Water Quality in the Willamette Basin

Oregon, 1991–95

U.S. Department of the Interior
U.S. Geological Survey

Circular 1161

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Coordination among agencies and organizations is an integral part of the NAWQA Program. We acknowledge the following agencies and organizations, who contributed to the success of the Willamette Basin NAWQA by serving as members of our liaison committee.

- Bureau of Land Management
- Bureau of Reclamation
- City of Eugene
- City of Portland
- City of Salem
- Columbia River Inter-Tribal Fish Commission
- Metro Regional Government
- National Resources Conservation Service
- Oregon Department of Agriculture
- Oregon Department of Environmental Quality
- Oregon Department of Fish and Wildlife
- Oregon Department of Forestry
- Oregon Department of Human Resources, Health Division
- Oregon Department of Land Conservation and Development
- Oregon State University
- Oregon Water Resources Department
- Portland State University
- Tualatin Valley Water District
- Unified Sewerage Agency
- U.S. Army Corps of Engineers
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service

All photography by Dennis Wentz, except page 12 by Ian Waite and page 14 by Steve Hinkle.

Front cover photograph: Little Abiqua Creek near Scotts Mills drains the Cascade Foothills of Marion County. The basin lies within a mostly protected and forested reserve, and serves as a reference area for water chemistry and ecological studies.

Back cover photographs: Left, Kurt Carpenter (left) and Ian Waite (right) use a backpack electroshocker to assess the fish community of Muddy Creek near Peoria; right, Kathy Kuivila (left, California District) and Martell Kiefer (right) collect a water sample from the Pudding River near Woodburn.

FOR ADDITIONAL INFORMATION ON THE NATIONAL WATER-QUALITY ASSESSMENT (NAWQA) PROGRAM:

Willamette Basin Study Unit contact:

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

NAWQA Program contact:

Chief, NAWQA Program
U.S. Geological Survey
Water Resources Division
12201 Sunrise Valley Drive, M.S. 413
Reston, VA 20192

Information on the NAWQA Program is also available on the Internet via the World Wide Web. You may connect to the NAWQA Home Page using the Universal Resources Locator (URL):
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Water Quality in the Willamette Basin, Oregon, 1991–95

By Dennis A. Wentz, Bernadine A. Bonn, Kurt D. Carpenter, Stephen R. Hinkle, Mary L. Janet, Frank A. Rinella, Mark A. Uhrich, Ian R. Waite, Antonius Laenen, *and* Kenneth E. Bencala

U.S. GEOLOGICAL SURVEY CIRCULAR 1161

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U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

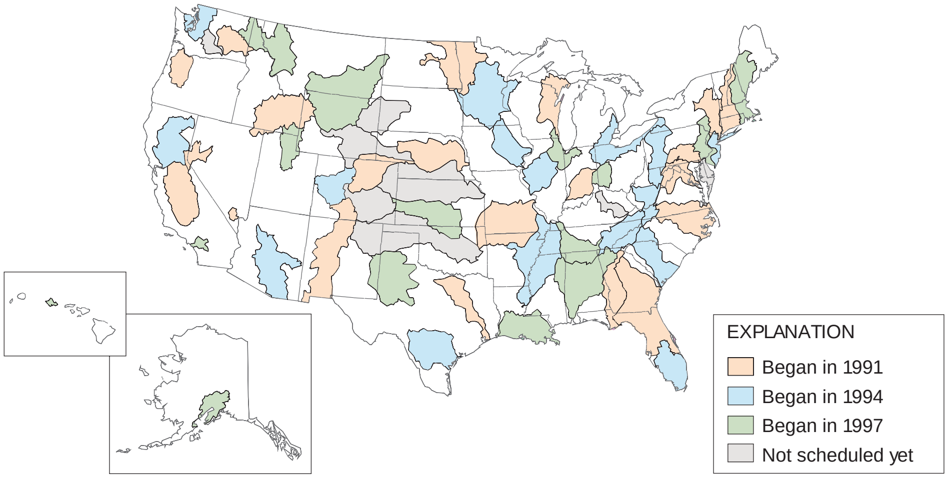
Thomas J. Casadevall, Acting Director

1998

Free on application to the
U.S. Geological Survey
Information Services
Box 25286 Federal Center
Denver, CO 80225

Library of Congress Cataloging in Publications Data

Water quality in the Willamette Basin, Oregon, 1991–95 / by Dennis A. Wentz ... [et al.].
p. cm.—(U.S. Geological Survey circular ; 1161)
Includes bibliographical references.
ISBN 0–607–89231–5 (pbk.)
1. Water quality—Oregon—Willamette River Watershed.
I. Wentz, Dennis A. II. Series.
TD224.O7W28 1998 98–16276
363.739’42’097953—dc21 CIP



Knowledge of the quality of the Nation's streams and aquifers is important because of the implications to human and aquatic health and because of the significant costs associated with decisions involving land and water management, conservation, and regulation. In 1991, the U.S. Congress appropriated funds for the U.S. Geological Survey (USGS) to begin the National Water-Quality Assessment (NAWQA) Program to help meet the continuing need for sound, scientific information on the areal extent of the water quality problems, how these problems are changing with time, and an understanding of the effects of human actions and natural factors on water quality conditions.

The NAWQA Program is assessing the water quality conditions of more than 50 of the Nation's largest river basins and aquifers, known as Study Units. Collectively, these Study Units cover about one-half of the United States and include sources of drinking water used by about 70 percent of the U.S. population. Comprehensive assessments of about one-third of the Study Units are ongoing at a given time. Each Study Unit is scheduled to be revisited every decade to evaluate changes in water quality conditions. NAWQA assessments rely heavily on existing information collected by the USGS and many other agencies as well as the use of nationally consistent study designs and methods of sampling and analysis. Such consistency simultaneously provides information about the status and trends in water quality conditions in a particular stream or aquifer and, more importantly, provides the basis to make comparisons among watersheds and improve our understanding of the factors that affect water quality conditions regionally and nationally.

This report is intended to summarize major findings that emerged between 1991 and 1995 from the water quality assessment of the Willamette Basin Study Unit and to relate these findings to water quality issues of regional and national concern. The information is primarily intended for those who are involved in water resource management. Indeed, this report addresses many of the concerns raised by regulators, water utility managers, industry representatives, and other scientists, engineers, public officials, and members of stakeholder groups who provided advice and input to the USGS during this NAWQA Study Unit investigation. Yet, the information contained here may also interest those who simply wish to know more about the quality of water in the rivers and aquifers in the area where they live.

Robert M. Hirsch

Robert M. Hirsch, Chief Hydrologist

> “The U.S. Geological Survey’s Willamette Basin NAWQA Program is a high quality, scientifically credible water quality assessment. The program took a comprehensive approach which included ground water, surface water, land use, conventional pollutants, toxic pollutants, habitat, physical conditions, and biological components. The information obtained through this program complements our state monitoring efforts to provide a much more accurate and complete understanding of water quality conditions within the Willamette watershed. Such an understanding is essential to the wise and effective management of these treasured water resources and their protection for present and future generations.”
>
> — *Greg Pettit, Manager, Water Quality Monitoring, Oregon Department of Environmental Quality*

SUMMARY OF MAJOR ISSUES AND FINDINGS IN THE WILLAMETTE BASIN

Water quality issues were identified at the start of the National Water-Quality Assessment of the Willamette Basin (Wentz and McKenzie, 1991). The findings summarized below represent our contribution to an increased understanding of these issues.

Relative abundances of fish species correlated best with instream and riparian habitat quality (p. 8–9). Habitat and fish communities in agricultural and urban streams were degraded compared with those in other NAWQA Study Units (p. 21).

- Pollution sensitive native fish, such as cutthroat trout and torrent sculpin, were found predominantly in forested streams with large riffle areas, high quality riparian habitat, and low water temperatures. No external anomalies were found on fish from these streams.
- Pollution tolerant introduced fish, such as carp and bullheads, were collected primarily from streams with few riffles, poor quality riparian habitat, and high water temperatures. External anomalies were most abundant on fish from these streams.
- Relative abundances of fish generally were not highly correlated with water chemistry; however, pollution tolerant native fish, including minnows and reticulate sculpin, were found mostly in agricultural and urban streams with the highest nutrient and pesticide concentrations. External anomalies were moderately high on fish from these streams.

Erosion has increased downstream from dams (p. 10).

- Suspended sediment transport has remained unchanged downstream from 10 dams since their construction, but average particle size of the transported sediment has decreased. These facts indicate that erosion has increased downstream from the dams to compensate for the sediment trapped by the reservoirs.
- Erosion of stream channels and/or recently developed land could account for much of the sediment presently transported downstream from the dams.

Ground water/surface water interactions are significant in large, gravel-bed rivers (p. 11).

- Dye injection studies and streamflow measurements demonstrate the widespread occurrence of significant ground water/surface water interactions in large, gravel-bed rivers.
- Interchange of water between streams and adjacent aquifers can result in changes to associated nutrient and pesticide concentrations.

Nutrients in streams and ground water are degrading water quality (p. 12–13).

- In 45 percent of streams sampled, total phosphorus concentrations exceeded 0.1 mg/L (milligram per liter), which is the maximum value cited by the U.S. Environmental Protection Agency (USEPA) as a goal for prevention of nuisance plant growth.
- Sixty-eight percent of streams where total phosphorus concentrations exceeded 0.1 mg/L drained predominantly agricultural land.
- Guidelines do not exist for evaluating the effects of nitrate concentrations on algal growth, but nitrate concentrations in only 2 of 51 of streams exceeded the 10 mg/L maximum contaminant level (MCL) established by the USEPA for drinking water. Neither stream was used as a source for drinking water.
- In streams of the Pudding Basin, nitrate and soluble reactive phosphorus concentrations during spring runoff increased as the percent of drainage area in agriculture increased.
- Nitrate concentrations in ground water exceeded the USEPA MCL in 6 of 70 shallow domestic wells drawing water from the alluvial aquifer of the Willamette Valley.
- Nitrate concentrations were higher downgradient from irrigated agricultural areas than from nonirrigated agricultural areas.
- Nitrate concentrations in ground water are likely to increase in the future because water sampled as part of the present study entered the ground water system when nitrogen fertilizer application rates were lower than in subsequent years.

Pesticides in streams are degrading water quality (p. 14–15).

- Fifty pesticides were detected in streams, and 10 pesticides exceeded criteria established by the USEPA for the protection of freshwater aquatic life from chronic toxicity.
- Atrazine exceeded the drinking water MCL of 3 μg/L (micrograms per liter) in one sample, and simazine exceeded the MCL of 4 μg/L in a different sample from the same stream; however, the stream was not used as a source of drinking water.
- Atrazine, simazine, metolachlor, deethylatrazine, diuron, and diazinon were detected in more than one-half of stream samples. Their concentrations varied seasonally in response to runoff and application rates.
- Forty-nine pesticides were detected in streams draining predominantly agricultural land, whereas 25 pesticides were detected in streams draining mostly urban areas. The highest pesticide concentrations generally occurred in streams draining predominantly agricultural land.
- In streams of the Pudding Basin, concentrations of atrazine, simazine, and metolachlor during spring runoff increased as the percent of drainage area in agriculture increased.

Ground water quality generally has not been degraded by pesticides or volatile organic compounds (VOCs) (p. 15). Radon and dissolved solids concentrations and pesticide detection rates were low when compared with other NAWQA Study Units (p. 22–23).

- Dinoseb (an herbicide) exceeded the MCL of 7 μg/L in ground water from one shallow domestic well, and tetrachloroethene (a VOC) exceeded the MCL of 5 μg/L in a second well. These were the only organic compounds detected at concentrations greater than USEPA drinking water MCLs in domestic wells.
- Pesticides were detected in water from about one-third of the shallow alluvial wells sampled, but concentrations typically were low. A greater variety of pesticides was found at higher concentrations in agricultural areas than in urban areas.
- VOCs were detected in water from about 20 percent of the shallow alluvial wells sampled. VOCs were found more frequently in urban areas than in agricultural areas.

Dioxins and furans were detected in all bed sediment and fish tissue samples, including those from forested reference basins (p. 16–17).

- Concentrations of total dioxins and furans in bed sediment from streams and lakes exceeded the USEPA guideline for risks to fish at 2 of 22 sites; both sites were downstream from industrial areas. Concentrations in fish tissue did not exceed the threshold for risks to predator fish at any of the 8 sites where fish were collected.
- Dioxin and furan concentrations in bed sediment from forested and agricultural basins are similar to those found in other areas of the United States where atmospheric deposition is the presumed source.

Although they have been banned since the late 1980s or earlier, organochlorine pesticides and PCBs are still present in bed sediment and aquatic biota from streams and lakes (p. 18).

- Concentrations in bed sediment exceeded USEPA guidelines for protection of aquatic life at 10 of 47 sites. Chlordane and its component compounds, and DDT and its degradation products accounted for most guideline exceedances.
- Concentrations in fish at 17 sites did not exceed National Academy of Sciences and National Academy of Engineering criteria for protection of fish-eating wildlife.
- The most commonly detected organochlorine compound both in bed sediment and aquatic biota was *p,p'*-DDE, a degradation product of DDT.

Concentrations of trace elements in bed sediment from streams and lakes exceeded Environment Canada draft guidelines for protection of aquatic life at 26 of 52 sites (p. 18–19); however, concentrations generally were low when compared with other NAWQA Study Units (p. 21).

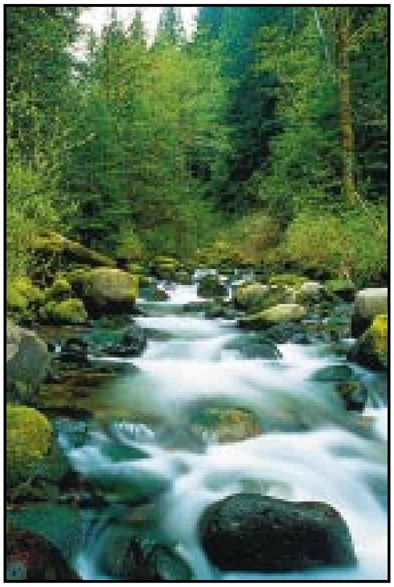
- Chromium and nickel, which are relatively abundant in Willamette Basin rocks, commonly exceeded guidelines.
- The highest concentrations of cadmium, lead, silver, and zinc in bed sediment were in urban streams.
- The highest mercury concentrations in bed sediment were downstream from an abandoned mercury mine. High mercury concentrations in fish have prompted the Oregon Health Division to issue advisories warning of health risks from consumption of fish taken from some streams and reservoirs.

The Willamette Basin NAWQA Study Unit comprises the Willamette and Sandy River Basins in northwestern Oregon. The 12,000-square-mile basin is bordered on the west by the Coast Range, where elevations exceed 4,000 feet, and on the east by the Cascade Range, with several peaks higher than 10,000 feet. The interlying Willamette Valley, with elevations near sea level, is filled mostly with sediment of alluvial origin.

The Willamette River is the 13th largest river in the conterminous United States in terms of streamflow and produces more runoff per square mile than any of the larger rivers (Kammerer, 1990). The Sandy River Basin includes the Bull Run watershed, which has been Portland’s primary drinking water supply for more than 100 years; it is one of the few surface supplies in the United States that the USEPA does not require to be filtered. The Willamette and Sandy Rivers are tributary to the Columbia River, which flows west to the Pacific Ocean along Oregon’s northern border.

The Willamette River flows through Portland—Oregon’s largest metropolitan area—before entering the Columbia River.

Land Use



Pristine headwater streams, such as Fir Creek in the Bull Run watershed, contribute to Portland’s drinking water supply.

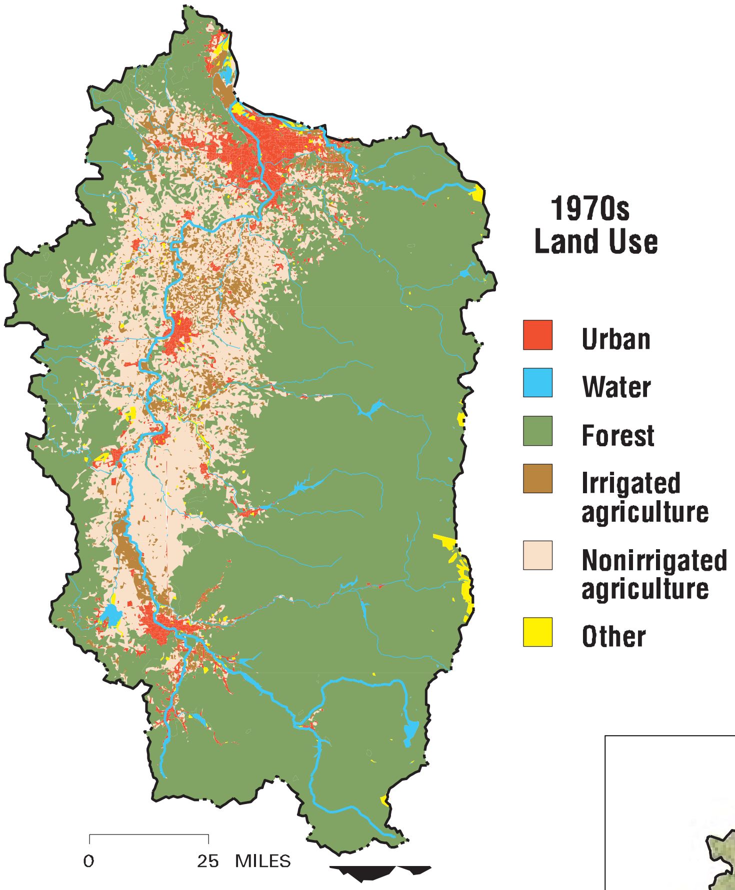
Land use in the Willamette Basin has been described based on 1970s high altitude aerial photography (U.S. Geological Survey, 1990) updated with 1990 census data (Hitt, 1994). Forested land (70 percent of the basin) dominates the foothills and mountains of the Coast and Cascade Ranges. Agricultural land is mostly cropland, comprises 22 percent of the basin, and is located predominantly in the Willamette Valley. About one-third of the agricultural land is irrigated (Oregon Water Resources Department, 1979; 1980; 1981), and most of this is adjacent to the main stem Willamette River in the southern basin or scattered throughout the northern valley. Urban land (6 percent of the basin) is located primarily in the valley along the main stem Willamette River. Other land uses and water account for less than 2 percent of the basin area.

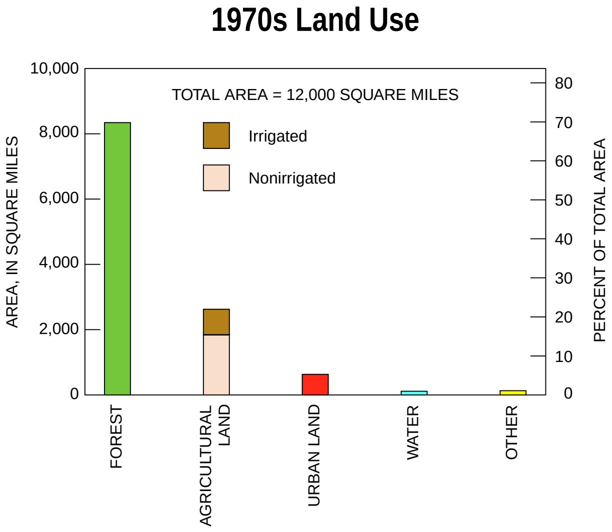
During 1992, the Willamette Basin accounted for 51 percent of Oregon’s total gross farm sales.

In contrast to the 1970s land use data described above, Landsat data collected during 1992–93 and analyzed as part of the present study provide considerably greater detail with regard to (1) crop types and native valley vegetation and (2) forest types and nonforest upland.

During 1992, the Willamette Basin accounted for 51 percent of Oregon’s total gross farm sales and 58 percent of Oregon’s crop sales (Oregon Agricultural Statistics Service, 1993). These sales came from nine counties that comprise most of the basin

The Willamette Basin is drained by the Willamette and Sandy Rivers and includes all or parts of 13 counties (boundaries shown in yellow).





Land use data from the 1970s (left and above) indicate that 22 percent of the basin was agricultural and that the area of nonirrigated land was about twice the area of irrigated land.

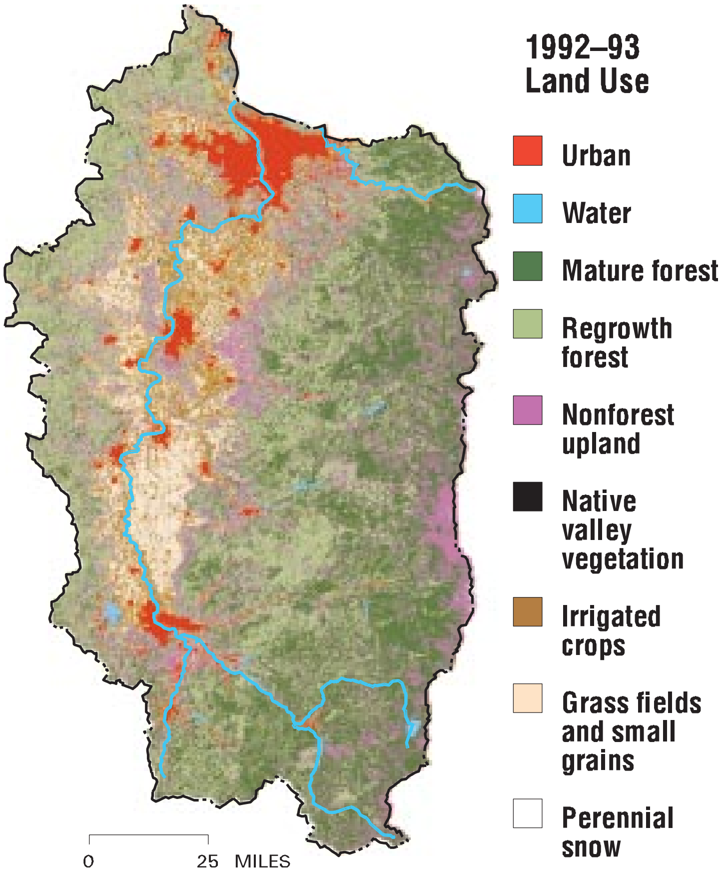
About 2 million people, or 70 percent of Oregon's population, lived in the Willamette Basin in 1990.

area, and were due to production of grass seed, wheat, hay, oats, corn, and many specialty crops.

About 2 million people, or 70 percent of Oregon's population, lived in the Willamette Basin in 1990 (Center for Population Research and Census, 1992). Portland, with 1.2 million people, is the State's largest metropolitan area. Population growth in the basin from 1990 to 1991 was about 3.5 percent and is expected to continue.

Top 10 crops (by acreage) grown in the Willamette Basin during 1987 (Rinehold and Witt, 1989)

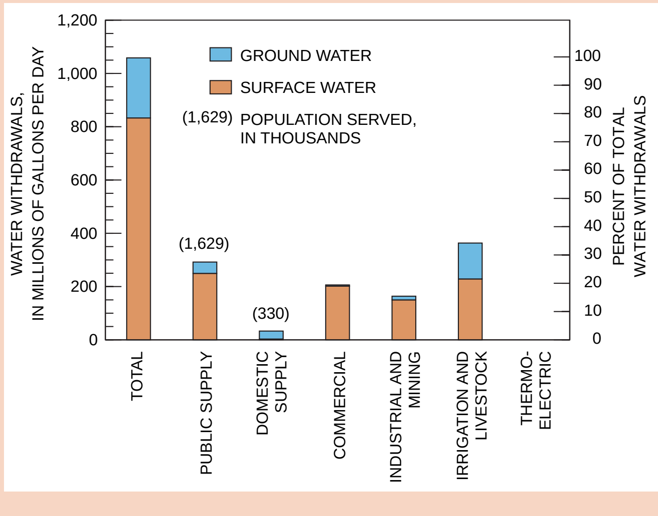
Rank	Crop	Acres
1	Grass seed	293,000
2	Wheat	173,000
3	Other hay	152,000
4	Oats	62,200
5	Clover and vetch seed	49,600
6	Sweet corn	35,500
7	Alfalfa hay	26,400
8	Filberts	25,000
9	Snap beans	21,400
10	Mint	17,000



Land use data from 1992–93 provide greater detail with regard to crop and forest types than do the 1970s land use data (top of page).

Water Use

More than three-fourths of the water used in the Willamette Basin during 1990 was surface water (Broad and Collins, 1996). The largest single use was for irrigation of crops, such as berries, hops, mint, nursery stock, sugar beets, and vegetables (including beans, broccoli, cabbage, corn, garlic, onions, and squash). Public supply (serving cities, towns, mobile home parks, apartment complexes) was the second largest use; it consisted mostly of withdrawals from Cascade streams, including the Bull Run in the Sandy Basin and the Clackamas, Santiam, and McKenzie Rivers.



Estimated water withdrawals in 1990 were mostly from surface water. Irrigation was the largest single use.

More than three-fourths of the water used in the Willamette Basin during 1990 was surface water.

The small amount of ground water used for public supply (10 percent of the total) came predominantly from alluvial aquifers located along Cascade streams or along the main stem Willamette River. Most commercial water use was by fish hatcheries, and most industrial use was by pulp-and-paper mills.

Climate and Hydrology

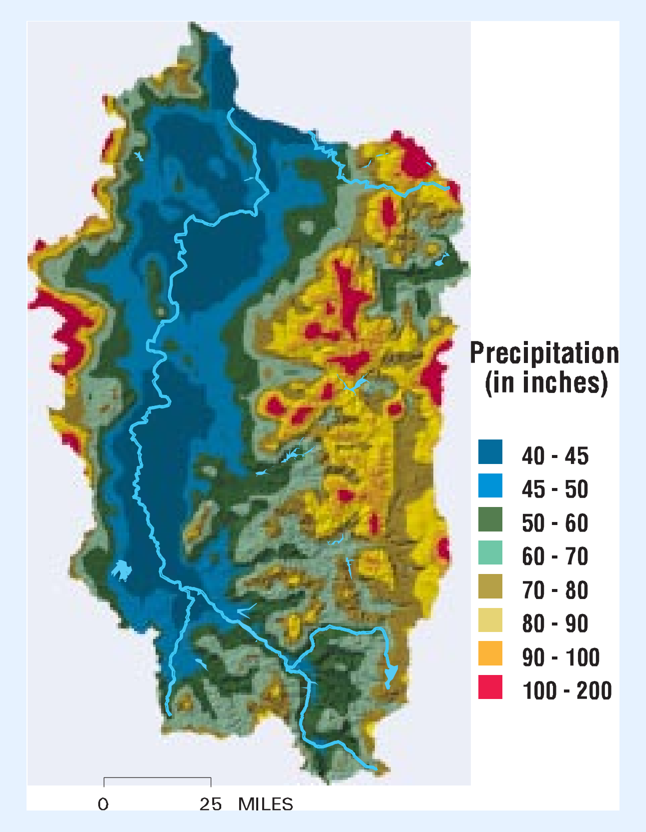
The Willamette Basin is characterized by cool, wet winters and warm, dry summers. About 70–80 percent of the annual precipitation falls from October through March, but less than 5 percent falls in July and August. Most precipitation falls as snow above about the 5,000-foot level of the Cascades; however, the Coast Range and Willamette Valley receive relatively little snow. Mean monthly air temperatures in the valley range from about 3–5^{o}C during January to 17–20^{o}C during August.

Although annual precipitation averaged 62 inches in the Willamette Basin during 1961–90, topography strongly influenced its distribution. Yearly amounts ranged from 40–50 inches in the valley to as much as 200 inches near the crests of the Coast and Cascade Ranges.

Streamflow in the Willamette Basin reflects the seasonal distribution of precipitation, with 60–85 percent of runoff occurring from October through March, but less than 10 percent occurring during July and August. Releases from 13 tributary reservoirs are managed for water quality enhancement by maintaining a flow of 6,000 cubic feet per second (ft^3/s) in the Willamette River at Salem during summer months (U.S. Army Corps of Engineers, 1989).

About 70–80 percent of the annual precipitation falls from October through March, but less than 5 percent falls in July and August.

Mean annual discharge of the Willamette River near its mouth at Portland was 32,400 ft^3/s during water years 1972–90. (A water year extends from October 1 of one year through September 30 of the following year and is designated by the calendar year in which it ends.) Typical monthly flows at Portland ranged from about 8,000 ft^3/s in August to about 70,000 ft^3/s in December. Recorded extreme flows were 4,200 ft^3/s in July 1978 and 283,000 ft^3/s in January 1974, although the river reached an estimated peak flow of 460,000 ft^3/s during the flood of February 1996.

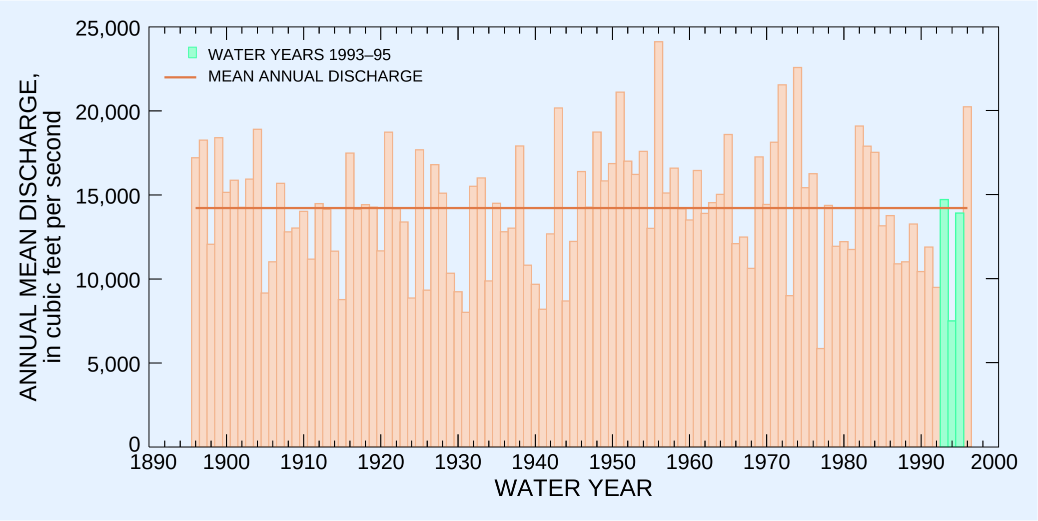


Mean annual precipitation during 1961–90 was as high as 200 inches near the mountain crests, but the Willamette Valley received only 40–50 inches.

Hydrologic Conditions During 1993–95

Hydrologic conditions during the intensive data collection phase (water years 1993–95) of the Willamette Basin NAWQA study were evaluated using discharge data for the Willamette River at Albany, about 20 miles south of Salem. This site has the longest continuous record in the basin and drains about 40 percent of its area. Annual mean discharges during water years 1993 and 1995 were about average, but discharge for water year 1994 was the second lowest on record. However, because streamflow at this site is regulated by nine tributary reservoirs, it may not strictly represent upstream hydrologic conditions.

An analysis of precipitation data from five National Oceanic and Atmospheric Administration sites distributed throughout the basin generally corroborated results from the streamflow analysis. Total precipitation was about 5 percent below the water years 1961–90 average during water year 1993, and it was 32 percent below average during water year 1994. However, water year 1995 (18 percent above average) was slightly wetter than indicated by the streamflow data.

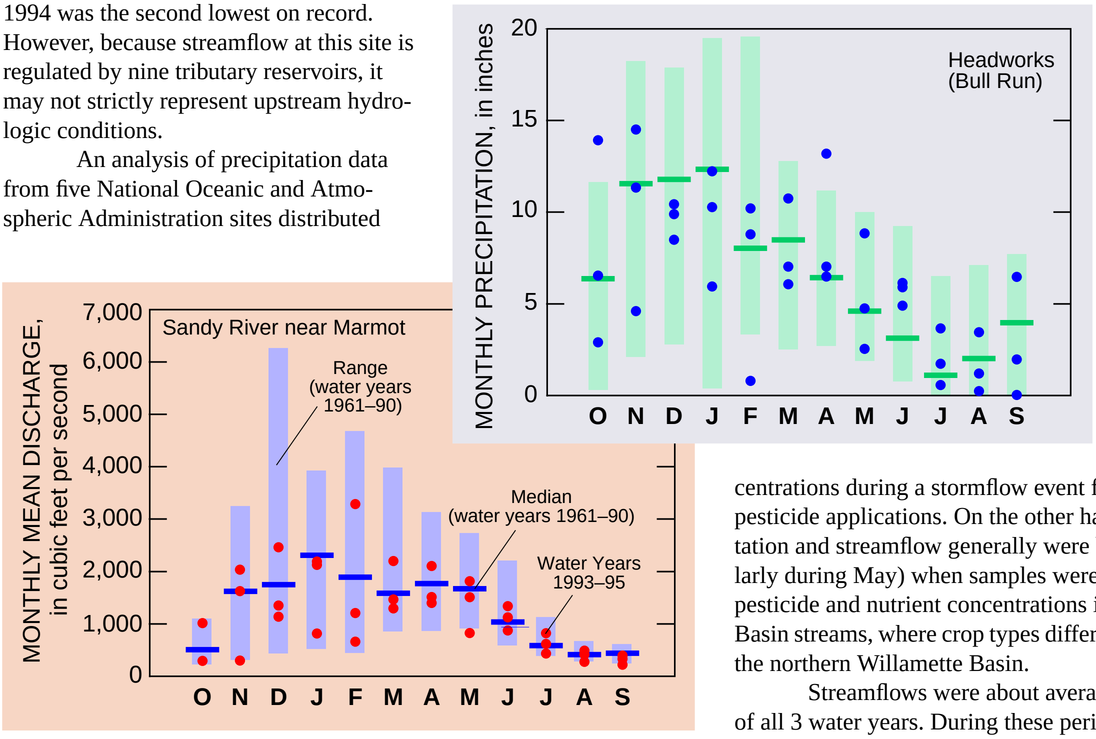


Annual mean discharges for the Willamette River at Albany indicate that water years 1993 and 1995 were typical of long term average conditions, but that discharge for water year 1994 was the second lowest on record.

> ***Annual mean discharges during water years 1993 and 1995 were about average, but discharge for water year 1994 was the second lowest on record.***

Monthly conditions during water years 1993–95 often differed considerably from long-term average conditions. For example, precipitation and streamflow were above average during April 1993 when samples were collected from northern Willamette Basin streams to determine nutrient and pesticide concentrations during a stormflow event following fertilizer and pesticide applications. On the other hand, spring 1994 precipitation and streamflow generally were below average (particularly during May) when samples were collected to evaluate pesticide and nutrient concentrations in southern Willamette Basin streams, where crop types differ somewhat from those in the northern Willamette Basin.

Streamflows were about average during July–October of all 3 water years. During these periods, many streams were wadable, most streams had stable beds, and conditions were ideal for collection of streambed sediment and aquatic biota and for measurement of aquatic habitat characteristics.



Monthly precipitation and monthly mean discharges show that conditions during water years 1993–95 (dots) usually were considerably above or below average (horizontal bars).

Stream sites in the Willamette Basin have been categorized on the basis of relative abundance of fish species (percentage of total fish collected at a given site) by Waite and Carpenter (in press). They distinguished four categories of sites:

- forested reference (n=3);
- small agricultural/urban (n=14);
- large agricultural (n=4); and
- highly impaired (n=3).

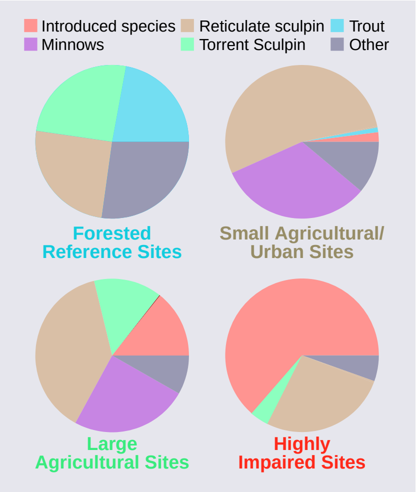
Although land use influences upstream from the highly impaired sites were primarily agricultural, the pie chart shows that fish communities at these sites were quite different from those at other agricultural sites.

A total of 29 fish species, including 10 non-native (introduced) species, were collected from the 24 sites during 1993–95. The most abundant species, in decreasing order of relative abundance, were reticulate sculpin, redside shiner, torrent sculpin, speckled dace, yellow bullhead, and cutthroat trout.

Site Characteristics

Forested reference sites were characterized by high abundances of trout (cutthroat, rainbow) and sculpin (mottled, Paiute, torrent, reticulate); no external anomalies were found on fish from these sites. Fish communities from the other three categories consisted of few or no trout and generally low abundances of pollution sensitive sculpin species (including mottled, Paiute, torrent). As seen in the bar graph, forested sites exhibited the largest riffle areas, most extensive canopies with best riparian quality (greatest species and diversity of vegetation and largest riparian zone), lowest maximum water temperatures, highest minimum dissolved oxygen (DO) percent saturation, lowest nutrient concentrations (example, total nitrogen), and no detections of pesticides (sum of atrazine, metolachlor and simazine).

Small agricultural/urban sites were characterized by high abundances of pollution tolerant fish species (including minnows and reticulate sculpin), low levels of external anomalies, and low abundances of introduced species, such as bullheads, carp, and sunfish. These sites exhibited small riffle areas, moderately open canopies of moderate riparian quality, relatively high maximum water temperatures, lowest minimum DO percent saturation, and highest nutrient and pesticide concentrations.



Fish communities varied significantly among site categories.

Large agricultural sites were characterized by relatively high abundances of torrent and reticulate sculpin, minnows, and introduced species, with moderate levels of external anomalies. These sites exhibited relatively small riffle areas, open canopies of low riparian quality, high maximum water temperatures, and intermediate nutrient and pesticide concentrations.

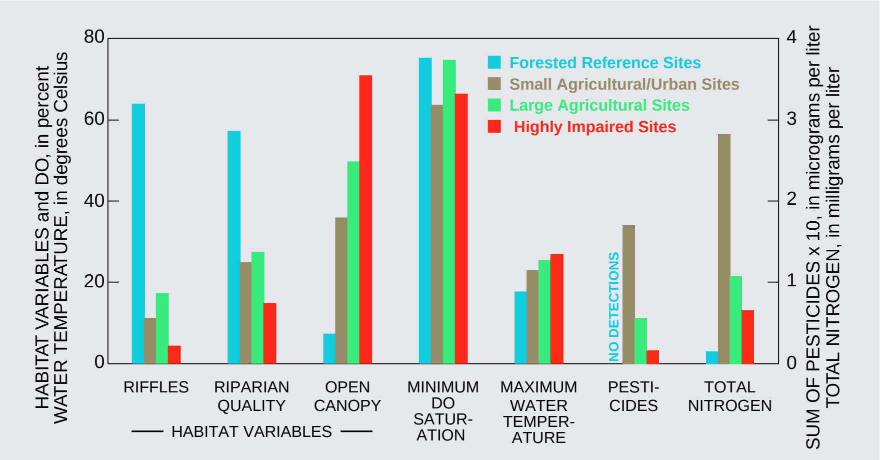
The highly impaired sites—Long Tom River, Bear Creek (tributary to the Long Tom River), and Little Muddy Creek (located north of Eugene and east of the Willamette River)—were characterized by high abundances of introduced species and tolerant reticulate sculpin, and high levels of external anomalies. The Long Tom and Little Muddy sites have been channelized; discharge of the Long Tom River is regulated by an upstream dam; and Bear Creek had poor quality instream habitat. All three sites exhibited relatively low concentrations of nutrients and pesticides; however, the highest maximum water temperatures and percent open canopies, poorest riparian quality, smallest riffle areas, and low minimum DO percent saturation were found at these sites.

Controlling Factors

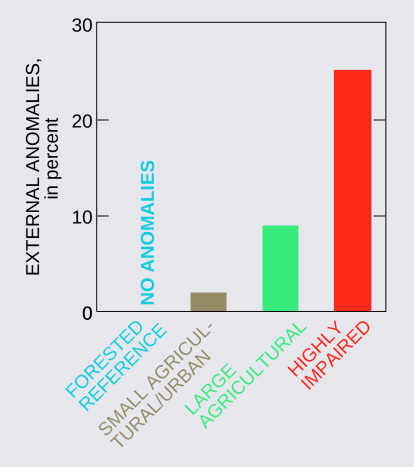
From a basinwide perspective, relative abundances of native fish species were most correlated with the quality of instream and riparian habitat (Waite and Carpenter, in press). Trout and sensitive sculpin species were common at forested reference sites characterized by abundant riffles, closed canopies, and lowest water temperatures. Tolerant reticulate sculpin and minnows dominated fish communities at small agricultural/urban sites, where riffles were rare, canopies were relatively open, and water temperatures were higher than at forested reference sites.

Relative abundances of native fish species were most correlated with the quality of instream and riparian habitat.

Within the small agricultural and urban sites, water chemistry became more important than habitat in controlling fish communities. For example, nutrient and pesticide concentrations and DO percent saturation were critical for understanding fish distributions (Waite and Carpenter, in press). Also, at highly impaired sites, high water



Site categories derived from fish relative abundances reflect average habitat conditions and water chemistry at the sites.



External anomalies were nonexistent at forested reference sites, greatest at highly impaired sites, and intermediate at remaining sites.

temperatures and low DO percent saturation were correlated with high relative abundance of introduced species and with external anomalies, such as anchor worms and lesions.

On the basis of other studies in Oregon and throughout the United States, occurrences of introduced species and external anomalies at rates greater than 2 percent are considered an indication of impaired conditions (Hughes and Gammon, 1987; Karr, 1991). The large agricultural and the highly impaired sites were characterized by introduced and tolerant fish species with relatively high percentages of external anomalies (9 and 25, respectively). Although small agricultural/urban sites exhibited smaller percentages of introduced species and lower numbers of anomalies (2 percent each), these sites also showed higher numbers of tolerant fish and generally were dominated by one or two species—another indication of impairment.

An Index of Biotic Integrity (IBI) (Hughes and others, in press), which expresses fish community structure numerically, has been developed for wadable streams in the Willamette Valley and was applied to the small agricultural/urban sites in the current study. The results suggest that all sites were at least moderately impaired; the five sites with the highest percentages of introduced species also reflected the poorest community structure (lowest IBI scores).

Assessment of fish communities revealed different patterns of impairment among sites and helped develop hypotheses to explain these differences. It also supported the conclusion that identification of all fish species, not just game fish, was needed to allow a complete assessment of ecological health and sound comparisons among all sites. This is demonstrated by the distributions of the four sculpin species commonly collected. Forested reference and small agricultural/urban sites exhibited similar percentages of total sculpins, but the small agricultural/urban sites were dominated by tolerant reticulate sculpin, whereas forested reference sites supported sensitive species that were either less abundant or absent from the other sites.

> ***Identification of all fish species, not just game fish, was needed to allow a complete assessment of ecological health.***

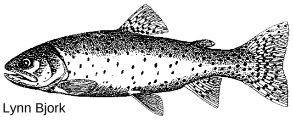
Additional Information

During spring and summer of 1993–95, fish communities, habitat, and water chemistry were evaluated at 6 intensive assessment and 18 synoptic assessment sites (p. 25). Site locations are shown on the ecoregion map on page 24. Fish were not collected at the most downstream (northernmost) Willamette River site on the map.

Fish were collected within a minimum reach length of 500 feet using backpack and boat electrofishing procedures, and all fish were identified to species (Meador and others, 1993*a*).

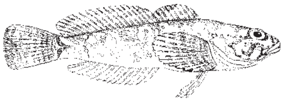
Habitat measurements were made along four to six transects aligned perpendicular to the stream channels. Thirty-eight instream variables (including discharge, velocity, depth, substrate size, percent riffles), and 40 stream channel and bank variables (including channel dimensions, bank height and stability, riparian quality, percent open canopy, tree size and density) were measured (Meador and others, 1993*b*).

Twenty-four water chemistry variables, including stream temperature, specific conductance, and concentrations of dissolved oxygen (DO), nutrients (nitrate, ammonia, total nitrogen, soluble reactive phosphate, total phosphorus), and dissolved pesticides (sum of atrazine, metolachlor, and simazine) were evaluated during high and low flow.



Lynn Bjork

Cutthroat trout was the predominant species in Gales Creek.



Reticulate sculpin dominated the fish community in the Little Pudding River.

Instream and riparian habitat differences are apparent when comparing a forested reference site, such as Gales Creek in the Coast Range (top left) with an agricultural site, such as the Little Pudding River in the Willamette Valley (bottom right).

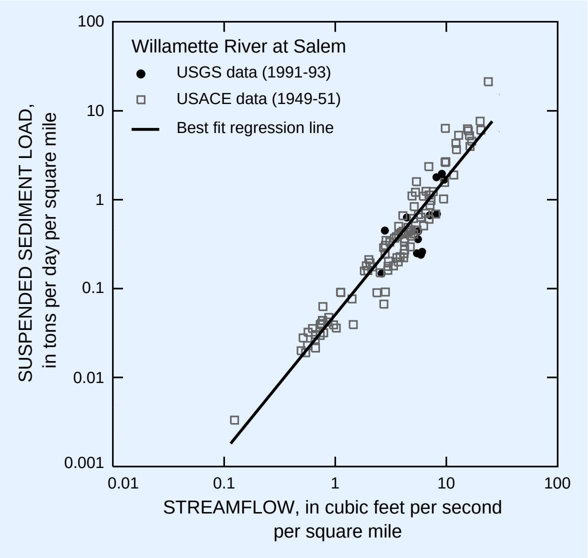
Eleven multipurpose and two reregulation reservoirs (1.88 million acre-feet of usable storage) are operated in the Willamette Basin by the U.S. Army Corps of Engineers (USACE) (Shearman, 1976). Measurements of suspended sediment in streams downstream from dam sites indicate that sediment sources have changed since completion of 10 reservoirs after 1949.

Sediment Transport

Reservoirs intercept sediment and may be expected to change the downstream relationship between suspended sediment load and stream discharge. However, data for Willamette Basin streams indicate that the relationships are similar for pre- and post-reservoir periods. This suggests that erosion has increased downstream from dams since their construction. Possible sources of sediment downstream from dams include channel erosion and erosion of land developed after dam construction.

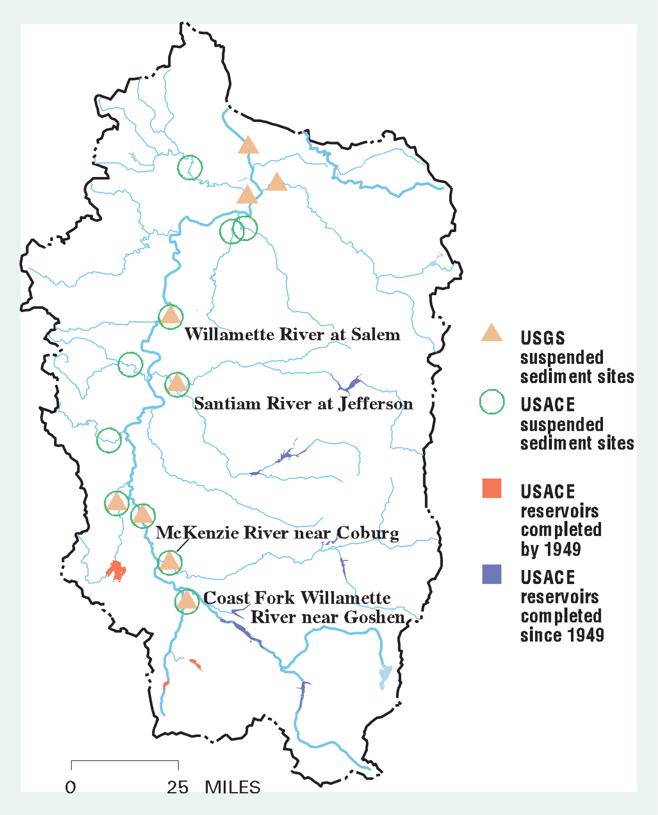
Measurements of suspended sediment in Willamette Basin streams suggest that erosion has increased downstream from dams since their construction.

The graph for the Willamette River at Salem is typical of relationships between suspended sediment load and streamflow for the 14 USGS and/or USACE sites shown on the map (Laenen, 1995). These relationships indicate that annual suspended sediment loads for Willamette Valley tributaries are about twice those for Coastal tributaries and nearly four times those for Cascade tributaries.



Construction of USACE dams since 1949 has not affected downstream relationships between suspended sediment load and streamflow.

At the four sites labeled on the map, data were sufficient to determine that relationships between suspended sediment load and stream discharge downstream from USACE dams were not different during pre- and post-reservoir periods. This is demonstrated by the clustering of 1991–93 data within the area of the graph outlined by the 1949–51 data. The similarity of sediment transport during pre- and post-reservoir periods suggests that the amount of sediment trapped by the reservoirs has been balanced by increased erosion of downstream sediment sources.



USACE reservoirs are located on major tributaries. Suspended sediment and streamflow were measured on the Willamette River and major tributaries.

Particle Size

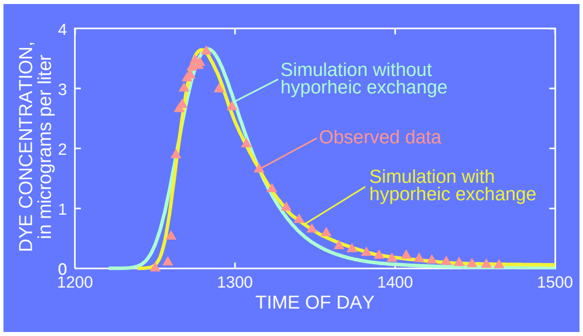
Decreased particle size of suspended sediment downstream from dams since their construction provides further evidence that sediment sources have changed. Particle sizes of suspended sediment for post-reservoir samples were finer than for pre-reservoir samples at some sites (Laenen, 1995). For example, the pre-reservoir average was 65 percent clay and silt for the Willamette River at Salem, whereas the post-reservoir average was 82 percent. For the Santiam River at Jefferson, the pre-reservoir average was 45 percent clay and silt, and the post-reservoir average was 68 percent. The smaller particle size measured since dam construction suggests that a new source is contributing the sediment now being measured downstream from the dams.

Decreased particle size may be important because nutrients, such as phosphorus, and toxic constituents, such as dioxins and furans, chlorinated pesticides, and trace elements, can be transported in association with fine sediment.

Additional Information

Stream discharge, suspended sediment concentrations, and percentages of clay and silt were determined for seven streamflow gaging stations during 1991–93 (Laenen, 1995). Similar data from two additional gaging stations were collected as part of the USGS National Stream Quality Accounting Network. These data were compared to published information available for 11 stream sites (U.S. Army Corps of Engineers, 1954) to evaluate possible changes in sediment transport downstream from USACE reservoirs completed since 1949.

Permeable, coarse-grained, alluvial deposits occur within the channel and flood plain of the main stem Willamette River and many of its tributaries, particularly those draining the Cascade Range. Within these permeable deposits, stream and ground water may exchange within an area known as the hyporheic (hy-po-**ree**-ic) zone—a diffuse and somewhat ill-defined region that forms the boundary between the stream channel and the adjacent ground water flow system. Water in the hyporheic zone flows along the overall downvalley direction of the stream channel, but fluctuates between the channel and the subsurface (Bencala, 1993).

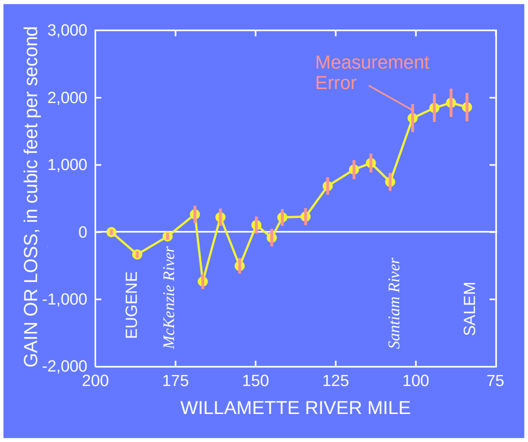


Measured and simulated dye concentrations in the Santiam River in June 1995 provide evidence that hyporheic storage may be important.

Evidence suggests that hyporheic exchange is significant in large streams of the Willamette Basin.

Hyporheic exchange can affect both the quantity and chemistry of water in streams and adjacent aquifers. For example, hyporheic exchange can cause a significant underestimate of stream discharge if a considerable volume of water is flowing within the channel deposits at the point of a streamflow measurement. In addition, because hyporheic exchange involves not only water, but also associated chemicals dissolved in the water, constituents, such as nutrients and pesticides, may undergo important biogeochemical transformations within the hyporheic zone.

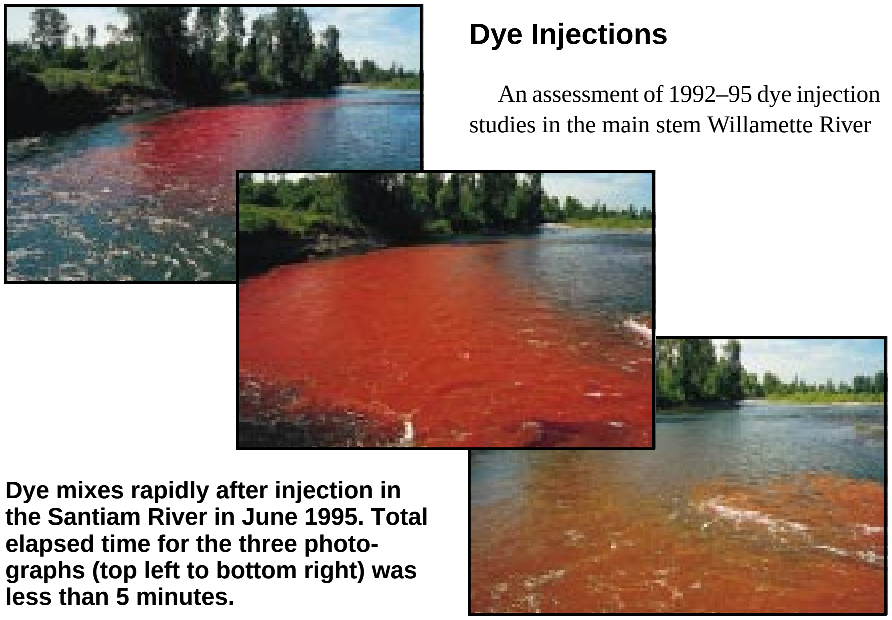
Two lines of evidence suggest that hyporheic exchange is significant in large streams of the Willamette Basin (Laenen and Bencala, 1997). First, injections of rhodamine WT dye in nine streams yielded graphs of dye concentration versus time with long recession times characteristic of active hyporheic exchange. Second, in the Willamette and Santiam Rivers, detailed measurements of water discharge revealed areas where streamflow losses and gains could not be accounted for by tributary inflows or diversions. These data are consistent with stream water entering and leaving the channel through coarse-grained riverbeds.



Willamette River streamflow gains and losses in June 1993 suggest hyporheic exchange.

Dye Injections

An assessment of 1992–95 dye injection studies in the main stem Willamette River and nine major tributaries located throughout the basin showed that the lower Santiam River had the highest potential spatial extent (area) of hyporheic storage relative to river cross-sectional area. In the lower Santiam River, which has a pool-and-riffle, gravel-bed channel, potential hyporheic storage averaged about three times that for Willamette Basin streams with silt-bed channels; the latter are not expected to exhibit much hyporheic exchange. Also, simulation of the dye injection experiment in the Santiam River by assuming no hyporheic exchange resulted in a less precise fit of the curve to the data and is further evidence that hyporheic processes are important.



Dye mixes rapidly after injection in the Santiam River in June 1995. Total elapsed time for the three photographs (top left to bottom right) was less than 5 minutes.

Streamflow Measurements

Detailed streamflow measurements made during periods of one to several days along reaches of the Santiam and Willamette Rivers in 1992–95 showed alternating streamflow gains and losses over short distances. In the main stem Willamette River during June 1993, gains and losses were as much as 15 percent of the total discharge and point to the likelihood of significant hyporheic exchange. The relatively large flow changes occurred between river miles 180 and 140, where the channel is gravelly and braided.

Additional Information

Simulations of dye injection experiments were made using the OTIS model for transport of dissolved constituents (Runkle and Broshears, 1991). An Acoustic Doppler Current Profiler (Simpson and Oltmann, 1993) was used to make multiple discharge measurements along stream reaches during short time periods.

During 1991, about 63,000 tons of nitrogen and 20,000 tons of phosphorus fertilizer were applied in the Willamette Basin (Rinella and Janet, 1998). These elements are essential nutrients for aquatic plants; however, in high concentrations, they can cause excessive growth (eutrophication) that chokes stream channels. In drinking water, high nitrate concentrations cause methemoglobinemia or "blue baby" syndrome, which can be fatal to infants.

Excessive algal growth in the Little Pudding River results from high nutrient concentrations.

Nitrate in Streams

Ninety-eight percent of stream samples contained detectable nitrate concentrations: values ranged from 0.054 to 22 mg/L as nitrogen. The lowest nitrate concentrations were in streams draining predominantly forested basins (greater than 90 percent forest, by area).

Although none of the streams sampled were used as a source of drinking water, the 10 mg/L maximum contaminant level (MCL) established for drinking water protection by the U.S. Environmental Protection Agency (USEPA, 1996) is a widely accepted standard for comparing nitrate concentrations. Nitrate concentrations exceeded the MCL in Bear and Zollner Creeks in the Pudding Basin northeast of Salem. Both streams drained predominantly agricultural land (greater than 50 percent agricultural land, by area).

Nitrate concentrations in streams increased as the percent of drainage area in agriculture increased.

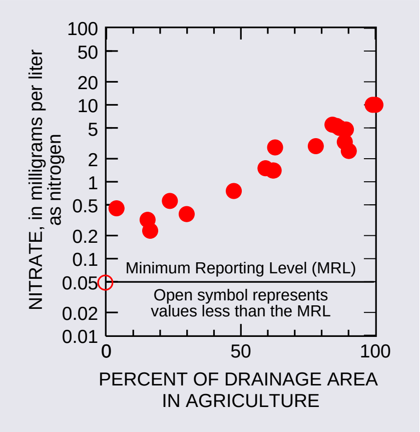
In general, nitrate concentrations in streams increased as the percent of drainage area in agriculture increased. An example of this relationship is presented for 20 watersheds, ranging in size from 3.4 to 490 square miles, in the Pudding and Molalla Basins during April 26–29, 1993.

Nitrate concentrations varied seasonally during 1993–95, as shown for the Pudding River at Aurora (drainage area, 490 square miles). The highest concentrations coincided with the beginning of rainfall induced runoff during late fall/early winter. A similar relationship was found for historic data in streams of the Willamette Basin (Bonn and others, 1995; 1996).

Phosphorus in Streams

Ninety-five percent of stream samples contained detectable concentrations of total (dissolved plus suspended) phosphorus, ranging from 0.01 to 1.3 mg/L. Soluble reactive phosphorus (SRP, essentially dissolved orthophosphate) was detected in 89 percent of stream samples and varied from 0.01 to 0.93 mg/L.

Forty-five percent of streams yielded total phosphorus concentrations that exceeded 0.1 mg/L, the maximum value cited by the USEPA (1986) as a goal for prevention of nuisance plant growth in streams. Sixty-eight percent of streams where total phosphorus concentrations exceeded 0.1 mg/L drained largely agricultural land. In Pudding and Molalla Basin streams during April 1993, SRP concentrations increased with the percent of drainage area in agriculture, in a manner similar to that for nitrate. The lowest total phosphorus and SRP concentrations were observed in streams draining predominantly forested basins.



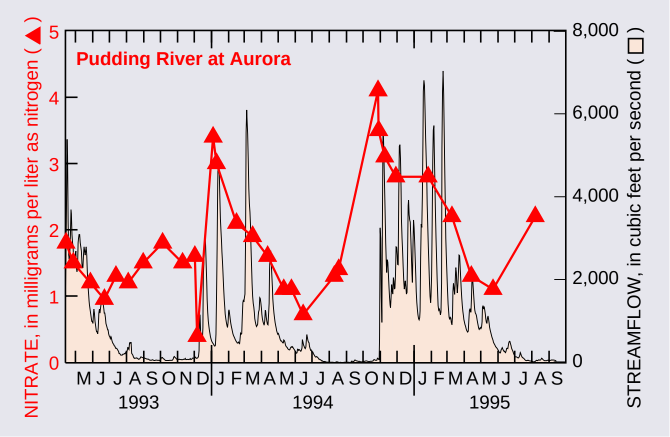
Nitrate concentrations in streams in the Pudding and Molalla Basins increased with percent of drainage area in agriculture, April 26–29, 1993.

Data for the Pudding River show that total phosphorus and SRP concentrations varied seasonally. The highest total phosphorus concentrations generally coincided with the beginning of the fall/winter runoff period and probably were associated with the transport of suspended sediment. SRP concentrations were high during winter, but generally were higher during summer when contributions from point sources were greater relative to streamflow and, thus, dilution was less. Point sources contributed most of the SRP during summer low flow in 1994.

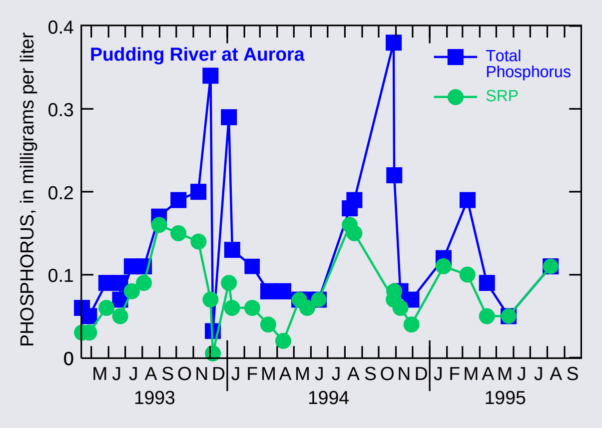
Forty-five percent of streams yielded total phosphorus concentrations that exceeded a value cited as a goal for prevention of nuisance plant growth.

Nitrate in Ground Water

Nitrate concentrations in ground water exceeded the USEPA MCL of 10 mg/L in 6 of 70 shallow domestic wells (about 9 percent) sampled in the Willamette Basin in



Maximum stream nitrate concentrations occurred when flows increased during late fall/early winter.



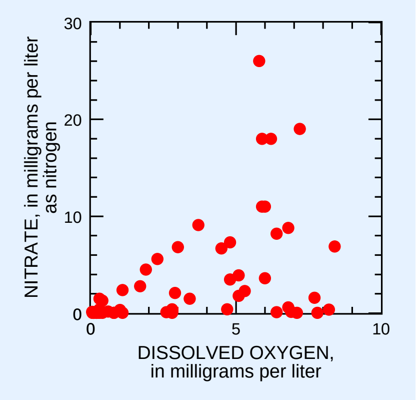
Total phosphorus concentrations in streams were highest in late fall/early winter when flows increased. SRP concentrations were highest in late summer when dilution by streamflow was minimal.

Irrigation can accelerate transport of nitrate to shallow ground water in heavily fertilized areas.

1993 as part of the NAWQA Program. In contrast, the MCL was exceeded for 21 percent of 123 shallow domestic wells sampled by Oregon Department of Environmental Quality (ODEQ) during the 1980s (Bonn and others, 1995). Because ODEQ focused on known or perceived problems, a greater percentage of exceedances for their data is not unexpected.

As seen from the graph, nitrate concentrations generally were higher in ground water with high dissolved oxygen (DO) concentrations than in ground water with low DO concentrations. Microbial reduction of nitrate, common in low DO ground water, is one likely explanation for the near absence of nitrate under low DO conditions.

Nitrate concentrations in ground water exceeded the USEPA MCL of 10 mg/L in 6 of 70 shallow domestic wells sampled in 1993.

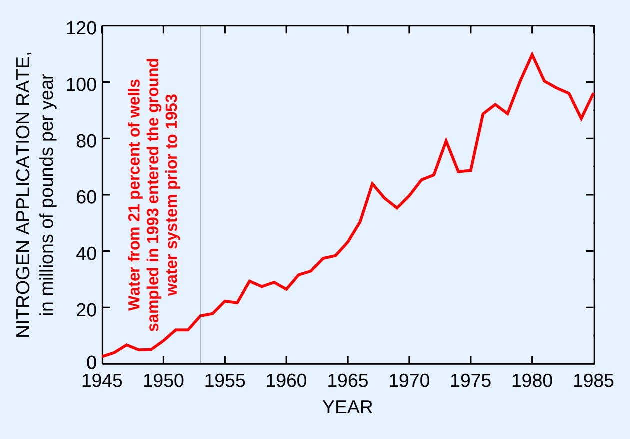


Nitrate concentrations in ground water were low where dissolved oxygen concentrations were low.

Nitrate concentrations were greater where aquifer permeability was high than where aquifer permeability was low. Ground water in aquifers with low permeability tends to be older than in aquifers with high permeability. Because nitrogen fertilizer application rates in the Willamette Basin have increased in recent decades, older ground water would be expected to contain lower nitrate concentrations.

Nitrate concentrations were greater downgradient from irrigated agricultural areas than from nonirrigated agricultural areas. This pattern may reflect the generally greater application rate of nitrogen on irrigated crops (compared with nonirrigated crops) and the flushing effect of irrigation.

To a large degree, nitrate concentrations in ground water reflect land use practices at the time the water infiltrated into the soil, and these practices may not have been the same as when the ground water was sampled. For example, low tritium concentrations in water from 21 percent of the wells sampled in 1993 indicate that this water entered the ground before 1953 when nitrogen application rates also were low.



Nitrogen fertilizer application rates in the Willamette Basin have increased since 1945. (Data from Alexander and Smith, 1990.)

Because nitrogen fertilizer application rates in the Willamette Basin have increased in recent decades, nitrate concentrations in ground water pumped during 1993 probably reflect application rates that were less than 1993 rates. Water pumped in the future may contain higher nitrate concentrations than in 1993, as the increasing fertilizer application rates of the past continue to influence ground water quality downgradient from application areas. Because of the time lag between infiltration of water into the ground and its arrival at a downgradient well, effects of past and present ground water management practices may take years or decades to become apparent in ground water pumped from shallow domestic wells.

Additional Information

During 1993–95, more than 260 stream samples were collected for analysis of nutrients from 51 sites located throughout the Willamette Basin (p. 25). Site locations are shown on the land use map on page 24.

In 1993, 70 shallow domestic wells from throughout the Willamette Valley were sampled for nutrients (p. 25). The wells selected for sampling were completed in alluvium because more than 80 percent of ground water used in the Willamette Basin is pumped from alluvial aquifers. Site locations are shown on the hydrogeology map on page 24.

Detailed analyses of the data are presented by Rinella and Janet (1998) for surface water and by Hinkle (1997) for ground water.

About 4.5 million pounds of pesticides are used each year in the Willamette Basin to control weeds, insects, and other pests in agricultural and urban settings (Rinehold and Witt, 1992). Many pesticides are relatively soluble in water, whereas others attach strongly to soil particles. Pesticides are transported from the land surface to streams through a combination of subsurface drainage, surface runoff, and soil erosion. Infiltration of rain and irrigation water facilitate transport of pesticides to ground water.

Herbicides, such as atrazine, are applied primarily in spring and early summer.

Volatile organic compounds (VOCs) are synthetic organic compounds that include two main categories: (1) non-halogenated, fuel-related components, such as benzene, toluene, ethylbenzene, and xylenes (BTEX), and (2) chlorinated solvents, such as chloroform, trichloroethene (TCE), and tetrachloroethene (PCE). Because of their uses, VOCs are typically associated with urban environments. Examples of VOC sources include leaky underground storage tanks and emissions from automobiles. In drinking water, they may be carcinogenic or otherwise harmful to human health.

Pesticides in Streams

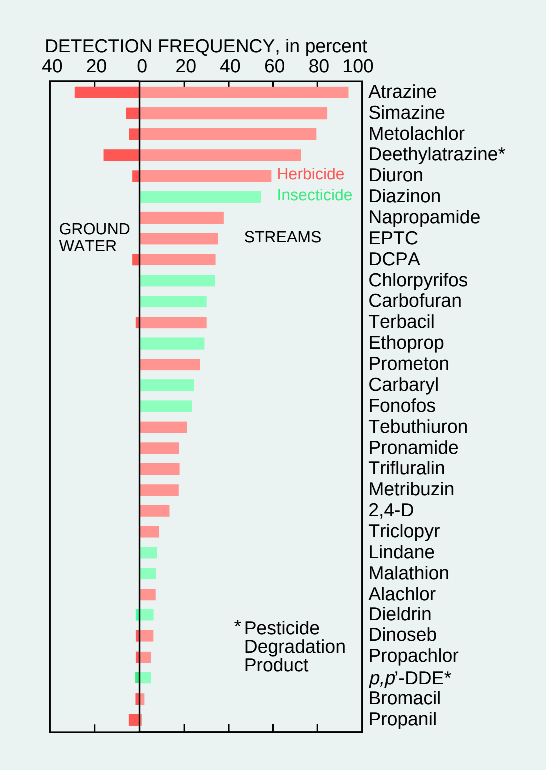
Of 86 dissolved pesticides (herbicides, insecticides, fungicides) and pesticide degradation products analyzed in streams as part of this study, 50 were detected at concentrations greater than or equal to about 0.001 µg/L (micrograms per liter). Of the most frequently detected pesticides, the majority were herbicides.

Atrazine, simazine, metolachlor, deethylatrazine, diuron, and diazinon were the most commonly detected pesticides in stream water. All were found in more than 50 percent of the samples analyzed. Other pesticides were detected in less than 50 percent of all samples.

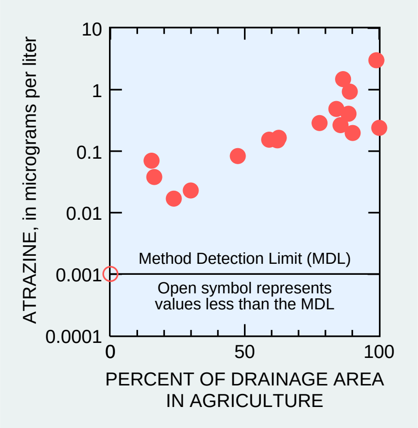
Maximum recorded pesticide concentrations in stream water were: diuron (14 µg/L), carbofuran (9.0 µg/L), simazine (5.8 µg/L), atrazine (4.5 µg/L), and metolachlor (3.3 µg/L). Eight pesticides were detected at 1–2 µg/L.

Criteria for the protection of freshwater aquatic life from chronic toxicity (as summarized by Gilliom and others, in press) were exceeded for 10 pesticides, including atrazine (4 of 183 detections), azinphos-methyl (3 of 3 detections), carbaryl (17 of 46 detections), carbofuran (3 of 51 detections), chlorpyrifos (4 of 65 detections), diazinon (66 of 105 detections), *p,p'*-DDE (6 of 8 detections), diuron (24 of 83 detections), lindane (1 of 13 detections), and malathion (1 of 12 detections).

In one sample each, atrazine and simazine exceeded their maximum contaminant levels (MCLs) of 3 and 4 µg/L, respectively, as established by the USEPA (U.S. Environmental Protection Agency, 1996) for protection of drinking water. Although the stream where the exceedances occurred (Zollner Creek, northeast of Salem) was not used as a drinking water source, the MCLs are widely accepted criteria for comparing concentrations.



Most of the pesticides detected in streams and ground water were herbicides.



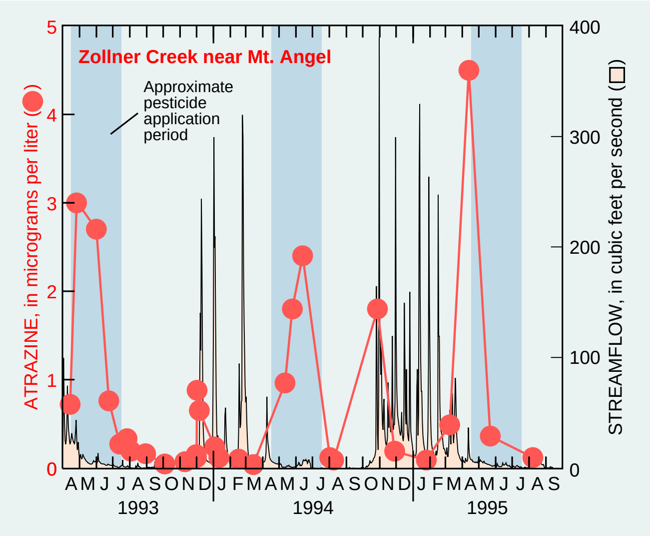
Atrazine concentrations increased with percent of drainage area in agriculture for Pudding and Molalla Basin streams, April 26–29, 1993.

All aquatic life criteria and MCL exceedances occurred at sites draining mostly (greater than 50 percent, by area) agricultural or urban land; the highest pesticide concentrations occurred in agricultural basins.

Atrazine concentrations in streams, like those for nitrate, increased with percent of drainage area in agricultural land, as seen for 20 watersheds less than 490 square miles in the Pudding and Molalla Basins during April 26–29, 1993. Simazine and metolachlor concentrations at these sites behaved similarly to atrazine.

Criteria for the protection of freshwater aquatic life from chronic toxicity were exceeded for 10 pesticides in streams.

Forty-nine pesticides were detected in streams draining predominantly agricultural land. Forty-three of these pesticides were found in Zollner Creek, which has a drainage basin that is 99 percent agricultural. In contrast, 25 pesticides were detected in urban streams, and 23 of these were found in Fanno Creek, a basin in the Portland metropolitan area that is 92 percent urbanized. Herbicides were detected at twice the rate of insecticides in both agri-



Atrazine concentrations were highest during spring following pesticide application, but relatively high concentrations also occurred during fall runoff.

cultural and urban streams. Only atrazine and deethylatrazine were detected in streams draining forested basins (greater than 90 percent forest, by area), and these compounds were present at extremely low concentrations (0.002 to 0.004 µg/L).

Of the six most frequently detected pesticides, all but diazinon were found at highest concentrations in predominantly agricultural streams. Diazinon concentrations were similar in agricultural and urban streams. Three herbicides—prometon, tebuthiuron, and dichlobenil—were detected most frequently in urban streams.

Concentrations of the six most frequently detected pesticides varied seasonally. For example, the graph for Zollner Creek shows that the highest atrazine concentrations generally coincided with spring runoff following application; however, relatively high concentrations also were found during late fall/early winter when increasing rainfall flushed land that had been dry most of the summer.

Pesticides and Volatile Organic Compounds in Ground Water

One to 5 pesticides were detected in water from each of 23 domestic wells (about one-third of the wells sampled); 13 different pesticides were detected at these sites. Concentrations ranged from less than 0.001 to 0.89 µg/L, with one exception: dinoseb (an herbicide) was detected in water from one well at 7.9 µg/L, which is greater than the MCL of 7 µg/L. This was the only measured exceedance of an MCL for pesticides in ground water.

Ground water with detected pesticides generally came from domestic wells penetrating smaller thicknesses of overlying clay than did ground water containing no detected pesticides. This is partly because pesticides tend to be retained by clay particles. In addition, ground water flows more slowly through clay than it does through coarser grained materials, and the increased contact time with the clay allows greater pesticide degradation.

Only one pesticide and one VOC were detected in ground water from domestic wells at concentrations greater than the USEPA MCL for drinking water.

Pesticides were present at lower concentrations and detection rates in water from urban monitoring wells than from the mostly agricultural domestic wells, possibly reflecting smaller pesticide application rates in urban areas compared to agricultural areas. Trace concentrations (less than 0.01 µg/L) of one or two pesticides were detected in water from three urban monitoring wells, but no USEPA MCLs were exceeded.

One to five VOCs were detected in water from each of seven domestic wells. Six different VOCs were detected, but only tetrachloroethene (one occurrence) exceeded the 5 µg/L MCL.

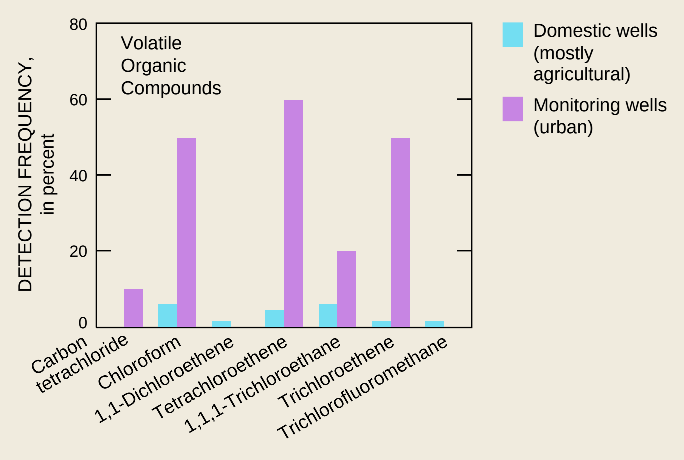
VOCs were detected in water from a greater percentage of urban monitoring wells than from the mostly agricultural domestic wells, probably reflecting a larger number of point and nonpoint sources of VOCs associated with urban land use practices. From one to four VOCs were detected in water from eight monitoring wells. Five different VOCs were detected; tetrachloroethene exceeded the MCL in one well.

Additional Information

During 1993–95, 195 samples were collected from 43 stream sites in the Willamette Basin for analysis of dissolved pesticides and pesticide degradation products (p. 25). At four sites, pesticides were analyzed monthly and during extremes in streamflow. Pesticides were analyzed at 39 additional sites during periods of one week or less to examine spatial distributions during high and low streamflow. Site locations are shown on the land use map on page 24.

During 1993–95, 69 of 70 shallow domestic wells and 10 shallow USGS monitoring wells were sampled for pesticides, whereas 65 of 70 shallow domestic wells and the 10 USGS monitoring wells were sampled for VOCs. Site locations are shown on the hydrogeology map on page 24. Because more than 80 percent of ground water used in the Willamette Basin is pumped from alluvial aquifers, only wells completed in alluvium were sampled. Most of the domestic wells were in agricultural settings. USGS monitoring wells were in urban areas comprising primarily residential land, with small amounts of interspersed commercial property.

Laboratory procedures for VOCs and pesticides are given by Rose and Schroeder (1995), Werner and others (1996), and Zaugg and others (1995). Detailed analyses of the Willamette Basin data are presented by Rinella and Janet (1998) for surface water and by Hinkle (1997) for ground water.



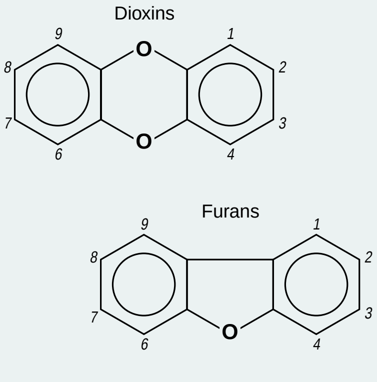
VOCs in ground water were detected mostly in urban areas.

Dioxins and furans are organic chemicals that are of environmental interest because of their acute toxicity to some animal species. Recently, they have been implicated as potential endocrine disrupters—chemicals that can interfere with the normal function of hormones, and thereby affect reproductive success. A review of health risks associated with dioxins and furans has been published in Environmental Science and Technology (1995, v. 29, p. 24A–35A).

Structure, Toxicity, and Sources

Dioxins and furans are not single chemicals, but rather families of related compounds that differ in the number and position of their chlorine atoms. Each different compound is called a congener. Congeners that have the same number of chlorine atoms form a congener class.

Toxicity varies among congeners. The most toxic congener is 2,3,7,8-TCDD (tetrachlorodibenzo-*p*-dioxin), which has four chlorine atoms located at the 2,3,7, and 8 positions. Toxicity decreases as chlorine atoms are added or removed. For example, OCDD (octachlorodibenzo-*p*-dioxin), the congener with eight chlorine atoms, is considered a thousand times less toxic than 2,3,7,8-TCDD. However, regardless of the number of chlorine atoms, the most toxic congeners are those that have chlorine atoms in at least the 2,3,7, and 8 positions. Because toxicity varies among congeners, concentrations of dioxins and furans can be expressed as equivalent concentrations of 2,3,7,8-TCDD in order to provide an indication of potential total toxicity.



Dioxins and furans contain from one to eight chlorine atoms located in the positions indicated by the numbers 1–4 and 6–9. There are 75 different dioxin congeners and 135 different furan congeners. Dioxins and furans containing four or more chlorine atoms were analyzed in this study.

Toxicity of dioxins and furans also varies widely among animal species. The USEPA has estimated that 2,3,7,8-TCDD equivalent concentrations below 60 pg/g (picograms per gram) in sediment are of low risk to fish exposed to the sediment (U.S. Environmental Protection Agency, 1993). Similarly, concentrations below 50 pg/g in fish tissue are estimated to be of low risk to predator fish.

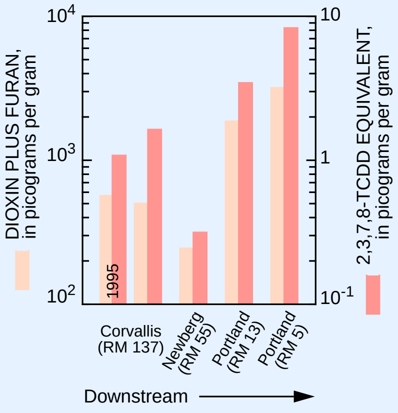
Dioxins and furans are not deliberately manufactured. Rather, small quantities of these compounds are inadvertently produced as by-products of a variety of industrial processes. Two important sources are waste incineration, especially of plastics, and effluent discharge from pulp and paper mills that use chlorine bleaching. In addition, dioxins and furans are trace contaminants in many chlorinated chemicals, such as some wood preservatives and pesticides. Chlorination of sewage effluent also may produce dioxins and furans.

Concentrations in Bed Sediment

A survey of dioxin and furan occurrence in the Willamette Basin during 1992–95 found a wide range of concentrations in bed sediment, with the highest concentrations being about 1,000 times greater than the lowest concentrations (Bonn, 1998; in press). Samples from industrial areas generally contained the highest concentrations. Concentrations of 2,3,7,8-TCDD equivalent were found at levels greater than the USEPA threshold for risk to fish at two sites (A-3 Channel in Eugene and Middle Fourth Lake near Albany), both of which are downstream from industrial areas.

Throughout the basin, total dioxin and furan concentrations were 100–1,000 times more than 2,3,7,8-TCDD equivalent concentrations because the most abundant congeners also were the least toxic. OCDD was the dominant congener found in bed sediment. It accounted for about 80 percent of total concentrations. The sum of concentrations for the TCDD congener class was usually about 100 times lower than the OCDD concentration at the same site, and 2,3,7,8-TCDD was rarely detected.

Dioxins were detected in every bed sediment sample, including those from forested reference basins, such as Mack Creek in the Cascade Range east of Eugene and Fir Creek in the Bull Run Watershed east of Portland. Concentrations below 100 pg/g occurred in sediment from Mack Creek and from Cottage Grove Reservoir, which receives drainage from a large forested basin. Concentrations at other forested sites were somewhat higher (100–300 pg/g) and were similar to those at agricultural sites.

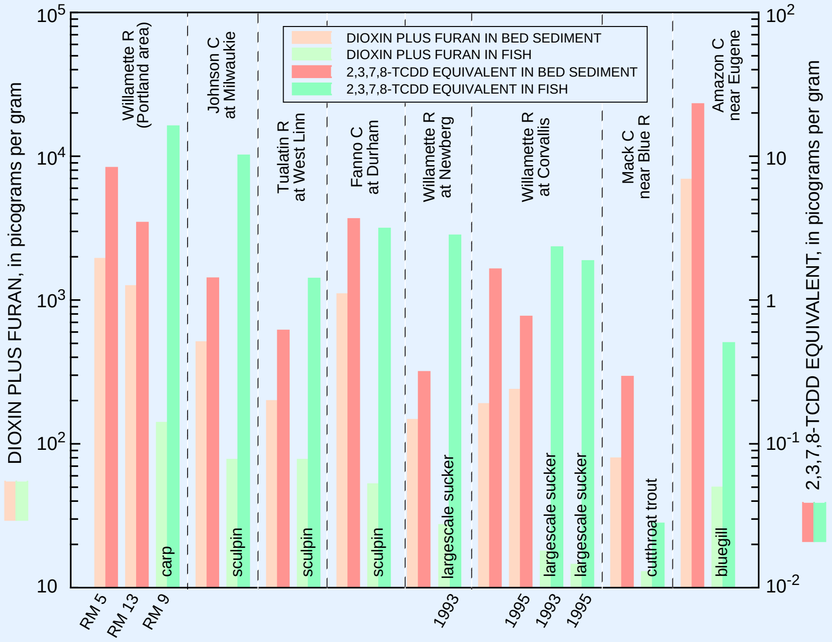


Dioxin and furan concentrations in bed sediment from the main stem Willamette River increased downstream from Newberg through the Portland area. Because the less toxic congeners predominated, 2,3,7,8-TCDD equivalent concentrations were 100–1,000 times less than total dioxin and furan concentrations. [Note different ordinate scales; samples collected in 1992 unless otherwise indicated.]

Atmospheric deposition contains low concentrations of dioxins and furans from wood burning and waste incineration. This is the most likely source of these compounds in bed sediment at forested and agricultural sites. Low concentrations at Mack Creek and Cottage Grove Reservoir probably result because these sites are farther from atmospheric sources than other sampling sites. In general, dioxin and furan concentrations at forested and agricultural sites in the Willamette Basin are similar to or less than those at reference sites located elsewhere in the United States where atmospheric deposition is the presumed source.

Atmospheric deposition is the most likely source of dioxins and furans in bed sediment at forested and agricultural sites.

In addition to atmospheric deposition, some sites may be influenced by specific local sources. For example, a bed sediment



Dioxin and furan concentrations in fish tissue were much lower than in bed sediment obtained from the same area. Fish tissue, however, generally contained greater proportions of the most toxic congeners (especially 2,3,7,8-TCDD) than sediment. Consequently, 2,3,7,8-TCDD equivalent concentrations usually were higher in fish than in bed sediment at a given site. [Note different ordinate scales; samples collected in 1992 unless otherwise indicated.]

sample obtained beneath a wooden bridge at one forested reference site showed unusually high concentrations of furans. Other samples obtained from the same general area, but upstream from the bridge, did not. The high furan concentrations may have been associated with wood preservatives used on the bridge.

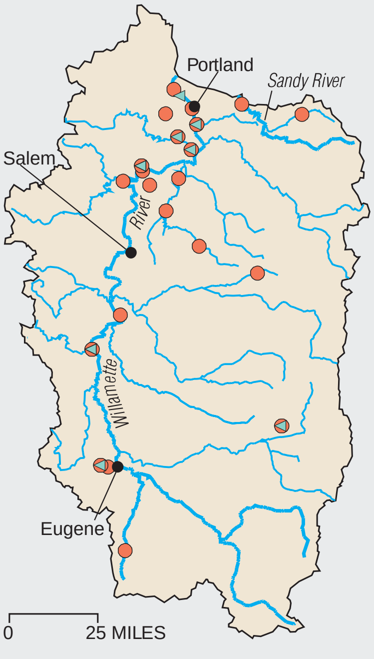
In the main stem Willamette River, dioxin and furan concentrations in bed sediment increased as the predominant adjacent land use changed from agricultural to industrial. Sediment from RM (river mile) 55 near Newberg exhibited essentially background concentrations. In contrast, higher concentrations at RMs 13 and 5 may reflect chemical use and production in the Portland Harbor area. Interestingly, sediment from Corvallis (RM 137) contained considerably higher 2,3,7,8-TCDD equivalent concentrations than that from Newberg, even though total concentrations were not very different. This is because the Corvallis site exhibited a larger proportion of 2,3,7,8-TCDD than the other sites. The Corvallis site is downstream from a pulp and paper mill that has used elemental chlorine bleaching—a process known to produce trace amounts of 2,3,7,8-TCDD. The measured decrease in concentration of 2,3,7,8-TCDD equivalent in bed sediment at Corvallis between 1992 and 1995 may be related to the mill's reduction of elemental chlorine use in 1993.

Concentrations in Fish Tissue

Dioxin and furan concentrations in whole fish generally were about 10 times less than in bed sediment from the same area. However, when expressed as 2,3,7,8-TCDD equivalent, concentrations in fish exceeded those in sediment at more than one-half the sites because fish contained a larger proportion of the most toxic compounds (2,3,7,8-chlorinated congeners and TCDD) than did sediment.

No fish analyzed in this study contained 2,3,7,8-TCDD equivalent concentrations that exceeded the USEPA threshold for risk to predator fish.

No fish analyzed in this study contained 2,3,7,8-TCDD equivalent concentrations that exceeded the USEPA threshold for risk to predator fish. The highest 2,3,7,8-TCDD equivalent concentrations in fish tissue occurred in carp (16 pg/g) from the Willamette River at RM 9 (an industrial section of the Portland Harbor) and in sculpin (10 pg/g) from lower Johnson Creek (an area with considerable adjacent urban land and light industry).



Additional Information

Bed sediment samples (●) were obtained from 22 sites; composite samples of 5–20 whole fish (◁) were obtained from 8 sites (p. 25). Industrial, urban, agricultural and forested reference areas were represented. Three reaches of the main stem Willamette River were sampled both for bed sediment and fish tissue.

All samples were analyzed for tetra- through octa-chlorinated congener class totals of dioxins and furans. In addition, concentrations of all congeners with chlorine atoms in at least the 2,3,7, and 8 positions were determined. Results are expressed as picograms per gram dry weight. Detailed analyses of the data are presented by Bonn (1998; in press).

Organochlorine pesticides and polychlorinated biphenyls (PCBs) are synthetic organic chemicals that have been linked to reproductive problems in aquatic invertebrates, fish, birds, and mammals. PCBs were used in the manufacture of electrical equipment, such as capacitors and transformers. Use and manufacture of PCBs and the pesticides chlordane, DDT, dieldrin, and toxaphene have been restricted or banned in the United States since the late 1980s or earlier, but they are still present in aquatic systems because of their environmental persistence. Similarly, many trace elements have important anthropogenic sources and are toxic at high concentrations; however, they also can have natural geologic sources, and some are essential for biological function. Organochlorine pesticides, PCBs, and trace elements are more likely to be associated with sediment or incorporated into tissue than to be dissolved in water. Thus, bed sediment and aquatic biota were used to evaluate general levels of occurrence and spatial distributions of these constituents.

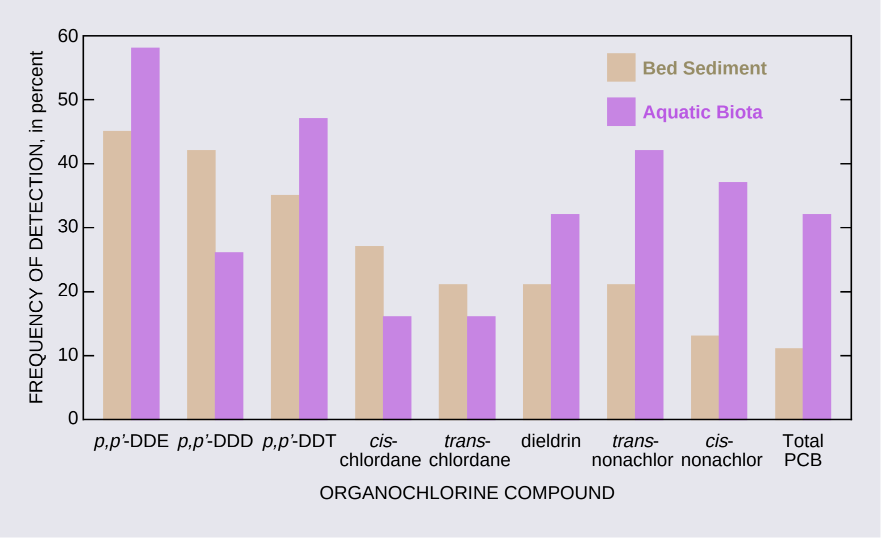
Organochlorine Pesticides and PCBs

Of 27 organochlorine compounds analyzed both in bed sediment and aquatic biota during 1992–95, 19 were detected in sediment, and 14 were detected in biota. The most common compound in sediment and biota was *p,p'*-DDE, a degradation product of DDT, which was used extensively to control insects from about 1940 until its ban in 1972. Concentrations of *p,p'*-DDE were detected at 45 percent of sites where bed sediment was collected and at 63 percent of sites where aquatic biota were collected. Detections were about equally divided among basins with predominantly agricultural, urban (residential, commercial, industrial), and mixed land uses. Detections were more common in biota than in sediment.

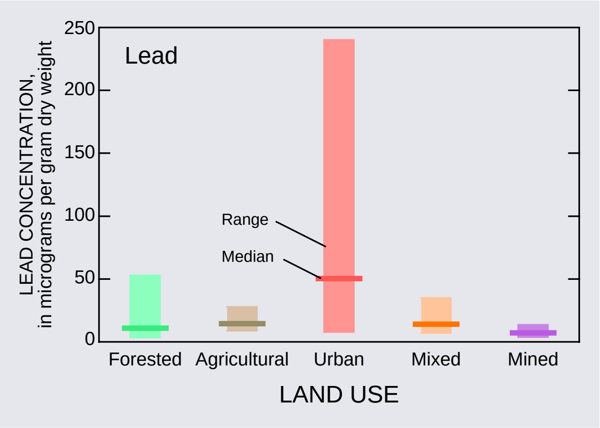
The largest concentration of *p,p'*-DDE in bed sediment (120 micrograms per kilogram dry weight) was found in upper Johnson Creek east of Portland, where the basin is mostly agricultural. This value is higher than reported for the agricultural Central Columbia Plateau Basin, Washington (Gruber and Munn, 1996), but it is less than one-tenth the maximum concentration reported for the Yakima Basin, Washington, where DDT contamination in runoff from agricultural land has been documented (Rinella and others, 1992; 1993).

The most common organochlorine compound was p,p'-DDE, a degradation product of DDT.

Total PCBs were detected at 11 percent of sites where bed sediment was collected, but detections were reported for 32 percent of sites where aquatic biota were collected. All sediment and biota with PCB detections were from streams draining areas with strong urban influences.



Most organochlorine compounds were detected more frequently in aquatic biota than in bed sediment.



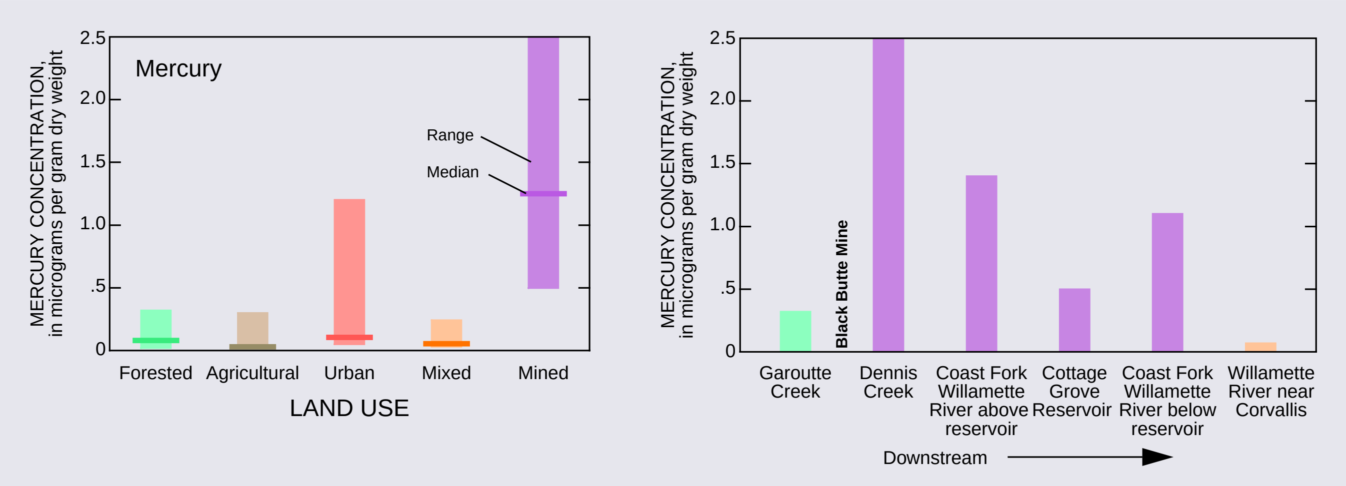
The highest lead concentrations in bed sediment were found in urban streams.

Recommended concentration guidelines for protection of aquatic life from organochlorine pesticides and PCBs in bed sediment are summarized by Gilliom and others (in press). Criteria for protection of fish-eating wildlife have been recommended by the National Academy of Sciences and National Academy of Engineering (NAS/NAE) (1973). Chlordane and its component compounds (six sites), and DDT and its degradation products (six sites) accounted for 94 percent of exceedances of recommended guidelines in bed sediment. Ten of 47 sites exhibited exceedances; two agricultural, one urban, and one urban/industrial basin accounted for 77 percent of the exceedances. Organochlorine pesticide and PCB concentrations in fish tissue from 17 sites did not exceed the NAS/NAE criteria.

Trace Elements

Arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc are of particular interest in the Willamette Basin because they are potentially toxic to aquatic organisms and are widespread by-products of human activities (Rickert and others, 1977). Of these, median chromium and nickel concentrations in bed sediment showed no obvious differences for streams draining forested, agricultural, urban, or mined areas.

Lead concentrations in bed sediment were significantly higher for streams draining urban areas than for streams draining other land uses. Median lead concentrations from urban areas were 50 µg/g (micrograms per gram) dry weight; the highest value was 240 µg/g dry weight



Mercury concentrations in bed sediment were higher in urban areas than in forested or agricultural areas (left). Mercury concentrations were highest below the Black Butte Mine, and they generally decreased downstream (right).

from Beaverton Creek—an urban stream in the Portland area. Median values for all other land uses were 14 µg/g dry weight or less. Common lead sources in urban environments include batteries, dyes, and paints. Much of the lead probably also was contributed by leaded gasoline, which is no longer sold but is persistent in the environment. Distributions of cadmium, silver, and zinc in relation to land use were similar to that for lead.

Mercury concentrations in bed sediment were highest downstream from an abandoned mercury mine.

Although mercury concentrations in bed sediment generally were higher in urban areas than in forested or agricultural areas, the highest values were downstream from the abandoned Black Butte Mine, south of Eugene. This area was mined for cinnabar until about 1968 and was the second largest producer of mercury in Oregon (Brooks, 1971). The relationship of arsenic to land use was similar to that for mercury; copper concentrations were elevated downstream from the mined area but were not consistently high in urban areas.

Mercury concentrations in bed sediment generally decreased downstream from the Black Butte Mine. The affected area includes Cottage Grove Reservoir (located on the Coast Fork Willamette River), where a mercury advisory warning of health risks from consumption of fish has been in effect since 1979 (Newell and others, 1996). Mercury concentrations as high as 1.79 µg/g wet weight have been reported for fillets from largemouth bass collected in this reservoir (Allen-Gil and others, 1995; Newell and others, 1996). In February 1997, the Oregon Health Division issued a mercury advisory for consumption of smallmouth bass, largemouth bass, and northern squawfish from the entire main stem Willamette River, including the Coast Fork to Cottage Grove Reservoir; a separate advisory was issued for consumption of all fish from Dorena Reservoir, which also is located in the Coast Fork Basin.

Guidelines for protection of aquatic life from trace element concentrations in bed sediment have been recommended by Environment Canada (1995). The most commonly exceeded guidelines were for nickel (12 sites) and chromium (15 sites), which occur naturally at high concentrations in basaltic rocks (Parker, 1967), such as those found in much of the Willamette Basin. The next most commonly exceeded guidelines were for arsenic (eight sites) and mercury (six sites); four of the mercury exceedances were for samples collected downstream from the abandoned Black Butte Mine. Zinc and lead concentrations exceeded guidelines at four and three sites, respectively, and no exceedances were found for cadmium or copper. Exceedances for at least one trace element occurred at 26 of 52 sites.

Although fewer samples of aquatic biota than bed sediment were collected for analysis of trace elements, results in relation to land use generally were similar. No well established guidelines were available for evaluating risks of trace elements in aquatic biota to fish-eating wildlife.

Additional Information

Twenty sites were sampled both for bed sediment and aquatic biota, and 32 additional sites were sampled for bed sediment only (p. 25). Site locations are shown on the land use map on page 24. The sites reflect important land uses in the basin, including forested (12 sites), agricultural (10 sites), urban (12 sites), mixed (14 sites), and mined (4 sites). Samples were collected following protocols given by Crawford and Luoma (1993) and Shelton and Capel (1994).

Bed sediment samples to be analyzed for trace elements were wet sieved through a 62-micrometer nylon cloth; samples for analysis of organochlorine pesticides and PCBs were passed through a 2-millimeter stainless-steel sieve. Aquatic biota samples were mostly composites of 6–10 sculpin (whole body) or 35–50 Asiatic clams (soft tissue only). Livers from carp, largemouth bass, and largescale suckers were analyzed for trace elements at three sites.

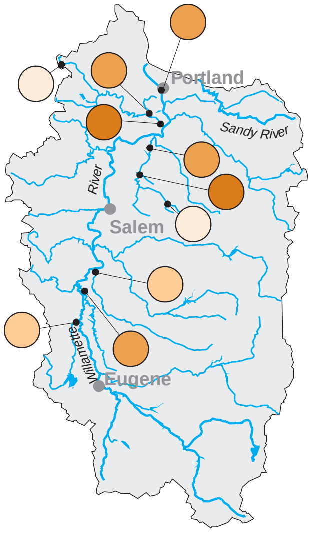
Analyses were performed by USGS laboratories in Denver, Colorado, following procedures described by Arbogast (1990), Foreman and others (1995), Leiker and others (1995), and Hoffman (1996).

Asiatic clams (above) and sculpin (left) were the main species analyzed.

WATER QUALITY CONDITIONS IN A NATIONAL CONTEXT
Comparison of Stream Quality in the Willamette Basin with Nationwide NAWQA Findings

Seven major water quality characteristics were evaluated for stream sites in each NAWQA Study Unit. Summary scores for each characteristic were computed for all sites that had adequate data. Scores for each site in the Willamette Basin were compared with scores for all sites sampled in the 20 NAWQA Study Units during 1992–95. Results are summarized by percentiles; higher percentile values generally indicate poorer quality compared with other NAWQA sites. Water quality conditions at each site also are compared to established criteria for protection of aquatic life. Applicable criteria are limited to nutrients and pesticides in water, semivolatile organic compounds in bed sediment, and organochlorine pesticides and PCBs in bed sediment. (Methods used to compute rankings and evaluate aquatic life criteria are described by Gilliom and others, in press.)

NUTRIENTS in water



Nutrient concentrations in water were similar to those found nationally. Concentrations in two streams were in the top 25 percent of data from the 20 NAWQA Study Units. One stream drained a small agricultural basin, and the other received sewage treatment plant effluent. No exceedances of the aquatic life criterion for unionized ammonia were found.

EXPLANATION

Ranking of stream quality relative to all NAWQA stream sites — Darker colored circles generally indicate poorer quality. **Bold outline** of circle indicates one or more aquatic life criteria were exceeded.

● **Greater than the 75th percentile** (among the highest 25 percent of NAWQA stream sites)

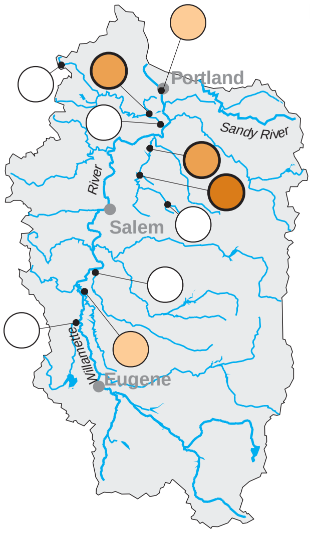
● **Between the median and the 75th percentile**

● **Between the 25th percentile and the median**

● **Less than the 25th percentile** (among the lowest 25 percent of NAWQA stream sites)

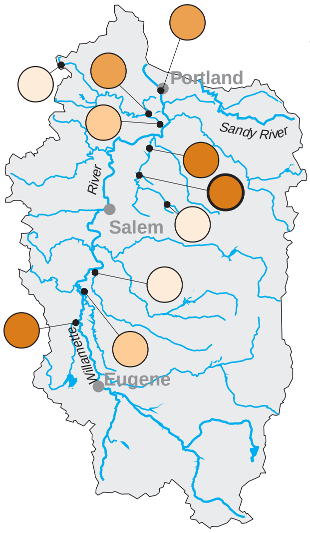
○ **No data**

PESTICIDES in water



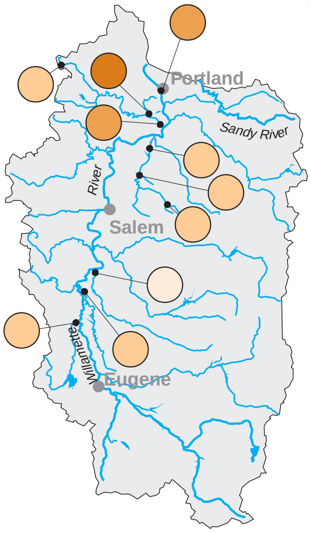
Pesticide concentrations in water generally were representative of those found in other NAWQA Study Units. At one urban and two agricultural sites, exceedances of aquatic life criteria occurred for azinphos-methyl, carbofuran, chlorpyrifos, and/or diazinon.

ORGANOCHLORINE PESTICIDES and PCBs in bed sediment and biological tissue



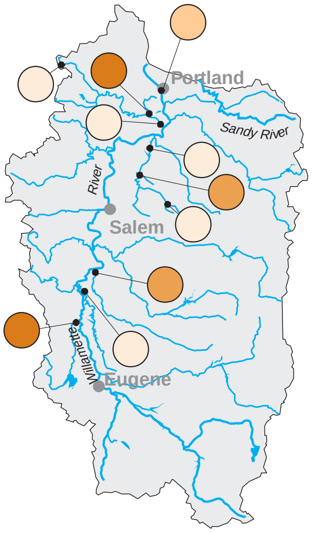
Concentrations of organochlorine pesticides and PCBs in bed sediment and biological tissue were typical of those in other NAWQA Study Units; however, concentrations were among the highest 25 percent at three mostly agricultural sites. Lindane in bed sediment exceeded the aquatic life standard at one of these sites.

TRACE ELEMENTS in bed sediment



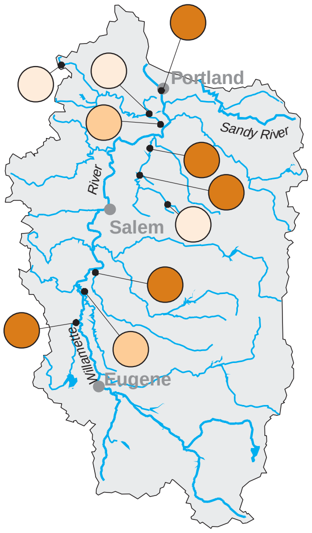
Trace element concentrations in bed sediment were lower than typically found nationally, with concentrations at 7 of 10 sites falling in the bottom 50 percent of data from the 20 NAWQA Study Units. The three streams with concentrations in the top 50 percent of NAWQA data were the only streams draining basins with large urban areas.

SEMIVOLATILE ORGANIC COMPOUNDS in bed sediment



Concentrations of semivolatile organic compounds in bed sediment were low compared with other NAWQA Study Units; however, one agricultural site and one urban site ranked in the top 25 percent nationally. No exceedances of aquatic life criteria were found at any of the sites shown.

FISH COMMUNITY DEGRADATION



Fish community conditions in five streams draining basins with agricultural and/or urban influences ranked among the poorest 25 percent of streams sampled in other NAWQA Study Units, as determined by percentages of external anomalies and of species that are pollution tolerant, omnivorous, and non-native. At one agricultural site, fish were 99 percent non-native and 61 percent exhibited anomalies.

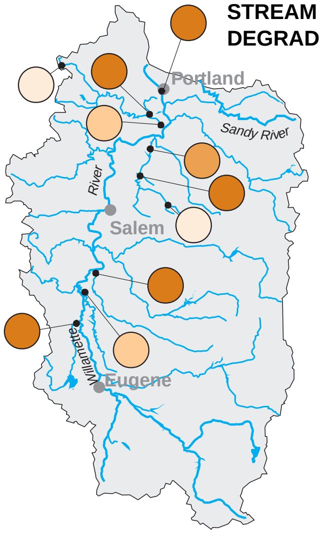
CONCLUSIONS

Nutrient and pesticide concentrations in Willamette Basin streams were typical of concentrations in streams from other NAWQA Study Units, as were concentrations of organochlorine pesticides and PCBs in streambed sediment and biological tissue.

Concentrations of trace elements and semivolatile organic compounds in bed sediment generally were low relative to other NAWQA Study Units.

Stream habitat and fish community conditions in agricultural and urban streams were among the most degraded compared with other NAWQA Study Units. Degraded habitat and fish community conditions generally occurred at the same sites.

STREAM HABITAT DEGRADATION

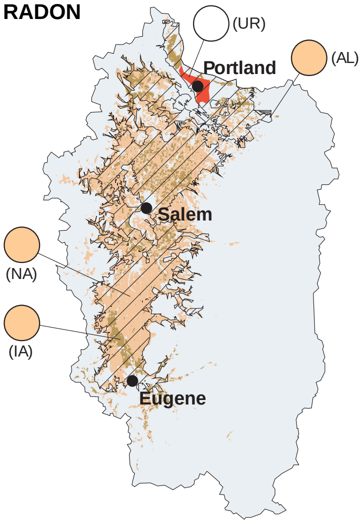


Stream habitat conditions for five streams draining basins with agricultural and/or urban influences were among the worst found when compared with other NAWQA Study Units. The most common factors contributing to these conditions were poor riparian quality, high susceptibility to bank erosion, and a high degree of channel modification.

WATER QUALITY CONDITIONS IN A NATIONAL CONTEXT
Comparison of Ground Water Quality in the Willamette Basin with Nationwide NAWQA Findings

Five major water quality characteristics were evaluated for ground water studies in each NAWQA Study Unit. Ground water resources were divided into two categories: (1) drinking water aquifers, and (2) shallow ground water underlying agricultural or urban areas. Summary scores were computed for each characteristic for all aquifers and shallow ground water areas that had adequate data. Scores for each aquifer and shallow ground water area in the Willamette Basin were compared with scores for all aquifers and shallow ground water areas sampled in the 20 NAWQA Study Units during 1992–95. Results are summarized by percentiles; higher percentile values generally indicate poorer quality compared with other NAWQA ground water studies. Water quality conditions for each drinking water aquifer also are compared to established drinking water standards and criteria for protection of human health. (Methods used to compute rankings and evaluate standards and criteria are described by Gilliom and others, in press.)

RADON



Radon concentrations in ground water were low relative to national conditions, with all areas falling in the lowest 50 percent of data from the 20 NAWQA Study Units.

EXPLANATION

Drinking water aquifers

▨ Alluvium (AL) *(70 wells)*

Shallow ground water areas

🟫 Irrigated Agriculture (IA) *(16 wells)*

🟧 Nonirrigated Agriculture (NA) *(37 wells)*

🟥 Urban (UR) *(10 wells)*

Ranking of ground water quality relative to all NAWQA ground water studies — Darker colored circles generally indicate poorer quality. **Bold outline** of circle indicates one or more drinking water standards or criteria were exceeded.

● **Greater than the 75th percentile** (among the highest 25 percent of NAWQA ground water studies)

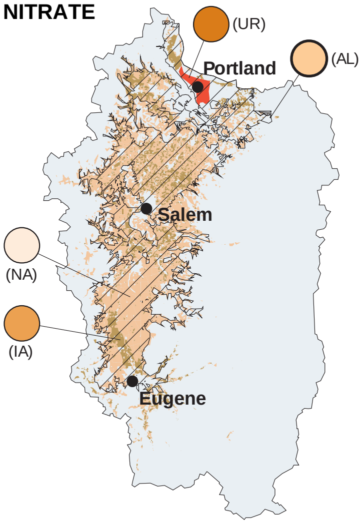
● **Between the median and the 75th percentile**

● **Between the 25th percentile and the median**

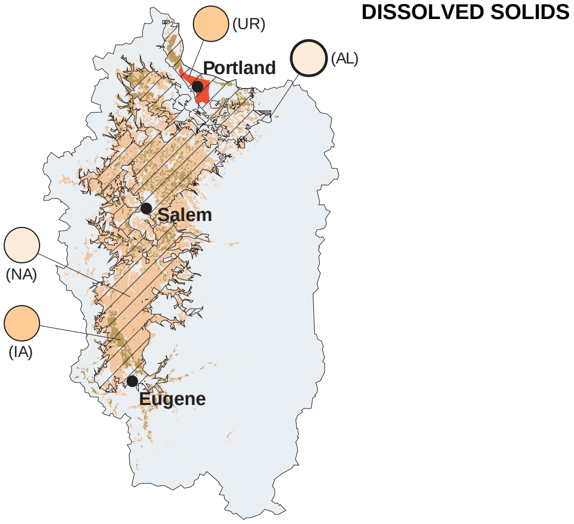
○ **Less than the 25th percentile** (among the lowest 25 percent of NAWQA ground water studies)

○ **No data**

NITRATE



Nitrate concentrations in ground water were similar to those found in other NAWQA Study Units . Nitrate concentrations generally were low in ground water from domestic wells in the alluvial aquifer, although almost 10 percent of samples exceeded the USEPA MCL for nitrate in drinking water.



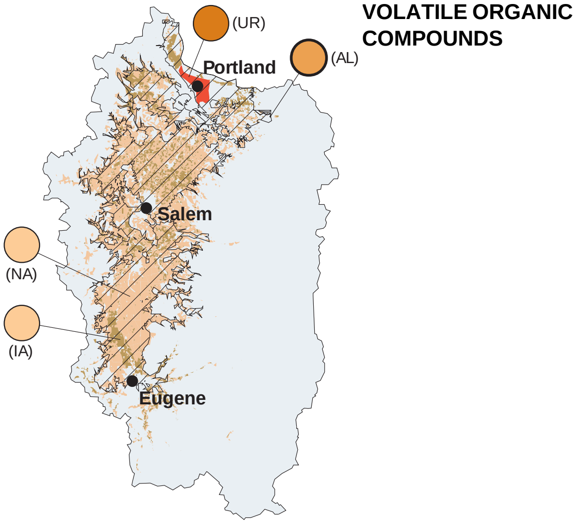
Dissolved solids concentrations in ground water were low compared with other NAWQA Study Units. This is consistent with the maritime climate and the paucity of easily dissolved minerals in the geologic source rock of the Willamette Basin. The USEPA Secondary MCL for dissolved solids in drinking water was exceeded in water from two domestic wells in the alluvial aquifer.

CONCLUSIONS

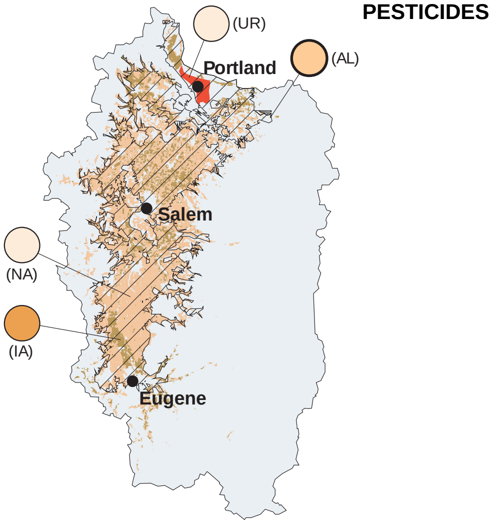
Radon and dissolved solids concentrations, and pesticide detection rates in Willamette Basin ground water generally were low when compared with other NAWQA Study Units.

Nitrate concentrations and detection rates for volatile organic compounds were fairly typical of those found in other NAWQA Study Units.

Although a few exceedances of USEPA drinking water standards were noted in ground water from domestic wells in the alluvial aquifer, water quality generally was good.



Detections of volatile organic compounds in ground water were typical of those found nationwide, but detection rates in urban wells in the Portland area were within the top 25 percent of NAWQA data. The USEPA drinking water MCL for tetrachloroethylene was exceeded in water from one domestic well in the alluvial aquifer.

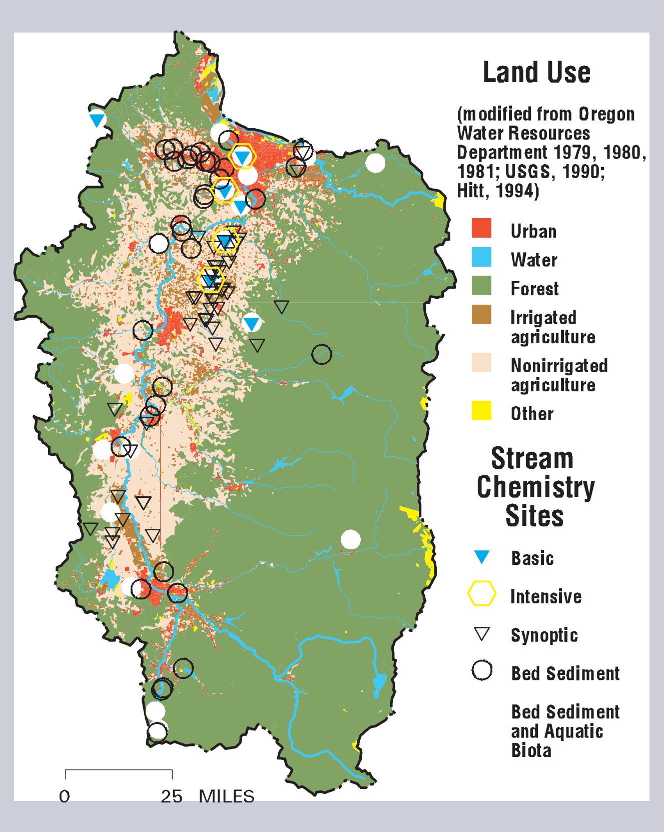


Pesticide detection rates in ground water typically were low compared with other NAWQA Study Units, especially for urban and nonirrigated agriculture areas. The MCL for dinoseb was exceeded in water from one domestic well in the alluvial aquifer.

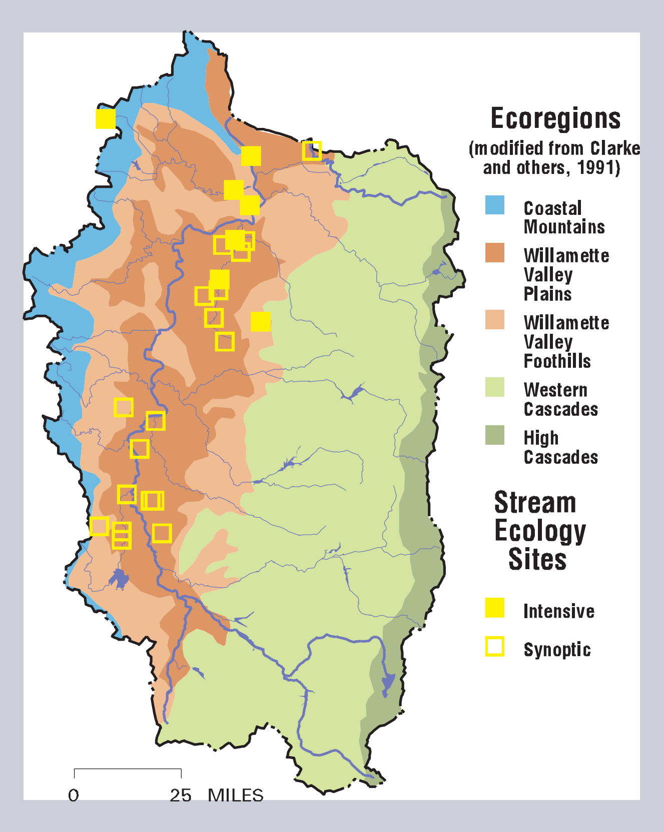
STUDY DESIGN AND DATA COLLECTION IN THE WILLAMETTE BASIN

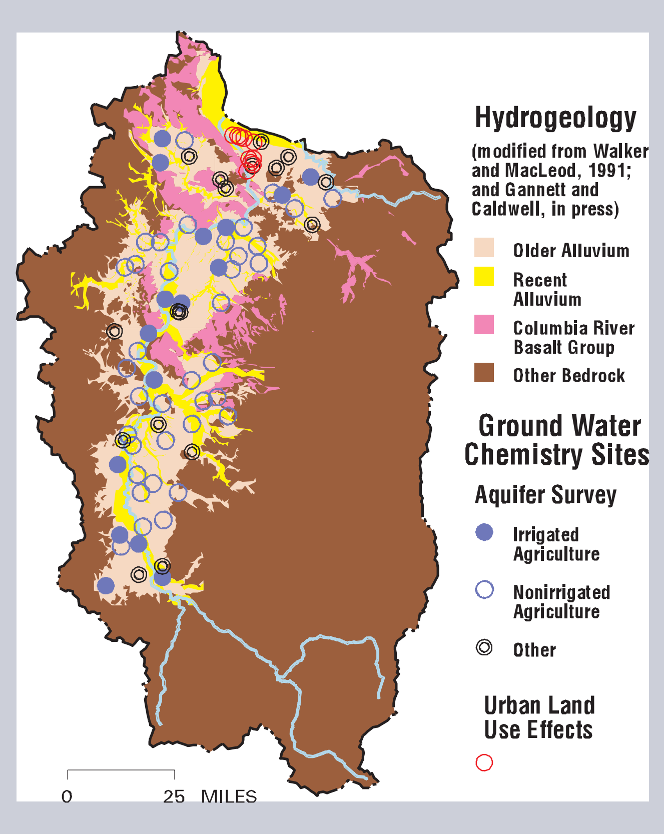
To the extent possible, sampling sites represent homogeneous areas relative to ecoregions, hydrogeology, and land use (Uhrich and Wentz, in press). Ecoregions provided a first, or basinwide, level of stratification. Hydrogeology, the second level of stratification, was useful in subdividing the Willamette Valley into major aquifers. Land use provided a third, or local, level of stratification that was important because of the emphasis of this study on nutrients and pesticides from nonpoint sources.

One of the hallmarks of the NAWQA design is the use of multiple lines of evidence to describe water quality conditions (Gilliom and others, 1995). Thus, the 1991–95 data collection activities in the Willamette Basin provided information on stream water chemistry, contaminants in bed sediment and aquatic biota, stream ecological conditions, and chemistry of ground water. The sampling sites associated with the various study components are plotted on the maps, and the designs of the individual study components are described in the table on the following page.



Finally, it should be noted that data collected for this study are based on multiple scales. For example, samples for analysis of water chemistry were collected from streams draining basins with areas of 1.76 to 11,200 square miles. This range of scales provided an opportunity to consider land use and streamflow effects in relation to basin size.





SUMMARY OF DATA COLLECTION IN THE WILLAMETTE BASIN STUDY UNIT, 1991–95

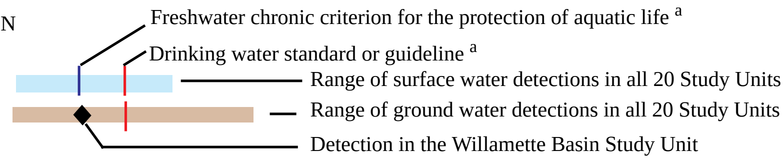
Study component	What data were collected and why	Types of sites sampled	Number of sites	Sampling frequency and period
Stream Chemistry				
Basic sites—general water quality	Streamflow, nutrients, major chemical constituents, organic carbon, suspended sediment, water temperature, specific conductance, pH, and dissolved oxygen were determined to describe concentrations and seasonal variations.	Streams draining basins ranging in size from 7.10 to 11,200 square miles and representing forested, agricultural, urban, and mixed land uses were sampled.	7	Monthly plus storms April 1993–August 1995
Intensive sites—pesticides	In addition to the above constituents, approximately 86 dissolved pesticides were analyzed to describe concentrations and seasonal variations.	A subset of basic water chemistry sites draining agricultural and urban land uses was sampled.	4	Monthly plus storms April 1993–August 1995
Synoptic studies—nutrients and pesticides	Streamflow, nutrients and/or pesticides, organic carbon, suspended sediment, water temperature, specific conductance, pH, and dissolved oxygen were determined during high and/or low flow conditions to describe concentrations and spatial distributions.	Streams draining basins ranging in size from 1.76 to 403 square miles and representing forested, agricultural, urban, and mixed land uses were sampled.	44 total 17 high flow 12 high flow 32 low flow	Once for each study April 1993 May–June 1994 July–August 1994
Contaminants in bed sediment	Total PCBs, 32 organochlorine pesticides, 63 semivolatile organic compounds, and 44 trace elements were analyzed to determine occurrence and spatial distribution.	Depositional zones of all basic and intensive sites and most synoptic sites were sampled.	52	Once in 1992–95; four sites sampled multiple times
Contaminants in aquatic biota	Total PCBs, 30 organochlorine pesticides, and 24 trace elements were analyzed to determine occurrence and spatial distribution. Clam and mussel tissue and whole fish were analyzed for organic contaminants. Clam tissue, whole fish (sculpin), fish livers (several species), and caddisflies were analyzed for trace elements.	All basic and intensive sites and some synoptic sites were sampled.	20	Once in 1992–93; three sites sampled multiple times
Stream Ecology				
Intensive assessments	Fish, macroinvertebrates, algae, and aquatic and riparian habitat were described to assess aquatic biological community structure.	Stream reaches were colocated with basic water chemistry sites. The basins represent forested, agricultural, and urban land uses, and each of the primary ecoregions.	7 (1993) 5 (1994–95)	Once in 1993, ‘94, ‘95; three reaches sampled at each of four sites in 1995
Synoptic studies	Fish, macroinvertebrates, algae, and aquatic and riparian habitat were described to assess spatial distribution of aquatic biological community structure.	Stream reaches were colocated with a subset of synoptic stream chemistry sites sampled during July–August 1994. The basins represent forested, agricultural, urban, and mixed land uses.	18	Once in July–September 1994
Ground Water Chemistry				
Aquifer survey—alluvial	Major chemical constituents, nutrients, 85 pesticides, 60 volatile organic compounds, radon, and arsenic were analyzed to describe the spatial distribution of shallow ground water quality in alluvial aquifers used for domestic drinking water supply.	Existing domestic wells less than 83 feet deep and screened within 67 feet of the water table were chosen using a statistically random selection process.	70	Once in 1993
Land use effects—agricultural	Data from the alluvial aquifer survey were reinterpreted to determine effects of irrigated and nonirrigated agricultural land use on the quality of recently recharged ground water.	Only wells representing agricultural land use were included; wells were categorized as irrigated or nonirrigated.	16 irrigated 37 nonirrigated	Once in 1993
Land use effects—urban	Major chemical constituents, nutrients, pesticides, volatile organic compounds, and 17 trace elements were analyzed to determine effects of urban land use on the quality of recently recharged ground water in alluvial aquifers.	Monitoring wells were drilled to depths of less than 147 feet in the Portland metropolitan area and were screened within 52 feet of the water table.	10	Once in 1995
Special Studies				
Suspended sediment	Streamflow, suspended sediment concentration, and sediment particle size were analyzed and compared to historical data collected during 1949–51 to determine changes in sediment transport before and after dam construction.	Data were collected on the Willamette River and major tributaries. (See map, p. 10.)	7	12–18 times in 1991–93
Ground water/surface water interactions	Dye injection studies and streamflow gain/loss measurements were interpreted to quantify the extent of ground water/surface water interactions.	Dye studies were conducted in nine streams, including the Willamette River. Streamflow gain/loss measurements were made on two of these streams.	41 reaches	Once in 1992–95; two reaches measured multiple times
Dioxins and furans	Bed sediment and whole fish were analyzed for 15 congeners and 10 congener classes of tetra- through octachlorinated dioxins and furans to determine occurrence, spatial distribution, and congener patterns.	Sites were a subset of those sampled for organochlorine compounds and trace elements in bed sediment and tissue. (See map, p. 17.)	22 sediment 8 tissue	Once in 1992–95; three sites were sampled multiple times

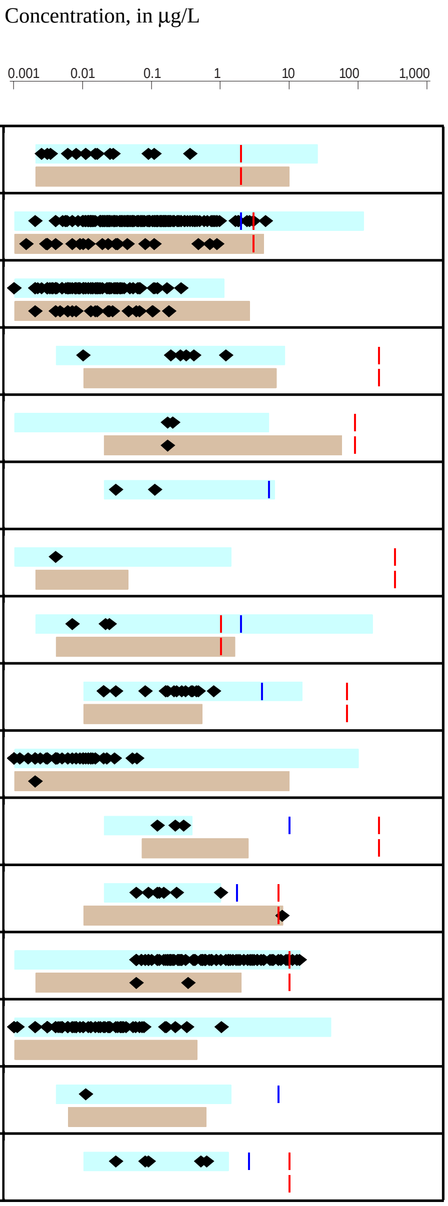
SUMMARY OF COMPOUND DETECTIONS AND CONCENTRATIONS

The following tables summarize data collected for NAWQA studies during 1992–95 by showing results for the Willamette Basin Study Unit compared to the NAWQA national range for each compound detected. The data were collected at a wide variety of places and times. In order to represent the wide concentration ranges observed among Study Units, logarithmic scales are used to emphasize the general magnitude of concentrations (such as 10, 100, or 1,000), rather than the precise number. The complete data set used to construct these tables is available upon request. (The tables were designed and constructed by Sarah Ryker, Jonathon Scott, and Alan Haggland.)

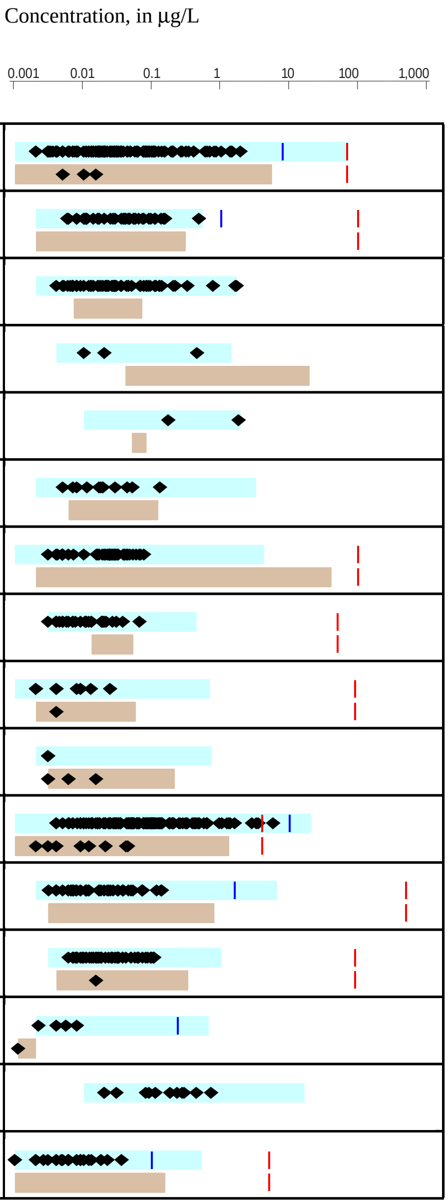
Concentrations of herbicides, insecticides, volatile organic compounds, nutrients, and radon detected in ground and surface waters of the Willamette Basin Study Unit. [mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; %, percent; <, less than; - -, not measured; trade names may vary]

EXPLANATION

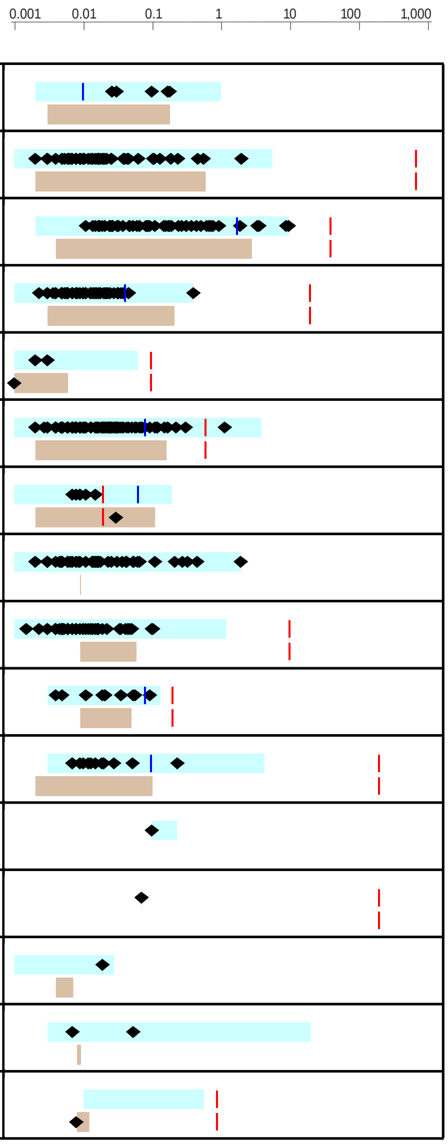




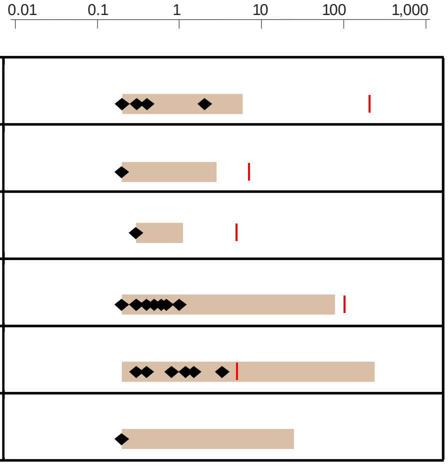
Herbicide (Trade or common name)	Rate of detection [b]
Alachlor (Lasso)	5% 0%
Atrazine (AAtrex)	85% 16%
Deethylatrazine[c] (Atrazine metabolite)	38% 15%
Bentazon (Basagran, bentazone)	4% 0%
Bromacil (Bromax)	2% 1%
Bromoxynil (Buctril)	1% 0%
Butylate (Sutan +, butilate)	<1% 0%
Cyanazine (Bladex)	1% 0%
2,4-D (Dacamine, Weedar 64)	12% 0%
DCPA (Dacthal, chlorthal-dimethyl)	10% <1%
Dicamba (Banvel)	2% 0%
Dinoseb (DNBP, dinosebe)	5% 1%
Diuron (Karmex)	53% 3%
EPTC (Eptam, Eradicane)	17% 0%
Linuron (Lorox, Linex)	1% 0%
MCPA	4% 0%



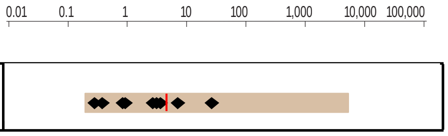
Herbicide (Trade or common name)	Rate of detection [b]
Metolachlor (Dual, Pennant, Goal)	62% 3%
Metribuzin (Lexone, Sencor)	19% 0%
Napropamide (Devrinol)	26% 0%
Norflurazon (Evital, Solicam)	2% 0%
Oryzalin (Surflan)	1% 0%
Pendimethalin (Prowl)	4% 0%
Prometon (Pramitol, prometone)	19% 0%
Pronamide (Kerb, propyzamid)	9% 0%
Propachlor (Ramrod, propachlore)	1% <1%
Propanil (Stampede, Prostar)	<1% 1%
Simazine (Princep)	77% 5%
Tebuthiuron (Spike)	15% 0%
Terbacil[c] (Sinbar)	24% 1%
Triallate (Far-Go)	<1% <1%
Triclopyr (Garlon, Crossbow)	9% 0%
Trifluralin (Treflan)	4% 0%



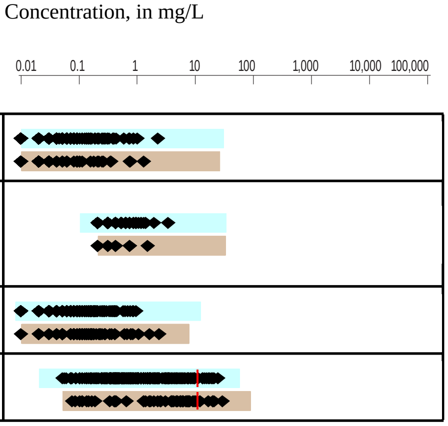
Insecticide (Trade or common name)	Rate of detection [b]
Azinphos-methyl[c] (Guthion)	3% 0%
Carbaryl[c] (Sevin)	18% 0%
Carbofuran[c] (Furadan)	29% 0%
Chlorpyrifos (Dursban, Lorsban)	21% 0%
p,p'-DDE (*p,p'*-DDT metabolite)	<1% <1%
Diazinon	35% 0%
Dieldrin	1% 1%
Ethoprop (Mocap, ethoprophos)	15% 0%
Fonofos (Dyfonate)	12% 0%
gamma-HCH (Lindane, *gamma*-BHC)	4% 0%
Malathion (malathon, Cythion)	5% 0%
Methiocarb (Grandslam)	1% 0%
Oxamyl (Vydate, oxamil)	1% 0%
cis-Permethrin[c] (Pounce)	1% 0%
Propargite (Omite, Comite)	<1% 0%
Terbufos (Counter)	0% <1%



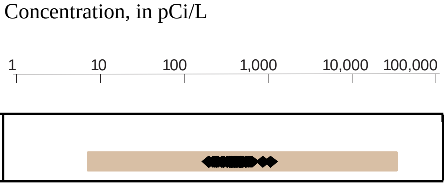
Volatile organic compound (Trade or common name)	Rate of detection [b]
1,1,1-Trichloroethane (Methylchloroform)	-- 8%
1,1-Dichloroethene (Vinylidene chloride)	-- 1%
Tetrachloromethane (Carbon tetrachloride)	-- 1%
total Trihalomethanes	-- 12%
Trichloroethene (TCE)	-- 8%
Trichlorofluoromethane (CFC 11, Freon 11)	-- 1%



Volatile organic compound (Trade or common name)	Rate of detection [b]
Tetrachloroethene (Perchloroethene, PCE)	-- 12%

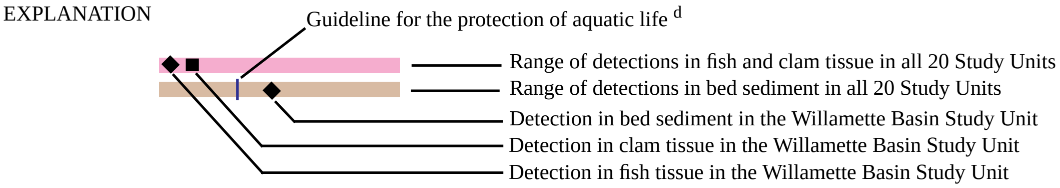


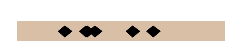
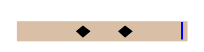
Nutrient	Rate of detection [b]
Dissolved ammonia	93% 86%
Dissolved ammonia plus organic nitrogen as nitrogen	53% 13%
Dissolved phosphorus as phosphorus	91% 99%
Dissolved nitrite plus nitrate	98% 71%

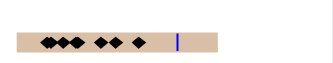
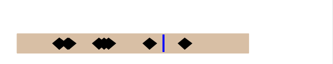
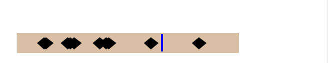
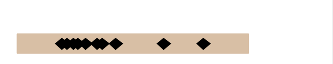
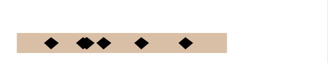
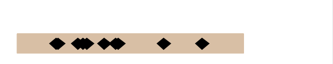
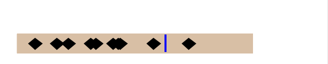
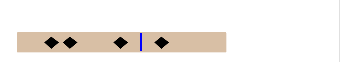
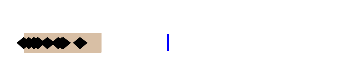
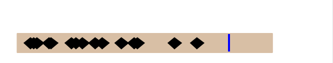


Other	Rate of detection [b]
Radon 222	-- 100%

Concentrations of semivolatile organic compounds, organochlorine compounds, and trace elements detected in fish and clam tissue and bed sediment of the Willamette Basin Study Unit. [µg/g, micrograms per gram; µg/kg, micrograms per kilogram; %, percent; <, less than; - -, not measured; trade names may vary]

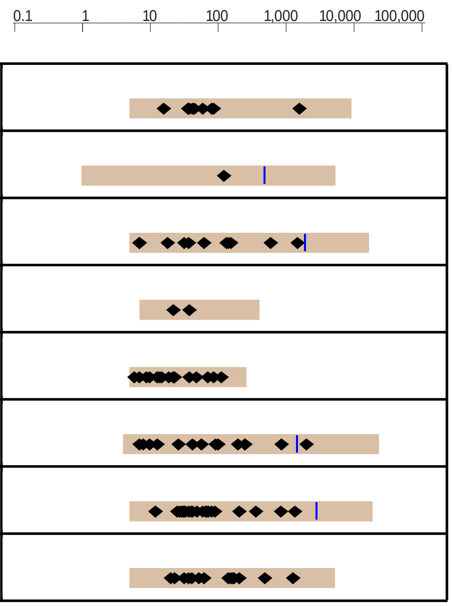


Semivolatile organic compound	Rate of detection[b]	Concentration, in µg/kg dry weight 0.1 1 10 100 1,000 10,000 100,000
1,2-Dimethylnaphthalene	-- 4%	
1,6-Dimethylnaphthalene	-- 19%	
1-Methyl-9H-fluorene	-- 4%	
1-Methylphenanthrene	-- 15%	
1-Methylpyrene	-- 15%	
2,2-Biquinoline	-- 4%	
2,3,6-Trimethylnaphthalene	-- 4%	
2,6-Dimethylnaphthalene	-- 41%	
2,6-Dinitrotoluene	-- 4%	
2-Ethylnaphthalene	-- 4%	
2-Methylanthracene	-- 7%	
4,5-Methylenephenanthrene	-- 22%	
4-Chloro-3-methylphenol	-- 4%	
9H-Carbazole	-- 15%	
9H-Fluorene	-- 15%	
Acenaphthene	-- 7%	
Acenaphthylene	-- 19%	

Semivolatile organic compound	Rate of detection[b]	Concentration, in µg/kg dry weight 0.1 1 10 100 1,000 10,000 100,000
Acridine	-- 15%	
Anthracene	-- 30%	
Anthraquinone	-- 15%	
Benz[*a*]anthracene	-- 33%	
Benzo[*a*]pyrene	-- 37%	
Benzo[*b*]fluoranthene	-- 37%	
Benzo[*ghi*]perylene	-- 30%	
Benzo[*k*]fluoranthene	-- 37%	
Butylbenzylphthalate	-- 52%	
Chrysene	-- 37%	
Di-*n*-butylphthalate	-- 96%	
Di-*n*-octylphthalate	-- 4%	
Dibenz[*a,h*]anthracene	-- 15%	
Dibenzothiophene	-- 11%	
Diethylphthalate	-- 41%	
Dimethylphthalate	-- 11%	
Fluoranthene	-- 56%	

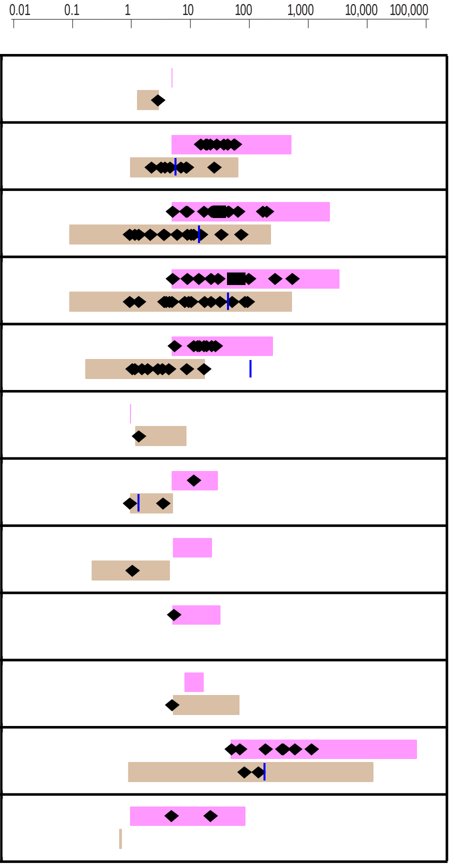
Semivolatile organic compound	Rate of detection [b]
Indeno[1,2,3- *cd*] pyrene	-- 33%
Naphthalene	-- 4%
Phenanthrene	-- 44%
Phenanthridine	-- 7%
Phenol	-- 67%
Pyrene	-- 52%
bis(2-Ethyl-hexyl)phthalate	-- 93%
p-Cresol	-- 52%

Concentration, in µg/kg dry weight



Organochlorine compound (Trade name)	Rate of detection [b]
Aldrin	0% 3%
total-Chlordane[e]	45% 28%
p,p'-DDE[f] (*p,p'*-DDT metabolite)	64% 52%
total-DDT[f]	64% 55%
Dieldrin	36% 31%
Endosulfan I (*alpha*-endosulfan, Thiodan)	-- 3%
gamma-HCH (Lindane, *gamma*-BHC)	5% 7%
Heptachlor epoxide (heptachlor metabolite)	0% 3%
Hexachlorobenzene	5% --
p,p'-Methoxychlor (Marlate)	0% 3%
PCB, total	32% 7%
Pentachloroanisole	9% 0%

Concentration, in µg/kg wet weight (tissue)
Concentration, in µg/kg dry weight (sediment)



Trace element	Rate of detection [b]
Arsenic	65% 100%
Cadmium	20% 100%
Chromium	90% 100%
Copper	100% 100%
Lead	25% 88%
Mercury	50% 82%
Nickel	90% 100%
Selenium	40% 100%
Zinc	100% 100%

Concentration, in µg/g dry weight

Herbicides, insecticides, volatile organic compounds, and nutrients not detected in ground and surface waters of the Willamette Basin Study Unit.

Herbicides

2,4,5-T
2,4,5-TP (Silvex, Fenoprop)
2,4-DB (Butyrac, Butoxone, Embutox Plus, Embutone)
2,6-Diethylaniline (Metabolite of Alachlor)
Acetochlor (Harness Plus, Surpass)
Acifluorfen (Blazer, Tackle 2S)
Benfluralin (Balan, Benefin, Bonalan, Benefex)
Chloramben (Amiben, Amilon-WP, Vegiben)
Clopyralid (Stinger, Lontrel, Reclaim, Transline)
Dacthal mono-acid (Dacthal metabolite)
Dichlorprop (2,4-DP, Seritox 50, Kildip, Lentemul)
Ethalfluralin (Sonalan, Curbit)
Fenuron (Fenulon, Fenidim)
Fluometuron (Flo-Met, Cotoran, Cottonex, Meturon)
MCPB (Thistrol)
Molinate (Ordram)
Neburon (Neburea, Neburyl, Noruben)
Pebulate (Tillam, PEBC)
Picloram (Grazon, Tordon)
Propham (Tuberite)
Thiobencarb (Bolero, Saturn, Benthiocarb, Abolish)

Insecticides

3-Hydroxycarbofuran (Carbofuran metabolite)
Aldicarb (Temik, Ambush, Pounce)
Aldicarb sulfone (Standak, aldoxycarb, aldicarb metabolite)
Aldicarb sulfoxide (Aldicarb metabolite)
Disulfoton (Disyston, Di-Syston, Frumin AL, Solvirex, Ethylthiodemeton)
Methomyl (Lanox, Lannate, Acinate)
Methyl parathion (Penncap-M, Folidol-M, Metacide, Bladan M)
Parathion (Roethyl-P, Alkron, Panthion, Phoskil)
Phorate (Thimet, Granutox, Geomet, Rampart)
Propoxur (Baygon, Blattanex, Unden, Proprotox)
alpha-HCH (*alpha*-BHC, *alpha*-lindane, *alpha*-hexachlorocyclohexane, *alpha*-benzene hexachloride)

Volatile organic compounds

1,1,1,2-Tetrachloroethane (1,1,1,2-TeCA)
1,1,2,2-Tetrachloroethane
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113, CFC 113)
1,1,2-Trichloroethane (Vinyl trichloride)
1,1-Dichloroethane (Ethylidene dichloride)
1,1-Dichloropropene
1,2,3-Trichlorobenzene (1,2,3-TCB)
1,2,3-Trichloropropane (Allyl trichloride)
1,2,4-Trichlorobenzene
1,2,4-Trimethylbenzene (Pseudocumene)
1,2-Dibromo-3-chloropropane (DBCP, Nemagon)
1,2-Dibromoethane (EDB, Ethylene dibromide)
1,2-Dichlorobenzene (*o*-Dichlorobenzene, 1,2-DCB)
1,2-Dichloroethane (Ethylene dichloride)
1,2-Dichloropropane (Propylene dichloride)
1,3,5-Trimethylbenzene (Mesitylene)
1,3-Dichlorobenzene (*m*-Dichlorobenzene)
1,3-Dichloropropane (Trimethylene dichloride)
1,4-Dichlorobenzene (*p*-Dichlorobenzene, 1,4-DCB)
1-Chloro-2-methylbenzene (*o*-Chlorotoluene)
1-Chloro-4-methylbenzene (*p*-Chlorotoluene)
2,2-Dichloropropane
Benzene
Bromobenzene (Phenyl bromide)
Bromochloromethane (Methylene chlorobromide)
Bromomethane (Methyl bromide)
Chlorobenzene (Monochlorobenzene)
Chloroethane (Ethyl chloride)
Chloroethene (Vinyl chloride)
Chloromethane (Methyl chloride)
Dibromomethane (Methylene dibromide)
Dichlorodifluoromethane (CFC 12, Freon 12)
Dichloromethane (Methylene chloride)
Dimethylbenzenes (Xylenes (total))
Ethenylbenzene (Styrene)
Ethylbenzene (Phenylethane)
Hexachlorobutadiene
Isopropylbenzene (Cumene)
Methyl *tert*-butyl ether (MTBE)
Methylbenzene (Toluene)
Naphthalene
cis-1,2-Dichloroethene ((Z)-1,2-Dichloroethene)
cis-1,3-Dichloropropene ((Z)-1,3-Dichloropropene)
n-Butylbenzene (1-Phenylbutane)
n-Propylbenzene (Isocumene)
p-Isopropyltoluene (*p*-Cymene)
sec-Butylbenzene
tert-Butylbenzene
trans-1,2-Dichloroethene ((E)-1,2-Dichlorothene)
trans-1,3-Dichloropropene ((E)-1,3-Dichloropropene)

Nutrients

No non-detects

Semivolatile organic compounds, organochlorine compounds, and trace elements not detected in fish and clam tissue and bed sediment of the Willamette Basin Study Unit.

Semivolatile organic compounds

1,2,4-Trichlorobenzene
1,2-Dichlorobenzene (*o*-Dichlorobenzene, 1,2-DCB)
1,3-Dichlorobenzene (*m*-Dichlorobenzene)
1,4-Dichlorobenzene (*p*-Dichlorobenzene, 1,4-DCB)
2,4-Dinitrotoluene
2-Chloronaphthalene
2-Chlorophenol
3,5-Dimethylphenol
4-Bromophenyl-phenylether
4-Chlorophenyl-phenylether
Azobenzene
Benzo [*c*] cinnoline
C8-Alkylphenol
Isophorone
Isoquinoline
N-Nitrosodi-*n*-propylamine
N-Nitrosodiphenylamine
Nitrobenzene
Pentachloronitrobenzene
Quinoline
bis (2-Chloroethoxy)methane

Organochlorine compounds

Chloroneb (chloronebe, Demosan, Soil Fungicide 1823)
DCPA (Dacthal, chlorthal-dimethyl)
Endrin (Endrine)
Heptachlor (Heptachlore, Velsicol 104)
Isodrin (Isodrine, Compound 711)
Mirex (Dechlorane)
Toxaphene (Camphechlor, Hercules 3956)
alpha-HCH (*alpha*-BHC, *alpha*-lindane, *alpha*-hexachlorocyclohexane, *alpha*-benzene hexachloride)
beta-HCH (*beta*-BHC, *beta*-hexachlorocyclohexane, *alpha*-benzene hexachloride)
cis-Permethrin (Ambush, Astro, Pounce, Pramex, Pertox, Ambushfog, Kafil, Perthrine, Picket, Picket G, Dragnet, Talcord, Outflank, Stockade, Eksmin, Coopex, Peregin, Stomoxin, Stomoxin P, Qamlin, Corsair, Tornade)
delta-HCH (*delta*-BHC, *delta*-hexachlorocyclohexane, *delta*-benzene hexachloride)
o,p'-Methoxychlor
trans-Permethrin (Ambush, Astro, Pounce, Pramex, Pertox, Ambushfog, Kafil, Perthrine, Picket, Picket G, Dragnet, Talcord, Outflank, Stockade, Eksmin, Coopex, Peregin, Stomoxin, Stomoxin P, Qamlin, Corsair, Tornade)

Trace elements

No non-detects

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[a] Selected water quality standards and guidelines (Gilliom and others, in press).

[b] Rates of detection are based on the number of analyses and detections in the Study Unit, not on national data. Rates of detection for herbicides and insecticides were computed by only counting detections equal to or greater than 0.01 μg/L in order to facilitate equal comparisons among compounds, which had widely varying detection limits. For herbicides and insecticides, a detection rate of "<1%" means that all detections are less than 0.01 μg/L, or the detection rate rounds to less than one percent. For other compound groups, all detections were counted and minimum detection limits for most compounds were similar to the lower end of the national ranges shown. Method detection limits for all compounds in these tables are summarized in (Gilliom and others, in press).

[c] Detections of these compounds are reliable, but concentrations are determined with greater uncertainty than for the other compounds and are reported as estimated values (Zaugg and others, 1995).

[d] Selected sediment quality guidelines (Gilliom and others, in press).

[e] Total-chlordane includes chlordane, *cis*-chlordane, *trans*-chlordane, *cis*-nonachlor, *trans*-nonachlor, and oxychlordane.

[f] Total-DDT includes *o,p'*-DDT, *p,p'*-DDT, *o,p'*-DDE, *p,p'*-DDE, *o,p'*-DDD, and *p,p'*-DDD; *p,p'*-DDE also is presented separately.

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Old growth can still be found in Forest Park, which is located within Portland’s city limits.

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Opal Creek drains one of the few protected old growth forest reserves remaining in the Willamette Basin.

ACKNOWLEDGMENTS

We thank the following individuals, agencies, and organizations for contributing to the success of this study.

- Lynn Bjork and Carl Bond granted permission to use the fish illustrations on page 9.
- Betty Brickson provided patience, encouragement, and occasional reviews of the report.
- Gail Cordy and Dave Mueller (USGS), Greg Pettit (Oregon Department of Environmental Quality), and Mike Wolf (Oregon Department of Agriculture) provided technical reviews of the report.
- Chris Daley (Oregon Climate Service) contributed Willamette Basin precipitation data.
- Alan Donner (U.S. Army Corps of Engineers) estimated peak Willamette River flow for February 1996.
- Steve Ellis (TetraTech, Inc.) and Chuck Henny (USGS, BRD) furnished fish from the Willamette River for tissue analysis.
- Stan Fox (Natural Resources Conservation Service) provided information on Willamette Basin snowfall.
- Susan Hathaway-Marxer and Dave Gray (City of Portland, Parks and Recreation) granted access to city parks to drill wells.
- Chip Hill and Doug Markle (Oregon State University) identified and vouchered fish specimens.
- Kathy Kuivila (USGS, California District) contributed field support and analyses of selected pesticides during April 1993.
- Mount Angel Abbey (Norman Hettwer) provided access to Little Abiqua Creek.
- National Biological Service (now USGS, Biological Resources Division) contributed funds for dioxin and furan analyses.
- Oregon Department of Environmental Quality (ODEQ) contributed data from Phases I and II of the Willamette River Basin Water Quality Study.
- Greg Pettit (ODEQ) analyzed ground water for selected pesticides during 1993.
- Paul Seevers (USGS, EROS Data Center) provided land use based on 1992–93 Landsat data.
- Unified Sewerage Agency contributed data from the Tualatin River Basin Water Quality Study.
- Dave Wills (U.S. Fish and Wildlife Service) provided and operated boat electroshocking equipment.
- Shamsul Alam, Dorie Brownell, Doug Cushman, Ben Davis, Mike DeVolder, Tom Edwards, Phil Gallaway, Ned Gates, Howard Harrison, Tim Jannsen, Martell Kiefer, Julie Laenen, Karl Lee, Dan McClelland, Jennifer Morace, Rick Mulder, Richard Norris, Greg Olsen, Ted Pogue, Dan Polette, Ines Ruiz-Huston, Roy Wellman, and Winston Woo (USGS, Oregon District), Kathryn Crepeau and Kathy Kuivila (USGS, California District), and Jeff Litteral (National Water Quality Laboratory) assisted with collection and compilation of data.

NAWQA

National Water-Quality Assessment (NAWQA) Program
Willamette Basin

Wentz and others • Water Quality in the Willamette Basin
USGS Circular 1161 • 1998

ISBN 0-607-89231-5
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