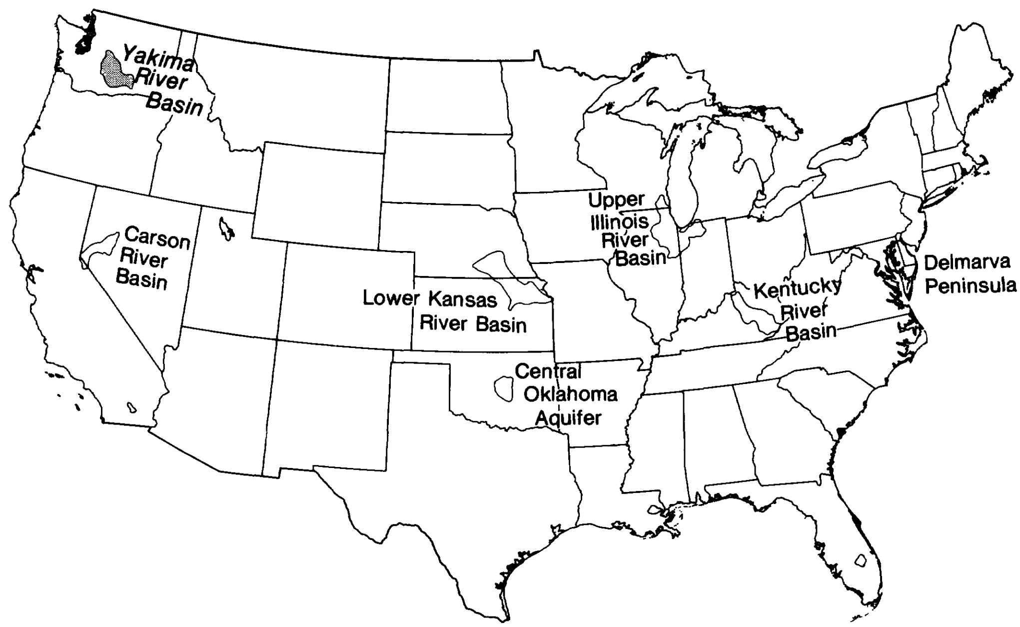
EXECUTIVE SUMMARY
SURFACE-WATER-QUALITY ASSESSMENT OF THE YAKIMA RIVER BASIN, WASHINGTON: ANALYSIS OF AVAILABLE WATER-QUALITY DATA THROUGH 1985 WATER YEAR

By J.F. Rinella, S.W. McKenzie, and G.J. Fuhrer



U.S. GEOLOGICAL SURVEY
Open-File Report 91—454

Portland, Oregon
1992

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
Water Resources Division
10615 S.E. Cherry Blossom Drive
Portland, Oregon 97216

Copies of this report can be purchased from:

Books and Open-File Reports
Box 25425
U.S. Geological Survey
Federal Center, Building 810
Denver, Colorado 80225

PREFACE

As part of the National Water-Quality Assessment Program, the U.S. Geological Survey recently published a report containing an analysis of historical water-quality data in the Yakima River basin. Because many planners, water managers, and the general public do not need all the information contained in the source report, this Executive Summary containing significant conclusions and findings is being published as a separate report.

The 244 page source report "Surface-water-quality assessment of the Yakima River basin, Washington: Analysis of available water-quality data through 1985 water year," by J. F. Rinella, S. W. McKenzie, and G. J. Fuhrer has been published as U.S. Geological Survey Open-File Report 91-453. The report is available from the U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, Colorado 80225.

Information on the Yakima River National Water-Quality Assessment project can be obtained from

District Chief
U.S. Geological Survey
10615 S.E. Cherry Blossom Drive
Portland, Oregon 97216
(Telephone: 503-231-2009)

CONTENTS

ILLUSTRATIONS

TABLES

EXECUTIVE SUMMARY

SURFACE-WATER-QUALITY ASSESSMENT OF THE YAKIMA RIVER BASIN, WASHINGTON: ANALYSIS OF AVAILABLE WATER-QUALITY DATA THROUGH 1985 WATER YEAR

--

By J. F. Rinella, S. W. McKenzie, and G. J. Fuhrer

--

INTRODUCTION

In 1986, the U.S. Geological Survey (USGS) began testing and refining concepts for the National Water-Quality Assessment (NAWQA) Program. The long-term goals of the program are to (1) provide a nationally consistent description of current water-quality conditions for a large part of the Nation's water resources; (2) define long-term trends in water quality; and (3) identify, describe, and explain, as possible, the major factors that affect water-quality conditions and trends.

At present (1990), the assessment program is in a pilot phase in seven project areas (four surface-water and three ground-water project areas) throughout the country that represent diverse hydrologic environments and water-quality conditions. One of the surface-water project areas is the Yakima River basin in Washington.

The first major activity undertaken in the Yakima pilot project was to compile, screen, and interpret available water-quality data. **The purpose of this report is to describe: (1) historical water-quality conditions in the basin, (2) long-term trends in water quality, and (3) relations of historical conditions and trends with natural and human factors.**

THE YAKIMA RIVER BASIN

The Yakima River basin drains 6,155 square miles in south-central Washington and contains a diversity of landforms, including high peaks and deep valleys of the Cascade Range, broad river valleys, and lowlands of the Columbia Plateau (fig. 1). Even though areas covered with irrigated agriculture (approximately 1,000 square miles) and urbanization (50 square miles) are smaller than those areas covered with timber harvesting (2,200 square miles) or grazing (2,900 square miles), the intensity of the activities makes agriculture and urbanization of primary importance with respect to effects on water quality.

The Yakima River basin is one of the most intensively irrigated areas in the United States. The basin has 6 large storage reservoirs, 14 major diversions on the main stem, more than 1,900 miles of canals and laterals, 3 hydroelectric plants, 6 major irrigation projects, and numerous small irrigation systems. Surface-water diversions for irrigation are large and equivalent to about 60 percent of the water use and 81 percent of the annual streamflow from the basin. **The quality of the agricultural-return flow determines the quality of water in the lower Yakima River (downstream from the City of Yakima), because return flows account for as much as 80 percent of the lower main-stem flow during irrigation season.**

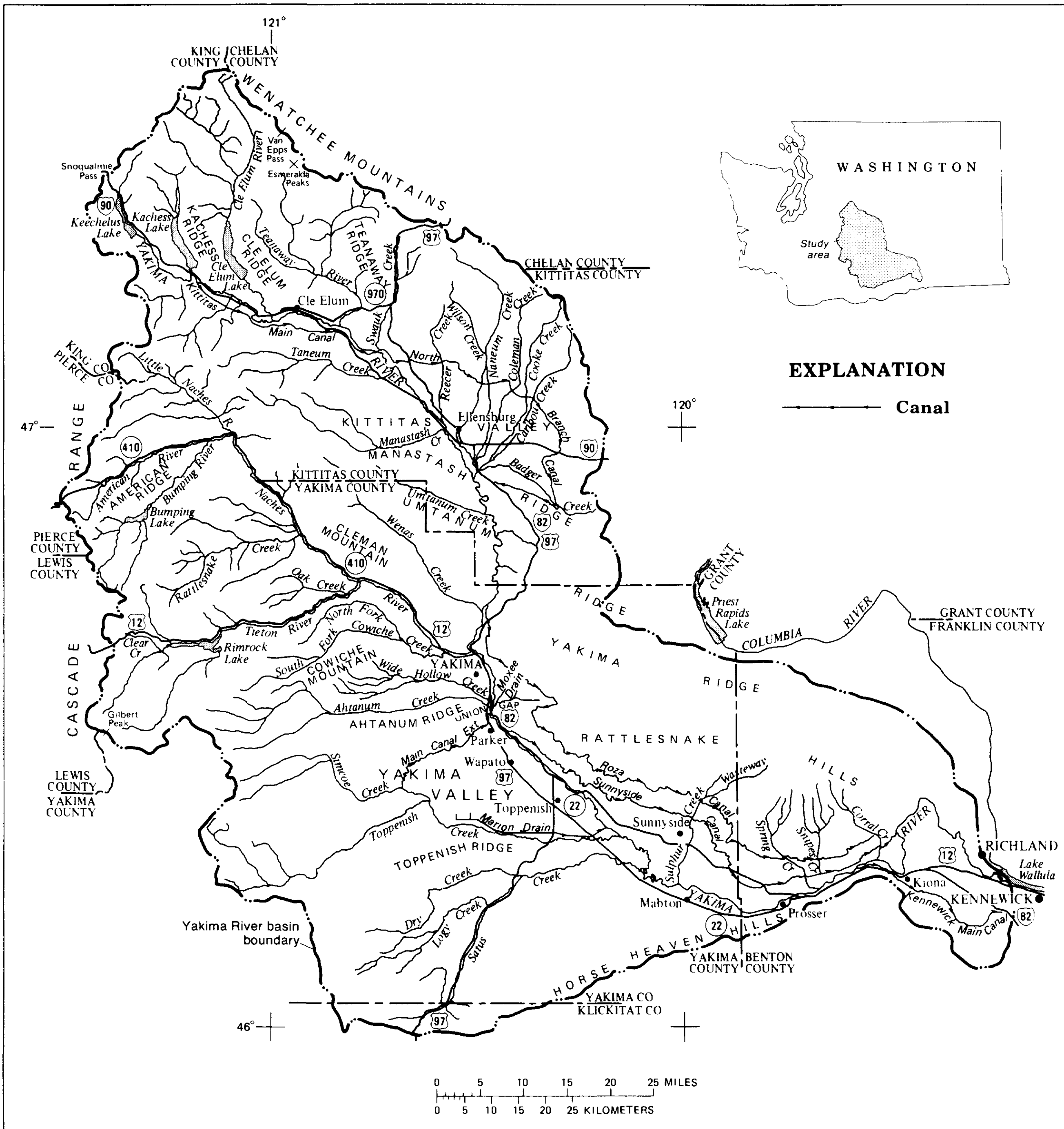


Figure 1.--Drainage and topographic features in the Yakima River basin in south-central Washington.

SURFACE-WATER-QUALITY CONDITIONS

Surface-water quality in the Yakima River basin is suitable for many designated uses. **Water quality in headwater streams is classified by the State of Washington (Washington State Administrative Code, 1988) as extraordinary (class AA--should exceed requirements for all beneficial uses)** and is controlled by the chemical properties of the precipitation, the mineralogy of the soils and geology, residence time in the ground-water system and storage reservoirs, forest management practices, and the nature and intensity of storm events. More than 70 percent of the irrigated land, 90 percent of the point-source nutrient loads, and more than 80 percent of the population are located in the lower basin downstream from Kittitas Valley. These point and nonpoint sources of contaminants affect water quality with measurable changes generally occurring downstream from Wilson Creek (Yakima RM [river mile] 147), which receives agricultural-return flow from Kittitas Valley. **Water quality downstream from the headwater reaches is classified by the State of Washington (Washington State Administrative Code, 1988) as good (class B for Sulphur Creek--should meet or exceed requirements for most beneficial uses) or excellent (class A--should meet or exceed requirements for all beneficial uses)**.

To describe water-quality conditions in the Yakima River basin, and to facilitate intersite comparison, selected monthly data collected from 1974-81 and in 1975 water year are summarized in tables 1 and 2, respectively. **Most water-quality constituent concentrations in the main stem increased in a downstream direction and were largest in tributaries that contained agricultural-return flow and point-source discharges.** These values indicate that current (1990) State standards were not met for stream temperature, pH, fecal-coliform bacteria, and dissolved oxygen. In addition, turbidity and phosphorus concentrations were detected at levels of concern relative to effects on aquatic life and eutrophication, respectively.

Observed trends in constituent concentrations at 43 locations in the Yakima River basin from 1974-81 water year indicate changes in stream quality (table 3). **Increases in stream temperature, specific conductance, and concentrations of orthophosphate (soluble-reactive phosphorus), ammonia, and nitrite plus nitrate were widespread in the basin from 1974-81 water years.** Flow-adjusted-trend results indicate that about 50 percent of the increasing specific conductance trends probably were associated with the decreasing streamflows. **General increases in ammonia, nitrite-plus-nitrate, and orthophosphate concentrations may be due to the increasing use of nitrogen and phosphorus fertilizers in the basin and to increasing populations of livestock. General decreases in turbidity levels, and concentrations of suspended sediment and suspended phosphorus may be due to changes in crop types from row crops to less erosive permanent crops (for example, orchards) and to efforts to control erosion (for example, sediment-detention ponds, and sprinkler- and drip-irrigation methods).**

Table 1.--Summary of monthly streamflow and physical-property measurements and nutrient concentrations at selected sites in the Yakima River basin, Washington, 1974-81 water years

[90-percentile value indicates that 90 percent of the values were less than or equal to the listed value; 50-percentile value indicates that 50 percent of the values were less than or equal to the listed value; 10-percentile value indicates that 10 percent of the values were less than or equal to the listed value; concentrations are expressed in milligrams per liter except as follows: streamflow (cubic feet per second), temperature (degrees Celsius), turbidity (NTU--nephelometric turbidity units), specific conductance (microsiemens per centimeter at 25 degrees Celsius), pH (standard units), "--" = no data or no Washington State standard; all sites listed are Washington State class A streams, except Sulphur Creek, which is class B; 1/ = Not to exceed 5 NTU above background levels; 2/ = Washington State standard varies with temperature and pH (U.S. Environmental Protection Agency, 1986; Washington State Administrative Code, 1988)]

Property or constituents	Yakima River at (river mile in parenthesis): Cle Elum (183.1)	Ellensburg (148.0)	Umtanum (140.4)	Terrace Heights Bridge (113.2)	Granger (82.7)	Mabton (59.8)	Kiona (29.9)	Selected agricultural drain: Wilson Creek at Thrall Road	Sulphur Creek at McGee Road	Washington State standard--class A streams
90-percentile values										
Streamflow	3,560	3,910	4,430	5,790	6,710	6,140	8,470	197	360	--
Stream temperature	16.0	15.5	15.5	16.0	18.9	21.0	22.0	15.5	19.0	21.0
Turbidity	8	13	14	16	16	17	22	12	54	1/ plus 5
Suspended sediment	16	20	32	32	60	59	113	38	285	--
Specific conductance	87	114	155	156	318	323	350	248	712	--
Dissolved oxygen	12.6	12.4	13.3	13.1	12.2	11.8	13.4	13.4	11.0	8.0
Chemical oxygen demand	9	16	14	14	16	16	--	21	32	--
pH	7.7	7.7	7.8	7.8	7.9	8.0	8.6	7.9	8.1	6.5-8.5
Ammonia, total as N	.02	.06	.05	.04	.18	.11	.17	.07	.47	2/
Nitrite + nitrate as N	.07	.18	.36	.26	1.3	1.4	1.5	.48	6.1	10
Phosphorus, total as P	.06	.12	.13	.12	.24	.22	.21	.24	.68	--
Orthophosphate, dissolved as P	.01	.03	.05	.03	.13	.10	.11	.10	.25	--
50-percentile values										
Streamflow	1,200	1,830	2,260	2,850	1,550	2,200	2,405	85.0	182	--
Stream temperature	8.8	8.7	8.2	9.0	11.0	12.8	11.6	9.8	12.7	21.0
Turbidity	1	1	2	3	6	6	7	4	13	1/ plus 5
Suspended sediment	4	6	8	10	22	23	26	12	45	--
Specific conductance	62	89	114	100	182	244	265	210	377	--
Dissolved oxygen	10.9	10.7	11.1	10.7	9.7	9.5	10.8	11.4	9.3	8.0
Chemical oxygen demand	4	6	7	7	10	10	--	13	16	--
pH	7.5	7.5	7.6	7.5	7.6	7.7	7.9	7.7	7.8	6.5-8.5
Ammonia, total as N	.01	.02	.01	.01	.05	.04	.07	.02	.16	2/
Nitrite + nitrate as N	.03	.06	.13	.06	.54	1.0	.89	.25	2.7	10
Phosphorus, total as P	.02	.03	.04	.04	.11	.12	.13	.12	.29	--
Orthophosphate, dissolved as P	<.01	.01	.01	.01	.05	.06	.08	.06	.16	--
10-percentile values										
Streamflow	235	424	709	1,050	415	840	1,040	40.0	57.7	--
Stream temperature	3.6	2.5	1.7	2.1	3.0	4.0	3.4	3.0	7.0	21.0
Turbidity	1	1	1	1	2	2	3	1	3	1/ plus 5
Suspended sediment	1	1	2	3	8	6	7	5	14	--
Specific conductance	42	65	86	75	107	142	149	155	262	--
Dissolved oxygen	9.1	9.1	9.2	8.7	7.5	8.1	8.7	9.3	7.7	8.0
Chemical oxygen demand	2	3	3	4	6	6	--	8.0	11	--
pH	7.2	7.3	7.4	7.3	7.4	7.5	7.6	7.5	7.6	6.5-8.5
Ammonia, total as N	<.01	<.01	<.01	<.01	.01	.01	<.01	<.01	.03	2/
Nitrite + nitrate as N	.01	.02	.02	.02	.14	.33	.37	.08	1.4	10
Phosphorus, total as P	.01	.01	.02	.02	.07	.08	.08	.07	.17	--
Orthophosphate, dissolved as P	<.01	<.01	<.01	<.01	.02	.03	.04	.03	.09	--

Table 2.--Summary of monthly bacteria and major-ion concentrations in the Yakima River, Washington, 1975 water year

[90-percentile value indicates that 90 percent of the values were less than or equal to the listed value; 50-percentile value indicates that 50 percent of the values were less than or equal to the listed value; 10-percentile value indicates that 10 percent of the values were less than or equal to the listed value; concentrations are expressed in milligrams per liter except fecal-coliform bacteria (colonies per 100 milliliters); "--" = no data or no standard; all sites listed are Washington State class A streams, except Yakima River mile 191 which is class AA; 1/ = Geometric mean shall not exceed 100 organisms per 100 milliliters; 2/ = Shall not be less than 20 nor greater than 300 milligrams per liter, except under natural conditions]

Constituents	Yakima River (river mile in parenthesis)						Washington State standard--class A streams
	Near Cle Elum (191.1)	Thorp Highway Bridge (165.4)	Terrace Heights Bridge (113.2)	Near Toppenish (93.0)	Mabton (59.8)	Kiona (29.9)	
			90-percentile values				
Fecal-coliform bacteria	11	17	132	330	804	400	1/ 100
Calcium	12	12	18	20	29	32	--
Magnesium	2.0	3.9	5.8	6.8	11	11	--
Sodium	4.2	3.4	8.0	10	18	20	--
Potassium	1.6	.6	5.0	2.6	3.4	3.7	--
Chloride	4.6	2.7	3.3	4.4	6.7	7.8	250
Sulfate	3.4	2.2	5.6	6.9	17	20	250
Alkalinity as calcium carbonate	30	43	67	78	117	137	2/ 20-300
			50-percentile values				
Fecal-coliform bacteria	2	2	17	22	230	135	1/ 100
Calcium	8.2	7.6	11	12	22	21	--
Magnesium	1.4	2.5	3.4	4.4	7.7	7.7	--
Sodium	2.6	2.2	4.8	6.6	12	12	--
Potassium	.7	.4	1.2	1.4	2.8	2.4	--
Chloride	2.8	1.6	2.2	3.0	4.6	5.1	250
Sulfate	2.2	1.4	3.1	4.4	12	10	250
Alkalinity as calcium carbonate	24	31	43	53	88	88	2/ 20-300
			10-percentile values				
Fecal-coliform bacteria	1	1	<1	1	80	62	1/ 100
Calcium	6.4	4.6	8.8	9.2	12	12	--
Magnesium	.6	1.6	2.6	2.6	3.4	4.1	--
Sodium	2.2	1.4	3.1	3.5	6.8	6.7	--
Potassium	.4	.2	.6	.8	1.4	1.5	--
Chloride	1.3	.8	.8	1.4	2.1	2.2	250
Sulfate	1.2	1.0	1.8	2.3	4.3	5.6	250
Alkalinity as calcium carbonate	16	20	32	36	51	53	2/ 20-300

Table 3.--Summary of temporal trends for streamflow and selected water-quality properties and constituents at sites having 4 to 8 years of monthly data, Yakima River basin, Washington, 1974-81 water years

["NA" indicates not applicable]

Property or constituent	Number of sites with 4 to 8 years of data	Non-flow-adjusted trends		Flow-adjusted trends	
		Number of sites with upward trends	Number of sites with downward trends	Number of sites with upward trends	Number of sites with downward trends
Streamflow	43	0	19	NA	NA
Stream temperature	43	12	0	8	2
Specific conductance	43	14	3	8	7
Total phosphorus	43	2	9	4	10
Dissolved orthophosphate	43	13	2	10	4
Suspended phosphorus	43	0	13	0	12
Total ammonia nitrogen	43	24	3	18	4
Dissolved nitrite plus nitrate	43	23	0	16	2
Turbidity	43	0	18	1	15
Suspended sediment	43	3	8	9	6

pH and Major Cations and Anions

Most (98 percent) of the pH measurements and alkalinity concentrations in the streams range from 6.4 to 8.6 pH units and 14 to 182 mg/L [milligrams per liter] (as calcium carbonate), respectively. **In general, these concentrations are typical of natural river water not influenced by contamination** (natural river water ranges from 6.5 to 8.5 pH units with alkalinities less than 165 mg/L; Hem, 1985). Alkalinity and pH values throughout most of the basin are indicative of water from noncalcareous (lacking calcium carbonate) igneous terrane along the eastern slopes of the Cascade Range. Increases in alkalinity and pH values down the main stem of the Yakima River probably result from agricultural-return flow and point-source effluent effects (including evapotranspiration and nutrient enrichment that causes eutrophication). **Most of the pH and alkalinity values meet State standards for the protection of freshwater aquatic life.** Many of the pH values that do not meet standards occurred during the summer months and probably were the result of increased photosynthetic activity from aquatic plants. Exceedance of the alkalinity guidelines for food canning (less than 1 percent of the values exceeded 300 mg/L as calcium carbonate) only occurred at two locations, both of which receive agricultural-return flow: South Drain near Satus and Yakima River at Kiona.

Headwater streams in the basin are poorly buffered and are susceptible to precipitation-induced acidification. **The pH and strong-acid-ion concentrations (sulfate and nitrate) of precipitation in the headwater streams in the Yakima River basin are similar to mean background levels in remote areas of the world; this similarity indicates that man's influences on the quality of precipitation in the upper basin might be small, when compared with levels in large population centers in the United States.**

Median major-ion concentrations of calcium, magnesium, sodium, potassium, chloride, sulfate, and total dissolved solids (13, 4.9, 7.1, 1.6, 2.5, 4.4, and 120 mg/L, respectively) **in the Yakima River basin are similar to or smaller than the mean concentrations observed in river water of the world** (14, 3.7, 5.7, 1.8, 6.8, 9.6, and 81 mg/L, respectively; Hem, 1985). The predominant major ions in surface water in the Yakima River basin are calcium and bicarbonate. The water generally has high calcium:sodium ratios and small fluoride concentrations (most less than 0.3 mg/L), which are typical of water from the basalt terrane located throughout much of the basin (White and others, 1963). Major-ion concentrations and specific conductance increase down the main stem of the Yakima River, but their relative ion composition is remarkably similar. Two mechanisms that could account for the observed increases in concentration are (1) evapotranspiration that equally concentrates all ions, and (2) uniform dissolution of ions from geologically similar rock and soil types. **Generally, major-ion concentrations do not pose a major alkali or salinity hazard nor should they affect soil properties through ion-exchange effects.** Few sulfate (less than 1 percent) and total-dissolved-solids concentrations (3 percent) exceeded State standards and U.S. Environmental Protection Agency guidelines for domestic water supplies and irrigation, respectively.

Suspended Sediment and Turbidity

Background levels of suspended sediment and turbidity in the Yakima River upstream from the Yakima River at Terrace Heights Bridge (Yakima RM 113.2) were small with median values less than 10 mg/L and 3 NTU, respectively. **These levels approximately doubled downstream from the Terrace Heights Bridge, primarily because of sediment contributed by turbid agricultural-return flows during irrigation season. The largest suspended-sediment concentrations in the Yakima River basin occurred in the Sunnyside subbasin, which has steep slopes that contribute to increased erosion.** In the main stem, the largest suspended-sediment concentrations generally occurred from April to June during high flows due to snowmelt; in the agricultural-return flows, large concentrations generally occurred during storm runoff, periods of peak irrigation, and at the start of irrigation season when soils were freshly tilled and irrigation ditches were layered with sediment from recent mechanical cleaning and windblown sources. **During the 1980 water year (a median flow year), the major loadings of suspended sediment in the Yakima River basin were from nonpoint sources.**

Nutrients

The Yakima River has small background concentrations of total phosphorus, dissolved orthophosphate, total ammonia, and dissolved nitrite plus nitrate (median values less than or equal to 0.04, 0.01, 0.02, and 0.13 mg/L, respectively) **from Cle Elum (RM 183.1) downstream to Terrace Heights Bridge (RM 113.2).** Total-phosphorus and nitrite-plus-nitrate concentrations upstream from Terrace Heights Bridge are about one-half of the median values for many rivers in the United States (Smith and others, 1987). The diluting effect of the Naches River at RM 116.3 reduces nutrient concentrations in the main stem. Farther downstream **in the vicinity of Parker (RM 104.6), however, median concentrations increase by about a factor of two or more,** and except for ammonia, which decreases downstream from Parker, **the nutrient concentrations continue to increase downstream to Kiona** (RM 29.9) [table 1]. **These median nutrient concentrations downstream from Parker are equal to or greater than those for many rivers in the United States (Smith and others, 1987).** The increased concentrations at Parker might be attributed to nutrient loadings from a sewage treatment plant at RM 111.0, Wide Hollow Creek at RM 107.4, Moxee Drain at RM 107.3, and Ahtanum Creek at RM 106.9.

Downstream from two large canal diversions (Wapato and Sunnyside Canals) near Parker, the streamflow in the Yakima River is low during most of the irrigation season (April through October). Consequently, **point and nonpoint discharges (including agricultural-return flows) downstream from Parker cause substantial increases in median nutrient concentrations.**

Nutrient enrichment during the warm summer months results in some scattered patches of dense attached and rooted plant growth in the sluggish-moving reaches of Yakima River downstream from its confluence with Satus Creek (RM 69.6). However, the temporal and spatial coverages of historical nutrient data are insufficient to define whether causes of eutrophication are from point or nonpoint sources.

Increased stream turbidity in the lower Yakima River might be limiting aquatic plant growth and other effects of eutrophication by decreasing sunlight penetration that is needed for photosynthesis. Major increases in turbidity in streams in the lower basin result from soil erosion in irrigated agricultural areas; if soil erosion was reduced without also reducing dissolved nutrient concentrations in the Yakima River, conditions could become more eutrophic.

On the basis of the evaluation of 6,475 and 7,900 determinations of total ammonia and dissolved nitrite plus nitrate, respectively, **about 2 percent of the ammonia determinations (mostly in agricultural-return flows and downstream from sewage treatment plants) exceeded the EPA (U.S. Environmental Protection Agency, 1989) chronic-toxicity criteria for the protection of salmonids or other sensitive coldwater fish species,** and one site (Satus Drain 302) had nitrite-plus-nitrate concentrations larger than EPA's National Primary Drinking-Water Regulation (10 mg/L as N). Streams having the largest nitrite-plus-nitrate concentrations generally were in the Sunnyside subbasin, where a large number of dairies might be contributing to the enrichment.

Largest total-phosphorus concentrations occurred during snowmelt and irrigation seasons when suspended-sediment concentrations also were large. Largest nitrite-plus-nitrate, ammonia, and orthophosphate concentrations occurred from October through March when much of the nutrient loading could be attributed to ground-water and point-source contributions. In addition, reduced primary productivity (consumption of nutrients by stream biota) during the cold fall and winter seasons, also would contribute to the increased nutrient concentrations.

Estimates of major point-source loads of total phosphorus and total nitrogen in the Yakima River basin for 1980 indicate that: (1) the annual, total phosphorus, point-source, load was larger than the annual, total-phosphorus load in the Yakima River at Kiona near the terminus of the basin, and (2) the annual, total-nitrogen, point-source, load was about 13 percent of the annual, total-nitrogen, load at Kiona. **Even though the point-source phosphorus load appears large, it is about 25 percent of the estimated annual amount of phosphorus fertilizer applied in the basin; the point-source, total-nitrogen, load is about than 5 percent of the annual amount of nitrogen fertilizer applied.**

Stream Temperature

The upper Yakima River originates from precipitation, snowmelt, and ground-water seepage from the high Cascade Mountains. Consequently, the initial river temperature is cold, and the water becomes warmer as it flows to the lower basin.

Analysis of 12,500 instantaneous stream-temperature measurements from about 400 sites from 1959-85 water years indicates that **7 percent of the temperature measurements at the class AA streams in the basin** (headwater sites in the national forest) **were above the 16 °C** (degrees Celsius) **State standard, 5 percent at the class A streams** (sites downstream from the national forest) **were above the 21 °C standard, and 2 percent at the class B stream** (Sulphur Creek Wasteway) **were above the 21 °C standard.** As expected, most of the exceedances occurred during the warm July-August period.

Increased stream temperatures in the main stem during the summer result from the dominant influence of air temperature in the lower basin in conjunction with: (1) low flows downstream from the Wapato and Sunnyside Canal diversions (Yakima RM 106.7 and 103.8, respectively), (2) slow velocities due to a small stream gradient between Yakima RM 69.6 and 47.1, and (3) low flows between Prosser Dam (Yakima RM 47.1) and Chandler Pumping Plant (Yakima RM 35.8).

A calibrated model was used to estimate water temperatures for natural conditions in the main stem for August 1981, based on the assumptions of no reservoir storage and no diversions. The model simulation indicated that the mean stream temperatures would exceed the class A temperature standard of 21 °C from Umtanum (Yakima RM 140.4) to Kiona (Yakima RM 29.9) by as much as 1 °C.

Dissolved Oxygen

On the basis of 6,165 measurements of DO (dissolved oxygen) from 185 sites in the Yakima River basin, **DO concentrations in the basin are similar to those in many rivers in the United States** (Smith and others, 1987; median DO for rivers in the United States is 9.8 mg/L compared to the median DO of 10.2 mg/L for the Yakima River basin). Most of the data from the Yakima River basin were collected during daylight periods; the concentrations should be near maximum, if the controlling effect on daytime concentrations was photosynthesis. In streams containing abundant aquatic plant and animal (bacteria, invertebrates, and fish) growth, nighttime DO concentrations would be smaller as a result of respiration and the absence of photosynthesis.

More than 50 percent of sites had one or more DO concentrations that did not meet State standards. Twenty-five percent of the DO concentrations at class AA streams were less than the 9.5 mg/L standard. The class AA standard might be naturally unattainable for some headwater streams during the summer months because of altitude and temperature effects on DO saturation. **Ten and 1 percent of the DO concentrations at the class A and B streams were less than the State standards of 8.0 and 6.5 mg/L, respectively.** Many of the smaller DO concentrations occurred during the warm summer months at streams that receive relatively large nutrient and organic-carbon loads from point and nonpoint sources. Potential causes for the smaller concentrations include increased water temperatures that decrease DO concentrations at saturation, and increased rates of respiration (plants and animals) and biochemical oxygen demand.

Organic Carbon and Related Measures

On the basis of 193 samples from 26 sites in the basin, **total organic carbon concentrations range from 0.1 to 17 mg/L with a median concentration of 4.4. These concentrations are similar to average concentrations in (1) many rivers in the United States, (2) snow in North America** (dissolved organic carbon ranging from 0.1 to 6 mg/L), **and (3) tree-canopy drip** (dissolved organic carbon ranging from 5 to 10 mg/L; tree-canopy drip is precipitation that contacts tree branches and leaves as it falls to the ground; Thurman, 1985). Main-stem data from the Yakima River basin indicate that (1) dissolved organic carbon constitutes more than 80 percent of the total organic carbon, which is typical of many rivers in the United States (Thurman, 1985), and (2) median monthly concentrations of total organic carbon are relatively constant throughout the year.

COD (chemical oxygen demand) concentrations increase downstream in the main stem, from a median of 4 mg/L at Cle Elum (RM 183.1) to a median of 10 mg/L at Mabton (RM 59.8), as a result of increasing organic contributions from domestic, industrial, and agricultural sources. Sites in the basin having the largest COD concentrations are agricultural-return flows that also receive point-source discharges and runoff from dairies and livestock. **Many of the agricultural-return flows have the largest COD concentrations and the smallest DO concentrations in the Yakima River basin, reflecting the bacterial consumption of dissolved oxygen and organic matter as a food source.**

Major Metals and Trace Elements

In the Yakima River basin, concentrations of suspended and dissolved elements in streams depend on (1) man's influences, including transportation, urbanization, industrialization, and pesticide application; (2) the natural weathering and erosion of rocks and soils; and (3) ash fallout from the volcanic eruption of Mount St. Helens. Estimates of iron and selected trace-element (arsenic, cadmium, chromium, copper, lead, mercury, and zinc) sources indicate that point sources (mostly sewage treatment plants) are contributing less than 10 percent of the annual element loads to surface water in the basin. However, most trace element data in the basin are spatially and temporally limited, and are inadequate for accurately defining water-quality conditions and source loads.

Generally, concentrations of major metals and trace elements in water and sediment samples from the Yakima River basin are not enriched above natural concentrations. The range of dissolved concentrations in the basin is similar to the range of concentrations observed in other rivers in the United States, and the median dissolved concentrations are similar to background concentrations that have been minimally affected by man's activities. For example, median dissolved concentrations of arsenic, cadmium, copper, lead, mercury, and zinc in the Yakima River basin are <5, <1, 3, 4, <0.1, and 11 mg/L compared with 2, 0.07, 1.8, 0.2, 0.01, and 10 mg/L, respectively, for inland water that is minimally affected by man's activities (Forstner and Wittman, 1979). Median concentrations of these elements in bed-sediment samples from the upstream mountainous regions of the basin fall within the expected 95-percentile confidence range for uncontaminated soils in the Western United States (R.C. Severson, U.S. Geological Survey, written commun., 1987, based on data in Shacklette and Boerngen, 1984). Because few water samples were collected from these mountainous regions, dissolved- or suspended-element concentrations could not be related directly to element concentrations in the bed sediment. **Except for arsenic, lead, and zinc, trace-element concentrations in 6-12 whole-fish samples from the Yakima River were similar to national baseline concentrations collected in U.S. Fish and Wildlife Service's National Contaminant Biomonitoring Program.** Eighty-fifth-percentile concentrations of arsenic, lead, and zinc in whole-fish samples from the Yakima River basin are 460, 1,260, and 77,900 compared with 230, 320, and 46,300 micrograms per kilogram (wet weight) for 85-percentile concentrations in whole-fish samples collected in the National Contaminant Biomonitoring Program (1978-79). A potential source of arsenic may be acid-lead-arsenate sprays used for controlling codling moths in apple orchards prior to 1947. High application rates of phosphate fertilizer increase the dissolution of arsenic from the soils and result in arsenic contamination in the shallow aquifers that feed drains in agricultural areas. A source of lead might be automotive exhaust from the combustion of leaded gasoline.

From 1953-85 water years, the dissolved elements that most often exceeded U.S. Environmental Protection Agency National Primary or Secondary Drinking-Water Regulations were iron (7 percent of the iron determinations), manganese (2 percent) and lead (2 percent). **Similarly, dissolved elements that most often exceeded State chronic-toxicity standards for aquatic life were lead (56 percent), mercury (43 percent), copper (23 percent), cadmium (12 percent), and zinc (3 percent).** The order of exceedances for total recoverable elements was similar to the order of exceedances for the dissolved elements, listed above, except that the frequencies of exceedances were larger.

In the Yakima River at Kiona (RM 29.9) near the terminus of the basin, dissolved lead and copper exhibited decreasing concentrations from the 1960s to 1985. Possible explanations for these decreases include the large decline in leaded-gasoline combustion during the 1970s, and a decreasing use of copper sulfate for eradicating nuisance aquatic plant growths in canals.

Radionuclides

The absence of baseline data prohibits any evaluation of radionuclides relative to spatial and temporal variability and to water-quality standards. The basin is near the Hanford Nuclear Facility (operated by the U.S. Department of Energy), and the collection of baseline radionuclide data would identify any need for concern.

Pesticides and Other Trace Organic Compounds

Even though the application of synthetic organic compounds is extensive on agricultural land in the Yakima River basin, relatively few samples have been collected to determine the spatial and seasonal distributions of these compounds in the aquatic environment. Data have been collected from about 30 sites in the basin, and about 50 percent of the samples have been collected from the Yakima River at Kiona near the terminus of the basin. **About 85 percent of the trace-organic-compound concentrations from 1968-83 water years were reported below the minimum analytical reporting levels** (note that historical reporting levels are generally 1 to 2 orders of magnitude larger than those that are currently--1990--available.)

Concentrations of several trace organic compounds in water exceeded State water standards for chronic toxicity of freshwater aquatic life, including aldrin/dieldrin, endosulfan, dichlorodiphenyltrichloroethane (DDT) and its metabolites, endrin, parathion, and polychlorinated

biphenyls (PCB). None of these concentrations exceeded standards for acute toxicity. Most of the exceedances occurred in the Yakima River at Kiona, partly because of the relatively large number of samples collected from the site.

The largest concentrations of the hydrophobic organic compounds (DDT and its metabolites, dieldrin, and others) in water occurred during irrigation season in agricultural-return flows that also contained the largest suspended-sediment concentrations. This pesticide-sediment relation indicates that concentrations of **hydrophobic contaminants could be reduced in streams by controlling sediment erosion of contaminated soils.** From 1968-82, **decreases in concentrations of DDT and its metabolites, and dieldrin in water and whole-fish tissues coincide with EPA's decision in December 1972 to ban further use of DDT due to health and environmental-hazard considerations and in 1974 to prohibit the manufacture of dieldrin in the United States.**

Routine fish monitoring by WDOE (Washington State Department of Ecology) from 1979 to 1984 showed that the largest concentrations of DDT plus metabolites in Washington State occurred in fish from the Yakima River basin. In 1985, concentrations of DDT plus metabolites in edible resident fish were below the Food and Drug Administration action level (5,000 µg/kg--micrograms per kilogram, wet weight), but they exceeded the maximum recommended concentration of 1,000 µg/kg (wet weight) established by the National Academy of Science for the protection of fish predators (such as fish-eating birds; Johnson and others, 1986).

Assuming an average fish consumption of 6.5 grams per day, the average lifetime (70 years) cancer risks (U.S. Environmental Protection Agency health assessment methodology; Johnson and others, 1986) for consumption of fish by humans from the lower Yakima River are $3x10^{-5}$, $8x10^{-5}$, $9x10^{-7}$, $2x10^{-6}$, and $1x10^{-5}$ for PCB, dieldrin, DDD, DDT, and DDE, respectively (a risk of $3x10^{-5}$ is 1 person per 300,000 people).

Fecal-coliform Bacteria

The presence of fecal-coliform bacteria indicates a potential health hazard from the transmission of pathogenic microorganisms in water from fecal contamination. Fecal-coliform-bacteria data are limited in both spatial and temporal coverage, so that the occurrence, temporal trends, and sources could not be quantitatively defined throughout the basin. **An evaluation of 2,235 fecal-coliform bacteria determinations at 200 sites from 1968-85 water yearsindicates that 49 percent of the determinations at 128 sites exceeded State standards.** About 32 percent of the determinations were made on main-stem samples and about 40 percent of these determinations exceeded standards. Most of the exceedances in the main stem occurred downstream from Granger (Yakima RM 82.7). **The largest percentage of exceedances occurred at the class B sites [Sulphur Creek] (93 percent of the class B determinations) and at the class A sites (54 percent),** whereas the class AA sites had 14 percent. Class AA sites are affected minimally by man's activities and exhibited the smallest bacteria concentrations. Prior to the 1970's, a source of fecal-coliform bacteria in the Yakima River basin was untreated and (or) improperly treated effluent from STPs (sewage treatment plants; Sylvester and others, 1951); since then, most of the

STP discharges in the basin have been treated with chlorine, substantially reducing the bacteria concentrations in the effluent (Jim Milton, Washington Department of Ecology, oral commun., August 24, 1989). **Data collected since 1970 indicate that nonpoint sources are controlling the bacterial quality of streams.** Areas with concentrations greater than 200 colonies per 100 mL (milliliters) of water (class A standard is 100 colonies per 100 mL, and class B standard is 200 colonies per 100 mL) include sites at most agricultural-return flows, on the main stem downstream from major agricultural-return flows, and in subbasins with large densities of dairies and livestock, such as Granger, Sunnyside, and Kittitas subbasins.

Fecal-coliform concentrations were increasing from 1977-85 water years in the Yakima River at Parker (RM 104.6) and Kiona (RM 29.9) by about 6 and 14 percent per year, respectively. These increasing concentrations were not associated with increasing streamflows and could be attributed to increases in the number of livestock in the basin.

Fish and Other Aquatic Biological Communities

Because of the commercial and recreational value of anadromous fish in the Yakima River basin, the emphasis of biological investigations has been on the description, quantification, protection, and enhancement of salmon and trout populations. Prior to 1880, anadromous fish runs were estimated to be more than one-half million fish (Davidson, 1965). By 1900, all summer streamflow in the Yakima River basin had been appropriated and diverted by private interests for irrigation. A serious water shortage had developed, leaving the lower Yakima River with increasing temperatures in stagnant pools. By 1905, the construction of large storage reservoirs and other water-resource developments for irrigation had seriously affected fish migrations in the Yakima River; the number of anadromous fish annually returning to the Yakima system declined to about 60,000 (Davidson, 1965). By 1920, anadromous fish runs further declined to 12,000 and have remained at approximately this level for 70 years.

Major habitat and water-sediment factors that currently (1990) are suspected of affecting fishery in the Yakima River basin are (Confederated Tribes and Bands of the Yakima Indian Nation and others, 1990): (1) fish passage problems associated with irrigation diversions in the tributaries, (2) passage and rearing habitat restrictions resulting from low streamflows in both the main stem and the tributaries, (3) adverse effects to spawning and rearing habitat associated with rapid daily-flow fluctuations downstream from large storage reservoirs, (4) erosion of agricultural soils and subsequent deposition of fine-grained sediment on fall chinook spawning beds in the lower river, (5) false-attraction flows associated with agricultural-return flows, (6) degraded rearing habitat, including the lack of large organic debris, caused by prolonged, excessively high-flow augmentation for irrigation, (7) stream temperatures higher than 24 °C in the lower river, which constitute a partial thermal block for fish passage and decrease available habitat for native, cold-water species, (8) pesticide concentrations above safe, chronic-exposure levels for fish in the main stem and in the agricultural-return flows, and (9) degradation of riparian cover caused by grazing and agricultural activities. The relative importance of each of these factors has not been quantified.

The fewest resident fish are found in the Yakima River from Prosser (RM 47.4) to Mabton (RM 59.8). Within this reach, the current is slow, the water is warm and turbid from agricultural-return flow, and the streambed is composed of silt and clay.

A limited number (both temporally and spatially) of benthic invertebrate and phytoplankton samples indicate changes in habitat and water-quality conditions along the main stem of Yakima River. Benthic invertebrate communities reflect downstream increases in fine-grained-sediment deposition, stream turbidity, temperature, and organic-carbon concentrations from point and nonpoint sources. Phytoplankton samples indicate that algal blooms occurred annually in the Yakima River at Kiona from 1975-81 water years. The codominant algal genera are tolerant of pollution, commonly being associated with nutrient-enriched water.

NEEDS FOR FUTURE DATA COLLECTION AND ANALYSIS

Future data-collection activities in the basin require close scrutiny of sampling, preservation, and analytical techniques to ensure that the data are representative of actual stream conditions. In addition, analytical procedures need to provide constituent reporting levels that are less than water-quality criteria and standards.

Water-quality issues that need to be addressed in future data-collection programs include: eutrophication (nutrients), erosion and deposition (suspended sediment and turbidity), sanitary quality (fecal indicator bacteria), toxic compounds (trace-organic compounds, trace elements, and radionuclides), habitat and contaminant effects on biological communities, high-water temperatures, and small dissolved-oxygen concentrations. Additional data are needed to describe spatial and temporal distributions as well as the sources of these contaminants in the aquatic environment.

REFERENCES

Confederated Tribes and Bands of the Yakima Indian Nation, Washington Department of Fisheries, and Washington Department of Wildlife, 1990, Yakima River subbasin, salmon and steel head production plan, draft report, April 11, 1990.

Davidson, Frederick A., 1965, The development of irrigation in the Yakima River basin and its effect on the migratory fish populations in the river: Reprint of a report prepared and published in mimeograph form for the Yakima Indian Nation, Toppenish, Washington, August 1953, 12 p.

Forstner, U., and Wittmann, G.T.W., 1979, Metal pollution in the aquifer environment: New York, Springer-Velag, 486 p.

Hem, John D., 1985, Study and interpretation of the chemical characteristics of natural water 3rd edition: U.S. Geological Survey Water-Supply Paper 2254, United States Government Printing Office, Washington, D.C., 263 p.

Johnson, Art, Norton, Dale, and Yake, Bill, 1986, Occurrence and significance of DDT compounds and other contaminants in fish, water, and sediment from the Yakima River basin: Washington Department of Ecology, Olympia, Washington, 89 p.

Shacklette, H. T., and Boergen, G. G., 1984, Element concentrations in soils and other surficial materials of the conterminous United States: U.S. Geological Survey Professional Paper 1270, 105 p.

Smith, R. A., Alexander, R. B., Wolman, M.G., 1987, Water-quality trends in the Nation's rivers: Science, March 27, 1987, v. 235, p. 1607-1615.

Sylvester, R. O., Westin, M. J., Suzuki, J. T., and Dailey, M.G., 1951, An investigation of pollution in the Yakima River basin: Washington State Pollution Control Commission, Olympia, Washington, Technical Bulletin No. 9, 47 p.

Thurman, E.M., 1985, Organic geochemistry of natural waters: Dordrecht, The Netherlands, Martinus Nijhoff/Dr. W. Junk Publishers, 497 p.

U.S. Environmental Protection Agency, 1986, Quality criteria for water 1986 and update no. 1 and update no. 2 (May 1, 1987): Washington, D.C., EPA 440/5-86-001.

Washington State Administrative Code, January 6, 1988, Chapters 173-201, 13 p.

White, D. E., Hem, J. D., and Waring, G. A., 1963, Data of geochemistry, 6th ed.: U.S. Geological Survey Professional Paper 440-F, 67 p.