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# Occurrence and Distribution of Dissolved Trace Elements in the Surface Waters of the Yakima River Basin, Washington

Water-Resources Investigations Report 02-4177



Cover Photographs:

**Top:** Yakima River near Prosser, Washington.

**Center:** Apple orchard in the Yakima River Valley, Washington.

**Bottom:** Yakima River facing upstream from Umtanum wayside bridge, Washington.

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U.S. Geological Survey**

# **Occurrence and Distribution of Dissolved Trace Elements in the Surface Waters of the Yakima River Basin, Washington, 1999–2000**

**By CURT A. HUGHES**

**Water-Resources Investigations Report 02–4177**

**Portland, Oregon: 2003**

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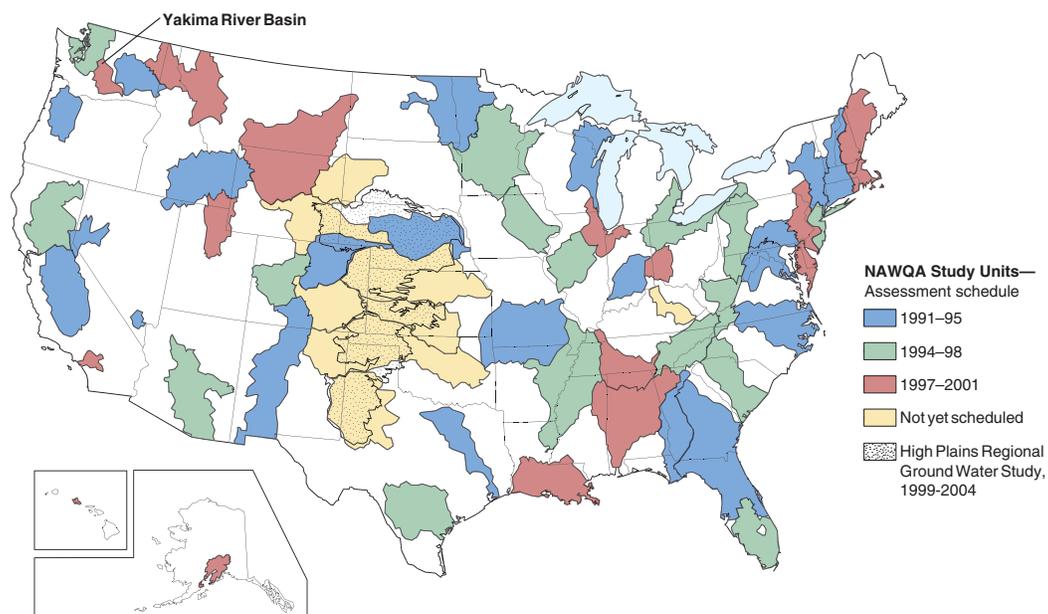
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## NATIONAL WATER-QUALITY ASSESSMENT PROGRAM



The quality of the Nation’s water resources is integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and also suitable for industry, irrigation, and habitat for fish and wildlife. Recognizing the need for long-term, nationwide understanding of water resources, the U.S. Congress has appropriated funds since 1991 for the U.S. Geological Survey (USGS) to conduct the National Water-Quality Assessment (NAWQA) Program. Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to assess the spatial extent of water-quality conditions, the changes in water quality over time, and the effects of human activities and natural factors on water quality. By synthesizing information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program contributes to informed decision-making on the management, protection, and monitoring of water resources in different hydrologic and land-use settings across the Nation.

In 1991, NAWQA began evaluating the quality of streams, ground water, and aquatic ecosystems in more than 50 major river basins and aquifer systems across the Nation, referred to as “Study Units.” Timing of the assessments varies within the Program’s rotational design: about one-third of all Study Units are intensively investigated for 3 to 4 years, which is followed by 6 to 7 years of low-level monitoring.

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

The Yakima River Basin assessment is one of two special studies activated in 1999 for the purpose of piloting study techniques for use in NAWQA's second decade of investigations. Specifically, techniques were piloted to (1) monitor trends in surface water, (2) evaluate transport of agricultural chemicals to streams, and (3) assess possible effects of agricultural chemicals from irrigated farmland on stream ecosystems. Results of this assessment improve our understanding of the types and amounts of agricultural chemicals that are entering, leaving, and accumulating within the watershed. In addition, the findings help to determine the long-term effects of farming practices, such as irrigation methods, on the ecosystems in different hydrologic and agricultural settings. The Yakima River Basin assessment builds upon monitoring data that the NAWQA Program collected previously in the basin from 1987 through 1991, as part of pilot studies conducted before full program implementation in 1991. These data provided a baseline characterization of pesticides, nutrients, trace elements, suspended solids, and aquatic life in streams.

This report is intended for individuals working with water-resource issues in other agencies—Federal, State, interstate, Tribal, and local—as well as non-governmental organizations, academia, and other stakeholder groups. The information contributes towards a fully integrated understanding of agricultural watersheds, and is useful for cost-effective management, regulation, and conservation of our water resources on agricultural lands. This report is also for individuals who wish to know more about the quality of streams in areas near where they live, and how that water quality compares to other areas across the Nation.

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

*"The USGS provides local, State, and Federal agencies with top quality data and accurate reporting that both the farming community and the environmental community can trust. NAWQA's ability to look at water quality over the long term helps to evaluate the effectiveness of water-management decisions, conservation activities, and certain farming practices that are used to reduce sediment and runoff of agricultural nutrients and chemicals from fields, such as related to conservation tillage, buffer strips along streams, manure management systems, and improved irrigation systems. High quality and consistent monitoring of our natural resource is even more critical now as we begin to implement the 2002 Farm Bill, which authorizes over \$39 billion for conservation—the highest level of funding in history for conservation programs that reduce soil erosion, preserve and restore wetlands, clean the air and water, and enhance wildlife habitat."* (Jeff Loser, National Leader for Clean Water Programs, USDA Natural Resources Conservation Service)

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## CONVERSION FACTORS AND ABBREVIATIONS

<b>Multiply</b>	<b>By</b>	<b>To obtain</b>
<b>Length</b>		
micrometers (μm)	0.00003937	inch (in)
millimeter (mm)	0.03937	inch
meter (m)	3.281	foot (ft)
kilometer (km)	.6214	mile (mi)
<b>Area</b>		
square kilometers (km <sup>2</sup> )	.386	square miles (mi <sup>2</sup> )
<b>Volume</b>		
milliliter	.001057	quart (qt)
liter (L)	1.057	quart
Liter	.2642	gallon
<b>Mass</b>		
nanogram (vg)	.0000000003527	ounce (oz avoirdupois)
microgram (μg)	.0000003527	ounce
milligram (mg)	.00003527	ounce
gram (g)	.03527	ounce
kilogram (kg)	2.205	pound (lb)
<b>Temperature</b>		
degrees Celsius (°C)	(1)	degrees Fahrenheit (°F)
<b>Discharge</b>		
cubic meters per second (m <sup>3</sup> /s)	35.31	cubic feet per second (ft <sup>3</sup> /s)
<b>Concentration, In Water</b>		
nanograms per liter (ng/L)	1	parts per trillion (ppt)
micrograms per liter (μg/L)	1	parts per billion (ppb)
milligrams per liter (mg/L)	1	parts per million (ppm)
<b>Load</b>		
kilograms per day (kg/d)	2.205	pounds per day (lb/d)
kilograms per day	.001102	tons per day (t/d)

<sup>1</sup>Temperature °F = 1.8 (temperature °C) + 32

## ABBREVIATIONS

<b>ACT</b>	action level for drinking water
<b>BSP</b>	USGS Blind Sample Project
<b>°C</b>	degrees Celsius
<b>CCC</b>	criterion continuous concentration
<b>CMC</b>	criteria maximum concentration
<b>CRB</b>	Columbia River Basalt
<b>cm</b>	centimeter
<b>E</b>	estimated value
<b>ft/mi</b>	feet per mile
<b>ft<sup>3</sup>/s</b>	cubic feet per second
<b>g</b>	gram
<b>gal</b>	gallon
<b>ft</b>	feet
<b>HAL</b>	health advisory level
<b>ICP-MS</b>	inductively coupled plasma–mass spectrometry
<b>lbs/d</b>	pounds per day
<b>LT-MDL</b>	long-term method detection level
<b>MCL</b>	maximum contaminant level
<b>MCLG</b>	maximum contaminant level goal
<b>MDL</b>	method detection level
<b>NTU</b>	nephelometric turbidity units
<b>µg/g</b>	microgram per gram
<b>µg/L</b>	microgram per liter
<b>µm</b>	micrometer
<b>µS/cm</b>	microsiemens per centimeter at 25 degrees Celsius
<b>mi<sup>2</sup></b>	miles squared
<b>mg/kg</b>	milligram per kilogram
<b>mg/L</b>	milligram per liter
<b>MAP</b>	mono ammonium phosphate
<b>MPV</b>	most probable value
<b>MRL</b>	minimum reporting level
<b>n</b>	number of observations
<b>N</b>	normal
<b>NAWQA</b>	U.S. Geological Survey National Water-Quality Assessment Program
<b>NWIS</b>	U.S. Geological Survey National Water Information System data base
<b>NWQL</b>	U.S. Geological Survey National Water Quality Laboratory
<b>PTFE</b>	polytetrafluorethylene
<b>QA/QC</b>	quality assurance/quality control
<b>RM</b>	river mile
<b>SMCL</b>	secondary maximum contaminant level
<b>USGS</b>	U.S. Geological Survey
<b>USEPA</b>	U.S. Environmental Protection Agency
<b>WWTP</b>	wastewater treatment plant

## ELEMENTS

<b>Al</b>	aluminum
<b>Sb</b>	antimony
<b>As</b>	arsenic
<b>Be</b>	beryllium
<b>B</b>	boron

<b>Cd</b>	cadmium
<b>Cr</b>	chromium
<b>Co</b>	cobalt
<b>Cu</b>	copper
<b>Fe</b>	iron
<b>Pb</b>	lead
<b>Mn</b>	manganese
<b>Mo</b>	molybdenum
<b>Ni</b>	nickel
<b>Se</b>	selenium
<b>Ag</b>	silver
<b>Sr</b>	strontium
<b>Tl</b>	thallium
<b>U</b>	uranium
<b>Zn</b>	zinc

#### COMPOUNDS

<b>CaCO<sub>3</sub></b>	calcium carbonate
<b>HCL</b>	hydrochloric acid
<b>HNO<sub>3</sub></b>	nitric acid
<b>H<sub>2</sub>SO<sub>4</sub></b>	sulfuric acid
<b>PO<sub>4</sub></b>	phosphate

#### MAPPING SOURCES

Base map modified from U.S. Geological Survey data and other digital sources:  
 Basin: USGS-Digitized from DRGs and topographic maps, 1:24,000, compiled 1999  
 Counties: Washington State Department of Transportation, 1:500,000, compiled 1995  
 Cities: Washington State Department of Transportation, 1:24,000, compiled 2002;  
 USGS-GNIS, 1:24,000, compiled 2001  
 Roads: Washington State Department of Transportation, 1:24000, 1996, compiled 2000  
 Hydrography: Pacific Northwest River Reach Files, USGS, 1:100,000, compiled 1999  
 Canals: USGS, Digitized from DRGs and topographic maps, 1:24,000, compiled 2000

Projection: Albers Conical Equal Area;  
 Datum: North American Datum of 1983 (NAD83);  
 Spheroid: Geodetic Reference System 1980 (GRS 1980);  
 Standard parallels: 29 30 00 and 45 30 00, Central meridian: -119 00 00

# Occurrence and Distribution of Dissolved Trace Elements in the Surface Waters of the Yakima River Basin, Washington

By Curt A. Hughes

## Abstract

The occurrence, distribution, and transport of dissolved (filtered-water) trace elements in the surface waters of the Yakima River Basin were assessed using data collected between 1999 and 2000 as part of the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program. Samples were collected at 34 sites throughout the basin in August 1999, using a Lagrangian sampling design. From May 1999 through January 2000, samples also were collected weekly during the irrigation season and once per month during the nonirrigation season at three intensive fixed sites. Although the focus of this study was on 9 trace elements (aluminum, arsenic, barium, copper, iron, manganese, nickel, uranium, and zinc), 14 additional elements were analyzed in filtered water.

Concentrations for most trace elements in filtered water generally were low and there were no exceedances of the U.S. Environmental Protection Agency (USEPA) freshwater aquatic-life water-quality criteria. The USEPA drinking-water standard for arsenic (10  $\mu\text{g/L}$ ) was exceeded in two samples that were collected under base-flow conditions during the nonirrigation season at Granger Drain. Over 40 percent of all filtered-water samples collected during this study exceeded the USEPA health advisory level of 2.0  $\mu\text{g/L}$  for arsenic. Arsenic concentrations in agricultural drains were highest when the drains

were primarily fed by shallow ground water, and concentrations in the Yakima River were highest when the river was fed primarily by agricultural return flow. The USEPA secondary maximum contaminant level for manganese (50  $\mu\text{g/L}$ ) was exceeded in three samples collected at Granger Drain during the nonirrigation season.

Instantaneous arsenic loads calculated for August 1999 were similar to mean monthly loads determined in August 1989 at two intensive fixed sites located on the Yakima main stem. In August 1999, arsenic loads increased twofold between the Yakima River at river mile 72 above Satus and the Yakima River at Kiona at river mile 29.9. The dissolved arsenic loads for the Yakima River at Euclid Bridge at river mile 55 near Grandview and Yakima River at Kiona were within 13 percent of the August 1989 levels.

## INTRODUCTION

In 1986, the Yakima River Basin was selected as one of four surface-water pilot studies in the U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program (Hirsch and others, 1988). Full implementation of the Cycle-II NAWQA study in the Yakima River Basin, which was scheduled to start in 1997, was delayed until 1999. During 1999, filtered-water samples were collected from surface water throughout the Yakima River Basin. These were analyzed for dissolved trace elements, providing a set of data for analysis and for comparison with data collected during the 1987–91 pilot study (Fuhrer and others,

1999). To date, these comparisons appear to indicate that water-quality patterns are related to chemical use, land use, climate, geology, topography, and soil types. These comparative regional and national results have improved our understanding of how and why water quality varies in the Yakima River Basin.

## **Purpose and Scope**

This report describes the occurrence and distribution of dissolved (filtered water) trace-element concentrations in surface water in the Yakima River Basin. Data collected in August 1999 during a basinwide sampling (table 1) of surface water and wastewater discharges are used to examine relations between land use and trace-element concentrations and loads of arsenic. The report also describes how dissolved trace-element concentrations in surface water varied from May 1999 through January 2000, and the factors affecting those variations, for three sites sampled repeatedly over that period. The surface-water-quality data for all sites were compared to current drinking-water standards, health advisory levels, and freshwater aquatic-life water-quality criteria to identify sites where elements that could adversely affect human health or aquatic life (U.S. Environmental Protection Agency, 1999).

As stated above, the 1999–2000 trace-element concentrations were compared to surface-water data collected during the 1987–91 pilot study. The Yakima River at Kiona (the most downstream site in the basin) was sampled monthly during the pilot for cadmium, copper, mercury, and zinc in filtered-water samples. The Kiona site was sampled again from May 1999 through January 2000 for 23 trace elements excluding mercury. Additionally, surface-water data from 34 sites sampled in August 1999 during basinwide sampling were compared to surface-water data from a spatially limited synoptic performed in August 1987.

## **Obtaining Data Used in Report**

Data used in this report can be obtained by following the Data link on the Yakima River Basin NAWQA web page at URL <http://oregon.usgs.gov/yakima>.

## **Acknowledgments**

The author gratefully acknowledges the individuals and agencies who provided support and assistance to this project. Moses Squeochs and James Thomas (Yakama Indian Nation) worked with the Yakama Indian Nation Council to obtain access to sampling sites and accompanied us during site visits. Bill Rice, Roza Sunnyside Board of Joint Control, helped with selection of sampling sites, installed water-quality monitors, gaged streams, and collected samples, which he analyzed for turbidity. Steve Fancuillo, Bureau of Reclamation, arranged access to their stream gages and provided streamflow data and advice on the mass balance of water discharges needed for computing arsenic loads. Bob Stevens, soil scientist with Washington State University, provided land-use maps of the Granger Basin. Assistance during sample collection was provided by Jennifer Key, student at Central Washington University; Paivikki “Vickie” Pihl, student at Tampere University of Technology, Finland; and Brent Morace, USGS volunteer. Wastewater treatment plant operators in Cle Elum, Ellensburg, Selah, Yakima, Zillah, Granger, Sunnyside, and Prosser collected effluent samples during the August 1999 basinwide sampling.

## **BASIN DESCRIPTION AND PREVIOUS FINDINGS**

The Yakima NAWQA pilot study provided a comprehensive assessment of trace elements detected in surface water, suspended and streambed sediments, and aquatic biota in the Yakima River Basin for the period 1987–91 (Fuhrer and others, 1999; summarized by Morace and others, 1999).

The Yakima River flows 214.5 miles from the outlet of Keechelus Lake in the central Washington Cascades southeasterly to the Columbia River, draining an area of 6,155 square miles (fig. 1). The Yakima River Basin incorporates the high peaks and deep valleys of the Cascade Range, the broad valleys and basalt ridges of the Columbia Plateau, and lowlands. Altitude in the basin ranges from 340 ft above sea level at the mouth of the Yakima River, to about 8,184 ft in the headwaters, located in the Cascade Range. 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 (Fuhrer and others, 1999).

Results from the pilot study show that surface-water quality in the Yakima River Basin varied with land use/cover which ranges from forested headwaters to agriculture and rangeland, which cover most of the lower basin (fig. 2). The basin can be divided into three distinct river reaches on the basis of its physical characteristics. The upper reach, which drains the Kittitas Valley, has a high gradient, with an average streambed slope of 14 feet per mile (ft/mi) over the 74 miles from the foot of Keechelus Lake to just upstream from Umtanum. The middle reach, which drains the Mid-Valley, extends a distance of 33 miles from Umtanum (river mile [RM] 140.5) to just upstream from Union Gap and also has a high gradient, with an average streambed slope of 11 ft/mi. The lower reach of the Yakima River drains the Lower Valley and has an average streambed slope of 7 ft/mi over the 107 miles from Union Gap (RM 107.2) to the mouth of the Yakima River (fig. 3).

These reaches had differences in water-quality conditions related to the differences in agricultural activities and land use. Compared with the rest of the basin, the Kittitas Valley and headwaters of the Naches River Basin had relatively low concentrations and loads of dissolved trace elements. In general the Kittitas Valley is considered to be an area of less degraded water quality. Water-quality conditions in the Mid-Valley were similar to those in the Lower Valley in that water quality in both reaches was degraded by the effects of agriculture activities (Morace and others, 1999). Dissolved arsenic, cadmium, chromium, copper, lead, mercury, and zinc concentrations in these reaches exceeded screening values (based on USEPA ambient water-quality criteria for the protection of aquatic organisms) at two or more sites in the Yakima River Basin during the 1987–91 water years (Fuhrer and others, 1999).

The Yakima River Basin is one of the most intensively irrigated areas of the United States. Surface-water diversions for irrigation are equivalent to about 60 percent of the mean annual streamflow from the basin (Fuhrer and others, 1999). Irrigation return flow in the Lower Valley downstream from the city of Yakima contributes as much as 60 to 70 percent of the flow in the lower main stem during the irrigation season. A schematic diagram of selected inflows and

outflows is shown in figure 4. Many of these inflows carry agricultural return flow.

## STUDY DESIGN AND METHODS

Basinwide sampling of surface-water sites and wastewater discharges (fig. 5) was conducted August 2–6, 1999. Sampling of the Yakima River extended from Cle Elum (RM 182.5) to Kiona (RM 29.9). In addition to sampling points along the main stem, these locations included mouths of tributaries receiving agricultural runoff, water intakes for the cities of Yakima and Cle Elum, effluents from eight wastewater treatment plants (WWTPs), and three sites in the Satus Creek subbasin. More than 40 samples, including those for quality control, were collected at these sites (table 1). To the extent possible, the timing of the sampling from all sites was set according to the velocity of water moving downstream in the Yakima River. This is referred to as “Lagrangian” sampling, which can be visualized as sampling a distinct unit or “parcel” of water as it moves downstream. The advantage of Lagrangian sampling is that it may permit a determination of water and dissolved trace-element budgets as the parcel moves downstream. The resulting data were used to compute instantaneous arsenic loads during August 1999. In addition to the Lagrangian sampling, additional samples were collected to assess short-term temporal variations in dissolved trace-element concentrations.

In addition to basinwide sampling, three fixed sites—Yakima River at Kiona, Moxee Drain at Birchfield Road, and Granger Drain at Granger—were sampled repeatedly between May 1999 and January 2000 to assess seasonal changes in dissolved trace-element concentrations. Sampling frequency varied from once-per-month for fixed-site sampling during the nonirrigation season to multiple times daily during the August 1999 Lagrangian sampling program.

### Field Procedures

Representative cross-sectional stream samples were obtained by collecting depth-integrated subsamples at equally spaced verticals across the stream using either a DH-81 or D-77 isokinetic sampler (Edwards and Glysson, 1988; Shelton, 1994).

**Table 1.** Surface-water sites and wastewater treatment plants sampled in the Yakima River Basin, Washington, 1999–2000  
 [USGS, U.S. Geological Survey; RM, river mile; WWTP, wastewater treatment plant; abv, above; Cr, Creek; WW, wasteway; nr, near; Rd, road]

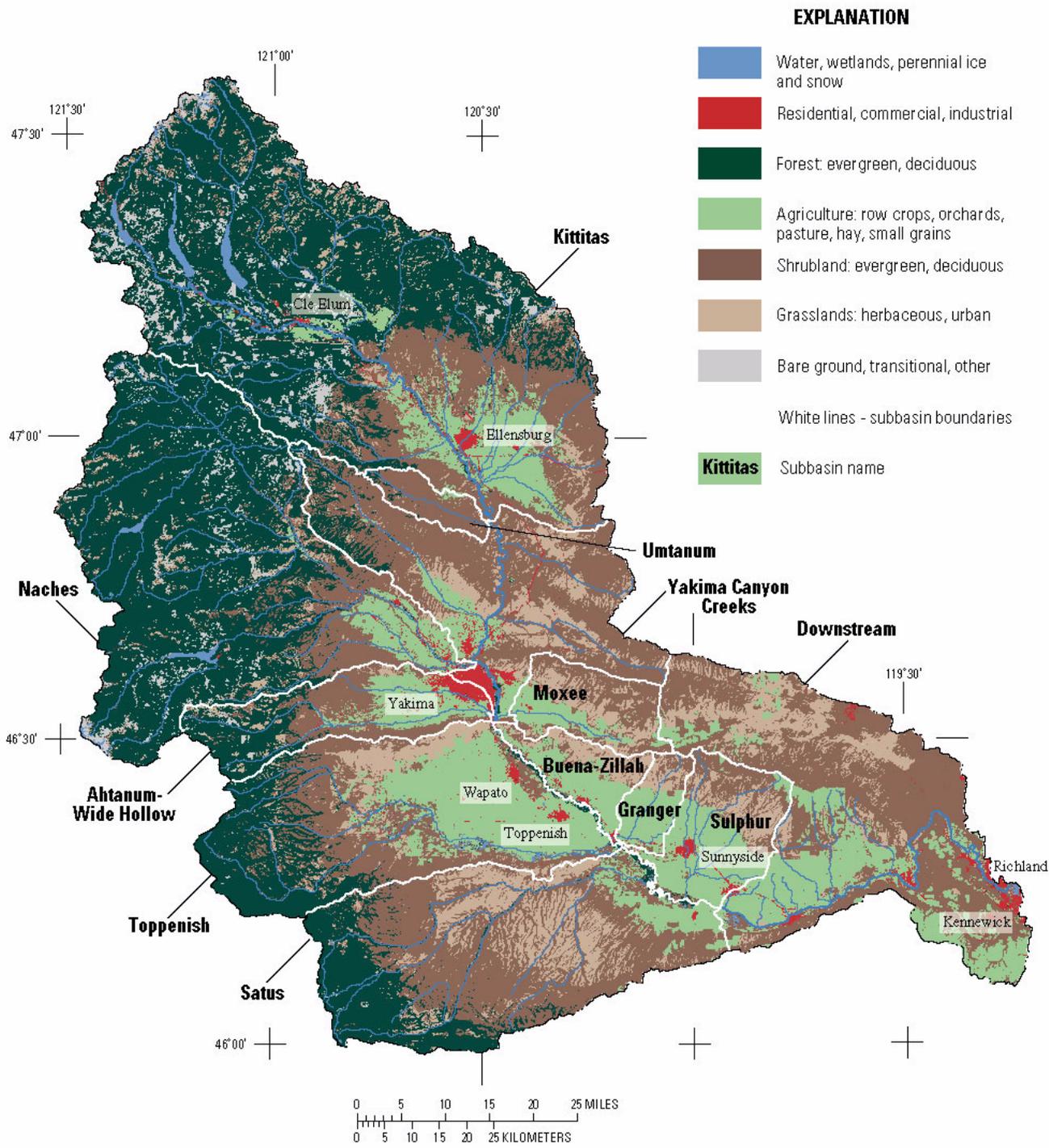
Map identification	USGS station number	Site name	RM <sup>1</sup>	RM sampled on tributary	Number of samples collected during basinwide sampling August 1999	Number of samples collected May 1999 through January 2000 at intensive fixed sites
1	12479500	Yakima River at Cle Elum	182.5		1	
2	4711211205434	Cle Elum WWTP	179.6		1	
3	4657481203252	Ellensburg WWTP	151.6		1	
4	12484100	Wilson Creek above Cherry Creek at Thrall	147	1.1	1	
5	12484480	Cherry Creek at Thrall <sup>2</sup>	147	.1	1	
6	12484500	Yakima River at Umtanum	140.4		1	
7	12484550	Umtanum Creek nr mouth at Umtanum	139.8	.1	1	
8	4638561203130	Selah WWTP	117		1	
9	12496510	Pacific Power & Light Company Wasteway <sup>3</sup>	116.3	9.7	1	
10	12499000	Naches River nr North Yakima	116.3	.1	1	
11	4634471202752	Yakima WWTP	111		1	
12	12500445	Wide Hollow Creek near mouth at Union Gap	107.4	.8	1	
13	12500420	Moxee Drain at Birchfield Road nr Union Gap	107.3	1.4	2	15
14	12500450	Yakima R at Union Gap abv Ahtanum Cr	107.3		1	
15	12502500	Ahtanum Creek at Union Gap	106.9	.8	1	
16	4623571201532	Zillah WWTP	89.5		1	
17	12505350	E Toppenish Drain at Wilson Rd nr Toppenish	86	1.3	1	
18	12505410	Sub 35 Drain at Parton Road nr Granger	83.2	1.7	1	
19	4620131201137	Granger WWTP	82.8		1	
20	12505450	Granger Drain at Granger	82.8	.8	2	15
21	12505510	Marion Drain at Indian Church Rd at Granger	82.6	1.4	1	
22	12507508	Toppenish Creek at Indian Church Rd nr Granger	80.4	2.4	1	
23	12507585	Yakima River at RM 72	72		1	
24	12507595	Satus Cr abv Shinado Creek nr Toppenish	69.6	41.3	1	
25	12508500	Satus Cr below Dry Cr near Toppenish	69.6	15	1	
26	12508620	Satus Creek at gage at Satus	69.6	2.7	1	
27	12508630	South Drain near Satus	69.3	1.8	2	
28	4618501200058	Sunnyside WWTP <sup>4</sup>	61		1	
29	12508850	Sulphur Cr Wasteway nr Sunnyside	61	.8	2	
30	12509050	Yakima R at Euclid Br at RM 55 nr Grandview	55		1	
31	4612461194547	Prosser WWTP	47		1	
32	4614041194104	Spring Creek at Hess Road nr Prosser	41.8	.4	1	
33	4614141194042	Snipes Creek below Chandler Canal nr Prosser	41.8	.4	1	
34	12510500	Yakima River at Kiona	29.9		3	16

<sup>1</sup>River mile sampled on the Yakima River or where tributary or WWTP discharges to the Yakima River.

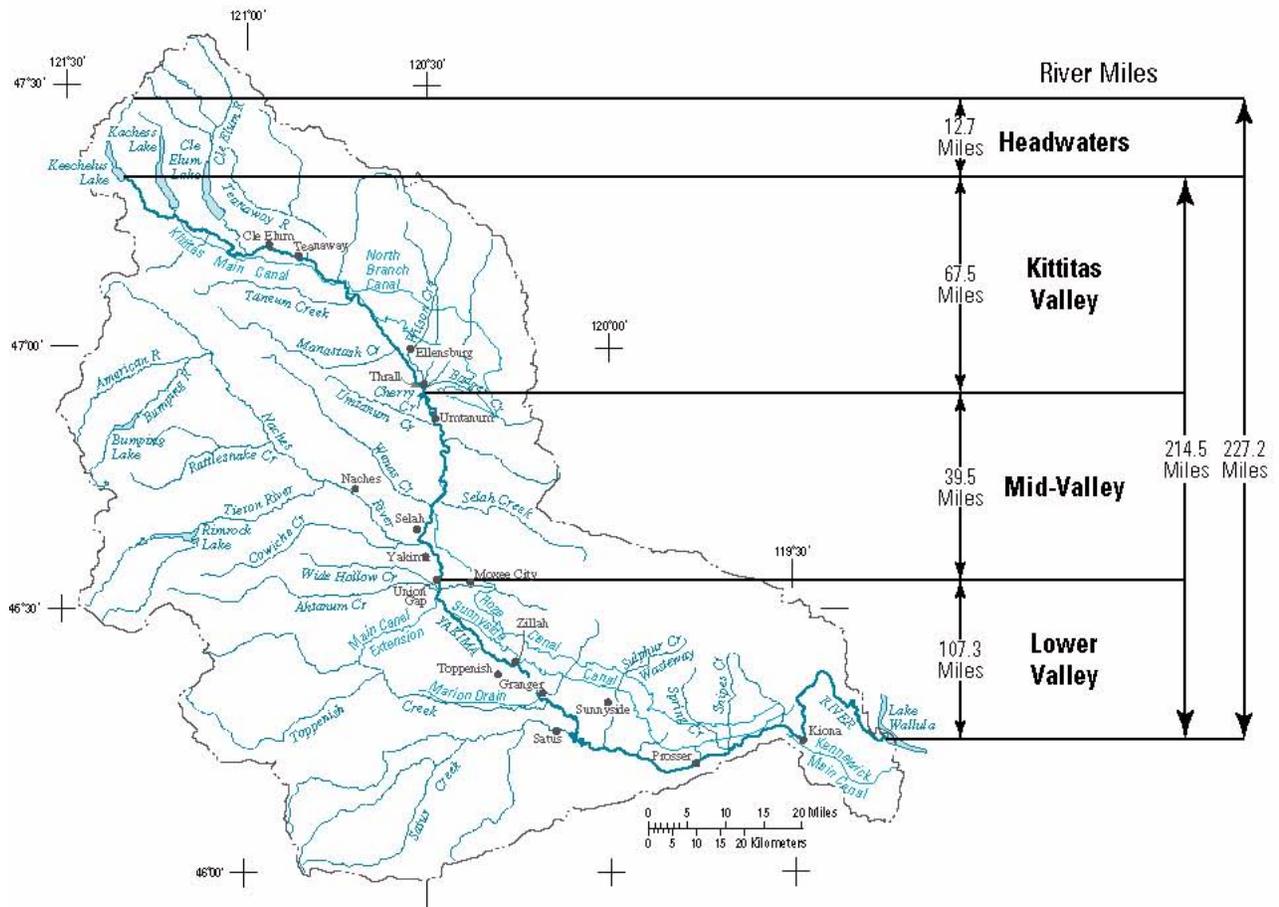
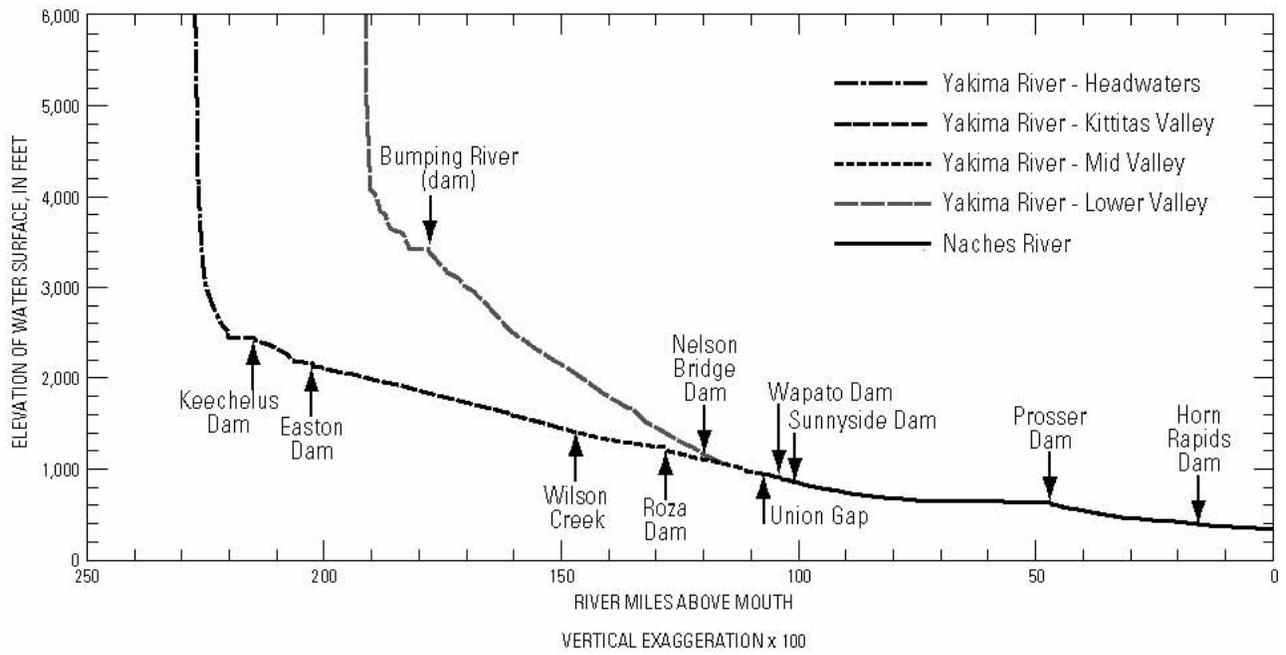
<sup>2</sup>Cherry Creek discharges to Wilson Creek at RM 1.1.

<sup>3</sup>Pacific Power and Light Wasteway discharges to the Naches River at RM 9.7 (sample collected on tributary to Naches River).

<sup>4</sup>Sunnyside WWTP discharges to DID 3, which discharges to Sulphur Creek.



**Figure 2.** Land use and land cover in the Yakima River Basin, Washington.



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

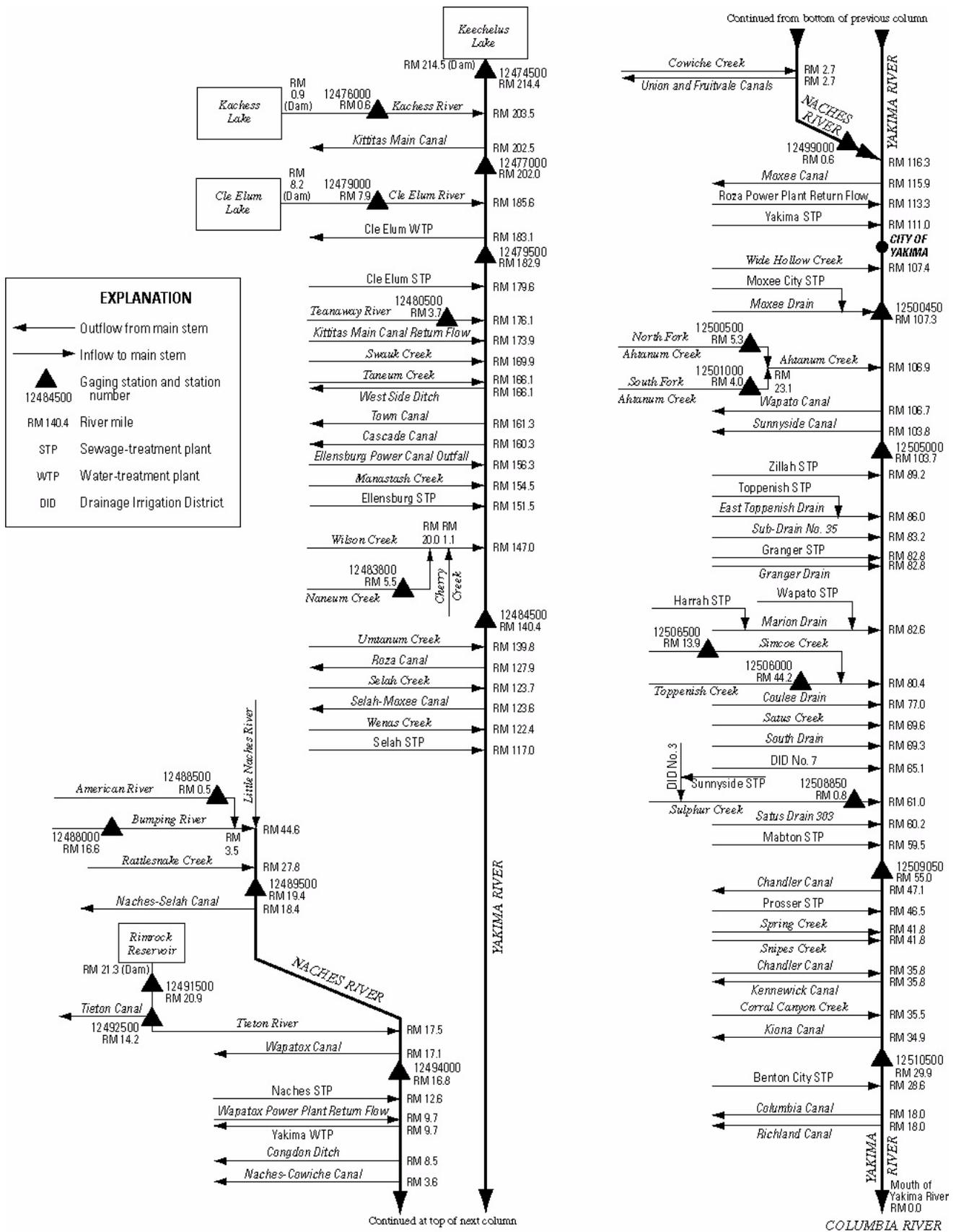
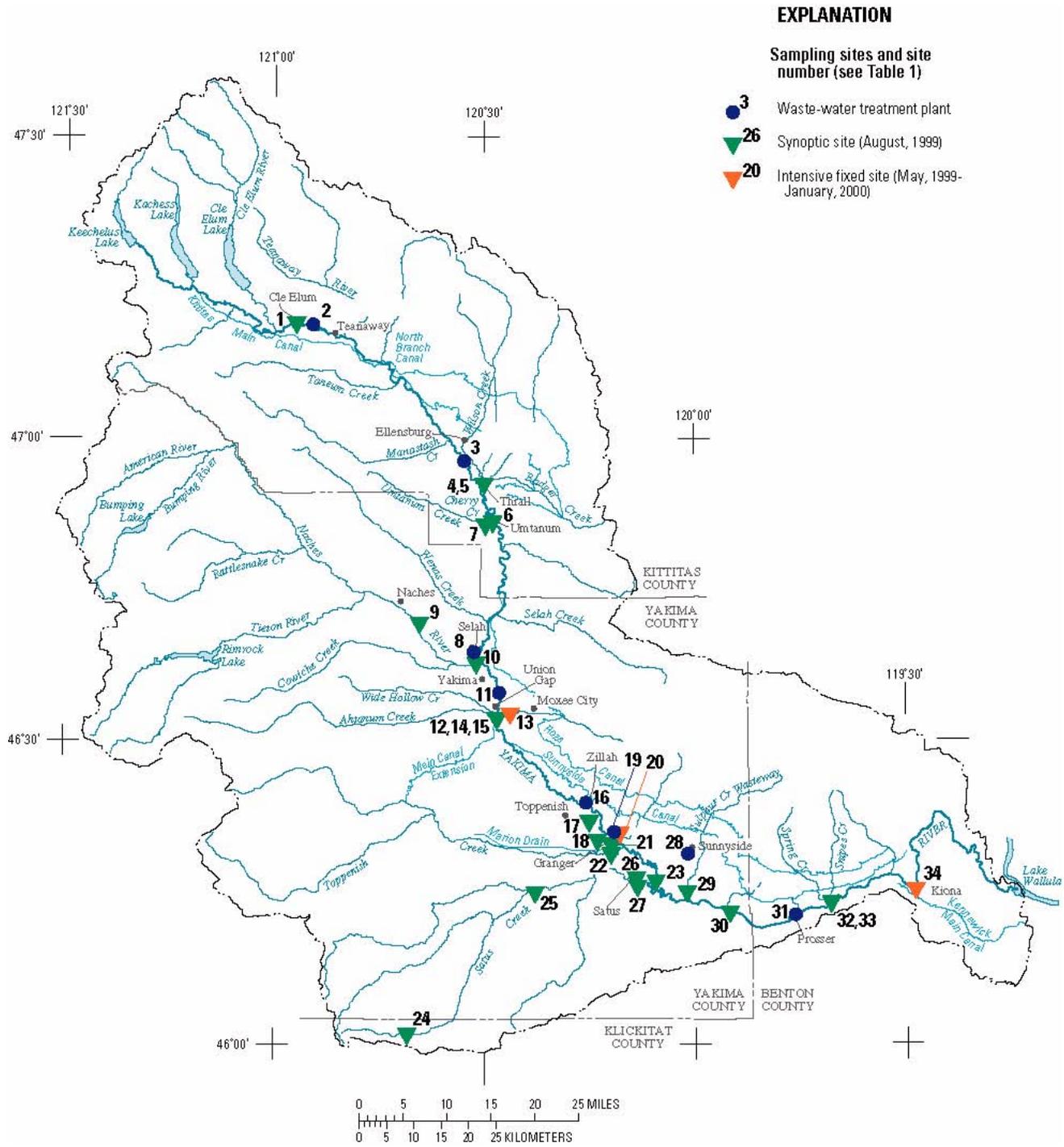


Figure 4. Schematic diagram of selected tributaries, diversion canals, return flows, and stream-gaging stations in the Yakima River Basin, Washington.



**Figure 5.** Location of sampling sites in the Yakima River Basin, Washington, 1999–2000. (See table 1 for site names and sample details.)

Both samplers employ a 3-liter polytetrafluorethylene (PTFE, a variety of Teflon) bottle and nozzle. Treated effluent samples from wastewater treatment plants were collected by dipping a 3-liter bottle directly into an open cement channel or by compositing the sample over a 24-hour period and drawing it through a peristaltic pump into a 3-liter bottle. All equipment used to collect and process samples was cleaned with a 0.1-percent nonphosphate detergent, acid rinsed with 5-percent (by volume) HCL, rinsed with deionized water, wrapped in aluminum foil, and stored in a dust-free environment prior to sample collection (Shelton, 1994). Prior to collecting the sample, all sampling equipment is rinsed three times at the site with native water. Water from all of the sample bottles was composited and split into aliquots for the various laboratory procedures using a Nalgene 14-liter churn splitter, as described by Shelton (1994). Samples were shipped on ice within 24 hours, to the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado, for analysis.

## Laboratory Procedures

Water samples were analyzed within 30 days (Pritt and Raese, 1995) for 23 dissolved trace elements using Inductively Coupled Plasma Mass Spectrophotometer (ICP-MS), Inductively Coupled Plasma Optical Emmission Spectroscopy (ICP-OES) (iron), or Graphite Furnace with Atomic Absorption (GFAA) (arsenic, chromium, and selenium) instrumentation (Perkin- Elmer Elan 6000, Thermo-Jarrel Ash ICAP-61E Purge, Perkin-Elmer 5100, respectively) at the NWQL. Once the instrument has passed its daily performance check, it is standardized using a blank and multiple calibration standards with varying concentration ranges.

This report uses the USGS National Water Quality Lab (NWQL) minimum reporting level (MRL) convention for all analytes reported (Childress and others, 1999), except as noted in table 3. Historically, the NWQL has defined the MRL as the “<” value reported when an analyte is not detected. Since the definition of the MRL is not statistically derived, an MRL can be set at any concentration acceptable to the data user and the laboratory as long as a reliable measurement is achieved. Since October 1, 2000, the NWQL uses the long-term method detection level (LT-MDL) and laboratory reporting level (LRL) protocol for trace elements in filtered water (Childress

and others, 1999). This new reporting convention provides estimates of analytes detected at low concentrations rather than censoring them at a higher MRL.

The LT-MDL is a detection level derived by determining the standard deviation of a minimum of 24 method detection level spike-sample measurements over an extended period of time. The LT-MDL controls false positive error. The chance of falsely reporting a concentration at or greater than the LT-MDL for a sample that did not contain the analyte is predicted to be less than or equal to 1 percent. The LRL controls false negative error. The probability of falsely reporting a nondetection for a sample that contained an analyte at a concentration equal to or greater than the LRL is predicted to be less than or equal to 1 percent. The LRL is generally equal to twice the yearly determined LT-MDL. Concentrations measured between the LRL and the LT-MDL are reported as estimated concentrations. Nondetections are censored to the LRL level (Childress and others, 1999). The water-quality data used in this report straddle both old and new reporting conventions. Data collected during the August 1999 synoptic sampling used the historic MRL reporting convention, whereas data collected after October 1, 2000, at the intensive fixed sites used the LRL.

## QUALITY-CONTROL SAMPLES

About 8 percent of all field samples submitted to the NWQL for chemical analysis were quality-control samples. Quality assurance included six field equipment blanks (blank samples), two replicates, and two standard reference samples (table 2).

A variety of measurements and analyses were used to determine the quality of the data produced in this study. For all laboratory methods, the standardization of instrumentation is verified with independently produced quality control solutions which are analyzed at a frequency of 10 percent and the analytical results rejected when the quality-control solutions produce results outside established quality-control limits, or approximately  $\pm 1.5$  standard deviations. For the elements determined by ICP-MS, internal standards are used throughout the analysis to correct for instrument drift and minimize matrix effects.

**Table 2.** Concentration and precision data for dissolved trace elements detected in more than one member of replicate surface-water samples, and recovery and accuracy data for standard reference samples, Yakima River Basin, Washington, 1999–2000

[Concentrations are in micrograms per liter; Al, Aluminum; Sb, Antimony; As, Arsenic; Ba, Barium; Be, Beryllium; B, Boron; Cd, Cadmium; Cr, Chromium; Co, Cobalt; Cu, Copper; Fe, Iron; Pb, Lead; Mn, Manganese; Mo, Molybdenum; Ni, Nickel; Se, Selenium; Ag, Silver; U, Uranium; Zn, Zinc; relative percent difference, absolute value of the difference between the replicate samples divided by the mean and multiplied by 100; most probable value is the median concentration reported for each constituent; percent recovery, measured value divided by most probable value multiplied by 100; <, less than; E, estimated values; number in parentheses below the constituent is the data parameter from the U.S. Geological Survey National Water Information System (NWIS) data base, —, no data; nc, not calculated; NA, not applicable]

Site name	Sample date	Al (01106)	Sb (01095)	As (01000)	Ba (01005)	Be (01010)	B (01020)	Cd (01025)	Cr (01030)	Co (01035)	Cu (01040)	Pb (01049)	Mn (01056)	Mo (01060)	Ni (01065)	Se (01145)	Ag (01075)	U (22703)	Zn (01090)
<b>Replicate Samples</b>																			
Granger Drain at Granger	May 20, 1999																		
	Sample #1	1.7	<1	4.3	41.3	<1	—	<1	<1	<1	1.2	<1	20.8	5.3	1.1	<1	<1	6.6	<1
	Sample #2	<1	<1	4.7	42.4	<1	—	<1	<1	<1	1.3	<1	21.8	5.4	<1	1.1	<1	7.1	<1
	Relative percent difference	nc	nc	8.9	2.6	nc	—	nc	nc	nc	8.0	nc	4.7	1.9	nc	nc	nc	7.3	nc
Granger Drain at Granger	January 12, 2000																		
	Sample #1	1.1	<1	10.9	80.8	<1	28.7	<1	E.6	<1	1.6	<1	62.9	11.8	4.4	2.9	<1	13.7	1.1
	Sample #2	1.2	<1	10.4	81.0	<1	27.5	<1	E.6	<1	1.4	<1	62.4	11.8	4.2	2.8	<1	13.7	<1
	Relative percent difference	8.7	nc	4.7	.2	nc	4.3	nc	nc	nc	13.3	nc	.8	0	4.6	3.6	nc	0	nc
<b>Standard Reference Samples</b>																			
NA	September 21, 2000																		
	Measured value	67.9	8.6	9.7	38.8	8.8	—	9.2	15.3	10.4	11.6	13.2	21.9	8.8	10.6	10.3	7.2	1.2	10
	Most probable value	67.6	—	9.9	37.1	9.0	—	9.3	—	10	11	12.7	20.9	9.2	11	10.1	7.5	1.1	10
	Percent recovery	100	—	98	105	98	—	99	—	104	105	104	105	96	96	102	96	109	100
NA	October 20, 1999																		
	Measured value	29.3	15.6	<2.0	65.1	5.2	—	6.6	18.1	<1	1.9	6.4	92.4	8.8	15.4	<2.4	<1	11	46
	Most probable value	30.5	—	.6	65	5.2	—	6.8	—	.04	1.9	6.3	98	8.9	15	1.3	.30	10	49.5
	Percent recovery	96	—	nc	100	100	—	97	—	nc	100	102	94	99	103	nc	nc	110	93

Contamination is monitored by analyzing quality-control blanks. If quality-control blank results are greater than the long-term method detection level (see section—Trace Elements Detected in Filtered-Water Samples), the set is reanalyzed for the element in question and the source of the contamination determined before resuming analysis (Tedmund Struzeski, USGS National Water Quality Laboratory, written commun., 2001). Also, since 1981 the USGS has operated an independent, external, quality-assurance program called the Blind Sample Program (Ludtke and Woodworth, 1997). The purpose of the Blind Sample Program is to monitor and evaluate the quality of laboratory analytical results through quality-control samples.

Accuracy is defined in this study as the measure of the degree of conformance of values generated by a specific analytical method compared with the true or expected value of that measurement. Accuracy is evaluated by measurement of standard reference materials. Standard reference materials are quantified by the percent recovery value. For standard reference materials, the percent recovery value was computed as:

$$\text{percent recovery} = \frac{\text{measured value}}{\text{most probable value}} \times 100 \quad (1)$$

There were no analytical determinations for antimony, boron, and chromium because these elements were not included in the USGS standard reference constituent schedule. Percent recovery was not calculated when the measured value was less than the MRL (see section—Trace Elements Detected in Filtered-Water Samples).

For all elements listed in table 2, percent recovery ranged from 93 to 110 percent. All elements (for which percent recovery was calculated) were within 10 percent or less of the most probable value and 21 of 26 elements (81 percent) were within 5 percent or less of the most probable value.

Blank samples were collected to test for contamination from any stage in the sampling/analytical process. Blank water is essentially free of the analytes of interest (Pritt and others, 1995). No trace elements were detected in field blanks, except for 2.6 µg/L boron, which was detected in one sample. These results indicate that the field and laboratory methods used for this study did not generate systematic contamination.

Variability in this report is defined as the concentration difference between replicate samples that were analyzed at the NWQL using identical laboratory protocols. Therefore only analytical variability was measured in this study. Replicate samples were collected from Granger Drain at Granger, and variability was evaluated by determining the relative percent difference, which is computed as:

$$\text{relative percent difference} = \frac{|\text{sample 1} - \text{sample 2}|}{\text{average of the two replicates}} \times 100 \quad (2)$$

For all elements listed in table 2, the relative percent differences were less than 14 percent with over three-fourths of the differences less than 5 percent. This result indicates that the variability between replicates was minimal.

## **DRINKING-WATER STANDARDS AND AQUATIC-LIFE WATER-QUALITY CRITERIA**

The surface-water-quality data for all sites were compared to current drinking-water standards and freshwater aquatic-life water-quality criteria (U.S. Environmental Protection Agency, 1999) (table 3).

The U.S. Environmental Protection Agency (USEPA) drinking-water standards are defined as the permissible level of a contaminant in water as delivered to users of a public water system. Maximum Contaminant Levels (MCLs) are health related standards and legally enforceable, whereas Secondary Maximum Contaminant Levels (SMCLs) apply to the esthetic qualities of water and are recommended nonenforceable levels. Action levels for drinking water (ACTs) are considered the lowest level to which water systems can reasonably be required to control a contaminant should it occur in drinking water. The USEPA Health Advisory Levels (HALs) used in this report are defined as the concentration of a contaminant in drinking water that is expected to cause adverse but noncarcinogenic effects over a lifetime of typical exposure. The typical exposure assumes that a 154-pound adult drinks about 0.5 gal of such water per day for 70 years (U.S. Environmental Protection Agency, 1996). The ACTs and HALs are nonenforceable guidelines. This report lists the current drinking water standards for the 23 trace elements detected in the Yakima River Basin from April 1999 through January 2000 for comparison purposes only.

**Table 3.** Trace-element summary statistics for water-quality properties and constituents analyzed or measured for all sites sampled in the Yakima River Basin, Washington, 1999–2000

[USGS, U.S. Geological Survey; USEPA, U.S. Environmental Protection Agency; NWIS, National Water Information System; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; na, not applicable; <, less than; E, estimated value; ACT, action level for drinking water; HAL, health-advisory level for drinking water; MCL, maximum contaminant level for drinking water; MCLG, maximum contaminant level goal; NTU, nephelometric turbidity units; SMCL, secondary maximum contaminant level for drinking water; concentration values in **bold italic** represent a exceedance of a MCL, HAL, or SMCL; —, no data]

Constituent or property	Number of detections/samples	Minimum reporting level	USEPA aquatic life water-quality criterion <sup>1</sup>	USEPA drinking-water standards or health advisory <sup>1</sup>	Minimum	25th	Median	75th	Maximum	
<b>Field Parameters</b>										
Water temperature (°C)	69/69	—	—	—	3.9	14	17.8	21	25.1	
Specific conductance (µS/cm)	77/77	—	—	—	43	218	255	352	1,530	
Oxygen, dissolved (mg/L)	78/78	—	—	—	6.9	8.6	9.0	9.7	12.8	
pH, field (standard units)	69/69	—	6.5–9	6.5–8.5 (SMCL)	7.1	8.0	8.1	8.2	8.6	
Turbidity (NTU)	76/76	—	—	5.0	.7	4.1	12	28	221	
Alkalinity (mg/L as CaCO <sub>3</sub> )	68/68	—	20,000	—	19	87	100	121	326	
Hardness, total (mg/L as CaCO <sub>3</sub> )	61/61	—	—	—	16	68	95	124	310	
Total Dissolved solids (mg/L)	63/63	—	—	500 (SMCL)	.7	4.1	12	28	221	
<b>Trace Elements, in micrograms per liter; sample filtered through a 0.45-micrometer filter</b>										
Aluminum	76/79	1.0	<sup>3</sup> 87	50–200 (SMCL)	<1.0	1.9	3.5	6.7	97	
Antimony	0/79	1.0	—	6.0 (MCL)	<1.0	—	—	—	—	
Arsenic	59/79	<sup>2</sup> 0.9–1.0	150	10 (MCL) 2.0 (HAL)	<1.0	<1.0	1.5	<b>3.7</b>	<b>11</b>	
Barium	79/79	1.0	—	2,000 (MCL)	1.6	2.7	20	39	96	
Beryllium	0/79	1.0	—	4.0 (MCL)	<1.0	—	—	—	—	
Boron	3/3	12	—	600 (HAL)	<12	—	27	—	54	
Cadmium	0/79	1.0	<sup>4</sup> 27	5.0 (MCL)	<1.0	—	—	—	—	
Chromium	4/79	<sup>2</sup> 0.9–1.0	<sup>4</sup> 74	100 (MCL)	<sup>5</sup> E .5	—	<sup>5</sup> E .5	—	1.2	
Cobalt	0/79	1.0	—	—	<1.0	—	—	—	—	
Copper	55/79	1.0	<sup>4</sup> 9.0	1,300 (ACT) (MCLG)	<1.0	<1.0	1.2	1.6	9.5	
Iron	55/60	10	<sup>3,4</sup> 1,000	300 (SMCL)	<10	9.7	13	19	48	
Lead	1/79	1.0	<sup>4</sup> 2.5	15 (ACT)	<1.0	—	—	—	1.2	
Lithium	3/3	.3	—	—	1.1	—	9	—	19	
Manganese	76/79	1.0	—	50 (SMCL)	<1.0	3.5	8	19	<b>75</b>	
Molybdenum	44/79	1.0	—	40 (HAL)	<1.0	<1.0	1.2	4.4	35	
Nickel	48/79	1.0	<sup>4</sup> 52	100 (HAL)	<1.0	<1.0	1.1	1.3	4.2	
Selenium	17/79	<sup>2</sup> 0.7–1.0	<sup>3</sup> 5.0	50 (MCL)	<1.0	<1.0	<1.0	1.1	2.8	
Silver	0/79	1.0	<sup>6</sup> 3.4	100 (HAL)	<1.0	—	—	—	—	
Strontium	3/3	.2	—	17,000 (HAL)	84	—	244	—	378	
Thallium	0/3	.9	—	2.0 (MCL)	<.9	—	—	—	—	
Uranium	49/79	1.0	—	20 (MCL)	<1.0	<1.0	1.3	5.1	16	
Vanadium	3/3	1.0	—	—	3.8	—	23	—	55	
Zinc	33/79	1.0	<sup>4</sup> 120	5,000 (SMCL)	<1.0	<1.0	<1.0	1.3	78	

<sup>1</sup>U.S. Environmental Protection Agency 1999, all aquatic-life water-quality criterion values are listed as criterion continuous concentrations (CCC), unless otherwise noted.

<sup>2</sup>LRL for this analyte was revised.

<sup>3</sup>Expressed in terms of total recoverable metal in the water column.

<sup>4</sup>Dissolved metal criteria were calculated using a hardness of 100 mg/L as CaCO<sub>3</sub> (for illustrative purposes only).

<sup>5</sup>USGS National Water Quality Laboratory (LRL).

<sup>6</sup>Criterion maximum concentration (CMC).

The USEPA drinking-water standards were listed in this report because the Yakima River from the mouth to the Cle Elum River (river mile [RM] 185.6) (including all tributaries except Sulphur Creek Wasteway) is listed by Washington State as a Class A surface water body. Water supplies from Class A surface water bodies may be used for domestic, industrial, and agricultural uses (State of Washington, 1997). The surface waters sampled are not necessarily representative of the quality of water after treatment and delivery to users of a public water system. Additionally, most surface-water sampling sites are not used presently for public water systems. However, water carrying agricultural runoff is diverted into the Kennewick Irrigation Canal (RM 35.8). This water is used to irrigate residential lawns and gardens in the cities of Kennewick and Richland.

The USEPA water-quality criteria for the protection of aquatic organisms and their uses, commonly called aquatic-life criteria, are national numerical criteria designed to prevent unacceptable long-term and short-term effects on (1) commercially, recreationally, and otherwise important species, (2) fish and benthic invertebrates in rivers and in streams, and (3) fish, benthic invertebrates and zooplankton in lakes, reservoirs, estuaries, and oceans. Concentrations at or below these criteria should not result in unacceptable effects on aquatic organisms and their uses during a short-term exposure (U.S. Environmental Protection Agency, 1986). The freshwater criterion continuous concentration (CCC), or chronic-toxicity guidelines, is an estimate of the highest chemical concentration in surface water to which an aquatic community can be exposed indefinitely without experiencing an unacceptable effect (U.S. Environmental Protection Agency, 1999). The freshwater criterion maximum concentration (CMC) is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect. Also, water-quality characteristics such as hardness (and other parameters that covary with hardness) influence the toxicity of metals on aquatic organisms (U.S. Environmental Protection Agency, 2001).

The USEPA freshwater aquatic-life water-quality criterion for cadmium, chromium, copper, lead, nickel, silver and zinc is expressed as a function of water hardness (mg/L). The individual hardness was determined for each water sample to calculate the aquatic-life water-quality criterion for each hardness-dependent trace element. Equations for

calculating hardness dependent criteria have been published by the USEPA (1999).

## TRACE ELEMENTS DETECTED IN FILTERED-WATER SAMPLES

Trace elements are defined as inorganic substances that usually occur in concentrations of less than 1,000 µg/L (micrograms per liter) (Hem, 1992). Among 23 trace elements for which water samples (filtered through 0.45 µm pore-size capsule filter) were analyzed, 17 elements were detected at 1 or more sampling sites (table 3). Antimony, beryllium, boron, chromium, cobalt, lead, lithium, molybdenum, selenium, silver, strontium, thallium, and vanadium are not discussed because they were reported as nondetections (censored data), or their observed detection frequency and/or number of samples was low.

In April 2001, the USEPA aquatic-life water-quality criterion for cadmium was revised (U.S. Environmental Protection Agency, 2001). This revision resulted in changes to the hardness-dependent freshwater (CCC) value. Four samples had hardness values low enough to result in a calculated cadmium CCC value that is below the MRL of 1.0 µg/L. Consequently, it is unknown if these four samples exceed the USEPA freshwater (CCC) value. Also, cadmium and other trace elements were analyzed the upper Yakima River (Cle Elum to Umtanum) from March 1999 to June 2000 to verify 303(d) listings for violations of State water-quality standards by the Washington State Department of Ecology. Cadmium was analyzed at reporting limits lower than the USEPA aquatic-life water-quality criterion and no violations were observed in over 30 samples (Johnson, 2000).

## Arsenic and Uranium

***Arsenic Detected during Basinwide Lagrangian Sampling, August 1999***—During basinwide sampling in August 1999, arsenic was detected at 19 of 34 sites. Concentrations ranged from <1.0 to 5.3 µg/L with a median concentration of 1.2 µg/L (appendix table A1, A19). The highest concentration (5.3 µg/L) was detected at South Drain near Satus (fig. 6). There were no arsenic detections in the Kittitas Valley. Arsenic was detected at five of eight WWTPs. Concentrations

ranged from <1.0 to 3.7 µg/L and had a median of 1.8 µg/L. The Granger Drain, South Drain, and Sulphur Creek sites, respectively, had concentrations of 4.1 µg/L, 5.3 µg/L, and 2.2 µg/L, which exceeded the 75<sup>th</sup> percentile concentration of 2.1 µg/L based on all tributary sites.

During the August 1999 basinwide sampling, five sites were sampled more than once to assess the variation in arsenic concentrations on a time scale of 1 day or less (table 4, fig. 7, appendix table A1). Arsenic concentrations at Moxee Drain at Birchfield Rd., South Drain near Satus, and Sulphur Creek Wasteway remained constant for the 24-hr period. The Granger site and the Yakima River at Kiona were more variable. For example, one of the two samples collected outside of the Lagrangian sampling period at Kiona varied from the Lagrangian arsenic concentration by a factor of two (see Study Design and Methods).



***Historic application of pesticides to former fruit orchards in the Yakima Basin.***

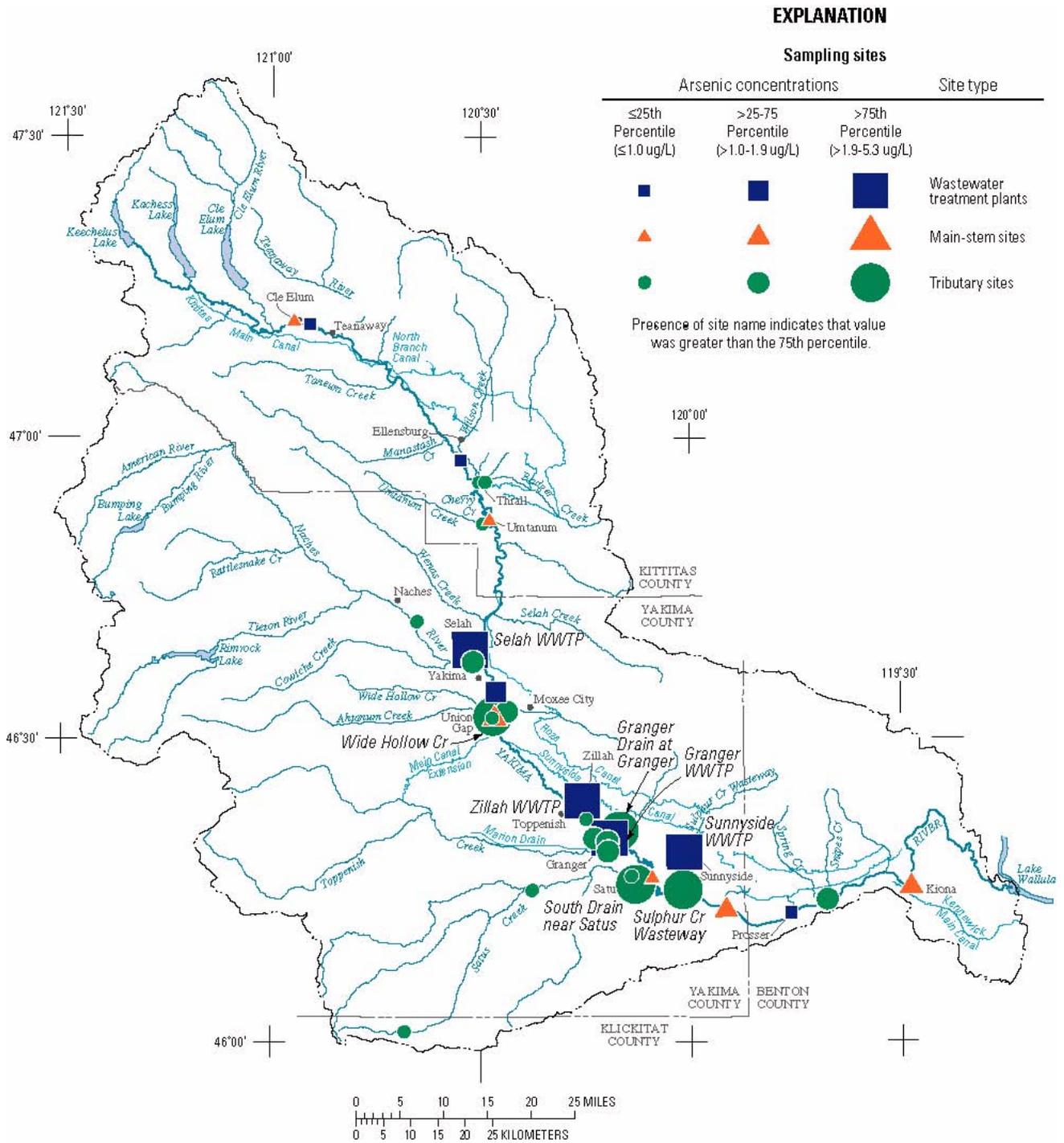
Sources of dissolved arsenic in surface water include the historic application of pesticides containing lead arsenate to existing and former deciduous fruit orchards throughout the basin (Peryea, 1989). In eastern Washington, beginning in 1908, lead-arsenate sprays were applied to control codling moths in apples. This practice continued until the introduction of dichlorodiphenyltrichloroethane (DDT) in 1947 (Peryea, 1989). Frequent applications of lead-arsenate sprays led to substantial lead and arsenic accumulations in orchard topsoils. Arsenic in lead-arsenate-contaminated soils can be assimilated by plants and is slowly



***Beginning in 1908, lead-arsenate sprays were applied to control codling moths in apples.***

mobile. When phosphate (PO<sub>4</sub>) fertilizers are applied to lead-arsenate contaminated soils, arsenic in soils can be released to solution by competitive phosphate-arsenate exchange. Ultimately, if sufficient water is available for leaching, arsenic will move downward through topsoil into uncontaminated subsoils, eventually entering shallow ground water. Consequently, the benefit of lowering the arsenic content of topsoils through irrigation and fertilizer application is offset by risk of increasing arsenic concentrations in ground water. Soil column tests show that the lead in lead-arsenate- contaminated topsoil will remain effectively immobile over short time periods under normal leaching conditions (Peryea and others, 1995).

PO<sub>4</sub> fertilizers have been applied in the basin since the late 1940's (Lynn Sheridan, Washington State Department of Agriculture, oral commun., 2001). PO<sub>4</sub> fertilizers are derived from phosphatic rock mined from the Western Phosphate Field, located in the northern Rocky Mountains, and from other locations in North America (Herring and others, 1999). This rock is enriched in arsenic and other trace elements. For example, arsenic concentrations ranged from <10 to 60 µg/g from two measured stratigraphic sections at the Smoky Canyon phosphate mine located in southeastern Idaho (Herring and others, 1999). Also, the concentration of arsenic in PO<sub>4</sub> fertilizer varies with the source of the phosphate rock used to produce the fertilizer (Alloway, 1990). Typically, in the fertilizer production process, the rock is chemically converted to



**Figure 6.** Distribution of arsenic concentrations detected during basinwide sampling, August 1999, Yakima River Basin, Washington. (WWTP, wastewater treatment plant)



**Present-day orchards and farmland may carry the legacy from historic applications of pesticides like lead-arsenate and DDT (dichlorodiphenyltrichloroethane).**

**Table 4.** Temporal differences in arsenic concentrations detected during basinwide sampling, Yakima River Basin, Washington, August 1999

[All concentrations in micrograms per liter; < = less than; **bolded** time is the Lagrangian sample]

Site name	USGS station identification	Date sampled	Time sampled	Concentration
Moxee Drain at Birchfield Road	12500420	August 3, 1999	<b>7:40 a.m.</b>	1.9
		August 3, 1999	7:40 p.m.	2.4
Granger Drain at Granger	12505450	August 3, 1999	5:30 p.m.	5.5
		August 4, 1999	<b>7:40 a.m.</b>	4.1
South Drain near Satus	12508630	August 4, 1999	<b>5:50 p.m.</b>	5.3
		August 5, 1999	10:50 a.m.	5.3
Sulphur Creek Wasteway	12508850	August 4, 1999	<b>6:10 p.m.</b>	2.3
		August 5, 1999	2:20 p.m.	2.5
Yakima River at Kiona	12510500	August 5, 1999	5:40 p.m.	2.3
		August 6, 1999	<b>10:30 a.m.</b>	1.3
		August 6, 1999	3:10 p.m.	1.3

mono-ammonium phosphate. These fertilizers, which can contain up to 17  $\mu\text{g/g}$  of arsenic (Washington State Department of Agriculture, 2001), are applied in early spring and late fall on row crops, turf grass and deciduous fruit orchards (Lynn Sheridan, Washington State Department of Agriculture, oral commun., 2001). It is unknown if arsenic-bearing mono-ammonium phosphate fertilizers that are applied to non-contaminated topsoils (in areas where lead-arsenate sprays have not historically been applied) are releasing arsenic in soluble forms.

During the Yakima River Basin NAWQA pilot study (1987–90) arsenic concentrations in filtered-water samples ranged from <1.0 to 9  $\mu\text{g/L}$  at seven intensive fixed sites (appendix table A20). The highest concentrations were detected in the lower Yakima Valley. Arsenic concentrations at Yakima River at Cle Elum, Yakima River at Umtanum, and Yakima River above Ahtanum Creek at Union Gap were below the MRL for arsenic (1.0  $\mu\text{g/L}$ ). At Sulphur Creek Wasteway, arsenic concentrations were lower during the irrigation season and higher during the nonirrigation season. Irrigation-season concentrations ranged from 2 to 4  $\mu\text{g/L}$  and nonirrigation-season concentrations ranged from 7 to 9  $\mu\text{g/L}$ . In contrast, arsenic concentrations at the Grandview and Kiona sites generally were higher during the irrigation season (Fuhrer and others, 1999). The lower arsenic concentrations at Sulphur Creek were probably the result of dilution from excess canal water spilled into Sulphur Creek from Roza Canal and by irrigation return flow (Fuhrer and others, 1999). The increase in arsenic concentrations during the irrigation season at the Grandview and Kiona sites coincided with decreased streamflows in the main stem and probably resulted from dilution processes—high concentrations of arsenic generally were associated with decreased streamflows and conversely, lower concentrations of arsenic generally were associated with increased streamflows (Fuhrer and others, 1999).

Although arsenic concentrations varied seasonally during the pilot study, mean monthly arsenic loads were similar in Sulphur Creek Wasteway (agricultural drain) between the irrigation and nonirrigation season. The large variation in arsenic concentrations between the irrigation and the nonirrigation seasons, as well as the similarity in loads among months suggests that Sulphur Creek Wasteway is a constant year-round source of arsenic to the Yakima River main stem. Also, the consistency among monthly arsenic loads at the Grandview and Kiona

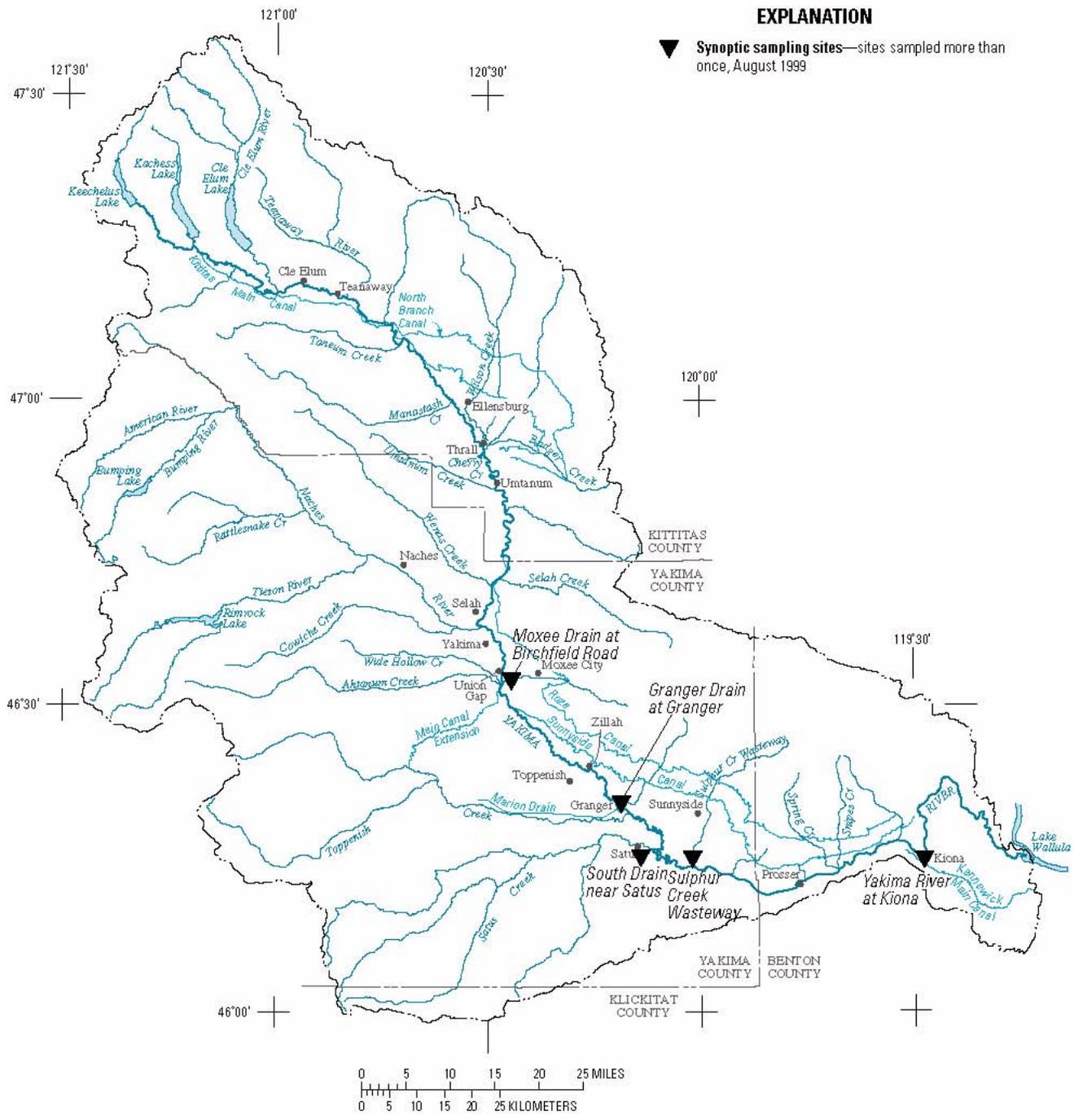


Figure 7. Sites sampled more than once during synoptic sampling, August 1999, Yakima River Basin, Washington.

sites indicates that arsenic is discharged to the main stem at a relatively constant rate (Fuhrer and others, 1999).

***Arsenic Detected at Intensive Fixed Sites, May 1999–January 2000***—Arsenic concentrations were determined at the three intensive fixed sites in the Yakima River Basin: Granger Drain at Granger, Moxee Drain at Birchfield Rd, and Yakima River at Kiona (fig. 8). For all sites, concentrations ranged from <1 to 11 µg/L, with a median of 2.1 µg/L (appendix table A2). The highest concentrations occurred at the agricultural return drains after mid-October, which coincides with the end of the irrigation season. At the Moxee and Granger sites, the median arsenic concentration in surface water varied by a factor of 2 between the irrigation and nonirrigation season. For example, the highest arsenic concentration (11 µg/L) was detected at Granger Drain at Granger in November 1999 (appendix table A2). Nonirrigation season concentrations at Granger ranged from 7.8 to 11 µg/L, with a median of 10 µg/L. Irrigation season concentrations ranged from 3.3 to 5.5 µg/L, with a median of 4.7 µg/L (figs. 8 and 9). Arsenic was detected in all samples at Granger Drain.

At Moxee Drain at Birchfield Rd., arsenic concentrations were similar to concentrations measured at Granger drain. During the nonirrigation season, arsenic concentrations at Moxee Drain ranged from 3.1 to 8.9 µg/L, with a median of 8.5 µg/L. Conversely, during the irrigation season, concentrations ranged from 1.1 to 2.4 µg/L, with a median of 1.4 µg/L (fig. 9). Arsenic was detected in all samples at Moxee Drain.

Unlike Granger Drain at Granger and Moxee Drain at Birchfield Rd., Yakima River at Kiona showed little seasonal variability for dissolved arsenic concentrations. For example, nonirrigation-season concentrations ranged from <0.9 to 1.9 µg/L, with a median of 1.3 µg/L. Irrigation-season concentrations ranged from <1 to 2.3 µg/L, with a median of 1.1 µg/L (fig. 9). Arsenic concentration were similar to the range of concentrations reported for Kiona during the pilot study (Fuhrer and others, 1999). Arsenic was detected in 10 of 16 samples (62 percent) at Yakima River at Kiona.

Dissolved arsenic concentrations in agricultural drains were highest when the drains were fed primarily by shallow ground water during baseflow conditions, and concentrations in the Yakima River were highest when the river was fed primarily by agricultural return flow. After the ground-water flowpath returns to

baseflow conditions during the winter months, the occurrence of higher arsenic concentrations in agricultural return drains could result from transport of arsenic from areas where arsenical pesticides have been applied. However, no ground-water flowpath analysis has been done for arsenic transport in the Yakima River Basin.

***Arsenic Aquatic-Life Water-Quality Criteria and Human Health***—Arsenic has been classified as a human carcinogen by the USEPA. Human systemic skin and gastrointestinal effects can be caused by ingestion (Sax, 1989). Chronic doses may lead to vascular disorders, such as Blackfoot disease (American Waterworks Association, 1990), and the accumulation of arsenic in body tissues can result in symptoms of severe poisoning. Arsenic is known to cause bladder, lung, and skin cancer at high levels of exposure (National Research Council, 1999). The trivalent form of arsenic, arsenite ( $\text{As}^{3+}$ ) is more toxic to aquatic life and (or) humans in drinking water than the pentavalent form, arsenate ( $\text{As}^{5+}$ ) because arsenite is more effectively bioaccumulated (McNelly and others, 1979). For this study, only total arsenic was measured therefore the ratio of  $\text{As}^{3+}$  to  $\text{As}^{5+}$  is unknown. Typically, under oxidizing conditions in surface water, the dominant form of arsenic occurs as the less toxic arsenate ( $\text{As}^{5+}$ ) species (Drever, 1997).

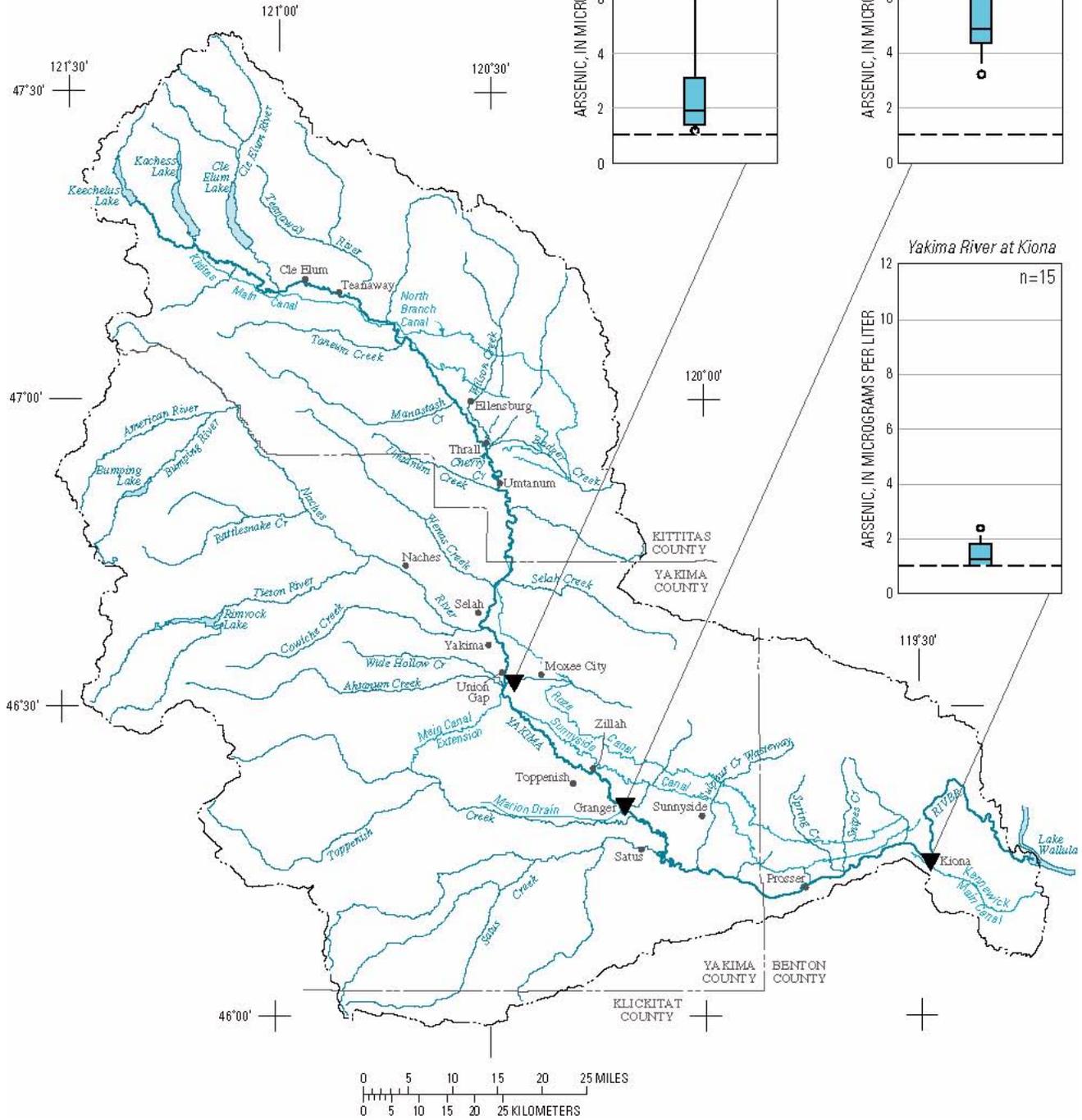
The USEPA freshwater aquatic-life water-quality criterion for arsenic is 150 µg/L. In December 2001 the USEPA lowered the arsenic MCL in drinking water from 50 µg/L to 10 µg/L. Concentrations in two samples collected at Granger Drain in Granger in November 1999 (11 µg/L) and January 2000 (10 µg/L) exceeded the arsenic MCL of 10 µg/L. The USEPA has developed a 2 µg/L Health Advisory Level (HAL) for arsenic. These guidance levels are for 1-day, 10-day, or longer-term exposures for children as well as for lifetime exposure for adults (U.S. Environmental Protection Agency, 2000a). Thirty-three of 79 (42 percent) surface-water samples exceeded the HAL for dissolved arsenic in the basin.

***Arsenic Transport during Basinwide Sampling, August 1999***—The Lagrangian sampling design is an ideal framework to evaluate the relative contributions of arsenic from the basin's various tributaries. These contributions were determined by calculating the pounds of arsenic per day (instantaneous load of arsenic) being transported to the main stem from the

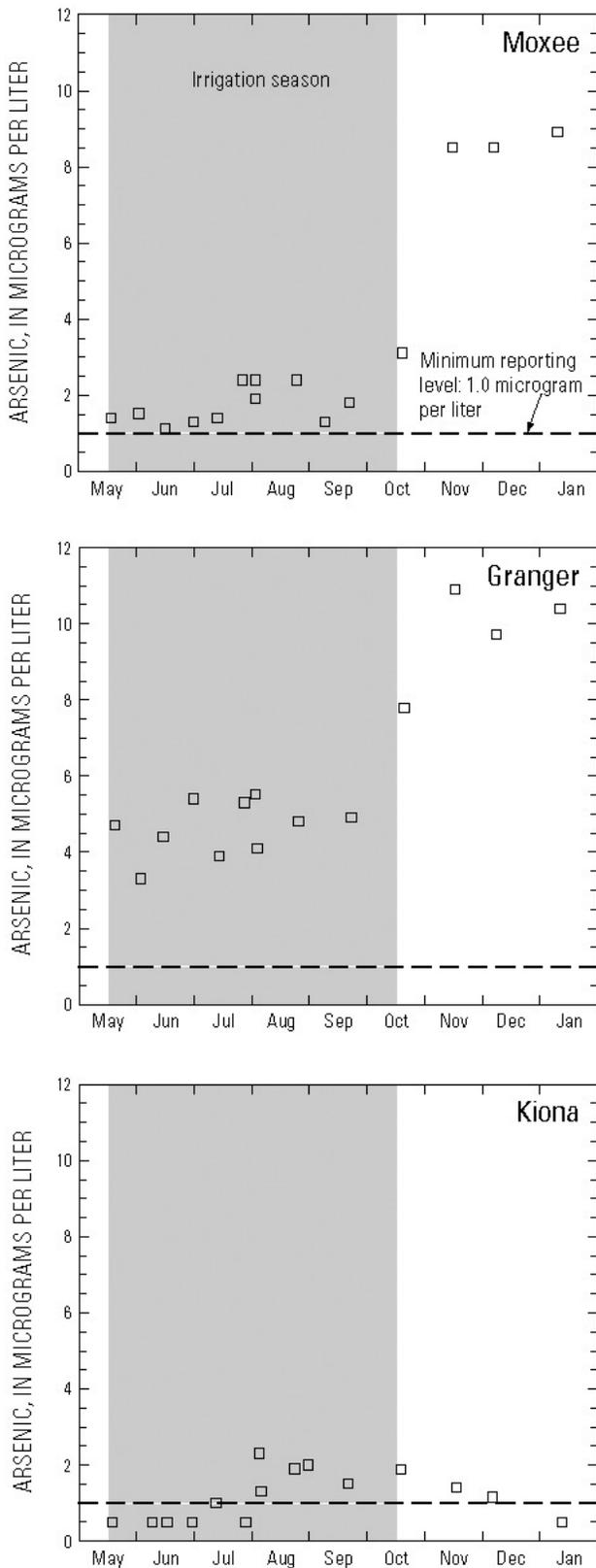
**EXPLANATION**

**Arsenic concentrations**

- Data value represents the 95th percentile
- 90th percentile
- 75th percentile
- Median
- 25th percentile
- 10th percentile
- Data value represents the 5th percentile
- Minimum reporting level 1.0 microgram per liter



**Figure 8.** Distribution of arsenic concentrations detected during intensive fixed site sampling, 1999–2000, Yakima River Basin, Washington.



**Figure 9.** Arsenic concentrations detected at intensive fixed sites, 1999–2000, Yakima River Basin, Washington. (Concentrations lower than the minimum reporting level [1.0 microgram per liter] are shown as 0.5 microgram per liter.)

tributaries. Instantaneous load is the product of the trace-element concentration in a single sample and instantaneous discharge at the time of collection. In order to determine the significance of the tributary loads within defined reaches of the main stem, the tributary loads for a given reach (tributary inflowing) were summed and subtracted from the instantaneous loads of arsenic diverted into canals (canal outflowing) and are reported in table 5 as the calculated load for the reach. The calculated load within each reach was subtracted from the actual load (measured) at the lower main-stem site in each reach to determine the unaccounted load of arsenic (difference) for the reach. This type of computation is known as a mass balance calculation.

The mass balance can be positive when the tributary loads do not account for all the arsenic measured at the lower main-stem site in the reach. This can occur, for example, when arsenic enters the reach directly through the discharge of ground water or through smaller pipe discharges from agricultural fields not measured in this study. The mass balances can be negative when the tributaries account for more arsenic load than measured at the lower main-stem site within the reach. In this study, these negative differences were small and imply that arsenic generally remains in the dissolved phase and is not sequestered to an appreciable degree in streambed sediment. Loads from the WWTPs were not used in the mass balance calculation because they were insignificant (<0.1 lbs/d). Determining the mass balance of arsenic in the Kittitas and Mid-Valley was hampered because arsenic concentrations were below the MRL of 1.0 µg/L. Dissolved arsenic concentrations at some localities were near the MRL, where analytical uncertainties can approach 13 percent (Jones and others, 1999).

The mass balance of arsenic in the Lower Valley was evaluated in three reaches of the main stem. Mass balances in the first two reaches were somewhat qualified because the dissolved arsenic concentration at RM 72 was less than the MRL of 1.0 µg/L. At first glance, in the reach spanning Parker to RM 72, canals and tributaries would appear to be accounting for at least 1.3 lbs/d more arsenic than actually measured. The mass balance of –1.3 lbs/d was derived from the difference between the measured load and the calculated load. Since the arsenic concentration measured at RM 72 was less than the MRL of 1.0 µg/L and because concentrations at or near the MRL can

**Table 5.** Estimated mass balances for instantaneous streamflows and dissolved arsenic loads in the main stem, selected major tributaries, and canals, Yakima River Basin, Washington, August 2–6, 1999

[Difference = measured – calculated; main-stem sampling sites in **bold**; WWTP, wastewater treatment plant; <, less than; —, no data; the formula used to compute instantaneous arsenic [load (in pounds per day [lbs/d]) = concentration (in micrograms per liter [mg/L]) x discharge (in cubic feet per second [ft<sup>3</sup>/s]) x 0.00539]

Site name	River mile (RM)	Streamflow (ft <sup>3</sup> /s)						Dissolved arsenic load (lbs/d)					
		Main stem			Tributary inflowing	Canal diversion	Concentration (µg/L)	Main stem					
		Measured	Calculated	Difference				Measured	Calculated	Difference	Tributary inflowing	Canal outflowing	
<b>Yakima River near Parker<sup>1</sup></b>	103.7	<b>685</b>	<b>540</b>	<b>145</b>	—	—	<b>1.3</b>	<b>4.8</b>	—	—	—	—	—
Return from the Sunnyside fish bypass	103.6	—	—	—	40	—	<sup>2</sup> 1.3	—	—	—	0.3	—	—
East Toppenish Drain at Wilson Rd near Toppenish	86	—	—	—	27.5	—	<1	—	—	—	<.1	—	—
Sub-Drain No. 35 at Parton Rd	83.2	—	—	—	62	—	1.3	—	—	—	.4	—	—
Granger Drain at Granger	82.8	—	—	—	62	—	4.1	—	—	—	1.4	—	—
Marion Drain at Indian Church Rd	82.6	—	—	—	67	—	1.4	—	—	—	.5	—	—
Toppenish Creek at Indian Church	80.4	—	—	—	117	—	1	—	—	—	.6	—	—
Coulee Drain	77	—	—	—	30	—	—	—	—	—	—	—	—
<b>Yakima River at RM 72 above Satus</b>	<b>72.4</b>	<b>1,270</b>	<b>1,090</b>	<b>180</b>	—	—	<b>&lt;1</b>	<b>&lt;6.8</b>	<b>8.1</b>	<b>&lt;-1.3</b>	—	—	—
Satus Creek at gage at Satus	69.6	—	—	—	128	—	<1	—	—	—	<.7	—	—
South Drain near Satus	69.3	—	—	—	33.1	—	5.3	—	—	—	1	—	—
Drainage Improvement District No. 7	65.1	—	—	—	25	—	—	—	—	—	—	—	—
Sulphur Creek Wasteway	61	—	—	—	260	—	2.2	—	—	—	3.1	—	—
Satus Drain 303	60.2	—	—	—	22	—	—	—	—	—	—	—	—
<b>Yakima River at Euclid Rd Bridge at RM 55 near Grandview</b>	<b>55</b>	<b>2,050</b>	<b>1,738</b>	<b>312</b>	—	—	<b>1.6</b>	<b>17.7</b>	<b>&lt;11.6</b>	<b><sup>6</sup>6.1</b>	—	—	—
Chandler Canal at Bunn Road at Prosser	47.1	—	—	—	—	1,209	<sup>3</sup> 1.6	—	—	—	—	10.4	—
Spring Creek at Hess Road	41.8	—	—	—	46.4	—	1.1	—	—	—	.3	—	—
Snipes Creek below Chandler Canal	41.8	—	—	—	12.5	—	1.8	—	—	—	.1	—	—
Chandler Power Return	35.8	—	—	—	900	—	<sup>4</sup> 1.6	—	—	—	7.8	—	—
Kiona Canal	34.9	—	—	—	—	20	<sup>5</sup> 1.6	—	—	—	—	.2	—
<b>Yakima River at Kiona</b>	<b>29.9</b>	<b>1,950</b>	<b>1,732</b>	<b>218</b>	—	—	<b>1.3</b>	<b>13.7</b>	<b>15.4</b>	<b>-1.7</b>	—	—	—

<sup>1</sup>Yakima River near Parker is used as upstream end of reach ending at river mile 72 because of large diversion between Ahtanum Creek (river mile 107.3) and Parker.

<sup>2</sup>Arsenic concentration (1.3 µg/L) was estimated (no sample was collected), the concentration value from Yakima River at Parker, the nearest upstream site, was used to calculate load.

<sup>3</sup>Arsenic concentration (1.6 µg/L) was estimated (no sample was collected), the concentration value from Yakima River at Euclid Road Bridge at RM 55 near Grandview was used to calculate load.

<sup>4</sup>Arsenic concentration (1.6 µg/L) was estimated (no sample was collected), the arsenic load from Yakima River at Euclid Road Bridge to Chandler Power Return should not change because the streamflow input from Spring Creek at Hess Road and Snipes Creek below Chandler Canal was <60 ft<sup>3</sup>/s.

<sup>5</sup>Arsenic concentration of 1.6 µg/L was estimated (no sample was collected), the concentration value from Yakima River at Euclid Road Bridge at RM 55 near Grandview was used to calculate load.

<sup>6</sup>The difference between the measured and the calculated arsenic load is a mass balance of not less than 6.1 lbs/d.

vary plus or minus 13 percent, the concentration of arsenic at RM 72 could have varied from 0.9 to 1.1 µg/L. The arsenic concentration at Yakima River at RM 72 was probably close to the MRL (1.0 µg/L) because concentration values upstream and downstream of RM 72 are close to the MRL. In this case, if the concentration had been 1.2 µg/L, the arsenic load would have been balanced. Within this reach, Granger Drain is the major source of arsenic by more than a factor of two, followed next by Toppenish Creek, Marion Drain, and Sub-Drain 35, all of which had loads of about 0.5 lbs/d (table 5).

As stated above, the mass balance computation in the second reach of the Lower Valley—spanning RM 72 to RM 55—has an arsenic concentration below the MRL of 1.0 µg/L at RM 72. If the dissolved arsenic concentration at RM 72 is set equal to the MRL, the computation indicates that as much as 6.8 lbs/d of arsenic could have been entering the reach at RM 72. With the addition of the arsenic loads from the tributaries, as much as 11.6 lbs/d of arsenic could have been transported through RM 55. The difference between the measured and the calculated arsenic load is a mass balance of not less than 6.1 lbs/d. A positive balance suggests that some sources of dissolved arsenic have not been accounted for in the RM 72 to RM 55 reach. Sulphur Creek Wasteway is the major contributor (3.1 lbs/d) in this reach; however, DID 7 and Satus Drain 303 were not measured in August 1999 and would offset some of the positive balance. Even if DID 7 and Satus Drain 303 had arsenic concentrations of 5 µg/L, together they would only account for 1.3 lbs/d of arsenic, which would reduce the mass balance from 6.1 to 4.8 lbs/d. Because the second lower reach is a gaining reach with respect to streamflow—312 cfs were unaccounted for at RM 55—ground water easily could account for the remaining 4.8 lbs/d of arsenic (table 5).

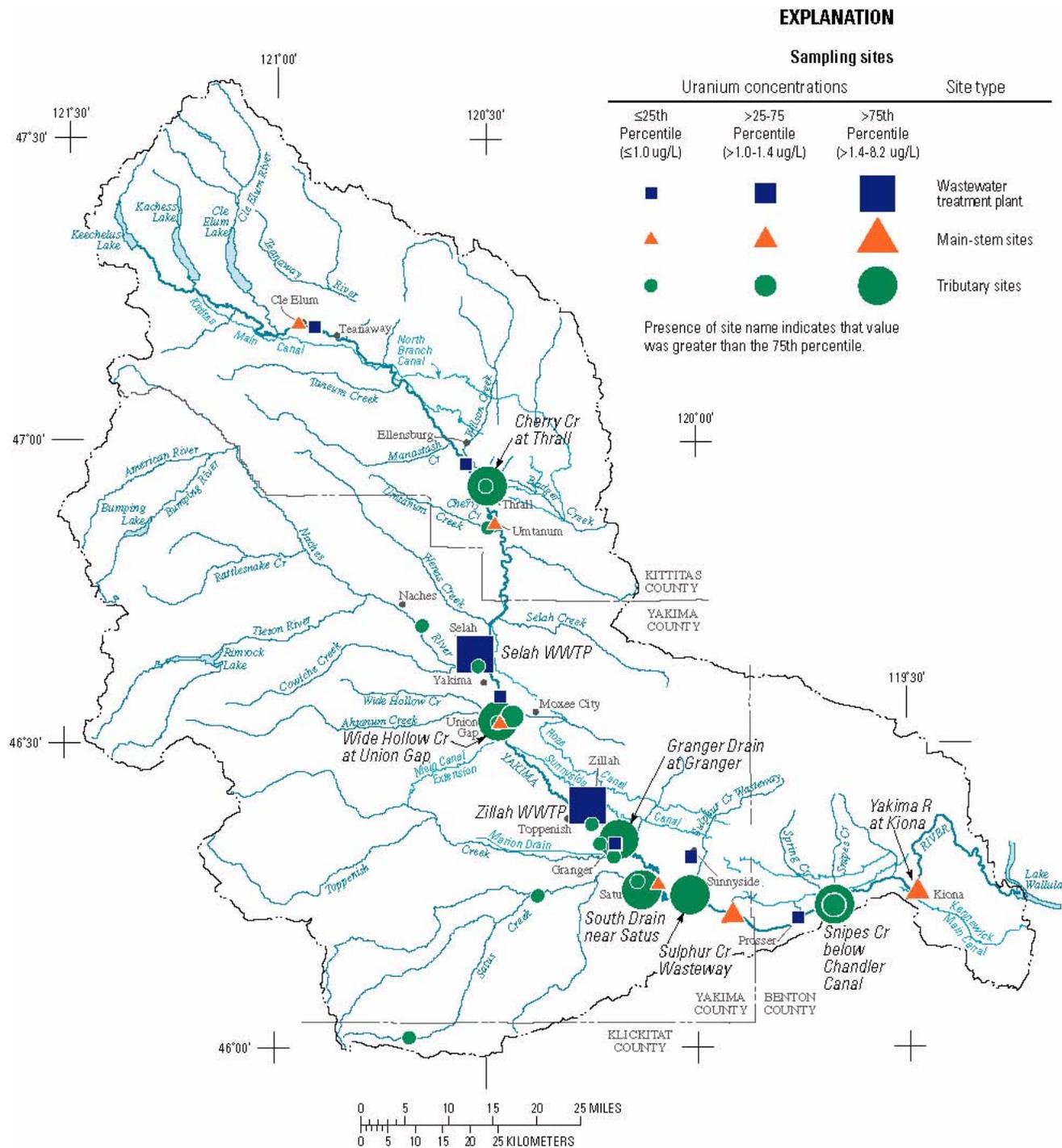
The third reach of the Lower Valley spans RM 55 to RM 29. Agricultural inputs of arsenic to this reach are from Spring Creek and Snipes Creek which together account for 0.4 lbs/d of arsenic. Both creeks receive agricultural runoff during the irrigation season and both creeks receive operational spillage from Roza Canal and Sunnyside Canal. The mass balance is small and slightly negative. Similar to the first reach, it easily could have balanced based on the uncertainty of arsenic determinations near the MRL.

A comparison of arsenic loads in the Yakima River main stem during the pilot study with loads from

August 1999 shows that sources of arsenic have not changed appreciably over the decade. The mean monthly load determined at Yakima River at RM 55 near Grandview in August 1989 was 16.5 lbs/d compared to an instantaneous load of 17.7 lbs/d in August 1999 (Fuhrer and others, 1999). Although a decade has passed, these two loads are within 7 percent of one another and are likely within analytical error. Results were similar for Yakima River at Kiona at RM 29.

***Uranium Detected during Basinwide Lagrangian Sampling, August 1999***—During basinwide sampling in August 1999, uranium concentrations ranged from <1.0 to 8.2 µg/L, with a median of <1.0 µg/L (appendix tables A3, A19; fig. 10). The highest concentrations were detected at Zillah WWTP (8.2 µg/L), Granger Drain at Granger (6.2 µg/L) and Selah WWTP (4.2 µg/L). Uranium was detected at 12 of 34 (35 percent) sites (appendix table A3). Tributary sites contained higher dissolved uranium concentrations than main-stem sites. For example, uranium concentrations ranged from <1.0 µg/L to 4.0 µg/L, whereas main-stem sites ranged from <1.0 to 1.4 µg/L. Uranium concentrations exceeding 3.8 µg/L, the 90th percentile for all tributary sites in the Yakima River Basin, were detected at Granger Drain and South Drain near Satus.

The source of dissolved uranium in surface water of the Yakima River Basin is unknown. A recent study of irrigated lands in the western United States showed that agricultural-return-flow sites contained higher uranium concentrations in surface water than reference sites not receiving irrigation-return flow, indicating that irrigation practices might contribute to increased uranium concentrations (Naftz, 1996). Data from regional reconnaissance of dissolved uranium in the Arkansas River Valley (Zielinski and others, 1995) suggest that agricultural practices can elevate uranium concentrations in shallow soils and in coexisting water, but definitive linkage to fertilizer sources is unknown. Phosphate fertilizer typically contains 10–200 µg/g uranium that originates from mined phosphate rock and correlates with PO<sub>4</sub> content (Zielinski and others, 1999). Uranium concentrations in fertilizers have been found to correlate positively with PO<sub>4</sub> compounds in the Mississippi River drainage system (Spalding and Sackett, 1972). In 26 irrigated areas in the western United States, the median uranium concentration in



**Figure 10.** Distribution of uranium concentrations detected during basinwide sampling, August 1999, Yakima River Basin.



***Dissolved trace elements and organic compounds can be mobilized and transported to nearby streams under rill irrigation.***

reference samples from surface water sites was 5.1  $\mu\text{g/L}$  ( $n = 198$ ) compared to a median concentration of 9.9  $\mu\text{g/L}$  ( $n = 937$ ) in agricultural-return-flow samples (Naftz, 1996). As noted by Zielinski and others (1995), the leaching of uranium-bearing rock and soil by irrigation water and the evaporative concentration of irrigation return flow can elevate concentrations of uranium in surface water.

***Uranium Detected at Intensive Fixed Sites, May 1999–January 2000***—Uranium concentrations were determined at the three intensive fixed sites in the Yakima River Basin: Granger Drain at Granger, Moxee Drain at Birchfield Rd, and Yakima River at Kiona (fig. 11). Concentrations ranged from  $<1$  to 16  $\mu\text{g/L}$ , with a median of 1.6  $\mu\text{g/L}$  (appendix table A4) and were similar to the 0.1 to 10  $\mu\text{g/L}$  range of concentrations for most natural waters (Hem, 1992). The highest levels were detected after mid-October, which coincides with the end of the irrigation season. At the Moxee and Granger sites, the median uranium concentration in surface water varied by a factor of 2 between the irrigation and nonirrigation season. For example, the highest uranium concentration (16  $\mu\text{g/L}$ ) was detected at Granger Drain at Granger in November and December, 1999. Nonirrigation-season concentrations at Granger ranged from 9.4 to 16  $\mu\text{g/L}$ , with a median of 13.7  $\mu\text{g/L}$ . Irrigation-season concentrations ranged from 5.1 to 7.1  $\mu\text{g/L}$  with a median of 5.5  $\mu\text{g/L}$  (fig. 12). Uranium was detected in all samples at Granger Drain.

At Moxee Drain at Birchfield Rd., uranium concentrations varied by a factor of 5 between the irrigation and nonirrigation season. During the

nonirrigation season, concentrations ranged from 3.3 to 7.8  $\mu\text{g/L}$ , with a median of 7.4  $\mu\text{g/L}$ . Irrigation-season concentrations ranged from 1.1 to 1.7  $\mu\text{g/L}$ , with a median of 1.4  $\mu\text{g/L}$  (fig. 12). Uranium was detected in all samples at Moxee Drain.

Unlike the Granger and Moxee sites, Yakima River at Kiona showed slight seasonal variability for dissolved uranium concentrations. For example, nonirrigation season concentrations ranged from  $<1$  to 1.7  $\mu\text{g/L}$ . Irrigation season concentrations ranged from  $<1$  to 1.5  $\mu\text{g/L}$  (fig. 12). Uranium was detected in 8 of 16 samples at Yakima River at Kiona.

As with arsenic, dissolved uranium concentrations in agricultural drains were highest when the drains were fed primarily by shallow ground water, and concentrations in the Yakima River were higher when the river was fed primarily by agricultural return flow.

***Uranium Aquatic-Life Water-Quality Criteria and Human Health***—Uranium is considered a human carcinogen (U.S. Environmental Protection Agency, 2000b). Uranium has no known metabolic function in animals and is regarded as a nonessential trace element (Health Canada, 1988). The chemical toxicity of uranium is related to other trace elements such as lead, thorium, and vanadium that incorporate uranium to form numerous metallic compounds as well as cationic and anionic salts (Venugopal and others, 1978). In 1991, the USEPA proposed an MCL of 20  $\mu\text{g/L}$  for uranium in drinking water based on kidney toxicity and a corresponding limit of 30 pCi/L (picocuries per liter) based on cancer risk. The MCLG was proposed at zero because of the carcinogenicity of uranium, and the MCL was proposed at the most sensitive endpoint, kidney toxicity. There is no USEPA freshwater aquatic-life water quality criterion for uranium. Although uranium was routinely detected at the intensive fixed sites, there was no exceedance of the proposed USEPA drinking-water standard.

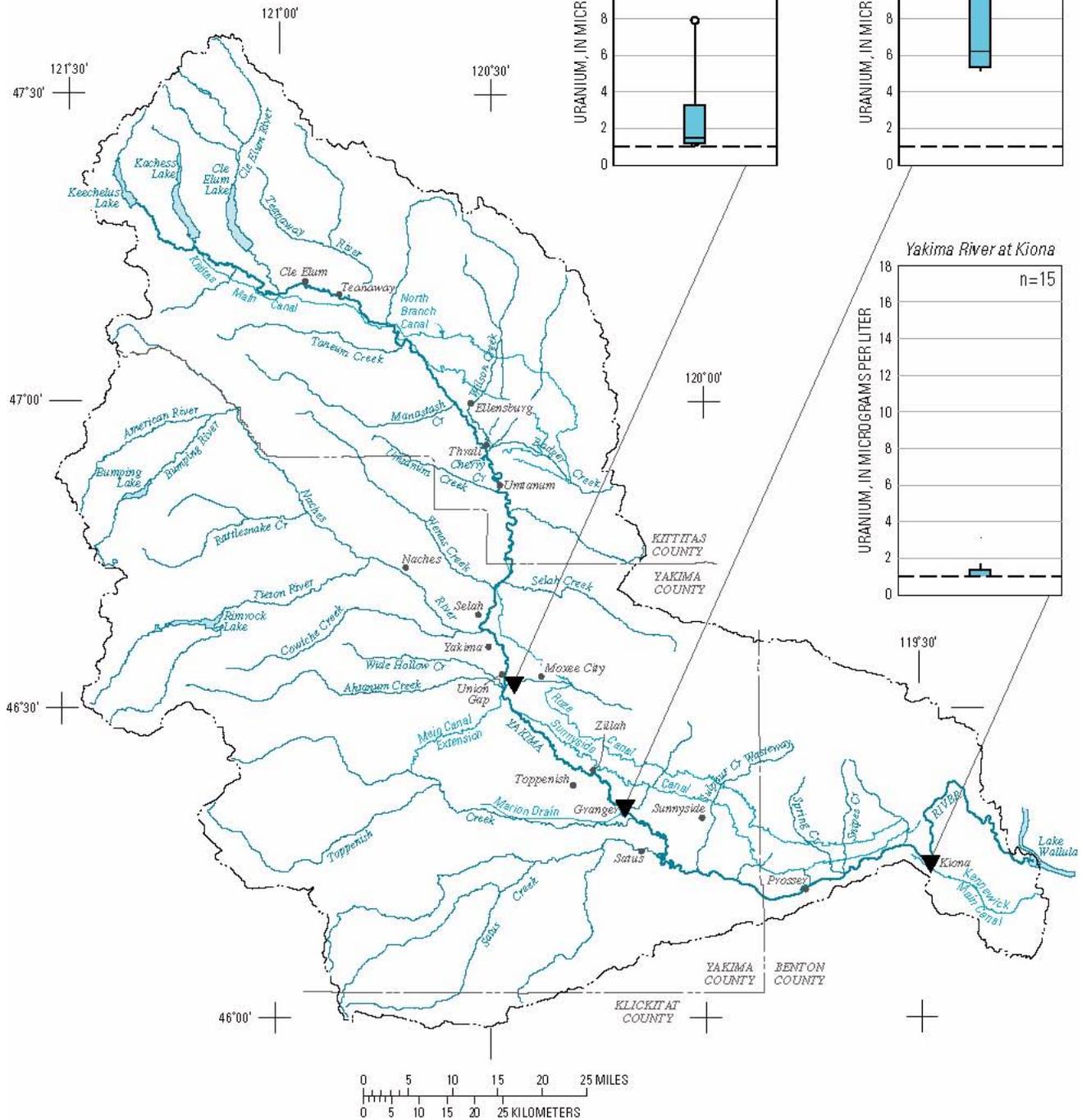
## **Aluminum, Iron, and Manganese**

***Aluminum Detected during Basinwide Lagrangian Sampling, August 1999***—Dissolved aluminum was detected in all surface water samples in the basin (fig. 13). For all sites, aluminum concentrations ranged from 1.1 to 97  $\mu\text{g/L}$ , with a

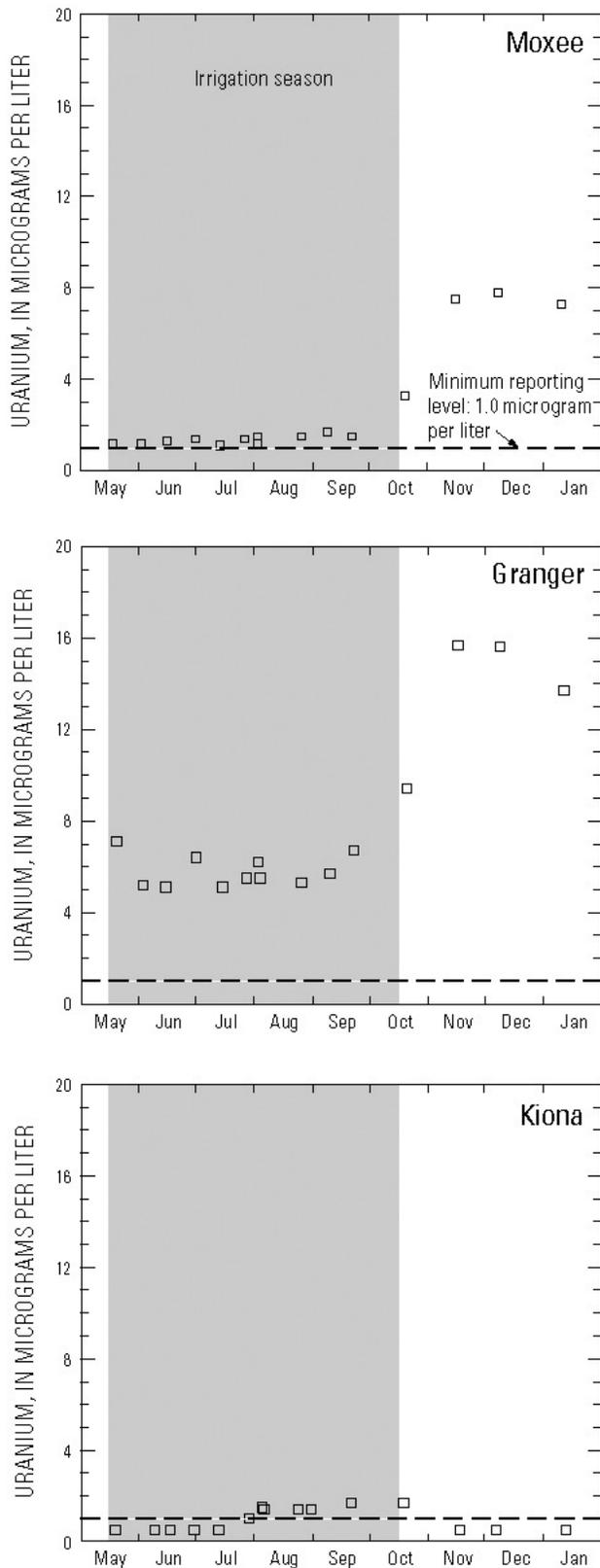
**EXPLANATION**

**Uranium concentrations**

- Data value represents the 95th percentile
- 90th percentile
- 75th percentile
- Median
- 25th percentile
- 10th percentile
- Data value represents the 5th percentile
- Minimum reporting level 1.0 microgram per liter



**Figure 11.** Distribution of uranium concentrations detected during intensive fixed site sampling, 1999–2000, Yakima River Basin, Washington.



**Figure 12.** Uranium concentrations detected at intensive fixed sites, 1999–2000, Yakima River Basin, Washington. (Concentrations lower than the minimum reporting level [1.0 microgram per liter] are shown as 0.5 microgram per liter.)

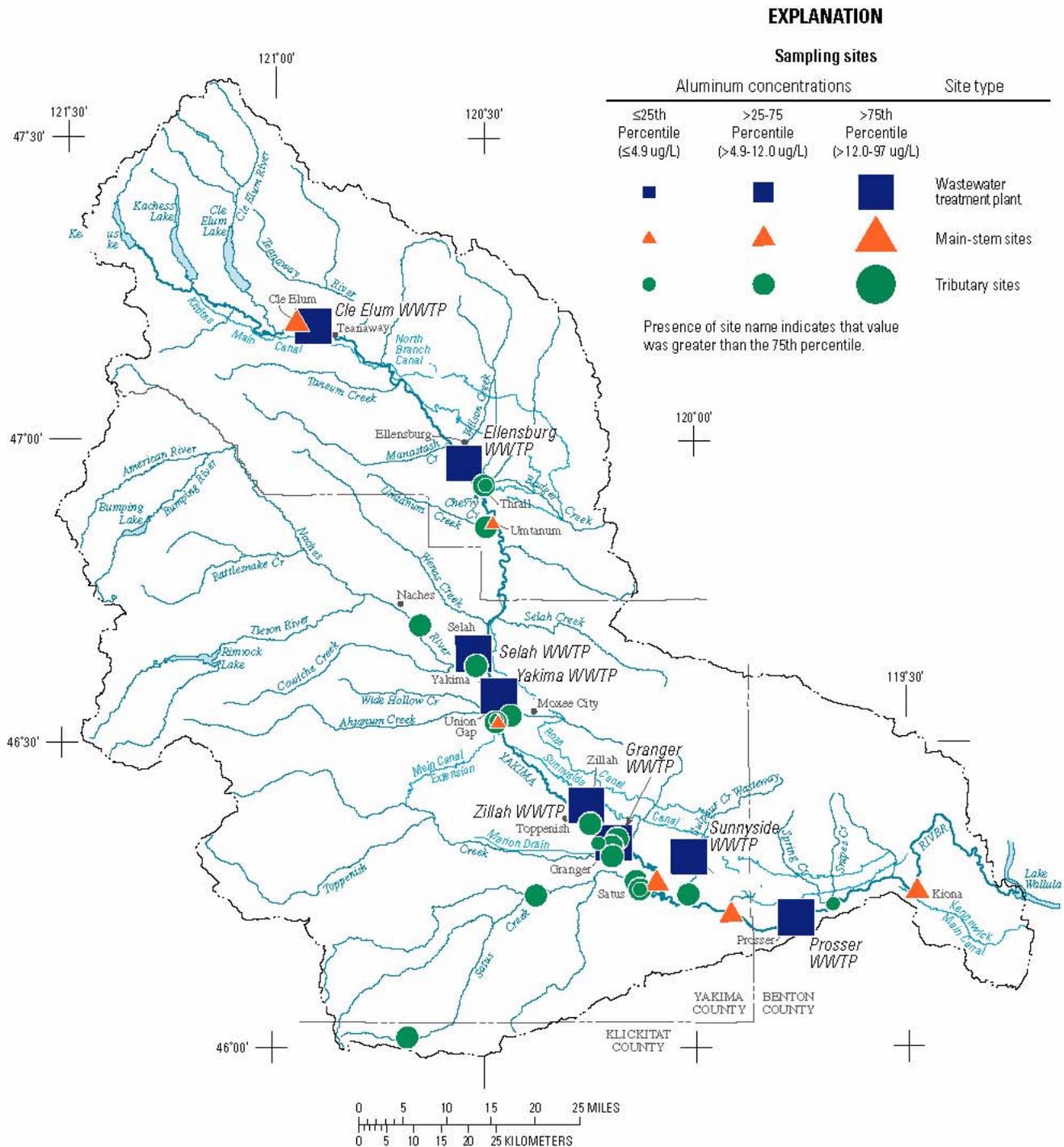
median of 6.5 µg/L (appendix tables A5, A19). The highest aluminum concentrations were detected at the WWTPs. The WWTP median concentration was 6 times higher than the median concentration for all other sites. For example, WWTP concentrations ranged from 31 to 97 µg/L, with a median of 38 µg/L, whereas main-stem and tributary concentrations ranged from 1.1 to 12 µg/L, with a median of 6 µg/L.

The basin is underlain by basaltic rocks of the Columbia River Basalt Group that contain approximately 13.5 weight-percent aluminum oxide (U.S. Geological Survey, 1998). Aluminum in surface water can originate from basalt rocks that have undergone weathering (Hem, 1992). As a result, varying amounts of aluminum are naturally present in surface water, including those used as sources of drinking water. In North American rivers, the concentration of aluminum ranges from 12 to 2,250 µg/L (Health Canada, 1998).

WWTPs also contribute dissolved aluminum to the main stem. Some WWTP's use aluminum sulfate (alum) to flocculate suspended particles, which commonly results in higher aluminum concentrations because aluminum can partition into a hydroxide phase  $Al(OH)_4^-$ , which yields fine-grained suspended particles (colloids) that typically pass through most water sample filters (Hem, 1992). Since the discharge rate at most WWTPs in the basin is less than 1 cfs, the aluminum load to the main stem is insignificant.

**Aluminum Detected at Intensive Fixed Sites, May 1999–January 2000**—Aluminum concentrations in filtered water were determined at the three intensive fixed sites in the Yakima River Basin: Granger Drain at Granger, Moxee Drain at Birchfield Rd., and Yakima River at Kiona (fig. 14, p. 30). For all sites, concentrations ranged from <1.0 to 14 µg/L, with a median of 2.4 µg/L (appendix table A6). At the Moxee site, the median aluminum concentration varied by a factor of 3 between irrigation and nonirrigation season. Irrigation-season concentrations ranged from 1.8 to 7.9 µg/L, with a median of 3 µg/L, whereas irrigation season concentrations ranged from <1.0 to 1.4 µg/L, with a median of 1.2 µg/L (fig 15).

Aluminum concentrations detected at the intensive fixed sites during 1999–2000 were considerably less than concentrations detected during the pilot study. For example, aluminum concentrations (1987–90) at Sulphur Creek Wasteway (agricultural return drain) ranged from <10 to 20 µg/L, whereas concentrations from 1999–2000 at Moxee and Granger (agricultural return drains) ranged from <1.0



**Figure 13.** Distribution of aluminum concentrations detected during basinwide sampling, August 1999, Yakima River Basin, Washington. (WWTP, wastewater treatment plant)

to 7.9 µg/L. A similar decrease in aluminum concentrations was observed at Yakima River at Kiona. Pilot study concentrations ranged from <10 to 50 µg/L, whereas 1999–2000 concentrations ranged from 1.1 to 14 µg/L.

***Aluminum Aquatic-Life Water-Quality Criteria and Human Health***—Aluminum has no known beneficial effect in humans. There is evidence that aluminum is neurotoxic in animals at higher doses (Health Canada, 1998). Several studies have reported a small increased relative risk of Alzheimer’s disease associated with high aluminum concentrations in drinking water (Health Canada, 1998). Because aluminum is ubiquitous in the environment and is used in a variety of products and processes, daily exposure of the general population to aluminum is inevitable. The USEPA freshwater aquatic-life water-quality criterion (expressed in terms of total recoverable metal in the water column) for aluminum in water with pH ranging from 6.5 to 9.0 is 87 µg/L. It is unknown if there was an exceedance of the aquatic-life criteria since all samples were filtered. The USEPA National Secondary Maximum Contaminant Level (SMCL) for aluminum in drinking water ranges from 50 to 300 µg/L. The USEPA recommends secondary standards for water systems but does not require systems to comply. There is no USEPA drinking-water standard for aluminum.

***Iron Detected during Basinwide Lagrangian Sampling, August 1999***—During basinwide sampling in August 1999, iron concentrations ranged from <10 to 48 µg/L, with a median concentration of 18 µg/L (appendix table A7, A19). Iron in filtered water was detected at 33 of 34 sites (fig. 16, p. 32). Many WWTPs had higher overall iron concentrations than main-stem or tributary sites. The median iron concentration at the WWTPs was 26.9 µg/L compared to the main-stem and tributary medians of 15.8 µg/L and 14.7 µg/L, respectively. The highest concentration (48 µg/L) was detected at the Sunnyside WWTP. During basinwide sampling, iron concentrations at Moxee, South Drain, and Sulphur Creek sites remained relatively constant for the 24-hr period, whereas concentrations at the Granger and Kiona sites were more variable. For example, one of the two samples collected outside of the Lagrangian sampling period at Kiona varied by a factor of 2.

As with aluminum, iron is naturally present in basaltic rocks. For example, the USGS Columbia River Basalt standard reference sample contains 13.8

weight-percent iron oxide (U.S. Geological Survey, 1998). Basalt undergoes chemical weathering, which causes iron-bearing minerals to partition into aqueous solution, usually in the form of ferrous iron at near neutral pH (Hem, 1992). The mobility of iron in surface water is strongly influenced by changes in oxidation-reduction processes. Iron also is present in organic wastes and in plant debris in soils, and activities in the biosphere may have a strong influence on the occurrence of iron in water (Hem, 1992).

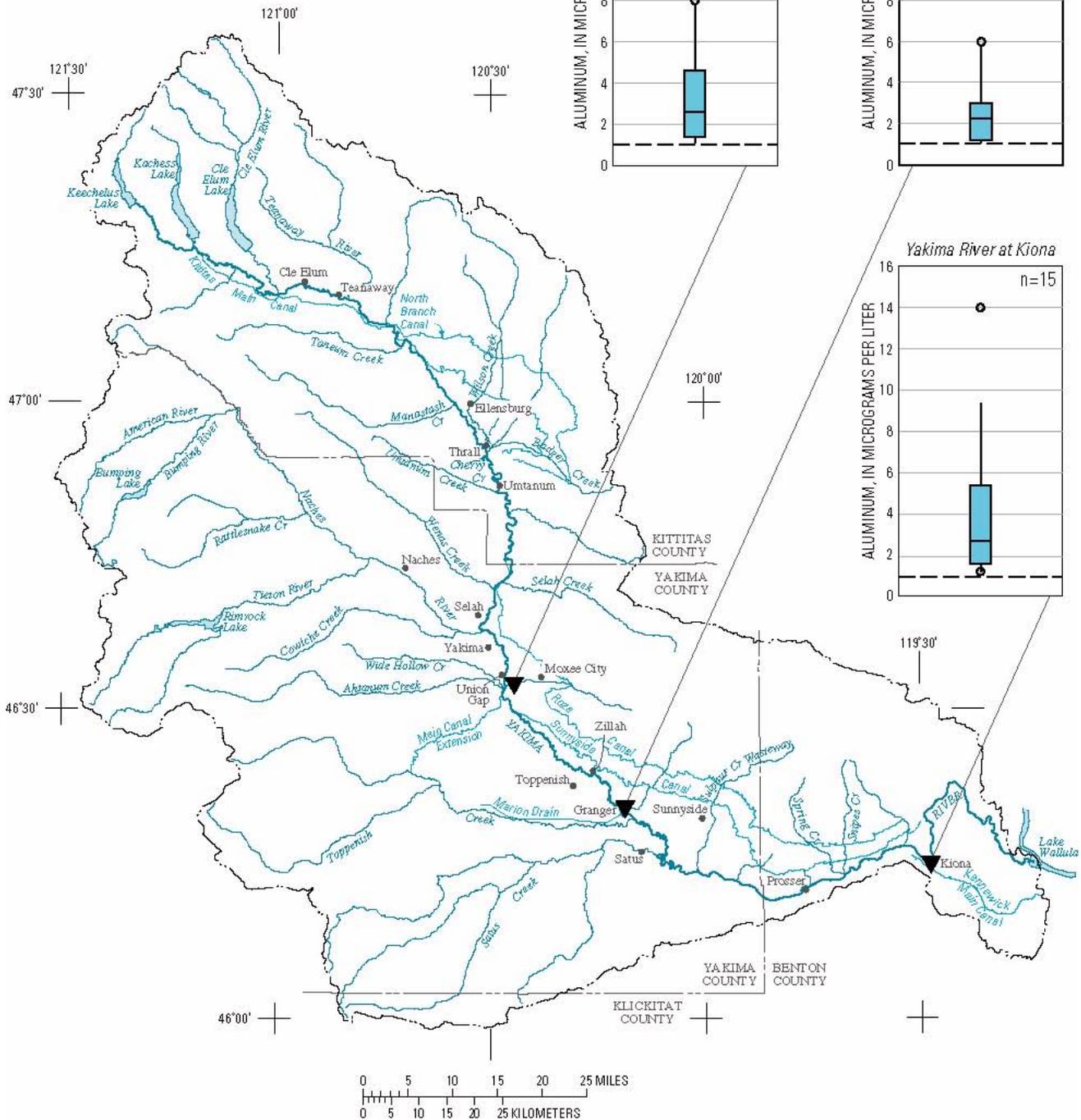
***Iron Detected at Intensive Fixed Sites, May 1999–January 2000***—Iron concentrations in filtered water were determined at the three intensive fixed sites in the Yakima River Basin: Granger Drain at Granger, Moxee Drain at Birchfield Rd and Yakima River at Kiona (fig. 17, p. 33). For all sites, concentrations ranged from <10 to 42 µg/L, with a median of 11 µg/L (appendix table A8). Iron concentrations were highest in July and August during peak irrigation. The highest iron concentration (42 µg/L) was detected at Yakima River at Kiona in July 1999. For 1999–2000, dissolved iron concentrations were more variable at Kiona than at Moxee or Granger. At Kiona, concentrations ranged from 11 to 42 µg/L, whereas at Moxee and Granger concentrations ranged from <10 to 17 µg/L and <10 to 20 µg/L, respectively (fig. 18, p. 34).

***Iron Aquatic-Life Water-Quality Criteria and Human Health***—Iron is the second most abundant metallic element in the Earth’s crust, but concentrations in water generally are small (Hem, 1992). Iron is an essential element in human nutrition. Iron in drinking water does not pose a known health threat and is not regulated under the USEPA Safe Drinking Water Act. In higher concentrations, iron forms reddish-brown precipitate that encrust pipes and stain laundry and plumbing fixtures. Iron also produces an unpleasant taste in drinking water and may promote bacterial growth in pipes and service mains. The taste threshold for iron occurs at about 4,000 µg/L (World Health Organization, 1996). Iron is necessary for the enzymatic synthesis of chlorophyll in plants; in animals, it is essential as a constituent of hemoglobin in the blood (Rose and others, 1979). Iron commonly exists in the ferrous (Fe<sup>2+</sup>) or ferric (Fe<sup>3+</sup>) oxidation state. Most iron salts are insoluble and settle out or are adsorbed onto surfaces; therefore, the concentration of iron in well-aerated waters is seldom high. The

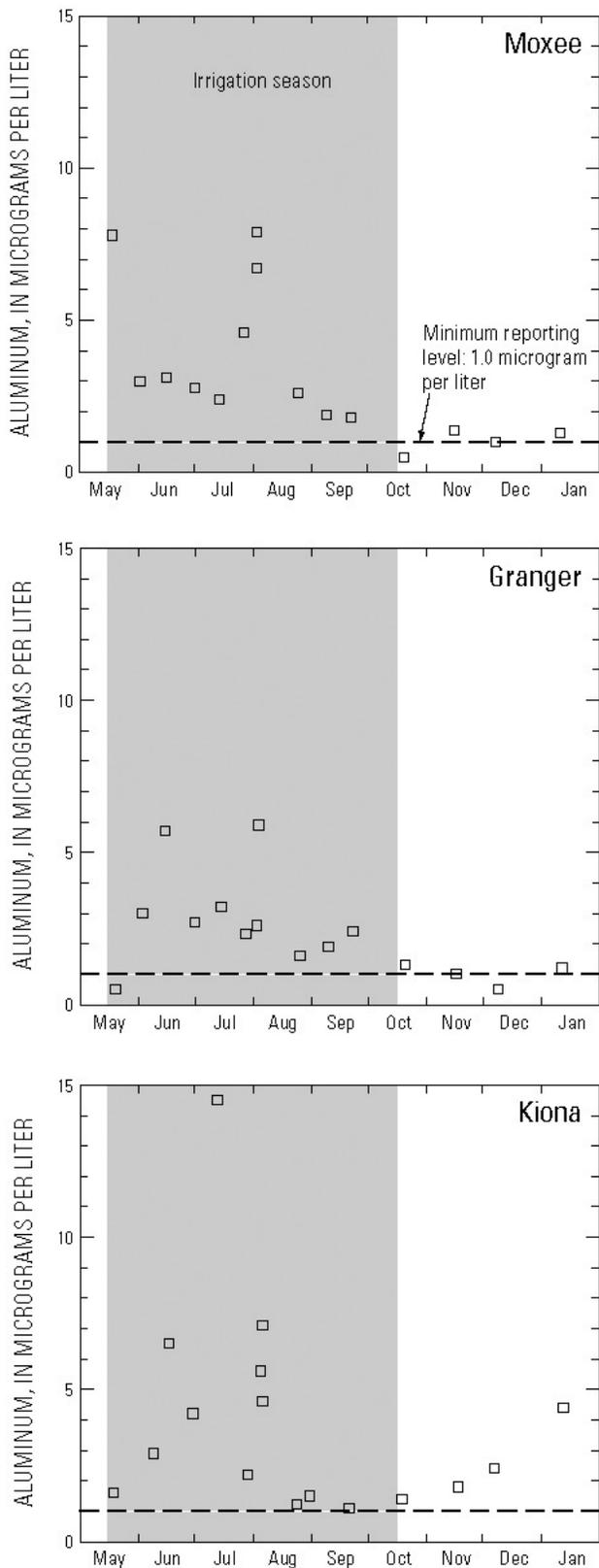
**EXPLANATION**

**Aluminum concentrations**

- Data value represents the 95th percentile
- 90th percentile
- 75th percentile
- Median
- 25th percentile
- 10th percentile
- Data value represents the 5th percentile
- Minimum reporting level 1.0 microgram per liter



**Figure 14.** Distribution of aluminum concentrations detected during intensive fixed site sampling, 1999–2000, Yakima River Basin, Washington.



**Figure 15.** Aluminum concentrations detected at intensive fixed sites, 1999–2000, Yakima River Basin, Washington. (Concentrations lower than the minimum reporting level [1.0 microgram per liter] are shown as 0.5 microgram per liter.)

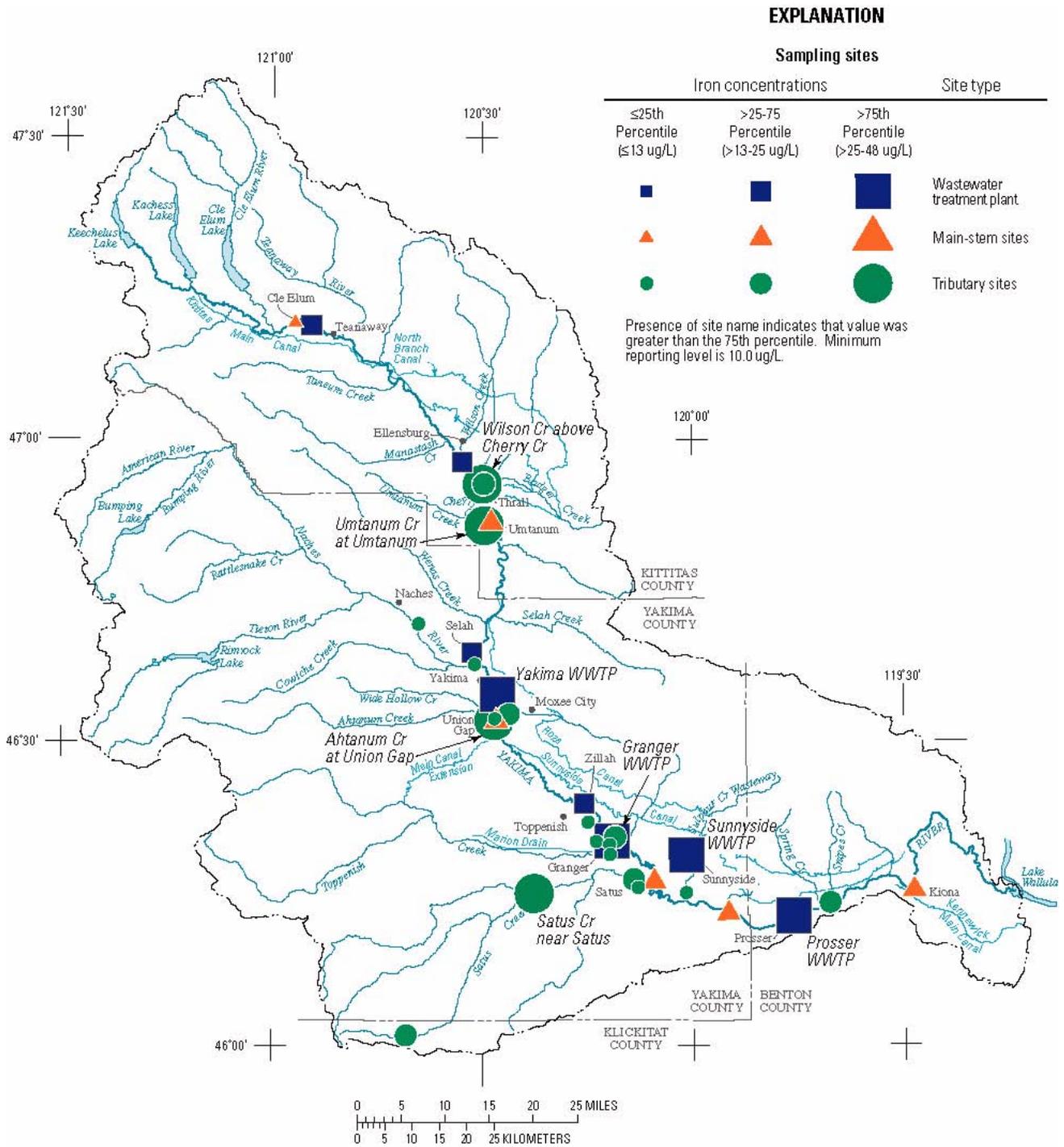
geochemistry of iron is complex and its mobility in the environment is linked to its oxidation state.

The USEPA freshwater aquatic-life water-quality criterion (expressed in terms of total recoverable metal in the water column) for iron in water is 1,000 µg/L. The USEPA National Secondary Maximum Contaminant Level (SMCL) for iron in drinking water is 300 µg/L. The USEPA recommends secondary standards for water systems but does not require compliance. No sites in the Yakima River Basin exceed the USEPA SMCL drinking-water standard. It is unknown if there was an exceedance of the aquatic-life criterion for iron since all samples were filtered.

**Manganese Detected during Basinwide Lagrangian Sampling, August 1999**—During basinwide sampling in August 1999, manganese concentrations ranged from <1.0 to 47 µg/L, with a median concentration of 7.1 µg/L (appendix tables A9, A19). The highest concentrations were detected at South Drain near Satus (47 µg/L) and Granger WWTP (36 µg/L). Manganese was detected at 31 of 34 (91 percent) sites (fig. 19, p. 35). Like filtered iron, tributary sites had slightly higher manganese concentrations than WWTPs or main-stem sites. For example, the median concentration for all tributary sites was 8.7 µg/L whereas the WWTPs and main-stem site medians were 7.9 µg/L and 5.1 µg/L respectively.

At Yakima River at Euclid Bridge (RM 55) downstream to Yakima River at Kiona (RM 29.9), manganese concentrations decreased from 18 µg/L to 1.9 µg/L. During the irrigation season, the lower Yakima River main stem is a low energy meandering flow system that represents an ideal environment for the deposition of fine-grained particles as well as flocculants that contain manganese. Manganese exhibits the same distribution pattern as arsenic and uranium.

Under reducing conditions in natural-water systems, dissolved manganese occurs as Mn<sup>2+</sup>. Exposure to air will oxidize Mn<sup>2+</sup> to its tetravalent form (Mn<sup>4+</sup>), which tends to precipitate as manganese oxides. Manganese is widely distributed in sediments, soils, and sedimentary and volcanic rocks, such as basalt, which provide a natural source of manganese through weathering processes.

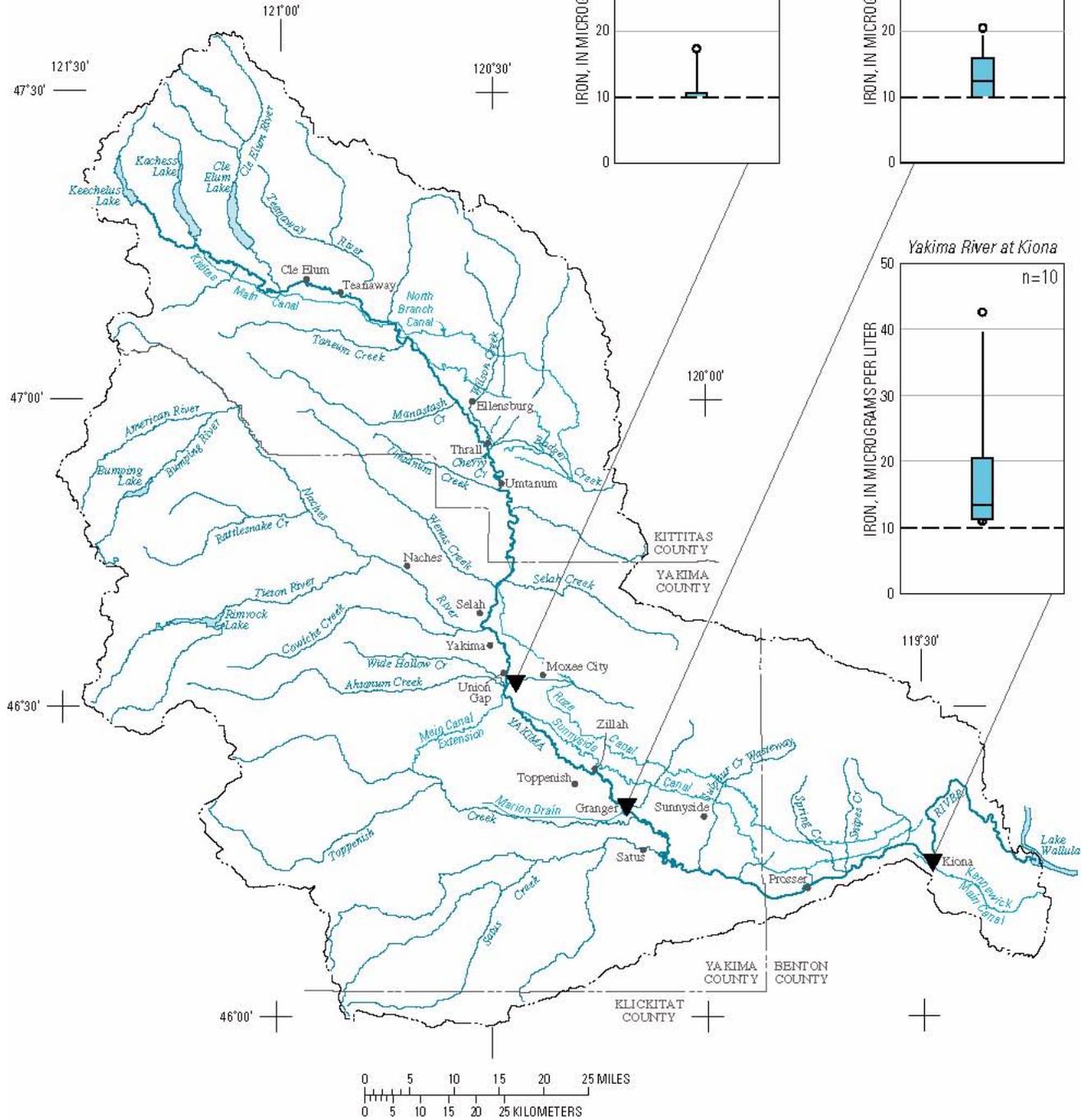


**Figure 16.** Distribution of iron concentrations detected during basinwide sampling, August 1999, Yakima River Basin, Washington. (WWTP, wastewater treatment plant)

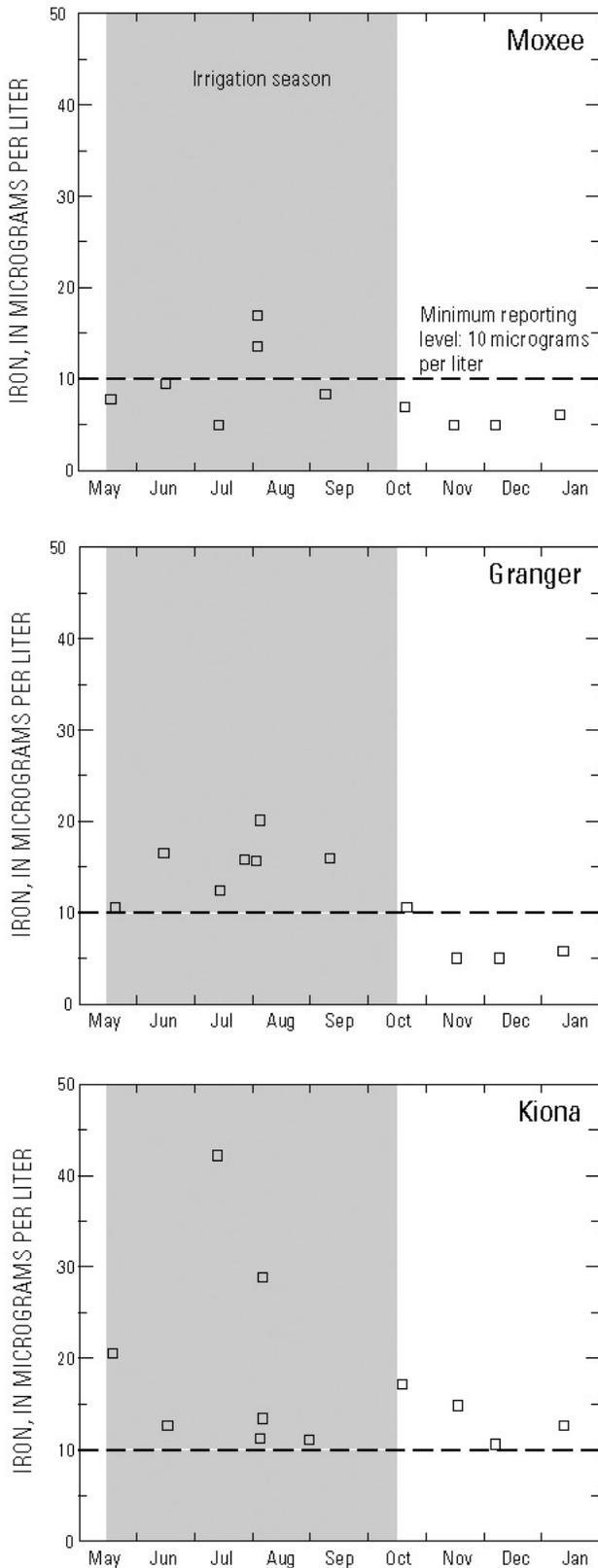
**EXPLANATION**

**Iron concentrations**

- Data value represents the 95th percentile
- 90th percentile
- 75th percentile
- Median
- 25th percentile
- 10th percentile
- Data value represents the 5th percentile
- Minimum reporting level 10 micrograms per liter



**Figure 17.** Distribution of iron concentrations detected during intensive fixed site sampling, 1999–2000, Yakima River Basin, Washington.



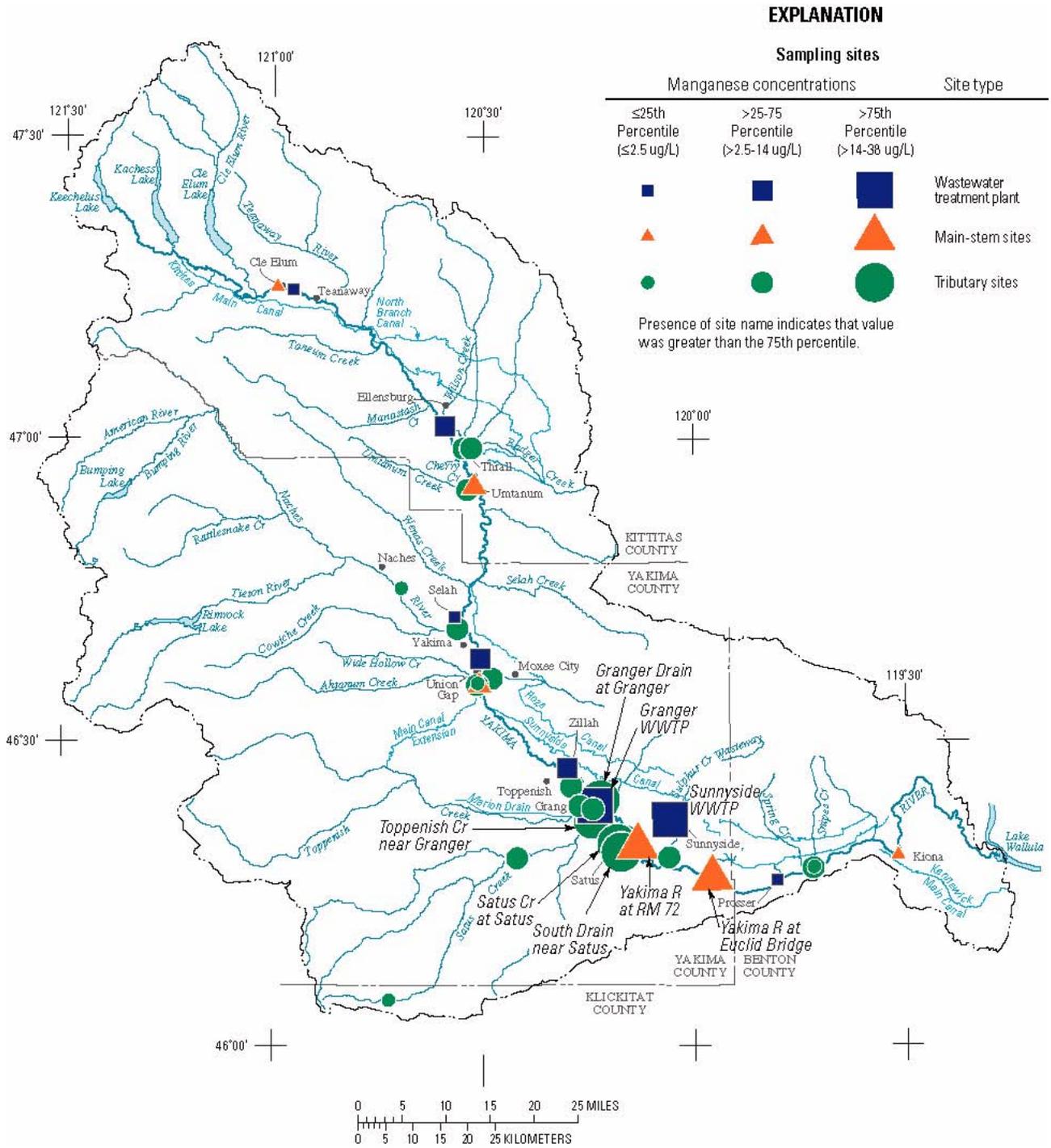
**Figure 18.** Iron concentrations detected at intensive fixed sites, 1999–2000, Yakima River Basin, Washington. (Concentrations lower than the minimum reporting level [10 micrograms per liter] are reported as estimated values.)

**Manganese detected at Intensive Fixed Sites, May 1999–January 2000**—Manganese concentrations in filtered water were determined at the three intensive fixed sites in the Yakima River Basin: Granger Drain at Granger, Moxee Drain at Birchfield Rd, and Yakima River at Kiona (fig. 20). For all sites, concentrations ranged from 1.3 to 75 µg/L, with a median of 8.3 µg/L (appendix table A10). Dissolved manganese was detected at significantly higher concentrations at Granger Drain than at the Moxee and Kiona sites (fig. 21, p. 37). Manganese concentrations exceeding 33 µg/L, the 90<sup>th</sup> percentile for the Yakima River Basin, were detected at Granger Drain from October through January, 2001. At Moxee, the irrigation-season median concentration was 6.5 µg/L, whereas the nonirrigation-season median was 14 µg/L. Manganese concentrations at Kiona were less variable, ranging from 1.6 to 9.1 µg/L throughout the sampling period and were similar to the range of concentrations reported for Kiona during the pilot study (Fuhrer and others, 1999). For example, irrigation-season concentrations ranged 1.6 to 6.0 µg/L, with a median concentration of 2.6 µg/L. Non-irrigation-season concentrations ranged from 3.4 to 9.1, with a median concentration of 6.0 µg/L.

**Manganese Aquatic-Life Water Quality Criteria and Human Health**—Manganese is an element considered essential to human health and is unlikely to be toxic at concentrations found in natural waters. However, at concentrations exceeding 1,000 µg/L, it imparts an undesirable taste to drinking water and stains plumbing fixtures and laundry (World Health Organization, 1996). As with iron, the presence of manganese in water may lead to the accumulation of microbial growths in the water supply system. The presence of “manganese bacteria”, which concentrate manganese, can give rise to taste, odor, and turbidity problems. The USEPA secondary maximum contaminant level (SMCL) for manganese in drinking water is 50 µg/L. At Granger Drain, there were three exceedances of the SMCL from November 1999 to January 2000, with concentrations ranging from 62 to 75 µg/L. There is no USEPA drinking water standard or aquatic-life water-quality criterion for manganese.

### Barium, Copper, Nickel, and Zinc

**Barium Detected during Basinwide Lagrangian Sampling, August 1999**—Dissolved barium was detected at all sites. During basinwide sampling in

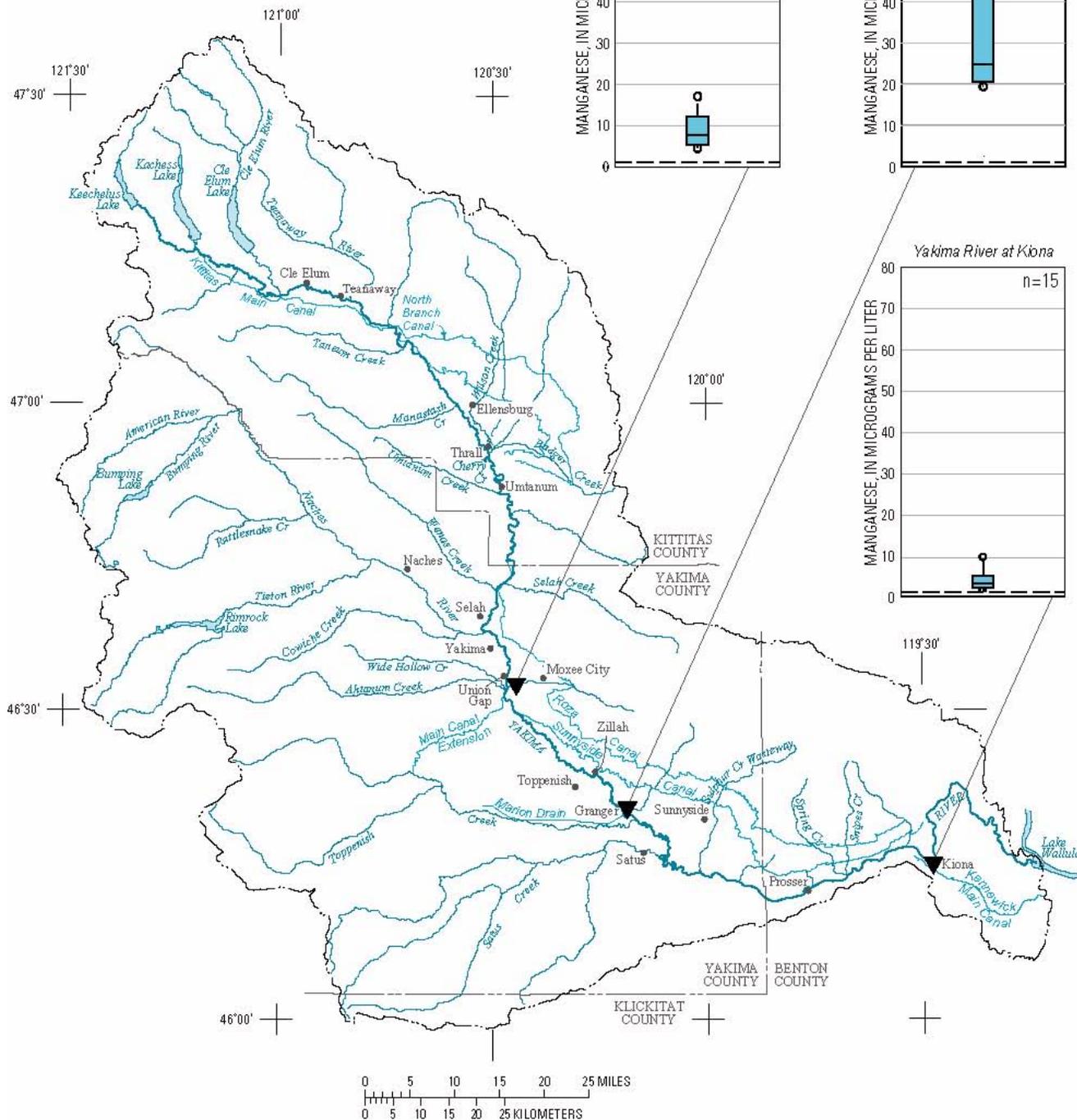


**Figure 19.** Distribution of manganese concentrations detected during basinwide sampling, August 1999, Yakima River Basin, Washington. (WWTP, wastewater treatment plant)

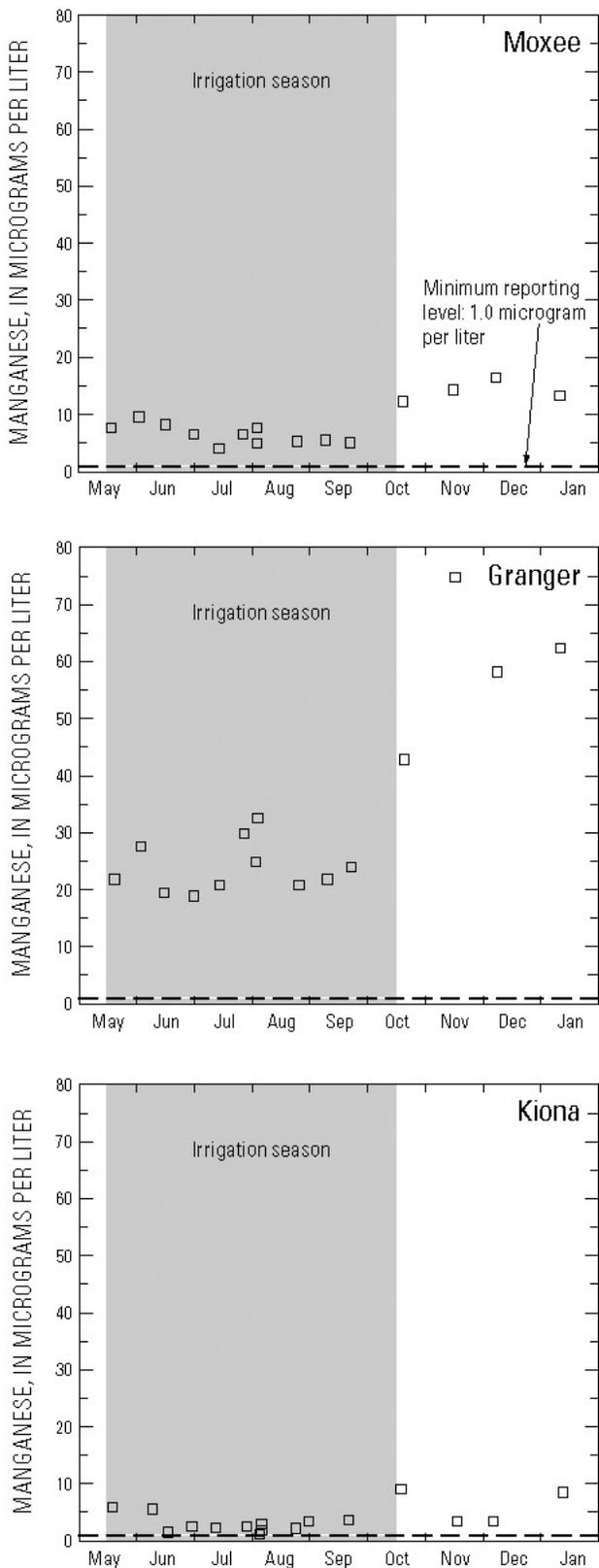
### EXPLANATION

#### Manganese concentrations

- Data value represents the 95th percentile
- 90th percentile
- 75th percentile
- Median
- 25th percentile
- 10th percentile
- Data value represents the 5th percentile
- Minimum reporting level 1.0 microgram per liter



**Figure 20.** Distribution of manganese concentrations detected during intensive fixed site sampling, 1999–2000, Yakima River Basin, Washington.



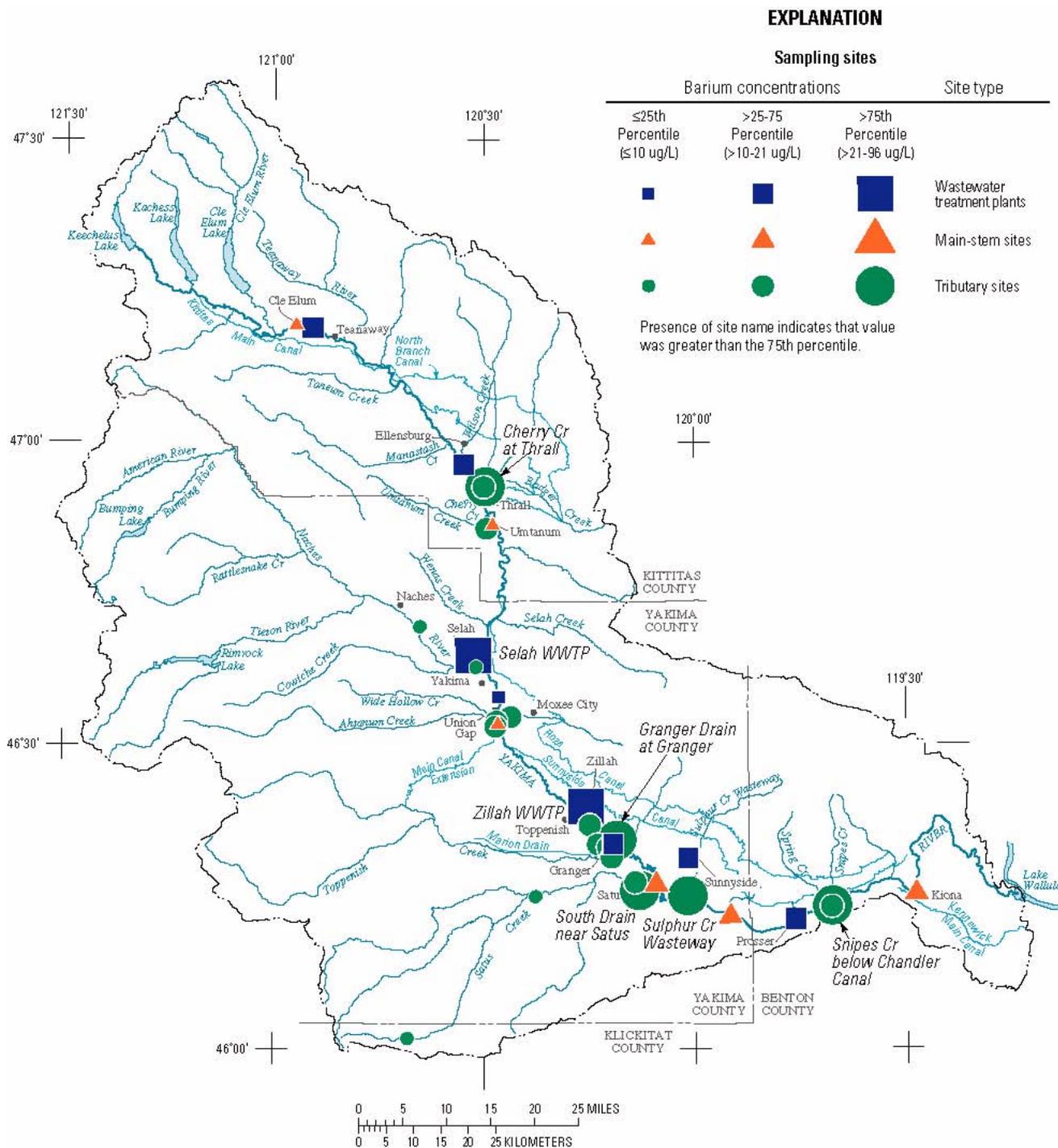
**Figure 21.** Manganese concentrations detected at intensive fixed sites, 1999–2000, Yakima River Basin, Washington.

August 1999, barium concentrations ranged from 1.6 to 96 µg/L, with a median concentration of 15 µg/L (appendix tables A11, A19). The highest concentration (96 µg/L) was detected at the Zillah WWTP (fig. 22).

The median concentration for all tributary sites was 16 µg/L, whereas the main-stem and WWTP median concentrations were 9.9 and 12 µg/L respectively. The highest concentrations were detected in the mid- to lower Yakima River Basin (fig. 22). A barium concentration of 40 µg/L and 47 µg/L, the 90<sup>th</sup> percentile for the Yakima River Basin, was detected at Sulphur Creek Wasteway and Granger Drain at Granger, respectively (appendix table A19). There was a general increase in dissolved barium concentrations from Yakima River at Cle Elum (2.6 µg/L) downstream to Yakima River at Kiona (21 µg/L).

**Barium Detected at Intensive Fixed Sites, May 1999–January 2000**—Barium concentrations in filtered water were determined at the three intensive fixed sites in the Yakima River Basin: Granger Drain at Granger, Moxee Drain at Birchfield Rd., and Yakima River at Kiona (fig. 23). For all sites, concentrations ranged from 6.5 to 89 µg/L, with a median concentration of 22 µg/L (appendix table A12). At the Moxee and Granger sites, barium concentrations were higher during the nonirrigation season. For example, the irrigation-season median concentration was 21 µg/L, whereas the nonirrigation-season median was 60 µg/L. At Granger, barium concentrations were also higher during winter baseflow conditions. The nonirrigation- season median was 42 µg/L, whereas the irrigation- season median concentration was 84 µg/L. At Yakima River at Kiona, barium showed little seasonal variability although concentrations dropped slightly during the nonirrigation season (fig. 24, p. 40). Barium concentrations exhibit the same temporal pattern as arsenic, uranium, and manganese.

**Barium Aquatic-Life Water-Quality Criteria and Human Health**—Barium is a yellowish-white metal of the alkaline earth group. In aqueous systems, barium originates primarily from natural sources including barite (BaSO<sub>4</sub>) and witherite (BaCO<sub>3</sub>), both of which are insoluble salts. Barium is not considered an essential element for human nutrition (World Health Organization, 1996). Many of the salts of barium are soluble in water, and soluble barium salts are reported to be poisonous (Lide, 1998). Experimental data indicate that soluble barium concentrations in fresh and



**Figure 22.** Distribution of barium concentrations detected during basinwide sampling, August 1999, Yakima River Basin, Washington. (WWTP, wastewater treatment plant)

## EXPLANATION

### Barium concentrations

- Data value represents the 95th percentile
- 90th percentile
- 75th percentile
- Median
- 25th percentile
- 10th percentile
- Data value represents the 5th percentile
- Minimum reporting level 1.0 microgram per liter

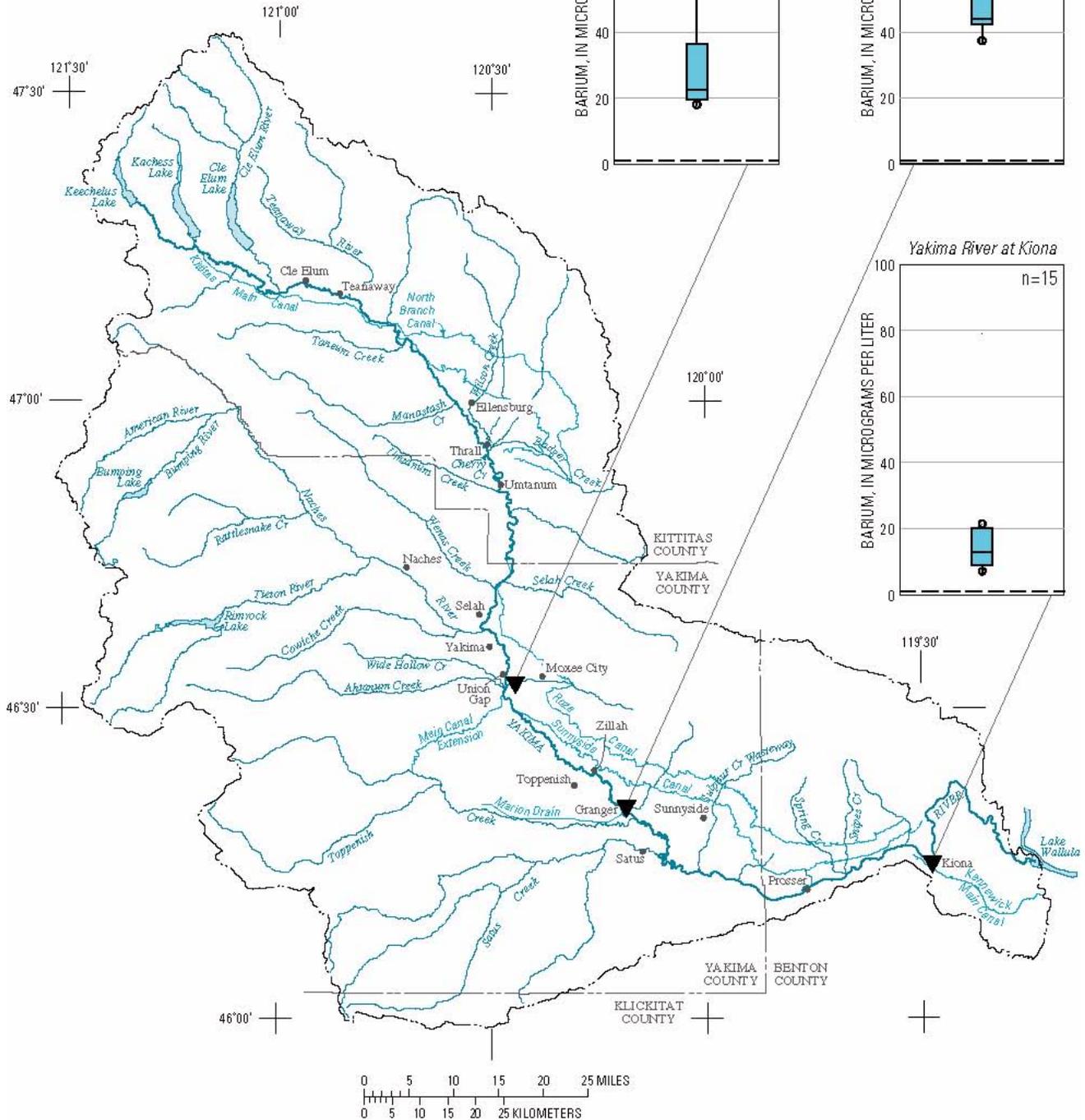
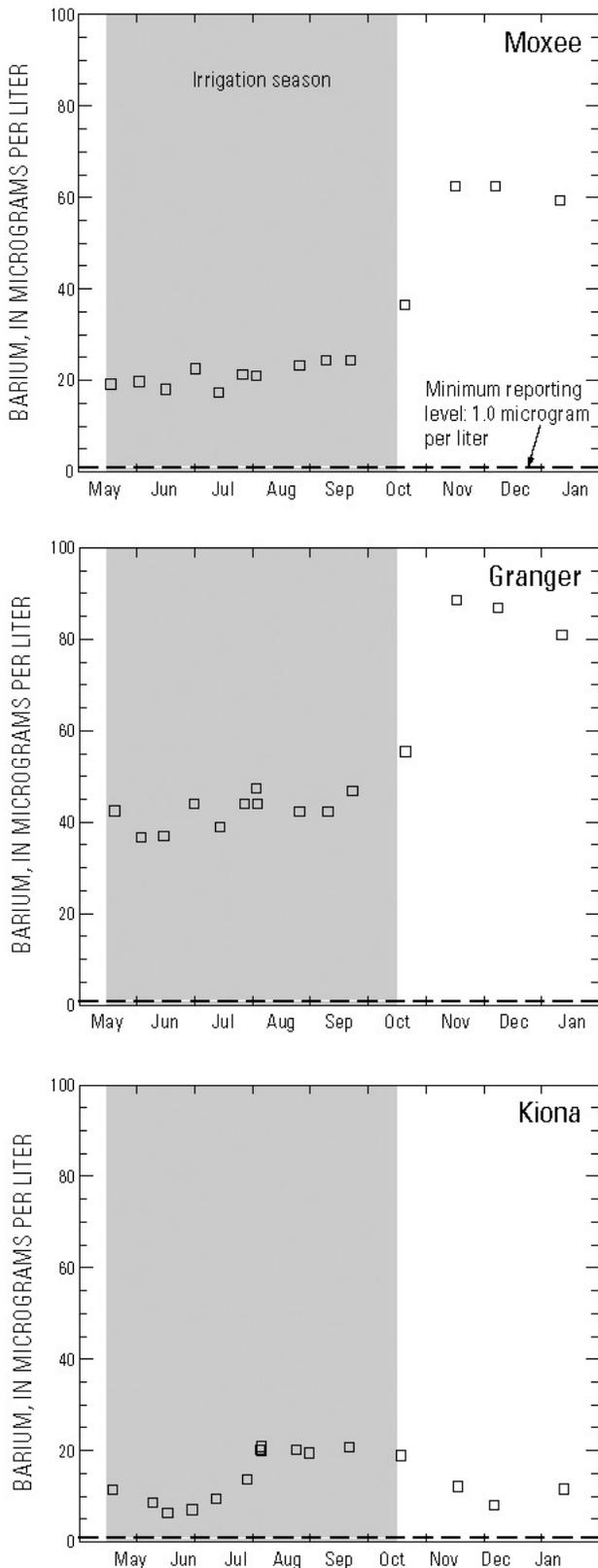


Figure 23. Distribution of barium concentrations detected during intensive fixed site sampling, 1999–2000, Yakima River Basin, Washington.



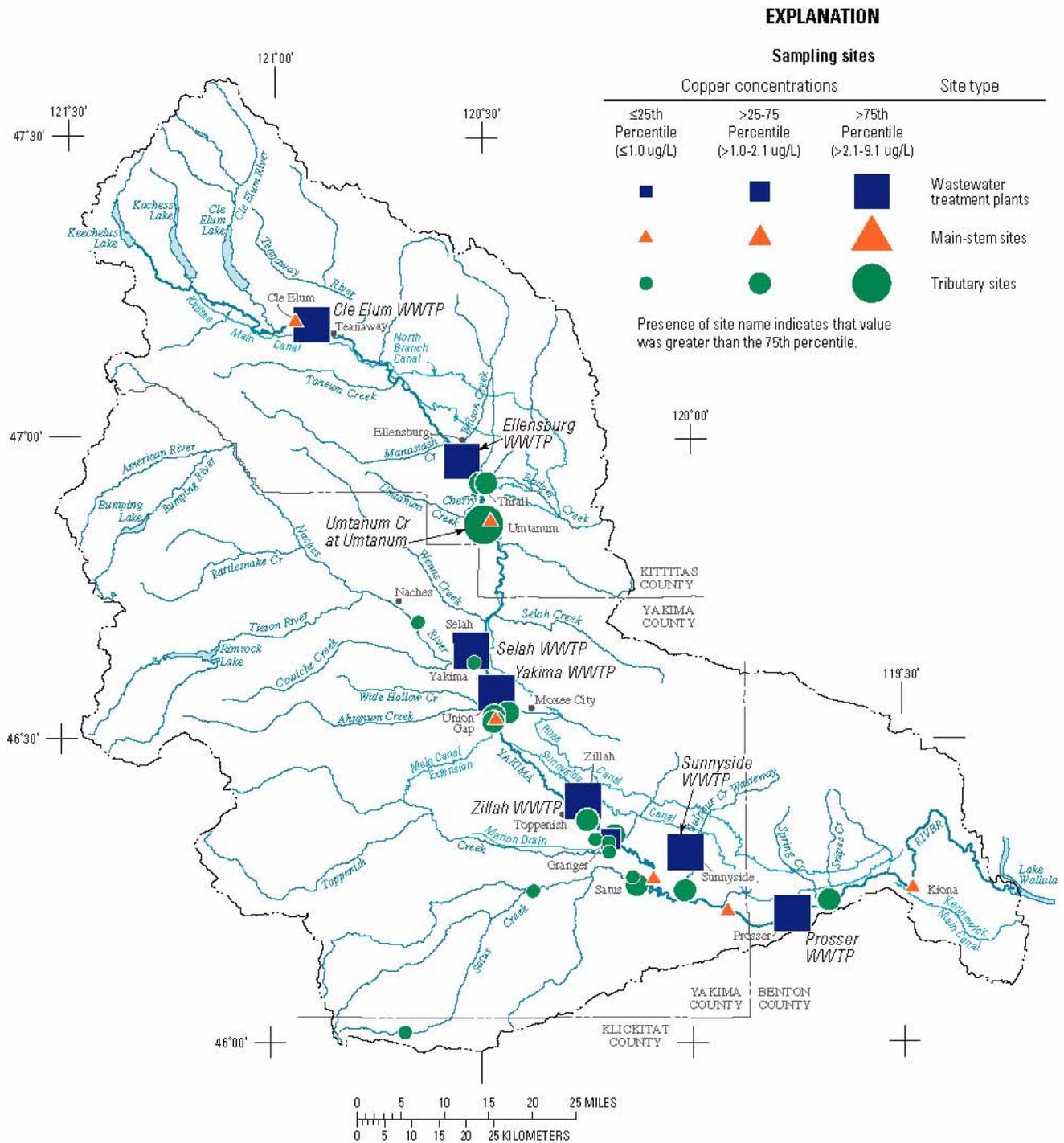
**Figure 24.** Barium concentrations detected at intensive fixed sites, 1999–2000, Yakima River Basin, Washington.

marine water generally would have to exceed 50,000 µg/L before toxicity to aquatic life would be expected (U.S. Environmental Protection Agency, 1986). However, in most natural waters, there is sufficient sulfate or carbonate to precipitate the barium as a insoluble, nontoxic compound (U.S. Environmental Protection Agency, 1986).

In a study of the water supplies of cities in the United States, a median value of 43 µg/L was reported; in 94 percent of all determinations, the concentrations were less than 100 µg/L (World Health Organization, 1996). There is no USEPA freshwater aquatic-life water-quality criterion for barium. The USEPA MCL drinking-water standard for barium is 2,000 µg/L. No sites in the Yakima River Basin exceed the MCL drinking-water standard for barium.

**Copper Detected during Basinwide Lagrangian Sampling, August 1999**—During basinwide sampling in August 1999, dissolved copper concentrations ranged from <1.0 to 9.1 µg/L, with a median concentration of 1.1 µg/L (appendix table A13, A19). Copper was detected at 21 of 34 (62 percent) sites (fig. 25). Dissolved copper concentrations were low at both tributary and main-stem sites, and in many cases concentrations were less than the MRL of 1.0 µg/L. For example, the median copper concentration for all tributary and main-stem sites was 1.1 µg/L and <1.0 µg/L respectively. Copper concentrations were slightly higher at the WWTPs. The median WWTP copper concentration was 3.8 µg/L. Several WWTP concentrations were above 3.9 µg/L, the 90th percentile for all samples collected during the August 1999 basinwide sampling (appendix table A19). The highest concentration was detected at Zillah WWTP (9.1 µg/L), but copper loads from all the WWTPs were insignificant (<0.1 lbs/d) because discharge rates were less than 1 ft<sup>3</sup>/s.

**Copper Detected at Intensive Fixed Sites, May 1999–January 2000**—Copper concentrations in filtered water were determined at the three intensive fixed sites in the Yakima River Basin: Granger Drain at Granger, Moxee Drain at Birchfield Rd, and Yakima River at Kiona (fig. 26). For all sites, concentrations ranged from <1.0 to 9.5 µg/L, with a median of 1.3 µg/L (appendix table A14). Dissolved copper concentrations showed no seasonal variability. At Moxee, the median copper concentration was 1.7 µg/L compared to 1.5 µg/L for the nonirrigation season. At Granger, irrigation and nonirrigation-season median concentrations were nearly identical at 1.3 and

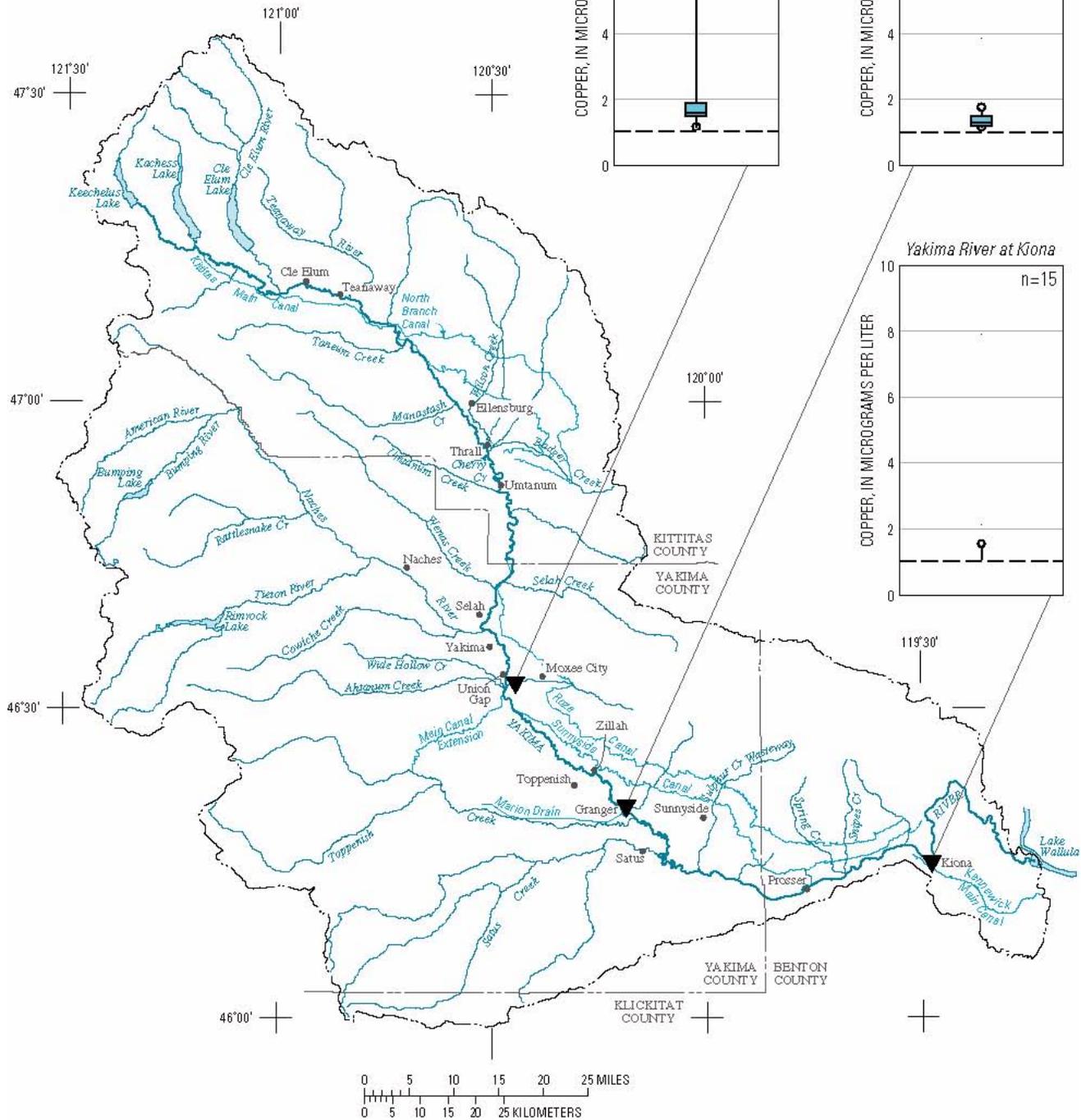


**Figure 25.** Distribution of copper concentrations detected during basinwide sampling, August 1999, Yakima River Basin, Washington. (WWTP, wastewater treatment plant)

**EXPLANATION**

**Copper concentrations**

- Data value represents the 95th percentile
- 90th percentile
- 75th percentile
- ▣ Median
- ▢ 25th percentile
- ▤ 10th percentile
- Data value represents the 5th percentile
- Minimum reporting level 1.0 microgram per liter



**Figure 26.** Distribution of copper concentrations detected during intensive fixed site sampling, 1999–2000, Yakima River Basin, Washington.

1.2 µg/L, respectively. The difference in concentration values is within the range of analytical error. Dissolved copper was detected in all samples at the Moxee and Granger sites. Copper concentrations at Kiona were less variable, ranging from <1.0 to 1.4 µg/L throughout the sample period and were similar to the range of concentrations reported for Kiona during the pilot study (Fuhrer and others, 1999). During peak irrigation in July of 1999, a copper concentration of 9.5 µg/L was measured at Moxee Drain (fig. 27). This concentration level could be the result of copper sulfate that is applied to control algal growth in agricultural drip systems (Mike Tobin, North Yakima Conservation District, oral commun., 2001).

***Copper Aquatic-Life Water-Quality Criteria and Human Health***—Copper is an essential element in human metabolism and is required in many enzymatic reactions (Health Canada, 1992). Copper can bind to proteins and is essential for the utilization of iron in the human diet. The USEPA freshwater aquatic-life water-quality criterion is 9 µg/L. The USEPA has not established an MCL drinking-water standard for copper. None of the samples from sites in the Yakima River Basin exceeded the USEPA freshwater aquatic-life water-quality criterion or MCLG for copper in drinking water.

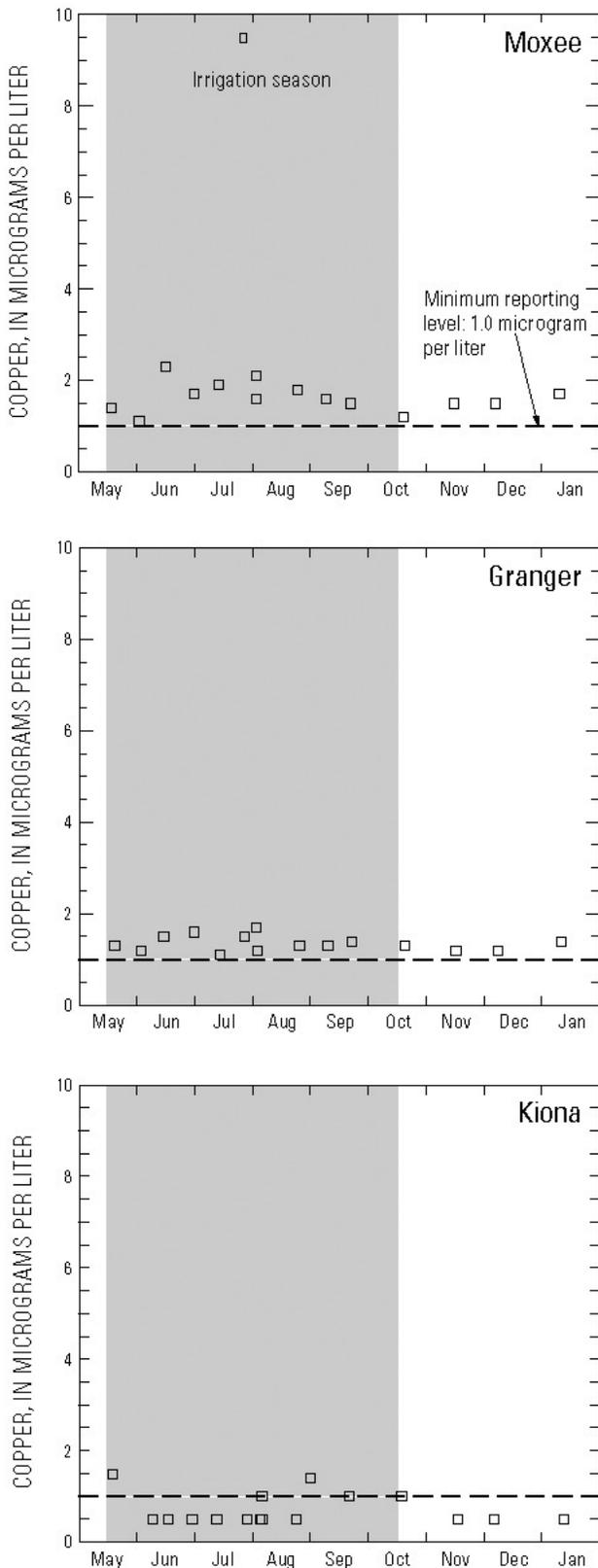
In aqueous solution, copper is usually soluble and present in the form of the Cu<sup>2+</sup> ion (U.S. Environmental Protection Agency, 1979). Copper also has a strong tendency to form complexes with both organic and inorganic solutes, especially humic substances and clays. The mobility of copper is high in oxidizing acidic waters, low in alkaline and reducing waters. Adsorption of copper by precipitating hydrous iron and manganese oxides is an effective control on dissolved copper concentrations where these metals are being actively weathered or otherwise introduced into unpolluted aquatic environments (U.S. Environmental Protection Agency, 1979). Copper is used extensively in pesticide formulations as a fungicide and antimicrobial agent, particularly for the treatment of wood (Health Canada, 1992). Copper is one of the most common contaminants found in urban runoff. Copper can be present in the leachate from municipal landfills and in sludges generated by sewage treatment plants (National Irrigation Water Quality Program Information, 1998).

***Nickel Detected during Basinwide Lagrangian Sampling, August 1999***—During basinwide sampling in August 1999, dissolved nickel concentrations ranged from <1.0 to 3.4 µg/L, with a median concentration of

1.2 µg/L (appendix tables A15, A19). At all sites, the dissolved nickel concentrations were low, at or near the MRL of 1.0 µg/L. Nickel was detected at 26 of 34 (76 percent) sites (fig. 28, p. 45). The highest concentration (3.4 µg/L) was detected at Zillah WWTP. Tributary and main-stem sites both contained a median concentration of 1.1 µg/L. Nickel shows the same distribution pattern as copper. Comparisons between nickel concentrations from the pilot study and in this study were hampered because nickel concentrations in the pilot study were below the MRL of 1.0 µg/L.

***Nickel Detected at Intensive Fixed Sites, May 1999–January 2000***—Nickel concentrations in filtered water were determined at the three intensive fixed sites in the Yakima River Basin: Granger Drain at Granger, Moxee Drain at Birchfield Rd., and Yakima River at Kiona (fig. 29, p. 46). Dissolved nickel concentrations were low, at or near the MRL of 1.0 µg/L in most samples. Concentrations ranged from <1.0 to 4.2 µg/L, with a median of 1.3 µg/L (appendix table A16). At Moxee and Granger, nickel was detected in 9 of 15 samples (60 percent), with a median concentration of 1.1 µg/L. A fourfold increase in concentration (4.1 and 4.2 µg/L) was observed at Moxee and Granger in January 2000. At Yakima River at Kiona, nickel in filtered water was detected in 5 of 16 samples (31 percent). Nickel concentrations at Kiona were less variable, ranging from <1.0 to 1.3 µg/L throughout the sampling period and were similar to the range of concentrations reported for Kiona during the pilot study (Fuhrer and others, 1999). With the exception of the January 2000 nickel anomaly at Moxee and Granger, there was little variability between the irrigation and nonirrigation seasons for dissolved nickel at all fixed sites (fig. 30, p. 47).

***Nickel Aquatic-Life Water-Quality Criteria and Human Health***—Nickel compounds have been classified as carcinogenic to humans (Gerhardsson and others, 1996). The MCL and MCLG for nickel in drinking water were remanded on February 1995; however, water suppliers continue to monitor nickel levels in their water. The USEPA freshwater aquatic-life water-quality criterion for nickel is 52 µg/L. The freshwater criterion is expressed as a function of hardness in the water column that corresponds to a hardness of 100 mg/L of calcium carbonate (CaCO<sub>3</sub>). The USEPA HAL for nickel is 100 µg/L. There were no exceedances of the USEPA aquatic-life water-quality criterion for nickel.



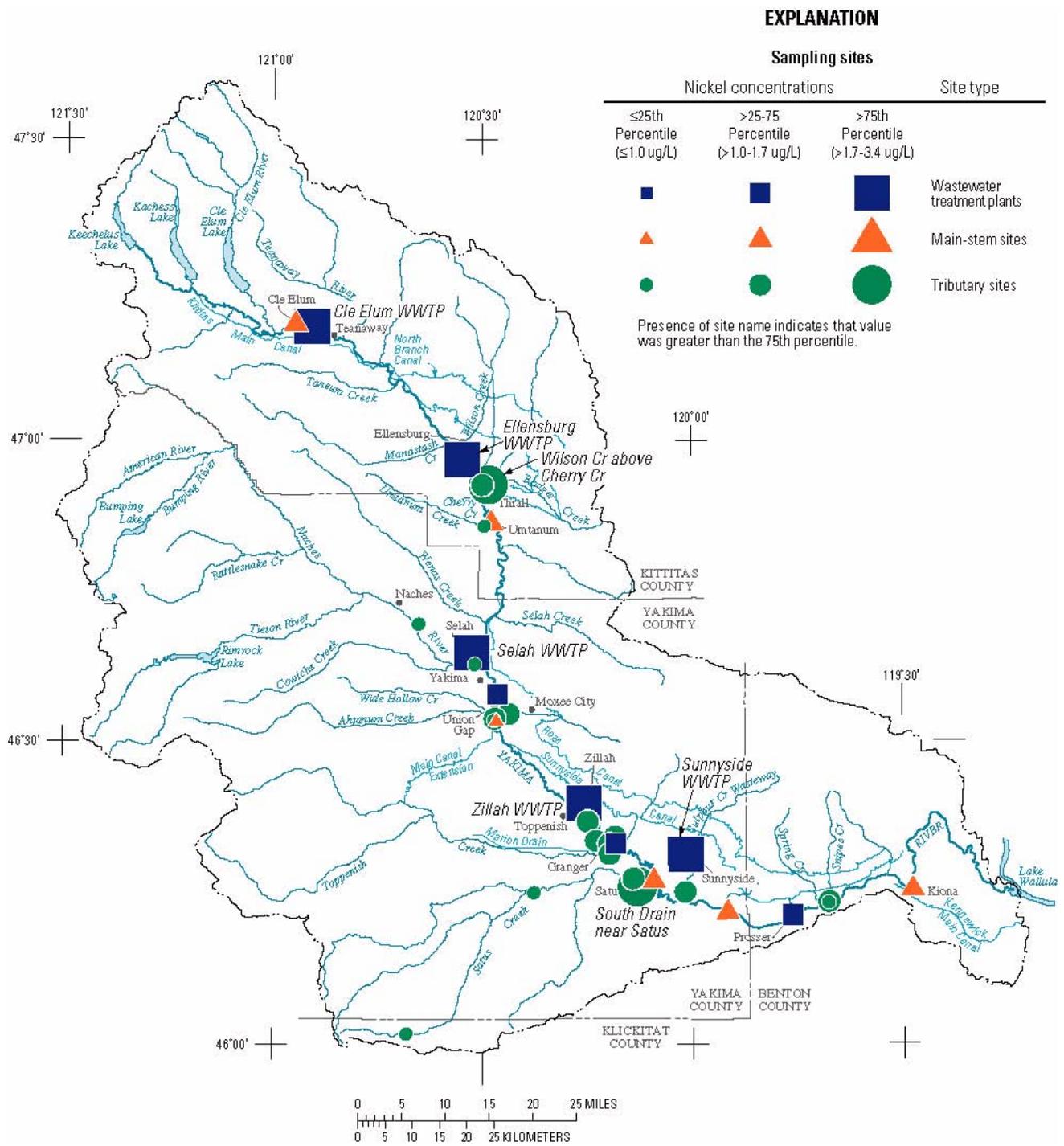
**Figure 27.** Copper concentrations detected at intensive fixed sites, 1999–2000, Yakima River Basin, Washington. (Concentrations lower than the minimum reporting level [1.0 microgram per liter] are shown as 0.5 microgram per liter.)

**Zinc Detected during Basinwide Lagrangian Sampling, August 1999**—During basinwide sampling in August 1999, dissolved zinc concentrations ranged from <1.0 to 78 µg/L, with a median concentration <1.0 µg/L (appendix tables A17, A19). Zinc was detected at 13 of 34 (38 percent) sites (fig. 31, p.48). Zinc concentrations at the main-stem and tributary sites were very low, at or near the MRL of 1.0 µg/L. With the exception of Yakima River at RM 72, all main-stem concentrations were less than 1.0 µg/L. Concentrations at tributary sites ranged from <1.0 to 1.5 µg/L. Elevated concentrations were observed at WWTPs (fig. 31, p. 48). For example, zinc concentrations exceeding the 90th percentile for all sites in the Yakima River Basin were detected at 28 µg/L at the Selah, Yakima, Zillah and Prosser WWTPs (appendix table A19). Although concentration values were high compared to main-stem and tributary sites, the WWTP load contribution to the main stem was only 0.5 lbs/day. This load represents a zinc concentration of 0.05 µg/L at the terminus of the basin, a value not measurable with our present analytical methods.

**Zinc Detected at Intensive Fixed Sites, May 1999–January 2000**—Zinc concentrations in filtered water were determined at three intensive fixed sites in the Yakima River Basin: Granger Drain at Granger, Moxee Drain at Birchfield Rd., and Yakima River at Kiona (fig. 32, p. 49). Zinc was detected in 20 out of 46 samples (43 percent) with concentrations ranging from <1.0 to 2.6 µg/L and a median concentration of <1.0 µg/L (appendix table A18). Like copper and nickel, zinc showed little seasonal variation in concentration values (fig. 33, p. 50).

During the pilot study (1987–90), zinc concentrations in filtered-water samples ranged from <3 to 40 µg/L at seven intensive fixed sites. The highest concentration (40 µg/L) was detected at Yakima River above Ahtanum Creek at Union Gap. In the mid-Yakima Valley, as much as 3,000 lbs of zinc-based pesticide Ziram (zinc dimethyldithio- carbamate) was applied to apple, pear, and peach orchards in 1989 to control shot hole, brown rot, and peach leaf curl (Fuhrer and others, 1999).

Zinc concentrations detected at the intensive fixed sites during 1999–2000 are considerably less than concentrations detected during the pilot study. For example, zinc concentrations (1987–90) at Sulphur Creek Wasteway (agricultural return drain) ranged from <3 to 9 µg/L, whereas concentrations from 1999–2000 at Moxee and Granger (agricultural return drains) ranged from <1.0 to 2.6 µg/L. A similar decrease in

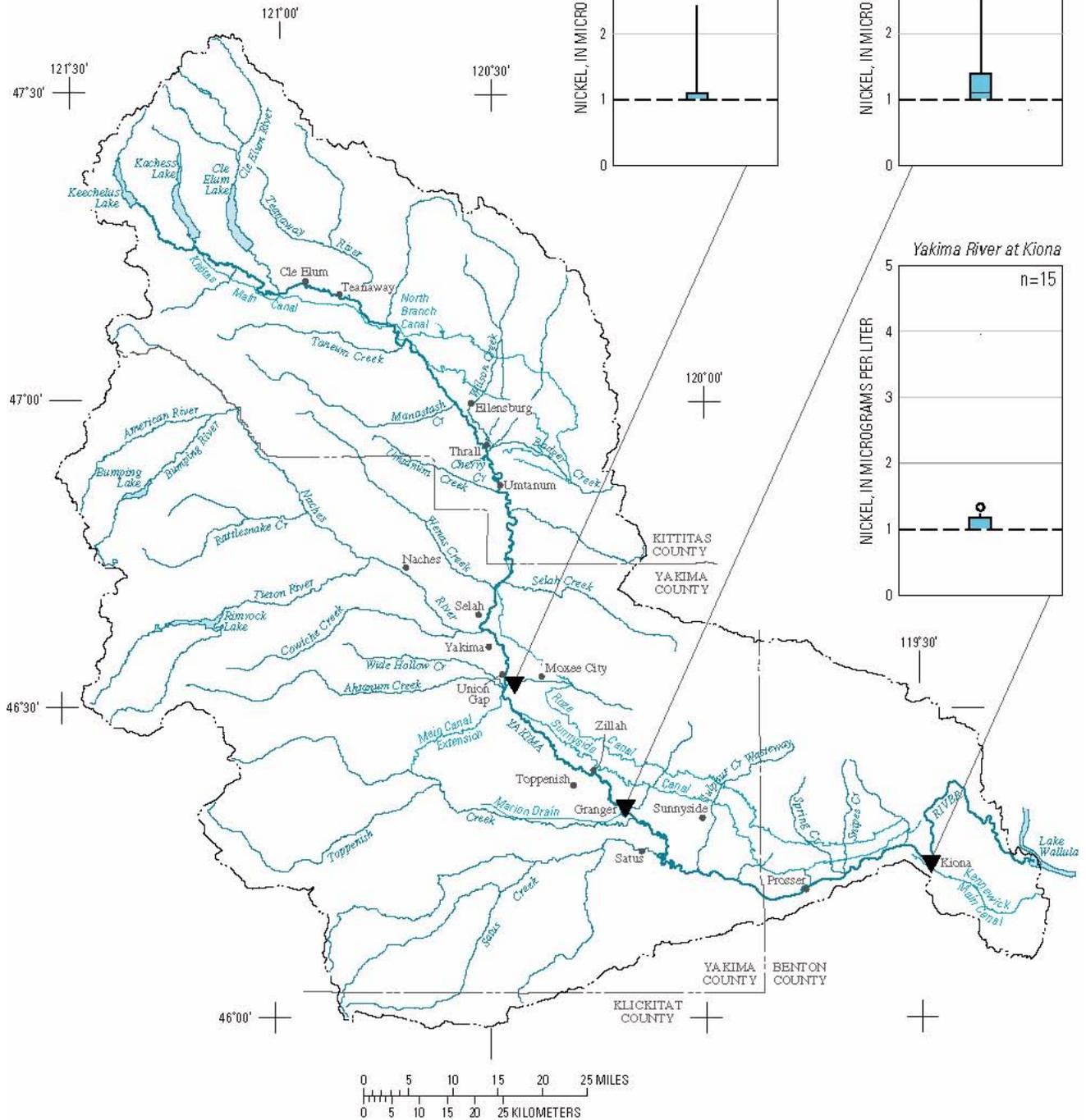


**Figure 28.** Distribution of nickel concentrations detected during basinwide sampling, August 1999, Yakima River Basin, Washington. (WWTP, wastewater treatment plant)

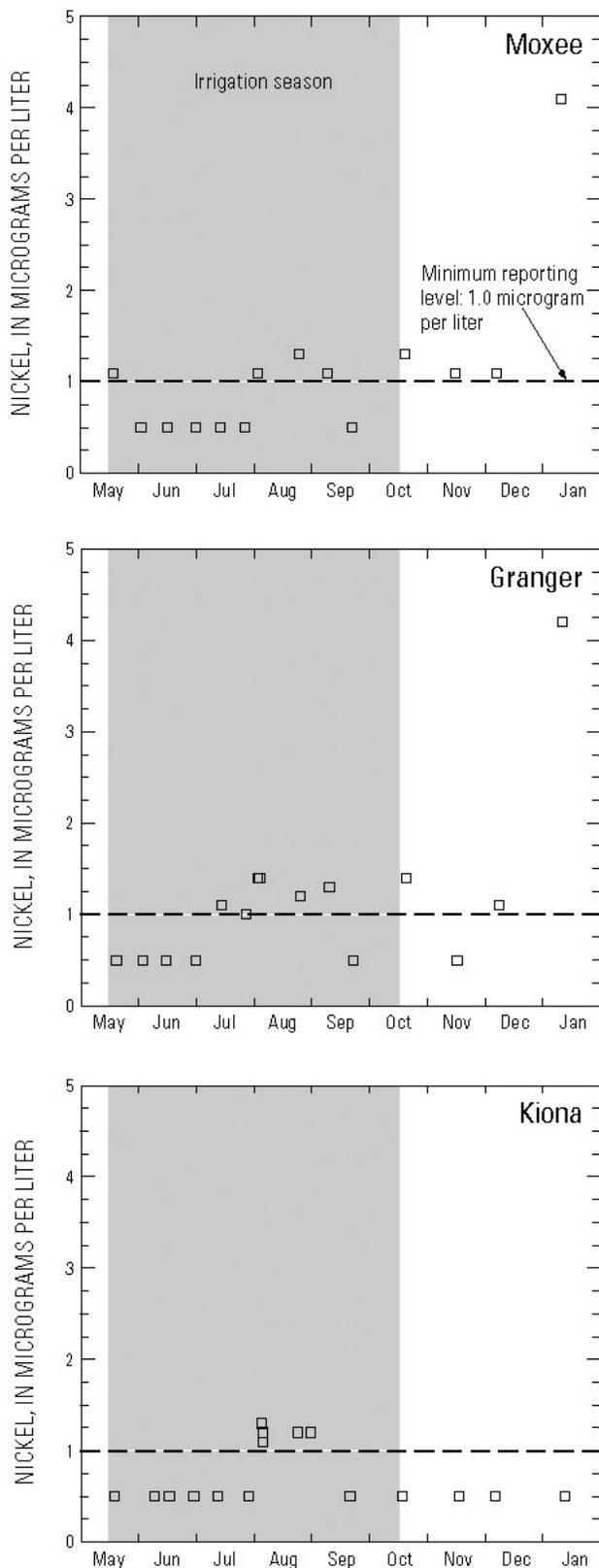
## EXPLANATION

### Nickel concentrations

- Data value represents the 95th percentile
- 90th percentile
- 75th percentile
- Median
- 25th percentile
- 10th percentile
- Data value represents the 5th percentile
- Minimum reporting level 1.0 microgram per liter



**Figure 29.** Distribution of nickel concentrations detected during intensive fixed site sampling, 1999–2000, Yakima River Basin, Washington.



**Figure 30.** Nickel concentrations detected at intensive fixed sites, 1999–2000, Yakima River Basin, Washington.

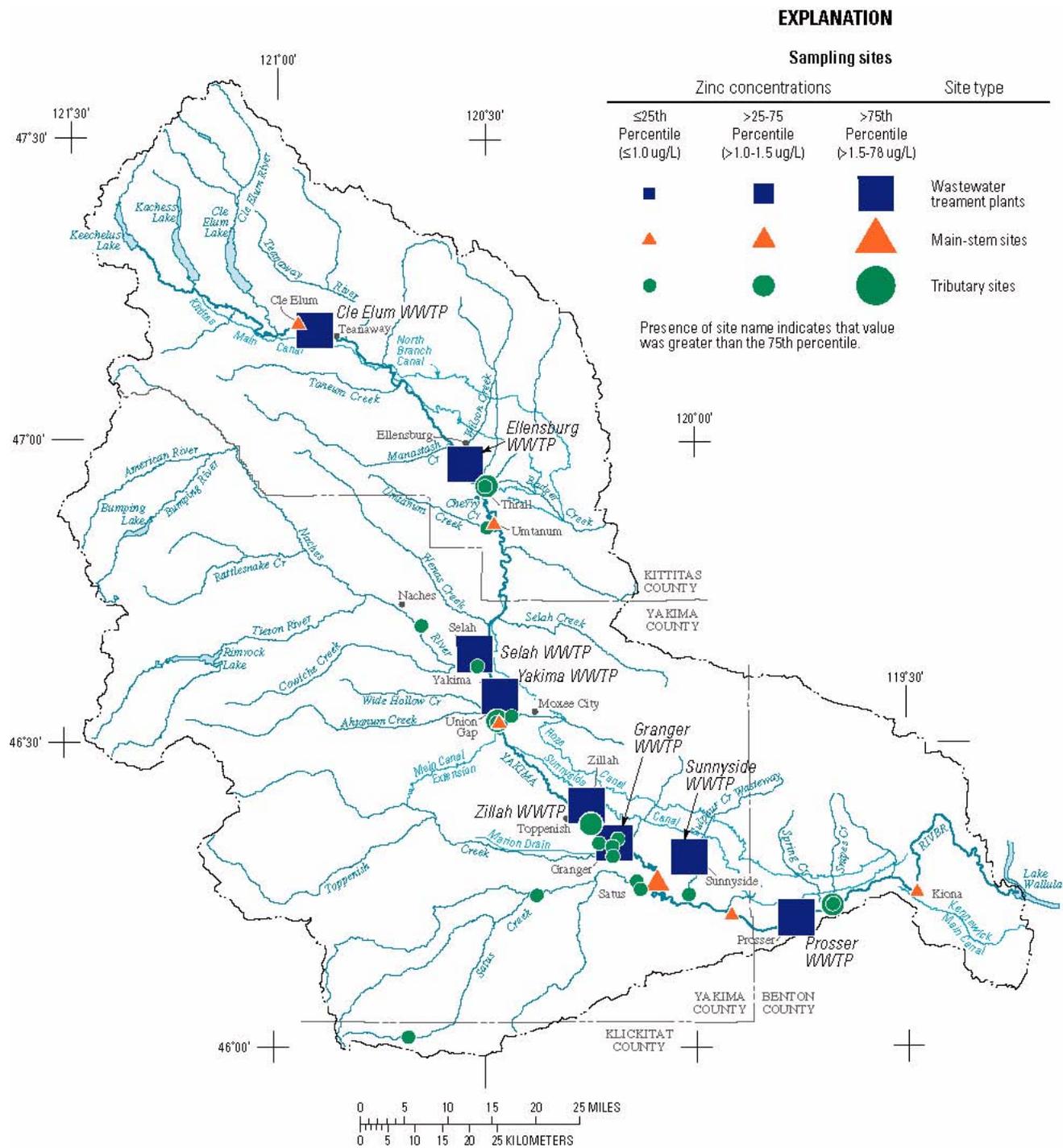
zinc concentrations occurred at Yakima River at Kiona. Pilot study concentrations ranged from <3 to 12 µg/L, whereas 1999-2000 concentrations ranged from <1.0 to 1.8 µg/L.

**Zinc Aquatic-Life Water-Quality Criteria and Human Health**—Zinc is an essential trace element found in virtually all food and water in the form of salts



**Zinc is applied to fruit trees in the form of zinc-based pesticide ziram (zinc dimethyldithiocarbamate) to promote blossoms and to control shothole, brown rot, and peach leaf curl.**

or organic complexes (National Irrigation Water Quality Program, 1998). In the aqueous environment zinc is stable as  $Zn^{2+}$  species. Since zinc solutes are soluble in neutral and acidic solutions, zinc is readily transported in most natural waters (U.S. Environmental Protection Agency, 1979). Adsorption on clay minerals, hydrous oxides, and organic matter is a probable limiting mechanism for the solubility of small concentrations of zinc found in aquatic environments (U.S. Environmental Protection Agency, 1979). The freshwater criterion is expressed as a function of hardness (mg/L) in the water column. The USEPA freshwater aquatic-life water-quality criterion for waters with 100 mg/L  $CaCO_3$  is 120 µg/L. The USEPA recommends secondary standards to water systems but does not require systems to comply. There is no USEPA drinking-water standard for zinc, but there is secondary maximum contaminant level goal of 5,000 µg/L. No samples exceeded the USEPA SMCL for drinking water or USEPA freshwater aquatic-life water-quality criterion.

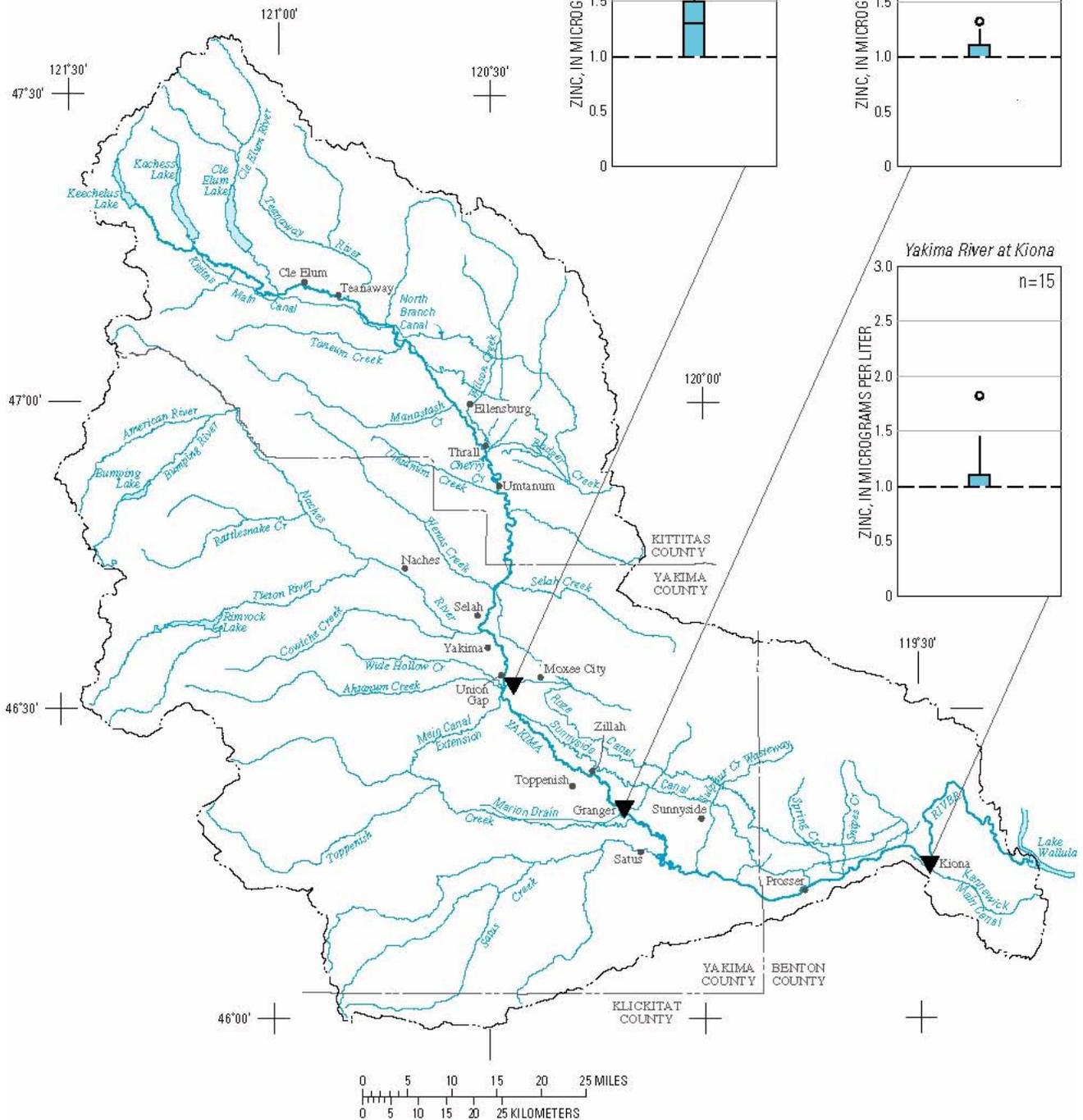


**Figure 31.** Distribution of zinc concentrations detected during basinwide sampling, August 1999, Yakima River Basin, Washington. (WWTP, wastewater treatment plant)

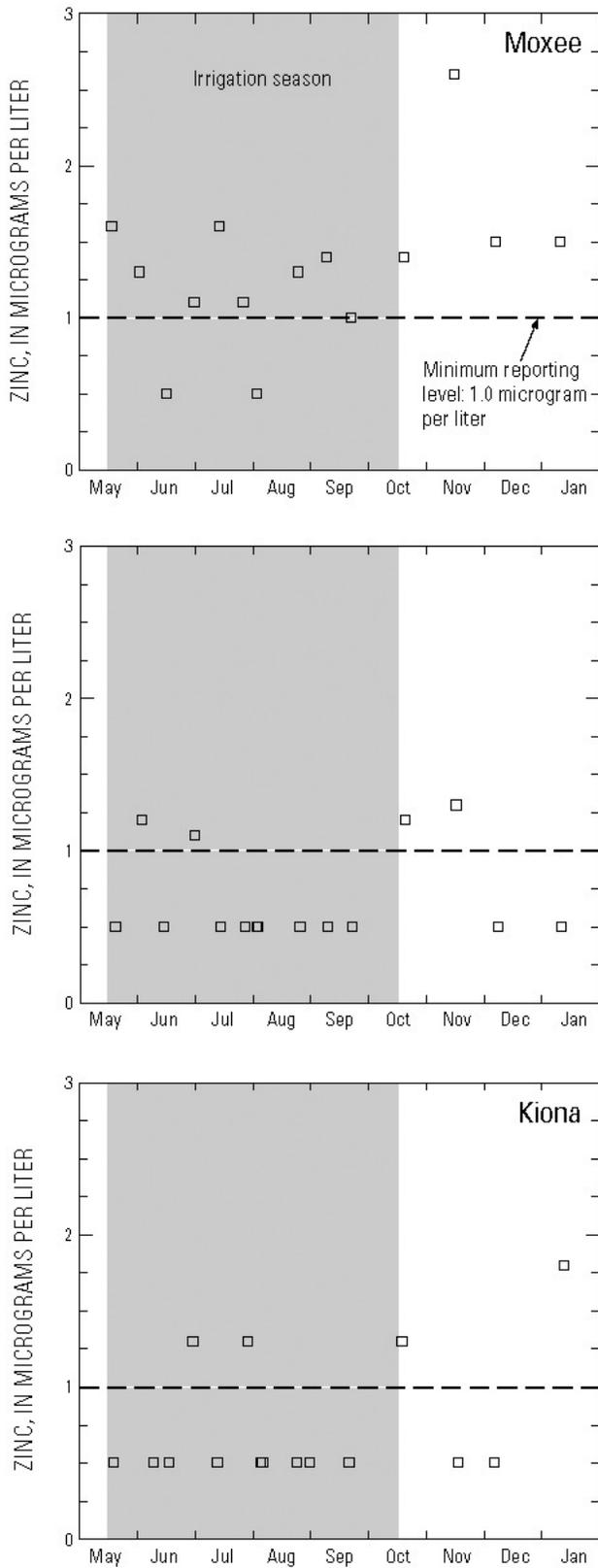
**EXPLANATION**

**Zinc concentrations**

- Data value represents the 95th percentile
- 90th percentile
- 75th percentile
- Median
- 25th percentile
- 10th percentile
- Data value represents the 5th percentile
- Minimum reporting level 1.0 microgram per liter



**Figure 32.** Distribution of zinc concentrations detected during intensive fixed site sampling, 1999–2000, Yakima River Basin, Washington.



**Figure 33.** Zinc concentrations detected at intensive fixed sites, 1999–2000, Yakima River Basin, Washington. (Concentrations lower than the minimum reporting level [1.0 microgram per liter] are shown as 0.5 microgram per liter.)

## SUMMARY

In August 1999, 34 surface-water sites were sampled using a Lagrangian sampling design to assess the occurrence and distribution of dissolved (filtered) trace elements in surface-water of the Yakima River Basin as part of the U.S. Geological Survey’s National Water-Quality Assessment (NAWQA) Program. Samples also were collected weekly and monthly from May 1999 through January 2000 at three intensive fixed sites. Twenty-three trace elements were measured in filtered-water and 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.

**Intensive Fixed Sampling Sites**—Trace-element concentrations detected in samples collected during fixed-site sampling (May 1999 through January 2000) were generally low and there were no exceedances of the USEPA freshwater aquatic-life water-quality criteria. All trace elements measured in this study, with the exception of arsenic at Granger Drain, were at concentrations below the USEPA drinking-water standard. This report lists the current drinking-water standards for trace elements detected in the Yakima River Basin from April 1999 through January 2000 for



**Hops in bloom in Moxee Basin.**

comparison purposes only. No public water supply wells were sampled during this study, and the surface waters sampled are not necessarily representative of the quality of water after treatment and delivery to users of a public water system. The USEPA drinking-water standard for arsenic (10 µg/L) was exceeded in two samples that were collected at baseflow conditions during the nonirrigation season at Granger Drain (agricultural return drain). Furthermore, over 40

percent of all samples collected during this study exceeded the USEPA health advisory level of 2.0 µg/L for arsenic. Exceedances of the arsenic health advisory level were measured predominantly in the lower Yakima Valley. Additionally, the presence of higher arsenic concentrations during the nonirrigation season at Moxee and Granger Drains (agricultural return drains) indicates that shallow ground water in areas of intense irrigation, although not sampled, also may be affected by arsenic. Arsenic concentrations in agricultural drains were highest when the drains were fed primarily by shallow ground water during winter baseflow conditions. Several elements, including barium, manganese, and uranium, were also detected at higher concentrations during the nonirrigation season at Moxee and Granger Drains when compared to irrigation season concentrations. In addition, the USEPA secondary maximum contaminant level for manganese (50 µg/L) was exceeded in three samples collected at Granger Drain during the nonirrigation season.

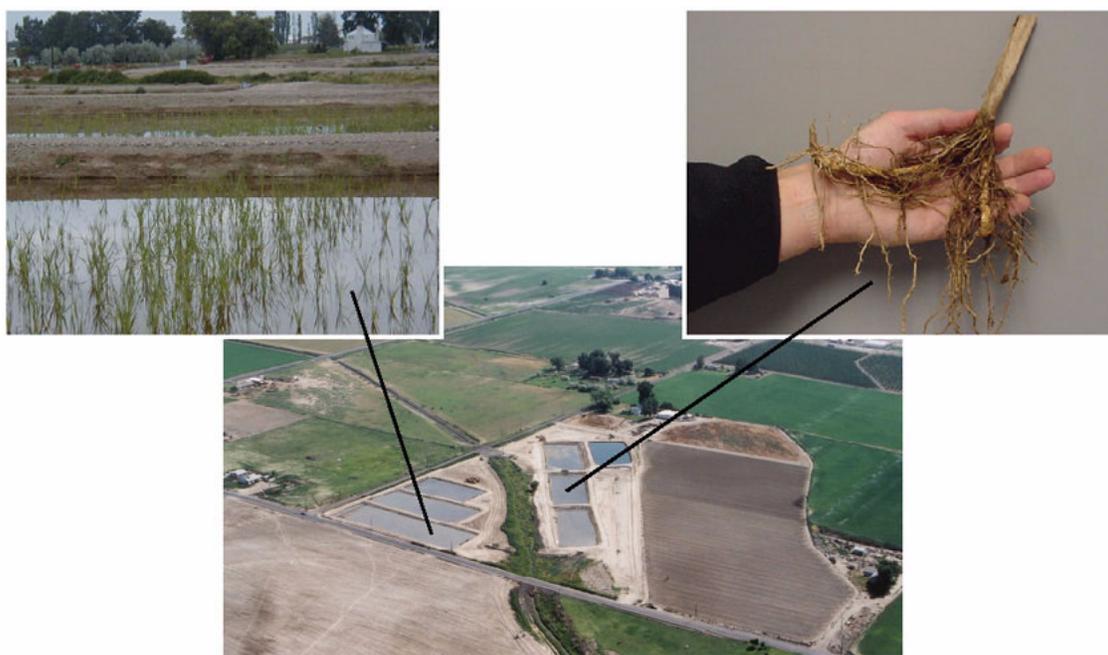
Data collected from May 1999 through January 2000 at Yakima River at Kiona show that aluminum, arsenic, and zinc concentrations in filtered water have decreased from concentrations levels detected during the 1987–90 pilot study.

***Basinwide Sampling Sites***—Trace-element concentrations detected in samples collected during basinwide Langrangian sampling (August 1999) were generally low and there were no exceedances of the

USEPA freshwater aquatic-life water-quality criteria, health advisory levels, or drinking water standards. In general, trace-element concentrations in the Yakima River were highest when the river was fed primarily by agricultural return flow. Many wastewater treatment plants effluent contained higher concentrations of aluminum, iron, copper, nickel uranium, and zinc compared to main-stem or tributary sites, but the loads to the Yakima River main stem were insignificant (<0.1 lbs/d) because discharge rates were less than 1 ft<sup>3</sup>/s.

Sources of dissolved arsenic in surface water include the historic application of pesticides containing lead arsensate to existing and former deciduous fruit orchards throughout the basin. Granger Drain, South Drain, and Sulphur Creek Wasteway (agricultural return drains) exceeded the 75<sup>th</sup> percentile of 2.1 µg/L for arsenic based on all tributary sites. In August 1999, arsenic loads increased twofold between Yakima River at river mile 72 above Satus and the Yakima River at Kiona at river mile 29.9. South Drain near Satus and Sulphur Creek Wasteway are major arsenic load contributors to the Yakima River main stem.

Instantaneous arsenic loads calculated during basinwide sampling were similar to mean monthly loads determined in August 1989 at two locations on the Yakima main stem. Specifically, the arsenic loads at Yakima River at Euclid Bridge at river mile 55 near Grandview and Yakima River at Kiona were within 13 percent of the August 1989 levels.



***Constructed wetland containing cattails and other aquatic plants that can sequester dissolved trace elements.***

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## APPENDIXES

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**APPENDIX A1. Arsenic concentrations detected during basinwide Lagrangian sampling, August 1999, Yakima River Basin, Washington**  
 [RM, river mile; wwtp, wastewater treatment plant; abv, above; Cr, Creek; WW, wasteway; nr, near; Rd, road; <, less than; µg/L, micrograms per liter]

Map identification	USGS station number	Site name	RM <sup>1</sup>	Site type	Date	Time	Concentration (µg/L)
1	12479500	Yakima River at Cle Elum	182.5	main stem	19990802	1300	<1.0
2	4711211205434	Cle Elum WWTP	179.6	wwtp	19990802	0800	<1.0
3	4657481203252	Ellensburg WWTP	151.6	wwtp	19990802	1630	<1.0
4	12484100	Wilson Creek abv Cherry Creek	147	tributary	19990802	1750	<1.0
5	12484480	Cherry Creek at Thrall <sup>2</sup>	147	tributary	19990802	1700	<1.0
6	12484500	Yakima River at Umtanum	140.4	main stem	19990802	1840	<1.0
7	12484550	Umtanum Creek at Umtanum	139.8	tributary	19990802	1740	<1.0
8	4638561203130	Selah WWTP	117	wwtp	19990803	0720	2.5
9	12496510	Pacific Power and Light WW <sup>3</sup>	116.3	tributary	19990803	0650	<1.0
10	12499000	Naches River nr North Yakima	116.3	tributary	19990803	0900	1.5
11	4634471202752	Yakima WWTP	111	wwtp	19990803	0710	1.2
12	12500445	Wide Hollow Cr at Union Gap	107.4	tributary	19990803	1220	2.1
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990803	0740	1.9
13	12500420	Moxee Drain at Birchfield Rd <sup>4</sup>	107.3	tributary	19990803	1940	2.4
14	12500450	Yakima River at Union Gap	107.3	main stem	19990803	1030	1.3
15	12502500	Ahtanum Cr at Union Gap	106.9	tributary	19990803	1420	<1.0
16	4623571201532	Zillah WWTP	89.5	wwtp	19990803	1600	3.0
17	12505350	East Toppenish Drain at Wilson Rd	86	tributary	19990803	1840	<1.0
18	12505410	Sub 35 Drain at Parton Rd	83.2	tributary	19990803	1740	1.3
19	4620131201137	Granger WWTP	82.8	wwtp	19990804	0900	3.3
20	12505450	Granger Drain at Granger <sup>4</sup>	82.8	tributary	19990803	1730	5.5
20	12505450	Granger Drain at Granger	82.8	tributary	19990804	0740	4.1
21	12505510	Marion Drain at Granger	82.6	tributary	19990804	0820	1.4
22	12507508	Toppenish Cr nr Granger	80.4	tributary	19990804	0840	1.0
23	12507585	Yakima River at RM 72	72	main stem	19990804	1230	<1.0
24	12507595	Satus Creek abv Shinado Creek	69.6	tributary	19990803	1340	<1.0
25	12508500	Satus Creek below Dry Creek	69.6	tributary	19990804	0950	<1.0
26	12508620	Satus Creek at Satus	69.6	tributary	19990804	1500	<1.0
27	12508630	South Drain near Satus	69.3	tributary	19990804	1750	5.3
27	12508630	South Drain near Satus <sup>4</sup>	69.3	tributary	19990805	1050	5.3
28	4618501200058	Sunnyside WWTP <sup>5</sup>	61	wwtp	19990804	1530	3.7
29	12508850	Sulphur Creek Wasteway	61	tributary	19990804	1810	2.2
29	12508850	Sulphur Creek Wasteway <sup>4</sup>	61	tributary	19990805	1420	2.5
30	12509050	Yakima River at Euclid Bridge	55	main stem	19990805	920	1.6
31	4612461194547	Prosser WWTP	47	wwtp	19990805	1130	<1.0
32	4614041194104	Spring Creek at Hess Rd	41.8	tributary	19990805	1740	1.1
33	4614141194042	Snipes Creek below Chandler Canal	41.8	tributary	19990805	1610	1.8
34	12510500	Yakima River at Kiona <sup>4</sup>	29.9	main stem	19990805	1740	2.3
34	12510500	Yakima River at Kiona	29.9	main stem	19990806	1030	1.3
34	12510500	Yakima River at Kiona <sup>4</sup>	29.9	main stem	19990806	1510	1.3

<sup>1</sup>River mile, sampled on the Yakima River or where tributary or WWTP discharges to the Yakima River.

<sup>2</sup>Cherry Creek discharges to Wilson Creek at RM 1.1.

<sup>3</sup>Pacific Power and Light Wasteway discharges to the Naches River at RM 9.7 (sample collected on tributary to Naches River).

<sup>4</sup>Non-Lagrangian sample.

<sup>5</sup>Sunnyside WWTP discharges to DID, which discharges to Sulphur Creek.

**APPENDIX A2. Arsenic concentrations detected at intensive fixed sites, 1999–2000, Yakima River Basin, Washington**

[RM, river mile; Rd, road; E, estimated value; <, less than; µg/L, micrograms per liter]

Map identification	USGS station number	Site name	RM	Site type	Date	Time	Concentration (µg/L)
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990518	1700	1.4
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990602	1030	1.5
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990616	0900	1.1
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990701	0920	1.3
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990714	0940	1.4
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990727	1130	2.4
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990803	0740	1.9
13	12500420	Moxee Drain at Birchfield Rd <sup>1</sup>	107.3	tributary	19990803	1940	2.4
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990825	1000	2.4
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990909	1030	1.3
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990922	1100	1.8
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991020	1150	3.1
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991116	1140	8.5
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991208	1030	8.5
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	20000111	1130	8.9
20	12505450	Granger Drain at Granger	82.8	tributary	19990520	1210	4.7
20	12505450	Granger Drain at Granger	82.8	tributary	19990603	0920	3.3
20	12505450	Granger Drain at Granger	82.8	tributary	19990615	1320	4.4
20	12505450	Granger Drain at Granger	82.8	tributary	19990701	1430	5.4
20	12505450	Granger Drain at Granger	82.8	tributary	19990715	0940	3.9
20	12505450	Granger Drain at Granger	82.8	tributary	19990728	1130	5.3
20	12505450	Granger Drain at Granger	82.8	tributary	19990803	1730	5.5
20	12505450	Granger Drain at Granger	82.8	tributary	19990804	0740	4.1
20	12505450	Granger Drain at Granger	82.8	tributary	19990826	0930	4.8
20	12505450	Granger Drain at Granger	82.8	tributary	19990910	0930	4.5
20	12505450	Granger Drain at Granger	82.8	tributary	19990923	0910	4.9
20	12505450	Granger Drain at Granger	82.8	tributary	19991021	0950	7.8
20	12505450	Granger Drain at Granger	82.8	tributary	19991117	1000	11
20	12505450	Granger Drain at Granger	82.8	tributary	19991209	1020	9.7
20	12505450	Granger Drain at Granger	82.8	tributary	20000112	1010	10
34	12510500	Yakima River at Kiona	29.9	main stem	19990519	1650	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990609	1220	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990617	1040	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990630	1020	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990713	1120	1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990729	1000	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990805	1740	2.3
34	12510500	Yakima River at Kiona	29.9	main stem	19990806	1030	1.3
34	12510500	Yakima River at Kiona <sup>1</sup>	29.9	main stem	19990806	1510	1.3
34	12510500	Yakima River at Kiona	29.9	main stem	19990824	1120	1.9
34	12510500	Yakima River at Kiona	29.9	main stem	19990831	1150	2.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990921	1210	1.5
34	12510500	Yakima River at Kiona	29.9	main stem	19991019	1140	E1.9
34	12510500	Yakima River at Kiona	29.9	main stem	19991118	1200	E1.4
34	12510500	Yakima River at Kiona	29.9	main stem	19991207	1100	E1.2
34	12510500	Yakima River at Kiona	29.9	main stem	20000113	1140	<0.9

<sup>1</sup>Multiple samples collected within a day or week.

**APPENDIX A3. Uranium concentrations detected during basinwide Lagrangian sampling, August 1999, Yakima River Basin, Washington**  
 [RM, river mile; wwtp, wastewater treatment plant; abv, above; Cr, Creek; WW, wasteway; nr, near; Rd, road; <, less than; µg/L, micrograms per liter]

Map identification	USGS station number	Site name	RM <sup>1</sup>	Site type	Date	Time	Concentration (µg/L)
1	12479500	Yakima River at Cle Elum	182.5	main stem	19990802	1300	<1.0
2	4711211205434	Cle Elum WWTP	179.6	wwtp	19990802	0800	<1.0
3	4657481203252	Ellensburg WWTP	151.6	wwtp	19990802	1630	<1.0
4	12484100	Wilson Creek abv Cherry Creek	147	tributary	19990802	1750	<1.0
5	12484480	Cherry Creek at Thrall <sup>2</sup>	147	tributary	19990802	1700	1.5
6	12484500	Yakima River at Umtanum	140.4	main stem	19990802	1840	<1.0
7	12484550	Umtanum Creek at Umtanum	139.8	tributary	19990802	1740	<1.0
8	4638561203130	Selah WWTP	117	wwtp	19990803	0720	4.2
9	12496510	Pacific Power and Light WW <sup>3</sup>	116.3	tributary	19990803	0650	<1.0
10	12499000	Naches River nr North Yakima	116.3	tributary	19990803	0900	<1.0
11	4634471202752	Yakima WWTP	111	wwtp	19990803	0710	<1.0
12	12500445	Wide Hollow Cr at Union Gap	107.4	tributary	19990803	1220	1.7
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990803	0740	1.2
13	12500420	Moxee Drain at Birchfield Rd <sup>4</sup>	107.3	tributary	19990803	1940	1.5
14	12500450	Yakima River at Union Gap	107.3	main stem	19990803	1030	<1.0
15	12502500	Ahtanum Cr at Union Gap	106.9	tributary	19990803	1420	<1.0
16	4623571201532	Zillah WWTP	89.5	wwtp	19990803	1600	8.2
17	12505350	East Toppenish Drain at Wilson Rd	86	tributary	19990803	1840	<1.0
18	12505410	Sub 35 Drain at Parton Rd	83.2	tributary	19990803	1740	<1.0
19	4620131201137	Granger WWTP	82.8	wwtp	19990804	0900	<1.0
20	12505450	Granger Drain at Granger <sup>4</sup>	82.8	tributary	19990803	1730	6.2
20	12505450	Granger Drain at Granger	82.8	tributary	19990804	0740	5.5
21	12505510	Marion Drain at Granger	82.6	tributary	19990804	0820	<1.0
22	12507508	Toppenish Cr nr Granger	80.4	tributary	19990804	0840	<1.0
23	12507585	Yakima River at RM 72	72	main stem	19990804	1230	<1.0
24	12507595	Satus Creek abv Shinado Creek	69.6	tributary	19990803	1340	<1.0
25	12508500	Satus Creek below Dry Creek	69.6	tributary	19990804	0950	<1.0
26	12508620	Satus Creek at Satus	69.6	tributary	19990804	1500	<1.0
27	12508630	South Drain near Satus	69.3	tributary	19990804	1750	4.0
27	12508630	South Drain near Satus <sup>4</sup>	69.3	tributary	19990805	1050	3.6
28	4618501200058	Sunnyside WWTP <sup>5</sup>	61	wwtp	19990804	1530	<1.0
29	12508850	Sulphur Creek Wasteway	61	tributary	19990804	1810	3.7
29	12508850	Sulphur Creek Wasteway <sup>4</sup>	61	tributary	19990805	1420	3.5
30	12509050	Yakima River at Euclid Bridge	55	main stem	19990805	0920	1.3
31	4612461194547	Prosser WWTP	47	wwtp	19990805	1130	<1.0
32	4614041194104	Spring Creek at Hess Rd	41.8	tributary	19990805	1740	1.2
33	4614141194042	Snipes Creek below Chandler Canal	41.8	tributary	19990805	1610	1.5
34	12510500	Yakima River at Kiona <sup>4</sup>	29.9	main stem	19990805	1740	1.5
34	12510500	Yakima River at Kiona	29.9	main stem	19990806	1030	1.4
34	12510500	Yakima River at Kiona <sup>4</sup>	29.9	main stem	19990806	1510	1.4

<sup>1</sup>River mile, sampled on the Yakima River or where tributary or WWTP discharges to the Yakima River.

<sup>2</sup>Cherry Creek discharges to Wilson Creek at RM 1.1.

<sup>3</sup>Pacific Power and Light Wasteway discharges to the Naches River at RM 9.7 (sample collected on tributary to Naches River).

<sup>4</sup>Non-Lagrangian sample.

<sup>5</sup>Sunnyside WWTP discharges to DID, which discharges to Sulphur Creek.

**APPENDIX A4.** Uranium concentrations detected at intensive fixed sites, 1999–2000, Yakima River Basin, Washington

[RM, river mile; Rd, road; <, less than; µg/L, micrograms per liter]

Map identification	USGS station number	Site name	RM	Site type	Date	Time	Concentration (µg/L)
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990518	1700	1.2
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990602	1030	1.2
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990616	0900	1.3
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990701	0920	1.4
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990714	0940	1.1
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990727	1130	1.4
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990803	0740	1.2
13	12500420	Moxee Drain at Birchfield Rd <sup>1</sup>	107.3	tributary	19990803	1940	1.5
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990825	1000	1.5
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990909	1030	1.7
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990922	1100	1.5
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991020	1150	3.3
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991116	1140	7.5
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991208	1030	7.8
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	20000111	1130	7.3
20	12505450	Granger Drain at Granger	82.8	tributary	19990520	1210	7.1
20	12505450	Granger Drain at Granger	82.8	tributary	19990603	0920	5.2
20	12505450	Granger Drain at Granger	82.8	tributary	19990615	1320	5.1
20	12505450	Granger Drain at Granger	82.8	tributary	19990701	1430	6.4
20	12505450	Granger Drain at Granger	82.8	tributary	19990715	0940	5.1
20	12505450	Granger Drain at Granger	82.8	tributary	19990728	1130	5.5
20	12505450	Granger Drain at Granger	82.8	tributary	19990803	1730	6.2
20	12505450	Granger Drain at Granger	82.8	tributary	19990804	0740	5.5
20	12505450	Granger Drain at Granger	82.8	tributary	19990826	0930	5.3
20	12505450	Granger Drain at Granger	82.8	tributary	19990910	0930	5.7
20	12505450	Granger Drain at Granger	82.8	tributary	19990923	0910	6.7
20	12505450	Granger Drain at Granger	82.8	tributary	19991021	0950	9.4
20	12505450	Granger Drain at Granger	82.8	tributary	19991117	1000	16
20	12505450	Granger Drain at Granger	82.8	tributary	19991209	1020	16
20	12505450	Granger Drain at Granger	82.8	tributary	20000112	1010	14
34	12510500	Yakima River at Kiona	29.9	main stem	19990519	1650	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990609	1220	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990617	1040	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990630	1020	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990713	1120	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990729	1000	1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990805	1740	1.5
34	12510500	Yakima River at Kiona	29.9	main stem	19990806	1030	1.4
34	12510500	Yakima River at Kiona <sup>1</sup>	29.9	main stem	19990806	1510	1.4
34	12510500	Yakima River at Kiona	29.9	main stem	19990824	1120	1.4
34	12510500	Yakima River at Kiona	29.9	main stem	19990831	1150	1.4
34	12510500	Yakima River at Kiona	29.9	main stem	19990921	1210	1.7
34	12510500	Yakima River at Kiona	29.9	main stem	19991019	1140	1.7
34	12510500	Yakima River at Kiona	29.9	main stem	19991118	1200	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19991207	1100	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	20000113	1140	<1.0

<sup>1</sup>Multiple samples collected within a day or week.

**APPENDIX A5.** Aluminum concentrations detected during basinwide Lagrangian sampling, August 1999, Yakima River Basin, Washington

[RM, river mile; wwtp, wastewater treatment plant; abv, above; Cr, Creek; WW, wasteway; nr, near; Rd, road; µg/L, micrograms per liter]

Map identification	USGS station number	Site name	RM <sup>1</sup>	Site type	Date	Time	Concentration (µg/L)
1	12479500	Yakima River at Cle Elum	182.5	main stem	19990802	1300	12
2	4711211205434	Cle Elum WWTP	179.6	wwtp	19990802	0800	34
3	4657481203252	Ellensburg WWTP	151.6	wwtp	19990802	1630	24
4	12484100	Wilson Creek abv Cherry Creek	147	tributary	19990802	1750	6.2
5	12484480	Cherry Creek at Thrall <sup>2</sup>	147	tributary	19990802	1700	2.0
6	12484500	Yakima River at Umtanum	140.4	main stem	19990802	1840	3.8
7	12484550	Umtanum Creek at Umtanum	139.8	tributary	19990802	1740	6.4
8	4638561203130	Selah WWTP	117	wwtp	19990803	0720	48
9	12496510	Pacific Power and Light WW <sup>3</sup>	116.3	tributary	19990803	0650	9.0
10	12499000	Naches River nr North Yakima	116.3	tributary	19990803	0900	9.0
11	4634471202752	Yakima WWTP	111	wwtp	19990803	0710	31
12	12500445	Wide Hollow Cr at Union Gap	107.4	tributary	19990803	1220	4.9
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990803	0740	6.7
13	12500420	Moxee Drain at Birchfield Rd <sup>4</sup>	107.3	tributary	19990803	1940	7.9
14	12500450	Yakima River at Union Gap	107.3	main stem	19990803	1030	3.2
15	12502500	Ahtanum Cr at Union Gap	106.9	tributary	19990803	1420	5.6
16	4623571201532	Zillah WWTP	89.5	wwtp	19990803	1600	32
17	12505350	East Toppenish Drain at Wilson Rd	86	tributary	19990803	1840	6.3
18	12505410	Sub 35 Drain at Parton Rd	83.2	tributary	19990803	1740	1.1
19	4620131201137	Granger WWTP	82.8	wwtp	19990804	900	48
20	12505450	Granger Drain at Granger <sup>4</sup>	82.8	tributary	19990803	1730	2.6
20	12505450	Granger Drain at Granger	82.8	tributary	19990804	0740	5.9
21	12505510	Marion Drain at Granger	82.6	tributary	19990804	0820	6.5
22	12507508	Toppenish Cr nr Granger	80.4	tributary	19990804	0840	5.1
23	12507585	Yakima River at RM 72	72	main stem	19990804	1230	5.7
24	12507595	Satus Creek abv Shinado Creek	69.6	tributary	19990803	1340	8.6
25	12508500	Satus Creek below Dry Creek	69.6	tributary	19990804	0950	7.8
26	12508620	Satus Creek at Satus	69.6	tributary	19990804	1500	6.3
27	12508630	South Drain near Satus	69.3	tributary	19990804	1750	2.1
27	12508630	South Drain near Satus <sup>4</sup>	69.3	tributary	19990805	1050	6.9
28	4618501200058	Sunnyside WWTP <sup>5</sup>	61	wwtp	19990804	1530	43
29	12508850	Sulphur Creek Wasteway	61	tributary	19990804	1810	7.1
29	12508850	Sulphur Creek Wasteway <sup>4</sup>	61	tributary	19990805	1420	6.3
30	12509050	Yakima River at Euclid Bridge	55	main stem	19990805	0920	4.9
31	4612461194547	Prosser WWTP	47	wwtp	19990805	1130	97
32	4614041194104	Spring Creek at Hess Rd	41.8	tributary	19990805	1740	2.5
33	4614141194042	Snipes Creek below Chandler Canal	41.8	tributary	19990805	1610	1.3
34	12510500	Yakima River at Kiona <sup>4</sup>	29.9	main stem	19990805	1740	5.6
34	12510500	Yakima River at Kiona	29.9	main stem	19990806	1030	7.1
34	12510500	Yakima River at Kiona <sup>4</sup>	29.9	main stem	19990806	1510	4.6

<sup>1</sup>River mile, sampled on the Yakima River or where tributary or WWTP discharges to the Yakima River.

<sup>2</sup>Cherry Creek discharges to Wilson Creek at RM 1.1.

<sup>3</sup>Pacific Power and Light Wasteway discharges to the Naches River at RM 9.7 (sample collected on tributary to Naches River).

<sup>4</sup>Non-Lagrangian sample.

<sup>5</sup>Sunnyside WWTP discharges to DID, which discharges to Sulphur Creek.

**APPENDIX A6.** Aluminum concentrations detected at intensive fixed sites, 1999–2000, Yakima River Basin, Washington

[RM, river mile; Rd, road; <, less than; µg/L, micrograms per liter]

Map identification	USGS station number	Site name	RM	Site type	Date	Time	Concentration (µg/L)
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990518	1700	7.8
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990602	1030	3.0
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990616	0900	3.1
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990701	0920	2.8
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990714	0940	2.4
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990727	1130	4.6
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990803	0740	6.7
13	12500420	Moxee Drain at Birchfield Rd <sup>1</sup>	107.3	tributary	19990803	1940	7.9
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990825	1000	2.6
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990909	1030	1.9
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990922	1100	1.8
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991020	1150	<1.0
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991116	1140	1.4
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991208	1030	1.0
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	20000111	1130	1.3
20	12505450	Granger Drain at Granger	82.8	tributary	19990520	1210	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19990603	0920	3.0
20	12505450	Granger Drain at Granger	82.8	tributary	19990615	1320	5.7
20	12505450	Granger Drain at Granger	82.8	tributary	19990701	1430	2.7
20	12505450	Granger Drain at Granger	82.8	tributary	19990715	0940	3.2
20	12505450	Granger Drain at Granger	82.8	tributary	19990728	1130	2.3
20	12505450	Granger Drain at Granger	82.8	tributary	19990803	1730	2.6
20	12505450	Granger Drain at Granger	82.8	tributary	19990804	0740	5.9
20	12505450	Granger Drain at Granger	82.8	tributary	19990826	0930	1.6
20	12505450	Granger Drain at Granger	82.8	tributary	19990910	0930	1.9
20	12505450	Granger Drain at Granger	82.8	tributary	19990923	0910	2.4
20	12505450	Granger Drain at Granger	82.8	tributary	19991021	0950	1.3
20	12505450	Granger Drain at Granger	82.8	tributary	19991117	1000	1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19991209	1020	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	20000112	1010	1.2
34	12510500	Yakima River at Kiona	29.9	main stem	19990519	1650	1.6
34	12510500	Yakima River at Kiona	29.9	main stem	19990609	1220	2.9
34	12510500	Yakima River at Kiona	29.9	main stem	19990617	1040	6.5
34	12510500	Yakima River at Kiona	29.9	main stem	19990630	1020	4.2
34	12510500	Yakima River at Kiona	29.9	main stem	19990713	1120	14
34	12510500	Yakima River at Kiona	29.9	main stem	19990729	1000	2.2
34	12510500	Yakima River at Kiona	29.9	main stem	19990805	1740	5.6
34	12510500	Yakima River at Kiona	29.9	main stem	19990806	1030	7.1
34	12510500	Yakima River at Kiona <sup>1</sup>	29.9	main stem	19990806	1510	4.6
34	12510500	Yakima River at Kiona	29.9	main stem	19990824	1120	1.2
34	12510500	Yakima River at Kiona	29.9	main stem	19990831	1150	1.5
34	12510500	Yakima River at Kiona	29.9	main stem	19990921	1210	1.1
34	12510500	Yakima River at Kiona	29.9	main stem	19991019	1140	1.4
34	12510500	Yakima River at Kiona	29.9	main stem	19991118	1200	1.8
34	12510500	Yakima River at Kiona	29.9	main stem	19991207	1100	2.4
34	12510500	Yakima River at Kiona	29.9	main stem	20000113	1140	4.4

<sup>1</sup>Multiple samples collected within a day or week.

**APPENDIX A7. Iron concentrations detected during basinwide Lagrangian sampling, August 1999, Yakima River Basin, Washington**

[RM, river mile; wwtp, wastewater treatment plant; abv, above; Cr, Creek; WW, wasteway; nr, near; Rd, road; E, estimated; <, less than; µg/L, micrograms per liter]

Map identification	USGS station number	Site name	RM <sup>1</sup>	Site type	Date	Time	Concentration (µg/L)
1	12479500	Yakima River at Cle Elum	182.5	main stem	19990802	1300	E5.3
2	4711211205434	Cle Elum WWTP	179.6	wwtp	19990802	0800	14
3	4657481203252	Ellensburg WWTP	151.6	wwtp	19990802	1630	18
4	12484100	Wilson Creek abv Cherry Creek	147	tributary	19990802	1750	45
5	12484480	Cherry Creek at Thrall <sup>2</sup>	147	tributary	19990802	1700	16
6	12484500	Yakima River at Umtanum	140.4	main stem	19990802	1840	16
7	12484550	Umtanum Creek at Umtanum	139.8	tributary	19990802	1740	38
8	4638561203130	Selah WWTP	117	wwtp	19990803	0720	23
9	12496510	Pacific Power and Light WW <sup>3</sup>	116.3	tributary	19990803	0650	E6.3
10	12499000	Naches River nr North Yakima	116.3	tributary	19990803	0900	10
11	4634471202752	Yakima WWTP	111	wwtp	19990803	0710	40
12	12500445	Wide Hollow Cr at Union Gap	107.4	tributary	19990803	1220	<10
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990803	0740	17
13	12500420	Moxee Drain at Birchfield Rd <sup>4</sup>	107.3	tributary	19990803	1940	14
14	12500450	Yakima River at Union Gap	107.3	main stem	19990803	1030	16
15	12502500	Ahtanum Cr at Union Gap	106.9	tributary	19990803	1420	37
16	4623571201532	Zillah WWTP	89.5	wwtp	19990803	1600	25
17	12505350	East Toppenish Drain at Wilson Rd	86	tributary	19990803	1840	13
18	12505410	Sub 35 Drain at Parton Rd	83.2	tributary	19990803	1740	E5.3
19	4620131201137	Granger WWTP	82.8	wwtp	19990804	0900	30
20	12505450	Granger Drain at Granger <sup>4</sup>	82.8	tributary	19990803	1730	16
20	12505450	Granger Drain at Granger	82.8	tributary	19990804	0740	20
21	12505510	Marion Drain at Granger	82.6	tributary	19990804	0820	E7.4
22	12507508	Toppenish Cr nr Granger	80.4	tributary	19990804	0840	12
23	12507585	Yakima River at RM 72	72	main stem	19990804	1230	18
24	12507595	Satus Creek abv Shinado Creek	69.6	tributary	19990803	1340	20
25	12508500	Satus Creek below Dry Creek	69.6	tributary	19990804	0950	46
26	12508620	Satus Creek at Satus	69.6	tributary	19990804	1500	25
27	12508630	South Drain near Satus	69.3	tributary	19990804	1750	13
27	12508630	South Drain near Satus <sup>4</sup>	69.3	tributary	19990805	1050	16
28	4618501200058	Sunnyside WWTP (5)	61	wwtp	19990804	1530	48
29	12508850	Sulphur Creek Wasteway	61	tributary	19990804	1810	13
29	12508850	Sulphur Creek Wasteway <sup>4</sup>	61	tributary	19990805	1420	14
30	12509050	Yakima River at Euclid Bridge	55	main stem	19990805	0920	19
31	4612461194547	Prosser WWTP	47	wwtp	19990805	1130	29
32	4614041194104	Spring Creek at Hess Rd	41.8	tributary	19990805	1740	19
33	4614141194042	Snipes Creek below Chandler Canal	41.8	tributary	19990805	1610	13
34	12510500	Yakima River at Kiona <sup>4</sup>	29.9	main stem	19990805	1740	11
34	12510500	Yakima River at Kiona	29.9	main stem	19990806	1030	13
34	12510500	Yakima River at Kiona <sup>4</sup>	29.9	main stem	19990806	1510	29

<sup>1</sup>River mile, sampled on the Yakima River or where tributary or WWTP discharges to the Yakima River.

<sup>2</sup>Cherry Creek discharges to Wilson Creek at RM 1.1.

<sup>3</sup>Pacific Power and Light Wasteway discharges to the Naches River at RM 9.7 (sample collected on tributary to Naches River).

<sup>4</sup>Non-Lagrangian sample.

<sup>5</sup>Sunnyside WWTP discharges to DID, which discharges to Sulphur Creek.

**APPENDIX A8. Iron concentrations detected at intensive fixed sites, 1999–2000, Yakima River Basin, Washington**

RM, river mile; Rd, road; E, estimated value; <, less than; ---, no data; µg/L, micrograms per liter]

Map identification	USGS station number	Site name	RM	Site type	Date	Time	Concentration (µg/L)
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990518	1700	E7.8
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990602	1030	---
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990616	0900	E9.5
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990701	0920	---
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990714	0940	<10
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990727	1130	---
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990803	0740	17
13	12500420	Moxee Drain at Birchfield Rd <sup>1</sup>	107.3	tributary	19990803	1940	14
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990825	1000	---
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990909	1030	E8.4
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990922	1100	---
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991020	1150	E7.0
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991116	1140	<10
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991208	1030	<10
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	20000111	1130	E6.1
20	12505450	Granger Drain at Granger	82.8	tributary	19990520	1210	11
20	12505450	Granger Drain at Granger	82.8	tributary	19990603	0920	---
20	12505450	Granger Drain at Granger	82.8	tributary	19990615	1320	16
20	12505450	Granger Drain at Granger	82.8	tributary	19990701	1430	---
20	12505450	Granger Drain at Granger	82.8	tributary	19990715	0940	12
20	12505450	Granger Drain at Granger	82.8	tributary	19990728	1130	16
20	12505450	Granger Drain at Granger	82.8	tributary	19990803	1730	16
20	12505450	Granger Drain at Granger	82.8	tributary	19990804	0740	20
20	12505450	Granger Drain at Granger	82.8	tributary	19990826	0930	---
20	12505450	Granger Drain at Granger	82.8	tributary	19990910	0930	16
20	12505450	Granger Drain at Granger	82.8	tributary	19990923	0910	---
20	12505450	Granger Drain at Granger	82.8	tributary	19991021	0950	11
20	12505450	Granger Drain at Granger	82.8	tributary	19991117	1000	<10
20	12505450	Granger Drain at Granger	82.8	tributary	19991209	1020	E5.0
20	12505450	Granger Drain at Granger	82.8	tributary	20000112	1010	E5.8
34	12510500	Yakima River at Kiona	29.9	main stem	19990519	1650	20
34	12510500	Yakima River at Kiona	29.9	main stem	19990609	1220	---
34	12510500	Yakima River at Kiona	29.9	main stem	19990617	1040	13
34	12510500	Yakima River at Kiona	29.9	main stem	19990630	1020	---
34	12510500	Yakima River at Kiona	29.9	main stem	19990713	1120	42
34	12510500	Yakima River at Kiona	29.9	main stem	19990729	1000	---
34	12510500	Yakima River at Kiona	29.9	main stem	19990805	1740	11
34	12510500	Yakima River at Kiona	29.9	main stem	19990806	1030	13
34	12510500	Yakima River at Kiona <sup>1</sup>	29.9	main stem	19990806	1510	29
34	12510500	Yakima River at Kiona	29.9	main stem	19990824	1120	---
34	12510500	Yakima River at Kiona	29.9	main stem	19990831	1150	11
34	12510500	Yakima River at Kiona	29.9	main stem	19990921	1210	---
34	12510500	Yakima River at Kiona	29.9	main stem	19991019	1140	17
34	12510500	Yakima River at Kiona	29.9	main stem	19991118	1200	15
34	12510500	Yakima River at Kiona	29.9	main stem	19991207	1100	11
34	12510500	Yakima River at Kiona	29.9	main stem	20000113	1140	13

<sup>1</sup>Multiple samples collected within a day or week.

**APPENDIX A9. Manganese concentrations detected during basinwide Lagrangian sampling, August 1999, Yakima River Basin, Washington**

[RM, river mile; wwtp, wastewater treatment plant; abv, above; Cr, Creek; WW, wasteway; nr, near; Rd, road; <, less than; µg/L, micrograms per liter]

Map identification	USGS station number	Site name	RM <sup>1</sup>	Site type	Date	Time	Concentration (µg/L)
1	12479500	Yakima River at Cle Elum	182.5	main stem	19990802	1300	1.2
2	4711211205434	Cle Elum WWTP	179.6	wwtp	19990802	0800	<1.0
3	4657481203252	Ellensburg WWTP	151.6	wwtp	19990802	1630	10
4	12484100	Wilson Creek abv Cherry Creek	147	tributary	19990802	1750	14
5	12484480	Cherry Creek at Thrall <sup>2</sup>	147	tributary	19990802	1700	7.8
6	12484500	Yakima River at Umtanum	140.4	main stem	19990802	1840	3.8
7	12484550	Umtanum Creek at Umtanum	139.8	tributary	19990802	1740	4.1
8	4638561203130	Selah WWTP	117	wwtp	19990803	0720	<1.0
9	12496510	Pacific Power and Light WW <sup>3</sup>	116.3	tributary	19990803	0650	1.6
10	12499000	Naches River nr North Yakima	116.3	tributary	19990803	0900	2.9
11	4634471202752	Yakima WWTP	111	wwtp	19990803	0710	6.5
12	12500445	Wide Hollow Cr at Union Gap	107.4	tributary	19990803	1220	2.3
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990803	0740	4.9
13	12500420	Moxee Drain at Birchfield Rd <sup>4</sup>	107.3	tributary	19990803	1940	7.6
14	12500450	Yakima River at Union Gap	107.3	main stem	19990803	1030	6.3
15	12502500	Ahtanum Cr at Union Gap	106.9	tributary	19990803	1420	14
16	4623571201532	Zillah WWTP	89.5	wwtp	19990803	1600	9.2
17	12505350	East Toppenish Drain at Wilson Rd	86	tributary	19990803	1840	12
18	12505410	Sub 35 Drain at Parton Rd	83.2	tributary	19990803	1740	13
19	4620131201137	Granger WWTP	82.8	wwtp	19990804	0900	36
20	12505450	Granger Drain at Granger <sup>4</sup>	82.8	tributary	19990803	1730	25
20	12505450	Granger Drain at Granger	82.8	tributary	19990804	0740	33
21	12505510	Marion Drain at Granger	82.6	tributary	19990804	0820	9.5
22	12507508	Toppenish Cr nr Granger	80.4	tributary	19990804	0840	15
23	12507585	Yakima River at RM 72	72	main stem	19990804	1230	22
24	12507595	Satus Creek abv Shinado Creek	69.6	tributary	19990803	1340	1.6
25	12508500	Satus Creek below Dry Creek	69.6	tributary	19990804	0950	6.3
26	12508620	Satus Creek at Satus	69.6	tributary	19990804	1500	34
27	12508630	South Drain near Satus	69.3	tributary	19990804	1750	38
27	12508630	South Drain near Satus <sup>4</sup>	69.3	tributary	19990805	1050	47
28	4618501200058	Sunnyside WWTP <sup>5</sup>	61	wwtp	19990804	1530	34
29	12508850	Sulphur Creek Wasteway	61	tributary	19990804	1810	11
29	12508850	Sulphur Creek Wasteway <sup>4</sup>	61	tributary	19990805	1420	16
30	12509050	Yakima River at Euclid Bridge	55	main stem	19990805	0920	18
31	4612461194547	Prosser WWTP	47	wwtp	19990805	1130	<1.0
32	4614041194104	Spring Creek at Hess Rd	41.8	tributary	19990805	1740	4.4
33	4614141194042	Snipes Creek below Chandler Canal	41.8	tributary	19990805	1610	2.5
34	12510500	Yakima River at Kiona <sup>4</sup>	29.9	main stem	19990805	1740	1.3
34	12510500	Yakima River at Kiona	29.9	main stem	19990806	1030	1.9
34	12510500	Yakima River at Kiona <sup>4</sup>	29.9	main stem	19990806	1510	2.9

<sup>1</sup>River mile, sampled on the Yakima River or where tributary or WWTP discharges to the Yakima River.

<sup>2</sup>Cherry Creek discharges to Wilson Creek at RM 1.1.

<sup>3</sup>Pacific Power and Light Wasteway discharges to the Naches River at RM 9.7 (sample collected on tributary to Naches River).

<sup>4</sup>Non-Lagrangian sample.

<sup>5</sup>Sunnyside WWTP discharges to DID, which discharges to Sulphur Creek.

**APPENDIX A10.** Manganese concentrations detected at intensive fixed sites, 1999–2000, Yakima River Basin, Washington

[RM, river mile; Rd, road; <, less than; µg/L, micrograms per liter]

Map identification	USGS station number	Site name	RM	Site type	Date	Time	Concentration (µg/L)
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990518	1700	7.7
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990602	1030	9.6
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990616	0900	8.2
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990701	0920	6.5
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990714	0940	4.0
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990727	1130	6.5
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990803	0740	4.9
13	12500420	Moxee Drain at Birchfield Rd <sup>1</sup>	107.3	tributary	19990803	1940	7.6
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990825	1000	5.3
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990909	1030	5.5
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990922	1100	5.1
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991020	1150	12
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991116	1140	14
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991208	1030	16
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	20000111	1130	13
20	12505450	Granger Drain at Granger	82.8	tributary	19990520	1210	22
20	12505450	Granger Drain at Granger	82.8	tributary	19990603	0920	28
20	12505450	Granger Drain at Granger	82.8	tributary	19990615	1320	19
20	12505450	Granger Drain at Granger	82.8	tributary	19990701	1430	19
20	12505450	Granger Drain at Granger	82.8	tributary	19990715	0940	21
20	12505450	Granger Drain at Granger	82.8	tributary	19990728	1130	30
20	12505450	Granger Drain at Granger	82.8	tributary	19990803	1730	25
20	12505450	Granger Drain at Granger	82.8	tributary	19990804	0740	33
20	12505450	Granger Drain at Granger	82.8	tributary	19990826	0930	21
20	12505450	Granger Drain at Granger	82.8	tributary	19990910	0930	22
20	12505450	Granger Drain at Granger	82.8	tributary	19990923	0910	24
20	12505450	Granger Drain at Granger	82.8	tributary	19991021	0950	43
20	12505450	Granger Drain at Granger	82.8	tributary	19991117	1000	75
20	12505450	Granger Drain at Granger	82.8	tributary	19991209	1020	58
20	12505450	Granger Drain at Granger	82.8	tributary	20000112	1010	62
34	12510500	Yakima River at Kiona	29.9	main stem	19990519	1650	6.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990609	1220	5.6
34	12510500	Yakima River at Kiona	29.9	main stem	19990617	1040	1.6
34	12510500	Yakima River at Kiona	29.9	main stem	19990630	1020	2.6
34	12510500	Yakima River at Kiona	29.9	main stem	19990713	1120	2.3
34	12510500	Yakima River at Kiona	29.9	main stem	19990729	1000	2.5
34	12510500	Yakima River at Kiona	29.9	main stem	19990805	1740	1.3
34	12510500	Yakima River at Kiona	29.9	main stem	19990806	1030	1.9
34	12510500	Yakima River at Kiona <sup>1</sup>	29.9	main stem	19990806	1510	2.9
34	12510500	Yakima River at Kiona	29.9	main stem	19990824	1120	2.2
34	12510500	Yakima River at Kiona	29.9	main stem	19990831	1150	3.4
34	12510500	Yakima River at Kiona	29.9	main stem	19990921	1210	3.8
34	12510500	Yakima River at Kiona	29.9	main stem	19991019	1140	9.1
34	12510500	Yakima River at Kiona	29.9	main stem	19991118	1200	3.5
34	12510500	Yakima River at Kiona	29.9	main stem	19991207	1100	3.4
34	12510500	Yakima River at Kiona	29.9	main stem	20000113	1140	8.5

<sup>1</sup>Multiple samples collected within a day or week.

**APPENDIX A11.** Barium concentrations detected during basinwide Lagrangian sampling, August 1999, Yakima River Basin, Washington  
 [RM, river mile; wwtp, wastewater treatment plant; abv, above; Cr, Creek; WW, wasteway; nr, near; Rd, road; <, less than; µg/L, micrograms per liter]

Map identification	USGS station number	Site name	RM <sup>1</sup>	Site type	Date	Time	Concentration (µg/L)
1	12479500	Yakima River at Cle Elum	182.5	main stem	19990802	1300	2.6
2	4711211205434	Cle Elum WWTP	179.6	wwtp	19990802	0800	10
3	4657481203252	Ellensburg WWTP	151.6	wwtp	19990802	1630	10
4	12484100	Wilson Creek abv Cherry Creek	147	tributary	19990802	1750	15
5	12484480	Cherry Creek at Thrall <sup>2</sup>	147	tributary	19990802	1700	50
6	12484500	Yakima River at Umtanum	140.4	main stem	19990802	1840	7.8
7	12484550	Umtanum Creek at Umtanum	139.8	tributary	19990802	1740	21
8	4638561203130	Selah WWTP	117	wwtp	19990803	0720	34
9	12496510	Pacific Power and Light WW <sup>3</sup>	116.3	tributary	19990803	0650	1.6
10	12499000	Naches River nr North Yakima	116.3	tributary	19990803	0900	2.7
11	4634471202752	Yakima WWTP	111	wwtp	19990803	0710	5.4
12	12500445	Wide Hollow Cr at Union Gap	107.4	tributary	19990803	1220	21
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990803	0740	21
13	12500420	Moxee Drain at Birchfield Rd <sup>4</sup>	107.3	tributary	19990803	1940	21
14	12500450	Yakima River at Union Gap	107.3	main stem	19990803	1030	5.7
15	12502500	Ahtanum Cr at Union Gap	106.9	tributary	19990803	1420	17
16	4623571201532	Zillah WWTP	89.5	wwtp	19990803	1600	96
17	12505350	East Toppenish Drain at Wilson Rd	86	tributary	19990803	1840	10
18	12505410	Sub 35 Drain at Parton Rd	83.2	tributary	19990803	1740	11
19	4620131201137	Granger WWTP	82.8	wwtp	19990804	0900	15
20	12505450	Granger Drain at Granger <sup>4</sup>	82.8	tributary	19990803	1730	47
20	12505450	Granger Drain at Granger	82.8	tributary	19990804	0740	44
21	12505510	Marion Drain at Granger	82.6	tributary	19990804	0820	13
22	12507508	Toppenish Cr nr Granger	80.4	tributary	19990804	0840	13
23	12507585	Yakima River at RM 72	72	main stem	19990804	1230	12
24	12507595	Satus Creek abv Shinado Creek	69.6	tributary	19990803	1340	2.4
25	12508500	Satus Creek below Dry Creek	69.6	tributary	19990804	0950	6.2
26	12508620	Satus Creek at Satus	69.6	tributary	19990804	1500	16
27	12508630	South Drain near Satus	69.3	tributary	19990804	1750	40
27	12508630	South Drain near Satus <sup>4</sup>	69.3	tributary	19990805	1050	39
28	4618501200058	Sunnyside WWTP <sup>5</sup>	61	wwtp	19990804	1530	19
29	12508850	Sulphur Creek Wasteway	61	tributary	19990804	1810	32
29	12508850	Sulphur Creek Wasteway <sup>4</sup>	61	tributary	19990805	1420	31
30	12509050	Yakima River at Euclid Bridge	55	main stem	19990805	0920	19
31	4612461194547	Prosser WWTP	47	wwtp	19990805	1130	10
32	4614041194104	Spring Creek at Hess Rd	41.8	tributary	19990805	1740	20
33	4614141194042	Snipes Creek below Chandler Canal	41.8	tributary	19990805	1610	25
34	12510500	Yakima River at Kiona <sup>4</sup>	29.9	main stem	19990805	1740	20
34	12510500	Yakima River at Kiona	29.9	main stem	19990806	1030	21
34	12510500	Yakima River at Kiona <sup>4</sup>	29.9	main stem	19990806	1510	20

<sup>1</sup>River mile, sampled on the Yakima River or where tributary or WWTP discharges to the Yakima River.

<sup>2</sup>Cherry Creek discharges to Wilson Creek at RM 1.1.

<sup>3</sup>Pacific Power and Light Wasteway discharges to the Naches River at RM 9.7 (sample collected on tributary to Naches River).

<sup>4</sup>Non-Lagrangian sample.

<sup>5</sup>Sunnyside WWTP discharges to DID, which discharges to Sulphur Creek.

**APPENDIX A12.** Barium concentrations detected at intensive fixed sites, 1999–2000, Yakima River Basin, Washington

[RM, river mile; Rd, road; E, estimated value; <, less than; µg/L, micrograms per liter]

Map identification	USGS station number	Site name	RM	Site type	Date	Time	Concentration (µg/L)
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990518	1700	19
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990602	1030	20
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990616	0900	18
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990701	0920	22
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990714	0940	17
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990727	1130	21
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990803	0740	21
13	12500420	Moxee Drain at Birchfield Rd <sup>1</sup>	107.3	tributary	19990803	1940	21
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990825	1000	23
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990909	1030	24
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990922	1100	24
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991020	1150	36
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991116	1140	62
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991208	1030	62
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	20000111	1130	59
20	12505450	Granger Drain at Granger	82.8	tributary	19990520	1210	42
20	12505450	Granger Drain at Granger	82.8	tributary	19990603	0920	37
20	12505450	Granger Drain at Granger	82.8	tributary	19990615	1320	37
20	12505450	Granger Drain at Granger	82.8	tributary	19990701	1430	44
20	12505450	Granger Drain at Granger	82.8	tributary	19990715	0940	39
20	12505450	Granger Drain at Granger	82.8	tributary	19990728	1130	44
20	12505450	Granger Drain at Granger	82.8	tributary	19990803	1730	47
20	12505450	Granger Drain at Granger	82.8	tributary	19990804	0740	44
20	12505450	Granger Drain at Granger	82.8	tributary	19990826	0930	42
20	12505450	Granger Drain at Granger	82.8	tributary	19990910	0930	42
20	12505450	Granger Drain at Granger	82.8	tributary	19990923	0910	47
20	12505450	Granger Drain at Granger	82.8	tributary	19991021	0950	55
20	12505450	Granger Drain at Granger	82.8	tributary	19991117	1000	89
20	12505450	Granger Drain at Granger	82.8	tributary	19991209	1020	87
20	12505450	Granger Drain at Granger	82.8	tributary	20000112	1010	81
34	12510500	Yakima River at Kiona	29.9	main stem	19990519	1650	11
34	12510500	Yakima River at Kiona	29.9	main stem	19990609	1220	8.6
34	12510500	Yakima River at Kiona	29.9	main stem	19990617	1040	6.5
34	12510500	Yakima River at Kiona	29.9	main stem	19990630	1020	7.2
34	12510500	Yakima River at Kiona	29.9	main stem	19990713	1120	9.6
34	12510500	Yakima River at Kiona	29.9	main stem	19990729	1000	14
34	12510500	Yakima River at Kiona	29.9	main stem	19990805	1740	20
34	12510500	Yakima River at Kiona	29.9	main stem	19990806	1030	21
34	12510500	Yakima River at Kiona <sup>1</sup>	29.9	main stem	19990806	1510	20
34	12510500	Yakima River at Kiona	29.9	main stem	19990824	1120	20
34	12510500	Yakima River at Kiona	29.9	main stem	19990831	1150	20
34	12510500	Yakima River at Kiona	29.9	main stem	19990921	1210	21
34	12510500	Yakima River at Kiona	29.9	main stem	19991019	1140	19
34	12510500	Yakima River at Kiona	29.9	main stem	19991118	1200	12
34	12510500	Yakima River at Kiona	29.9	main stem	19991207	1100	8
34	12510500	Yakima River at Kiona	29.9	main stem	20000113	1140	12

<sup>1</sup>Multiple samples collected within a day or week.

**APPENDIX A13.** Copper concentrations detected during basinwide Lagrangian sampling, August 1999, Yakima River Basin, Washington

[RM, river mile; wwtp, wastewater treatment plant; abv, above; Cr, Creek; WW, wasteway; nr, near; Rd, road; <, less than; µg/L, micrograms per liter]

Map identification	USGS station number	Site name	RM <sup>1</sup>	Site type	Date	Time	Concentration (µg/L)
1	12479500	Yakima River at Cle Elum	182.5	main stem	19990802	1300	<1.0
2	4711211205434	Cle Elum WWTP	179.6	wwtp	19990802	0800	3.6
3	4657481203252	Ellensburg WWTP	151.6	wwtp	19990802	1630	3.2
4	12484100	Wilson Creek abv Cherry Creek	147	tributary	19990802	1750	1.3
5	12484480	Cherry Creek at Thrall <sup>2</sup>	147	tributary	19990802	1700	2.0
6	12484500	Yakima River at Umtanum	140.4	main stem	19990802	1840	<1.0
7	12484550	Umtanum Creek at Umtanum	139.8	tributary	19990802	1740	2.6
8	4638561203130	Selah WWTP	117	wwtp	19990803	0720	2.9
9	12496510	Pacific Power and Light WW <sup>3</sup>	116.3	tributary	19990803	0650	<1.0
10	12499000	Naches River nr North Yakima	116.3	tributary	19990803	0900	<1.0
11	4634471202752	Yakima WWTP	111	wwtp	19990803	0710	5.8
12	12500445	Wide Hollow Cr at Union Gap	107.4	tributary	19990803	1220	1.1
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990803	0740	2.1
13	12500420	Moxee Drain at Birchfield Rd <sup>4</sup>	107.3	tributary	19990803	1940	1.6
14	12500450	Yakima River at Union Gap	107.3	main stem	19990803	1030	<1.0
15	12502500	Ahtanum Cr at Union Gap	106.9	tributary	19990803	1420	1.6
16	4623571201532	Zillah WWTP	89.5	wwtp	19990803	1600	9.1
17	12505350	East Toppenish Drain at Wilson Rd	86	tributary	19990803	1840	1.1
18	12505410	Sub 35 Drain at Parton Rd	83.2	tributary	19990803	1740	<1.0
19	4620131201137	Granger WWTP	82.8	wwtp	19990804	0900	1.1
20	12505450	Granger Drain at Granger <sup>4</sup>	82.8	tributary	19990803	1730	1.7
20	12505450	Granger Drain at Granger	82.8	tributary	19990804	0740	1.2
21	12505510	Marion Drain at Granger	82.6	tributary	19990804	0820	<1.0
22	12507508	Toppenish Cr nr Granger	80.4	tributary	19990804	0840	<1.0
23	12507585	Yakima River at RM 72	72	main stem	19990804	1230	<1.0
24	12507595	Satus Creek abv Shinado Creek	69.6	tributary	19990803	1340	<1.0
25	12508500	Satus Creek below Dry Creek	69.6	tributary	19990804	950	<1.0
26	12508620	Satus Creek at Satus	69.6	tributary	19990804	1500	<1.0
27	12508630	South Drain near Satus	69.3	tributary	19990804	1750	1.7
27	12508630	South Drain near Satus <sup>4</sup>	69.3	tributary	19990805	1050	1.5
28	4618501200058	Sunnyside WWTP <sup>5</sup>	61	wwtp	19990804	1530	4.1
29	12508850	Sulphur Creek Wasteway	61	tributary	19990804	1810	1.2
29	12508850	Sulphur Creek Wasteway <sup>4</sup>	61	tributary	19990805	1420	1.1
30	12509050	Yakima River at Euclid Bridge	55	main stem	19990805	0920	<1.0
31	4612461194547	Prosser WWTP	47	wwtp	19990805	1130	3.9
32	4614041194104	Spring Creek at Hess Rd	41.8	tributary	19990805	1740	1.1
33	4614141194042	Snipes Creek below Chandler Canal	41.8	tributary	19990805	1610	1.1
34	12510500	Yakima River at Kiona <sup>4</sup>	29.9	main stem	19990805	1740	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990806	1030	<1.0
34	12510500	Yakima River at Kiona <sup>4</sup>	29.9	main stem	19990806	1510	1.0

<sup>1</sup>River mile, sampled on the Yakima River or where tributary or WWTP discharges to the Yakima River.

<sup>2</sup>Cherry Creek discharges to Wilson Creek at RM 1.1.

<sup>3</sup>Pacific Power and Light Wasteway discharges to the Naches River at RM 9.7 (sample collected on tributary to Naches River).

<sup>4</sup>Non-Lagrangian sample.

<sup>5</sup>Sunnyside WWTP discharges to DID, which discharges to Sulphur Creek.

**APPENDIX A14.** Copper concentrations detected at intensive fixed sites, 1999–2000, Yakima River Basin, Washington

[RM, river mile; Rd, road; <, less than; µg/L, micrograms per liter]

Map identification	USGS station number	Site name	RM <sup>1</sup>	Site type	Date	Time	Concentration (µg/L)
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990518	1700	1.4
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990602	1030	1.1
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990616	0900	2.3
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990701	0920	1.7
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990714	0940	1.9
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990727	1130	9.5
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990803	0740	2.1
13	12500420	Moxee Drain at Birchfield Rd <sup>1</sup>	107.3	tributary	19990803	1940	1.6
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990825	1000	1.8
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990909	1030	1.6
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990922	1100	1.5
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991020	1150	1.2
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991116	1140	1.5
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991208	1030	1.5
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	20000111	1130	1.7
20	12505450	Granger Drain at Granger	82.8	tributary	19990520	1210	1.3
20	12505450	Granger Drain at Granger	82.8	tributary	19990603	0920	1.2
20	12505450	Granger Drain at Granger	82.8	tributary	19990615	1320	1.5
20	12505450	Granger Drain at Granger	82.8	tributary	19990701	1430	1.6
20	12505450	Granger Drain at Granger	82.8	tributary	19990715	0940	1.1
20	12505450	Granger Drain at Granger	82.8	tributary	19990728	1130	1.5
20	12505450	Granger Drain at Granger	82.8	tributary	19990803	1730	1.7
20	12505450	Granger Drain at Granger	82.8	tributary	19990804	0740	1.2
20	12505450	Granger Drain at Granger	82.8	tributary	19990826	0930	1.3
20	12505450	Granger Drain at Granger	82.8	tributary	19990910	0930	1.3
20	12505450	Granger Drain at Granger	82.8	tributary	19990923	0910	1.4
20	12505450	Granger Drain at Granger	82.8	tributary	19991021	0950	1.3
20	12505450	Granger Drain at Granger	82.8	tributary	19991117	1000	1.2
20	12505450	Granger Drain at Granger	82.8	tributary	19991209	1020	1.2
20	12505450	Granger Drain at Granger	82.8	tributary	20000112	1010	1.4
34	12510500	Yakima River at Kiona	29.9	main stem	19990519	1650	1.5
34	12510500	Yakima River at Kiona	29.9	main stem	19990609	1220	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990617	1040	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990630	1020	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990713	1120	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990729	1000	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990805	1740	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990806	1030	<1.0
34	12510500	Yakima River at Kiona <sup>1</sup>	29.9	main stem	19990806	1510	1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990824	1120	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990831	1150	1.4
34	12510500	Yakima River at Kiona	29.9	main stem	19990921	1210	1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19991019	1140	1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19991118	1200	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19991207	1100	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	20000113	1140	<1.0

<sup>1</sup>Multiple samples collected within a day or week.

**APPENDIX A15.** Nickel concentrations detected during basinwide Lagrangian sampling, August 1999, Yakima River Basin, Washington

[RM, river mile; wwtp, wastewater treatment plant; abv, above; Cr, Creek; WW, wasteway; nr, near; Rd, road; <, less than; µg/L, micrograms per liter]

Map identification	USGS station number	Site name	RM <sup>1</sup>	Site type	Date	Time	Concentration (µg/L)
1	12479500	Yakima River at Cle Elum	182.5	main stem	19990802	1300	1.6
2	4711211205434	Cle Elum WWTP	179.6	wwtp	19990802	0800	2.4
3	4657481203252	Ellensburg WWTP	151.6	wwtp	19990802	1630	1.8
4	12484100	Wilson Creek abv Cherry Creek	147	tributary	19990802	1750	1.8
5	12484480	Cherry Creek at Thrall <sup>2</sup>	147	tributary	19990802	1700	1.7
6	12484500	Yakima River at Umtanum	140.4	main stem	19990802	1840	1.2
7	12484550	Umtanum Creek at Umtanum	139.8	tributary	19990802	1740	<1.0
8	4638561203130	Selah WWTP	117	wwtp	19990803	0720	2.3
9	12496510	Pacific Power and Light WW <sup>3</sup>	116.3	tributary	19990803	0650	<1.0
10	12499000	Naches River nr North Yakima	116.3	tributary	19990803	0900	<1.0
11	4634471202752	Yakima WWTP	111	wwtp	19990803	0710	1.7
12	12500445	Wide Hollow Cr at Union Gap	107.4	tributary	19990803	1220	1.0
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990803	0740	1.1
13	12500420	Moxee Drain at Birchfield Rd <sup>4</sup>	107.3	tributary	19990803	1940	1.1
14	12500450	Yakima River at Union Gap	107.3	main stem	19990803	1030	<1.0
15	12502500	Ahtanum Cr at Union Gap	106.9	tributary	19990803	1420	<1.0
16	4623571201532	Zillah WWTP	89.5	wwtp	19990803	1600	3.4
17	12505350	East Toppenish Drain at Wilson Rd	86	tributary	19990803	1840	1.2
18	12505410	Sub 35 Drain at Parton Rd	83.2	tributary	19990803	1740	1.2
19	4620131201137	Granger WWTP	82.8	wwtp	19990804	0900	1.3
20	12505450	Granger Drain at Granger <sup>4</sup>	82.8	tributary	19990803	1730	1.4
20	12505450	Granger Drain at Granger	82.8	tributary	19990804	0740	1.4
21	12505510	Marion Drain at Granger	82.6	tributary	19990804	0820	1.3
22	12507508	Toppenish Cr nr Granger	80.4	tributary	19990804	0840	1.2
23	12507585	Yakima River at RM 72	72	main stem	19990804	1230	1.1
24	12507595	Satus Creek abv Shinado Creek	69.6	tributary	19990803	1340	<1.0
25	12508500	Satus Creek below Dry Creek	69.6	tributary	19990804	0950	<1.0
26	12508620	Satus Creek at Satus	69.6	tributary	19990804	1500	1.2
27	12508630	South Drain near Satus	69.3	tributary	19990804	1750	1.8
27	12508630	South Drain near Satus <sup>4</sup>	69.3	tributary	19990805	1050	1.8
28	4618501200058	Sunnyside WWTP <sup>5</sup>	61	wwtp	19990804	1530	2.4
29	12508850	Sulphur Creek Wasteway	61	tributary	19990804	1810	1.4
29	12508850	Sulphur Creek Wasteway <sup>4</sup>	61	tributary	19990805	1420	1.2
30	12509050	Yakima River at Euclid Bridge	55	main stem	19990805	0920	1.1
31	4612461194547	Prosser WWTP	47	wwtp	19990805	1130	1.7
32	4614041194104	Spring Creek at Hess Rd	41.8	tributary	19990805	1740	<1.0
33	4614141194042	Snipes Creek below Chandler Canal	41.8	tributary	19990805	1610	1.2
34	12510500	Yakima River at Kiona <sup>4</sup>	29.9	main stem	19990805	1740	1.3
34	12510500	Yakima River at Kiona	29.9	main stem	19990806	1030	1.1
34	12510500	Yakima River at Kiona <sup>4</sup>	29.9	main stem	19990806	1510	1.2

<sup>1</sup>River mile, sampled on the Yakima River or where tributary or WWTP discharges to the Yakima River.

<sup>2</sup>Cherry Creek discharges to Wilson Creek at RM 1.1.

<sup>3</sup>Pacific Power and Light Wasteway discharges to the Naches River at RM 9.7 (sample collected on tributary to Naches River).

<sup>4</sup>Non-Lagrangian sample.

<sup>5</sup>Sunnyside WWTP discharges to DID, which discharges to Sulphur Creek.

**APPENDIX A16.** Nickel concentrations detected at intensive fixed sites, 1999–2000, Yakima River Basin, Washington

[RM, river mile; Rd, road; <, less than; µg/L, micrograms per liter]

Map identification	USGS station number	Site name	RM	Site type	Date	Time	Concentration (µg/L)
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990518	1700	1.1
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990602	1030	<1.0
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990616	0900	<1.0
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990701	0920	<1.0
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990714	0940	<1.0
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990727	1130	<1.0
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990803	0740	1.1
13	12500420	Moxee Drain at Birchfield Rd <sup>1</sup>	107.3	tributary	19990803	1940	1.1
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990825	1000	1.3
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990909	1030	1.1
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990922	1100	<1.0
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991020	1150	1.3
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991116	1140	1.1
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991208	1030	1.1
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	20000111	1130	4.1
20	12505450	Granger Drain at Granger	82.8	tributary	19990520	1210	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19990603	0920	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19990615	1320	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19990701	1430	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19990715	0940	1.1
20	12505450	Granger Drain at Granger	82.8	tributary	19990728	1130	1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19990803	1730	1.4
20	12505450	Granger Drain at Granger	82.8	tributary	19990804	0740	1.4
20	12505450	Granger Drain at Granger	82.8	tributary	19990826	0930	1.2
20	12505450	Granger Drain at Granger	82.8	tributary	19990910	0930	1.3
20	12505450	Granger Drain at Granger	82.8	tributary	19990923	0910	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19991021	0950	1.4
20	12505450	Granger Drain at Granger	82.8	tributary	19991117	1000	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19991209	1020	1.1
20	12505450	Granger Drain at Granger	82.8	tributary	20000112	1010	4.2
34	12510500	Yakima River at Kiona	29.9	main stem	19990519	1650	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990609	1220	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990617	1040	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990630	1020	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990713	1120	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990729	1000	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990805	1740	1.3
34	12510500	Yakima River at Kiona	29.9	main stem	19990806	1030	1.1
34	12510500	Yakima River at Kiona <sup>1</sup>	29.9	main stem	19990806	1510	1.2
34	12510500	Yakima River at Kiona	29.9	main stem	19990824	1120	1.2
34	12510500	Yakima River at Kiona	29.9	main stem	19990831	1150	1.2
34	12510500	Yakima River at Kiona	29.9	main stem	19990921	1210	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19991019	1140	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19991118	1200	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19991207	1100	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	20000113	1140	<1.0

<sup>1</sup>Multiple samples collected within a day or week.

**APPENDIX A17.** Zinc concentrations detected during basinwide Lagrangian sampling, August 1999, Yakima River Basin, Washington

[RM, river mile; wwtp, wastewater treatment plant; abv, above; Cr, Creek; WW, wasteway; nr, near; Rd, road; <, less than; µg/L, micrograms per liter]

Map identification	USGS station number	Site name	RM <sup>1</sup>	Site type	Date	Time	Concentration (µg/L)
1	12479500	Yakima River at Cle Elum	182.5	main stem	19990802	1300	<1.0
2	4711211205434	Cle Elum WWTP	179.6	wwtp	19990802	0800	9.2
3	4657481203252	Ellensburg WWTP	151.6	wwtp	19990802	1630	19
4	12484100	Wilson Creek abv Cherry Creek	147	tributary	19990802	1750	<1.0
5	12484480	Cherry Creek at Thrall <sup>2</sup>	147	tributary	19990802	1700	1.5
6	12484500	Yakima River at Umtanum	140.4	main stem	19990802	1840	<1.0
7	12484550	Umtanum Creek at Umtanum	139.8	tributary	19990802	1740	<1.0
8	4638561203130	Selah WWTP	117	wwtp	19990803	0720	51
9	12496510	Pacific Power and Light WW <sup>3</sup>	116.3	tributary	19990803	0650	<1.0
10	12499000	Naches River nr North Yakima	116.3	tributary	19990803	0900	<1.0
11	4634471202752	Yakima WWTP	111	wwtp	19990803	0710	42
12	12500445	Wide Hollow Cr at Union Gap	107.4	tributary	19990803	1220	1.2
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990803	0740	<1.0
13	12500420	Moxee Drain at Birchfield Rd <sup>4</sup>	107.3	tributary	19990803	1940	<1.0
14	12500450	Yakima River at Union Gap	107.3	main stem	19990803	1030	<1.0
15	12502500	Ahtanum Cr at Union Gap	106.9	tributary	19990803	1420	<1.0
16	4623571201532	Zillah WWTP	89.5	wwtp	19990803	1600	78
17	12505350	East Toppenish Drain at Wilson Rd	86	tributary	19990803	1840	1.0
18	12505410	Sub 35 Drain at Parton Rd	83.2	tributary	19990803	1740	<1.0
19	4620131201137	Granger WWTP	82.8	wwtp	19990804	0900	17
20	12505450	Granger Drain at Granger <sup>4</sup>	82.8	tributary	19990803	1730	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19990804	0740	<1.0
21	12505510	Marion Drain at Granger	82.6	tributary	19990804	0820	<1.0
22	12507508	Toppenish Cr nr Granger	80.4	tributary	19990804	0840	<1.0
23	12507585	Yakima River at RM 72	72	main stem	19990804	1230	1.3
24	12507595	Satus Creek abv Shinado Creek	69.6	tributary	19990803	1340	<1.0
25	12508500	Satus Creek below Dry Creek	69.6	tributary	19990804	0950	<1.0
26	12508620	Satus Creek at Satus	69.6	tributary	19990804	1500	<1.0
27	12508630	South Drain near Satus	69.3	tributary	19990804	1750	<1.0
27	12508630	South Drain near Satus <sup>4</sup>	69.3	tributary	19990805	1050	<1.0
28	4618501200058	Sunnyside WWTP <sup>5</sup>	61	wwtp	19990804	1530	19
29	12508850	Sulphur Creek Wasteway	61	tributary	19990804	1810	<1.0
29	12508850	Sulphur Creek Wasteway <sup>4</sup>	61	tributary	19990805	1420	<1.0
30	12509050	Yakima River at Euclid Bridge	55	main stem	19990805	0920	<1.0
31	4612461194547	Prosser WWTP	47	wwtp	19990805	1130	28
32	4614041194104	Spring Creek at Hess Rd	41.8	tributary	19990805	1740	1.1
33	4614141194042	Snipes Creek below Chandler Canal	41.8	tributary	19990805	1610	<1.0
34	12510500	Yakima River at Kiona <sup>4</sup>	29.9	main stem	19990805	1740	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990806	1030	<1.0
34	12510500	Yakima River at Kiona <sup>4</sup>	29.9	main stem	19990806	1510	<1.0

<sup>1</sup>River mile, sampled on the Yakima River or where tributary or WWTP discharges to the Yakima River.

<sup>2</sup>Cherry Creek discharges to Wilson Creek at RM 1.1.

<sup>3</sup>Pacific Power and Light Wasteway discharges to the Naches River at RM 9.7 (sample collected on tributary to Naches River).

<sup>4</sup>Non-Lagrangian sample.

<sup>5</sup>Sunnyside WWTP discharges to DID, which discharges to Sulphur Creek.

**APPENDIX A18.** Zinc concentrations detected at intensive fixed sites, 1999–2000, Yakima River Basin, Washington

[RM, river mile; Rd, road; <, less than; mg/L, micrograms per liter]

Map identification	USGS station number	Site name	RM	Site type	Date	Time	Concentration (µg/L)
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990518	1700	1.6
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990602	1030	1.3
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990616	0900	<1.0
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990701	0920	1.1
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990714	0940	1.6
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990727	1130	1.1
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990803	0740	<1.0
13	12500420	Moxee Drain at Birchfield Rd <sup>1</sup>	107.3	tributary	19990803	1940	<1.0
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990825	1000	1.3
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990909	1030	1.4
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19990922	1100	1.0
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991020	1150	1.4
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991116	1140	2.6
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	19991208	1030	1.5
13	12500420	Moxee Drain at Birchfield Rd	107.3	tributary	20000111	1130	1.5
20	12505450	Granger Drain at Granger	82.8	tributary	19990520	1210	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19990603	0920	1.2
20	12505450	Granger Drain at Granger	82.8	tributary	19990615	1320	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19990701	1430	1.1
20	12505450	Granger Drain at Granger	82.8	tributary	19990715	0940	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19990728	1130	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19990803	1730	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19990804	0740	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19990826	0930	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19990910	0930	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19990923	0910	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	19991021	0950	1.2
20	12505450	Granger Drain at Granger	82.8	tributary	19991117	1000	1.3
20	12505450	Granger Drain at Granger	82.8	tributary	19991209	1020	<1.0
20	12505450	Granger Drain at Granger	82.8	tributary	20000112	1010	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990519	1650	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990609	1220	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990617	1040	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990630	1020	1.3
34	12510500	Yakima River at Kiona	29.9	main stem	19990713	1120	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990729	1000	1.3
34	12510500	Yakima River at Kiona	29.9	main stem	19990805	1740	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990806	1030	<1.0
34	12510500	Yakima River at Kiona <sup>1</sup>	29.9	main stem	19990806	1510	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990824	1120	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990831	1150	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19990921	1210	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19991019	1140	1.3
34	12510500	Yakima River at Kiona	29.9	main stem	19991118	1200	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	19991207	1100	<1.0
34	12510500	Yakima River at Kiona	29.9	main stem	20000113	1140	1.8

<sup>1</sup>Multiple samples collected within a day or week.

**APPENDIX A19.** Summary of selected trace-element concentrations detected during basinwide Lagrangian sampling, August 1999, Yakima River Basin, Washington

[All concentrations are in micrograms per liter; <, less than]

Element	Number of samples	Minimum value	Value at indicated percentile						Maximum value
			10	25	50	75	90	95	
Aluminum	34	1.1	2.1	4.9	6.5	12	43	48	97
Arsenic	34	<1.0	<1.0	<1.0	1.2	1.9	3.3	4.1	5.3
Barium	34	1.6	2.7	9.9	15	21	40	50	96
Copper	34	<1.0	<1.0	<1.0	1.1	2.1	3.9	5.8	9.1
Iron	34	<10	6.3	13	18	25	40	46	48
Manganese	34	<1.0	1.2	2.5	7.1	14	34	36	47
Nickel	34	<1.0	<1.0	1.0	1.2	1.7	2.3	2.4	3.4
Uranium	34	<1.0	<1.0	<1.0	<1.0	1.4	4.0	5.5	8.2
Zinc	34	<1.0	<1.0	<1.0	<1.0	5.3	28	51	78

**APPENDIX A20. Arsenic concentrations detected at intensive fixed sites, 1987–1990, Yakima River Basin, Washington**

[All concentrations are in micrograms per liter; <, 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	
1	Cle Elum	16	<1	<1	<1	<1	<1	<1	<1	<1
6	Umtanum	11	<1	<1	<1	<1	<1	<1	<1	<1
10	Naches	15	<1	<1	<1	<1	<1	<1	1	1
14	Union Gap	23	<1	<1	<1	<1	<1	<1	1	1
29	Sulphur Creek	15	2	2	2	3	7	8	9	9
30	Grandview	14	<1	<1	<1	1	2	2	3	3
34	Kiona	25	<1	<1	<1	1	1	2	3	4