Water Quality in the Puget Sound Basin

Washington and British Columbia, 1996–98

U.S. Department of the Interior
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Circular 1216

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Front cover: The Port of Tacoma in foreground looking up the Puyallup River Valley toward Mount Rainier in the background. *(Photograph © by Kemer Nelson, Aequalis Aerial Photography, Tacoma, Washington. Used with permission.)*

Back cover: The Port of Tacoma in foreground looking northwest toward the Olympic Mountains. *(Photograph © by Kemer Nelson, Aequalis Aerial Photography, Tacoma, Washington. Used with permission.)*

Water Quality in the Puget Sound Basin, Washington and British Columbia, 1996–98

By James C. Ebbert, Sandra S. Embrey, Robert W. Black, Anthony J. Tesoriero, *and* Alan L. Haggland

U.S. GEOLOGICAL SURVEY CIRCULAR 1216

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2000

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Library of Congress Cataloging-in-Publications Data

Water-quality assessment of the Puget Sound basin, Washington and British Columbia, 1996–98 / by James C. Ebbert…[et al.].
p. cm. -- (U.S. Geological Survey Circular ; 1216)
Includes bibliographical references.
ISBN 0-607-95420-5 (alk. paper)
1. Water quality--Washington (State)--Puget Sound Region. 2. Water quality--British Columbia. I. Ebbert, J. C. II. Series.

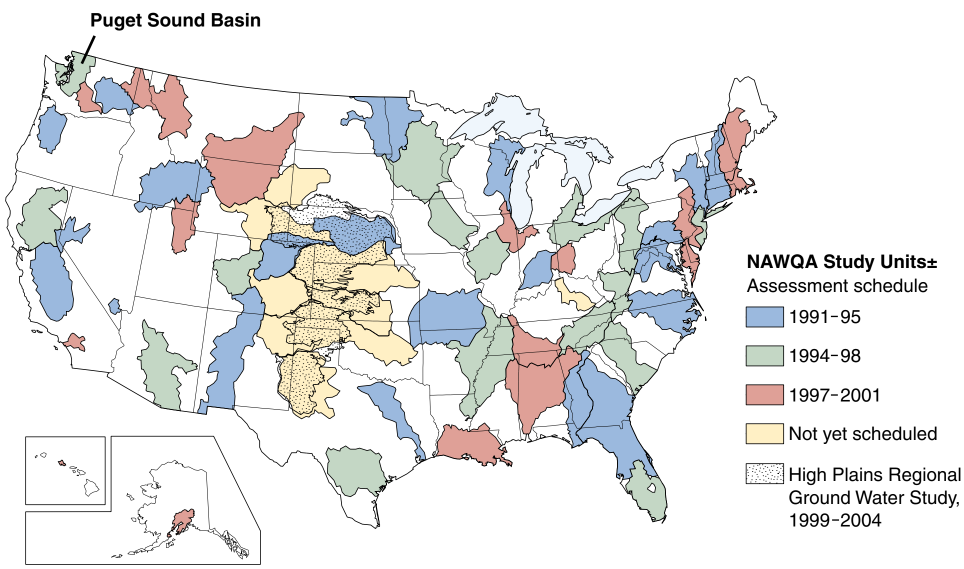
TD224.C3 W394 2000
363.739'42'097977--dc21

00-049456

CONTENTS

THIS REPORT summarizes major findings about water quality in the Puget Sound Basin that emerged from an assessment conducted between 1996 and 1998 by the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program. Water quality is discussed in terms of local and regional issues and compared to conditions found in all 36 NAWQA study areas, called Study Units, assessed to date. Findings are also explained in the context of selected national benchmarks, such as those for drinking-water quality and the protection of aquatic organisms. The NAWQA Program was not intended to assess the quality of the Nation's drinking water, such as by monitoring water from household taps. Rather, the assessments focus on the quality of the resource itself, thereby complementing many ongoing Federal, State, and local drinking-water monitoring programs. The comparisons made in this report to drinking-water standards and guidelines are only in the context of the available untreated resource. Finally, this report includes information about the status of aquatic communities and the condition of in-stream habitats as elements of a complete water-quality assessment.

Many topics covered in this report reflect the concerns of officials in State and Federal agencies, water-resource managers, and members of stakeholder groups who provided advice and input during the Puget Sound River Basin assessment. Basin residents who wish to know more about water quality in the areas where they live will find this report informative as well.

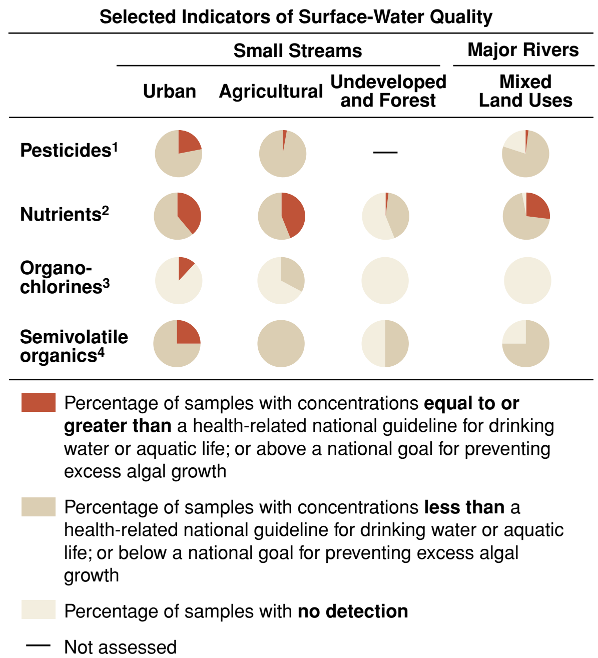


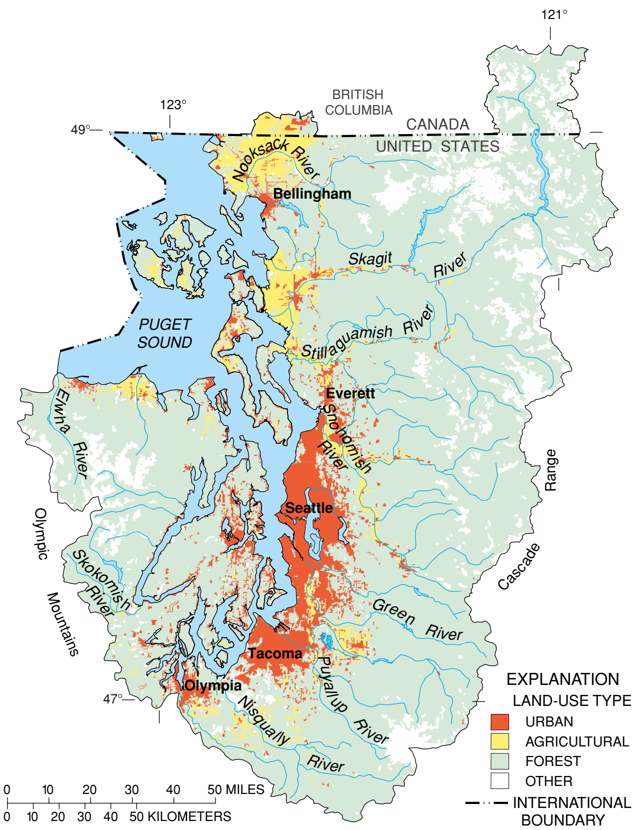
THE NAWQA PROGRAM seeks to improve scientific and public understanding of water quality in the Nation's major river basins and ground-water systems. Better understanding facilitates effective resource management, accurate identification of water-quality priorities, and successful development of strategies that protect and restore water quality. Guided by a nationally consistent study design and shaped by ongoing communication with local, State, and Federal agencies, NAWQA assessments support the investigation of local issues and trends while providing a firm foundation for understanding water quality at regional and national scales. The ability to integrate local and national scales of data collection and analysis is a unique feature of the USGS NAWQA Program.

The Puget Sound Basin is one of 51 water-quality assessments initiated since 1991, when the U.S. Congress appropriated funds for the USGS to begin the NAWQA Program. As indicated on the map, 36 assessments have been completed, and 15 more assessments will conclude in 2001. Collectively, these assessments cover about one-half of the land area of the United States and include water resources that are available to more than 60 percent of the U.S. population.

Stream and River Highlights

Streams and rivers in the Puget Sound Basin met most Federal and State water-quality guidelines. In general, large rivers were more likely to meet guidelines than were small streams. Concentrations of fecal bacteria frequently exceeded U.S. Environmental Protection Agency (USEPA) recreational criteria and State standards protecting beneficial uses of surface water, and insecticide concentrations were occasionally higher than guidelines recommended to protect aquatic life. A total of 74 man-made organic chemicals were detected in streams and rivers, with different mixtures of chemicals linked to agricultural and urban settings. Though most chemical concentrations appeared to be low, guidelines for drinking water and aquatic life that are needed to make a full assessment do not exist for more than half the compounds detected.





The Puget Sound Basin is a 13,700-square-mile area of mountains and coastal lowlands in western Washington State and portions of British Columbia. About 4 million people live in the basin, mainly in metropolitan areas of Seattle, Tacoma, Everett, Bellingham, and Olympia. Headwaters of major rivers provide much of the drinking water for these metropolitan areas. Ground water is the primary source of drinking water in rural areas and, increasingly, for new suburbs.

- The insecticide diazinon, commonly used by homeowners on lawns and gardens, was frequently detected in urban streams at concentrations that exceeded guidelines for protecting aquatic life (p. 6).

- The average concentration of total nitrogen in small streams draining agricultural lands was twice the concentration in streams draining urban areas and over 40 times the concentration in streams draining undeveloped areas. Concentrations of total phosphorus were less dependent on land use, and concentrations above the USEPA desired goal of 0.1 mg/L to prevent excessive plant growth were detected in rivers and streams in all but undeveloped areas (p. 11).

- Concentrations of *E. coli* bacteria exceeded USEPA criteria for moderate water-contact recreation, including swimming, in 15 of 31 small streams. Livestock, pet, and wildlife wastes, and to some extent human sewage, are likely sources of these bacteria (p. 13).

[1] Insecticides, herbicides, and pesticide metabolites, sampled in water.
[2] Total phosphorus and nitrate (as nitrogen), sampled in water.
[3] Organochlorine compounds including DDT and PCBs, sampled in fish tissue.
[4] Miscellaneous industrial chemicals and combustion by-products, sampled in sediment.

- Urban expansion into forested areas is changing stream habitats, in part because of changes in water quality. Streams in urban and agricultural areas are warmer and support less diverse populations of insects than those in forested areas (p. 14).

Trends in Surface-Water Quality

Concentrations of nitrate and phosphorus in the Nooksack and Green Rivers did not change between 1980 and 1997. During the same period, concentrations of nitrate in the Skokomish River and in Big Soos and Newaukum Creeks increased slightly (p. 12).

> **Major Influences on Streams and Rivers**
>
> - Contaminants in runoff from urban and agricultural land surfaces
> - Degraded stream habitat in urban and agricultural areas

Ground-Water Highlights

Reliance on ground water as a source of drinking water is increasing with urban and suburban development. With some exceptions, ground water is of high quality. However, as indicated by elevated concentrations of nitrate and the presence of pesticides and other organic compounds, shallow ground water in both urban and agricultural settings is vulnerable to contamination. Monitoring wells in urban residential areas generally contained low-concentration mixtures of chemicals associated with transportation and household activities. Shallow ground water, at depths tapped for domestic supply in agricultural areas, contained fertilizer residues (nitrate) at concentrations that commonly exceeded the drinking-water standard. Other agricultural chemicals were also frequently detected, though mostly at concentrations below current Federal and State drinking-water guidelines.

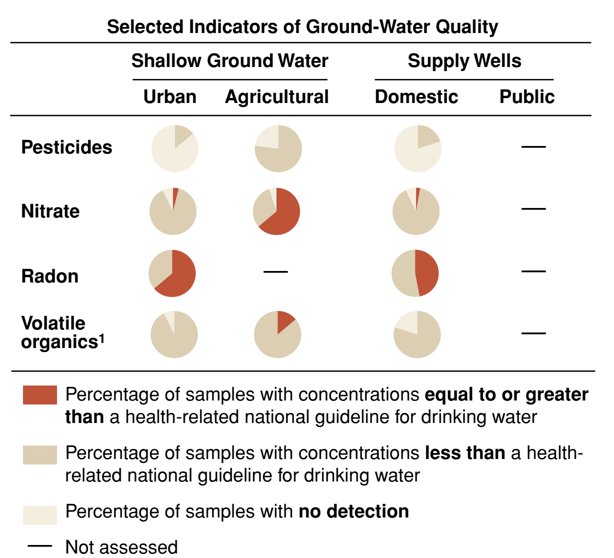
- Use of fertilizers on urban lawns and gardens and drainage from septic systems have elevated nitrate concentrations in shallow ground water beneath urban residential areas. In most samples, these concentrations were substantially less than the drinking-water standard (p. 17).

- Pesticides were not detected in wells that are more than 120 feet deep, the depth below which most large public-supply wells withdraw water. Pesticides were detected in wells that are less than 100 feet deep, the range of many rural and suburban domestic wells, but concentrations met drinking-water guidelines. Only about half of the detected pesticides have guidelines, and no benchmarks are available to assess the significance of low-concentration mixtures of pesticides (p. 16).

- Applications of fertilizers and dairy and poultry manure to cropland in agricultural areas of the Nooksack River Basin have increased nitrate concentrations above the USEPA drinking-water standard in about 60 percent of the shallow ground water sampled (p. 18).

- Prior to 1977, 1,2-dichloropropane was one of the ingredients in fumigants used on potatoes and berries in the Nooksack River Basin. Currently used fumigants contain only trace amounts of this compound, and their application is not likely contaminating ground water to concentrations exceeding drinking-water standards (p. 19).

> **Major Influences on Ground Water**
>
> - Poultry and dairy waste
> - Lawn and garden fertilizers
> - Septic systems
> - Fumigants no longer in use



[1] Solvents, refrigerants, fumigants, and gasoline compounds, sampled in water.

The Puget Sound Basin encompasses the 13,700-square-mile area that drains to Puget Sound and adjacent marine waters. Included are all or part of 13 counties in western Washington, as well as the headwaters of the Skagit River and part of the Nooksack River in British Columbia, Canada. Streams and rivers drain three physiographic provinces—the Olympic Mountains in the west, the Cascade Range in the east, and the Puget Lowlands in the center of the basin (fig. 1).

Land Use Affects Water Quality and Stream Habitat

Nearly 4 million people, or about 70 percent of Washington State's population, live in the Puget Sound Basin. Urban growth is rapid; by 2020, the population is expected to increase by 1.1 million people, with most growth in urban and suburban areas. Urban and agricultural land uses, which cover about 9 and 6 percent of the basin, respectively (fig. 2), are concentrated in the lowlands. Forest dominates land use and cover in the basin and is concentrated in the foothills and mountains (see map, p. 1).

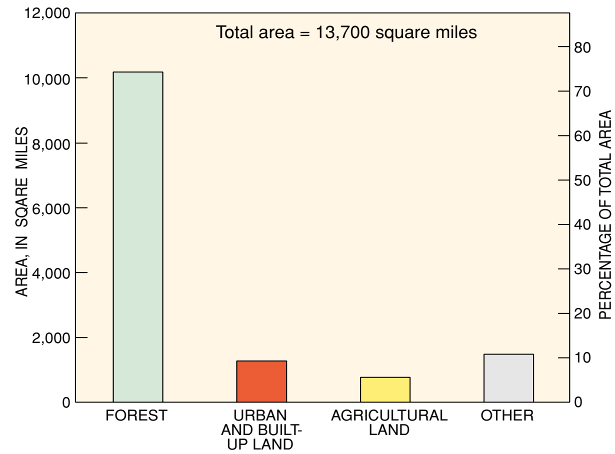
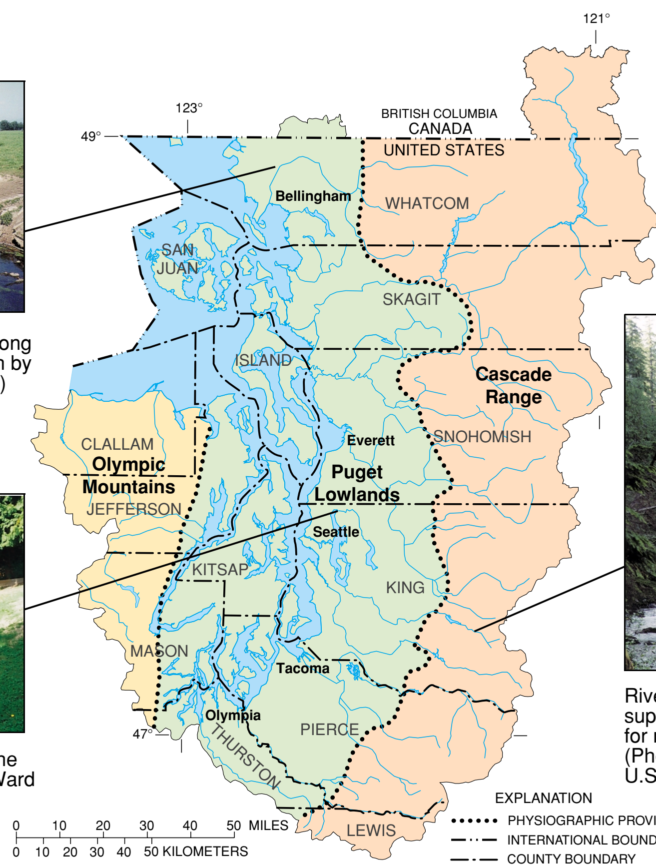


Figure 2. Land use and cover in the basin is predominantly forest.

The quality of water and aquatic biota has been affected by a range of forestry, agricultural, and urban development practices. The chemical quality of surface water in the foothills and mountains is generally suitable for most uses. However, the physical hydrology, water temperature, and biologic integrity of streams have been influenced to varying degrees by logging (Black and Silkey, 1998).

Streambank vegetation is sparse along an agricultural stream. (Photograph by Bob Black, U.S. Geological Survey.)

Urban land use is concentrated in the Puget Lowlands. (Photograph by Ward Staubitz, U.S. Geological Survey.)



Rivers in forested headwaters supply most of the drinking water for major urban centers. (Photograph by Bob Black, U.S. Geological Survey.)

Figure 1. Streams and rivers drain three physiographic provinces in the Puget Sound Basin (Black and Silkey, 1998).

The quality of ground water in the upper watersheds probably differs little from natural conditions.

Because of development, many streams in the Puget Lowlands have undergone changes in structure and function with a trend toward simplification of stream channels and loss of habitat (Black and Silkey, 1998). Sources of contaminants to lowland streams and lower reaches of large rivers are largely nonpoint because most major point sources discharge directly to Puget Sound. Compared with that in small streams in the Puget Lowlands, the quality of water in the lower reaches of large rivers is better because much of the flow is derived from the forested headwaters.

More than half of the agricultural acreage in the basin is located in Whatcom, Skagit, and Snohomish Counties. Agricultural land use consists of about 60 percent cropland and 40 percent pasture. Livestock produce a large amount of manure that is applied as fertilizer to cropland, sometimes in excess amounts, resulting in runoff of nitrogen and phosphorus to surface water and leaching of nitrate to ground water. Runoff from agricultural areas also carries sediment, pesticides, and bacteria to streams (Staubitz and others, 1997). Pesticides and fumigant-related compounds are present, usually at low concentrations, in shallow ground water in agricultural areas.

Heavy industry is generally located on the shores of the urban bays and along the lower reaches of their influent tributaries, such as Commencement Bay and the Puyallup River in Tacoma and Elliott Bay and the Duwamish Waterway in Seattle. High-density commercial and residential development occurs primarily within and adjacent to the major cities. Development in recent years has continued around the periphery of these urban areas but has trended toward lower density. This trend has resulted in increasing urban sprawl in the central Puget Sound Basin (fig. 3).

Urban land-use activities have had a significant impact on the quality of streams in the Puget Sound Basin (Staubitz and others, 1997). Water-quality concerns related to urban development include providing adequate sewage treatment and disposal, transport of contaminants to streams by storm runoff, and preservation of stream corridors.

Water Availability Is a Major Issue

Although surface water provides most of the drinking water for the major urban centers (fig. 4), ground water is used in rural areas, and reliance on ground water as a source of drinking water is increasing with urban and suburban development (Staubitz and others, 1997).

Water availability has been and will continue to be a major, long-term issue in the Puget Sound Basin. It is now widely recognized that ground-water withdrawals can

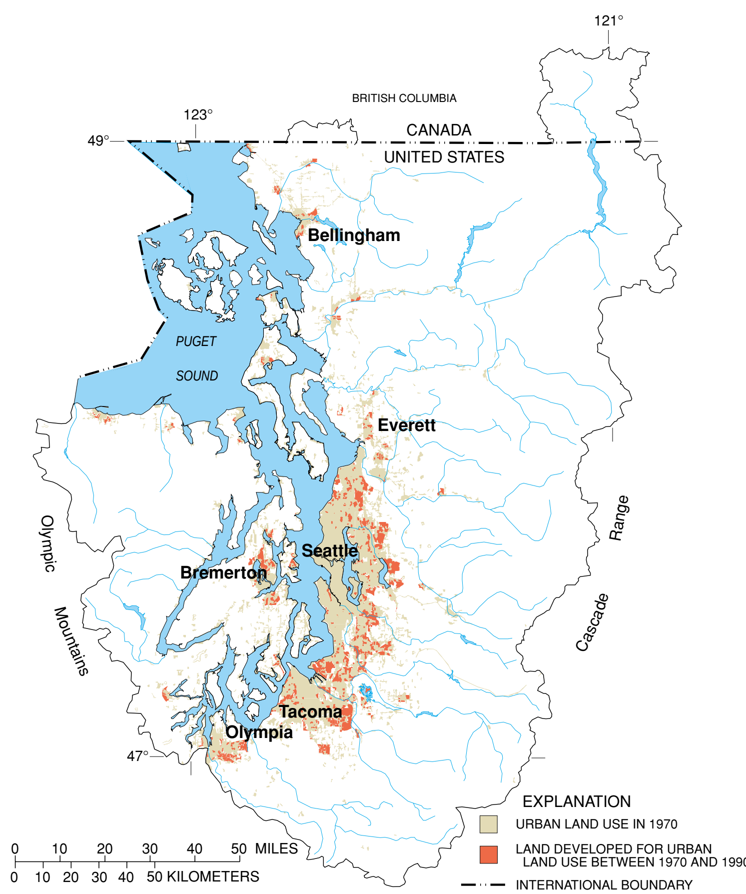


Figure 3. Recent urban development in the Puget Sound Basin has been around the periphery of established urban areas.

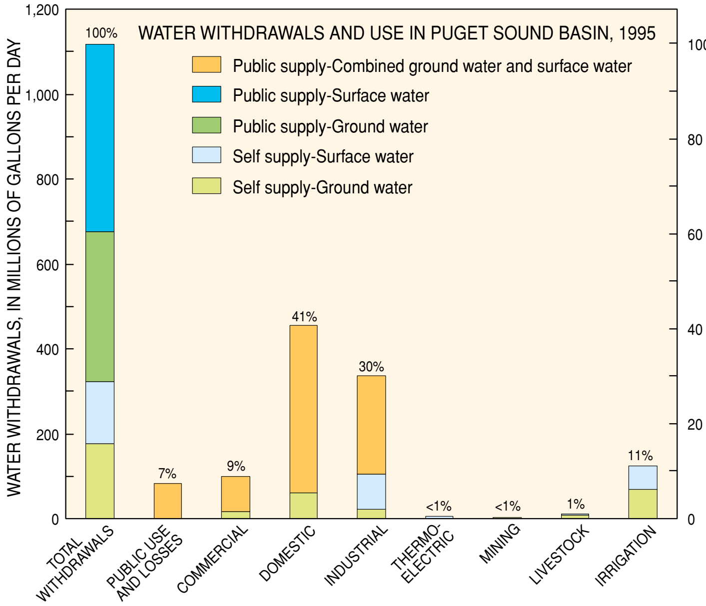


Figure 4. Excluding water used for hydroelectric power, 41 percent of water was used for domestic supply in 1995. Ground water accounted for 47 percent of all withdrawals.

deplete streamflows (Morgan and Jones, 1999), and one of the increasing demands for surface water is the need to maintain instream flows for fish and other aquatic biota.

Hydrologic Conditions Probably Affected Study Results

Surface water was sampled during 1996 and 1997 when rainfall and streamflows generally were above the 30-year average (fig. 5). Because of increased runoff during periods of rainfall, larger amounts of sediment, nutrients, pesticides, bacteria, and other contaminants may have been transported from the land surface into streams and rivers than during drier years. High flows due to runoff from paved surfaces can also alter stream habitat.

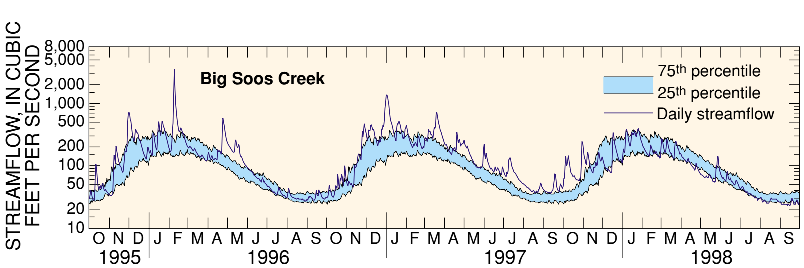


Figure 5. Streams and rivers were sampled during 1996 and 1997 when streamflows generally were above the 30-year average.

Some Ground Water Is Susceptible to Contamination

Shallow ground water (less than 100 feet deep) in the Puget Lowlands is more susceptible to contamination in areas where the overlying sediments are coarse grained than where they are fine grained (see p. 16 and map, p. 20). This is because rainfall, or applied irrigation water, seep relatively easily through coarse-grained sediments and can transport contaminants to ground water.

Study Design Focuses on Land Use

Chemical and biological samples were collected from a mix of rivers and streams in forested, urban, and agricultural areas to assess overall quality as well as the effects of specific land-use practices. At some sites, water samples were collected monthly and during storms to assess the effects of storm runoff on contaminant washoff. Other sites were sampled only once, usually during normal flows.

Shallow ground water was sampled from aquifers in coarse-grained glacial deposits considered to be the most at risk to contamination. Water from these aquifers was sampled to assess general water quality and specifically to assess the quality of water in agricultural and residential areas. Monitoring wells and domestic wells were sampled. Data from a previous sampling of public-supply wells (Ryker and Williamson, 1996) are used to help evaluate the quality of drinking water and the quality of deep ground water. (See table 3, page 21 for details on study design.)

Pesticides in Surface Water Were Indicative of Upstream Land Uses, and More Pesticides Were Detected in Streams Than in Rivers

Twenty-nine pesticides were detected in Fishtrap Creek, which drains an agricultural area in the Nooksack River Basin (see map, p. 20), compared with 21 in Thornton Creek, an urban stream. In Fishtrap Creek, the more frequent detections of the herbicides atrazine and metolachlor, used more in agricultural areas, and less frequent detections of the herbicides dichlobenil and prometon (fig. 6), used more in urban areas, are consistent with the predominant land use in the drainage basin. Urban-use pesticides in Fishtrap Creek are probably transported from urban areas in the upper and lower parts of the basin.

The two large rivers sampled for pesticides, the Nooksack and Duwamish (see map, p. 20), integrate land-use effects. The herbicides prometon, simazine, and tebuthiuron, which are used in urban settings, were detected frequently in the Duwamish River (fig. 6). This is indicative of the urban land use surrounding and immediately upstream from the sampling site. Metolachlor, an agricultural herbicide, was detected more often in the Duwamish River than in the Nooksack River, which was sampled in an agricultural setting. Metolachlor in the Duwamish River was likely transported from agricultural areas upstream from the mostly urbanized lower part of the basin, where samples were collected.

Table 1. Concentrations of three insecticides were sometimes above chronic guidelines for the protection of aquatic life

Insecticide	Aquatic life guideline (micrograms per liter)[1]	Percentage of all samples exceeding guideline	Site in exceedance and **(percentage of samples)**	Range of concentrations detected at the site (micrograms per liter)
Chlorpyrifos	0.041	1	Thornton **(2)**	0.006–0.074
Diazinon	0.08	9	Thornton **(20)** Fishtrap **(3)** Duwamish **(4)**	0.003–0.501 0.004–0.113 0.004–0.083
Lindane	0.01	1	Thornton **(2)**	0.02

[1] U.S. Geological Survey, 1999a.

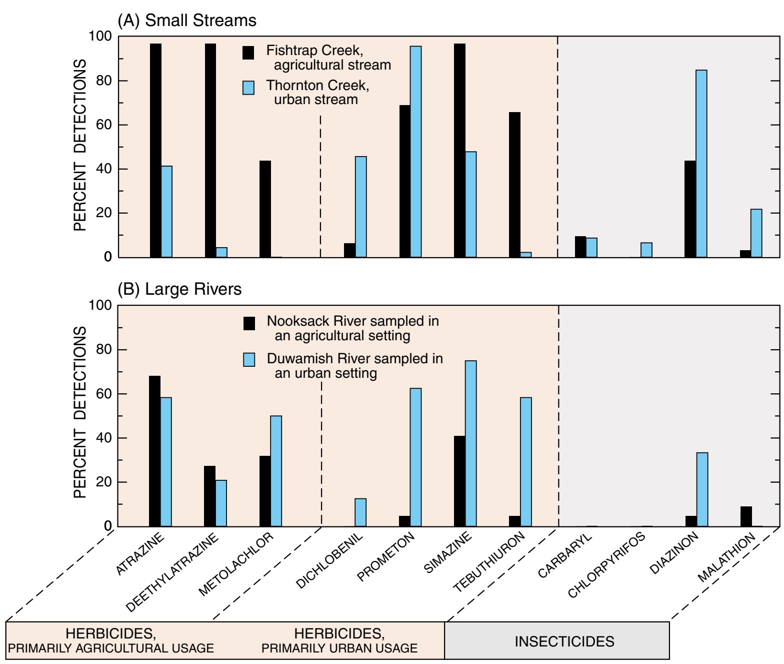


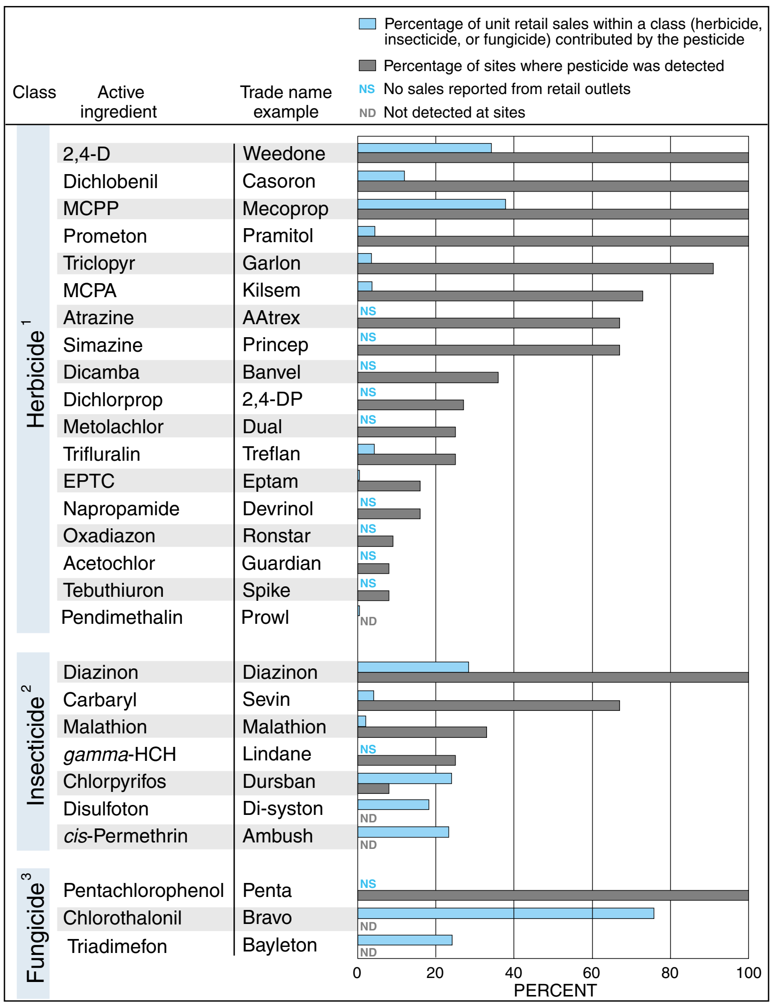
Figure 6. Pesticides detected in small streams (A) and large rivers (B) were indicative of land use, but detection frequencies in large rivers were lower because of dilution by flows from forested headwaters.

Pesticides transported to the Nooksack and Duwamish Rivers are diluted by the volume of high-quality water from forested headwaters, resulting in lower detection frequencies compared with Fishtrap and Thornton Creeks (fig. 6). In addition to lower detection frequencies, fewer pesticides were detected in the large rivers.

Diazinon was the most frequently detected insecticide in both small streams and large rivers (fig. 6). It is used heavily in urban areas of the Puget Sound Basin, and its frequent detection, sometimes at concentrations exceeding the chronic guideline for the protection of aquatic life (table 1), prompted a more focused study of pesticides in urban streams in Seattle and surrounding King County (see page 7).

Concentrations of Pesticides in Surface Water Draining Urban and Agricultural Areas Sometimes Exceeded Guidelines for the Protection of Aquatic Life

The insecticides chlorpyrifos, diazinon, and lindane were sometimes detected at concentrations above chronic guidelines for the protection of aquatic life (table 1). Concentrations of diazinon exceeded its guideline in 9 percent of all samples, and in Thornton Creek, concentrations exceeded the guideline in 20 percent of samples. It is estimated that about half the 83,000 pounds of diazinon applied annually in the Puget Sound Basin are applied in King County (Tetra Tech Incorporated, 1988). Diazinon is the insecticide purchased most frequently by King County residents (fig. 7).



[1] Unit retail sales for these herbicides total to 140,000 units.
[2] Unit retail sales for these insecticides total to 66,000 units.
[3] Unit retail sales for these fungicides total to 1,700 units.

Figure 7. A comparison of pesticides detected in urban streams with retail sales data suggests that homeowner and nonresidential applications both are sources of pesticides in streams. Sales were reported in units, which represent a bag, bottle, or other package containing the pesticide.

Pesticides Applied to Lawns and Gardens, As Well As Those Applied in Nonresidential Areas, Are Sources of Pesticides in Urban Streams

Because of the prevalence of diazinon and other pesticides in Thornton Creek, the USGS collaborated with the Washington State Department of Ecology and the King County Hazardous Waste Management Program to study pesticides in streams in 10 urban and suburban watersheds in King County (see map, p. 20). Samples were collected during April and May 1998 when retail sales of pesticides are highest (Voss and others, 1999), and they were collected during storms when runoff can transport pesticides to streams.

Because USGS and Washington State Department of Ecology laboratories both participated in the study, additional pesticides not included in the NAWQA study were analyzed. To help determine sources of pesticides detected, King County provided sales data for pesticides sold in 10 large home and garden stores during 1997.

Twenty-three of 98 pesticides analyzed for were detected in the urban streams. Homeowner use as a source of pesticides in streams is indicated for compounds like the herbicide 2,4-D and the insecticide diazinon, which were detected in all streams and were sold frequently in the home and garden stores (fig. 7). Some pesticides sold in stores were not detected in streams, indicating that other factors, like the rate at which a compound breaks down, affect the relation between usage and detection.

Almost half of the pesticides detected in the streams had no retail sales, indicating that they are usually not applied by homeowners. In urban areas, pesticides are also applied in commercial areas, along road rights-of-way, and in parks and recreational areas.

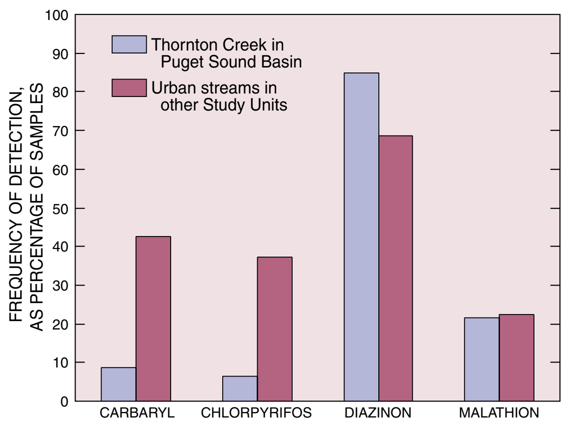
Insecticides in Thornton Creek Were Also Detected in Urban Streams Throughout the Nation

Throughout the Nation, the insecticides diazinon, carbaryl, chlorpyrifos, and malathion were detected much more frequently in streams draining urban basins than in streams draining agricultural basins (U.S. Geological Survey, 1999b). Except for carbaryl, these pesticides also were detected more frequently in Thornton Creek, an urban stream, than in Fishtrap Creek, an agricultural stream (fig. 6).

Detection of these pesticides is related to usage. For example, diazinon and chlorpyrifos, which nationally rank 1 and 4 among insecticides used for homes and gardens, rank 1 and 2 in unit sales of insecticides sold by home improvement stores in urban and suburban areas of King County (fig. 7).

Insecticides in streams are a concern because even at relatively low concentrations they can exceed guidelines for the protection of aquatic life (table 1).

Areas where pesticides are applied in urban settings are often in close proximity to streams. (Photograph by Sandra Embrey, U.S. Geological Survey.)



Although detection frequencies vary, insecticides in Thornton Creek were typical of those detected in urban streams in other Study Units throughout the Nation.

Historically Used Pesticides and PCBs Are Still Detected in Streambed Sediments and Fish Tissue

Streambed sediment and whole fish (sculpin, a bottom fish) tissue were analyzed at sites throughout the basin (see map, p. 20) in 1995 for organochlorine pesticides and PCBs. These compounds have been shown to have negative impacts on the health of aquatic organisms as well as the organisms that consume them. More organochlorine compounds were detected in both streambed sediments and fish tissue at sites surrounded by agricultural and urban land uses than at sites in undeveloped, forest, or mixed-land-use areas (fig. 8).

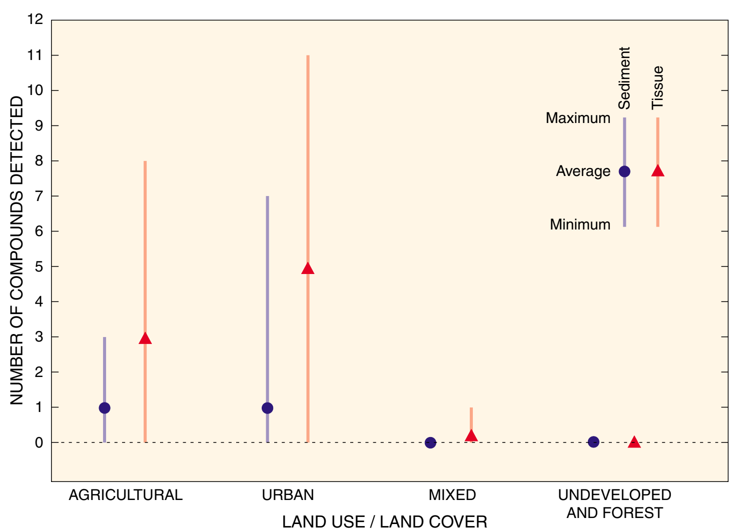


Figure 8. Organochlorine compounds, including the insecticide DDT and PCBs, in streambed sediments and fish tissue were primarily detected in urban and agricultural streams.

Fish Tissue Contamination is Related to Urban and Agricultural Land Uses

The relation between land use and the probability of detecting organochlorine compounds in fish (sculpin) tissue were statistically significant. This relation suggests that urban and agricultural land uses both contribute to the probability that a fish is contaminated with organochlorine pesticides. The probability of detecting total PCBs in fish was significantly related to urban land use only (Black and others, 2000). These relations also suggest that there is a land-use threshold below which the probability of finding organochlorine compounds in fish tissue is unlikely (fig. 9).

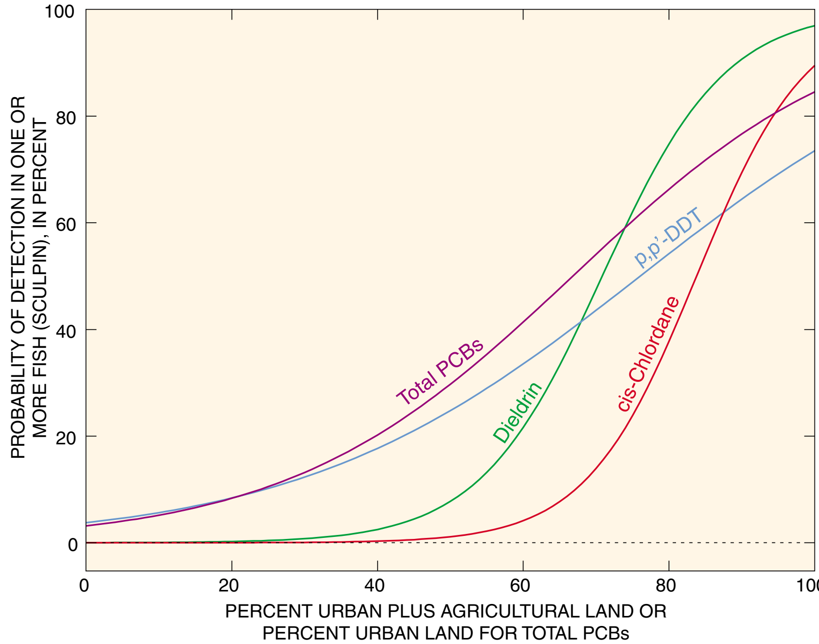


Figure 9. The probability of detecting specific organochlorine compounds in one or more fish (sculpin) at a site increased with the percentage of urban and agricultural land in the drainage basin. Dieldrin, *cis*-Chlordane, and *p,p'*-DDT relations are based on the percentage of agriculture plus urban land upstream from the sampling site. The total PCBs relation is based on the percent of urban land upstream from the sampling site.

Organochlorine Compounds in Streambed Sediment and Fish May Be a Concern for Aquatic Ecosystems

Organochlorine pesticides were detected in streambed sediment at 3 of 19 sites (fig. 10). At Thornton Creek, an urban stream, levels of DDE (a breakdown product of DDT) and DDT exceeded the Canadian Council of Ministers of the Environment's (Canadian Council of Ministers of the Environment, 1995) probable effects level (PEL). Compounds exceeding the PEL are likely to result in adverse effects on aquatic organisms. It is important to note that levels of DDT in Thornton Creek sediment were higher than either one of its breakdown products, DDD and DDE. This may indicate that land disturbances in the basin have reintroduced buried soils contaminated with DDT.

Organochlorine compounds were also detected in the tissue of whole bottom fish (sculpin) collected at 8 of 18 study sites (fig. 11).

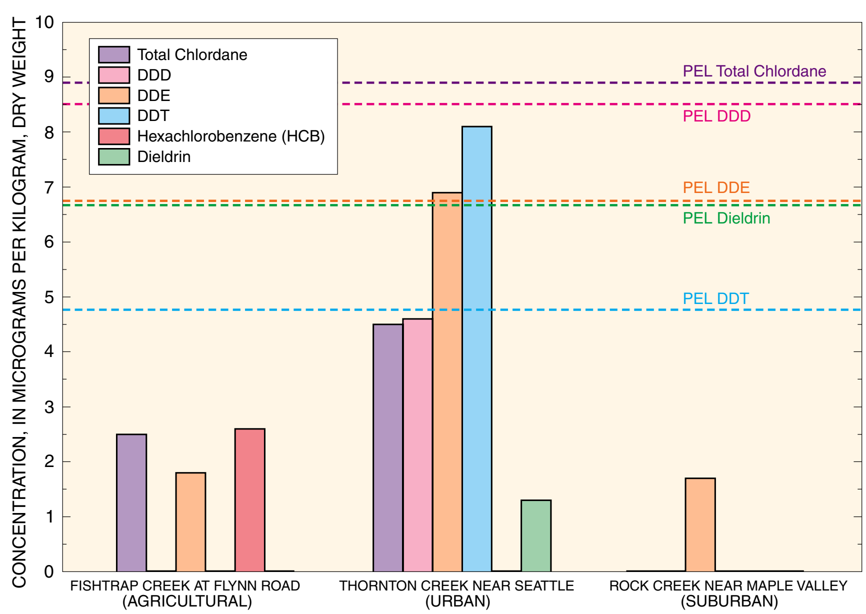


Figure 10. Concentrations of organochlorine compounds in streambed sediment in the Puget Sound Basin sometimes exceeded Canadian probable effects levels (PELs). Compounds above the PELs may have negative impacts on aquatic organisms.

The largest number and highest concentrations of these compounds were in the fish collected from urban sites. At some sites, total PCBs and DDT concentrations were equal to or above the New York State Department of Environmental Conservation (NYSDEC) criteria for the protection of fish-eating wildlife (Newell and others, 1987).

Generally, the concentrations of organochlorine compounds in sediment and fish tissue were in the middle 50 percent nationally (see Appendix). Occasionally, concentrations of DDE, total chlordane, and total DDT were in the upper 25 percent of those reported nationally.

Whole sculpin (*Cottus*) were analyzed for organochlorine compounds. (Photograph by Ward W. Staubitz, U.S. Geological Survey.)

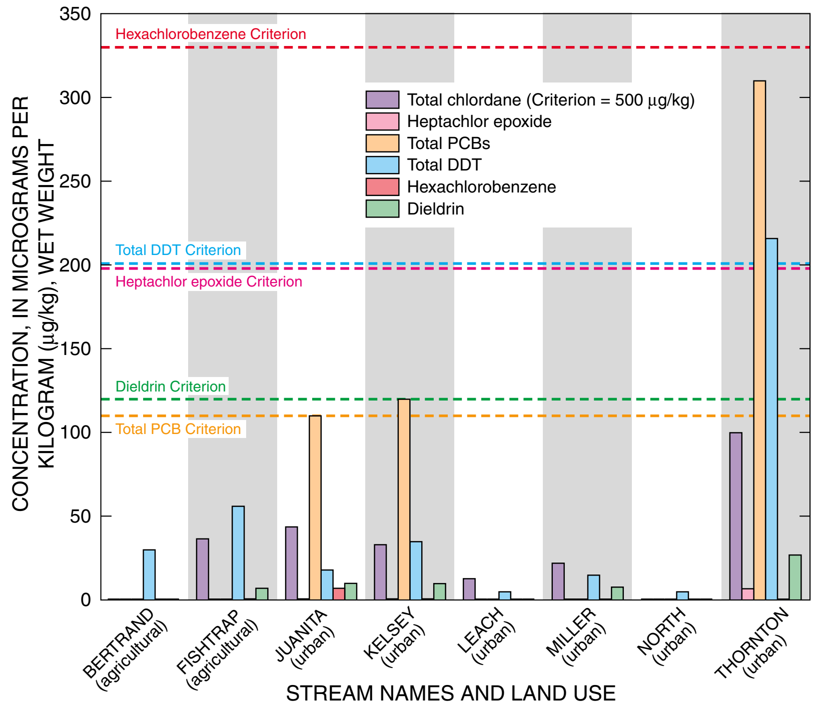


Figure 11. Concentrations of organochlorine compounds in fish (sculpin) tissue from streams in the Puget Sound Basin sometimes exceeded New York State Department of Environmental Conservation (NYSDEC) criteria. Concentrations above criteria may have a detrimental effect on fish-eating organisms.

Characteristics and historical uses of organochlorine compounds detected in Puget Sound Basin fish tissue and streambed sediment

Organochlorine compounds are synthetic organic compounds containing chlorine. As generally used, the term refers to compounds containing mostly or exclusively carbon, hydrogen, and chlorine. Examples include organochlorine insecticides, polychlorinated biphenyls, and some solvents containing chlorine.

Chlordane (Octachloro-4,7-methanotetrahydroindane) is an organochlorine insecticide no longer registered for use in the United States. Technical chlordane is a mixture in which the primary components are *cis*- and *trans*-chlordane, *cis*- and *trans*-nonachlor, and heptachlor.

DDT (Dichloro-diphenyl-trichloroethane) is an organochlorine insecticide no longer registered for use in the United States.

Dieldrin is an organochlorine insecticide no longer registered for use in the United States. It is also a breakdown product of the insecticide aldrin.

Heptachlor epoxide is a breakdown product of the organochlorine insecticide heptachlor. It was used in the United States until the 1970s.

Hexachlorobenzene (HCB) is a fungicide used as a seed and soil treatment. It was discontinued from use in the United States in the 1980s.

Polychlorinated biphenyls (PCBs) are a mixture of chlorinated derivatives of biphenyl, marketed under the trade name Aroclor with a number designating the chlorine content (such as Aroclor 1260). PCBs were used in transformers and capacitors for insulating purposes and in gas pipeline systems as a lubricant. Further sale for new use was banned by law in 1979.

Streams and Rivers in Developed Areas Were Enriched with Nutrients Relative to Those in Undeveloped Areas

The highest average concentrations of total nitrogen were in small streams draining agricultural areas. The concentrations were nearly twice those in streams draining urban areas and over 40 times the average concentrations in streams draining undeveloped land (table 2). Drainage basins in agricultural areas also yielded the most nitrogen per square mile (fig. 12). Concentrations and yields of total nitrogen in Puget Sound Basin streams and rivers correlate with usage and atmospheric deposition of nitrogen in drainage basins (Inkpen and Embrey, 1998). Fertilizers used in both agricultural and urban areas, manure associated with dairy farms, and atmospheric deposition are sources of nitrogen in Puget Sound Basin rivers (Embrey and Inkpen, 1998).

Concentrations of Phosphorus in Some Streams and Rivers May Promote Excessive Plant Growth

Average concentrations of total phosphorus exceeding the USEPA desired goal of 0.1 mg/L to prevent excessive plant growth were detected in streams and rivers in all land-use areas except undeveloped land (table 2). Unlike total nitrogen, concentrations of total phosphorus in streams and rivers in the Puget Sound Basin do not correlate with usage and atmospheric deposition of phosphorus in drainage basins (Inkpen and Embrey, 1998). This is because phosphorus attaches to soil particles and usually remains close to application areas unless it is transported to rivers by soil erosion.

Because of the importance of erosion in transporting phosphorus to streams, yields of total phosphorus correlate with yields of suspended sediment. The highest yields of both suspended sediment and total phosphorus were in the Nooksack River at North Cedarville, which drains a forested area.

Erosion of unstable streambanks and landslides transport sediment and phosphorus to headwater streams in the Nooksack River Basin. Most of the unstable streambanks are associated with road construction and logging (U.S. Forest Service, 1995).

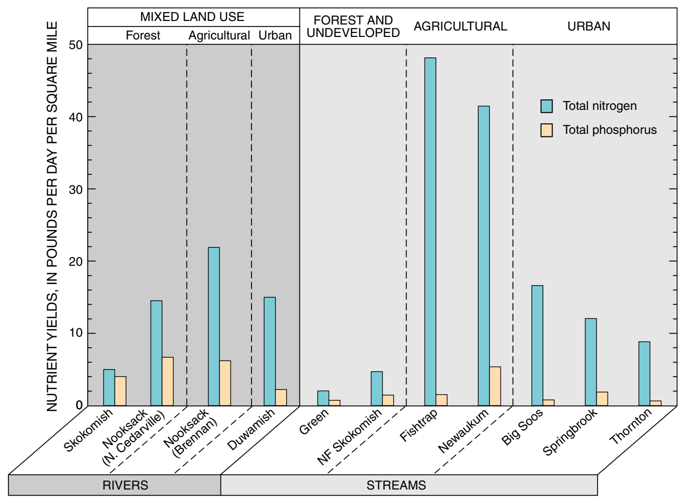


Figure 12. Basins in agricultural areas yielded the most nitrogen per square mile. The forested area upstream from the Nooksack River at North Cedarville yielded the most phosphorus. In basins with mixed land use, the dominant land use is indicated. The Green River above Twin Camp Creek and North Fork Skokomish River fall into the stream category because their drainage basins are relatively small.

Table 2. Highest average concentrations of total nitrogen were in streams draining agricultural areas. Average concentrations of total phosphorus exceeding the USEPA desired goal of 0.1 mg/L to prevent excessive plant growth (shown in bold) were present in streams in urban, agricultural, and forested basins

River or stream	Average total nitrogen concentration (milligrams per liter)	Average total phosphorus concentration (milligrams per liter)	Basin area size	Land use/land cover (dominant land use in mixed)[1]
Fishtrap	3.54	0.086	small	agricultural
Newaukum	2.82	**0.210**	small	agricultural
Thornton	1.73	**0.131**	small	urban
Big Soos	1.20	0.054	small	urban
Springbrook	1.10	**0.165**	small	urban
Nooksack, Brennan	0.66	**0.301**	large	mixed (agricultural)
Duwamish	0.65	0.089	large	mixed (urban)
Nooksack, North Cedarville	0.39	**0.152**	large	mixed (forest)
Skokomish	0.13	0.078	large	mixed (forest)
North Fork Skokomish	0.07	0.012	small	undeveloped
Green	0.07	0.012	small	forest

[1]Forest land that is not logged is designated undeveloped. In basins with mixed land use, the land use in the part of the basin where samples were collected is usually considered the dominant land use.

Concentrations of Nitrate and Phosphorus in Streams and Rivers Have Not Changed or Have Only Slightly Increased with Time

Concentrations of nitrate, one of the major forms of nitrogen in water, and of total phosphorus have not changed much over the period 1980 to 1997 in several Puget Sound Basin rivers and streams (fig. 13). In three streams, nitrate concentrations have increased by a small amount, 0.014 mg/L per year or less. Only in Newaukum Creek did concentrations of both nitrogen and phosphorus increase over time. Although data were not collected to determine the cause, trends often reflect land-use changes. For example, urban development might be a factor related to increasing nitrate concentrations in Big Soos Creek and in Newaukum Creek, which drains an agricultural basin with hobby farms and residential development.

Site name (land use and cover, dominant in mixed)	Nitrate, as N		Total phosphorus	
	Trend	Rate of change, in mg/L per year	Trend	Rate of change, in mg/L per year
Skokomish River (mixed, forest)	↑	0.004	—	—
Nooksack River at Brennan (mixed, agricultural)	—	—	—	—
Nooksack River at N. Cedarville (mixed, forest)	—	—	—	—
Green River at Renton Junction (mixed, urban)	—	—	—	—
Big Soos Creek (urban)	↑	0.010	—	—
Newaukum Creek (agricultural)	↑	0.014	↑	0.002

— No trend or no value; ↑ Significant upward trend; mg/L=milligrams per liter

Figure 13. In three of six rivers and streams monitored by the Washington State Department of Ecology and King County, nutrient concentrations have remained stable from 1980 to 1997. In three others, concentrations of nitrate have gradually increased with time.

Runoff During Rainstorms Contributes Contaminants to Streams, Indicating Nonpoint Sources

Washoff of nutrients and pesticides during storms causes both seasonal and short-term temporal variations in concentrations. A typical seasonal pattern for Puget Sound Basin streams and rivers is illustrated by lower concentrations of nitrogen and phosphorus in Newaukum Creek from July through October when rainfall amounts are lowest (fig. 14).

Commonly used pesticides, such as diazinon, often had higher concentrations during rainstorms when they were washed off from areas of application (fig. 15). Even when daily rainfall amounts were small, less than 0.05 inch, diazinon concentrations increased in Thornton Creek.

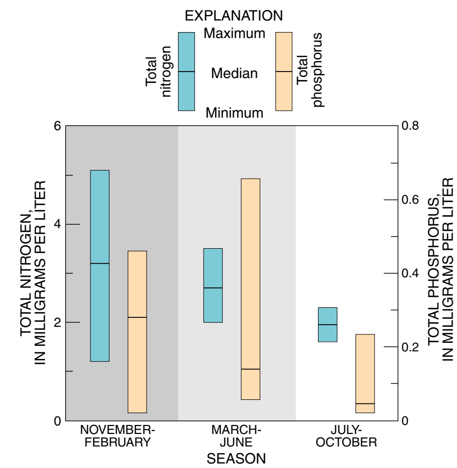


Figure 14. Nutrient concentrations in Newaukum Creek were highest during the rainy winter and spring periods. Concentrations were lowest during late summer-early fall when rainfall amounts are lowest.

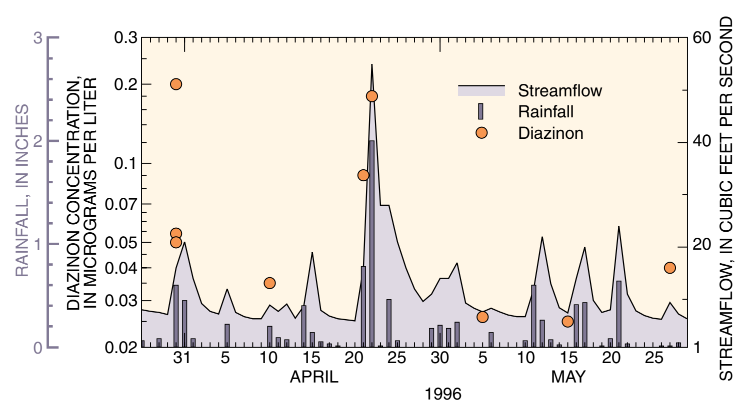


Figure 15. Peak concentrations of diazinon in Thornton Creek often occurred during spring rainstorms, which can produce an inch or more of rain in a day.

Bacteria Indicate the Presence of Fecal Contamination in Many Puget Lowland Streams

A study of 31 small lowland streams showed fecal coliform, *E. coli*, and enterococci bacteria to be present in every stream sampled during base flow. The presence of *E. coli* and enterococci bacteria is evidence that fecal contamination has occurred. During base flow, fecal contamination in urban streams could result from leaky sewer systems, failing septic systems, and direct fecal inputs from pets and wildlife, including waterfowl. In agricultural and rural streams, fecal contamination is likely to be mostly from animals, including farm animals (dairy and beef cattle, and horses). Other sources could be wildlife, with perhaps some input from onsite septic systems.

Concentrations of all three fecal-indicator bacteria frequently exceeded standards and criteria (fig. 16); 81 percent of all sites had concentrations of fecal coliforms exceeding Washington State standards, and 48 percent of all sites had levels of *E. coli* exceeding USEPA's recommended concentration for moderate water-contact recreation. Because concentrations of *E. coli* and enterococci are related to cases of gastrointestinal illness in swimmers (U.S. Environmental Protection Agency, 1986), there could be some risk of illness to children and adults playing and swimming in these accessible streams.

Concentrations of bacteria in urban streams, which are attractive recreation areas, often exceed recommended concentrations for moderate water-contact recreation. (Photograph by Ward W. Staubitz, U.S. Geological Survey.)

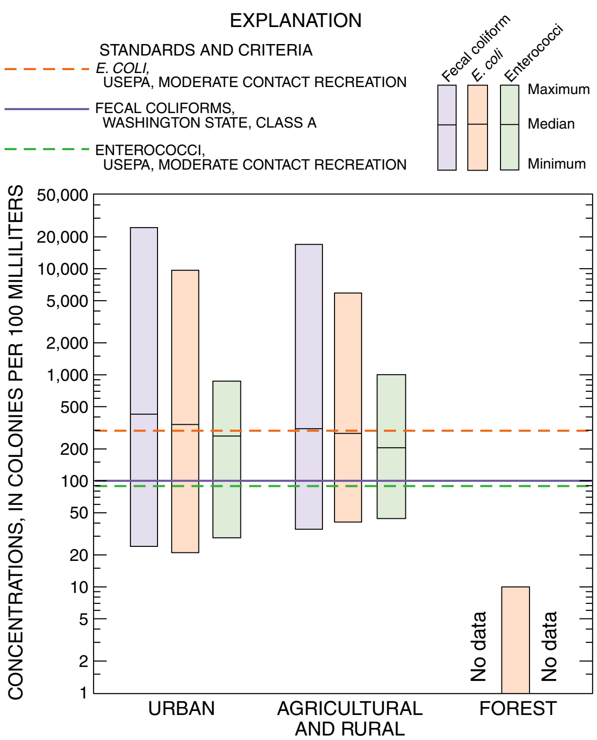


Figure 16. Concentrations of *E. coli* and enterococci bacteria exceeded U.S. Environmental Protection Agency recreational criteria, and fecal coliform bacteria exceeded Washington State standards in many lowland streams. Concentrations of bacteria in single samples were compared with criteria and standards. USEPA criteria for moderate full-body contact recreation apply to a single sample (U.S. Environmental Protection Agency, 1986). Washington State standards for fecal coliform bacteria apply to the geometric mean of concentrations in samples collected during a period of no more than 30 days (State of Washington, 1992). Because no minimum number of samples is specified, the standard is routinely applied to concentrations in single samples (Hallock and others, 1996).

The types of fecal bacteria and their concentrations in streams were similar among urban, agricultural, and rural areas (fig. 16). However, concentrations of *E. coli* in the urban and agricultural streams were all well above those in the upper Green River in the forested headwaters of the basin.

Stream Habitat and Health Are Degraded in Agricultural and Urban Streams

During the late summer and early fall, between 1995 and 1998, the USGS and the Washington State Department of Ecology evaluated instream and riparian (streamside) habitat conditions at 45 sites. These evaluations indicated that habitat conditions at streams draining urban

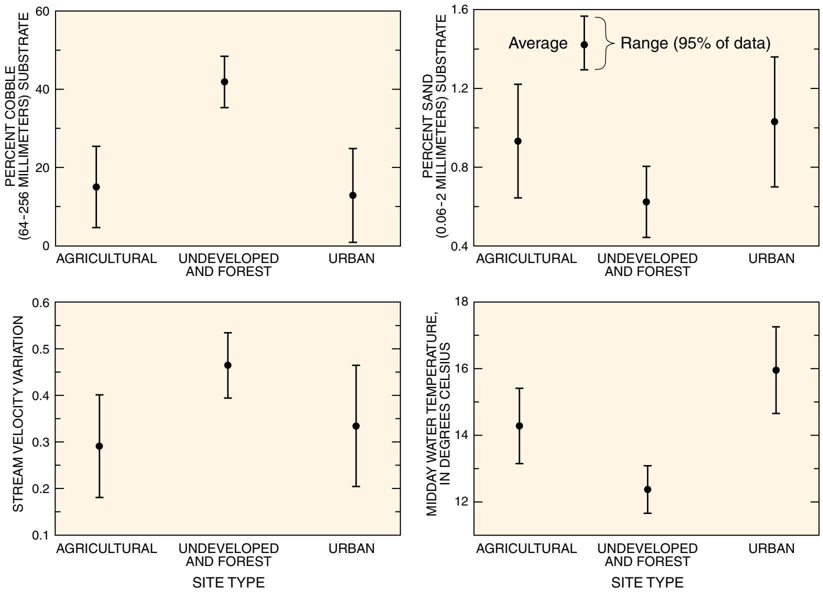


Figure 17. Values of selected habitat variables indicate that habitat conditions are degraded in agricultural and urban streams compared with streams in forest and undeveloped land. For each habitat variable, except temperature, multiple measurements were taken within a 330- to 660-foot-long stream reach at each study site.

and agricultural basins were significantly different from those at streams draining basins with forest and undeveloped land (fig. 17). Compared with either urban or agricultural sites, forest and undeveloped stream sites had a much higher percentage of cobble substrate, ideal for a diverse population of aquatic organisms, and a lower percentage of sand, detrimental to salmon spawning. In addition, forest and undeveloped sites had a much higher variability in water flow velocities than either urban or agricultural sites. More variability in flow velocities increases habitat diversity and wildlife diversity. Midday water temperatures were also much lower in the forested streams. The higher temperatures observed in the agricultural and urban streams are not ideal for native salmon and other aquatic organisms.

Human Activities Have Altered Aquatic Invertebrate Communities

As part of the USGS and Washington State Department of Ecology habitat data collection, aquatic invertebrates (insects and worms) were also collected from multiple riffle habitats at all 45 sites. A number of invertebrate community measures were examined to evaluate the status and quality of the aquatic invertebrate community. For each invertebrate community measure, values were lower, significantly so in some cases, at the urban and agricultural sites (fig. 18).

Urban development and agriculture can reduce habitat quality, alter typical stream flows, and increase chemical contaminants and temperatures, all of which are reflected in invertebrate community measures. A reduction in the total number of different invertebrates, stoneflies, mayflies, intolerant invertebrates, and percentage of predatory invertebrates indicates stream ecosystem degradation. For example, the total number of different invertebrates was much higher at the forest and undeveloped sites. A greater number of different invertebrates indicates a less degraded stream system capable of supporting more numerous desirable species such as salmon.

A summation of many invertebrate community measures is also shown in figure 18. This measure is known as a Benthic Index of Biological Integrity (BIBI) and is an overall indication of the biological integrity or health of a particular stream site (Black and MacCoy, 2000). As seen in figure 18, urban and agricultural systems have lower biological integrity scores than the forest and undeveloped sites.

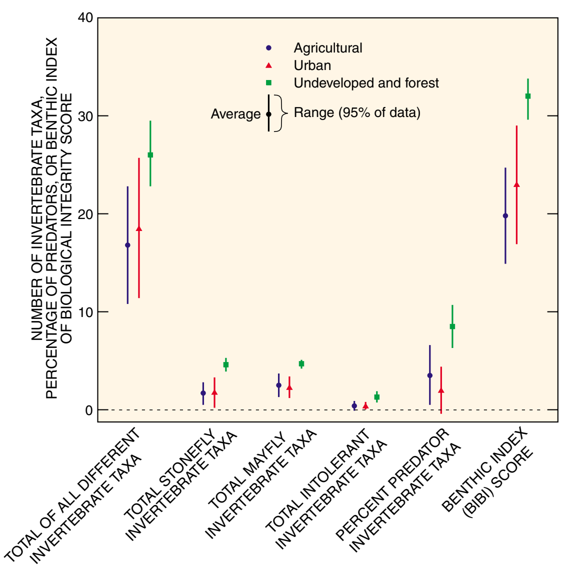


Figure 18. As indicated by the average values of six different invertebrate community indicators of stream ecosystem conditions, conditions were better at sites in forest and undeveloped land than at sites in urban and agricultural areas. Lower values suggest a more degraded stream site. Taxa are different types of invertebrates.

Streams in Urban and Agricultural Areas Have Less Than Optimal Amounts of Forest and Undeveloped Land to Support Healthy Aquatic Invertebrate Communities

A total of 46 different aquatic invertebrate taxa were identified at 45 sites throughout the Puget Sound Basin. Of the 46, only 4 taxa prefer watersheds with low forest/undeveloped land cover, whereas 19 taxa prefer watersheds with high forest/undeveloped land cover (fig. 19). These results indicate that streams in watersheds dominated by urban and agricultural land are optimally suited for only a few of the different taxa and many of these taxa are indicators of degraded stream ecosystems. Watersheds dominated by forest and undeveloped land are preferred by a much larger number of different invertebrate taxa, many of which are indicators of healthy stream systems.

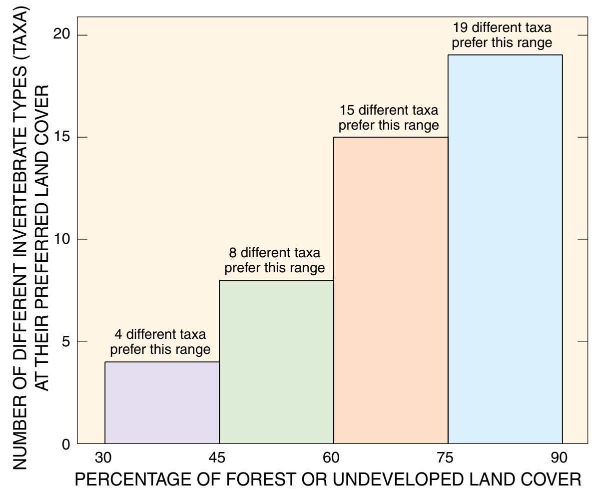
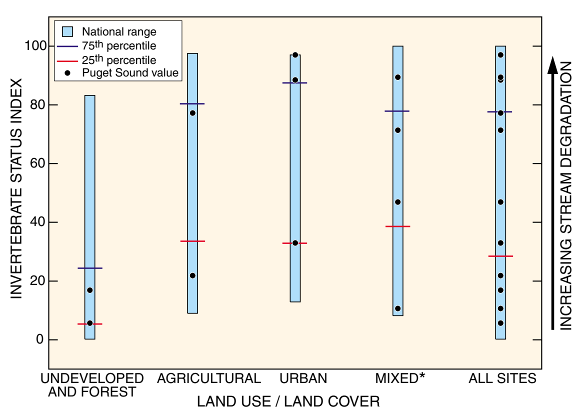


Figure 19. More different aquatic invertebrate types (taxa) prefer streams that have watersheds with greater than 75 percent forest/undeveloped land cover. Each bar represents the preferred range of forest/undeveloped land cover for the specified number of invertebrate taxa out of the 46 taxa identified in the Puget Sound Basin. An animal is healthiest when it is in its preferred range. This figure indicates that more different invertebrate taxa prefer sites in forested/undeveloped watersheds, but not that more invertebrate taxa or total numbers of invertebrates were found at these sites. The method used to determine preferred land-cover percentages was based on the work of Line and others (1994).

Puget Sound Stream Invertebrate Status Ranged from High to Low When Compared with National Levels

In the Puget Sound Basin, aquatic invertebrates collected at the 11 fixed monitoring sites were compared with those collected at 140 NAWQA sites nationwide. An **Invertebrate status index** (Tom Cuffney, U.S. Geological Survey, written commun., 2000) was developed by averaging 11 invertebrate metrics that summarized changes in richness, tolerance, food preference, and dominance associated with water-quality degradation. Invertebrate status scores in the basin ranged from low (less degraded) for streams in forest and undeveloped areas to high (more degraded) for other streams. As indicated by the invertebrate status scores, some Puget Sound Basin streams are highly degraded. This is the result of poor habitat conditions and possibly water chemistry. As shown in figure 17, high midday water temperatures and percent sand were observed in urban and agricultural streams, both of which have negative effects on aquatic organisms. In addition, numerous pesticides, some at concentrations above guidelines set to protect aquatic life, were detected at these sites (see Appendix).



Invertebrate status index by land use and cover for Puget Sound Basin sites in relation to national conditions. A low invertebrate status index score represents a less degraded stream site. *Mixed land uses can have an agricultural, urban, or forestry influence (table 2).

Ground-Water Quality is Generally Good

Prior to conducting field studies, an analysis of existing data was conducted to determine which Puget Sound Basin aquifers are most at risk to contamination. Unconfined aquifers that are overlain by coarse-grained glacial deposits (see map, p. 20) were found to be the most susceptible to contamination (see sidebar). Aquifers in coarse-grained glacial deposits in the Puget Sound Basin are collectively referred to as the Fraser aquifer. Three studies were conducted in the unconfined part of the Fraser aquifer (Inkpen and others, 2000). A study-unit survey was conducted by randomly selecting 30 domestic wells without regard to land use to evaluate the overall quality of shallow ground water. Ground-water-quality studies were also conducted in residential areas in Pierce and Thurston Counties and in an agricultural area in Whatcom County (see map, p. 20) to examine the influence of these important land-use categories on shallow ground water. Shallow ground water in all parts of the Fraser aquifer sampled is used for domestic supplies.

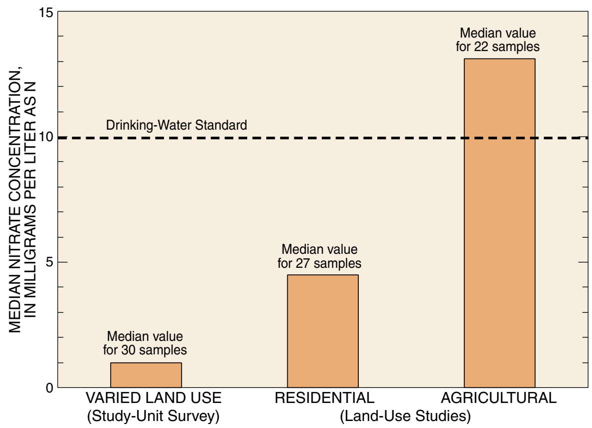
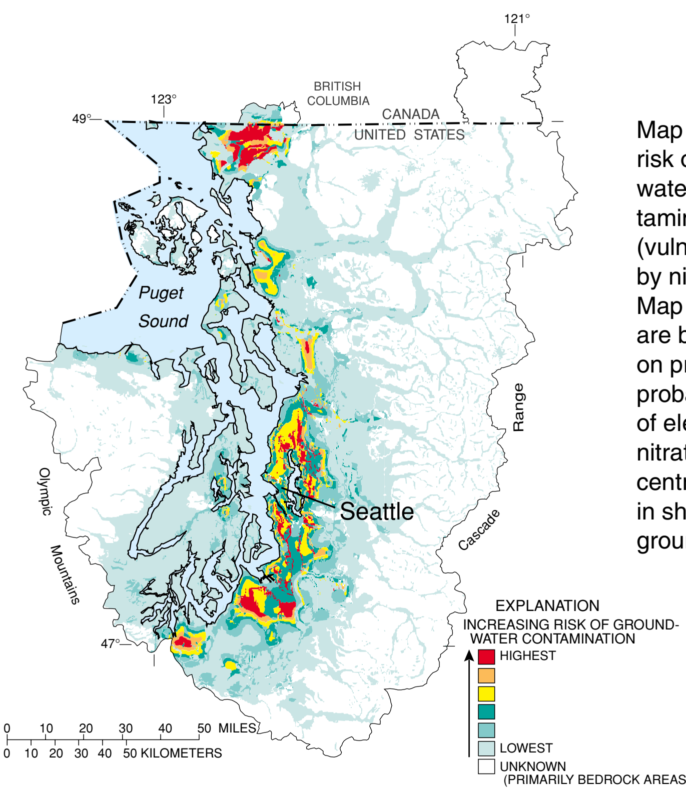


Figure 20. Median nitrate concentrations in shallow ground water sampled for the study-unit survey (varied land use) were low. Higher nitrate concentrations were more common in both the residential land-use and agricultural land-use studies.

The study-unit survey results indicate that ground water is of generally good quality, as only one well did not meet a drinking-water standard (for nitrate). Nitrate was detected in most wells, but the concentrations were low, having a median concentration of 1.0 mg/L (fig. 20). Pesticides were detected in 20 percent of study-unit survey wells (fig. 21) but were present at low concentrations (less than 0.2 µg/L) (micrograms per liter) and were well below drinking-water standards or guidelines. Based on data from a previous study (Ryker and Williamson, 1996), pesticides were not detected in wells more than

Predicting Ground-Water Susceptibility and Vulnerability

A statistical model (Tesoriero and Voss, 1997; Erwin and Tesoriero, 1997) was created to predict which areas are (1) most likely to become contaminated if sources of contaminants are present (susceptibility) and (2) at the greatest risk of contamination, based on current land-use practices (vulnerability). Well depth, surficial geology, and land use were the factors that significantly correlated with elevated nitrate concentrations and were used in the models. Shallow ground water in areas with coarse-grained glacial deposits at the surface were the most susceptible to contamination. These areas become increasingly vulnerable to nitrate contamination as the amount of agricultural and urban land use increases. Vulnerable areas include the intensive agricultural areas in the northern part of the Study Unit as well as urban areas extending north and south of Seattle.



Map shows risk of ground-water contamination (vulnerability) by nitrate. Map results are based on predicted probabilities of elevated nitrate concentrations in shallow ground water.

120 feet deep (Bortleson and Ebbert, 2000). Volatile organic compounds were detected frequently (80 percent of wells sampled) but were present at low concentrations (less than 1 µg/L).

Radon concentrations exceeded the proposed drinking-water standard of 300 picocuries per liter (U.S. Environmental Protection Agency, 1999a) in about 50 percent of the domestic and monitoring wells sampled for radon (table 3, p. 21). Radon is a naturally occurring product from the decay of uranium. The median concentration of radon in ground water in the Puget Sound Basin was 320 picocuries per liter. Elevated radon concentrations are by no means unique to the Puget Sound Basin. In fact, radon concentrations in ground water collected for NAWQA studies throughout the Nation exceeded the proposed standard more often and had a higher median value (420 picocuries per liter) than in the Puget Sound Basin (Wentz and others, 1999).

Nitrate Concentrations in Shallow Ground Water Beneath Residential Areas Were Elevated, but Concentrations of Other Compounds Were Low

Although nitrate concentrations in shallow ground water beneath the residential areas in Pierce and Thurston Counties were elevated compared with those in ground water sampled by the study-unit survey (fig. 20), only one sample exceeded the drinking-water standard. Stable isotope measurements of nitrogen in nitrate suggest that septic-system effluent is a significant source of nitrate in unsewered areas. Additional nitrate sources are indicated by the similar concentrations of nitrate in sewered and unsewered areas (Inkpen and others, 2000). Some nitrate in ground water in unsewered areas and most nitrate in sewered areas is likely from the application of fertilizers to lawns and gardens.

Pesticides Were Rarely Detected in Ground Water Beneath Residential Areas

In spite of the vulnerability of the unconfined Fraser aquifer, only a few pesticides were detected (fig. 21) and these were at low concentrations (less than 0.2 microgram per liter) beneath residential areas developed since 1970. These results suggest that pesticides currently used in residential areas may pose little risk to ground water. However, it should be noted that several commonly used pesticides (glyphosate, for example) were not analyzed.

Volatile Organic Compounds Were Detected Frequently at Low Concentrations in Ground Water Beneath Residential Areas

Although volatile organic compounds (VOCs) were detected in over 90 percent of shallow ground-water samples in residential areas, concentrations were low (fig. 22). Most detections were less than 0.05 µg/L,

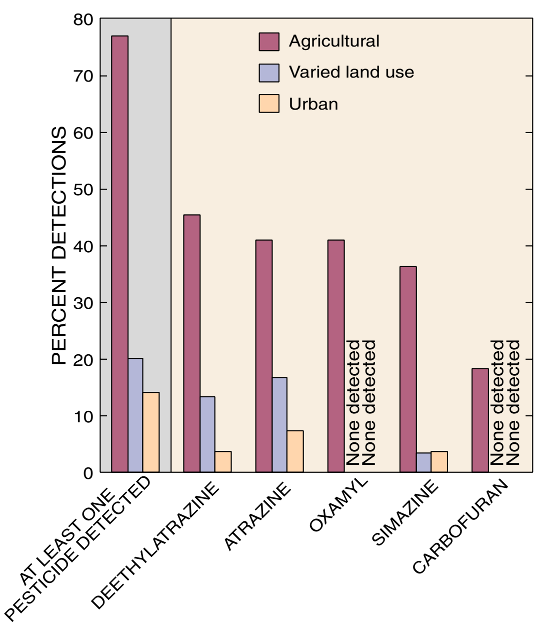


Figure 21. A pesticide was detected in less than 15 percent of shallow ground-water samples beneath residential areas, and the most frequently detected compounds were each detected in less than 10 percent of these samples.

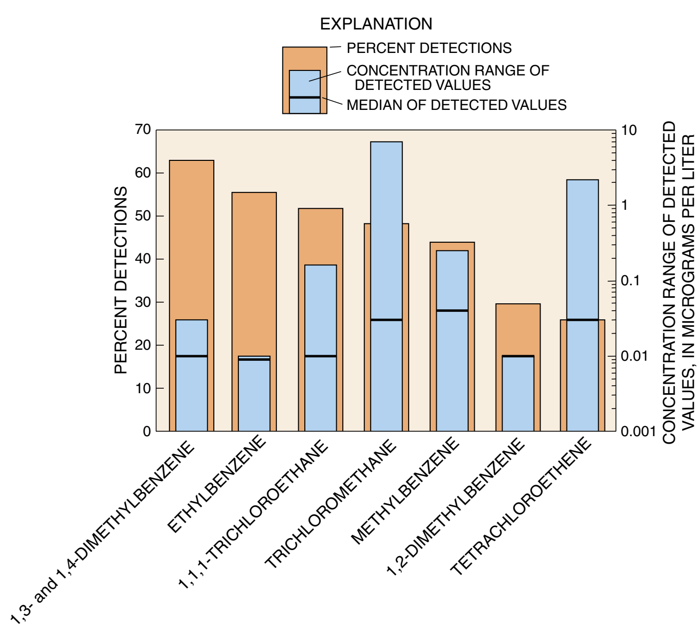


Figure 22. Volatile organic compounds were frequently detected at low concentrations in shallow ground water beneath residential areas.

and none was above drinking-water standards or guidelines. Solvents, chlorinated by-products, and fuel-related compounds were the most commonly detected VOCs.

High Nitrate Concentrations and Fumigant-Related Compounds Were Detected in Shallow Ground Water Beneath an Agricultural Area

Nitrate concentrations in more than half of the shallow ground water sampled for the agricultural land-use study exceeded the drinking-water standard. Major sources of nitrate are animal manure from poultry and dairy operations and fertilizers applied to crops. High concentrations of nitrate have persisted for many years in wells sampled in this aquifer (Hii and others, 1999), suggesting that land applications of manure and inorganic fertilizers are contributing nitrate to this aquifer at a sufficient rate to sustain these levels (fig. 23).

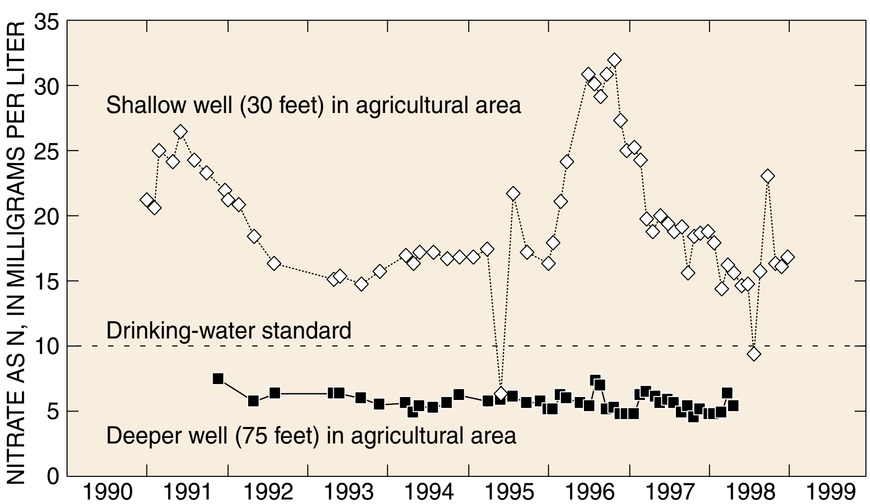


Figure 23. Nitrate concentrations in shallow ground water often exceeded the drinking-water standard (10 milligrams per liter), with high concentrations persisting for many years. Nitrate concentrations in deeper ground water, while elevated, generally met the drinking-water standard. Both the shallow and deeper ground water are used for domestic supplies.

Reactions in the Riparian Zone Remove Nitrate from Ground Water

Nitrate concentrations in ground water in the agricultural land-use study area commonly exceeded 10 mg/L, a concentration that can promote excessive plant growth in streams where this ground water discharges. A detailed analysis of water-quality changes along ground-water flow paths was conducted in this area (flow-path study area, p. 20). High nitrate concentrations persisted throughout much of the shallow aquifer. It was not until ground water reached the riparian zone of Fishtrap Creek that nitrate concentrations decreased to low levels (fig. 24). A decrease in nitrate concentrations in ground water concurrent with an increase in nitrogen gas (N_2) concentrations in this zone is evidence that nitrate is being converted to N_2 by denitrification (Tesoriero and others, 2000).

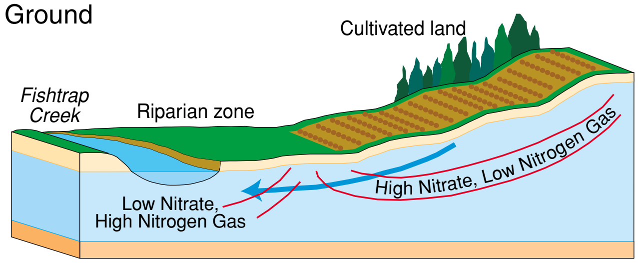


Figure 24. Nitrate concentrations in ground water remain high until water seeps through stream sediments that favor microbial denitrification. This process can effectively transform nitrate to nitrogen gas before the water discharges to the stream.

High Concentrations of 1,2-Dichloropropane Were Probably Caused by Applications of Older Fumigant Formulations

The most commonly detected volatile organic compounds in the agricultural land-use study area were associated with the application of fumigants to soils prior to planting. One or more fumigant-related compounds (1,2-dichloropropane, 1,2,2-trichloropropane, and 1,2,3-trichloropropane) were detected in over half of the samples. Each of these compounds is present in varying amounts in historically and/or presently used fumigants. Concentrations of 1,2-dichloropropane in water from two wells were above the drinking-water standard for this compound (fig. 25).

The amount of 1,2-dichloropropane and 1,2,3-trichloropropane in fumigant formulations has dropped substantially over the past few decades (Zebarth and others, 1998), while the amount of 1,2,2-trichloropropane has decreased only slightly.

The relative amounts of these chloropropanes in ground water were compared with those present in fumigant formulations to determine the origin of these compounds in ground water (Tesoriero and others, in press). Results indicate that high concentrations of 1,2-dichloropropane in ground water are largely due to older formulations (fig. 26).

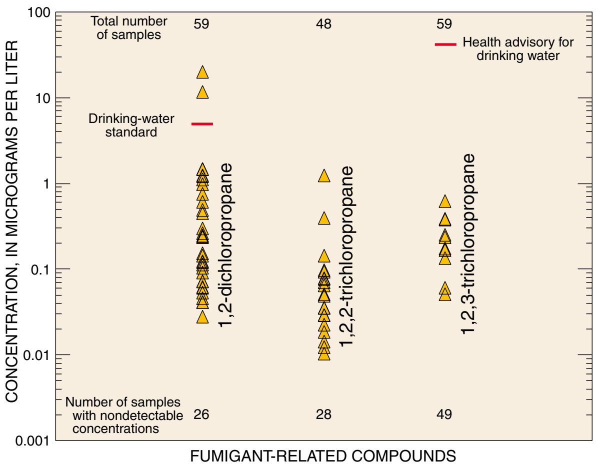


Figure 25. Fumigant-related compounds were detected frequently in shallow ground water in the agricultural land-use study area. Concentrations of 1,2-dichloropropane exceeded the drinking-water standard in two samples.

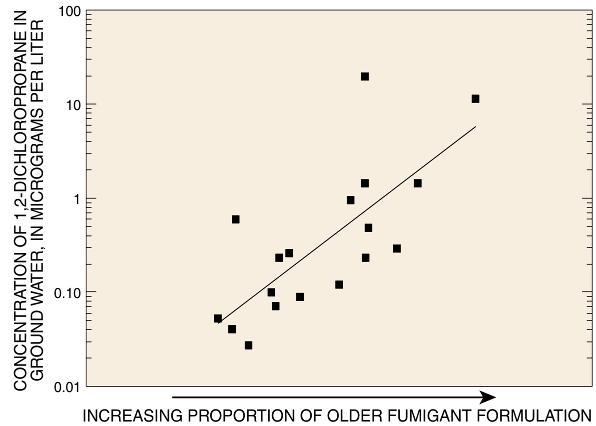
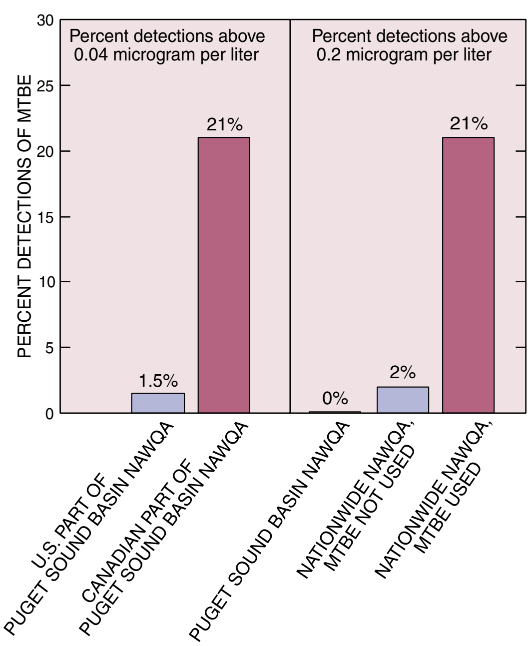


Figure 26. Based on the relative amounts of chloropropanes in samples, higher concentrations of 1,2-dichloropropane are likely derived from older fumigant formulations.

MTBE Was Rarely Detected in Ground Water in the Puget Sound Basin

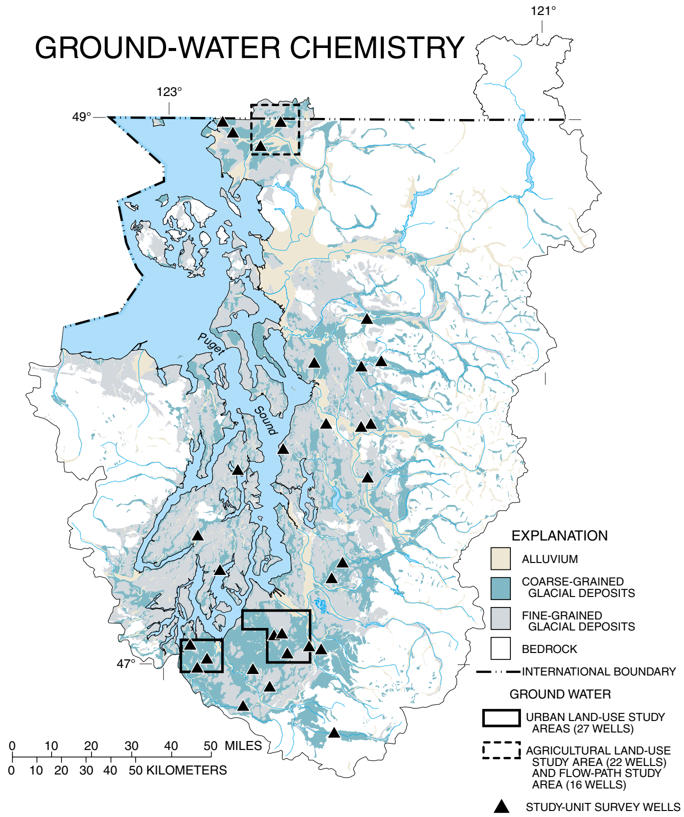
Areas that exceed air-quality standards for carbon monoxide are required to use a fuel oxygenate to comply with the Clean Air Act of 1990. Methyl *tert*-butyl ether (MTBE) is the most widely used oxygenate in the United States. However, frequent detections of MTBE, sometimes high concentrations, in ground water in areas where this compound is used has caused the USEPA to recommend that it be discontinued or reduced (U.S. Environmental Protection Agency, 1999b). MTBE is used in the Canadian part of the Puget Sound Basin but not in the U.S. part. Not surprisingly, detections of this compound were more frequent in the Canadian part of the Study Unit. When detected, MTBE concentrations were low (less than 0.2 microgram per liter). Low concentrations of MTBE are likely derived from nonpoint sources, such as stormwater runoff or atmospheric deposition, or from diluted point sources (Squillace and others, 1996).



The detection frequency of MTBE in shallow ground water in the Puget Sound Basin was less than detection frequencies in other parts of the Nation (Squillace, 1999). Ethanol, not MTBE, is used as a fuel oxygenate in the U.S. part of the Puget Sound Basin.

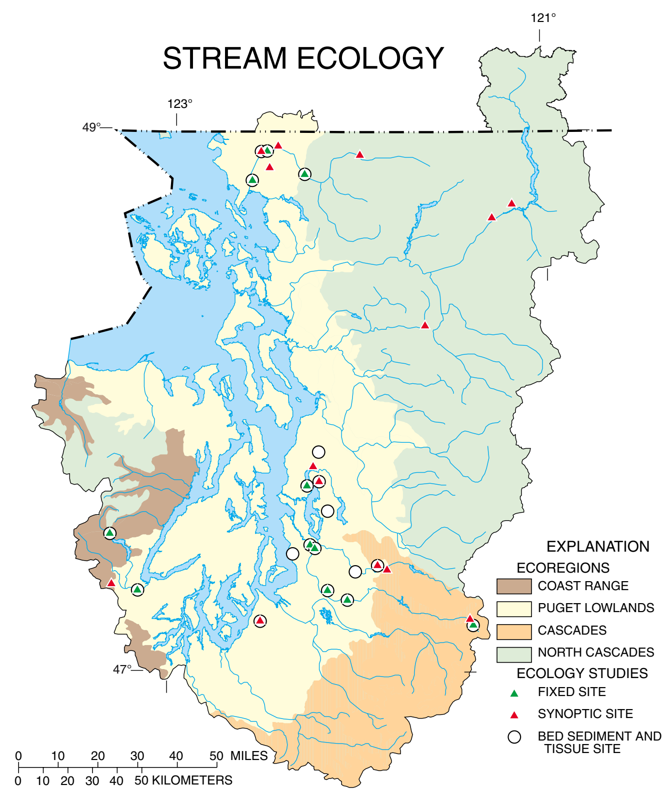
The Puget Sound Basin study was designed to address local and national goals of providing widely comparable water-quality data focused on stream chemistry, stream ecology, and ground-water chemistry.

Of the 12 major and numerous minor tributaries to the Puget Sound, sampling was concentrated in four representative drainage basins: the Nooksack and Green River Basins with varied land uses, the Thornton Creek Basin in a totally urban environment, and the Skokomish River Basin, which is mostly forested.



Some sampling was done outside these areas for special studies, such as the study of pesticides in urban streams.

Wells sampled for the survey of ground-water quality in the Study Unit were distributed throughout the Puget Lowlands. Agricultural effects on ground-water quality and changes in quality along flow paths were evaluated using wells located in the lower Nooksack River Basin. Wells sampled in residential areas surrounding Olympia and Tacoma were used for determining urban land-use effects on shallow ground-water quality.



Stream ecology, bed sediment, and aquatic biota sampling was done at all the fixed stream-chemistry sites, and one or more of these types of samples were collected at 14 other sites. Two-thirds of the sites were within the Puget Lowlands, while the remainder were in other ecoregions (Black and Silkey, 1998).

Table 3. Summary of data collection in the Puget Sound Basin, 1994–98[1]

Study component	What data were collected and why	Types of sites sampled	Number of sites	Sampling frequency and period
Stream Chemistry				
Basic fixed sites–general water quality	Streamflow, dissolved oxygen, pH, alkalinity, specific conductance, temperature, nutrients, major ions, trace elements, organic carbon, and suspended sediment were measured to determine occurrence and concentration.	Streams draining basins ranging in size from 12 to 790 square miles, reflecting forest and mixed land use, and widely distributed geographically within the Study Unit.	7	Monthly plus storms Mar. 1996–Apr. 1998
Intensive fixed-sites–pesticides and VOCs	Above constituents plus 87 pesticides and 85 volatile organic compounds.	Sites selected for closer proximity to and more direct influence from agricultural and urban land uses plus integration of mixed-use larger basins.	3 1	Weekly to monthly Mar. 1996–May 1997 Weekly to monthly Mar. 1996–May 1998
Synoptic sites–pesticides	Streamflow, pH, specific conductance, temperature plus pesticides during varying flow conditions to relate occurrences and concentrations to retail sales of pesticides.	Sites predominantly influenced by urban residential land use plus 1 reference site.	13	2 to 4 samples over storm hydrograph Apr.–May 1998
Contaminants in bed sediment	Trace elements and organic compounds to determine occurrence and distribution in streambed sediment.	Depositional zones of all basic and intensive stream-chemistry sites plus additional sites.	19	Once Sept. 1995
Contaminants in fish tissue	Trace elements and organic compounds in the tissue of whole fish.	Same sites from which bed sediment samples were collected.	18	Once Sept. 1995
Stream Ecology				
Fixed sites	Invertebrate, algae, and fish communities, streamflow, basic water chemistry, and riparian habitat conditions surveyed to assess biological communities in the basin.	Sites collected with basic and intensive stream-chemistry sites and having contributing drainage areas from 12 to 790 square miles.	11	Annually 1995–97
Synoptic	Invertebrate, algae, and fish communities, streamflow, nutrients, and habitat conditions surveyed to determine land-use effects on biological communities.	4 bed sediment and tissue sites and 10 other sites influenced by various land uses, with contributing drainage areas ranging from 3 to 48 square miles.	14	Once Sept.–Oct. 1996
Ground-Water Chemistry				
Study Unit–varied land use	Nutrients, major ions, pesticides, volatile organic compounds, and radon in shallow, unconfined glacial outwash aquifer to assess the drinking-water quality of domestic wells in the Fraser aquifer.	Existing domestic supply wells widely distributed through the Puget Lowlands.	30	Once 1996
Land use–residential	Above compounds to determine effects of urban land use on ground-water quality in the Fraser aquifer. One-half of the wells were sampled for radon.	Monitoring wells in urban residential areas with both sewer and private septic systems.	27	Once 1996–97
Land use–agricultural	Above compounds, except radon, to determine effects of agricultural land use on ground-water quality in the Fraser aquifer.	Monitoring wells (18) and existing domestic supply wells (4) in an area of intensive row crops (raspberries, for example).	22	Once 1997–98
Flow path–agricultural	Above compounds, except radon, to determine changes in water quality occurring as water moves from recharge to discharge areas.	Shallow and deep monitoring wells along flow paths in an agricultural watershed.	16	Varied 1997–98
Special Studies				
Synoptic study–microbiology and wastewater chemicals	Turbidity, pH, specific conductance, temperature, wastewater chemicals, fecal-indicator bacteria, coliphage, and coliphage serotypes to determine occurrence and distribution in the Puget Lowlands and infer sources of fecal contamination.	Sites predominantly influenced by urban and agricultural land use.	31	Once Aug. 1998
Land use and scale	Invertebrates, instream habitat, and riparian condition data from USGS and Washington State Department of Ecology sites (common protocol) were combined to evaluate land-use impacts at different spatial scales.	Indicator sites with smaller drainage basins and mixed land uses.	20 USGS 25 WDOE	Annually Aug.–Sept. 1995–97
Drinking-water assessment–pesticides	Pesticides collected in previous study used to estimate detection probability.	Public-supply wells throughout the Study Unit.	78	Once 1994

[1]Most data were collected 1996–98.

Aquatic guidelines - Specific levels of water quality which, if reached, may adversely affect aquatic life. These are nonenforceable guidelines issued by a governmental agency or other institution.

Aquifer - A water-bearing layer of soil, sand, gravel, or rock that will yield usable quantities of water to a well.

Atmospheric deposition - The transfer of substances from the air to the surface of the Earth, either in wet form (rain, fog, snow, dew, frost, hail) or in dry form (gases, aerosols, particles).

Base flow - Sustained, low flow in a stream; ground-water discharge is the source of base flow in most places.

Basic fixed sites - Sites on streams at which streamflow is measured and samples are collected for temperature, salinity, suspended sediment, major ions and metals, nutrients, and organic carbon to assess the broad-scale spatial and temporal character and transport of inorganic constituents of streamwater in relation to hydrologic conditions and environmental settings.

Benthic invertebrates - Insects, mollusks, crustaceans, worms, and other organisms without a backbone that live in, on, or near the bottom of lakes, streams, or oceans.

Breakdown product - A compound derived by chemical, biological, or physical action upon a pesticide. The breakdown is a natural process that may result in a more toxic or a less toxic compound and a more persistent or less persistent compound.

Chlorinated solvent - A volatile organic compound containing chlorine. Some common solvents are trichloroethylene, tetrachloroethylene, and carbon tetrachloride.

Coliphages - Bacteriaphages, a type of virus, that infect and replicate in coliform bacteria and appear to be present wherever total and fecal coliforms are found.

Coliphage serotypes - Groups of coliphages that can be identified and used to infer sources of coliform bacteria.

Community - In ecology, the species that interact in a common area.

Denitrification - A process by which oxidized forms of nitrogen such as nitrate (NO_3^-) are reduced to form nitrites, nitrogen oxides, ammonia, or free nitrogen: commonly brought about by the action of denitrifying bacteria and usually resulting in the release of nitrogen to the air.

Detection limit - The minimum concentration of a substance that can be identified, measured, and reported within 99 percent confidence that the analyte concentration is greater than zero; determined from analysis of a sample in a given matrix containing the analyte.

Drainage basin - The portion of the surface of the Earth that contributes water to a stream through overland runoff, including tributaries and impoundments.

Drinking-water standard or guideline - A threshold concentration in a public drinking-water supply, designed to protect human health. As defined here, standards are U.S. Environmental Protection Agency regulations that specify the maximum contamination levels for public water systems required to protect the public welfare; guidelines have no regulatory status and are issued in an advisory capacity.

Ecoregion - An area of similar climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables.

Fecal bacteria - Microscopic single-celled organisms (primarily fecal coliforms and fecal streptococci) found in the wastes of warm-blooded animals. Their presence in water is used to assess the sanitary quality of water for body-contact recreation or for consumption. Their presence indicates contamination by the wastes of warm-blooded animals and the possible presence of pathogenic (disease producing) organisms.

Flow-path study - A study to examine the relations of land-use practices, ground-water flow, and contaminant occurrence and transport. A flow-path study is conducted within a land-use study.

Freshwater chronic criteria - The highest concentration of a contaminant that freshwater aquatic organisms can be exposed to for an extended period of time (4 days) without adverse effects. See also Water-quality criteria.

Fumigant - A substance or mixture of substances that produces gas, vapor, fume, or smoke intended to destroy insects, bacteria, or rodents.

Habitat - The part of the physical environment where plants and animals live.

Headwaters - The source and upper part of a stream.

Intensive fixed sites - Basic fixed sites with increased sampling frequency during selected seasonal periods and analysis of dissolved pesticides and volatile organic compounds for 1 year. Most NAWQA Study Units have one to two integrator intensive fixed sites and one to four indicator intensive fixed sites.

Intolerant organisms - Organisms that are not adaptable to human alterations to the environment and thus decline in numbers where human alterations occur. See also Tolerant species.

Land-use study - A study that is a subset of the study-unit survey and has the goal of relating the quality of shallow ground water to land use. See also Study-unit survey.

Load - General term that refers to a material or constituent in solution, in suspension, or in transport; usually expressed in terms of mass or volume.

Median - The middle or central value in a distribution of data ranked in order of magnitude. The median is also known as the 50th percentile.

Metabolite - A substance produced in or by biological processes.

Micrograms per liter (µg/L) - A unit expressing the concentration of constituents in solution as weight (micrograms) of solute per unit volume (liter) of water; equivalent to one part per billion in most streamwater and ground water. One thousand micrograms per liter equals 1 mg/L.

Milligrams per liter (mg/L) - A unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water; equivalent to one part per million in most streamwater and ground water. One thousand micrograms per liter equals 1 mg/L.

Nonpoint source - A pollution source that cannot be defined as originating from discrete points such as pipe discharge. Areas of fertilizer and pesticide applications, atmospheric deposition, manure, and natural inputs from plants and trees are types of nonpoint source pollution.

Nutrient - Element or compound essential for animal and plant growth. Common nutrients in fertilizer include nitrogen, phosphorus, and potassium.

Pesticide - A chemical applied to crops, rights of way, lawns, or residences to control weeds, insects, fungi, nematodes, rodents, or other "pests."

Picocurie (pCi) - One trillionth (10^{-12}) of the amount of radioactivity represented by a curie (Ci). A curie is the amount of radioactivity that yields 3.7 x 10^{10} radioactive disintegrations per second (dps). A picocurie yields 2.22 disintegrations per minute (dpm) or 0.037 dps.

Radon - A naturally occurring, colorless, odorless, radioactive gas formed by the disintegration of the element radium; damaging to human lungs when inhaled.

Riparian - Areas adjacent to rivers and streams with a high density, diversity, and productivity of plant and animal species relative to nearby uplands.

Study Unit - A major hydrologic system of the United States in which NAWQA studies are focused. Study Units are geographically defined by a combination of ground- and surface-water features and generally encompass more than 4,000 square miles of land area.

Study-unit survey - Broad assessment of the water-quality conditions of the major aquifer systems of each Study Unit. The study-unit survey relies primarily on sampling existing wells and, wherever possible, on existing data collected by other agencies and programs. Typically, 20 to 30 wells are sampled in each of three to five aquifer subunits.

Synoptic sites - Sites sampled during a short-term investigation of specific water-quality conditions during selected seasonal or hydrologic conditions to provide improved spatial resolution for critical water-quality conditions.

Taxon (plural taxa) - Any identifiable group of taxonomically related organisms.

Tolerant species - Those species that are adaptable to (tolerant of) human alterations to the environment and often increase in number when human alterations occur.

Unconsolidated deposit - Deposit of loosely bound sediment that typically fills topographically low areas.

Volatile organic compounds (VOCs) Organic chemicals that have a high vapor pressure relative to their water solubility. VOCs include components of gasoline, fuel oils, and lubricants, as well as organic solvents, fumigants, some inert ingredients in pesticides, and some by-products of chlorine disinfection.

Water-quality criteria - Specific levels of water quality which, if reached, are expected to render a body of water unsuitable for its designated use. Commonly refers to water-quality criteria established by the U.S. Environmental Protection Agency. Water-quality criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.

Yield - The mass of material or constituent transported by a river in a specified period of time divided by the drainage area of the river basin.

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APPENDIX—WATER-QUALITY DATA FROM THE PUGET SOUND BASIN IN A NATIONAL CONTEXT

For a complete view of Puget Sound Basin data and for additional information about specific benchmarks used, visit our Web site at http://water.usgs.gov/nawqa/. Also visit the NAWQA Data Warehouse for access to NAWQA data sets at http://water.usgs.gov/nawqa/data.

This appendix is a summary of chemical concentrations and biological indicators assessed in the Puget Sound Basin. Selected results for this basin are graphically compared to results from as many as 36 NAWQA Study Units investigated from 1991 to 1998 and to national water-quality benchmarks for human health, aquatic life, or fish-eating wildlife. The chemical and biological indicators shown were selected on the basis of frequent detection, detection at concentrations above a national benchmark, or regulatory or scientific importance. The graphs illustrate how conditions associated with each land use sampled in the Puget Sound Basin compare to results from across the Nation, and how conditions compare among the several land uses. Graphs for chemicals show only detected concentrations and, thus, care must be taken to evaluate detection frequencies in addition to concentrations when comparing study-unit and national results. For example, simazine concentrations in Puget Sound Basin agricultural streams were similar to the national distribution, but the detection frequency was much higher (97 percent compared to 61 percent).

CHEMICALS IN WATER

Concentrations and detection frequencies, Puget Sound Basin, 1996–98—Detection sensitivity varies among chemicals and, thus, frequencies are not directly comparable among chemicals

◆ Detected concentration in Study Unit

66 38 Frequencies of detection, in percent. Detection frequencies were not censored at any common reporting limit. The left-hand column is the study-unit frequency and the right-hand column is the national frequency

-- Not measured or sample size less than two

12 Study-unit sample size. For ground water, the number of samples is equal to the number of wells sampled

National ranges of detected concentrations, by land use, in 36 NAWQA Study Units, 1991–98—Ranges include only samples in which a chemical was detected

- Streams in agricultural areas
- Streams in urban areas
- Streams and rivers draining mixed land uses
- Shallow ground water in agricultural areas
- Shallow ground water in urban areas
- Major aquifers

Lowest 25 percent — Middle 50 percent — Highest 25 percent

National water-quality benchmarks

National benchmarks include standards and guidelines related to drinking-water quality, criteria for protecting the health of aquatic life, and a goal for preventing stream eutrophication due to phosphorus. Sources include the U.S. Environmental Protection Agency and the Canadian Council of Ministers of the Environment

| Drinking-water quality (applies to ground water and surface water)

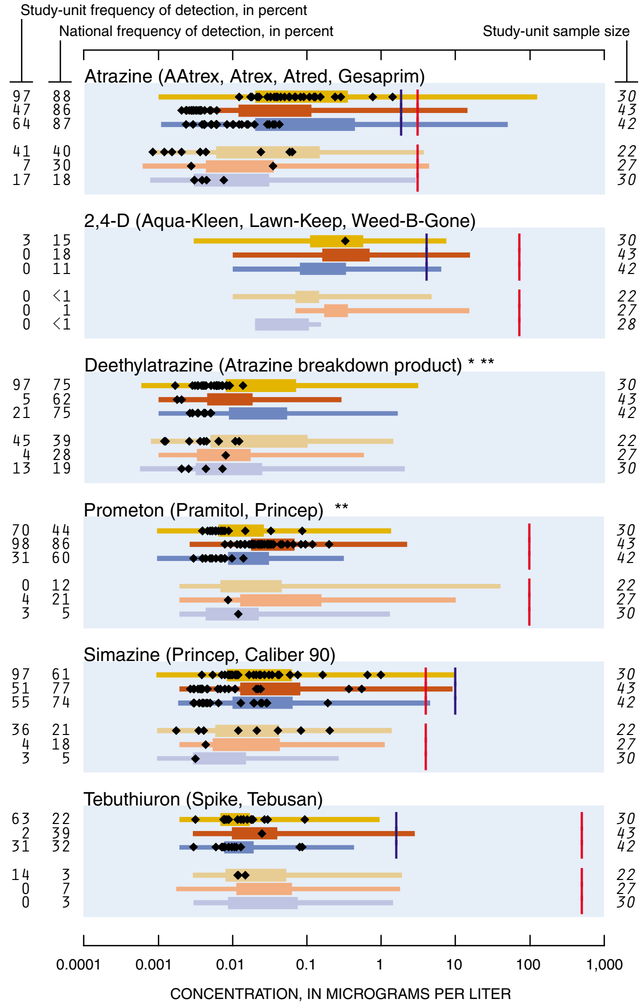
| Protection of aquatic life (applies to surface water only)

| Prevention of eutrophication in streams not flowing directly into lakes or impoundments

* No benchmark for drinking-water quality

** No benchmark for protection of aquatic life

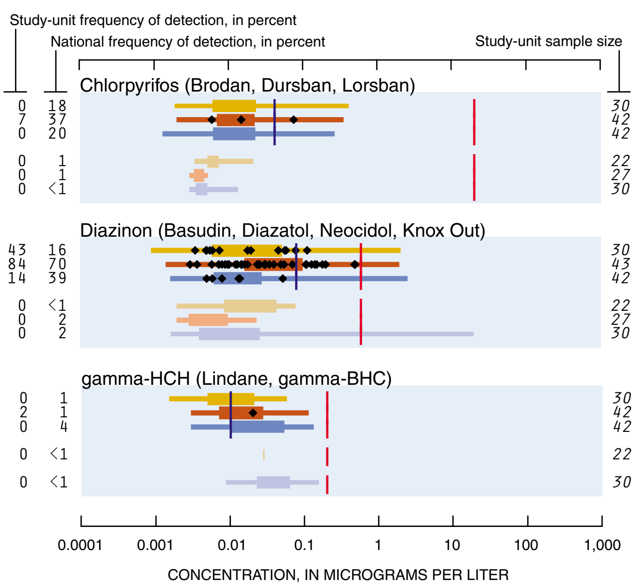
Pesticides in water—Herbicides



Other herbicides detected
Acetochlor (Harness Plus, Surpass) * **
Alachlor (Lasso, Bronco, Lariat, Bullet) **
Bromacil (Hyvar X, Urox B, Bromax)
DCPA (Dacthal, chlorthal-dimethyl) * **
Dicamba (Banvel, Dianat, Scotts Proturf)
Dinoseb (Dinosebe)
Diuron (Crisuron, Karmex, Diurex) **
EPTC (Eptam, Farmarox, Alirox) * **
Fluometuron (Flo-Met, Cotoran) **
Linuron (Lorox, Linex, Sarclex, Linurex, Afalon) *
MCPA (Rhomene, Rhonox, Chiptox)
Metolachlor (Dual, Pennant)
Metribuzin (Lexone, Sencor)
Molinate (Ordram) * **
Napropamide (Devrinol) * **
Norflurazon (Evital, Predict, Solicam, Zorial) * **
Oryzalin (Surflan, Dirimal) * **
Pebulate (Tillam, PEBC) * **
Pronamide (Kerb, Propyzamid) **
Terbacil (Sinbar) **
Triclopyr (Garlon, Grandstand, Redeem, Remedy) * **
Trifluralin (Treflan, Gowan, Tri-4, Trific)

Herbicides not detected
Acifluorfen (Blazer, Tackle 2S) **
Benfluralin (Balan, Benefin, Bonalan) * **
Bentazon (Basagran, Bentazone) **
Bromoxynil (Buctril, Brominal) *
Butylate (Sutan +, Genate Plus, Butilate) **
Chloramben (Amiben, Amilon-WP, Vegiben) **
Clopyralid (Stinger, Lontrel, Transline) * **
Cyanazine (Bladex, Fortrol)
2,4-DB (Butyrac, Butoxone, Embutox Plus, Embutone) * **
Dacthal mono-acid (Dacthal breakdown product) * **
Dichlorprop (2,4-DP, Seritox 50, Lentemul) * **
2,6-Diethylaniline (Alachlor breakdown product) * **
Ethalfluralin (Sonalan, Curbit) * **
Fenuron (Fenulon, Fenidim) * **
MCPB (Thistrol) * **
Neburon (Neburea, Neburyl, Noruben) * **
Pendimethalin (Pre-M, Prowl, Stomp) * **
Picloram (Grazon, Tordon)
Propachlor (Ramrod, Satecid) **
Propanil (Stam, Stampede, Wham) * **
Propham (Tuberite) **
2,4,5-T **
2,4,5-TP (Silvex, Fenoprop) **
Thiobencarb (Bolero, Saturn, Benthiocarb) * **
Triallate (Far-Go, Avadex BW, Tri-allate) *

Pesticides in water—Insecticides

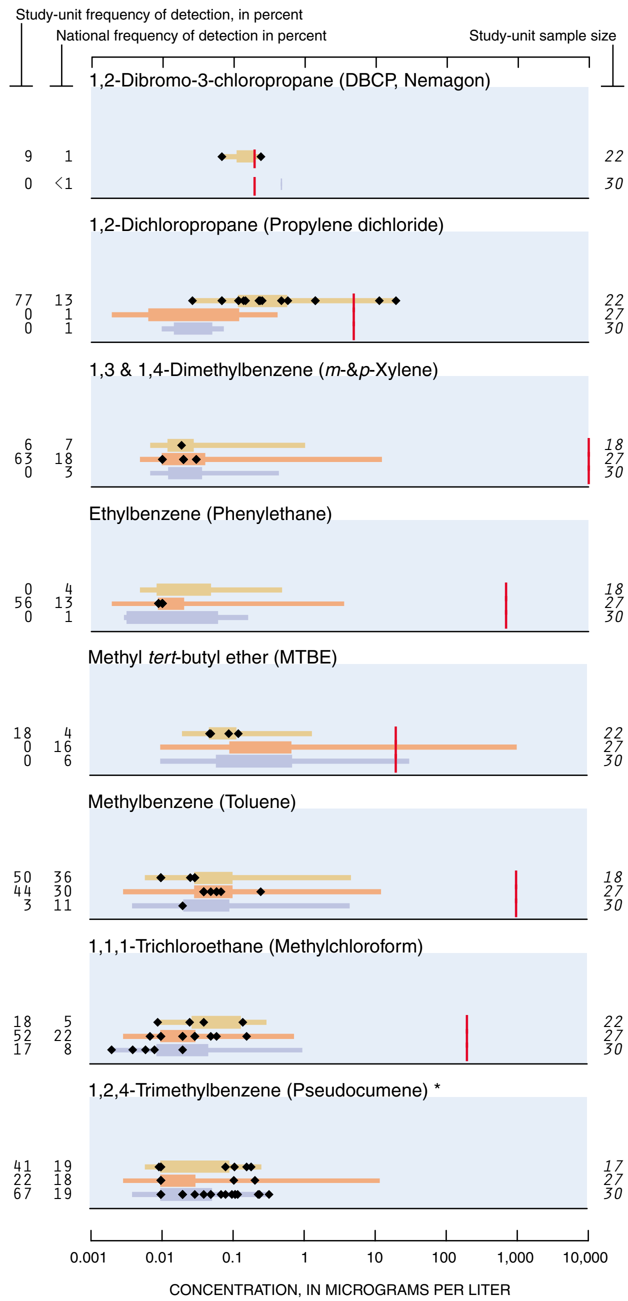


Other insecticides detected
Carbaryl (Carbamine, Denapon, Sevin)
Carbofuran (Furadan, Curaterr, Yaltox)
Ethoprop (Mocap, Ethoprophos) * **
Malathion (Malathion)
Oxamyl (Vydate L, Pratt) **
Propargite (Comite, Omite, Ornamite) * **

Insecticides not detected
Aldicarb (Temik, Ambush, Pounce)
Aldicarb sulfone (Standak, aldoxycarb)
Aldicarb sulfoxide (Aldicarb breakdown product)
Azinphos-methyl (Guthion, Gusathion M) *
p,p'-DDE
Dieldrin (Panoram D-31, Octalox, Compound 497)
Disulfoton (Disyston, Di-Syston) **
Fonofos (Dyfonate, Capfos, Cudgel, Tycap) **
alpha-HCH (alpha-BHC, alpha-lindane) **
3-Hydroxycarbofuran (Carbofuran breakdown product) * **
Methiocarb (Slug-Geta, Grandslam, Mesurol) * **
Methomyl (Lanox, Lannate, Acinate) **
Methyl parathion (Penncap-M, Folidol-M) **
Parathion (Roethyl-P, Alkron, Panthion, Phoskil) *
cis-Permethrin (Ambush, Astro, Pounce) * **
Phorate (Thimet, Granutox, Geomet, Rampart) * **
Propoxur (Baygon, Blattanex, Unden, Proprotox) * **
Terbufos (Contraven, Counter, Pilarfox) **

Volatile organic compounds (VOCs) in ground water

These graphs represent data from 16 Study Units, sampled from 1996 to 1998



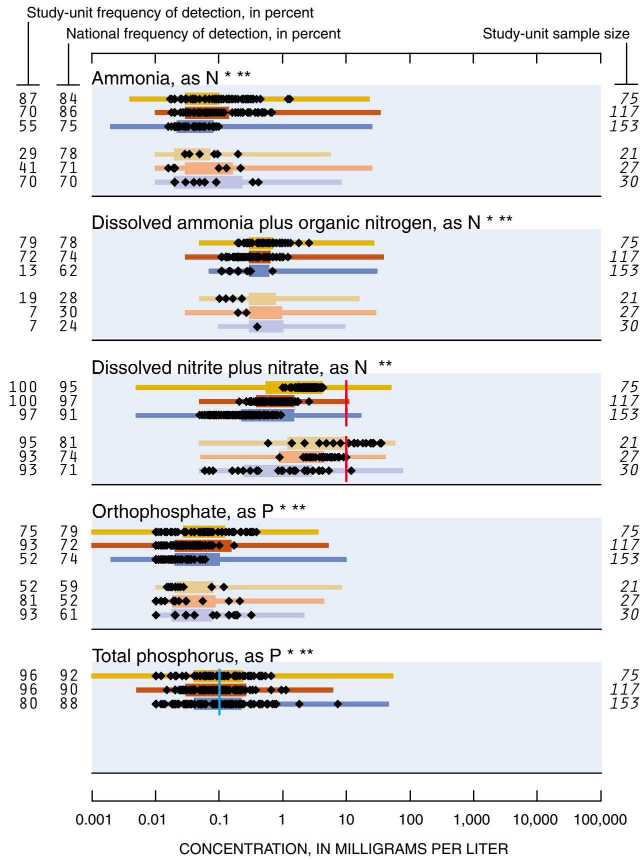
Other VOCs detected
Benzene
Bromodichloromethane (Dichlorobromomethane)
Carbon disulfide *
1-Chloro-2-methylbenzene (*o*-Chlorotoluene)
Chlorobenzene (Monochlorobenzene)
Chlorodibromomethane (Dibromochloromethane)
Chloromethane (Methyl chloride)

Dichlorodifluoromethane (CFC 12, Freon 12)
1,2-Dichloroethane (Ethylene dichloride)
Dichloromethane (Methylene chloride)
1,3-Dichloropropane (Trimethylene dichloride) *
1,2-Dimethylbenzene (*o*-Xylene)
1-4-Epoxy butane (Tetrahydrofuran, Diethylene oxide) *
1-Ethyl-2-methylbenzene (2-Ethyltoluene) *
Iodomethane (Methyl iodide) *
Isopropylbenzene (Cumene) *
2-Propanone (Acetone) *
n-Propylbenzene (Isocumene) *
Tetrachloroethene (Perchloroethene)
Trichloroethene (TCE)
Trichlorofluoromethane (CFC 11, Freon 11)
Trichloromethane (Chloroform)
1,2,3-Trichloropropane (Allyl trichloride)
1,2,3-Trimethylbenzene (Hemimellitene) *
1,3,5-Trimethylbenzene (Mesitylene) *

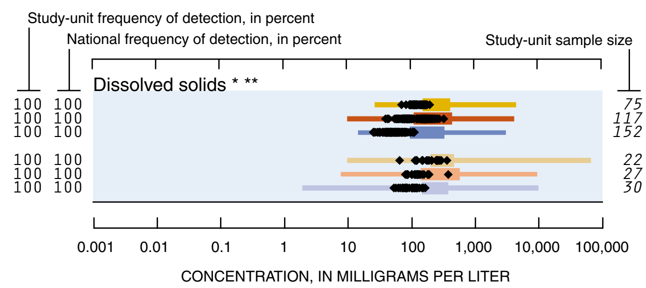
VOCs not detected

tert-Amylmethylether (*tert*-amyl methyl ether (TAME)) *
Bromobenzene (Phenyl bromide) *
Bromochloromethane (Methylene chlorobromide)
Bromoethene (Vinyl bromide) *
Bromomethane (Methyl bromide)
2-Butanone (Methyl ethyl ketone (MEK)) *
n-Butylbenzene (1-Phenylbutane) *
sec-Butylbenzene *
tert-Butylbenzene *
3-Chloro-1-propene (3-Chloropropene) *
1-Chloro-4-methylbenzene (*p*-Chlorotoluene)
Chloroethane (Ethyl chloride) *
Chloroethene (Vinyl chloride)
1,2-Dibromoethane (Ethylene dibromide, EDB)
Dibromomethane (Methylene dibromide) *
trans-1,4-Dichloro-2-butene ((Z)-1,4-Dichloro-2-butene) *
1,2-Dichlorobenzene (*o*-Dichlorobenzene)
1,3-Dichlorobenzene (*m*-Dichlorobenzene)
1,4-Dichlorobenzene (*p*-Dichlorobenzene)
1,1-Dichloroethane (Ethylidene dichloride) *
1,1-Dichloroethene (Vinylidene chloride)
trans-1,2-Dichloroethene ((E)-1,2-Dichlorothene)
cis-1,2-Dichloroethene ((Z)-1,2-Dichloroethene)
2,2-Dichloropropane *
trans-1,3-Dichloropropene ((E)-1,3-Dichloropropene)
cis-1,3-Dichloropropene ((Z)-1,3-Dichloropropene)
1,1-Dichloropropene *
Diethyl ether (Ethyl ether) *
Diisopropyl ether (Diisopropylether (DIPE)) *
Ethenylbenzene (Styrene)
Ethyl methacrylate*
Ethyl *tert*-butyl ether (Ethyl-*t*-butyl ether (ETBE)) *
Hexachlorobutadiene
1,1,1,2,2,2-Hexachloroethane (Hexachloroethane)
2-Hexanone (Methyl butyl ketone (MBK)) *
p-Isopropyltoluene (*p*-Cymene) *
Methyl acrylonitrile *
Methyl-2-methacrylate (Methyl methacrylate) *
4-Methyl-2-pentanone (Methyl isobutyl ketone (MIBK)) *
Methyl-2-propenoate (Methyl acrylate) *
Naphthalene
2-Propenenitrile (Acrylonitrile)
1,1,2,2-Tetrachloroethane *
1,1,1,2-Tetrachloroethane
Tetrachloromethane (Carbon tetrachloride)
1,2,3,4-Tetramethylbenzene (Prehnitene) *
1,2,3,5-Tetramethylbenzene (Isodurene) *
Tribromomethane (Bromoform)
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113) *
1,2,4-Trichlorobenzene
1,2,3-Trichlorobenzene *

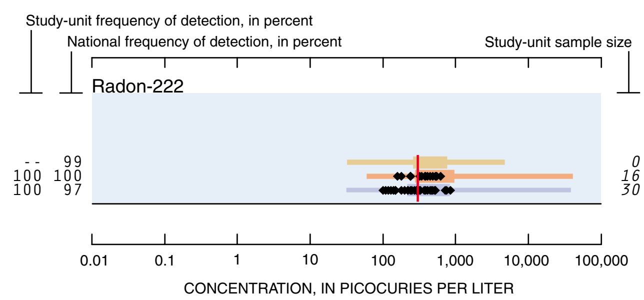
Nutrients in water



Dissolved solids in water



Trace elements in ground water



Other trace elements detected
Chromium

Trace elements not detected
Arsenic
Cadmium
Lead
Selenium
Uranium
Zinc

CHEMICALS IN FISH TISSUE AND BED SEDIMENT

Concentrations and detection frequencies, Puget Sound Basin, 1996–98—Detection sensitivity varies among chemicals and, thus, frequencies are not directly comparable among chemicals. Study-unit frequencies of detection are based on small sample sizes; the applicable sample size is specified in each graph

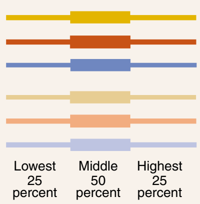
◆ Detected concentration in Study Unit

66 38 Frequencies of detection, in percent. Detection frequencies were not censored at any common reporting limit. The left-hand column is the study-unit frequency and the right-hand column is the national frequency

-- Not measured or sample size less than two

12 Study-unit sample size

National ranges of concentrations detected, by land use, in 36 NAWQA Study Units, 1991–98—Ranges include only samples in which a chemical was detected



Fish tissue from streams in agricultural areas
Fish tissue from streams in urban areas
Fish tissue from streams draining mixed land uses
Sediment from streams in agricultural areas
Sediment from streams in urban areas
Sediment from streams draining mixed land uses

National benchmarks for fish tissue and bed sediment

National benchmarks include standards and guidelines related to criteria for protection of the health of fish-eating wildlife and aquatic organisms. Sources include the U.S. Environmental Protection Agency, other Federal and State agencies, and the Canadian Council of Ministers of the Environment

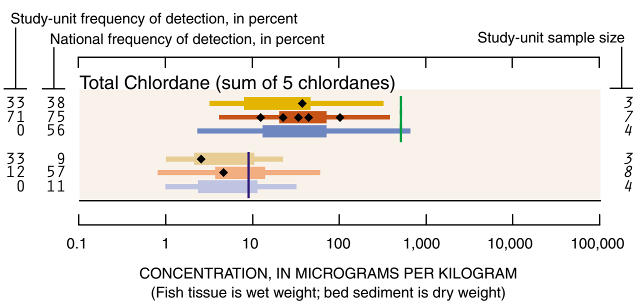
| Protection of fish-eating wildlife (applies to fish tissue)

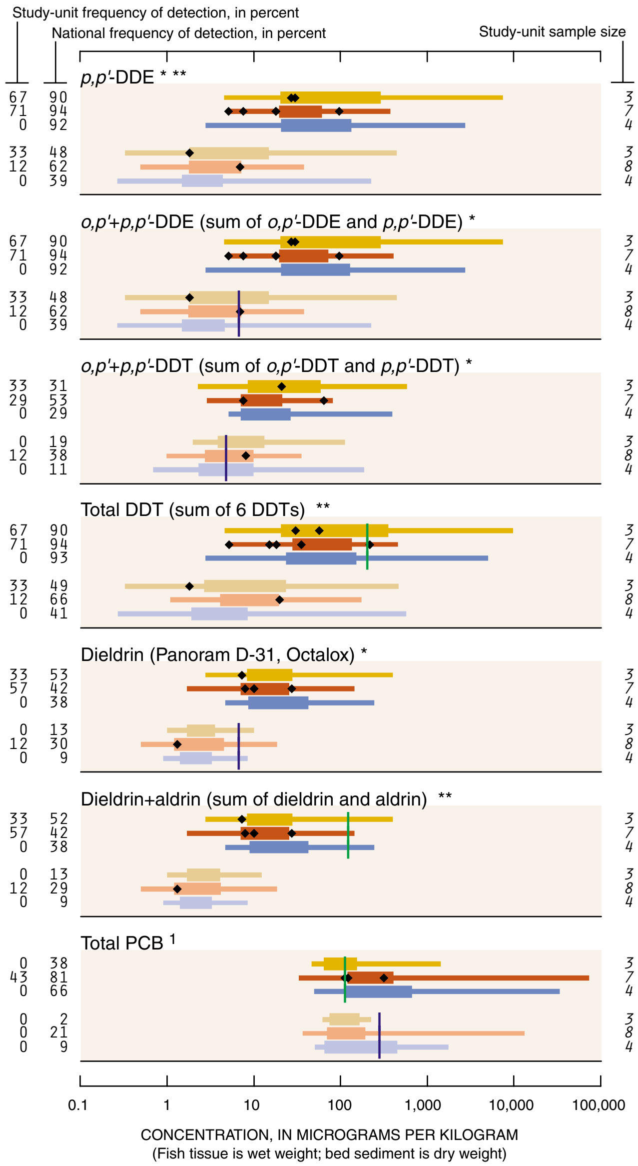
| Protection of aquatic life (applies to bed sediment)

* No benchmark for protection of fish-eating wildlife

** No benchmark for protection of aquatic life

Organochlorines in fish tissue (whole body) and bed sediment



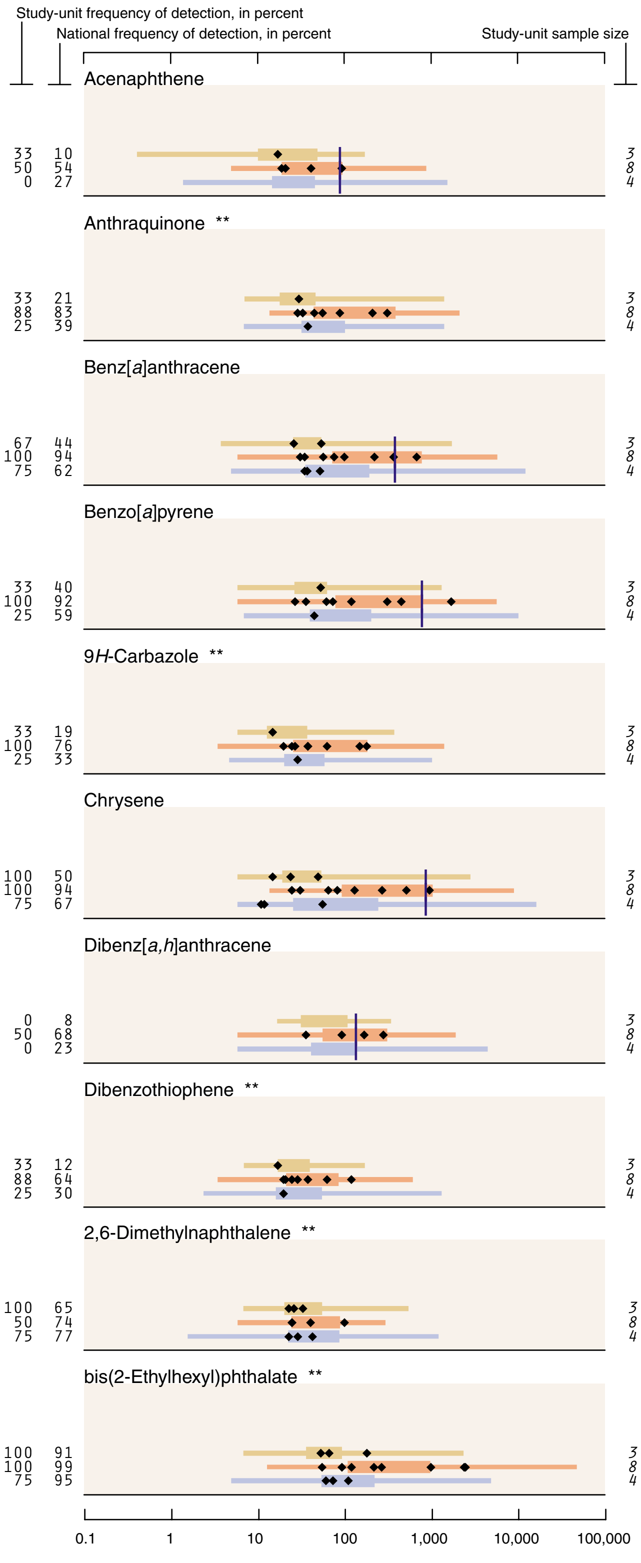


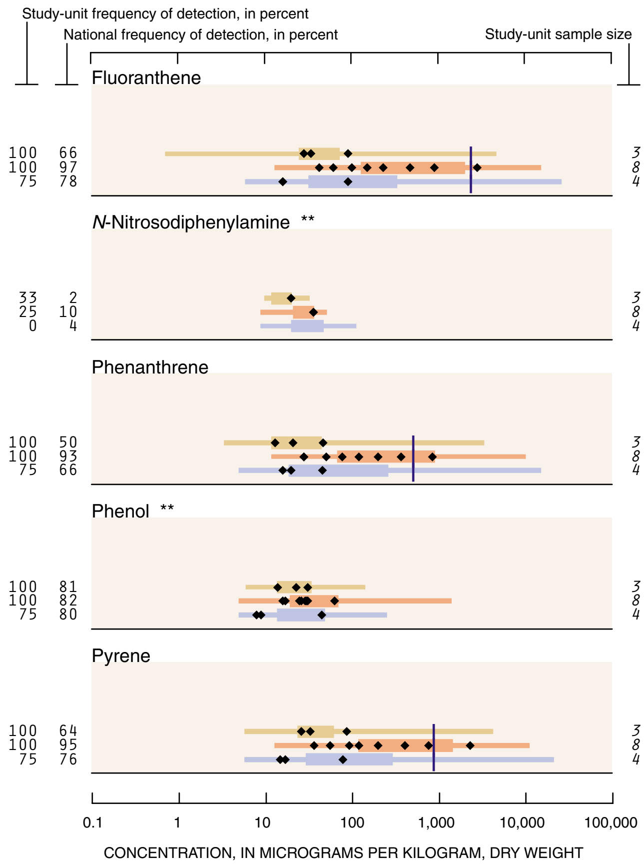
[1] The national detection frequencies for total PCB in sediment are biased low because about 30 percent of samples nationally had elevated detection levels compared to this Study Unit. See http://water.usgs.gov/nawqa/ for additional information.

Other organochlorines detected
o,p'+p,p'-DDD (sum of *o,p'*-DDD and *p,p'*-DDD) *
Heptachlor epoxide (Heptachlor breakdown product) *
Heptachlor+heptachlor epoxide (sum of heptachlor and heptachlor epoxide) **
Hexachlorobenzene (HCB) **
Pentachloroanisole (PCA) * **

Organochlorines not detected
Chloroneb (Chloronebe, Demosan) * **
DCPA (Dacthal, chlorthal-dimethyl) * **
Endosulfan I (alpha-Endosulfan, Thiodan) * **
Endrin (Endrine)
gamma-HCH (Lindane, gamma-BHC, Gammexane) *
Total-HCH (sum of alpha-HCH, beta-HCH, gamma-HCH, and delta-HCH) **
Isodrin (Isodrine, Compound 711) * **
p,p'-Methoxychlor (Marlate, methoxychlore) * **
o,p'-Methoxychlor * **
Mirex (Dechlorane) **
cis-Permethrin (Ambush, Astro, Pounce) * **
trans-Permethrin (Ambush, Astro, Pounce) * **
Toxaphene (Camphechlor, Hercules 3956) * **

Semivolatile organic compounds (SVOCs) in bed sediment





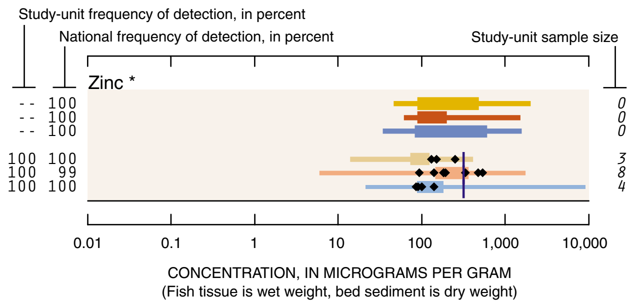
Other SVOCs detected

Acenaphthylene
Acridine **
Anthracene
Azobenzene **
Benzo[*b*]fluoranthene **
Benzo[*ghi*]perylene **
Benzo[*k*]fluoranthene **
2,2-Biquinoline **
Butylbenzylphthalate **
p-Cresol **
Di-*n*-butylphthalate **
Di-*n*-octylphthalate **
Diethylphthalate **
1,2-Dimethylnaphthalene **
1,6-Dimethylnaphthalene **
3,5-Dimethylphenol **
Dimethylphthalate **
9*H*-Fluorene (Fluorene)
Indeno[1,2,3-*cd*]pyrene **
Isoquinoline **
1-Methyl-9*H*-fluorene **
2-Methylanthracene **
4,5-Methylenephenanthrene **
1-Methylphenanthrene **
1-Methylpyrene **
Naphthalene
Phenanthridine **
2,3,6-Trimethylnaphthalene **

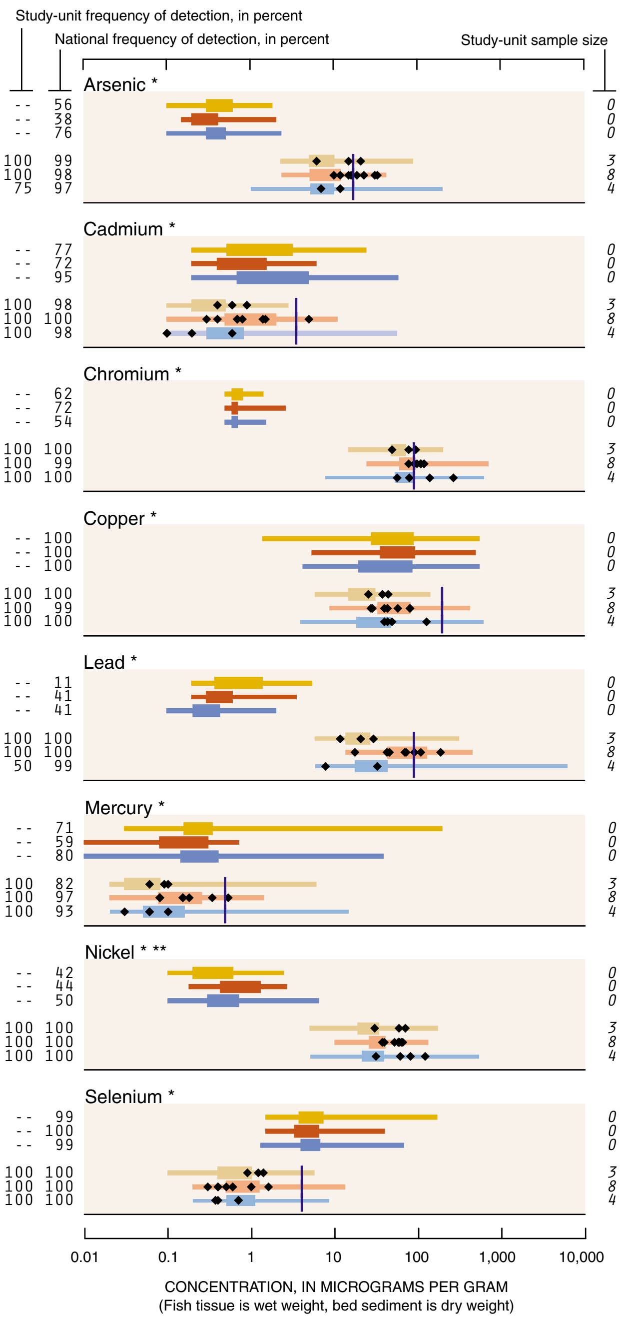
SVOCs not detected

C8-Alkylphenol **
Benzo[*c*]cinnoline **
4-Bromophenyl-phenylether **
4-Chloro-3-methylphenol **
bis(2-Chloroethoxy)methane **

2-Chloronaphthalene **
2-Chlorophenol **
4-Chlorophenyl-phenylether **
1,2-Dichlorobenzene (*o*-Dichlorobenzene) **
1,3-Dichlorobenzene (*m*-Dichlorobenzene) **
1,4-Dichlorobenzene (*p*-Dichlorobenzene) **
2,4-Dinitrotoluene **
Isophorone **
Nitrobenzene **
N-Nitrosodi-*n*-propylamine **
Pentachloronitrobenzene **
Quinoline **
1,2,4-Trichlorobenzene **



Trace elements in fish tissue (livers) and bed sediment



BIOLOGICAL INDICATORS

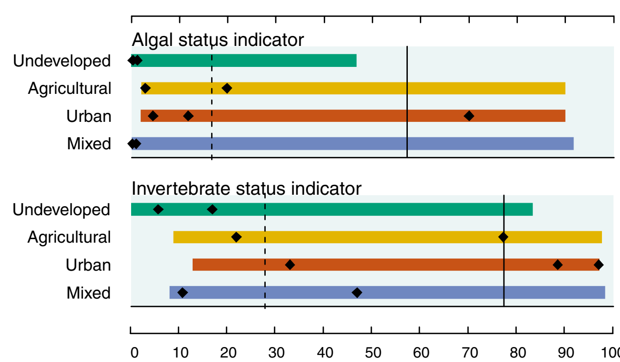
Higher national scores suggest habitat disturbance, water-quality degradation, or naturally harsh conditions. The status of algae, invertebrates (insects, worms, and clams), and fish provide a record of water-quality and stream conditions that water-chemistry indicators may not reveal. **Algal status** focuses on the changes in the percentage of certain algae in response to increasing siltation, and it often correlates with higher nutrient concentrations in some regions. **Invertebrate status** averages 11 metrics that summarize changes in richness, tolerance, trophic conditions, and dominance associated with water-quality degradation. **Fish status** sums the scores of four fish metrics (percent tolerant, omnivorous, non-native individuals, and percent individuals with external anomalies) that increase in association with water-quality degradation

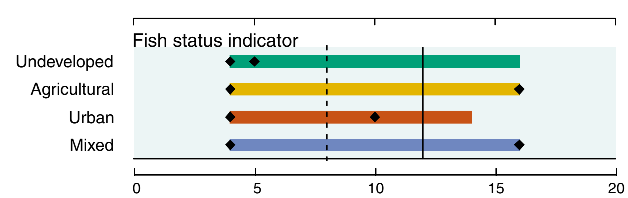
Biological indicator value, Puget Sound Basin, by land use, 1996–98

◆ Biological status assessed at a site

National ranges of biological indicators, in 16 NAWQA Study Units, 1994–98

- Streams in undeveloped areas
- Streams in agricultural areas
- Streams in urban areas
- Streams in mixed-land-use areas
- 75th percentile
- 25th percentile





Coordination with agencies and organizations in the Puget Sound Basin was integral to the success of this water-quality assessment. We thank those who served as members of our liaison committee.

Federal Agencies
Bureau of Indian Affairs
National Marine Fisheries Service
National Park Service
Northwest Indian Fisheries Commission
U.S. Army Corps of Engineers
U.S. Environmental Protection Agency
U.S. Fish and Wildlife Service
U.S. Forest Service

Canadian Agencies
British Columbia Ministry of Environment
Environment Canada

State Agencies
Puget Sound Water Quality Action Team
Washington State Department of Agriculture
Washington State Department of Ecology
Washington State Department of Fish and Wildlife
Washington State Department of Health
Washington State Department of Natural Resources
Washington State Department of Transportation

Local Agencies
City of Auburn
City of Bremerton
City of Lacey
City of Olympia
City of Renton
City of Seattle
City of Tacoma
King County
Kitsap County
Pierce County
Seattle Public Utilities
Snohomish County
Tacoma-Pierce County Health Department
Thurston County
Whatcom County

Native American Tribes and Nations
Lummi Tribe
Muckleshoot Tribe
Nooksack Tribe
Puyallup Tribe
Skokomish Tribe

Universities
University of Washington
Washington State University

Other Public and Private Organizations
Adopt a Stream Foundation
People for Puget Sound
Thornton Creek Project
Washington Environmental Council
Washington Toxics Coalition

We thank the following individuals for contributing to this effort.

- Gil Bortleson (USGS, Washington District) participated in the design of the study and authored several reports.
- Dale Davis (Washington State Department of Ecology) was a partner and coauthor in the study of pesticides in streams.
- Sue Davis (Thurston County), Mindy Fohn (City of Bremerton), Keith Grellner (Kitsap County), Ray Hanowell (Pierce County), Joe Joy (Washington State Department of Ecology), and Ginny Stern (Washington State Department of Health) helped in the design of the microbiological studies.
- Annette Frahm and George Perry (King County) provided sales data for pesticides, conducted toxicity tests, and coauthored a fact sheet about pesticides in urban streams.
- Kathleen Greene, Joseph Gilbert, Gary Holloway, Brett Smith, and Greg Justin (USGS, Washington District) played a major role in the collection and compilation of water-quality and streamflow data.
- Emily Inkpen (USGS, Washington District) collected and compiled water-quality data and authored a number of reports.
- Dr. James Karr (University of Washington) provided advice on the analysis of macroinvertebrate data.
- Moon Kim, Raegan Huffman, Stephanie Leisle, Mark Munn, Steve Sumioka, and Ann Vanderpool (USGS, Washington District); Steve Goodbred and Terry Short (USGS, Western Region); Mariabeth Silkey and Michael Hummling (University of Washington); and Dave Serdar and Art Johnson (Washington State Department of Ecology) provided field support and assisted in data collection.
- Hugh Liebscher and Basil Hii (Environment Canada) provided water level and chemistry data for wells in Canada.
- Dorene MacCoy (USGS, Idaho District) helped collect and interpret biological data and helped produce a number of reports.
- Rob Plotnikoff (Washington State Department of Ecology) provided macroinvertebrate and habitat data.
- Dr. Mark Sobsey, Fu-Chih Hsu, and Douglas Wait (University of North Carolina, Chapel Hill) provided technical assistance and laboratory analyses for the microbiological study.
- Ward Staubitz (USGS, Virginia District), project chief until April 1997, played a major role in the design of the study.
- Ian Waite and Dennis Wentz (USGS, Oregon District) provided fish tissue data from the Willamette Basin, Oregon.
- Frank Voss (USGS, Washington District) managed the project data base and produced a number of reports.

Appreciation is extended to those individuals who reviewed this report or helped prepare it.

Joe Joy, Washington State Department of Ecology
Cindy Moore, Washington State Department of Agriculture
Richard Ramsey, Staff to the Washington State Environmental Quality and Water Resources Committee
Dennis Wentz, USGS, Oregon District
Ginger Renslow, Editor, USGS, Washington District
Robert Crist, Illustrator, USGS, Washington District

NAWQA

National Water-Quality Assessment (NAWQA) Program
Puget Sound Basin

Ebbert and others—Water Quality in the Puget Sound Basin
U.S. Geological Survey Circular 1216

ISBN 0-607-95420-5
9 780607 954203