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Water Quality in the Yakima River Basin

Washington, 1999–2000

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

Circular 1237

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Front cover: Wapato Irrigation Canal Diversion (right) from the Yakima River (photograph by Henry Ngan).
Back cover: Left to right, grapes, pears, apples (photographs by Yakima NAWQA Staff).

Water Quality in the Yakima River Basin, Washington, 1999–2000

By Gregory J. Fuhrer, Jennifer L. Morace, Henry M. Johnson, Joseph F. Rinella,
James C. Ebbert, Sandra S. Embrey, Ian R. Waite, Kurt D. Carpenter,
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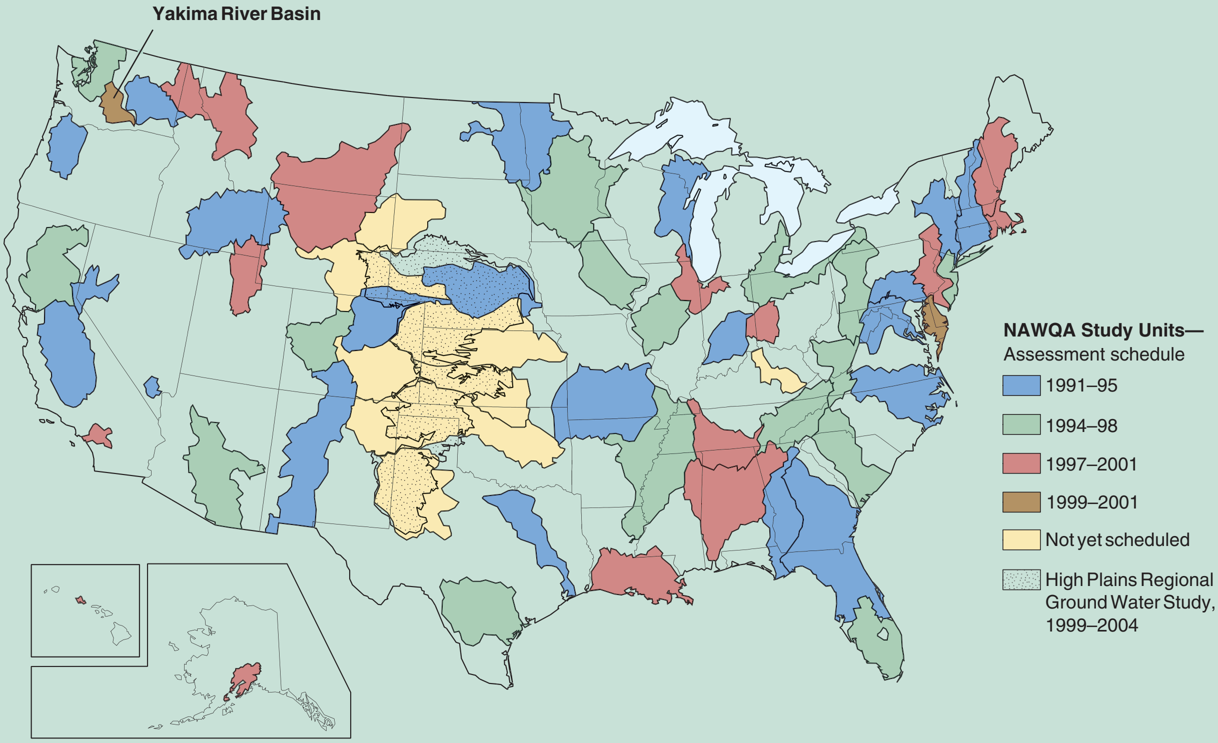
Contents

National Water-Quality Assessment Program

In 1991, the U.S. Congress began to appropriate funds to the USGS to conduct the **National Water-Quality Assessment (NAWQA) Program**. Since that time, NAWQA has evaluated the quality of streams, ground water, and aquatic ecosystems in more than 50 major river basins and aquifer systems across the Nation, referred to as "Study Units." As indicated on the map, timing of the assessments varies within the program's rotational design: about one-third of all Study Units are intensively investigated for 3 to 4 years, which is followed by 6 to 7 years of low-level monitoring.



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

The Yakima River Basin assessment is one of two special studies activated in 1999 for the purpose of piloting study techniques for use in NAWQA's second decade of investigations. Specifically, the Yakima River Basin assessment piloted techniques to (1) monitor trends in surface water, (2) evaluate transport of agricultural chemicals to streams, and (3) assess the possible effects of agricultural chemicals from irrigated farmland on stream ecosystems. The Yakima River Basin assessment builds upon monitoring data that the NAWQA Program collected previously in the basin from 1987 through 1991 as part of pilot studies conducted before full program implementation in 1991. These data provided a baseline characterization of pesticides, nutrients, trace elements, suspended solids, and aquatic life in streams.

What kind of water-quality information does the NAWQA Program provide?

The NAWQA Program assesses the quality of the Nation's water resources, which is integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and also suitable for industry, irrigation, and habitat for fish and wildlife. Assessments in the major river basins and aquifer systems include water resources available to more than 60 percent of the population and cover about one-half of the land area of the conterminous United States. Scientists in the NAWQA Program work with partners in government, research, and public-interest groups to assess the spatial extent of water-quality conditions, the way water quality changes with time, and the effects of human activities and natural factors on water quality. This information is useful for guiding water-management and protection strategies, research, and monitoring in different hydrologic and land-use settings across the Nation.

Water-quality assessments by a single program cannot possibly address all of the Nation's water-resources needs and issues. Therefore, it is necessary to define the most pertinent context for NAWQA information.

- Total resource assessment—NAWQA assessments are long-term and interdisciplinary, and include information on water chemistry, hydrology, land use, stream habitat, and aquatic life. Assessments are not limited to a specific geographic area or water-resource problem at a specific time. Therefore, the findings describe the general health of the total water resource, as well as emerging water issues, thereby helping managers and decision makers to set priorities.
- Source-water characterization—Assessments focus on the quality of the available, untreated resource and thereby complement (rather than duplicate) Federal, State, and local programs that monitor drinking water. Findings are compared to drinking-water standards and health advisories, if available, as a way to characterize the resource.
- Compounds studied—Assessments focus on chemical compounds that have well-established methods of investigation. It is not financially or technically feasible to assess all the contaminants in our Nation's waters. In general, the NAWQA Program investigates those pesticides, nutrients, volatile organic compounds, and metals that have been or are currently used commonly in agricultural and urban areas across the Nation. A complete list of compounds studied is on the NAWQA web site at *http://water.usgs.gov/nawqa*.
- Detection relative to risk—Compounds are measured at very low concentrations, often 10 to 100 times lower than Federal or State standards and health advisories. Detection of compounds, therefore, does not necessarily translate to risks to human health or aquatic life. However, these analyses are useful for identifying and evaluating emerging issues, such as the presence of new contaminants or the occurrence of mixtures, as well as for tracking contaminant levels over time.
- Consistent approach—Assessments are guided by a nationally consistent study design and uniform methods of sampling and analysis. Findings thereby pertain not only to water quality of a particular stream or aquifer, but also contribute to the larger picture of how and why water quality varies regionally and nationally. This consistent approach helps to determine if a water-quality issue is isolated or pervasive. It also allows direct comparisons of how human activities and natural processes affect water quality in the Nation's diverse environmental settings.

Introduction to this Report

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

Jeff Loser,
National Leader for
Clean Water Programs,
USDA Natural Resources
Conservation Service

This report contains the major findings of a 1999–2000 assessment of water quality in streams and drains in the Yakima River Basin. It is one of a series of reports by the NAWQA Program that present major findings on water resources in 51 major river basins and aquifer systems across the Nation.

In these reports, water quality is assessed at many scales—from large rivers that drain lands having many uses to small agricultural watersheds—and is discussed in terms of local, State, and regional issues. Conditions in the Yakima River Basin are compared to those found elsewhere and to selected national benchmarks, such as those for drinking-water quality and the protection of aquatic organisms.

This report is intended for individuals working with water-resource issues in Federal, Tribal, State, or local agencies; universities; public interest groups; or the private sector. The information will be useful in addressing a number of current issues, such as source-water protection, pesticide registration, human health, drinking water, hypoxia and excessive growth of algae and plants, the effects of agricultural land use on water quality, and monitoring and sampling strategies. This report is also for individuals who wish to know more about the quality of water resources in areas near where they live, and how that water quality compares to the quality of water in other areas across the Nation.

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

Water-quality sampling in Granger Drain

Summary of Major Findings

The following list highlights the major findings from this study of surface-water quality in the Yakima River Basin. A wide variety of water-quality topics are addressed—including an update on historically used pesticides like DDT and lead arsenate, documentation of the widespread occurrence of azinphos-methyl in streams and drains, the potential implications of elevated concentrations of arsenic and phosphorus on the shallow ground-water system, and the positive influence of best management practices on some measures of water quality.

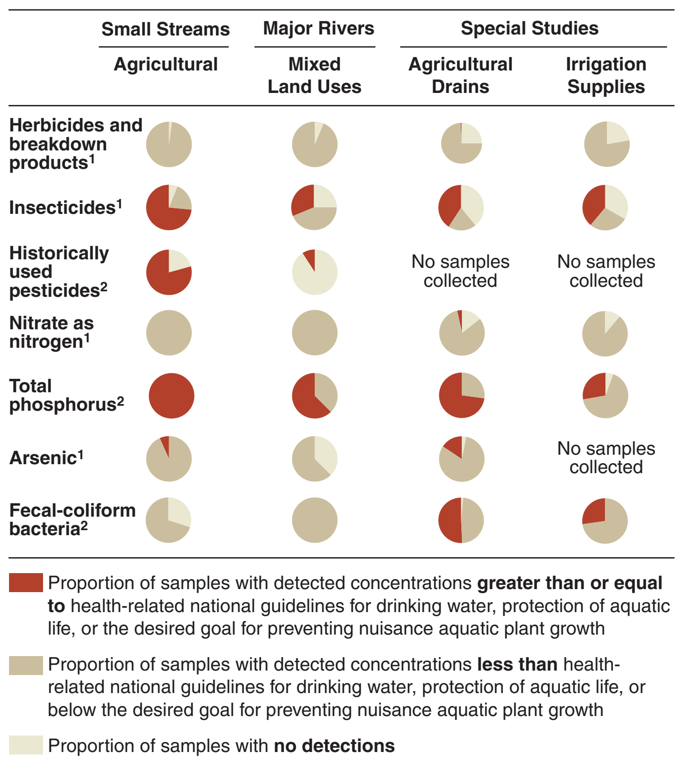
The Yakima River flows 214 miles from its headwaters in the forested Cascade Foothills to its confluence with the Columbia River near Richland. Inflows from streams and drains in the highly productive agricultural areas result in degraded water quality in the river.

- The extensive irrigation-water delivery and drainage system in the Yakima River Basin greatly controls water-quality conditions and aquatic health in agricultural streams, drains, and the Yakima River (p. 6).
- Nitrate and orthophosphate were the dominant forms of nitrogen and phosphorus found in the Yakima River and its agricultural tributaries. These forms of nitrogen and phosphorus are highly water soluble, and concentrations in some agricultural drains were high enough to support nuisance-level growths of algae (p. 8).
- Concentrations of total phosphorus have begun to decrease in the major agricultural tributaries in the Lower Valley, but concentrations frequently exceeded the U.S. Environmental Protection Agency (USEPA) desired goal to prevent nuisance growths of aquatic plants in streams (p. 10).
- The combination of best management practices (BMPs) and improvements resulting from total maximum daily load (TMDL) assessments have reduced concentrations of sediment and sediment-sorbed contaminants (p. 11).
- The majority of the agricultural streams and drains sampled exceeded the Washington State fecal-coliform bacteria standard for multiple water uses. No samples from the Yakima River exceeded the standard (p. 12).
- Concentrations of fecal-coliform bacteria in the Yakima River and the mouths of major tributaries increased with increasing suspended sediment, turbidity, nutrients, and specific conductivity. Such relations are not as evident in smaller agricultural streams and drains (p. 12).
- Arsenic, a known human carcinogen, was detected in agricultural drains at elevated concentrations during the nonirrigation season when ground water is the primary source of streamflow. Elevated concentrations of arsenic during the nonirrigation season are a cause for concern since many rural-area residents rely on wells less than 100 feet deep for their drinking water (p. 13).
- Historically used organochlorine insecticides were frequently detected in agricultural streams and drains in the Yakima River Basin. DDT, DDE, DDD, dieldrin, and heptachlor epoxide exceeded the USEPA chronic water-quality criteria for the protection of aquatic life (p. 14).
- Concentrations of total DDT in water have decreased since 1991. The reductions were associated, in large part, with decreases in concentrations of suspended sediment and sorbed DDT that resulted from the agricultural community's implementation of erosion-controlling BMPs (p. 16).
- Recent data show that the total DDT criterion could be met when concentrations of suspended sediment are well above 7 mg/L, which suggests that the TMDL target for suspended sediment could be increased (p. 16).
- Concentrations of azinphos-methyl, an insecticide heavily used on orchards in the Yakima River Basin, routinely exceeded the USEPA freshwater chronic-toxicity criterion for the protection of aquatic life. The insecticides carbaryl, diazinon, and malathion and the herbicide metribuzin infrequently exceeded aquatic-life guidelines (p. 18).

Dormant orchards near Zillah

- Azinphos-methyl was not detected during the nonirrigation season and is likely not present in the ground-water system (p. 19).
- Shallow ground water underlying agricultural areas contributes soluble pesticides (mostly herbicides, such as atrazine) and nutrients (such as nitrate) to streams all year (p. 9, 19).
- The types of pesticides in streams reflects the types of crops grown in the areas they drain. The median number of pesticide detections from the Lower Valley, which has a large diversity of crop types, was twice that in the Kittitas Valley, which is dominated by hay and pasture land (p. 20).
- Transport of a pesticide to streams depends, in large part, on its tendency to dissolve in water or adhere to soil (as reflected by the organic-carbon partitioning coefficient, or K_{oc}). Pesticides that strongly adhere to soil (high K_{oc} value) were detected at a lower frequency than expected for their application amounts, while pesticides that weakly adhere to soil (low K_{oc} value) were detected at a higher frequency than expected for their application amounts (p. 21).
- The yield of high-K_{oc} (more sorptive) pesticides increased in proportion to the amount of rill-irrigated farmland, whereas the yield of low-K_{oc} (less sorptive) pesticides was relatively constant. Generally, yields of low-K_{oc} pesticides were higher than yields of high-K_{oc} pesticides (p. 22).
- As overall stream conditions decline, benthic-invertebrate assemblages are less diverse and increasingly composed of pollution-tolerant species, and algal assemblages are increasingly dominated by species indicative of high concentrations of nutrients (p. 23).
- Algal biomass at most agricultural streams and drains was most likely limited by light from high turbidity, by sedimentation that smothers suitable substrate where algae may attach, or by herbicides that interfere with algal photosynthesis (p. 24).
- The dominant types of algae found in agricultural streams and drains were those that prefer or require high concentrations of nutrients and alkaline conditions (p. 25).

Selected Indicators of Stream-Water Quality



[1] In filtered water. [2] In unfiltered water.

Bing cherries ripening in the Lower Valley

Introduction to the Yakima River Basin

The Yakima River drains 6,155 square miles of forest, rangeland, and agricultural land in south-central Washington (fig. 1). The river originates in the Cascade Range and flows 214 river miles southeastward to the Columbia River. The western part of the basin contains high peaks and deep valleys, and the central and eastern parts feature broad valleys and basalt ridges of the Columbia Plateau. The western part of the basin is predominantly forested, whereas the eastern uplands are dominated by sagebrush and grasses. The lowlands in the central and eastern basin support the agricultural community. The Yakama Indian Nation lands, located in the southwestern portion of the basin, occupy about 15 percent of the basin.

The basin lies in the rain shadow of the snow-covered Cascade Range, and mean annual precipitation in the basin ranges from 140 inches in the mountains to less than 10 inches in the eastern lowlands. The Yakima River and its largest tributary, the Naches River, are both perennial streams with peak runoff during snowmelt, usually in April and May.

The livelihood for many of the basin's 293,700 residents is based in some way on agriculture. The Kittitas Valley produces predominantly hay, cereal crops, and irrigated pasture, whereas the Mid and Lower Valleys produce fruits, vegetables, grapes, and other specialty crops, such as hops and mint. A rapid expansion in the dairy and beef industries has occurred in the past decade, and Yakima County currently ranks first in the State for milk production (Laurie Crowe, South Yakima Conservation District, oral commun., 2003). Yakima County also ranks first nationally in the production of apples, mint, and hops and ranks fifth in total agricultural production. Timber harvesting and recreation are the major uses in the forested areas, and cattle grazing occurs primarily in the rangeland. Most people reside in the Mid and Lower Valleys with about half in rural areas [*1, 2*].

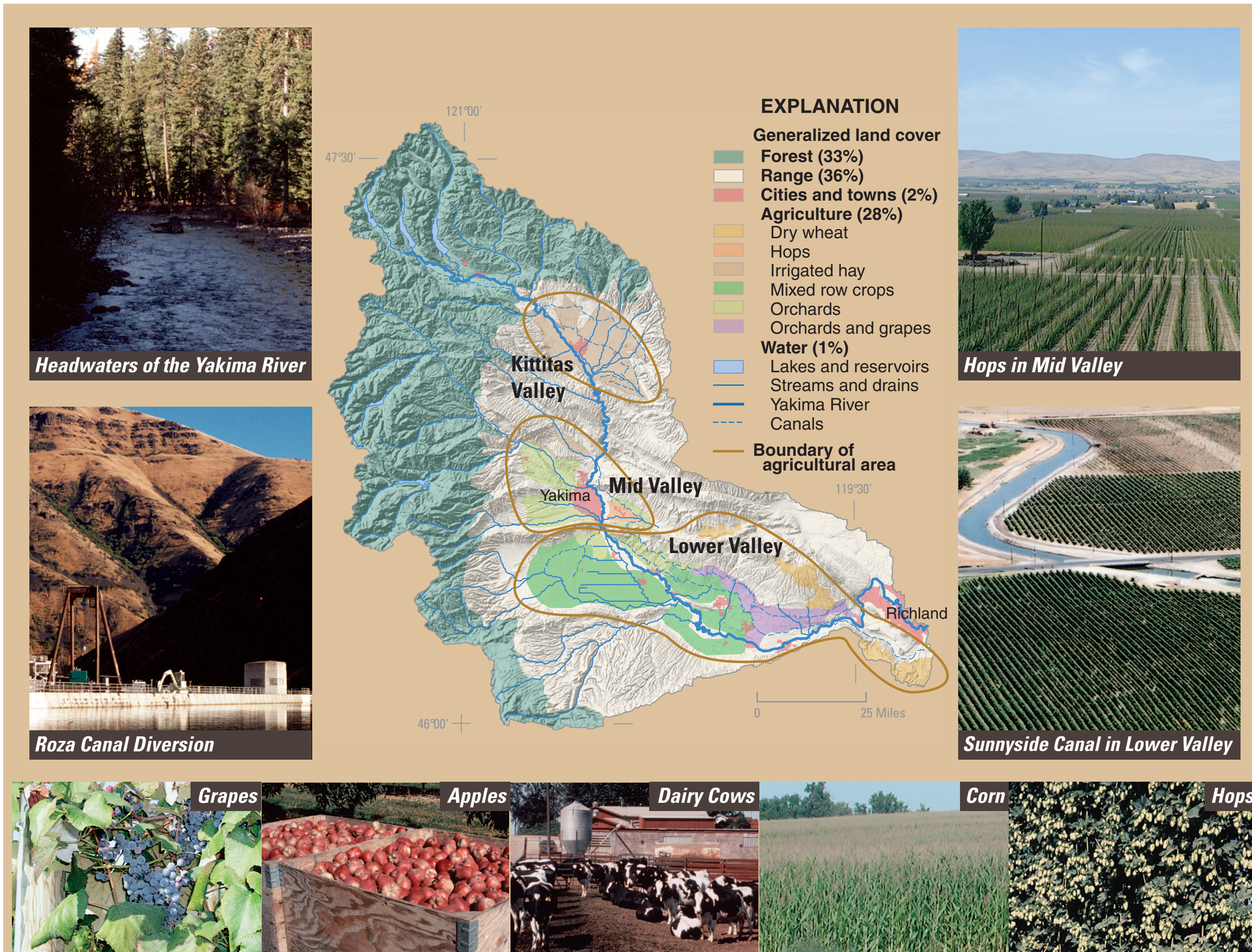


Figure 1. The Yakima River integrates many landscapes and ultimately yields most of its flow to canals that supply water for irrigation.

Water is the life blood of the Yakima River Basin

The Yakima River Basin is one of the most intensively irrigated areas in the United States. The Bureau of Reclamation's Yakima Project has six irrigation districts and one storage division and provides water to irrigate almost one-half million acres. Its facilities include 6 storage reservoirs, 416 miles of canals, 145 miles of drains, 30 pumping plants, and 2 small hydroelectric plants [*3*]. Surface-water **diversions** are equivalent to about 60 percent of the mean annual **streamflow** from the basin. During the summer, return flows downstream from the city of Yakima range from 50 to 70 percent of the flow in the lower Yakima River.

The extensive irrigation system, coupled with a ready supply of commercial fertilizers and pesticides, has made the Yakima River Basin one of the most agriculturally productive areas in the Nation. In addition to the productivity and economic challenges inherent in agriculture, today's farmers face a myriad of environmental concerns related to water-quantity and water-quality issues. Runoff from irrigated fields can carry sediment, pesticides, nutrients, and pathogenic bacteria to waterways, which has resulted in degraded water quality and violations of water-quality standards. In addition, infiltration of irrigation water transports soluble agricultural chemicals into the ground water.

Water managers and farmers work to balance environmental concerns and agricultural production

When a waterway fails to meet drinking-water standards or aquatic-life **criteria**, the Clean Water Act directs the State environmental regulatory agency, in this case the Washington Department of Ecology, to perform a total maximum daily load (TMDL) assessment to develop a cleanup plan. Four TMDL assessments have been completed for water bodies within the Yakima River Basin [*4*]. These assessments focus on improving water temperatures and reducing concentrations of **suspended sediment**, organochlorine pesticides (including **DDT**), and fecal-coliform bacteria in several areas in the basin.

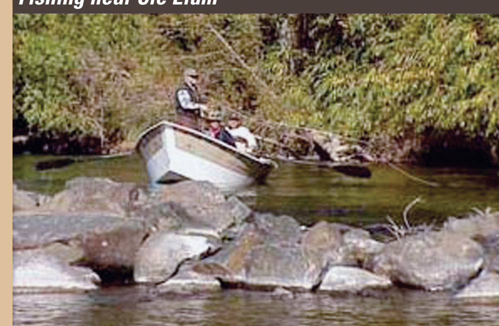
The Endangered Species Act (ESA) also has played a large role in shaping policy in the Yakima River Basin. Bull trout and summer steelhead are currently listed as threatened under the ESA. The agricultural community and water managers have worked diligently to improve the health of the Yakima River while maintaining a delicate balance with agricultural production. Improvements include enhancements to irrigation systems, screens to keep fish from entering irrigation canals, and improvements in fish and **riparian habitat**.

Harvesting alfalfa

Water-quality issues in the Yakima River Basin are affected by both agricultural production and environmental concerns.

Drain water entering the Yakima River

Fishing near Cle Elum



The Previous Yakima NAWQA Study during 1987–91

A great deal was learned about water quality and its effects on aquatic life in the Yakima River Basin during the previous NAWQA study more than a decade ago [*5*]. The scope of the earlier study was broad and covered surface-water-quality and ecological conditions associated with forested, range, and agricultural land uses. Based on the broad array of chemical and ecological measures employed in the previous study, the most affected areas were those associated with agriculture, and the measures of concern were pesticides, nutrients, arsenic, and fecal-indicator bacteria. Historically used pesticides, like DDT and its metabolites, were common in the surface water, streambed sediment, and aquatic biota. Another area of concern was habitat degradation, which resulted in impacts to aquatic insects, fish, and algae. More than 20 reports and journal articles were produced by the USGS detailing results from the previous sampling period [see *http://oregon.usgs.gov/yakima/pubs.html* for a complete listing]. To build on this previous work, the current assessment focuses exclusively on agricultural impacts to surface-water quality, aquatic insects, and algae.

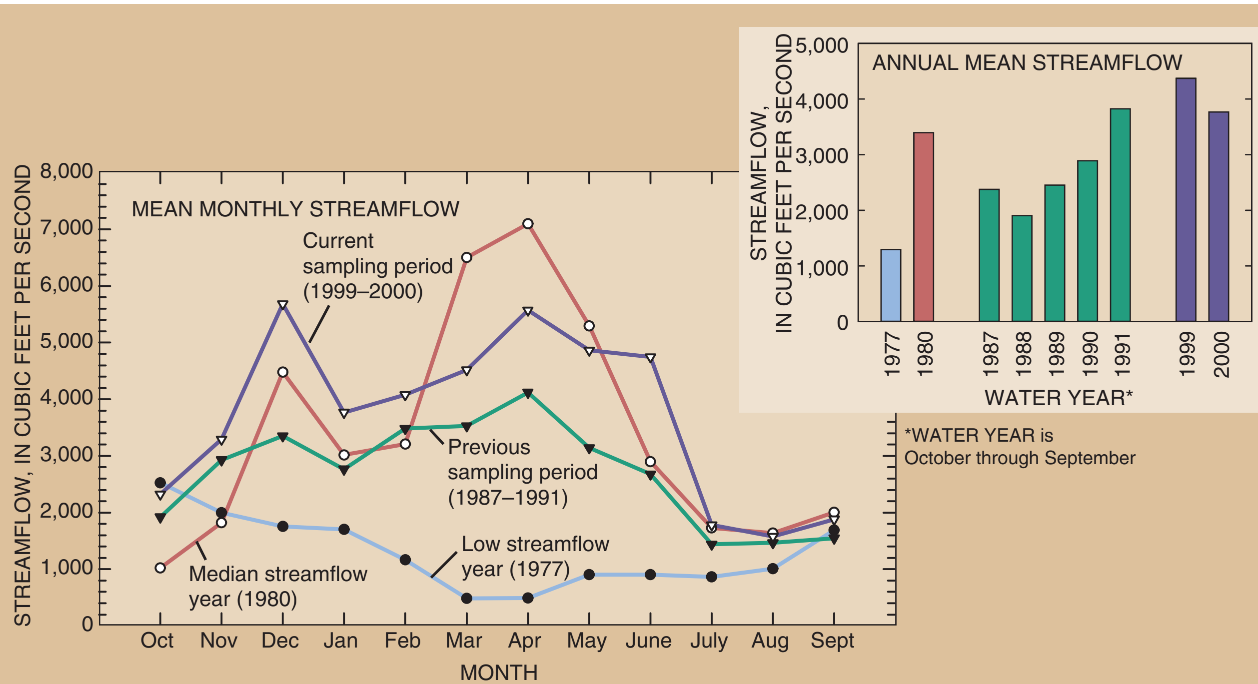


Figure 2. The amount of water measured near the mouth of the Yakima River can vary greatly from year to year. In early spring, the streamflow reflects the quantity of water stored in the High Cascades snowpack, while during the dry summer months it reflects the quantity of water released from the basin's storage reservoirs.

Streamflow can have a large effect on water quality

Streamflows in the Yakima River Basin can be highly variable from year to year and must be considered when evaluating the results of water-quality assessment studies from one year to the next. Depending on the winter snowfall in the Cascade Range, summertime flows in the Yakima River can be either plentiful or inadequate to meet all of the competing water demands. Onni Perala, retired chief engineer for the Roza Irrigation District, states, "When the water supply is plentiful, there is more operational spill and more return flow." The normal operation of an open-channel irrigation canal results in the return of unused water to the Yakima River at certain points along the system. This water is termed operational spill and is usually of higher quality than that in the agricultural drains. Operational spill has an effect on the water quality of the drains and the Yakima River by diluting the concentrations of sediment and chemicals that have been washed off the fields and into the waterways. Therefore, water availability and potential dilution effects must be considered when comparing water quality between years and when examining findings from a particular year. Both annual mean streamflows and mean monthly streamflows during the current sampling period were generally higher than those of the previous sampling period (1987–91), implying that more land may have been irrigated during the current period, and thus more water may have been available to dilute the sediment and chemicals washed from agricultural fields (fig. 2).

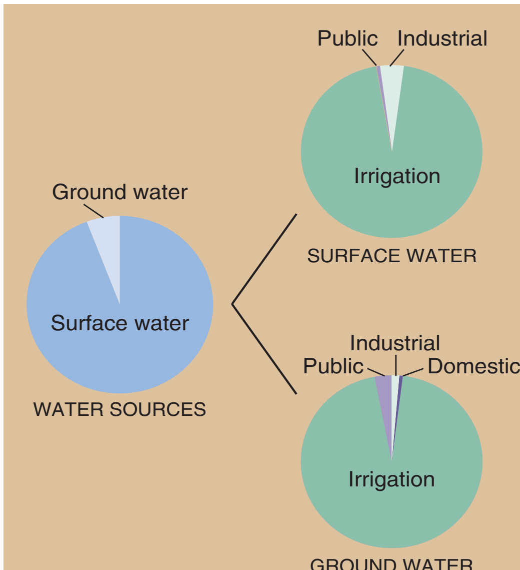


Figure 3. Nearly all the water withdrawals in the Yakima River Basin are from surface-water sources. The primary irrigation season generally spans the period March 15 to October 15.

Surface water supplies most water needs in the Yakima River Basin

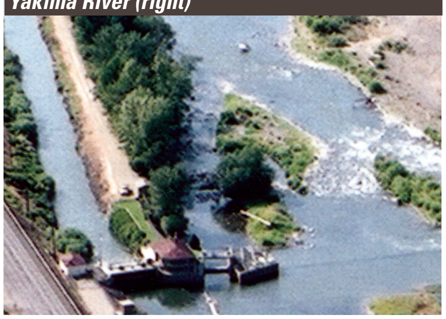
Water **withdrawals** in the Yakima River Basin are primarily from surface-water sources, with 95 percent of surface-water withdrawals used for irrigation (fig. 3). Surface water also provides drinking water for cities like Yakima and towns such as Cle Elum, but most of the drinking water comes from wells. Consequently, the movement of agricultural chemicals from the land surface into the ground-water system has important human-health implications, especially for rural residents.

Basin farmers employ diverse irrigation and agricultural practices

Water Delivery and Drainage Systems

To meet the water demands of crops during the hot, dry summer, an extensive irrigation network has been constructed over the last 100 years. Water delivery and water drainage are integral components of the irrigation network. The water delivery system consists of four parts: (1) reservoirs that collect winter rain and snowmelt from the Cascade Range, (2) the Yakima River, which delivers water released from the reservoirs to the canal diversions, (3) irrigation canals that convey water from the Yakima River to the agricultural lands, and (4) delivery laterals that move water from the canals to the fields. The water drainage system consists of natural and constructed channels, which transport tailwater from farms and operational spill from the irrigation network back to the Yakima River.

Sunnyside Canal diversion (left) from the Yakima River (right)



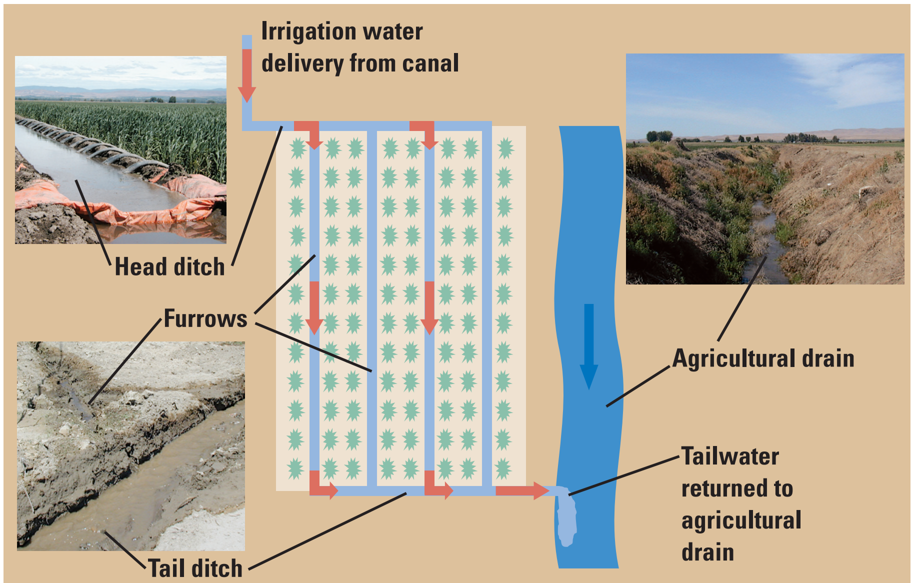
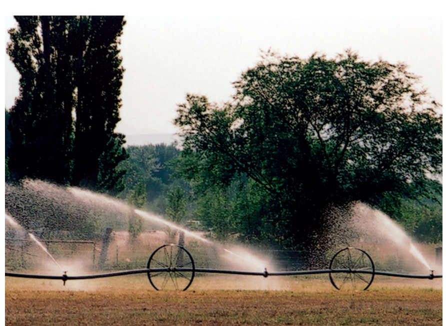


Figure 4. Rill irrigation uses gravity to deliver water to crops and removes the unused portion by way of ditches and drains.

Irrigation Methods

Irrigation in the Yakima River Basin is accomplished using one of three methods: rill, sprinkler, or drip. **Rill irrigation** is the oldest and simplest form in use (fig. 4). In its simplest form, an open channel (head ditch) delivers water to the high point of a field. Water is siphoned out of the head ditch and into small furrows cut into the field between each crop row. Water exits the furrows at the low point of the field, and is collected in a second open channel (tail ditch). The tailwater in the tail ditch is routed to a drain that feeds into the regional drainage network. On many rill-irrigated fields, the open head ditch has been replaced with PVC pipe. Instead of siphon tubes, manually operated spigots or sliding gates direct irrigation water into the furrows.

A variety of sprinkler systems are used throughout the Yakima River Basin, and each system varies in its efficiency of delivering water. Portable solid set, wheel lines, and big guns are examples of simple systems to operate, but typically do not provide a uniform coverage of water to a field. They also require manual labor to move from place to place in a field. Fixed solid set, center pivots, and linears are more expensive to install and more complex to operate, but they provide a more even coverage and give the farmer greater control over the irrigation process. These systems can be fully automated, enabling the farmer to irrigate a large area with less labor. The most sophisticated systems use feedback from soil-moisture probes to cycle the irrigation system off and on.



Wheel line sprinkler

Drip irrigation employs plastic lines with small openings to deliver water directly to the base of the plant.

Sand filters and chemical-storage tanks for a drip-irrigation system

The drip lines may be installed above or below the soil. A properly operating drip-irrigation system enables a farmer to make maximum use of his allotment of water—very little water is lost to evaporation, no tailwater is generated, and virtually no water is lost to the ground-water system. Drip systems also enable the farmer to deliver nutrients and some pesticides through the lines, significantly reducing the amount of chemicals used on the field and reducing the potential for the chemical to leave the field.

Most basin farmers use best management practices

The earliest modern **best management practices (BMPs)** in the Yakima River Basin were not implemented for the purpose of maintaining instream flows or water-quality concerns, but because they were in the best interest of the farmer. For example, the drought of 1977 resulted in significantly reduced water deliveries to the holders of junior water rights. Farmers in the Roza Irrigation District were among the most heavily affected. This drought prompted many farmers to reevaluate the type of crops they were growing and how they were irrigating their crops. In the years following the drought, thousands of acres of rill-irrigated row crops in the Roza Irrigation District were converted to sprinkler-irrigated orchards. Additionally, most irrigation systems in existing orchards were converted to sprinkler systems.

Today, most farmers employ multiple BMPs to reduce water use and to minimize soil erosion from their fields. For example, irrigation districts throughout the Yakima River Basin are required by State and Federal regulatory agencies to reduce contamination in **agricultural return flow** that enters the Yakima River. As a result, farmers in the Roza and Sunnyside Valley Irrigation Districts who are consistently in violation of district water-quality standards face cuts in their water allotments. It is, therefore, in the interest of the farmer to implement BMPs.

Commonly Used BMPs

Irrigation-Method Conversion

Converting from rill irrigation to sprinkler or drip irrigation or upgrading an older sprinkler system to a more efficient one provides many benefits to the farmer, including water conservation, reduced erosion, and decreased runoff. It is an expensive undertaking and is not an operationally viable option for all crops. Conversion costs range from $300 to $1,600 per acre.

Polyacrylamide (PAM)

The use of PAM is an effective, low-cost method to improve the quality of tailwater from rill-irrigated fields. PAM is a chemical added to the irrigation water that causes soil particles in the furrows to adhere to one another. PAM has been used very effectively to reduce erosion from rill-irrigated fields. It also enhances water infiltration into the soil, thereby leading to a more uniform irrigation of the crops along a row.

Piping Irrigation Laterals and Head Ditches

Many irrigation districts are upgrading their open, earthen or concrete delivery laterals to PVC pipe. The PVC pipe virtually eliminates water losses to the ground water and atmosphere. The irrigation water arrives at the farms cleaner, and, in some cases, with enough pressure to operate the irrigation system without a pump. On many rill-irrigated fields, the open, earthen head ditch has been replaced with PVC pipe with the same benefits.

Sediment-Retention Ponds

Sediment-retention ponds are located at low point of a rill-irrigated field. The ponds reduce the velocity of the irrigation tailwater, which allows some of the sediment to settle out before the water is returned to the agricultural drain system. Some farmers have installed pumps that enable them to reuse water from these ponds rather than allowing it leave their farm. To be effective, sediment-retention ponds must be properly sized for the amount of inflow and they must be cleaned periodically.

Sediment-retention pond at the bottom of a corn field

Riparian Fencing

Controlling livestock access to waterways can reduce concentrations of nutrients, suspended sediment, and fecal coliform bacteria in streams. The reduced traffic encourages the growth of vegetation in and along the waterway. Riparian vegetation removes nutrients from the water, provides habitat for insects (both beneficial and problematic), and is important for stream shading.

Riparian fencing along a drain

New or Experimental BMPs

Constructed Wetlands

Routing irrigation-return flow through a constructed managed wetland can reduce concentrations of nutrients and suspended sediment. Increased populations of pest insects and increased concentrations of fecal-coliform bacteria from birds and mammals attracted to the wetlands must be addressed before this promising BMP can be widely implemented.

Soil-Moisture Probes

Electronic sensors installed at multiple depths in the soil enable farmers to monitor the downward movement of irrigation water on their fields. With experience and experimentation, the data from the moisture probes can be used to fine-tune irrigation systems, so the plants get the water they need without flushing water and dissolved minerals, nutrients, and pesticides into the ground water.

Major Findings

High concentrations of nutrients result from agricultural activities

During the irrigation season, most of the water in the lower Yakima River is agricultural return flow. Concentrations of nutrients (nitrogen and phosphorus) in the river reflect the influx of agricultural chemicals. In August 1999, concentrations of total phosphorus in the Yakima River increased from 0.01 mg/L in the headwaters near Cle Elum to 0.14 mg/L near the mouth at Kiona (fig. 5). Although high, the concentrations of nutrients in the Yakima River at Kiona were similar to those in other large rivers nationally (see Appendix, p. 34).

Concentrations of phosphorus were higher in the agricultural tributaries than in the Yakima River (fig. 5). At two frequently sampled sites, Moxee Drain and Granger Drain (see p. 27), concentrations of total phosphorus were higher than those in most other agricultural streams nationwide (see Appendix, p. 34).

Nitrate and orthophosphate were the dominant forms of nitrogen and phosphorus found in the Yakima River and its agricultural tributaries. These forms of nitrogen and phosphorus are highly water-soluble, and are transported to streams and drains in irrigation runoff. After the irrigation season, they continue to enter streams and drains through ground-water discharges (fig. 6). Concentrations of nutrients in some agricultural drains were high enough to support nuisance-level growths of algae (see p. 24). Although not assessed in this study, heavy growths of algae and rooted aquatic plants have been observed in the lower Yakima River. Large diurnal fluctuations in pH and dissolved oxygen due to excessive algal and plant growth can

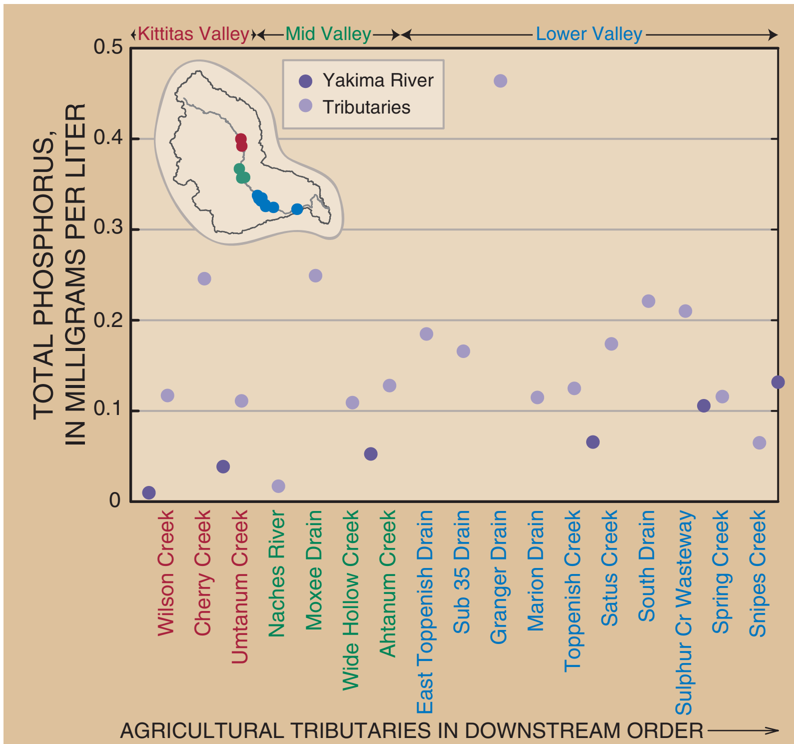
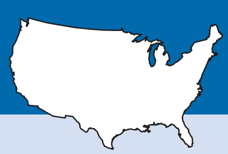
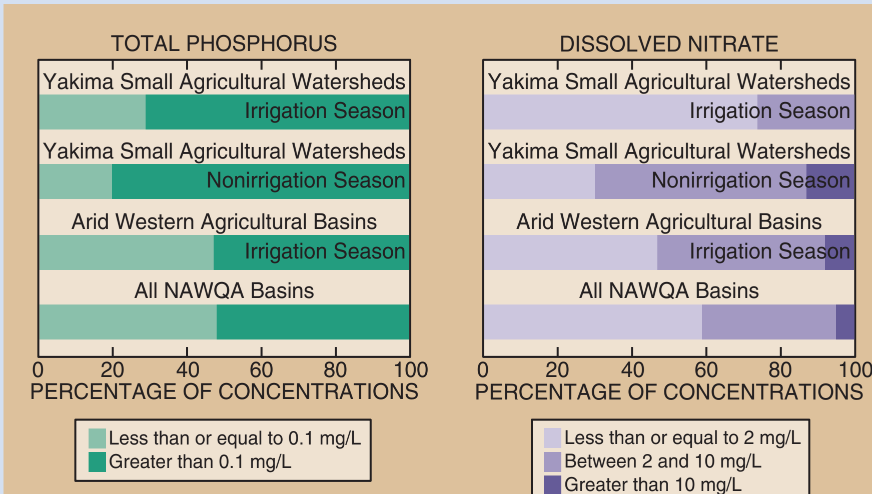


Figure 5. Concentrations of total phosphorus increase downstream in the Yakima River, particularly in the Lower Valley, where most of the water is from agricultural return flow.



Small agricultural watersheds had large percentages of elevated concentrations of nutrients

In a special study of small agricultural watersheds in the Yakima River Basin, concentrations of phosphorus in 71 percent of the irrigation-season samples and 80 percent of the nonirrigation-season samples exceeded the USEPA desired goal of 0.1 mg/L to prevent nuisance growth of plants in streams [*6*]. In the same study, 13 percent of the nonirrigation-season concentrations of nitrate exceeded 10 mg/L—the USEPA drinking-water standard [*7*]. These percentages are high compared to other NAWQA studies in the West and throughout the Nation (see figure).



The data from the Yakima small agricultural watersheds are not shown in the Appendix on p. 34.

Reporting Conventions

Concentrations of nutrients are reported as elemental nitrogen and phosphorus. References to dissolved nitrate refer to an analysis of dissolved nitrate plus nitrite. Because nitrite was rarely detected or was detected at very low concentrations, it is more convenient to simply refer to these as dissolved nitrate.

produce conditions that are unhealthy for fish and other aquatic life. Furthermore, when die-offs of aquatic vegetation occur, drifting algal or plant material may become an aesthetic nuisance along stream banks and can foul water intakes, canals, and fish screens.

Seasonal differences between nitrogen and phosphorus reflect source differences

Concentrations of total phosphorus in Granger Drain were as much as five times higher during the irrigation season than during the nonirrigation season (fig. 6). The high concentrations were commonly associated with high concentrations of suspended sediment, suggesting most of the phosphorus is bound to soil particles. The consistent elevated concentrations observed during the nonirrigation season most likely reflect a large reservoir of dissolved orthophosphate in the shallow ground water that will challenge water managers trying to meet lower nutrient standards.

In contrast to total phosphorus, concentrations of nitrate were lowest during the irrigation season and increased in the fall, when ground-water discharge becomes the dominant source of streamflow. Nitrate is highly water-soluble and readily leaches into ground water, where it is transported to streams and drains. During the irrigation season, unused irrigation water and overland runoff provide dilution water that lowers concentrations of nitrate. Once irrigation ends, streamflows subside and concentrations of nitrate increase. In Granger Drain, for example, concentrations of nitrate increased to more than 6 mg/L once the irrigation season ended (fig. 6 and table 1). Thirteen percent of the concentrations from small-watershed sites (see p. 27) sampled during the nonirrigation season exceeded the USEPA drinking-water standard for nitrate of 10 mg/L, indicating a potential health risk to nearby residents with shallow wells.

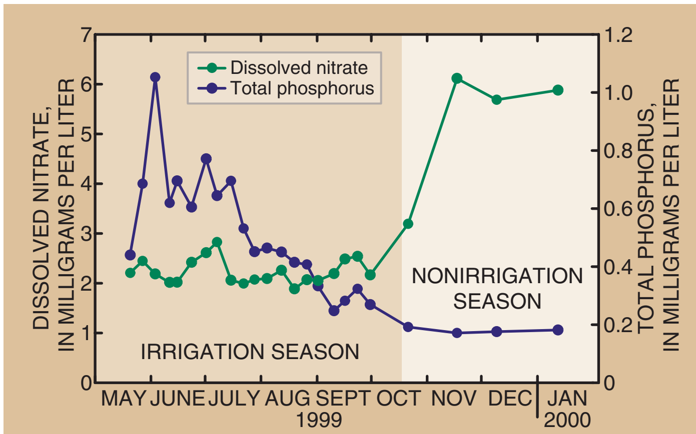


Figure 6. Concentrations of dissolved nitrate were highest during the nonirrigation season when ground water is the primary source of water to Granger Drain. Concentrations of total phosphorus, however, were highest during the irrigation season, when overland runoff delivers phosphorus-rich sediment to the drain.

Concentrations of nutrients in agricultural streams and drains exceeded criteria

The USEPA has suggested regional nutrient criteria for concentrations of total phosphorus and total nitrogen in streams of the Xeric West (Nutrient Ecoregion III) to protect against the adverse effects of nutrient enrichment [*8*]. These guidelines provide an upper limit that is protective of aquatic life, and is to be used as a starting point for States and Tribes in the development of their own criteria. The Yakima River Basin is part of the Columbia Plateau Ecoregion 10, where the suggested reference conditions for total nitrogen and total phosphorus are 0.36 mg/L and 0.03 mg/L, respectively.

Concentrations of total nitrogen at four reference sites in the Yakima River Basin ranged from 0.30 to 0.34 mg/L, which is slightly below the reference condition. All other streams and drains had much higher concentrations of total nitrogen, some exceeding 10 mg/L. Concentrations of total phosphorus at the reference sites ranged from 0.034 to 0.10 mg/L, with the highest concentration occurring in Umtanum Creek.

Table 1. Concentrations of nutrients sometimes exceeded USEPA guidelines for controlling nuisance plants and algae in streams

Site name	Site type	Range of concentrations (milligrams per liter)	Percentage of samples exceeding desired goal	
			Yakima NAWQA site	Western NAWQA sites
Total phosphorus (Desired goal = 0.1 milligrams per liter) [*8*]				
Yakima R at Kiona	Yakima River	0.08–0.27	44	55
Moxee Drain	Agricultural tributary	0.16–0.37	100	55
Granger Drain	Agricultural tributary	0.17–1.1	100	55
Dissolved nitrate (Desired goal = 0.072 milligrams per liter) [*8*]				
Yakima R at Kiona	Yakima River	0.3–1.2	100	97
Moxee Drain	Agricultural tributary	0.8–5.9	100	97
Granger Drain	Agricultural tributary	1.9–6.2	100	97

Although the concentrations of total phosphorus in all reference streams exceeded the suggested reference condition, none exceeded 0.10 mg/L, the USEPA desired goal to prevent nuisance growths of aquatic plants in streams. In contrast, concentrations of total phosphorus in all drains and streams affected by agriculture exceeded 0.10 mg/L, sometimes by as much as a factor of nearly five. In 1999, all of the concentrations of total phosphorus measured in both Moxee and Granger Drains [*9*] exceeded this goal (table 1).

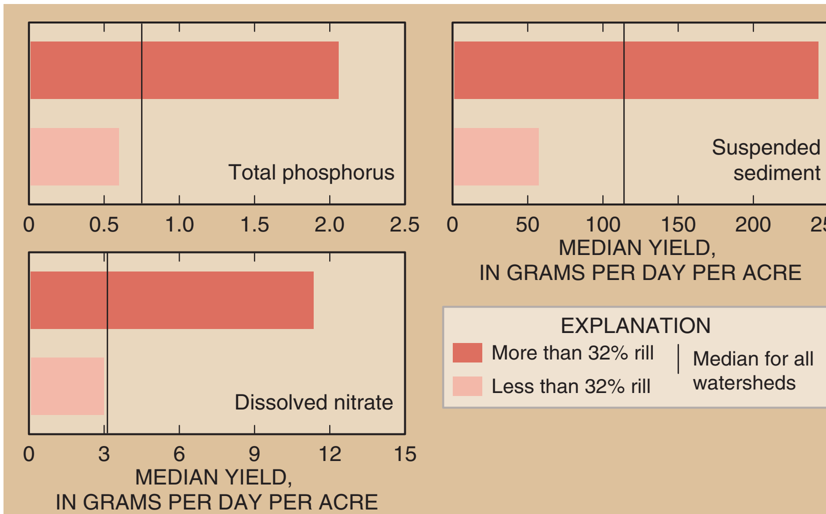


Figure 7. Small agricultural watersheds with large amounts of rill-irrigated farmland lost more total phosphorus, dissolved nitrate, and suspended sediment per acre than those with more sprinkler- or drip-irrigated land.

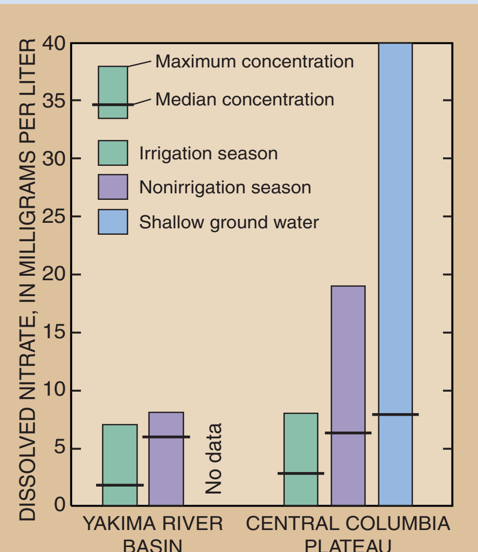
Irrigation method and landscape differences affect nutrient contributions to streams

The tailwater from a rill-irrigated field provides a direct path for nutrients, pesticides, and suspended sediment to enter agricultural drains. Through the use of PAM and other BMP implementations, great progress has been made in the Yakima River Basin in reducing the amount of suspended sediment in rill tailwater and decreasing the amount of runoff. Data from the small agricultural watersheds (see p. 27), however, clearly show that rill irrigation still results in a larger per acre loss of sediment and nutrients than sprinkler or drip irrigation (Hank Johnson and Dan Wise, U.S. Geological Survey, unpub. data, 2004). High rill-irrigation watersheds lost four times more total phosphorus and dissolved nitrate and five times more suspended sediment than low rill-irrigation watersheds (fig. 7).

The landscape characteristics of the areas also factor into these differences in nutrient contribution. In the Yakima River Basin, rill irrigation tends to be used on land with slopes less than 3 percent—typically found near the valley floor. These relatively flat areas are where streams and drains commonly flow year-round in response to continuous upwelling of shallow ground water. The proximity to flowing water and shallow ground-water upwelling mean that the chemicals lost from rill-irrigated fields are more likely to reach agricultural tributaries. Also, crops that tend to be rill irrigated, such as corn, generally require a higher per acre appli-

Ground-water discharges are a major source of surface-water nitrate in irrigated areas of the Western United States

Discharge of agriculturally affected ground water to the Snake River from springs accounts for about 70 to 80 percent of the nitrate leaving the upper Snake River Basin in Idaho [*10*]. Nitrate contributions from subsurface agricultural drains to the San Joaquin River in California has increased steadily since the 1950s [*11*]. In the Central Columbia Plateau in Washington, the similarities between concentrations of nitrate in shallow ground water and concentrations in agricultural drains and wasteways sampled during the nonirrigation season were used to infer trends in concentrations of nitrate in shallow ground water over time [*12*]. Maximum concentrations of nitrate in agricultural drains and wasteways in the Central Columbia Plateau were higher than those in the Yakima River Basin, but median values and seasonal patterns were similar. This strongly suggests that shallow ground water underlying some agricultural areas in the Yakima River Basin also has elevated concentrations of nitrate. These findings raise concerns that some shallow domestic wells in agricultural areas have concentrations of nitrate that are above the drinking-water standard of 10 mg/L.



cation of fertilizer than those that are usually drip or sprinkler irrigated, such as grapes. Consequently, these factors also contribute to increased nutrient loss from rill-irrigated areas.

Agricultural BMPs have decreased concentrations of sediment and phosphorus

During the past several years, the implementation of BMPs, such as the use of PAM and conversion from rill-irrigation to sprinkler- and drip-irrigation methods, have diminished the amount of agricultural runoff entering Yakima River Basin streams and drains. Concentrations of suspended sediment and total phosphorus in Granger Drain (fig. 8) and Sulphur Creek Wasteway, for example, have decreased—especially during 1999 and 2000 [*7*]. These improvements in water quality support the continued implementation of BMPs. Similar improvements in water quality were not, however, noted in the Yakima River during 1997–2000 [*7*]. Because of its larger size, it may take longer to improve than the smaller drains and tributaries. Alternatively, annual differences in flow in the Yakima River may mask improvements in water quality. Although it may be somewhat early to see the full extent of improvements in water quality from the BMPs implemented thus far, the 1999–2000 suspended sediment and total phosphorus data are encouraging (fig. 8).

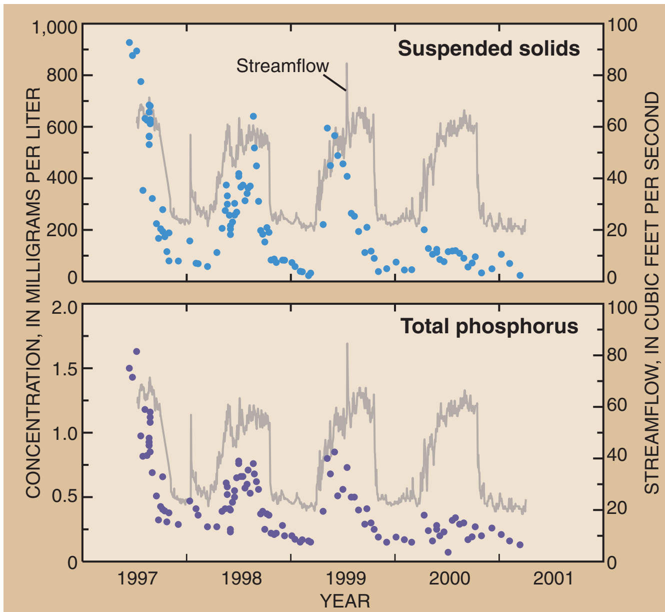


Figure 8. Concentrations of suspended sediment and total phosphorus in Granger Drain show slight decreases since 1997 that may correspond with the increased use of agricultural BMPs in the Granger Basin. Data provided by the Roza-Sunnyside Board of Joint Control (RSBOJC).

BMPs are needed to reduce nitrate contamination in ground water

Concentrations of nitrate in the agricultural drains and streams were high, especially after the irrigation season, when ground-water discharges dominate flow in the drains. Concentrations of dissolved nitrate in Granger Drain have increased over the period 1991–2000 [7]. Most BMPs are designed to control erosion and therefore aim to reduce the transport of sediment and pollutants associated with sediment such as phosphorus and DDT. Such BMPs are less effective in controlling the movement of water-soluble agricultural pollutants such as nitrate and dissolved pesticides, which leach into ground water during the irrigation season. As a result, despite the implementation of BMPs, reductions in concentrations of nitrate have not yet occurred (fig. 9). Some farmers are now using soil-moisture monitors to prevent over-irrigation, a practice that should help reduce nitrate leaching. Nutrient data collected in 2001 by the Roza-Sunnyside Board of Joint Control suggest that concentrations of nitrate in the agricultural drains may be leveling off [7]. Because **aquifers** flush slowly, however, it may take years or decades to flush clean such agricultural pollutants, even without additional contamination.

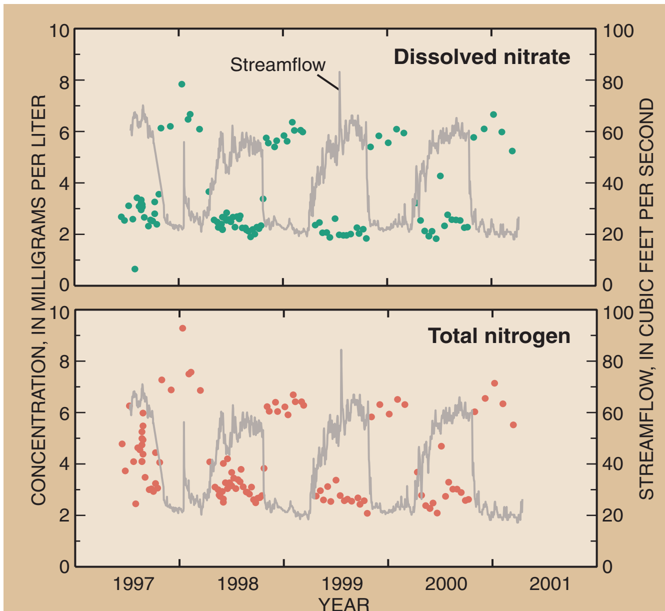
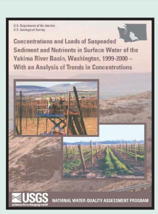


Figure 9. Dissolved nitrate, the principal component of the total nitrogen found in Granger Drain, is not associated with sediments and therefore has not decreased in response to BMP implementation. Data provided by the RSBOJC.



Detailed information on nutrients and suspended sediment in surface water in the Yakima River Basin can be found in the following report:

Concentrations and loads of suspended sediment and nutrients in surface water of the Yakima River Basin, Washington, 1999–2000—With an analysis of trends in concentrations, by J.C. Ebbert and others: U.S. Geological Survey Water-Resources Investigations Report 03–4026 at **http://pubs.water.usgs.gov/wri034026/**

Bacteria indicate the presence of fecal contamination

Water from streams with poor sanitary quality can transmit diseases such as cholera, typhoid fever, and bacillary and amoebic dysentery. Fecal-coliform bacteria are indicators of fecal contamination that have been correlated with the incidence of gastrointestinal disease resulting from bodily contact with certain freshwater sources. Wastes from warm-blooded animals, including humans, are sources of fecal contamination. In 1998, the Washington Department of Ecology, under the guidelines of the Clean Water Act, listed 18 river reaches in the Yakima River Basin as impaired or threatened water bodies, based on concentrations of bacteria.

During the summer, concentrations of fecal-coliform bacteria in streams and drains in the Yakima River Basin commonly exceed the Washington State water-quality standard (200 colonies per 100 milliliters) for multiple water uses [*13*]. During two irrigation-season samplings in August 1999 and July 2000, concentrations of fecal-coliform bacteria at 56 and 65 percent of the sites sampled, respectively, exceeded the standard (fig. 10). None of these exceedances, however, were observed in the mainstem Yakima River. Instead, the highest concentrations were measured in tributaries draining predominantly agricultural and(or) urban areas.

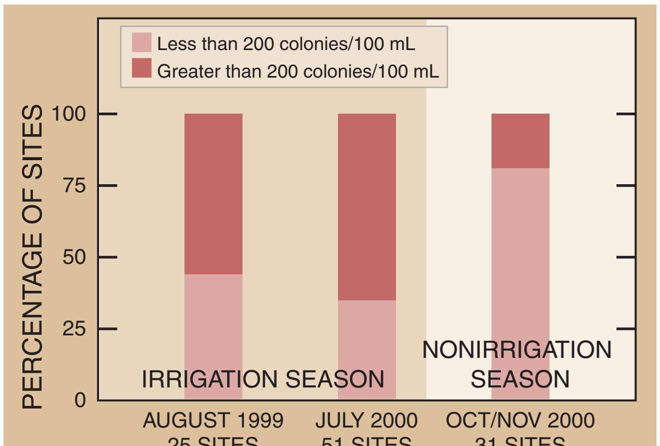


Figure 10. Fecal-coliform bacteria concentrations commonly exceed the Washington State water-quality standard of 200 colonies per 100 milliliters, particularly during the irrigation season.

During the fall nonirrigation-season sampling, only 19 percent of the sites sampled exceeded the standard (fig. 10). Four of the six sites that exceeded the standard in the fall are agricultural drains located in the Granger Drain and Sulphur Creek Wasteway subbasins in the Lower Valley. These two subbasins have the highest livestock densities in the basin and, therefore, also have more manure applications to agricultural fields for fertilization. Several other tributaries with high concentrations of bacteria, however, could not be explained by livestock density or manure application. The issue is much more complex, with potential sources including, but not limited to, humans (for example, failing septic systems), pets, livestock, birds, and wildlife.

In an effort to better understand some of these high concentrations, the bacteria data were tested for relations with other physical and chemical variables [*14*]. The concentrations of bacteria measured in the Yakima River and the mouths of major streams and drains increased significantly with increasing suspended sediment, **turbidity**, nutrients, and specific conductance. For example, the three major tributaries with the highest concentrations of fecal-coliform bacteria, including Moxee Drain, Granger Drain, and Sulphur Creek Wasteway, also had some of the highest concentrations of suspended sediment.

Summer is a time of increased recreation in the Yakima River

In contrast, the concentrations of bacteria measured in streams and drains in small agricultural watersheds were not as strongly associated with these factors, except selected nutrients and water temperature. These differences illustrate how important it is to consider the scale of sampling (large subbasin compared to small watershed) and the complexity of potential sources when analyzing fecal-coliform bacteria data.

Looking forward to future monitoring goals, research needs, and BMP development, subjects that need further investigation were identified [*14*]. These include (a) the transport mechanisms of fecal-coliform bacteria from land surfaces to streams through overland runoff, (b) the specific role played by suspended sediment in the occurrence and transport of bacteria, and (c) the quantification of the relations between fecal-coliform contamination in streams and wildlife, livestock, and people in the basin.

Detailed information on fecal contamination in surface water in the Yakima River Basin can be found in the following report:

Fecal-indicator bacteria in the Yakima River Basin, Washington—An examination of 1999 and 2000 synoptic-sampling data and their relation to historical data, by J.L. Morace and S.W. McKenzie: U.S. Geological Survey Water-Resources Investigations Report 02–4054 at **http://pubs.water.usgs.gov/wri024054/**

Arsenic, a known human carcinogen, was detected at levels of concern

Although nearly all trace elements in the aquatic environment are from natural sources, some are enriched by human activities. In general, concentrations of trace elements in the Yakima River Basin were small and of no known concern to human or aquatic health. Of the 23 trace elements for which samples were analyzed [*14*], only arsenic exceeded the Maximum Contaminant Level (see box below).

Arsenic enters the environment from applications of pesticides and fertilizers, the release of volcanic gases and geothermal water, and the weathering of arsenic minerals [*15*]. Lead arsenate has been used in the past to control codling moths in apple orchards in eastern Washington. Currently, commercial fertilizers containing phosphate are also a potential source of arsenic [*14*]. Fuhrer and others [*16*] reported natural sources of arsenic in the headwaters of the Yakima River Basin and agricultural sources of arsenic in the Sulphur Creek subbasin in the Yakima Valley agricultural area.

In 1999, concentrations of arsenic in the Yakima River near the mouth were at their highest level in August (fig. 11); only two samples, however, exceeded the Risk-Specific Dose (RSD4) value of 2 **micrograms per liter** (µg/L) that corresponds to a cancer risk of 1 in 10,000. At the end of the irrigation season, concentrations slowly declined and returned to a nondetectable level by January. In contrast, concentrations of arsenic in two agricultural drains (Granger Drain and Moxee Drain) were highest during the nonirrigation season. All samples from Granger Drain exceeded 2 µg/L, and two samples exceeded the existing MCL of 10 µg/L. Most irrigation-season samples from Moxee Drain were near or below 2 µg/L, while all nonirrigation-season samples exceeded 2 µg/L and three were near 10 µg/L.

Elevated concentrations of arsenic during the nonirrigation season were again observed in Moxee Drain and Granger Drain in 2000. An additional 30 agricultural streams and drains from throughout the Yakima River Basin were sampled for arsenic in October and November of 2000. Of the 32 sites, 18 had concentrations of arsenic exceeding the RSD4 value of 2 µg/L and 5 had concentrations exceeding the MCL of 10 µg/L. Concentrations in agricultural drains in the Moxee, Granger, and Sulphur Creek Subbasins were higher than concentrations from Ahtanum Creek, Spring Creek, Snipes Creek, and most drains in the Kittitas Valley.

During the irrigation season, agricultural drains in the Yakima River Basin contain a mixture of ground water and agricultural return flow. During the nonirrigation season, most of the water in the drains is discharge from the shallow ground-water system. The increase in the concentration of arsenic in the drains during the nonirrigation season is highly suggestive of elevated concentrations in the shallow ground-water system. Because many rural-area residents rely on wells less than 100 feet deep for their drinking water, nonirrigation-season concentrations of arsenic in the drains near the MCL are a cause for concern. Subsequent samplings of Lower Valley wells have shown that concentrations of arsenic in more than half of the 74 wells sampled exceeded 2 µg/L [*17*].

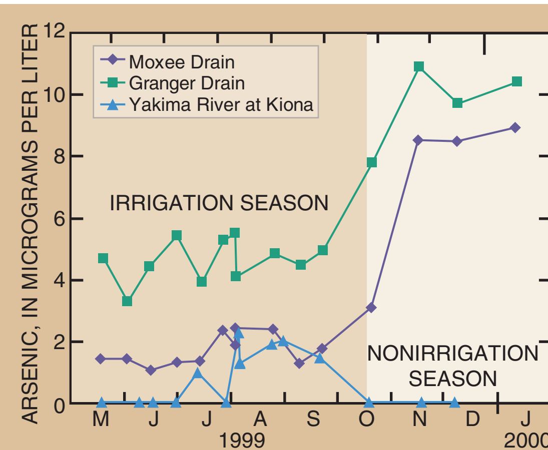


Figure 11. Concentrations of arsenic in two agricultural drains were highest during the nonirrigation season, when ground water is the primary source of water, whereas concentrations in the Yakima River were highest during the irrigation season, when irrigation return flow influences water quality.

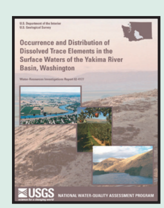
Standards and Guidelines for Arsenic in Water

Arsenic has been classified as a human carcinogen by the USEPA; therefore, the unenforceable Maximum Contaminant Level Goal (MCLG) is zero. The enforceable Maximum Contaminant Level (MCL) is “set as close to the MCLG as feasible using the best available analytical and treatment technologies and taking cost into consideration [*18*].” In January 2001, USEPA lowered the MCL for arsenic from 50 µg/L to 10 µg/L.

The USEPA has also established Risk-Specific Dose (RSD) values, which represent the concentrations of a chemical in drinking water that corresponds to defined levels of increased lifetime cancer risk. For arsenic, the RSD4 value corresponding to a cancer risk of 1 in 10,000 is 2 µg/L [*19*].

Detailed information on trace elements in surface water in the Yakima River Basin can be found in the following report:

Occurrence and distribution of dissolved trace elements in the surface waters of the Yakima River Basin, Washington, 1999–2000, by C.A. Hughes: U.S. Geological Survey Water-Resources Investigations Report 02–4177 at **http://pubs.water.usgs.gov/wri024177/**



Historically used pesticides are still present in the Yakima River Basin

In the mid-1900s, DDT and other organochlorine insecticides were used to control a wide variety of pests in the Yakima River Basin and throughout the Nation. After several decades of use, however, the adverse impacts on ecosystems were found to outweigh the benefits. These insecticides are relatively insoluble in water and tend to adhere to soil particles and stream sediment. They are persistent in the environment and are easily transported to streams during irrigation or precipitation-induced erosion. In the 1970s and 1980s, uses of most of the organochlorine insecticides were cancelled because they are carcinogenic, accumulate in the food chain, and are hazardous to wildlife [*20*]. Since 1968, organochlorine insecticides that have been detected most frequently in the Yakima River Basin are total DDT (DDT and its breakdown products, DDE and DDD) and dieldrin [*21*].

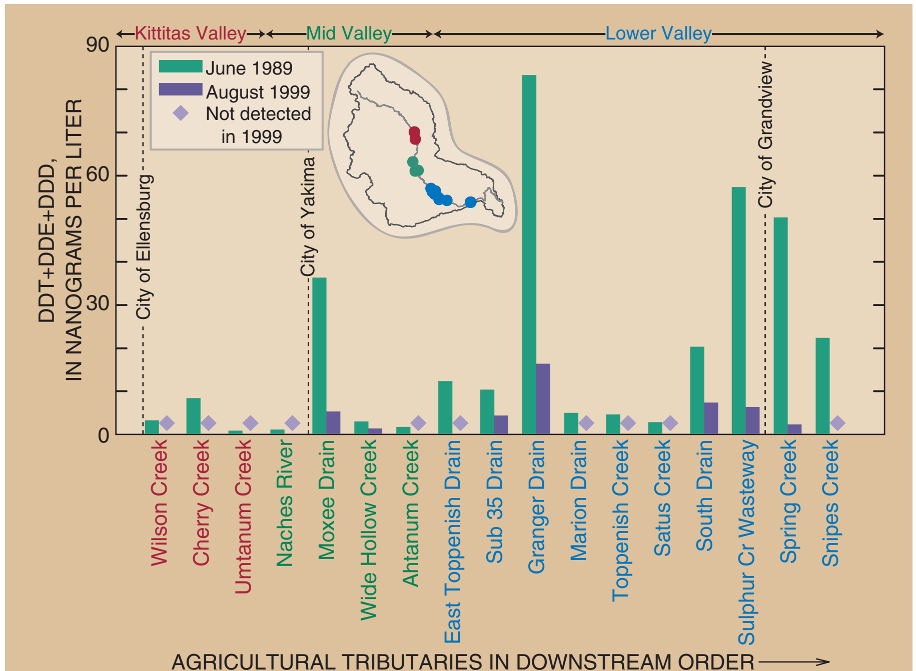


Figure 12. Concentrations of total DDT in water samples from major tributaries to the Yakima River decreased sharply between 1989 and 1999.

Concentrations of DDT in fish and surface water are decreasing

From 1988 to 1991, USGS sampling determined that DDT and several other organochlorine insecticides were distributed widely in agricultural soils, stream water, suspended sediment, and resident fish [*22*]. Concentrations of total DDT in bottom fish in the lower Yakima River in the late 1980s were among the highest in the Nation. Based on these findings, the Washington Department of Health issued a warning in 1993 stating, “people who frequently eat bottom fish caught in the Yakima River may suffer adverse health effects,” and recommended that people limit their consumption of bottom fish from the lower Yakima River to one meal per week [*22*]. More recent data collected on largescale sucker, smallmouth bass, and carp from the Yakima River at Granger and Prosser in 1996–98 showed that concentrations of total DDT had decreased to about one-half of those in 1989–90 [*23, 24*] but still exceeded the guidelines for the protection of fish-eating wildlife (200 micrograms of total DDT per kilogram of whole fish, wet weight) [*25*].

Twelve of 23 organochlorine compounds analyzed in **unfiltered-water samples** in August 1999 were detected in agricultural areas throughout the basin [*26*], with DDT, DDE, DDD, dieldrin, and heptachlor epoxide exceeding the USEPA chronic water-quality criteria for the protection of freshwater aquatic life. Many of the compounds detected in August 1999 also were detected in June 1989; however, the number of sites with detections in 1999 generally decreased by more than 50 percent.

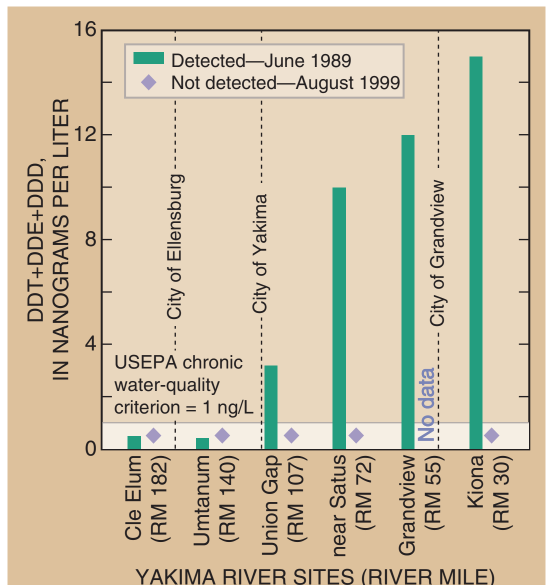


Figure 13. Although total DDT was ubiquitous in the Yakima River in 1989, it was not detected in water samples in the Yakima River in 1999.

DDT, DDE, and DDD were the most frequently detected organochlorine compounds in both June 1989 and August 1999. Most of the detections in August 1999 occurred in drains and tributaries that received agricultural runoff downstream from the city of Yakima (fig. 12). In 1989, concentrations of total DDT in the lower Yakima River commonly exceeded the USEPA chronic water-quality criterion of 1 **nanogram per liter** (ng/L) for the protection of freshwater aquatic life. In August 1999, however, total DDT was not detected at the 1-ng/L level (fig. 13). In the drains and tributaries that received agricultural runoff, concentrations generally

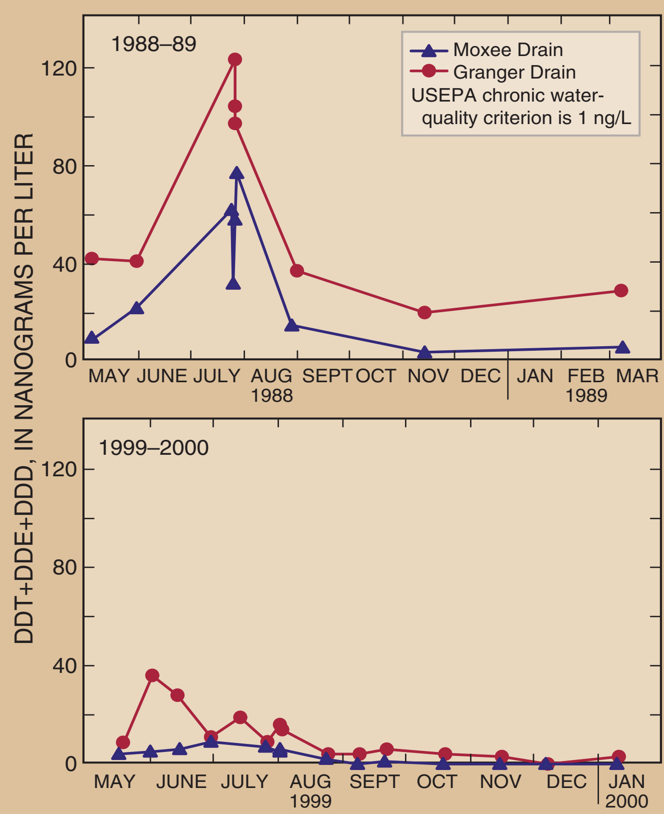


Figure 14. Concentrations of total DDT in water samples from Moxee and Granger Drains decreased sharply from 1988 to 1999 during the irrigation season, when concentrations typically are highest.

were five or more times lower in 1999 than those measured in 1989, although some concentrations still exceeded the aquatic-life criterion. In August 1999, concentrations of DDT, DDE, or DDD in unfiltered water from several of the drains and tributaries also were well above the USEPA human-health criteria for consumption of fish. In tributaries where DDT was detected in water at 1 ng/L or more, the increase in cancer risk is estimated to be at least 1 in 1,000,000 for people who consume one fillet (4 ounces of resident fish) per month from that stream [*18*].

In Granger and Moxee Drains, which were previously identified as major sources of DDT in 1989 [*21*], concentrations of total DDT and suspended sediment in 1999 continued to peak during periods of increased irrigation-induced erosion in the June–July period. Although the concentrations of total DDT in water samples in 1999–2000 were still above the USEPA chronic aquatic-life criterion, they were four or more times lower than those measured in 1988–89 (fig. 14). In the Yakima River at Kiona, concentrations of total DDT in water have decreased almost two orders of magnitude since the cancellation of DDT products in 1972 (fig. 15). Detections observed after 1985 were made possible by achieving a lower reporting level for the analysis of these compounds in unfiltered water. From May 1999 through January 2000, concentrations of total DDT in the Yakima River at Kiona were at or below the USEPA chronic aquatic-life criterion.

Best management practices reduce erosion and concentrations of DDT—an agricultural community works together to improve water quality

In the 1990s, stakeholders in the basin, including Federal, Tribal, State, and local agencies, farmers, irrigation districts, and conservation districts, began working together to control the amount of total DDT entering the river system from agricultural fields. Because DDT primarily is attached to soil particles and enters the streams during episodes of erosion, farmers began implementing BMPs to control irrigation-induced erosion. Widely implemented BMPs included less erosive irrigation practices (for example, drip and sprinkler systems), cover crops and ground cover, sediment-retention basins, and the use of PAM.

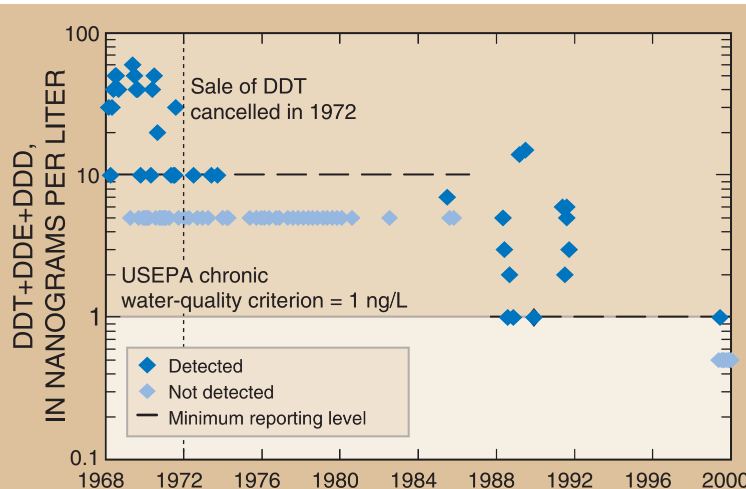


Figure 15. Concentrations of total DDT in water samples from the Yakima River at Kiona have decreased almost two orders of magnitude since the cancellation of DDT in 1972.

The reduction in concentrations of total DDT detected in the Yakima River Basin in 1999 was associated, in large part, with decreases in concentrations of suspended sediment and sorbed DDT that resulted from the agricultural community's implementation of erosion-controlling BMPs. For example, in Moxee Drain, maximum concentrations of suspended sediment decreased sharply from more than 600 mg/L in 1988–89 to about 200 mg/L in 1999–2000 (fig. 16). This decrease in suspended sediment is a consequence of the conversion of rill irrigation to less erosive drip irrigation over the last decade (fig. 17).

In Granger Drain, the amount of total DDT associated with the eroded soil particles (suspended sediment) has decreased notably over time, possibly due to (1) degradation of total DDT in soils and in bed sediment over the last decade, (2) dilution of suspended sediment with uncontaminated eroded soils, or (3) use of PAM in the flocculation and sedimentation of fine-grained, organically enriched soil particles that tend to sorb total DDT. For example, the total DDT concentration for a given concentration of suspended sediment in Granger Drain has decreased by a factor of three or more from 1988–89 to 1999–2000 (fig. 16).

The decrease in concentrations of total DDT and suspended sediment in surface water in the Lower Valley has implications for targets established by the Washington Department of Ecology for TMDLs. According to the TMDL, the target concentration of 7 mg/L of suspended sediment was established to meet the total DDT water-quality criterion of 1 ng/L [*27*]. The 1999 data, however, show that the total DDT criterion could be met when concentrations of suspended sediment are well above 7 mg/L. This finding suggests that the TMDL target for suspended sediment could be increased if the higher concentrations of suspended sediment are not a concern.

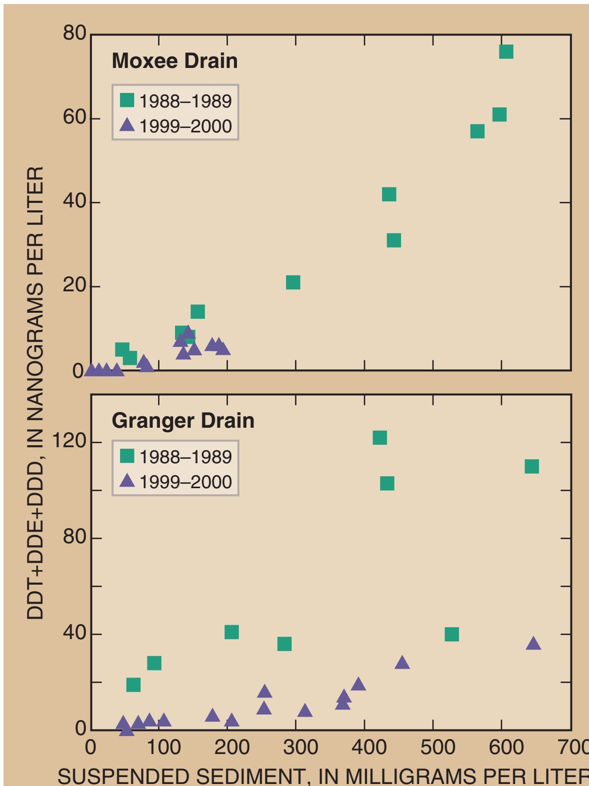


Figure 16. Since 1988–89, the relation between total DDT and suspended sediment has changed in Moxee and Granger Drains. The suspended sediment is now less contaminated with total DDT.

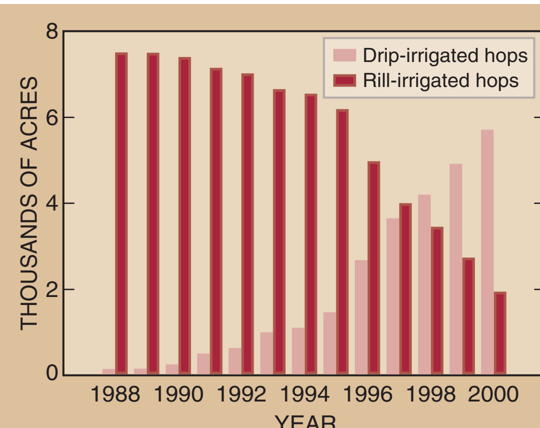
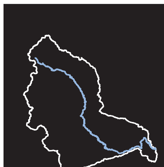


Figure 17. Conversion of rill irrigation to less-erosive drip irrigation has probably resulted, in large part, in the sharp decrease in concentrations of suspended sediment and total DDT in Moxee Drain (see figure 16).



Low levels of steroids and other organic wastewater contaminants have been detected in the Yakima River

In the first round of sampling for pharmaceuticals, hormones, steroids, personal care products, and other wastewater contaminants in U.S. streams, 8 chemicals were detected in the Yakima River downstream from intense agricultural activities [*28*].

Chemical	Use
Cholesterol	Plant/animal steroid
Coprostanol	Fecal steroid
N,N-diethyl toluamide	Insect repellent
Triclosan	Antimicrobial disinfectant
Tri(2-chloroethyl) phosphate	Fire retardant
Tri(dichloroisopropyl) phosphate	Fire retardant
Carbaryl	Insecticide
Naphthalene	Polyaromatic hydrocarbon

Concentrations of all these compounds were low and were comparable to national data. The first five chemicals listed above were among the most frequently detected in the Nation. Except for carbaryl and naphthalene, which did not exceed drinking-water health advisories, aquatic-life guidelines or drinking-water standards have not been established for the chemicals listed above .

Currently used pesticides were routinely detected

Pesticides were detected in 98 percent or more of the samples from streams and drains in the Yakima River Basin. Seventy-six pesticide compounds were detected—38 herbicides, 17 insecticides, 15 **breakdown products**, and 6 others. The compounds selected for analysis represent the 176 most heavily applied compounds nationally. Compounds detected in the Yakima River Basin represent 43 percent of this national list. Agricultural crops receive the largest application of pesticides in the Yakima River Basin, but several compounds detected also are used for weed and pest control in urban areas and along roadsides, fences, and canals.

Insecticides were detected frequently but at low concentrations

Insecticides were detected more frequently in agricultural drains and streams in the Yakima River Basin than in other agricultural areas across the Nation (table 2). For example, insecticides were detected more than twice as often in Moxee and Granger Drains than in other agricultural streams sampled nationally, and about one-third more often in the Yakima River at Kiona than in other major rivers. The high frequency of detection of insecticides in the Yakima River Basin is due, in large part, to the heavy use of insecticides, such as azinphos-methyl, in apple, pear, cherry, and other fruit orchards.

Although the frequency of detection of insecticides in the Yakima River Basin differed from that found in streams sampled nationally, the concentrations of insecticides in the agricultural streams and drains of the basin (as reflected by a summed cumulative concentration of all compounds) are not notably different than those in other parts of the Nation. For example, a cumulative concentration of insecticides greater than 100 ng/L was reported in only 12 percent of the samples collected in Moxee and Granger Drains, which is slightly higher than in other agricultural streams sampled nationally (table 2). No concentrations exceeded 100 ng/L in the Yakima River at Kiona, which is slightly lower than other major rivers sampled nationally (7 percent).

In contrast to insecticides, the frequency of detection of herbicides in streams and drains draining agricultural areas in the Yakima River Basin is no greater than that in other agricultural areas sampled nationally. Data collected within the basin and across the Nation indicate that herbicides were detected in more than 90 percent of the samples. Differences are noted, however, in the concentrations of herbicides. Specifically, cumulative concentrations of herbicides are lower in agricultural streams of the Yakima River Basin than in those sampled nationally; only 12 percent of the concentrations exceeded 100 ng/L in Moxee and Granger Drains and in the Yakima River at Kiona, whereas concentrations in 70 percent of samples collected nationally from other agricultural streams and in 52 percent of the samples collected from major rivers exceeded 100 ng/L.

Common Screening Level

Because laboratory reporting limits can vary among pesticides, a common screening level of 21 ng/L was adopted. This common level allows meaningful comparisons among pesticides with varying reporting limits. Without screening, pesticides with lower reporting limits could have higher detection frequencies than those with higher reporting limits.

2,4-D, terbacil, and azinphos-methyl were the most frequently detected pesticides

Pesticides were detected more frequently, and generally at higher concentrations, in the agricultural tributaries than in the Yakima River (fig. 18). Screened detection frequencies (see above) in the tributaries decreased in the order: 2,4-D, terbacil, azinphos-methyl, atrazine, carbaryl, and deethylatrazine. In contrast, many fewer compounds were detected above the common screening level in the Yakima River. The two most frequently detected pesticides in the tributaries also were the most frequently detected pesticides in the Yakima River.

Azinphos-methyl (Guthion)

An organophosphate insecticide used extensively on fruit orchards in the Yakima River Basin. It is highly toxic to fish and benthic invertebrates.

Table 2. Insecticides were detected more frequently in the Yakima River Basin than in other agricultural areas in the Nation, but at comparably lower concentrations. [1,000 nanograms per liter (ng/L) = 1 microgram per liter (µg/L); %, percent]

		Insecticides				Herbicides			
		Agricultural streams		Mixed land-use streams		Agricultural streams		Mixed land-use streams	
		Moxee and Granger Drains	National average	Yakima River at Kiona	National average	Moxee and Granger Drains	National average	Yakima River at Kiona	National average
Frequency of detection		80%	37%	71%	53%	91%	96%	90%	96%
Frequency of cumulative concentrations exceeding:	**10 ng/L**	59	25	54	38	86	93	90	90
	100 ng/L	12	7	0	7	12	70	12	52
	1,000 ng/L	1	1	0	1	0	20	0	9

SCREENED DETECTION FREQUENCY		
Compound	Yakima River	Tributaries
AZINPHOS-METHYL	0%	47%
CARBARYL	17	29
2,4-D	67	59
TERBACIL	33	47
2,4-METHYL ESTER	17	18
ATRAZINE	0	41
DEETHYL ATRAZINE	0	24
DIURON	0	23
BENTAZON	0	12
SIMAZINE	0	6

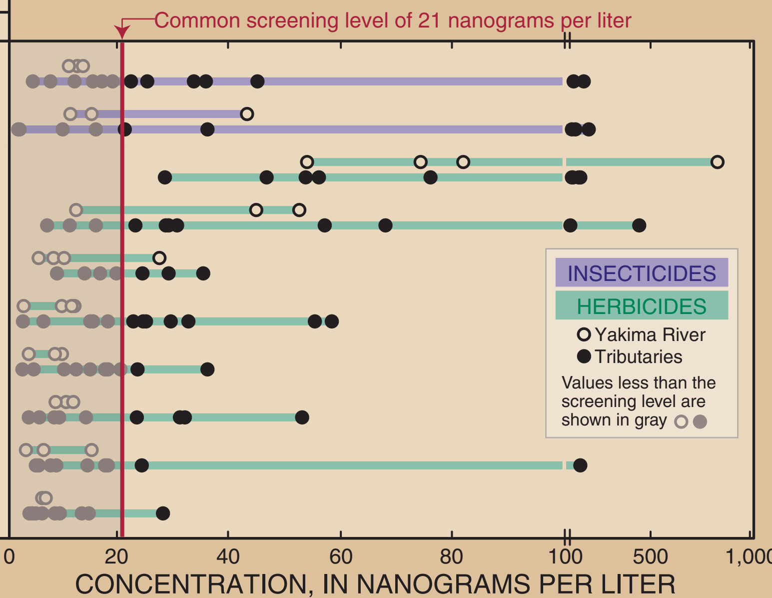


Figure 18. Herbicides were detected frequently in agricultural tributaries while oftentimes undetected in the Yakima River, when based on a common screening level of 21 nanograms per liter.

Pesticides were detected year-round

Pesticides generally were detected more frequently and at higher concentrations during the irrigation season than during the nonirrigation season (figs. 19 and 20). This is because (1) most pesticides are applied during the irrigation season and (2) water is available to transport the chemicals from the fields and into streams, drains, and the shallow ground water. Insecticides were rarely detected during the nonirrigation season, whereas some herbicides were detected year-round, although concentrations were lower during the nonirrigation season. Many herbicides are relatively water soluble to facilitate their uptake by the target weeds. This solubility, however, also enhances their movement in the shallow ground-water system, which is the primary source of water in most agricultural drains during the nonirrigation season. For Moxee and Granger Drains (fig. 20) and the Yakima River at Kiona, the herbicide atrazine and its breakdown product, deethylatrazine, were the most commonly detected pesticide compounds during the nonirrigation season [*29*].

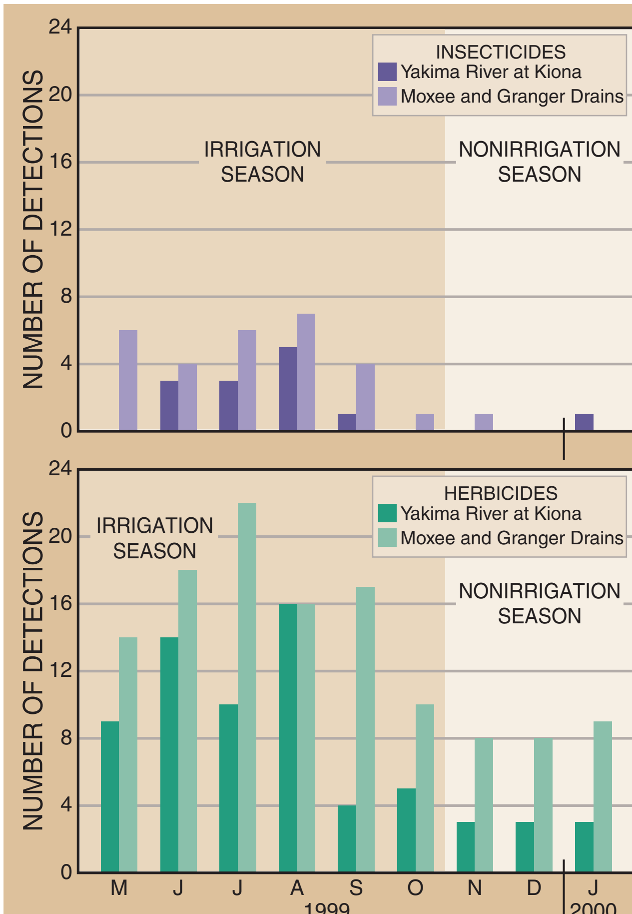


Figure 19. Insecticides were most commonly detected during the irrigation season, whereas herbicides were detected year-round in the Yakima River at Kiona and Moxee and Granger Drains.

Concentrations of azinphos-methyl frequently exceeded the aquatic-life guideline

Concentrations of azinphos-methyl in Moxee and Granger Drains (fig. 20) and the Yakima River at Kiona routinely exceeded the USEPA freshwater chronic-toxicity criterion for the protection of aquatic life [*18*]. Likewise, most samples collected from the small agricultural watersheds during the 2000 irrigation season (see p. 27) exceeded the azinphos-methyl criterion. In Granger Drain, the insecticides carbaryl and diazinon exceeded their aquatic-life chronic-toxicity guidelines only infrequently [*30, 31*]. In the summer of 2000, however, concentrations of carbaryl in three small agricultural watersheds in the Granger subbasin exceeded the aquatic-life criterion, and one detection of the insecticide malathion exceeded its criterion [*18*]. One detection of the insecticide disulfoton exceeded a nonenforceable human-health advisory for drinking water [*7*].

None of the herbicide detections in Moxee and Granger Drains or in the Yakima River at Kiona exceeded aquatic-life chronic-toxicity criteria. One detection of the herbicide metribuzin, however, exceeded its guideline [*30*] in the small agricultural watersheds. Even these occasional exceedances may affect the aquatic biota. In addition, most human-health and aquatic-life guidelines are based on single chemical toxicities, while chemicals in surface water often occur in mixtures. The potentially adverse effects of exposure to mixtures of pesticides on humans and aquatic biota is not fully understood and may be underestimated (see box below).

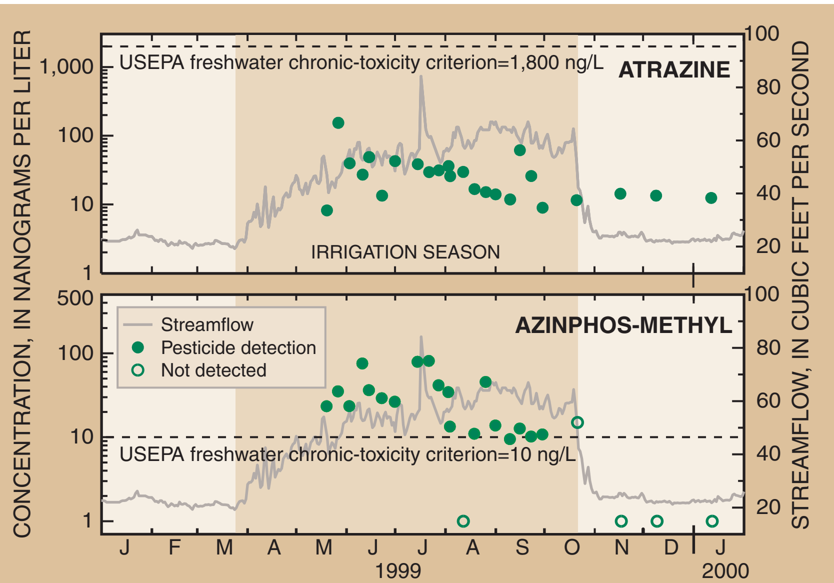
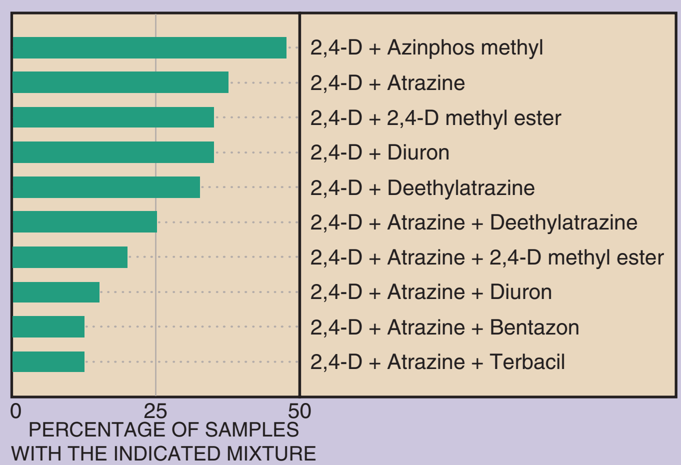


Figure 20. Because soluble pesticides like atrazine can percolate to the ground water, they are detected not only during the irrigation season when they are applied, but also during the nonirrigation season when ground water discharges to Granger Drain. In contrast, azinphos-methyl is detected only during the irrigation season, but almost always at levels exceeding the aquatic-life criterion.

Mixtures of pesticides and pesticide breakdown products occurred at most sites

Ninety-one percent of the samples collected from the small agricultural watersheds contained at least two pesticides or pesticide breakdown products. The median number of chemicals in a mixture was 8, and the maximum was 26. The herbicide 2,4-D occurred most often in the mixtures. This was due to its widespread use not only on agricultural land, but also along roads, irrigation canals, and agricultural drains to control weeds. Azinphos-methyl, the most heavily applied pesticide, and atrazine, one of the most mobile in water, also occurred often in the mixtures.



The most frequently occurring mixtures of pesticides at sites sampled in July 2000 at concentrations greater than at the 21 ng/L screening level.

Research to understand the effect of mixtures of pesticides on human health and aquatic life is in its early stages [*32, 33*]. For some pesticide mixtures, laboratory studies have shown that test organisms respond to each compound in the mix as if it were exposed to a solution containing just that compound (additive). For other mixtures, test organisms respond as if they were exposed to lower concentrations of both compounds; that is, the mixture is less toxic than the individual compounds (antagonistic or protective). The opposite effect also has been observed—mixtures of some pesticides are more toxic than their individual components (synergistic) [*34*].

The USEPA has taken the initial steps to regulate mixtures of pesticides by conducting exposure and risk assessments for groups of chemicals having a common mode of toxicity. The first of these assessments has been completed for the organophosphate insecticides, which includes azinphos-methyl and diazinon [*35*]. These initial cumulative risk assessments only address human exposure in foods. Acute and chronic aquatic-life guidelines are still based on a single chemical exposure.

Cropping patterns and river management affect pesticide detections

Regional differences in cropping patterns in the Yakima River Basin are reflected in the occurrence of pesticides in water samples. An August 1999 sampling along the Yakima River and its tributary mouths showed more pesticide detections in the Lower Valley than in the Kittitas or Mid Valleys (fig. 21). The same pattern was evident in data collected in July 2000 from the small agricultural watersheds. These differences reflect regional cropping patterns. As an example, in the Kittitas Valley, 89 percent of the irrigated agricultural land draining to the sampled sites was hay or pasture. Samples collected from these sites in July 2000 contained 19 unique pesticides or pesticide breakdown products, with a median of 8 compounds detected per site (fig. 22). In comparison, at sites near Sunnyside in the Lower Valley, six different crops made up 90 percent of the irrigated agricultural land. Samples collected from these sites contained 56 pesticide or pesticide breakdown products, with a median of 16 detections per site.

In addition to differences in crop types among the Kittitas, Mid, and Lower Valleys, there are differences in water volume in the Yakima River. For example, there is less water in the Yakima River in the Lower Valley. Three large irrigation canals divert water from the Yakima River downstream from the Kittitas Valley; however, there is only one significant natural inflow to the river along this reach (the Naches River). Less water in the river equates to less water available to dilute contaminants in agricultural return flow to the river. In August 1999, the flow of the Yakima River where it left the Kittitas Valley was 2,700 cubic feet per second (ft^3/s), of which approximately 300–350 ft^3/s was from agricultural drains and streams. Just downstream from where the river leaves the Mid Valley, the flow in the Yakima River was about 700 ft^3/s. At Kiona, the flow in the Yakima had increased to about 2,000 ft^3/s. Of the 1,300 ft^3/s that the river gained between the Mid Valley and Kiona, inputs from agricultural streams and drains can account for approximately 900 ft^3/s [*7*]. The reduced flow, combined with an increase in the agricultural return flows, resulted in an increase in the number of pesticides detected in the Yakima River. For example, the few detections in the sample collected from the Yakima River between Toppenish and Satus Creeks contrasts sharply

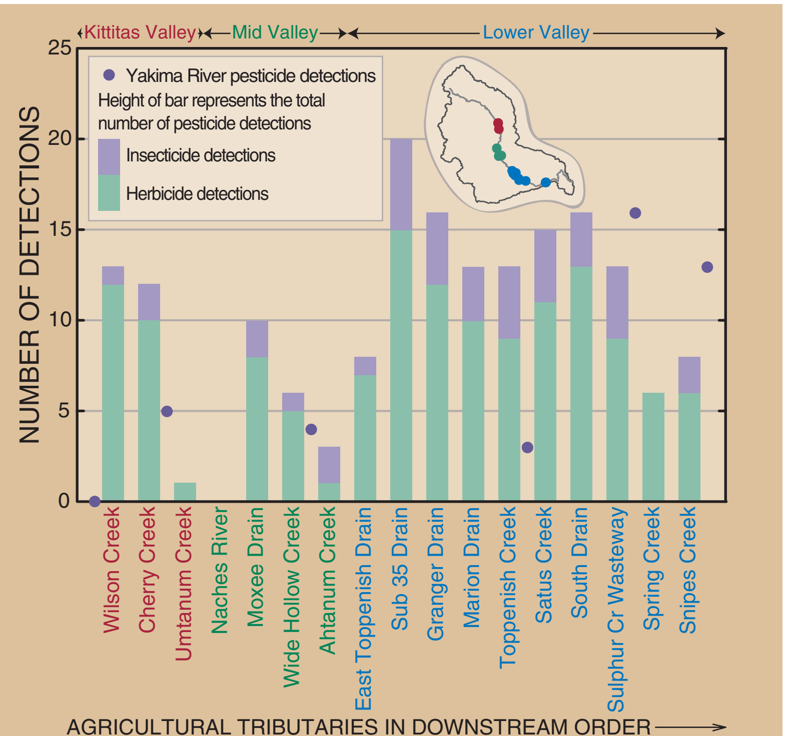


Figure 21. The number of pesticides detected in the Yakima River and its major agricultural tributaries increased from the Kittitas Valley to the Lower Valley due to an increase in the crop diversity and a decrease in the volume of water in the Yakima River.

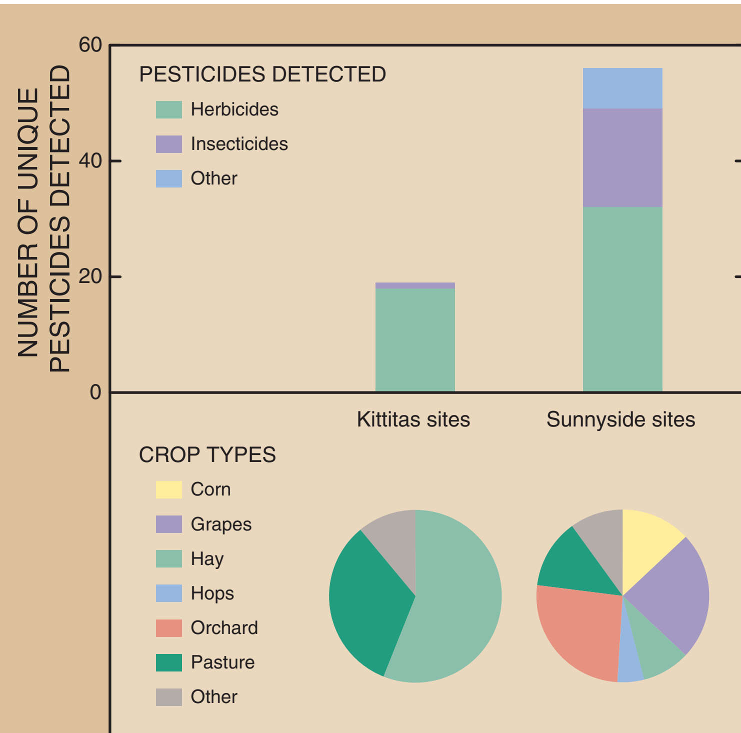


Figure 22. Many more pesticides were detected in the Lower Valley near Sunnyside than in the Kittitas Valley. This difference can be explained by the high diversity of crops grown in the Lower Valley compared with the Kittitas Valley, which is dominated by hay and pasture.

with the large number of detections in the two samples collected downstream from Sulphur Creek Wasteway (fig. 21).

Pesticide loading to the Yakima River was highest in the Lower Valley

To evaluate relative contributions of pesticides to the Yakima River, the **load** or mass of pesticide issuing from each tributary was calculated (fig. 23). Loads were used in the calculations because small tributaries with low flows and high concentrations can contribute as much pesticide mass as large tributaries with high flows and small concentrations. Pesticide loads were relatively small in the upper reaches of the Yakima River and throughout the Kittitas Valley [*29*], where hay, alfalfa, and cattle dominate the agricultural landscape. In the Lower Valley, however, where agricultural return flows from orchards, vineyards, and fields of corn, hops, grains, and other crops influence water quality, the loads of atrazine, terbacil, azinphos-methyl, and carbaryl from agricultural tributaries were notable (fig. 23). The chemical signature of each tributary contribution varied. For example, East Toppenish Drain contributed a significant portion of the terbacil load to the reach below the city of Yakima, whereas Toppenish Creek was a significant contributor of carbaryl.

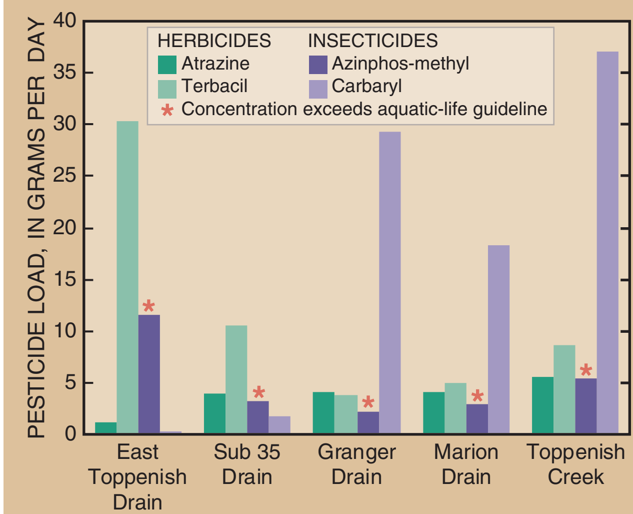


Figure 23. The composition of pesticide loads discharged from agricultural tributaries in the Lower Valley varied greatly.

Pesticide mobility is highly dependent on its tendency to adhere to soil particles

Many factors affect the mobility of pesticides in the environment, including the manner, amount, frequency, and timing of application; the method of irrigation; and the chemical properties of the pesticide. Other important factors are associated with landscape characteristics, such as soil properties, slope, and the proximity to flowing water. Two key factors help to explain pesticide occurrence in small agricultural watersheds in the Yakima River Basin: (1) the tendency of the pesticide to adhere to soil (as reflected by the organic-carbon partitioning coefficient, or K_{oc}; see box on page 22) and (2) the method of irrigation (Hank Johnson and Dan Wise, U.S. Geological Survey, unpub. data, 2004).

For many pesticides, there was little correlation between the amount applied and the frequency of detection in streams and drains (fig. 24). For example, the two most frequently detected pesticides, 2,4-D and azinphos-methyl, differed markedly in the amount of active ingredient applied annually. Approximately nine times more azinphos-methyl was applied than 2,4-D, and yet it was detected about half as often. Similarly, the herbicides bentazon, dicamba, and terbacil ranked 35th, 33d, and 28th in use, respectively, but were the 7th, 8th, and 9th most frequently detected pesticides. The insecticides chlorpyrifos and endosulfan were the 2d and 7th most heavily applied pesticides but were rarely detected. A general pattern emerges when the K_{oc} values of these pesticides are compared (fig. 24): specifically, pesticides that strongly adhere to soil (high K_{oc} value) were detected at a lower frequency than expected for their application amounts, while pesticides that weakly adhere to soil (low K_{oc} value) were detected at a higher frequency than expected for their application amounts.

The method of irrigation affects the movement of high-K_{oc} pesticides more than low-K_{oc} pesticides. For example, in watersheds with a large percentage of

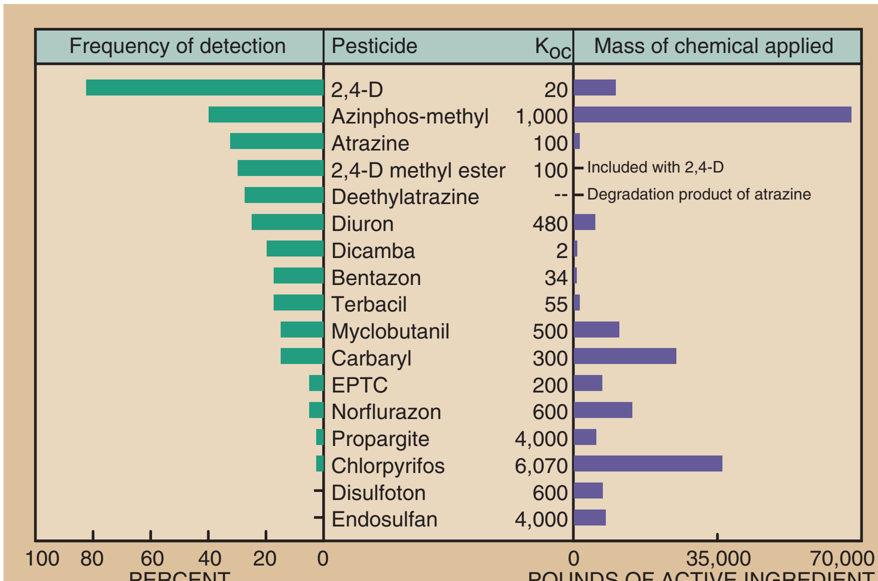
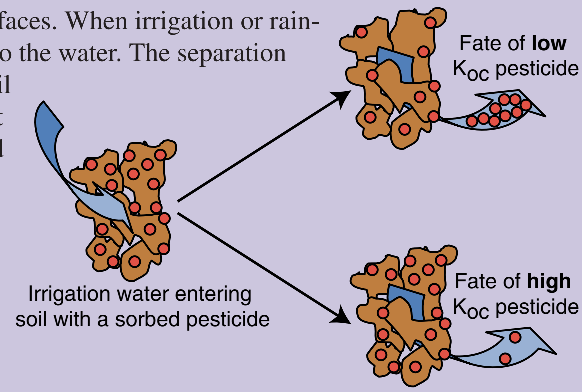


Figure 24. Pesticides in irrigation runoff were not always detected in proportion to the quantity applied to agricultural land. Other factors, including the degree to which certain pesticides adhere to soil, affected how often pesticides were detected in agricultural runoff (see explanation of K_{oc} in box on page 22).

Organic-carbon partitioning coefficient, K_{oc}

When a pesticide is first applied, most of it attaches to soil or plant surfaces. When irrigation or rainwater reaches a treated field, a portion of the pesticide will dissolve into the water. The separation of a pesticide into two phases—dissolved in the water and bound to soil and plant material—is called partitioning. The amount of pesticide that dissolves in the water is controlled by a property of the pesticide called its organic-carbon partitioning coefficient, or K_{oc}. A pesticide with a large K_{oc} value will remain largely bound to the soil or plant material and only a small amount will dissolve in the water (see figure at right). Conversely, a pesticide with a small K_{oc} value will more readily detach from the soil or plant material and dissolve in the water. K_{oc} values for currently used pesticides range from less than 10 (dicamba, clopyralid) to more than 100,000 (bifenthrin, oxyfluorfen).



rill-irrigated fields, the **yield** (see box below) of high-K_{oc} pesticides was larger than in watersheds with a small percentage of rill-irrigated fields (fig. 25). Pesticides with high K_{oc} values tend to remain bound to the soil when irrigation water is applied. Downward migration through the soil is slow and provides the opportunity for a variety of processes to break down the pesticide. Therefore, the primary mechanism for the movement of these pesticides off the field is through the movement of the soil itself. In contrast, the yield of low-K_{oc} pesticides was similar for all watersheds, regardless of irrigation method. Low-K_{oc} pesticides do not strongly partition into the soil. They are easily transported off the field, either dissolved in rill tailwater or downward through the soil and into the shallow ground-water system where they enter the streams and drains as base flow.

Reducing soil erosion and irrigation runoff are two effective means of minimizing the transport of high-K_{oc} pesticides. Many BMPs designed to control erosion and runoff are commonly used in the Yakima River Basin, including irrigation-system conversions, settling ponds at the bottom of rill-irrigated fields, and the use of PAM in rill furrows and tail ditches. Continued implementation and proper operation of these and similar BMPs should continue to minimize the movement of high-K_{oc} compounds, including many of the most toxic insecticides such as azinphos-methyl, chlorpyrifos, and diazinon. Additional considerations are needed to control the transport of low-K_{oc} pesticides. For these compounds, it is necessary to minimize both the surface and subsurface movement of water from the field. The use of soil-moisture sensors in conjunction with sprinkler or drip irrigation may help to reduce the transport of low-K_{oc} pesticides to drains and streams.

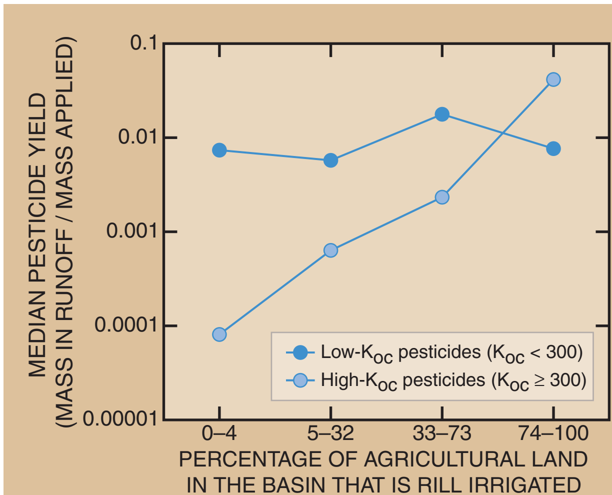
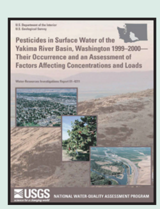


Figure 25. The yield of high-K_{oc} (more sorptive) pesticides increased in proportion to the amount of rill-irrigated farmland, whereas the yield of low-K_{oc} (less sorptive) pesticides was relatively constant. Generally, yields of low-K_{oc} pesticides were higher than yields of high-K_{oc} pesticides.

Pesticide Yield

The yield of a pesticide describes how much of an applied pesticide reaches a sampled water body. The yield value is useful as a descriptive term to compare the relative mobility of one pesticide with another; however, it should not be used as a measurement of the actual amount of pesticide lost from an applied area. The yield is defined as the mass of a pesticide detected in the drain or stream water sample divided by the mass of the pesticide that was applied in that basin. Yields were calculated for each pesticide detected during the 2000 growing season (Hank Johnson and Dan Wise, U.S. Geological Survey, unpub. data, 2004).



Detailed information on pesticides and breakdown products in surface water in the Yakima River Basin can be found in the following report:

Pesticides in surface water of the Yakima River Basin, Washington 1999–2000—Their occurrence and an assessment of factors affecting concentrations and loads, by J.C. Ebbert and S.S. Embrey: U.S. Geological Survey Water-Resources Investigations Report 01–4211 at **http://pubs.water.usgs.gov/wri014211/**

Aquatic communities are affected by poor water-quality and habitat conditions in intensely agricultural areas

The composition of algae and **benthic invertebrates** in streams and drains in the Yakima River Basin reflects the water-quality and habitat conditions in which they are found. In an effort to characterize the overall conditions at a site and allow comparisons among sites, a stream condition index (SCI) was developed based on water-quality and habitat conditions at each site. In general, streams and drains with higher SCI scores (good-condition sites) support more diverse and complex aquatic communities with fewer pollution-**tolerant species**. In the Yakima River Basin, the good-condition sites are associated with little or no agriculture. At sites with lower SCI scores (poor-condition sites), however, benthic-invertebrate **assemblages** are less diverse and increasingly composed of pollution-tolerant species, and algal assemblages are increasingly dominated by species indicative of high concentrations of nutrients. The poor-condition sites in the Yakima River Basin are associated with intensive agriculture.

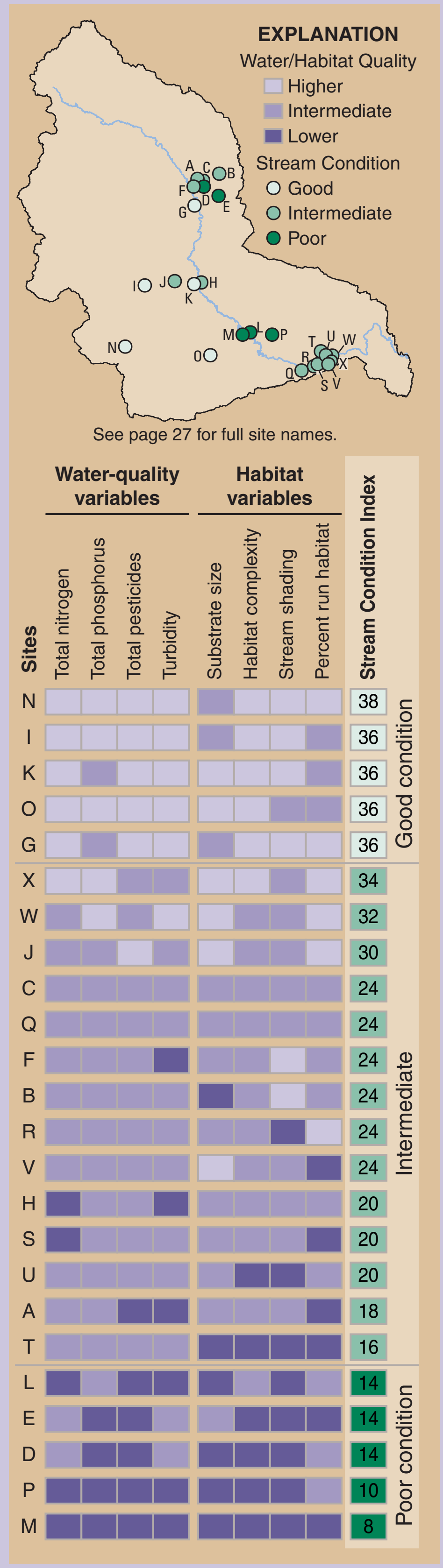
Agricultural activities affect stream-water quality and habitat

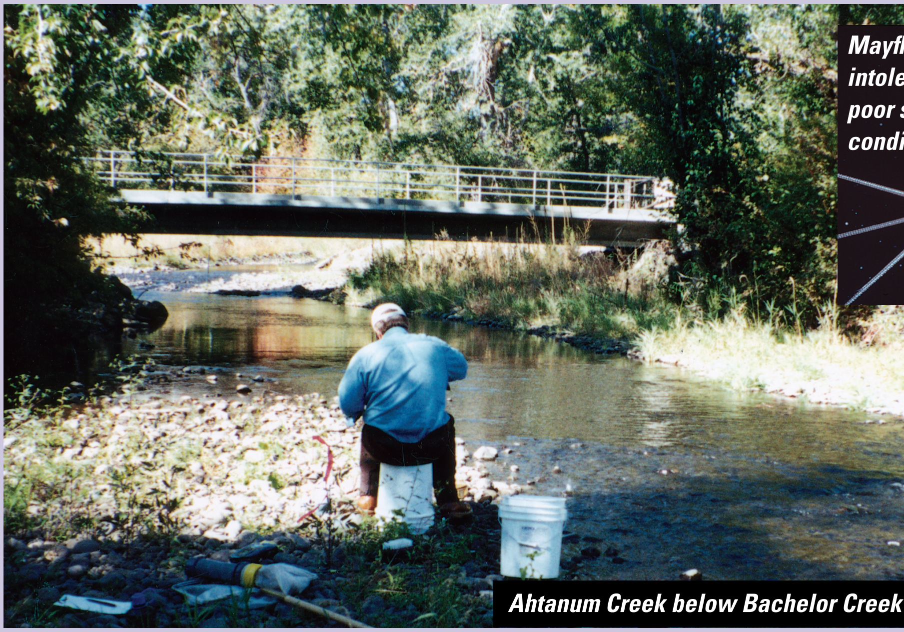
Agricultural activities in the Yakima River Basin have the potential to degrade water quality through the inputs of sediment, nutrients, and pesticides to streams. Additionally, habitat conditions in streams draining agricultural land may not be of sufficient quality to support diverse aquatic communities. Features such as woody debris, boulders, and side channels provide important habitats for aquatic life and help sustain productive aquatic ecosystems. These features commonly are lacking in constructed agricultural drains and stream channels modified to receive agricultural return flow. The low-quality habitat in modified channels does not provide adequate conditions for diverse aquatic assemblages to exist and is one of the major factors affecting aquatic communities in streams [*36*].

Natural-channel streams in the Yakima River Basin usually provide a mix of habitat types, such as **riffles** and pools that are critical for aquatic life. In contrast, instream habitat in agricultural drains and modified streams often lacks complexity and is often dominated by relatively deep and slow-moving **runs**. Agriculturally affected streams and drains also exhibit a high degree of substrate embeddedness (indicative of the degree of streambed siltation) and are sheltered by little riparian vegetation. Stream shading provided by riparian vegetation helps maintain lower water temperatures and also helps to stabilize stream banks. Riparian buffer zones can intercept sediment and other agricultural pollutants before they reach streams. When buffers are not present, erosion may result in stream sedimentation and negative effects to aquatic communities.

Stream Condition Index (SCI)

A stream condition index (SCI) was developed to characterize the overall water-quality and habitat conditions at a site. The SCI provides an overall measure of stream quality by using variables important for the health of aquatic organisms. The SCI includes four measures of water quality—turbidity and the concentrations of total nitrogen, total phosphorus, and total pesticides—and four measures of habitat quality—substrate size, habitat complexity, stream shading, and the percentage of run habitat (see p. 28 for details about calculating SCI scores). Though the five streams with poor stream condition are associated with intensive agriculture, there is no distinct geographic pattern—two sites are in the Kittitas Valley and three are in the Sulphur and Granger subbasins. All sites with good stream condition, however, are associated with little or no agriculture and are located on the west side of the basin.





Ahtanum Creek below Bachelor Creek

Mayflies are intolerant of poor stream conditions

Photograph by Howell Daly, North American Benthological Society

Good Habitat Conditions

- Diversity of habitat types—riffles, runs, and pools
- Good stream shading (dense riparian canopy)
- Variety of substrate sizes with minimal fine sediment

Midges are tolerant of poor stream conditions

Photograph by Dave Penrose, North American Benthological Society

JD 27.5 at VanBelle Road

Poor Habitat Conditions

- Low habitat complexity—dominated by runs
- No stream shading (lack of riparian canopy)
- No coarse substrates—mostly silt-sized sediments

Algal assemblages reflect nutrient availability in streams and drains

Algal **biomass** (as indicated by the amount of chlorophyll *a* in algae attached to stream rocks) in the Yakima River Basin was not especially high, with most sites having values less than 25 milligrams per square meter (mg/m^2). Nevertheless, there was a notable difference in biomass—good-condition sites had biomass values five times lower than those in intermediate- or poor-condition sites. The expected low biomass in the forested streams is due to the relatively low availability of nutrients and(or) light. In contrast, algal biomass in the agriculturally affected streams and drains was lower than expected. Here, biomass may be limited by light from high turbidity, by sedimentation that smothers suitable substrate where algae may attach, or by herbicides that interfere with algal photosynthesis. In the Yakima River Basin, only Moxee and Granger Drains had biomass values (180 and 210 mg/m^2, respectively) exceeding nuisance conditions (100–150 mg/m^2 [*37, 38*]). High algal biomass at these sites may be due to the greater availability of nutrients and(or) sunlight (from poor stream shading). Another possibility is that insecticides may be reducing the density of benthic-invertebrate scrapers that would normally eat the algae. Although insecticide concentrations in Moxee and Granger Drains were relatively high and may have reduced the insect grazer population, variable streamflows or poor habitat also may have negatively affected benthic invertebrates in these drains, thereby indirectly increasing algal biomass.

Algal species composition in Yakima River Basin streams and drains was determined in part by the availability of nutrients, especially nitrogen. During this and the previous NAWQA study [*39*], the dominant types of algae found were those that prefer or require high concentrations of nutrients and alkaline conditions (pH greater than 7). In contrast, algae indicative of low or moderate nitrogen concentrations were mostly restricted to sites with high SCI scores (fig. 26), where the lowest nitrogen concentrations occurred. Here, the primary algal types were blue-green algae, including *Nostoc*, and diatoms in the family Epithemiaceae, which are able to fix their own nitrogen. Nitrogen-fixing algae were notably absent, however, in nearly all of the agriculturally affected streams and drains. At these sites, higher concentrations of nitrogen create conditions favorable for other types of algae, especially eutrophic (high nutrient indicating) diatoms and high-biomass forms, such as *Cladophora*, a filamentous green algae.

Benthic-invertebrate assemblages respond negatively to poor stream conditions in agricultural areas

Benthic invertebrates are good indicators of overall stream conditions, both water-quality and habitat conditions, due to the large number of organisms with widely diverse environmental requirements [*40*]. Sensitive or **intolerant** benthic invertebrates, such as EPT insects (see box below), generally live in streams with cool, clean water and diverse habitats. These organisms are usually found at sites with higher SCI scores. In the Yakima River Basin, average total benthic invertebrates were more abundant at sites with high SCI scores than at sites with low SCI scores (fig. 27).

When just EPT insects are considered, the average abundance was 12 times higher at the sites with high SCI scores than at the sites with low SCI scores (fig. 27). EPT insects, calculated as a percentage of each site total, also showed a general increase as the SCI scores increased (fig. 28). Most sites with SCI scores above 28 had twice the percent EPT abundance (greater than 70 percent) of sites with SCI scores below 18 (less than 35 percent).

EPT Insects

Insects in the Orders **E**phemeroptera (mayflies), **P**lecoptera (stoneflies), and **T**richoptera (caddisflies)—EPT insects—are generally considered intolerant of poor habitat or water-quality conditions.

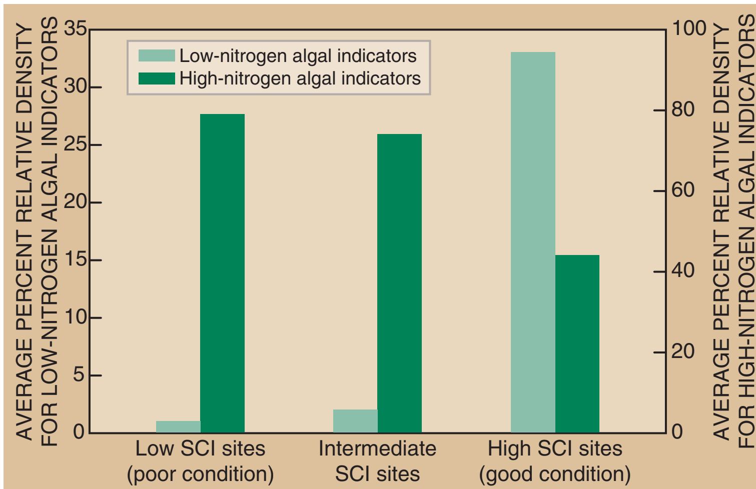


Figure 26. As the Stream Condition Index (SCI) scores increased, low-nitrogen algal indicators also increased, while high-nitrogen algal indicators decreased.

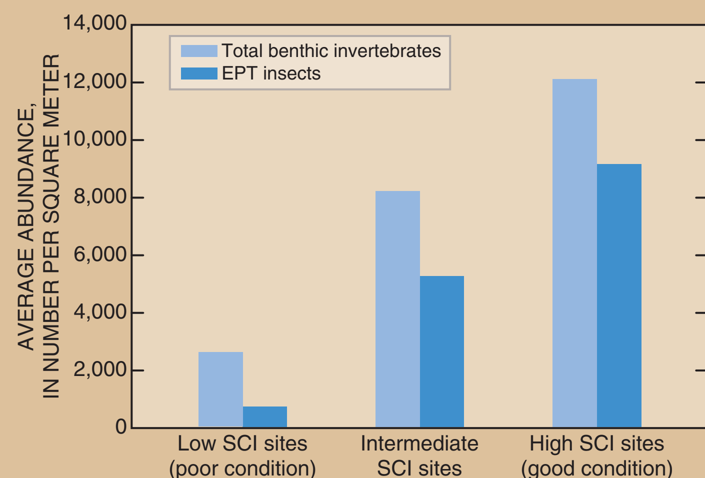


Figure 27. As the Stream Condition Index (SCI) scores increased, the average abundance of benthic invertebrates and EPT insects increased.

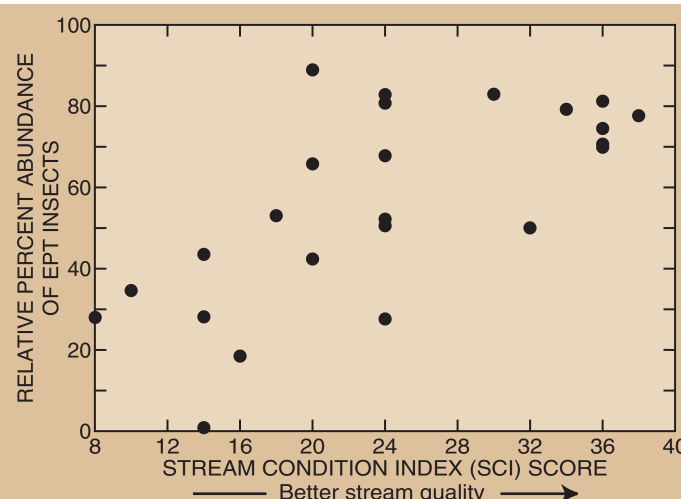


Figure 28. Relative abundance of EPT insects increased as SCI scores increased.

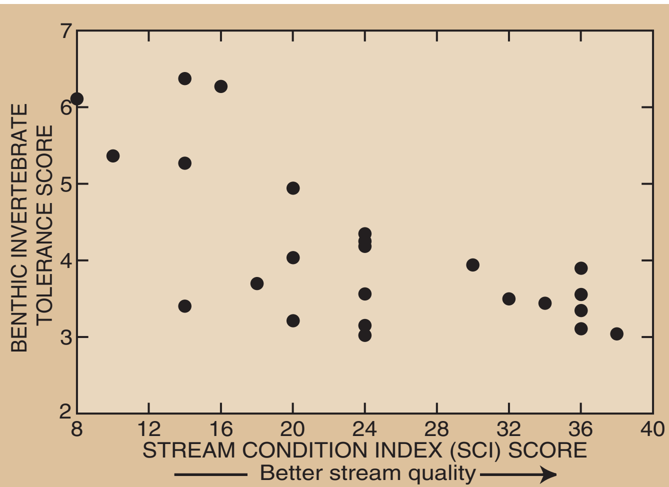


Figure 29. Tolerant benthic invertebrates decreased as SCI scores increased.

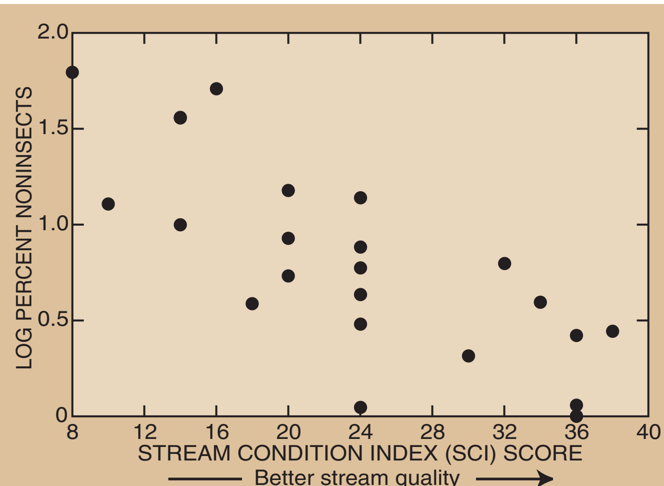


Figure 30. Proportion of noninsects was highest at sites with low SCI scores.

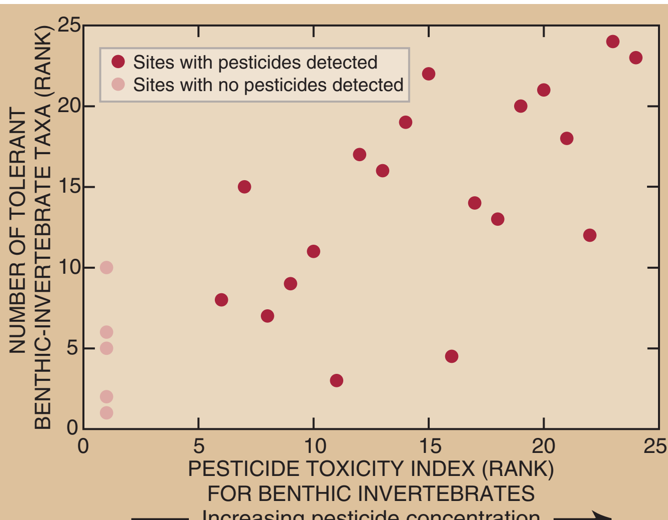


Figure 31. The number of tolerant taxa increased as the Pesticide Toxicity Index (PTI) scores increased. A high PTI rank does not necessarily mean the water was toxic to the benthic invertebrates.

In contrast to the mostly intolerant EPT insects, tolerant organisms can thrive in streams with varying combinations of high water temperatures; high amounts of sediment, nutrients, and pesticides; and simplified or poor habitat conditions. These tolerant benthic invertebrates, such as Dipterans (flies), oligochaetes (worms), and amphipods (scuds), are usually found in higher numbers at poor-condition sites (low SCI scores). This was indicated by a general decrease in the score of tolerant benthic invertebrates (based upon the USEPA tolerance value weighted by taxon abundance) as the SCI scores increased (fig. 29). The proportion of noninsects (primarily oligochaetes and amphipods) also decreased as the SCI scores increased (fig. 30).

Benthic invertebrates can be classified into functional feeding groups based on how they obtain their food. A stream with good biological integrity generally has a diverse assemblage of feeding groups, not dominated by a few types. Scrapers are a functional feeding group of insects that graze algae and other microorganisms from rocks and plant surfaces. They are a vital link between the primary producers (algae) and higher trophic levels (fish) in stream food webs. The average scraper abundance among sites with high SCI scores (good water quality and habitat) was about 2,500 organisms/m^2, while the average scraper abundance among sites with a low SCI was less than 600 organisms/m^2.

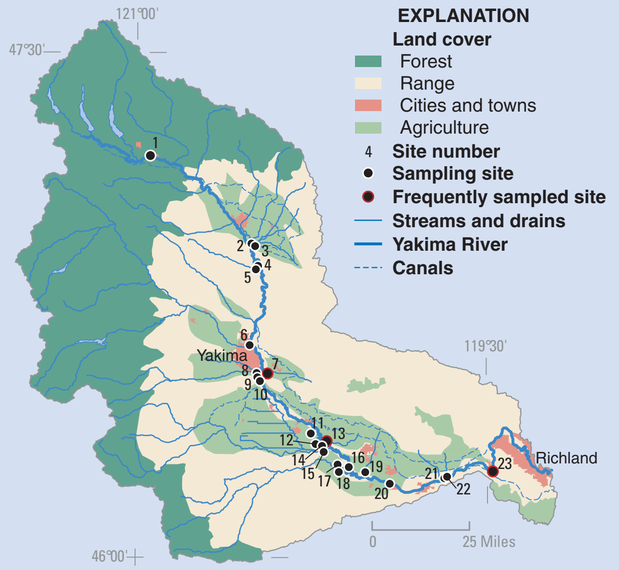
As previously discussed, benthic-invertebrate assemblages are affected by both water-quality and habitat conditions in streams, and it is difficult to isolate the effects of multiple factors. One of the factors that may affect aquatic life in streams is pesticides. Pesticides were commonly detected in streams and drains throughout the basin, often at concentrations exceeding the chronic aquatic-life criteria for one or more pesticides. To assess the relative toxicity of the waters in each stream or drain sampled, a pesticide toxicity index (PTI) was applied [*41*]. Although the PTI does not verify whether water in a sample is toxic, its values can be used to rank or compare the relative toxicity of samples. In general, sites where insecticides were found had higher PTI scores compared to sites where only herbicides were detected because insecticides are more toxic to benthic invertebrates than herbicides. Furthermore, as the PTI scores increased, the number of tolerant taxa increased (fig. 31). The higher number of tolerant taxa at these sites, however, may also be related to other factors, such as poor habitat quality.

Study-Unit Design

Water Quality in the Yakima River and Major Agricultural Tributaries*

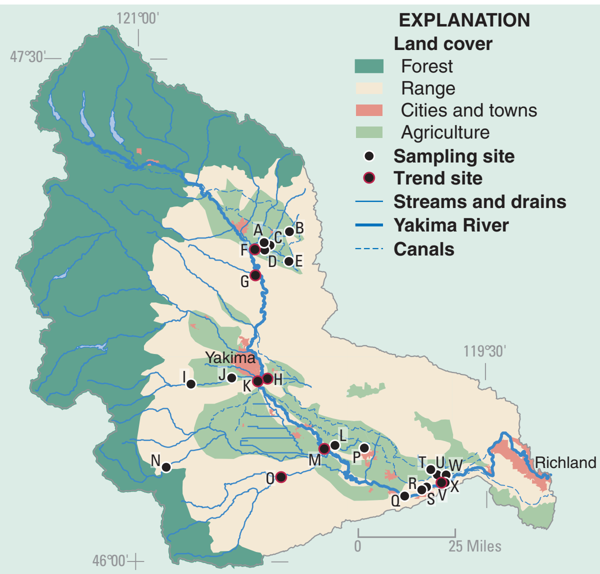
1. Yakima River at Cle Elum
2. Wilson Creek
3. Cherry Creek
4. Umtanum Creek
5. Yakima River at Umtanum
6. Naches River
7. Moxee Drain
8. Wide Hollow Creek
9. Yakima River at Union Gap
10. Ahtanum Creek
11. East Toppenish Creek
12. Sub 35 Drain
13. Granger Drain
14. Marion Drain
15. Toppenish Creek
16. Yakima R at river mile 72
17. Satus Creek
18. South Drain
19. Sulphur Creek Wasteway
20. Yakima River at Grandview
21. Spring Creek
22. Snipes Creek
23. Yakima River at Kiona

*Umtanum Creek (site 4) was sampled to assess natural background conditions and does not receive agricultural return flow.



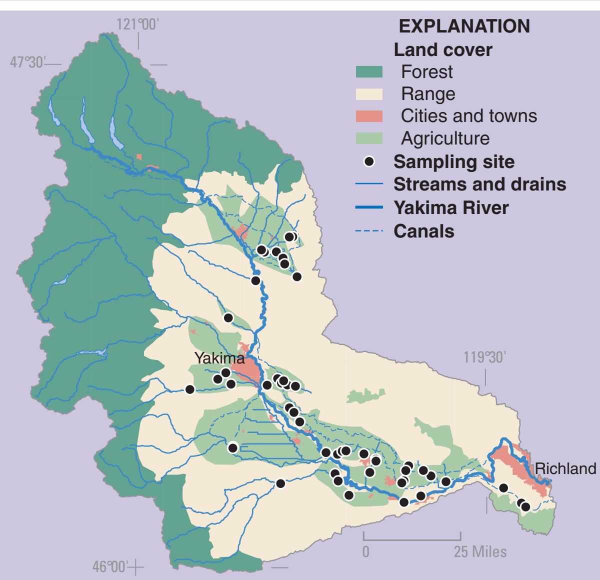
Aquatic Ecological Conditions of Streams and Drains

A. Caribou Creek
B-C. Park Creek
 B. at Park Creek Road
 C. at South Ferguson Rd
D. Johnson Drain
E. Badger Creek
F. Cherry Creek
G. Umtanum Creek
H. Moxee Drain
I-K. Ahtanum Creek
 I. below Bachelor Creek
 J. at 62d Avenue
 K. at Union Gap
L. JD 27.5 at VanBelle Road
M. Granger Drain
N. Toppenish Creek
O. Satus Creek
P. JD 34.2 at Woodin Road
Q. JD 51.4 at Yakima River
R. JD 52.8 Wamba Road
S. JD 55.1 at Bettinson Road
T-V. Spring Creek
 T. at Hanks Road
 U. at McCreadie Road
 V. at mouth at Whitstran
W-X. Snipes Creek
 W. at McCreadie Road
 X. at mouth at Whitstran



Water Quality in Small Agricultural Watersheds

Small agricultural watersheds were studied to understand how sediment and agricultural chemicals move from fields into waterways in the Yakima River Basin. Sampling sites for water chemistry and suspended sediment were located at the outflows of 44 agricultural watersheds and 2 nonagricultural reference watersheds. Nine irrigation-water delivery canals also were sampled. Sites were sampled two times during the 2000 irrigation season and once immediately after the canals were shut down for the winter. Detailed information on soil properties, crops grown, irrigation methods used, nutrients and pesticides used, slope of the land surface, and elevation were gathered for each watershed. Environmentally relevant physical and chemical properties were obtained for each chemical known to have been applied in the watersheds.



The Yakima NAWQA Study during 1999–2000

Study component	What data were collected and why	Types of sites sampled	Number of sites sampled	Sampling frequency and period
Stream Chemistry				
Intensive fixed sites	Streamflow, field parameters,[1] 102 currently used[2] and 23 historically used pesticides and their breakdown products,[3] 23 trace elements, nutrients, major ions, and suspended sediment to describe concentrations.	Yakima River at Kiona (12510500) near the mouth of the basin and two agricultural drains—Moxee Drain at Birchfield Road (12500420) and Granger Drain at Granger (12505450)	3	Biweekly at Kiona and weekly at Moxee and Granger Drains during the irrigation season (May–September 1999) and monthly during the nonirrigation season (October 1999–January 2000)
Synoptic sampling—general water quality	The same constituents as above to examine occurrence, distribution, and transport.	6 Yakima River sites, mouths of 17 major tributaries, 3 reference sites, and 8 wastewater-treatment plants	34	August 2–6, 1999
Aquatic Ecology				
Aquatic biology—single-reach assessment	Aquatic insects, algae, chlorophyll *a*, stream habitat, 176 pesticides and breakdown products,[3] and nutrients to assess the response of the ecological community to agricultural influences.	Mouths of 7 major tributaries (these trend sites were sampled in 1990 also), 17 streams and drains in medium-sized agricultural watersheds	24	September–October 2000 (habitat, algae, aquatic insects) July–September 2000 (water quality)
Special Studies				
Synoptic samplings—agricultural chemicals	Streamflow, field parameters,[1] 176 currently used pesticides and breakdown products,[3] and nutrients to examine how agricultural practices and landscape characteristics affect runoff.	Streams and drains in small agricultural watersheds	51 57 45	June 12–22, 2000 July 10–20, 2000 October 30–November 2, 2000
Synoptic samplings—fecal-indicator bacteria	Fecal coliform bacteria, *Escherichia coli*, and enterococci to examine occurrence and distribution.	Streams and drains included in the general water-quality and agricultural chemical synoptic samplings listed above	25 57 43	August 2–6, 1999 July 10–20, 2000 October 30–November 2, 2000
Synoptic samplings—emerging contaminants	28 antibiotic compounds, 21 human prescription and nonprescription drugs, 46 organic wastewater contaminants, and 14 steroid compounds as part of a nationwide reconnaissance.	Yakima River at Kiona (12510500) near the mouth of the basin and a well in an animal feeding operation in the Lower Valley	2	July 19, 2000 (Kiona) August 28, 2000 (well)

[1]Field parameters are turbidity, dissolved oxygen, pH, specific conductance, and water temperature.

[2]Between March 1999 and March 2000, the method [*42*] used for analyzing some of these pesticide compounds was not yet approved and analysis protocols were not always met; therefore, the data were qualified [*43*].

[3]The listing of current pesticides analyzed was derived from a national listing based on pesticide use and was not designed to be exhaustive.

Calculation of the Stream Condition Index (SCI)

Individual scores for each water-quality and habitat measure at a site were assigned a categorical value based on percentile distributions (5=0–25th, 3=25–75th, and 1=75–100th). For substrate size, habitat complexity, and stream shading, scoring was reversed so that a categorical value of 5 always represents the highest quality condition. The SCI score is the sum of all eight categorical values for all of the water-quality and habitat measures combined, with scores ranging from 8 (poor condition) to 40 (good condition).

For example, concentrations of total phosphorus ranged from 0.03 to 0.48 mg/L. The 25th percentile was 0.08 mg/L and the 75th percentile was 0.21 mg/L. Sites with concentrations of total phosphorus less than or equal to 0.08 mg/L received a score of 5, while sites with concentrations between 0.08 and 0.21 mg/L received a score of 3. Likewise, sites with concentrations greater than 0.21 mg/L received a score of 1. A similar analysis was performed for each site on all eight measures used in the SCI.

The Yakima NAWQA Study during 1987–91

Study component	What data were collected and why	Types of sites sampled	Number of sites sampled	Sampling frequency and period
Stream Chemistry				
Intensive fixed sites—general water quality	Streamflow, field parameters,[1] nutrients, major ions, suspended sediment, and trace elements (both in water and on suspended sediment) to describe concentrations and determine occurrence.	Yakima R at Cle Elum (12479500), Umtanum (12484500), Union Gap (12500450), Grandview (12509050), Kiona (12510500); Naches River (12499000); Sulphur Creek Wasteway (12508850)	7	Monthly (April 1987–90) and several storm events
Intensive fixed sites—pesticides	Streamflow, field parameters,[1] organic compounds,[2] and suspended sediment to describe concentrations and examine seasonal variability.	Seven major tributaries and the Yakima River at Kiona (12510500)	8	May, June, July, August, November 1988; March 1989
Synoptic samplings—pesticides	Streamflow, field parameters,[1] organic compounds,[2] and suspended sediment to determine spatial distribution and to examine transport characteristics.	Yakima River sites, major and minor tributaries, and agricultural streams and drains	18 (unfiltered) ~30 (filtered and suspended)	July 1988 (unfiltered water) June 1989; May–July, September 1991 (filtered and suspended phases)
Synoptic samplings—nutrients and trace elements	Streamflow, field parameters,[1] trace elements, and nutrients to examine occurrence, distribution, and seasonal variability.	Yakima River sites, major and minor tributaries, and agricultural streams and drains	~100 (nutrients) ~30 (trace elements)	August 1986; July, November 1987; March, July 1988 (nutrients) July, November 1987; May 1989; March 1990 (trace elements)
Contaminants in streambed sediment	Organic and semivolatile organic compounds, organic carbon, and trace elements to determine occurrence, distribution, and associations with crops.	Yakima River sites, major and minor tributaries, and agricultural streams and drains	~30 (organics) ~460 (trace elements)	Varied 1987–90 (organics) Varied 1987–91 (trace elements)
Contaminants in tissues of aquatic organisms	Historically used pesticides, polycyclic aromatic hydrocarbons (PAHs), and trace elements in fish, insects, clams, and plants to describe concentrations.	Yakima River sites, major and minor tributaries, and agricultural streams and drains	~50 (organics) ~30 (trace elements)	May, October, November 1989; October, November 1990 (organics) May, November 1989; November 1990; October 1991 (trace elements)
Aquatic Ecology				
Aquatic biology	Aquatic insects, algae, fish community structure, stream habitat, and more than 140 variables to assess linkages between biological characteristics and land use.	Large-river sites and sites from each of the three ecoregions—Cascades, Eastern Cascades, and Columbia Basin	25	October–November 1990
Special Studies				
Synoptic samplings—radionuclides	Gross alpha and beta activities in filtered water and suspended sediment to assess conditions.	The general water-quality intensive fixed sites shown above	7	April, May, August, November 1987; December 1989; January 1990
Synoptic sampling—fecal-indicator bacteria	Fecal coliform bacteria, *Escherichia coli*, turbidity, and suspended sediment to examine occurrence and distribution.	Yakima River sites, major and minor tributaries, and agricultural streams and drains	58	July 1988

[1]Field parameters are turbidity, dissolved oxygen, pH, specific conductance, and water temperature.

[2]Carbamates, chlorophenoxy-acid herbicides, organophosphorus compounds, and triazine herbicides.

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Glossary

Agricultural return flow—The water in an aquifer or surface-water body that comes from delivered but unused irrigation water, operational discharges from canals, and the portion of irrigation water applied to a field that is not consumed by evapotranspiration or uptake by plants.

Algae—Chlorophyll-bearing nonvascular, primarily aquatic species that have no true roots, stems, or leaves; most algae are microscopic, but some species can be as large as vascular plants.

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

Assemblage—A grouping of species from the same general category of living organisms such as fish, aquatic insects, hard wood trees, or riparian vegetation.

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.

Best management practice (BMP)—An agricultural practice that has been determined to be an effective, practical means of preventing or reducing nonpoint-source pollution.

Biomass—The amount of living matter, in the form of organisms, present in a particular habitat, usually expressed as weight per unit area.

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 that is either more persistent or less persistent than the parent compound.

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

Criterion—A standard rule or test on which a judgment or decision can be based.

DDT—Dichloro-diphenyl-trichloroethane. An organochlorine insecticide no longer registered for use in the United States.

Diversion—A turning aside or alteration of the natural course of a flow of water, normally considered physically to leave the natural channel. In some States, this can be a consumptive use direct from another stream, such as by livestock watering. In other States, a diversion must consist of such actions as taking water through a canal, pipe, or conduit.

Drip irrigation—An irrigation system in which water is applied directly to the root zone of plants by means of applicators (orifices, emitters, porous tubing, perforated pipe, and so forth) operated under low pressure. The applicators can be placed on or below the surface of the ground or can be suspended from supports.

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

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.

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.

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 (ppb) in most stream water and ground water. One thousand micrograms per liter equals 1 milligram per liter.

Nanograms per liter (ng/L)—A unit expressing the concentration of constituents in solution as weight (nanograms) of solute per unit volume (liter) of water; equivalent to one part per trillion in most stream water and ground water. One thousand nanograms per liter equals 1 µg/L.

Riffle—A shallow part of the stream where water flows swiftly over completely or partially submerged obstructions to produce surface agitation.

Rill irrigation—A type of surface irrigation in which water is applied at the upper end of a field and flows in furrows to the lower end.

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

Run—A relatively shallow part of a stream with moderate velocity and little or no surface turbulence.

Streamflow—A type of channel flow, applied to that part of surface runoff in a stream whether or not it is affected by diversion or regulation.

Suspended sediment—Particles of rock, sand, soil, and organic detritus carried in suspension in the water column, in contrast to sediment that moves on or near the streambed.

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.

Turbidity—Reduced clarity of surface water because of suspended particles, usually sediment.

Unfiltered water—Water that has not been filtered or centrifuged, or altered in any way from the original matrix.

Withdrawal—The act or process of removing; such as removing water from a stream for irrigation or public water supply.

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.

Appendix—Water-Quality Data from the Yakima River Basin in a National Context

Concentrations and detection frequencies of the most commonly detected constituents, constituents that exceed a drinking-water standard or aquatic-life guideline, or constituents that are of regulatory or scientific importance, are presented below. Plots of other pesticides and nutrients assessed in the Yakima River Basin are available at our Web site at:

http://water.usgs.gov/nawqa/graphs

These summaries of chemical concentrations and detection frequencies from the Yakima River Basin are compared to findings from 51 NAWQA Study Units investigated from 1991 to 2001 and to water-quality benchmarks for human health, aquatic life, fish-eating wildlife, or prevention of nuisance plant growth. These graphical summaries provide a comparison of chemical concentrations and detection frequencies in surface-water resources between agricultural and mixed land uses.

For example, the graph for atrazine shows that in the Yakima River Basin, frequency of detection is slightly higher than national findings in streams, and concentrations are generally lower in streams in mixed land-use areas than concentrations in agricultural streams, but nowhere are concentrations in excess of the USEPA drinking-water standard.

NOTE to users:

- The analytical detection limit varies among the monitored chemicals; thus, frequencies of detections are not comparable among chemicals.
- It is important to consider the frequency of detection along with concentration. For example, atrazine was detected more frequently in agricultural streams in the Yakima River Basin than in agricultural streams nationwide (100 percent compared to 92 percent) but generally was detected at lower concentrations.

CHEMICALS IN WATER

Concentrations and detection frequencies, Yakima River Basin, 1999–2000

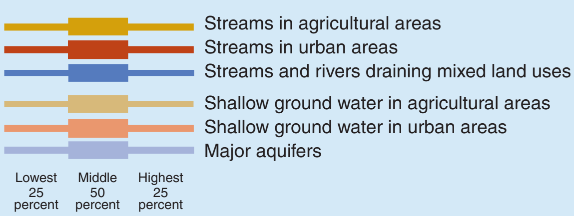
◆ Detected concentration in Study Unit

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 51 NAWQA Study Units, 1991–2001—Ranges include only samples in which a chemical was detected



National water-quality benchmarks

National benchmarks include standards and guidelines related to drinking-water quality, criteria for protecting the health of aquatic life, and the desired goal for preventing nuisance plant growth 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 nuisance plant growth in streams

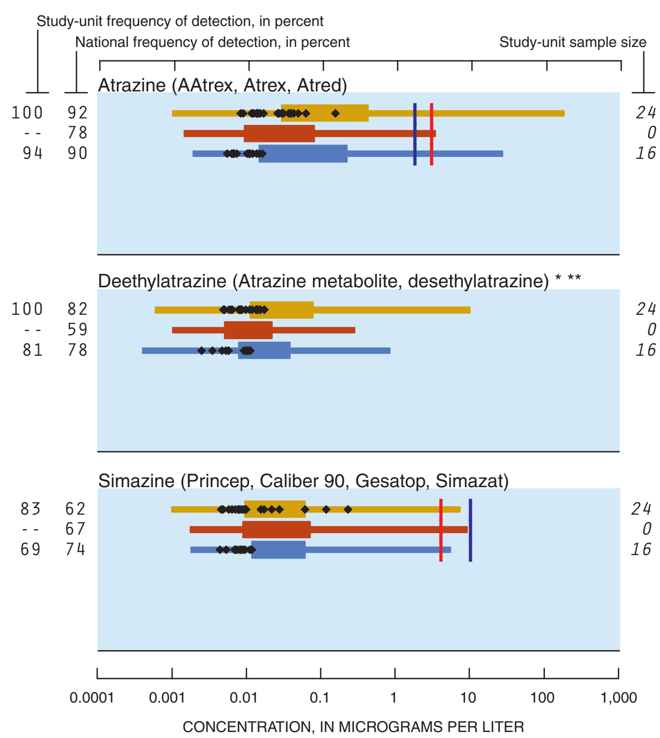
* No benchmark for drinking-water quality

** No benchmark for protection of aquatic life

Quality-control data for these analytes indicate relatively frequent low-level contamination of samples during sample processing for analysis. Results for these analytes cannot, therefore, be presented using the generalized methods that were applied to other analytes in this Appendix. Analysis of results for analytes potentially affected by contamination requires special statistical treatment beyond the scope of this report. For more information about these analytes and how to interpret data on their occurrence and concentrations, please contact the appropriate NAWQA Study Unit.

Insecticides in water: *p,p'*-DDE

Pesticides in water—Herbicides



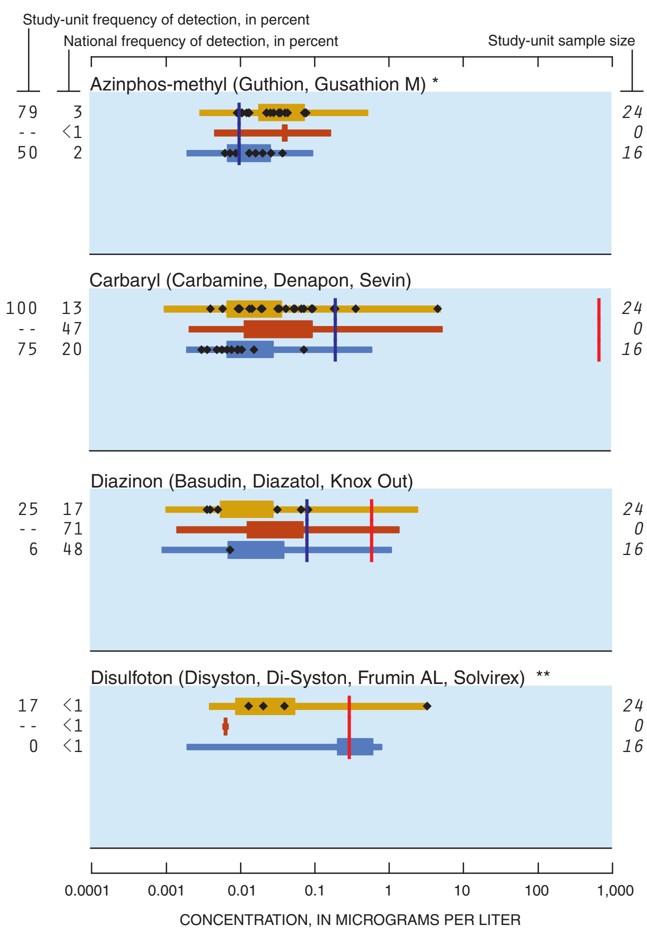
Other herbicides detected

Acetochlor (Harness Plus, Surpass) * **
Alachlor (Lasso, Bronco, Lariat, Bullet) **
Cyanazine (Bladex, Fortrol)
EPTC (Eptam, Farmarox, Alirox) * **
Ethalfluralin (Sonalan, Curbit) * **
Metolachlor (Dual, Pennant)
Pendimethalin (Pre-M, Prowl, Weedgrass Control, Stomp, Herbadox) * **
Prometon (Pramitol, Princep, Gesagram 50, Ontracic 80) **
Tebuthiuron (Spike, Tebusan)
Terbacil (Sinbar) **
Trifluralin (Treflan, Gowan, Tri-4, Trific, Trilin)

Herbicides not detected

Benfluralin (Balan, Benefin, Bonalan, Benefex) * **
Butylate (Sutan +, Genate Plus, Butilate) **
DCPA (Dacthal, chlorthal-dimethyl) **
2,6-Diethylaniline (metabolite of Alachlor) * **
Linuron (Lorox, Linex, Sarclex, Linurex, Afalon) *
Metribuzin (Lexone, Sencor)
Molinate (Ordram) * **
Napropamide (Devrinol) * **
Pebulate (Tillam, PEBC) * **
Pronamide (Kerb, Propyzamid) **
Propachlor (Ramrod, Satecid) **
Propanil (Stam, Stampede, Wham, Surcopur, Prop-Job) * **
Thiobencarb (Bolero, Saturn, Benthiocarb, Abolish) * **
Triallate (Far-Go, Avadex BW, Tri-allate) *

Pesticides in water—Insecticides



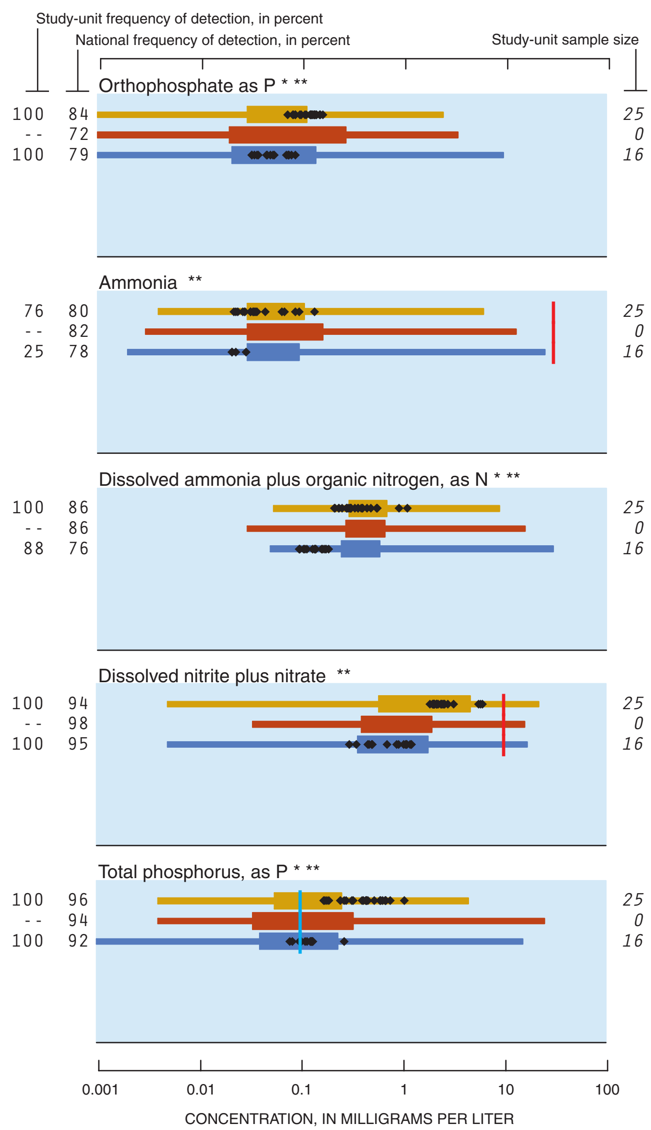
Other insecticides detected

Chlorpyrifos (Brodan, Dursban, Lorsban)
Dieldrin (Panoram D-31, Octalox)
Ethoprop (Mocap, Ethoprophos) * **
Malathion (Malathion)
Propargite (Comite, Omite, Ornamite) * **

Insecticides not detected

Carbofuran (Furadan, Curaterr, Yaltox)
Fonofos (Dyfonate, Capfos, Cudgel, Tycap) **
alpha-HCH (alpha-BHC, alpha-lindane) **
gamma-HCH (Lindane, gamma-BHC, Gammexane)
Methyl parathion (Penncap-M, Folidol-M, Metacide, Bladan M) **
Parathion (Roethyl-P, Alkron, Panthion) *
cis-Permethrin (Ambush, Astro, Pounce) * **
Phorate (Thimet, Granutox, Geomet, Rampart) * **
Terbufos (Contraven, Counter, Pilarfox) **

Nutrients in water



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Federal Agencies
U.S. Environmental Protection Agency
Bureau of Reclamation
USDA–Forest Service
U.S. Fish and Wildlife Service
U.S. Bureau of Indian Affairs
Natural Resources Conservation Service

Indian Nations
Yakama Indian Nation

State Agencies
Washington Department of Agriculture
Washington Department of Ecology
Washington Department of Fisheries
Washington Department of Health
Washington Department of Wildlife

Universities
Washington State University

Local Agencies
Benton Conservation District
Kittitas County Conservation District
North Yakima Conservation District
South Yakima Conservation District
Kittitas Reclamation District
Yakima County
Roza Irrigation District
Sunnyside Valley Irrigation District
Wapato Irrigation District
Roza–Sunnyside Board of Joint Control

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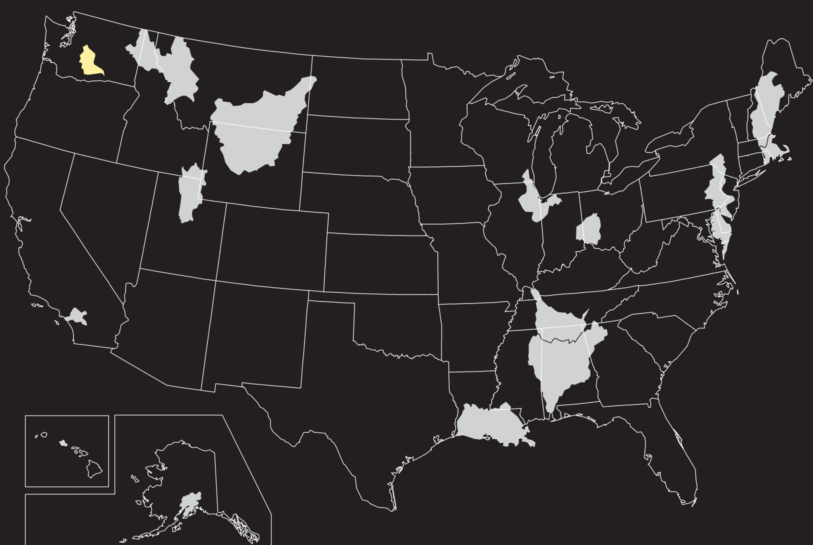
NAWQA

National Water-Quality Assessment (NAWQA) Program
Yakima River Basin



Fuhrer and others— Water Quality in the Yakima River Basin
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