almost wholly of serpentine-group minerals derived from the alteration of previously existing ferromagnesian silicate minerals.

**shale.** A fine-grained sedimentary rock that has a pronounced splitting capability.

**siltstone.** An indurated or somewhat indurated silt having the texture and composition, but lacking the fine lamination or fissility, of shale.

**snowmelt season.** An operational period defined as April through May for the Yakima River Basin.

**sphalerite (zinc-iron sulfide).** A brown or black, sometimes yellow or white, isometric mineral: $(Zn, Fe)S$; a widely distributed ore of zinc.

**Tertiary.** The first period of the Cenozoic era (after the Cretaceous of the Mesozoic era and before the Quaternary), thought to have covered the span of time between 65 and 3 to 2 million years ago.

**third-order tributary.** Stream receiving only first- and second-order tributaries.

**tuff.** A rock formed from fine-grained pyroclastic particles (ash and dust).

**ultramafic rock.** Referring to igneous rock composed mostly of magnesium-iron silicates such as olivine and pyroxene.

**unfiltered water.** An operational definition referring to the chemical analysis of a water sample that has not been filtered or centrifuged, nor in any way altered from the original matrix.

**volcanic rock.** A generally finely crystalline or glassy igneous rock resulting from volcanic action at or near the Earth's surface, either ejected explosively or extruded as lava.

**volcaniclastic.** Pertaining to a clastic rock containing volcanic material in whatever proportion, and without regard to its origin or environment.

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