Water Quality on the Island of Oahu

Hawaii, 1999–2001

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

Circular 1239

Points of Contact and Additional Information

The companion Web site for NAWQA summary reports:

http://water.usgs.gov/nawqa/nawqa_sumr.html/

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Potomac River Basin (Circular 1166)
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Yakima River Basin (Circular 1237)
Yellowstone River Basin (Circular 1234)

National Assessments

The Quality of Our Nation's Waters—Nutrients and Pesticides (Circular 1225)

Front cover: Island of Oahu as seen by Landsat satellite (cloud-free mosaic by the Pacific Disaster Center).
Back cover: Left, the city of Honolulu looking north (photograph by Douglas Peebles); right, shaded relief map of Oahu.

Water Quality on the Island of Oahu, Hawaii, 1999–2001

By Stephen S. Anthony, Charles D. Hunt, Jr., Anne M.D. Brasher, Lisa D. Miller, and Michael S. Tomlinson

Circular 1239

U.S. Department of the Interior
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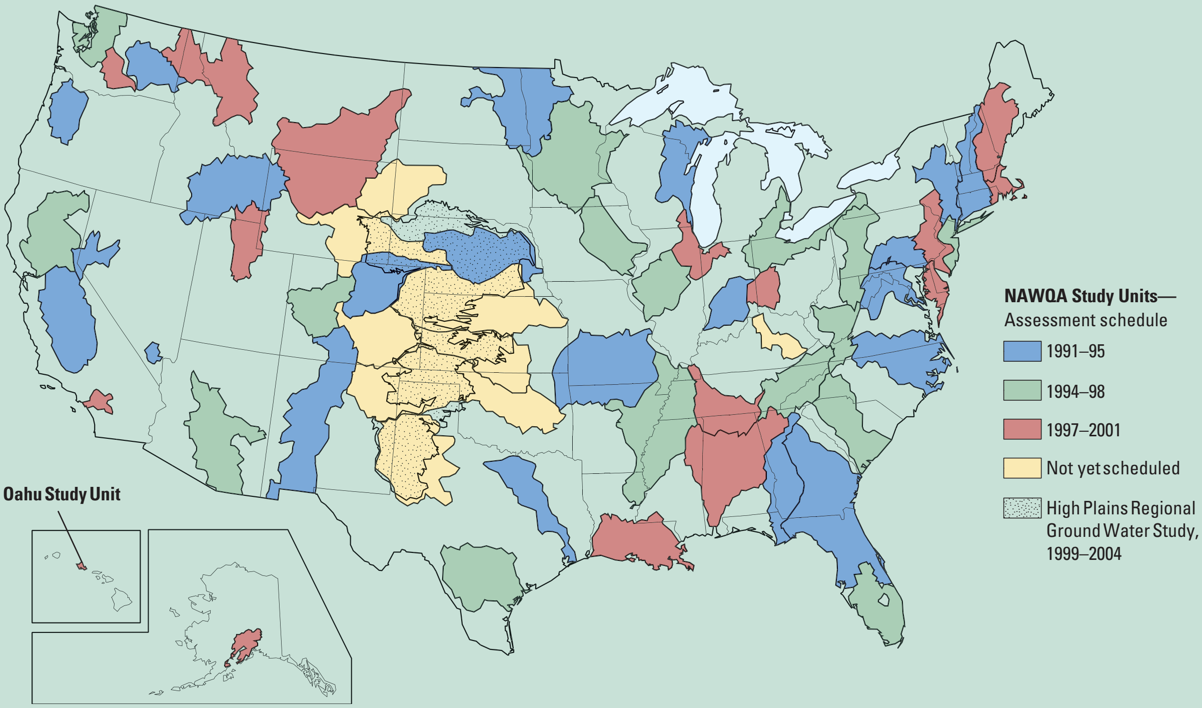
Contents

National Water-Quality Assessment Program

The quality of the Nation's water resources is integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and also suitable for industry, irrigation, and habitat for fish and wildlife. Recognizing the need for long-term, nationwide assessments of water resources, the U.S. Congress has appropriated funds since 1991 for the USGS to conduct the **National Water-Quality Assessment (NAWQA) Program**. Scientists in the NAWQA Program work with partners in government, research, and public interest groups to assess the spatial extent of water-quality conditions, how water quality changes with time, and how human activities and natural factors affect 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.



The island of Oahu is one of 51 water-quality assessments initiated since 1991. Together, the 51 major river basins and aquifer systems, referred to as "Study Units," include water resources used by more than 60 percent of the population in watersheds that cover about one-half of the land areas of the conterminous United States. Timing of the assessments varies because of the program's rotational design in which one-third of all Study Units are intensively investigated for 3 to 4 years, with trends assessed every 10 years. As indicated on the map, the island of Oahu is part of the third set of intensive investigations, which began in 1997.

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

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 context within which NAWQA information is most useful.

- 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 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, as well as for tracking contaminant levels over time.
- Multiple scales—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, multiscale 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

This report contains the major findings of a 1999–2001 assessment of water quality on the island of Oahu, Hawaii. It is one of a series of reports by the National Water-Quality Assessment (NAWQA) Program that present major findings in 51 major river basins and aquifer systems across the Nation.

In these reports, water quality is discussed in terms of local, State, and regional issues. Conditions in a particular basin or aquifer system are compared to conditions 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, State, or local agencies, universities, public interest groups, or in the private sector. The information will be useful in addressing a number of current issues, such as the effects of agricultural and urban land use on water quality, human health, drinking water, source-water protection, and excessive growth of algae and plants, pesticide registration, and monitoring and sampling strategies. This report is also for individuals who wish to know more about the quality of streams and ground water in areas near where they live, and how that water quality compares to the quality of water in other areas across the Nation.

The water-quality conditions on Oahu summarized in this report are discussed in detail in other reports that can be accessed from (*http://hi.water.usgs.gov/nawqa*). Detailed technical information, data and analyses, collection and analytical methodology, models, graphs, and maps that support the findings presented in this report in addition to reports in this series from other basins can be accessed from the national NAWQA Web site (*http://water.usgs.gov/nawqa*).

Electrofishing in an Oahu stream. (Photograph by Anne Brasher, U.S. Geological Survey.)

"The NAWQA study results provide Hawaii with an important database describing the status of water quality in aquifers, and the status of water quality, habitat, and aquatic communities in selected streams on Oahu. Many of Oahu's surface and ground waters have been subject to only limited monitoring in the past, so these data will represent a baseline to which results from future studies can be compared. Reports on chemical contaminants in aquifers, stream sediments and fish tissues are particularly useful because these data are expensive to obtain and thus rarely collected. Similar data sets from the other Hawaiian islands are sorely needed."

Dr. June Harrigan,
Hawaii Department of Health,
Environmental Planning Office

"The data on benthic invertebrates is a major contribution of this study, because such data have seldom been collected for Hawaiian streams and never before in conjunction with such a wealth of other water-quality parameters. This information could provide the basis for an important new component in water-quality monitoring in Hawaii, which would be especially useful for volunteer monitors and educational groups."

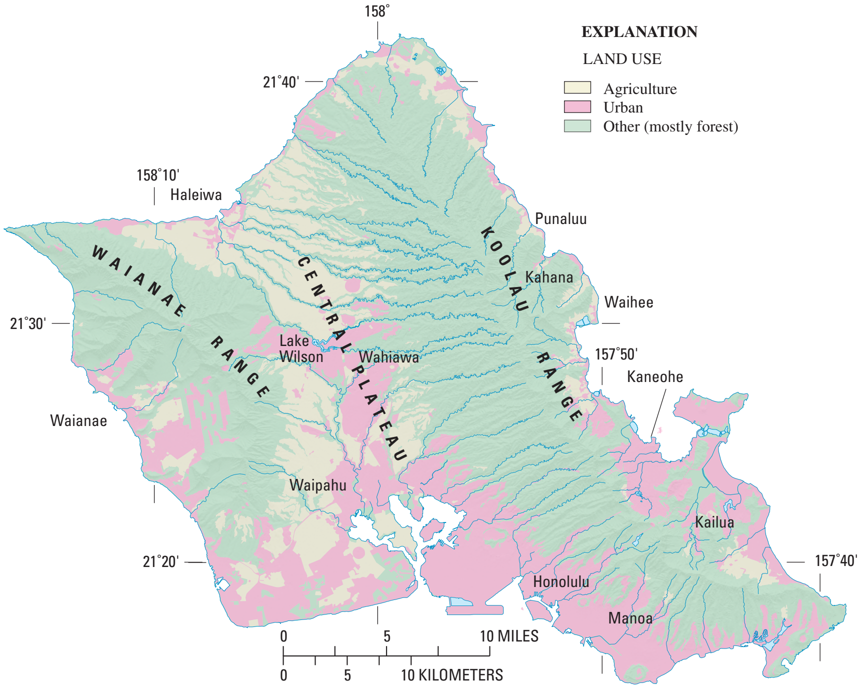
Dr. Carl Evenson,
University of Hawaii at Manoa,
College of Tropical Agriculture and
Human Resources

Summary of Major Findings

Stream Highlights

Urban and agricultural land use greatly influence the water quality and ecology of Oahu streams. Although streams do not supply drinking water, they do provide irrigation water and **habitat**[1] for aquatic life. Guidelines established to protect freshwater aquatic life and fish-eating wildlife were exceeded for several organic compounds, **nutrients**, and **trace elements**; however, guidelines have not been established for all detected chemicals.

- Urban alteration of stream habitat has adversely affected native aquatic species, interfering with migration cycles of native fish, shrimp, and snails. Introduced species are more tolerant of altered habitat and proliferate where native species cannot. Few native fish were collected (p. 18).
- Streams in different land-use settings contain different **pesticides**. **Herbicides** were detected more frequently than **insecticides** in Waikele Stream (which drains agricultural and urban land), whereas insecticides were detected more frequently in urban Manoa Stream (p. 10).
- **Contamination** also depends on rainfall and ground-water inflow. At Waikele Stream, for example, insecticides were detected more frequently in storm **runoff**, whereas herbicides and nutrients were detected more frequently and at highest **concentrations** in fair-weather **base flow** supplied by ground water (p. 11).
- The insecticides carbaryl, diazinon, dieldrin, and malathion exceeded aquatic-life guidelines in water. Dieldrin, used to control termites, was detected in almost all water samples from urban Manoa Stream and exceeded the aquatic-life guideline in 26 percent of the samples (p. 12).
- **Organochlorine** pesticides, polychlorinated biphenyls (PCBs), and **semivolatile organic compounds** (SVOCs) were pervasive in urban and agricultural-urban streams. Concentrations exceeded **aquatic-life guidelines** in **bed sediment** and wildlife guidelines in fish. Chlordane and dieldrin concentrations were among the highest in the Nation (p. 14–17).
- Nitrogen and **phosphorus** concentrations frequently exceeded State stream-water standards and were highest in agricultural-urban Waikele Stream Basin, where fertilizers were applied intensively for decades (p. 13–14).



Oahu is the most urbanized island in Hawaii and home to the State capital and largest city, Honolulu. The resident and visitor population is about 1 million people. The island is a fully enclosed hydrologic system that encompasses 586 square miles and includes two mountain ranges. Public water supplies are provided entirely by ground water, whereas streams provide irrigation water and aquatic habitat.

- Excessive nutrients in streams and ground water could have adverse effects on coastal ecosystems such as estuaries and coral reefs (p. 13–14).
- Trace elements were elevated above **background** levels in streambed sediments in urban and agricultural basins. Arsenic exceeded aquatic-life guidelines at 67 percent of agricultural sites, and lead and zinc exceeded guidelines at 50 and 75 percent of urban sites, respectively. Chromium and copper exceeded guidelines in all land uses as a result of high natural abundance in Hawaii rocks and soil (p. 16).
- Urban streams had fewer numbers of **invertebrates** but a greater number of invertebrate taxa than forested streams, reflecting **ecosystem** degradation and dominance by nonnative species (p. 19).

Major Influences on Streams

- Contaminants in runoff from urban and agricultural land
- Pesticides and nutrients in ground-water-fed base flow
- Degraded stream habitat in urban and agricultural areas

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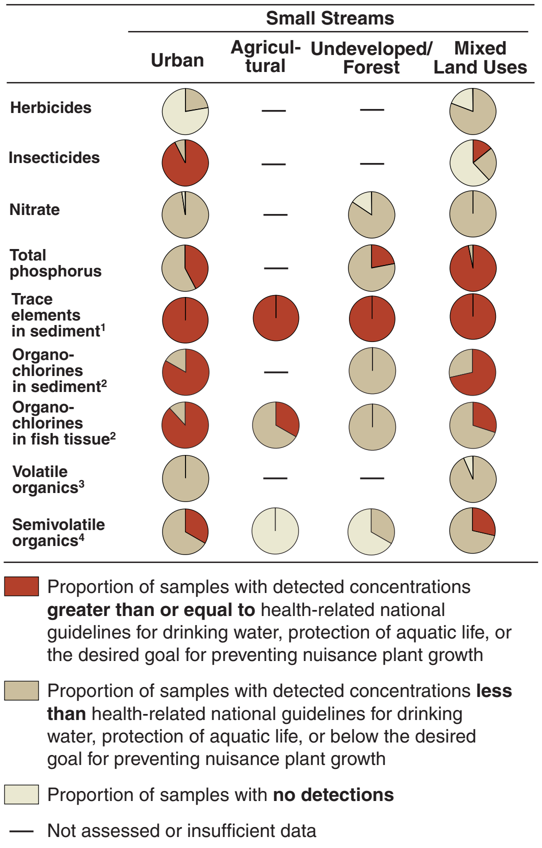
[1] Terms defined in the Glossary (p. 24) are shown in **boldface type** where they first appear.

Selected Indicators of Stream-Water Quality



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[1] Metals.

[2] Organochlorine pesticides and PCBs.

[3] Solvents, refrigerants, fumigants, gasoline compounds, and trihalomethanes in water.

[4] Byproducts of fossil-fuel combustion; components of coal and crude oil in sediment.

Ground-Water Highlights

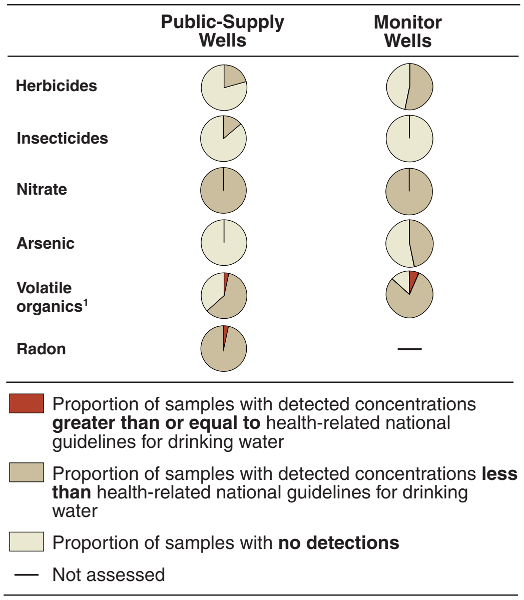
Ground water provides virtually all drinking water on Oahu, and much of the Study Unit is a U.S. Environmental Protection Agency (USEPA) designated **sole-source aquifer**. The most common chemicals detected in untreated water from public-supply and monitor wells were **fumigants**, solvents, herbicides, and elevated concentrations of nutrients. The chemical quality of the untreated water does not necessarily reflect that of treated drinking water delivered to the public.

- Few chemicals exceeded **drinking-water standards** in ground water. USEPA standards were exceeded by the solvent trichloroethene and the radioactive gas radon in one public-supply well each. Fumigants exceeded more stringent State standards in four supply wells (p. 6–8).
- Ground-water contamination is determined largely by chemical use, land use, and **aquifer** vulnerability. Contamination is greatest in central Oahu, where solvents, herbicides, and fertilizers are used over vulnerable **unconfined aquifers**. In contrast, minimal contamination was detected in urban Honolulu, where chemicals are used and stored mostly over less vulnerable **confined aquifers** (p. 8–9).
- Current contamination reflects historical use of chemicals more than present use; for example, there were numerous detections of fumigants, herbicides, and fertilizers formerly used on agricultural land. Ground-water movement is slow (about 5 feet per day), and chemicals take decades to be flushed through the aquifer system. Single detections of three turfgrass herbicides used only since 1990 suggest that chemicals used in urban areas converted from cropland have begun to reach the water table (p. 10).
- Detection frequencies in Oahu public-supply wells were highest in the Nation for fumigants and third highest for solvents out of more than 80 NAWQA assessments of VOCs in major aquifers. Fumigants are applied for pineapple cultivation, and solvent use is widespread in military and civilian sectors of the urban environment (p. 9).
- **Nitrate** concentrations were elevated in agricultural areas but did not exceed the USEPA drinking-water standard. Phosphorus concentrations were high enough to potentially promote nuisance plant growth (**eutrophication**) where ground water discharges to streams (p. 7).
- Trace-element concentrations were within drinking-water standards. Arsenic, which is a concern in the Northeastern and Western United States, was not detected in public-supply wells on Oahu (p. 6).

Major Influences on Ground Water

- Solvents from military and civilian urban sources and from pesticide formulations
- Fumigants applied to pineapple fields
- Agricultural herbicides and fertilizers from agriculture and from urban lands, including parks and golf courses

Selected Indicators of Ground-Water Quality



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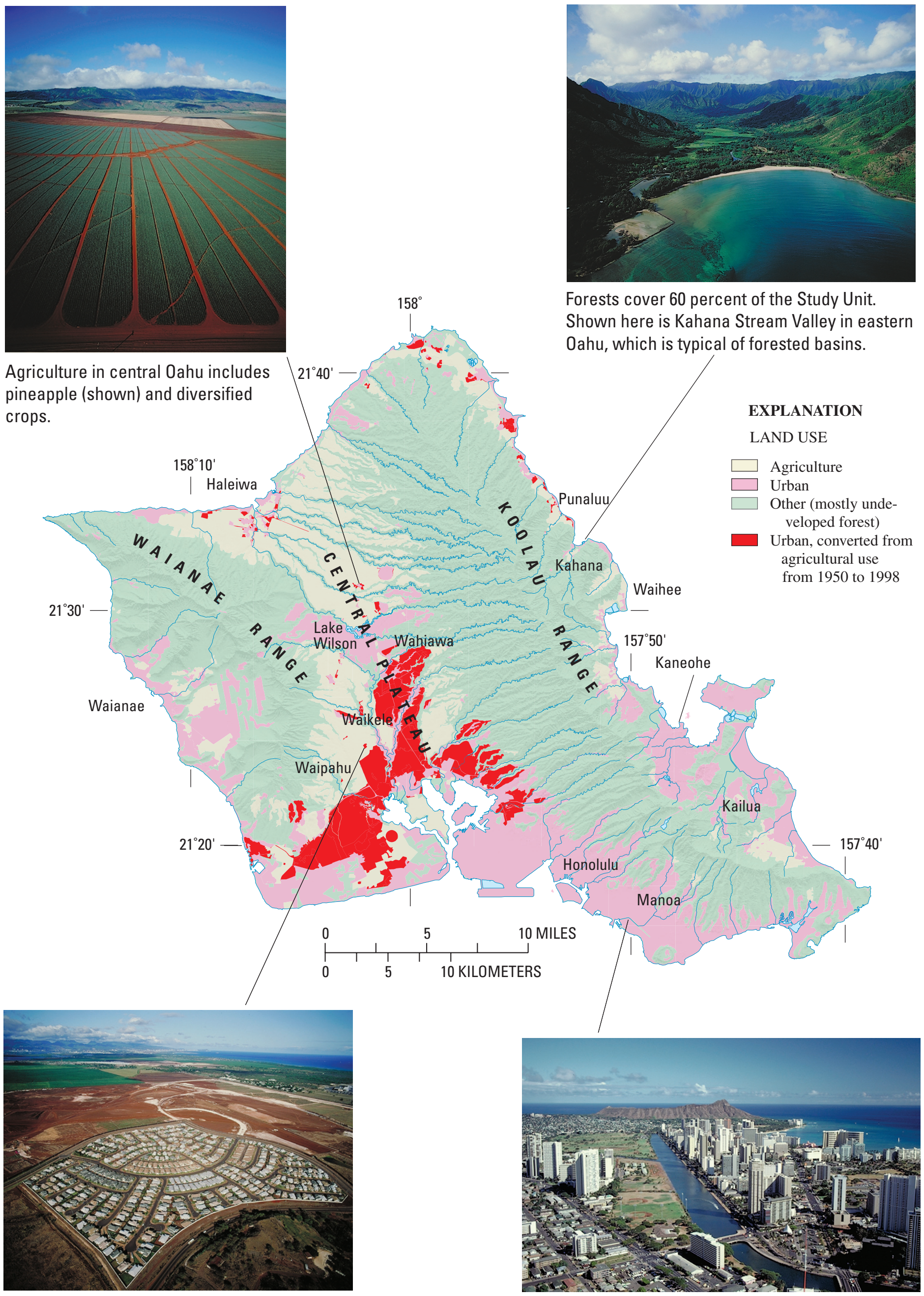
[1] Solvents, refrigerants, fumigants, gasoline compounds, and trihalomethanes.

Introduction to the Oahu Study Unit

Oahu is the center of population and commerce in Hawaii and home to the State capital and largest city, Honolulu. The 586-mi^2 landscape is dominated by two volcanic mountain ranges dissected by deep valleys (fig. 1). A gently sloping central plateau separates the mountain ranges, and a coastal plain extends around the island margin. The island is a fully enclosed hydrologic system, encompassing entire streams from their headwaters to their mouths and entire ground-water flow systems from inland **recharge** areas to coastal discharge zones. Waikele Stream has the largest **drainage basin**, which occupies much of south-central Oahu. Manoa Stream is a prominent urban stream that drains a broad valley in urban Honolulu and empties into a large drainage canal that borders the tourist enclave of Waikiki. Streams are short and steep, and streamflow is flashy (stormflows peak and recede within hours). Most streams are **intermittent** through their mid-**reach**; flow is **perennial** at high altitudes where rainfall is persistent and along low-altitude gaining reaches where streams intersect the water table near their mouths. Streams in northeastern Oahu intercept high-level, dike-impounded ground water and are perennial over most of their lengths.

Climate is subtropical, with mild temperatures, moderate humidity, and prevailing northeasterly trade winds. Rainfall variation is extreme over short distances, ranging from 280 inches per year near the crest of the Koolau Range to 20 inches per year in the rain-shadowed lowlands of western Oahu (fig. 2; Giambelluca and others, 1986). As a result, microenvironments range from rain forest to dry grassland with cactus and kiawe (similar to mesquite). Rainfall is seasonal: November through April are relatively wet months, and May through October are drier. Storms can occur at any time of the year.



Agriculture in central Oahu includes pineapple (shown) and diversified crops.

Forests cover 60 percent of the Study Unit. Shown here is Kahana Stream Valley in eastern Oahu, which is typical of forested basins.

Urban residential developments now occupy former sugarcane land in south-central Oahu. Sugarcane cultivation was discontinued in the 1990s.

Urban Honolulu houses a dense population of residents and visitors. Shown here is the Waikiki area with the extinct volcanic crater of Diamond Head in the background.

Figure 1. Urban and agricultural development are concentrated along the coast and throughout the gently sloping plateau of central Oahu. Forests blanket the more rugged, mountainous terrain. (All photographs by Douglas Peebles.)

Land use is changing from agriculture to urban

The dominant land cover on Oahu (fig. 1) is undeveloped forest (about 60 percent); about 25 percent is urbanized, and the remaining 15 percent is used for agriculture (Klasner and Mikami, 2003). The principal industry is tourism, followed by military activity and agriculture. The resident population was 876,000 in 2000, which is more than double the population in 1950. Some 80,000 additional people visit the island at any time, on average. Because much of the island is covered by protected forest reserves, developed areas on Oahu are some of the most densely populated areas in the United States.

Major land-use changes are underway in central Oahu (fig. 1) following a period of about 100 years in which plantation agriculture dominated the landscape. Before 1950, urban and industrial development was concentrated in Honolulu, on the coastal plain near Pearl Harbor, and at several military bases and a nearby town (Wahiawa) in central Oahu. In recent decades, large tracts of land used for sugarcane and pineapples in central Oahu have been converted to suburban use (in the south) and diversified-crop agriculture (in both north and south) (Oki and Brasher, 2003). These conversions may result in hydrologic changes such as increased runoff and reduced ground-water recharge and water-quality changes related to new types and amounts of chemicals.

Ground water provides public supplies, streams provide aquatic habitat and irrigation water

Ground water provides all public drinking-water supply on Oahu (fig. 3), while streams provide irrigation water and **riparian** and instream habitat for native species and other aquatic life. Stream habitat has been degraded by poor water quality, channel alteration, and flow diversion. The same factors responsible for degrading aquatic habitat also cause large sediment and chemical **loads** in streams, which can adversely affect the ecology and esthetics of receiving waters. The bays, estuaries, and nearshore marine waters of Oahu are critical to the tourism-based economy.

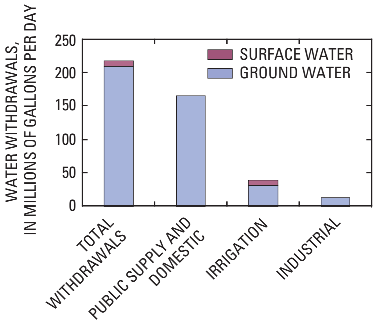


Figure 3. Ground water is the sole source of public drinking-water supplies on Oahu and accounts for most other withdrawals as well. Surface water is used only for irrigation and provides habitat for aquatic life.

Drinking-water aquifer is vulnerable to contamination

The deep volcanic-rock aquifer in central Oahu and Honolulu supplies more than 90 percent of the island's public water supply and is designated as a Sole Source Drinking-Water Aquifer by the USEPA. The aquifer is highly permeable and unconfined except near the coast (see map, p. 20), making it vulnerable to contamination despite depths to water of hundreds of feet in most places. Although overlying rock is weathered to depths of 50–200 feet (Hunt, 1996), this soil and clay-rich overburden does not prevent downward migration of chemicals applied or spilled at land surface (fig. 4). Contaminants reach the deep water table within a few years and persist in the aquifer and unsaturated zone for several decades (Hunt, 2004; Oki and Brasher, 2003). Agricultural and industrial chemicals have been detected in many wells, and some ground water requires treatment to meet drinking-water standards. Unresolved ground-water issues include flushing times of chemicals through the aquifer and effects of ongoing land-use changes on chemical use and migration.

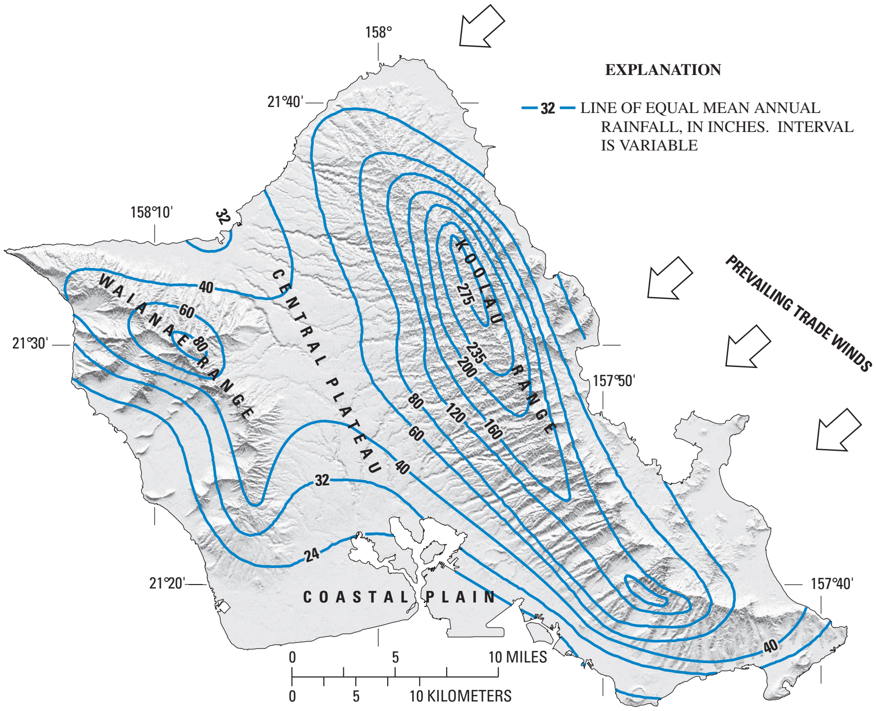


Figure 2. Oahu's mountainous landscape and moist trade winds cause steep rainfall gradients. (Modified from Giambelluca and others, 1986).

Below-normal rainfall may have affected water quality

Lower than normal rainfall and streamflow throughout this 3-year study (fig. 5) may have reduced the amount of sediment being washed into streams, as well as contaminants that attach to sediment particles, such as phosphorus and some trace elements. In contrast, concentrations of **dissolved constituents**, particularly those contributed by ground water and wastewater effluent, may have been higher than normal during this relatively dry period.

Ground-water quality probably was less affected by the dry conditions than were streams. Ground water tends to integrate and "smooth" year-to-year climatic effects more than streams do and tends to more closely reflect recharge and chemical-use patterns that persist for a decade or longer.

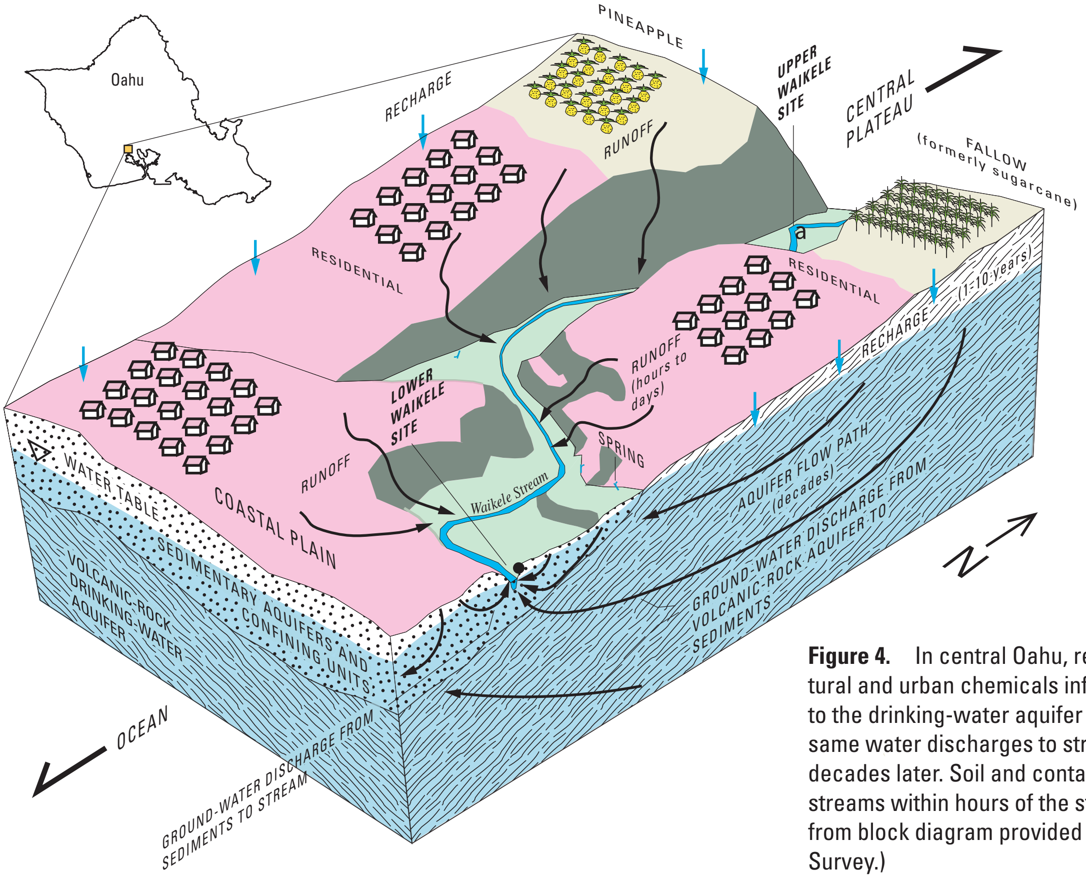


Figure 4. In central Oahu, recharge containing agricultural and urban chemicals infiltrates from land surface to the drinking-water aquifer in a matter of years. That same water discharges to streams and coastal sediments decades later. Soil and contaminants are washed into streams within hours of the start of a rainstorm. (Modified from block diagram provided by Scot Izuka, U.S. Geological Survey.)

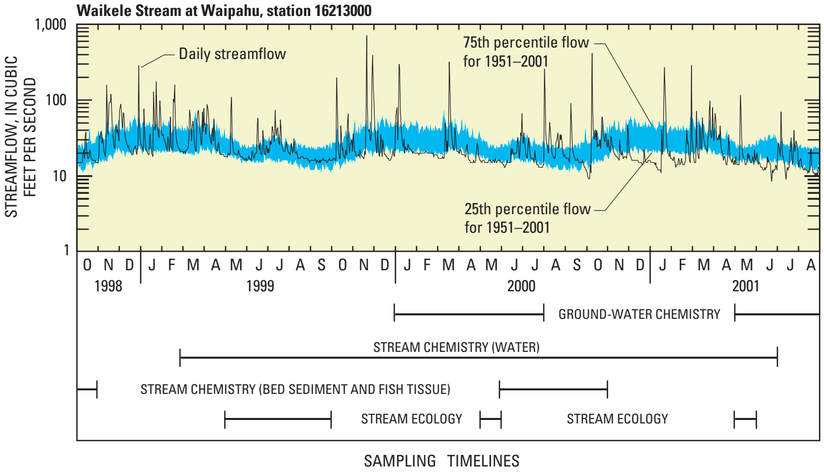


Figure 5. Annual streamflow at Waikele Stream was less than long-term average flow in all 3 years of this study (21, 23, and 40 percent below normal).

Additional Information

Oahu NAWQA study:
http://hi.water.usgs.gov/nawqa/

USGS water programs in Hawaii:
http://hi.water.usgs.gov/

Ground water and aquifers in Hawaii: *http://capp.water.usgs.gov/gwa/ch_n*

Major Findings

These findings are supported by the Study-Unit Design presented on pages 20 and 21 of this report.

Ground Water

Organic compounds were detected in most wells, but few concentrations exceeded drinking-water standards

Organic compounds were detected in 73 percent of 30 public-supply wells and in all 15 monitor wells (Hunt, 2004; see map, p. 20, for well locations). Forty-two different organic compounds were detected at least once: 25 **volatile organic compounds** (VOCs), 16 pesticides, and caffeine. Sixty-three percent of public-supply wells contained at least one VOC or pesticide (fig. 6). Types of compounds detected most commonly were solvents (cleaning and degreasing agents), fumigants (used locally to combat rootworms in pineapple), trihalomethanes (generally thought to originate from chlorinated water), and herbicides. Gasoline components and insecticides were detected in only a few wells.

Chemicals and concentrations were similar in public-supply and monitor wells

Many of the same compounds were detected in public-supply wells and monitor wells, and at roughly similar concentrations (figs. 7 and 8). This is not surprising because both groups of wells tap the same deep aquifer, although most monitor wells are open at the water table, whereas most supply wells are protectively solid-cased for some distance below it (median depth below water table to top of open interval is 60 feet).

The solvent trichloroethene had the highest VOC concentration at 20.4 micrograms per liter (fig. 8). The most common VOC was chloroform (trichloromethane), which was detected in 47 percent of supply wells (fig. 7). Chloroform is used as a solvent and is a breakdown product of carbon tetrachloride (tetrachloromethane). On Oahu, solvents appear to be the main source of chloroform because it was at highest concentration where other solvents (including carbon tetrachloride) were highest. But chloroform also can form as a disinfection byproduct where chlorine contacts organic material (the reaction can take place in wastewater disinfected with chlorine, or in soils where chlorinated drinking water is used to water lawns). A disinfection origin cannot be ruled out for Oahu because chlorinated water is used for landscape irrigation, and wastewater discharged to a central Oahu stream and lake was chlorinated for decades, although it is no longer.

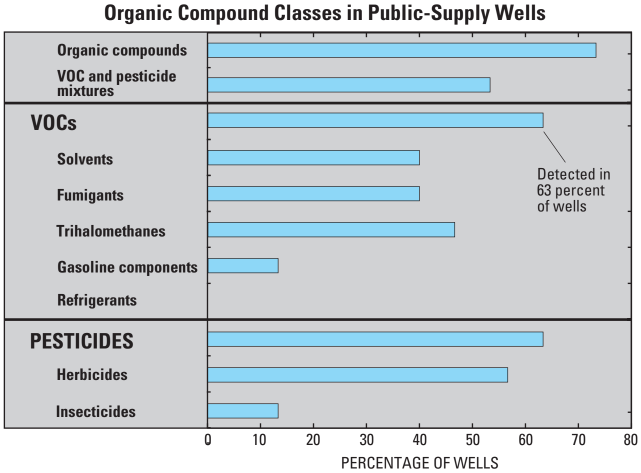


Figure 6. Solvents, fumigants, and herbicides were detected in many public-supply wells. The high detection rate for trihalomethanes was due to a single compound, chloroform.

The most common pesticide in ground water was the herbicide bromacil, which was detected in 41 percent of public-supply wells (fig. 7) and had the highest concentration among pesticides, 1.08 micrograms per liter (fig. 8). Bromacil has been applied in pineapple cultivation in central Oahu. Three other commonly detected herbicides—atrazine, diuron, and hexazinone—have been used on both sugarcane and pineapple. Breakdown products of atrazine and diuron were detected in more public-supply wells than were their parent compounds (fig. 7). Only two insecticides were detected: dieldrin (a termiticide) and p,p'-DDE (a breakdown product of **DDT**). Three turfgrass herbicides that were first used in the 1990s (bentazon, imazaquin, and metsulfuron methyl) were detected in monitor wells that tap shallow ground water beneath a golf course and a cemetery.

Monitoring programs that only test for primary chemicals would not reveal the pesticide breakdown products detected in this study, some of which persist longer in the environment and have similar or greater toxicity than parent compounds.

Federal drinking-water standards were exceeded in two public-supply wells

Although organic compounds commonly were detected, most concentrations were low (less than 1 microgram per liter) and only a few concentrations exceeded drinking-water standards (table 1 and Appendix, p. 26–28). [Note: all supply wells exceeding standards are either out of service or have water-treatment equipment installed to reduce contaminants to acceptable levels.]

Federal drinking-water standards (U.S. Environmental Protection Agency, 2002a) were exceeded in two public-supply wells: one central Oahu well in which trichloroethene (TCE) concentration was 20.4 micrograms per liter (the USEPA standard is 5) and one Honolulu well in which radon concentration was 397 picocuries per liter (the proposed USEPA standard is 300). Trichloroethene is a common solvent, and radon is a radioactive gas formed naturally by decay of uranium, which is present in volcanic rock. Trichloroethene also exceeded the USEPA standard in one monitor well (fig. 8). Concentrations of trace elements did not exceed standards, and arsenic was not detected in public-supply wells.

State drinking-water standards (State of Hawaii, 1999) were exceeded in four central Oahu public-supply wells by fumigants: 1,2-dibromo-3-chloropropane (DBCP) and 1,2,3-trichloropropane (TCP) in one well each, and by both compounds in two wells (table 1). State standards are more stringent (substantially lower) than USEPA standards or guidelines for these fumigants. Two central Oahu monitor wells also had fumigant concentrations that exceeded State standards (fig. 8).

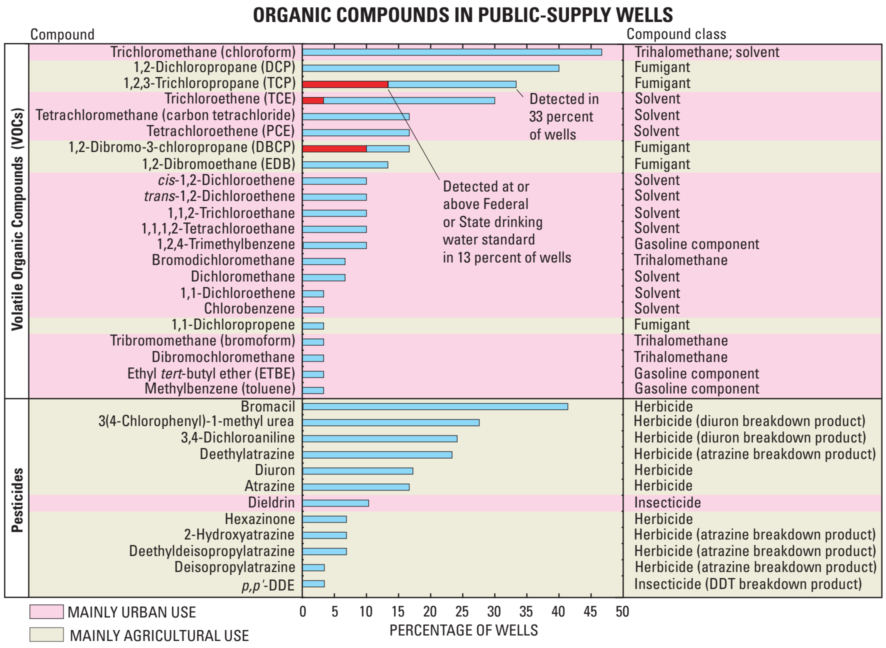


Figure 7. Organic compounds detected in public-supply wells included 22 VOCs and 12 pesticides. Only three compound concentrations exceeded drinking-water standards.

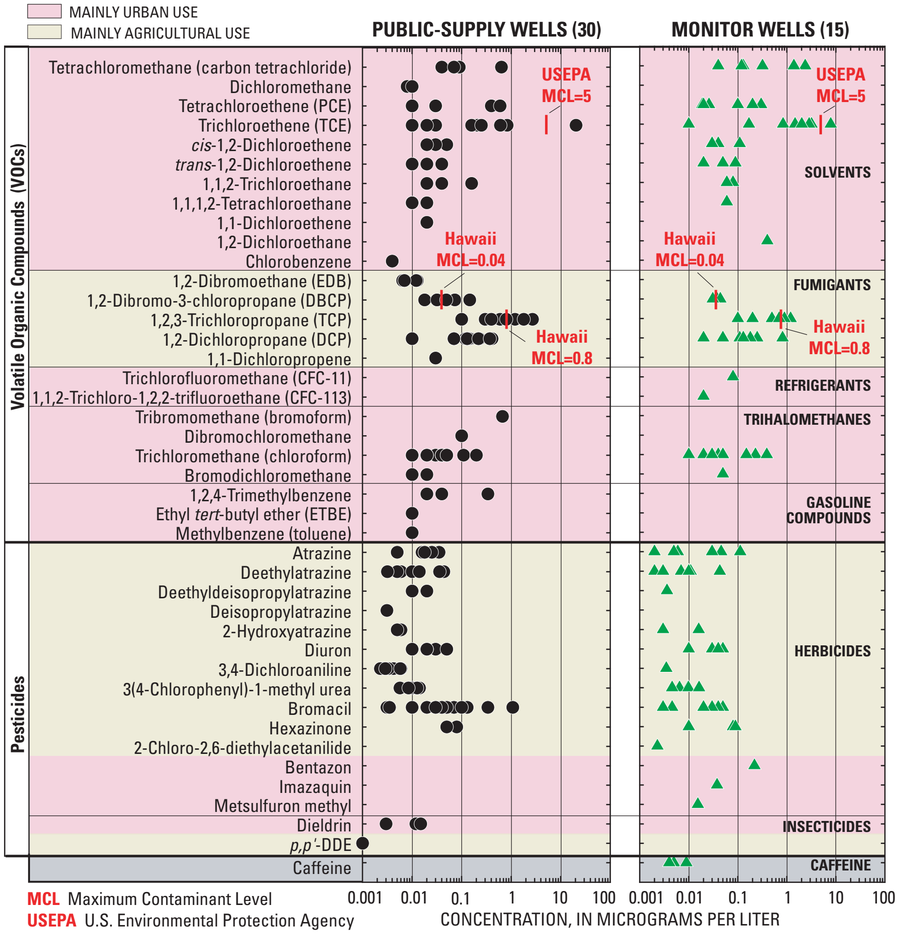


Figure 8. Detected compounds and concentrations were similar in public-supply and monitor wells. Trichloroethene and bromacil were the highest-concentration VOC and pesticide.

Nutrient concentrations were elevated in agricultural areas but did not exceed drinking-water standards

Nutrient concentrations in central Oahu ground water were greater than background concentrations, most likely as a result of decades of agricultural fertilizer application. Background concentrations of nitrate in forested areas were 1 milligram per liter or less as nitrogen, whereas the median concentration in agricultural areas was 2.5 and the maximum was 5.2 (about one-half the USEPA drinking-water standard of 10 milligrams per liter). Phosphorus background concentrations were 0.1 milligram per liter or less, as compared to a median of 0.2 and maximum of 0.4 in agricultural areas. There is no drinking-water standard for phosphorus, but two-thirds of ground-water samples had phosphorus concentrations that exceeded the USEPA recommended goal of 0.1 milligram per liter for preventing nuisance plant growth in streams. Excessive nutrients in ground-water discharge may foster excessive plant or algal growth (eutrophication) that can interfere with stream or coral-reef ecology. Oahu NAWQA surface-water studies (Tomlinson and Miller, in press) have attributed high nitrate and phosphorus concentrations in stream base flow to nutrient-rich ground water (see p. 13, “Ground water contributes nutrients to gaining streams”).

How NAWQA findings relate to drinking-water standards

NAWQA studies are designed to characterize ambient ground water within aquifers. Although aquifers provide source water for drinking supplies, NAWQA collects samples at the wellhead before any water treatment or blending of sources prior to consumption. NAWQA analyses differ from tests performed to check whether drinking water complies with Federal or State drinking-water standards and do not reflect the quality of finished (treated) drinking water delivered to the public. Nevertheless, this report discusses chemical concentrations in relation to existing USEPA and State drinking-water standards, which are set to ensure that drinking water does not pose health risks. Drinking-water standards have not been established for all chemicals, however. Out of 25 VOCs and 16 pesticides detected in Oahu NAWQA ground-water samples, 4 VOCs and 10 pesticide compounds do not have USEPA drinking-water standards or health advisory guidelines.

Table 1. Four chemicals in untreated water from public-supply wells exceeded drinking-water standards.

[All concentrations in micrograms per liter except 222-Radon in picocuries per liter; USEPA, U.S. Environmental Protection Agency; MCL, Maximum Contaminant Level standard; HAL, Lifetime Health Advisory Level guideline; --, not applicable; 222-Radon MCL is a proposed standard]

		Maximum concentration in public-supply wells	Drinking-water standards or guidelines			Number of wells with concentrations exceeding standards	
Chemical	Type of chemical		USEPA MCL	Hawaii MCL	USEPA HAL	USEPA MCL	Hawaii MCL
Trichloroethene (TCE)	Solvent	20.4	5	5	--	1	1
222-Radon	Radionuclide	397	300	300	--	1	1
1,2-Dibromo-3-chloropropane (DBCP)	Fumigant	0.146	0.2	0.04	--	0	3
1,2,3-Trichloropropane (TCP)	Fumigant	2.7	--	0.8	40	0	3

Land use and aquifer vulnerability influence ground-water contamination

Characteristic suites of chemicals in ground water were associated with particular land uses and locales. Specifically:

1. Solvents were prevalent throughout central Oahu (fig. 9), with highest concentrations beneath urban areas and military installations and mostly trace concentrations beneath agricultural lands.
2. Fumigants (fig. 10), herbicides, and elevated nutrient concentrations were prevalent beneath central Oahu agricultural lands.
3. Minimal contamination was detected in urban Honolulu, including 2–3 detections each of gasoline components, herbicides, and the insecticide dieldrin.

Widespread ground-water contamination in central Oahu is a consequence of intensive chemical use in recharge areas over unconfined aquifers. Large tracts of agricultural land have received repeated applications of fumigants, herbicides, and fertilizers for decades

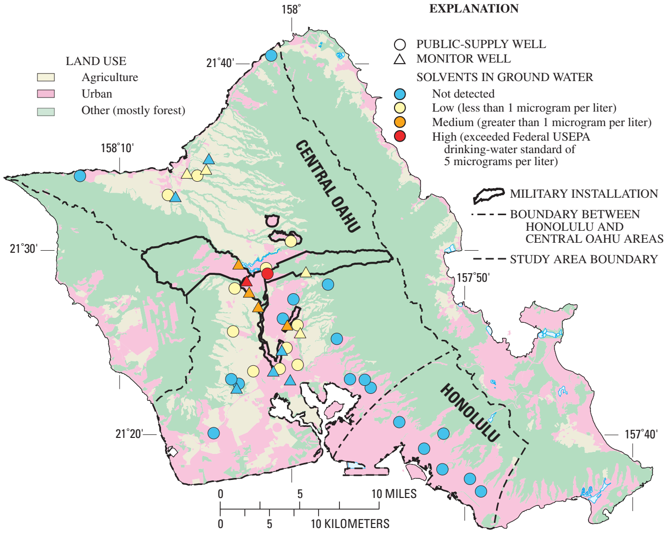


Figure 9. Solvents were detected in central Oahu ground water near urban areas and military installations.

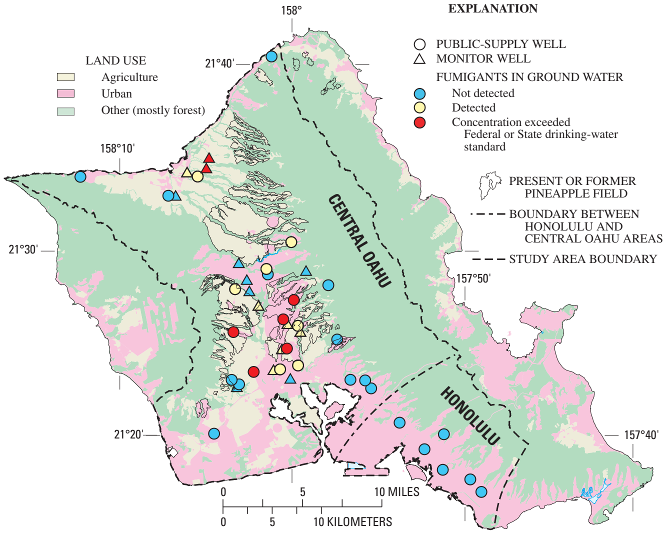


Figure 10. Fumigants were detected in central Oahu ground water, in and near present and former pineapple fields.

Detection rates in ground water were highest in the Nation for fumigants and among the highest for solvents, VOCs, and insecticides

Out of more than 80 NAWQA studies of VOCs in major aquifers nationwide, Oahu ranked first in the percentage of wells in which fumigants were detected, third in solvent detections, and fourth in overall VOC detections using data screened at 0.2 microgram per liter (see “NAWQA measures compounds at trace concentrations” below). The high fumigant ranking reflects a combination of factors, including extensive pineapple acreage in central Oahu, high fumigant application rates (for example, 1.8 million pounds in 1970 at a rate of 115 pounds per acre; Takahashi, 1982), and high rainfall (40–80 inches per year) that promotes leaching from soil to ground water. The high solvent ranking is believed to reflect past military use of solvents in central Oahu dating back to the 1940s at aircraft and automotive maintenance shops (Harding Lawson Associates, 1995; U.S. Environmental Protection Agency, 2000). The high VOC ranking simply reflects the high rankings for the fumigant and solvent VOC subclasses.

For pesticides, Oahu ranked 12th in insecticide detections and 51st in herbicide detections out of more than 90 NAWQA studies of pesticides in major aquifers. The insecticide ranking resulted from four detections in public-supply wells: dieldrin in three wells and p,p'-DDE (a DDT breakdown product) in one well. Notably, the herbicide ranking does not tell the entire herbicide story for Oahu. More than 75 percent of Oahu herbicide detections were from two supplemental lists of pesticides (Hunt, 2004) that were not factored into the national rankings because they were not analyzed in all Study Units. The supplemental lists contain several of the most widely used and detected herbicides on Oahu, namely bromacil, diuron, and hexazinone.

(Yim and Dugan, 1975; Oki and Brasher, 2003). Solvents and petroleum products have been used and stored at several military installations since the 1940s (Harding Lawson Associates, 1995; U.S. Environmental Protection Agency, 2000), and potential civilian sources of these contaminants include gasoline stations and automotive repair shops in suburban residential areas.

In contrast to central Oahu, few organic compounds were detected in Honolulu wells despite the high urban density there. Much of Honolulu is underlain by sedimentary confining units or lies in the zone of aquifer discharge near the coast. Lands that do overlie unconfined recharge zones are mainly residential, with little industrial or military use. This reflects nearly a century of sound urban planning and watershed protection by State and county agencies that directed intensive chemical use and storage away from inland recharge areas of urban Honolulu.

Mixtures of organic compounds were common in ground water

Organic compounds seldom occurred alone in ground water on Oahu (fig. 11). Multiple organic compounds were detected in 63 percent of public-supply wells, and combinations of VOCs and pesticides were detected in 53 percent (fig. 6). Many wells in central Oahu contained several types of compounds, such as solvents, fumigants, and herbicides. Sampled wells contained as many as 10 solvent compounds, and samples with the highest fumigant concentrations contained 3 to 4 fumigants, as well as trace concentrations of herbicides and solvents. Herbicides also occurred together, with as many as 10 herbicide compounds detected in one sample.

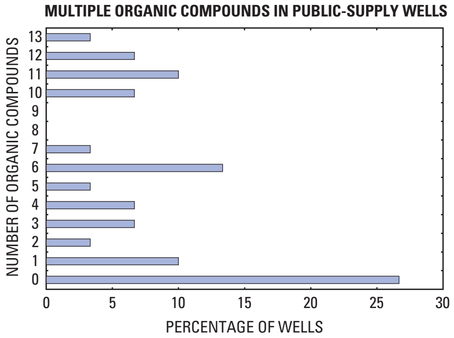


Figure 11. Most public-supply wells contained 2 or more organic compounds, and as many as 13 were detected in one well.

NAWQA measures compounds at trace concentrations

NAWQA measures compounds at trace levels, commonly 10 to 1,000 times lower than drinking-water standards and aquatic-life guidelines. Trace concentrations are useful in assessing contaminant occurrence, distribution, and variation over time. Detection rates and concentrations contained in this report include all chemical detections, including trace-level detections. Higher reporting levels are sometimes used to screen data when making comparisons among NAWQA Study Units nationwide. This is done to include early NAWQA studies that had higher laboratory reporting levels than later studies (in the case of VOCs) or to include results of several different laboratory methods, each having different reporting levels (such as multiple pesticide methods). Of the 25 VOCs and 16 pesticides detected in ground water on Oahu, only 9 VOCs and 5 pesticides were detected at concentrations at or above screening levels commonly used in NAWQA Study-Unit comparisons (0.2 microgram per liter for VOCs and 0.05 microgram per liter for pesticides).

Toxicological evaluations of risks to human health have been used to establish drinking-water standards for many individual compounds. Risks associated with compound mixtures, however, are not as well understood but have been reported to be greater than those of the individual compounds in some cases (Bartsch and others, 1998; Carpenter and others, 1998).

Ground-water contamination in central Oahu reflects decades-old releases and former land use

Ground-water ages estimated from analyses of chlorofluorocarbons (CFCs) and sulfur hexafluoride (SF_6) spanned the last 60 years or so, coinciding with increasingly widespread and intensive chemical use in the second half of the 20th century. Only 1 of 45 ground-water samples had a pre-1940 apparent recharge date (no CFCs present), and 6 samples (13 percent) consisted of water that was recharged as recently as the 1990s (Hunt, 2004). The young ages and the prevalence of organic compounds in central Oahu highlight the vulnerability of Hawaii's unconfined volcanic-rock aquifers to contamination from human activities: water can travel from land surface to the deep water table within a decade or so, carrying spilled or applied chemicals with it.

From a land-use perspective, however, it is notable that most water samples had apparent ages from the 1950s to 1980s. Therefore, much of the observed organic and nutrient contamination on Oahu corresponds to historical chemical releases and applications and, in some cases, to discontinued chemicals and outmoded practices. Several detected compounds such as EDB, DBCP, and DDT (whose breakdown product p,p'-DDE was detected) were discontinued from use in the 1970s and 1980s.

One objective of the Oahu NAWQA study was to detect changes in water quality that might accompany the recent conversion of former plantation lands to residential use and diversified-crop agriculture in central Oahu. Only a few unambiguously "new" urban chemicals were detected in monitor wells: the post-1990 turfgrass herbicides bentazon, imazaquin, and metsulfuron methyl beneath a golf course and cemetery. The prevalence of several older agricultural chemicals in ground-water samples suggests that there has not yet been a wholesale changeover to a newer "urban" ground-water quality. This likely reflects a combination of factors: (1) older water and chemicals have not yet been fully flushed out of the aquifer and unsaturated zone by younger water, (2) some newer chemicals may break down more rapidly or leach less than older chemicals, and (3) wells selected for this study inadequately sampled younger water. Short-screened monitor wells (such as the 15 monitor wells sampled in this study) are useful for early detection of new contaminants arriving at the water table. Sampling of shallower unsaturated-zone water would provide even earlier warning of future contamination.

Additional Information

Oahu NAWQA ground water: *http://hi.water.usgs.gov/nawqa/gw.html*

USEPA drinking-water regulations: *http://epa.gov/safewater/mcl.html*

Hawaii drinking-water regulations: *http://state.hi.us/doh/rules/11-20.pdf*

Surface Water

Contaminants in stream water varied with land use, storms, and ground-water inflow

Some chemicals are used primarily for agriculture and others primarily in urban environments, so land use largely determines which chemicals are present in a particular stream. The linkage between chemical use and contamination is important because managing chemical use and improving application efficiency can help reduce contaminant levels in both urban and agricultural settings. Also important are the properties of the chemicals themselves: some chemicals break down rapidly and others persist in the environment for decades; some chemicals dissolve readily in water and infiltrate to ground water, whereas other chemicals bind strongly to soil particles and are washed into streams by storm runoff.

Of the 47 pesticides detected in stream water, insecticides were detected more frequently than herbicides in urban Manoa Stream, whereas herbicides were detected more frequently in Waikele Stream, which drains mixed agricultural and urban land (Tomlinson and Miller, in press). Both streams contained more herbicides than insecticides. Different pesticides were present at low and high flow, with herbicides generally detected more frequently in base flow and insecticides generally detected more frequently in storm runoff. Many of the pesticides detected frequently in base flow also were present in ground water.

Volatile organic compounds (VOCs) also showed a distinct pattern: VOCs detected in urban Manoa Stream included gasoline components (benzene, toluene, m- and p-xylene, 1-isopropyl-4-ethylbenzene, styrene) and solvents (acetone, chloromethane), whereas VOCs detected in agricultural-urban Waikele Stream were the fumigants 1,2,3-trichloropropane (TCP), 1,2-dichloropropane (DCP), and 1,2-dibromoethane (EDB); the solvent trichloroethene (TCE); the trihalomethane chloroform; and a gasoline hydrocarbon, toluene. The fumigants were highest in concentration at base flow and also were detected in central Oahu wells. Ground water is the main source of elevated concentrations of chemicals in stream base flow at Waikele Stream (fig. 12).

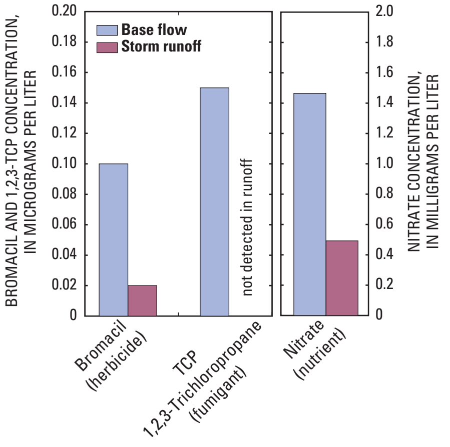


Figure 12. Ground-water inflow elevates herbicide, fumigant, and nutrient concentrations in Waikele Stream base flow.

Land use largely determined which pesticides were detected in streams

Herbicides detected most frequently in agricultural-urban Waikele Stream were bromacil, atrazine, diuron, breakdown products of atrazine and diuron, and imazaquin (fig. 13). Herbicides detected most frequently in urban Manoa Stream were prometon and bentazon. The insecticides diazinon, carbaryl, and malathion were detected frequently in both settings, but dieldrin was detected only in urban Manoa Stream, and chlorpyrifos was detected only in agricultural-urban Waikele Stream.

Ground water supplies older herbicides to streams

Different pesticides were present in base flow than in storm runoff in agricultural-urban Waikele Stream, and many of the pesticides detected frequently in base flow also were present in ground water. The herbicides bromacil, atrazine, and diuron were detected more frequently and at higher concentrations in base flow than during storms (fig. 13). These herbicides have been used extensively since the 1950s and 1960s to control weeds in sugarcane and pineapple and were detected widely in wells in central Oahu (see p. 6, “Chemicals and concentrations were similar in public-supply and monitor wells”). Because it takes decades for water to move through the ground-water system, the deep volcanic aquifer serves as a long-term reservoir that contributes herbicides and other constituents to stream base flow. The older herbicides were detected less frequently and at lower concentrations in runoff than in base flow because of increased dilution by rainfall.

In contrast to the older herbicides, bentazon and imazaquin (herbicides introduced on Oahu since 1990 and used on turfgrass) were detected more frequently or at higher concentrations in storm runoff than in base flow at Waikele Stream. Bentazon and imazaquin were detected in only one central Oahu monitor well. These newer herbicides appear to be washed off or flushed from soil during storms, and they either do not reach ground water in detectable concentrations or have not had sufficient time to accumulate in deep ground water like the older agricultural herbicides bromacil, atrazine, and diuron.

In urban Manoa Stream, prometon was detected more frequently in base flow than during storms, whereas diuron, 3,4-dichloroaniline (a diuron breakdown product), and the three post-1990 turfgrass herbicides bentazon, imazaquin, and metsulfuron methyl (not shown) were either detected more frequently or at highest concentrations in storm runoff. The causes of these associations are unclear but may have to do with compound mobility, relative affinity for water or sediment, date of introduction, and compound buildup in the valley-fill aquifer system that supplies base flow to Manoa Stream. Notably, the frequent detection of diuron and diuron breakdown products in storm runoff at urban Manoa Stream is opposite the pattern at agricultural-urban Waikele Stream. This may reflect a lesser ground-water reservoir of diuron at Manoa Stream in comparison to Waikele Stream.

Insecticides exceeded aquatic-life guidelines in water and are carried mainly by runoff

The insecticides carbaryl, diazinon, malathion, and chlorpyrifos were detected more frequently and at higher concentrations in storm runoff than in base flow (fig. 13). This indicates that they mainly are washed off or flushed from soil by rainstorms. Dieldrin was present in nearly all samples from urban Manoa Stream and was detected with nearly equal frequency at both high and low flow. Carbaryl, diazinon, and malathion have been used for vegetable crops and to control insects around the home. These insecticides were not detected in wells, probably because they break down relatively quickly or are not particularly soluble in water.

Dieldrin, carbaryl, diazinon, and malathion exceeded aquatic-life guide-

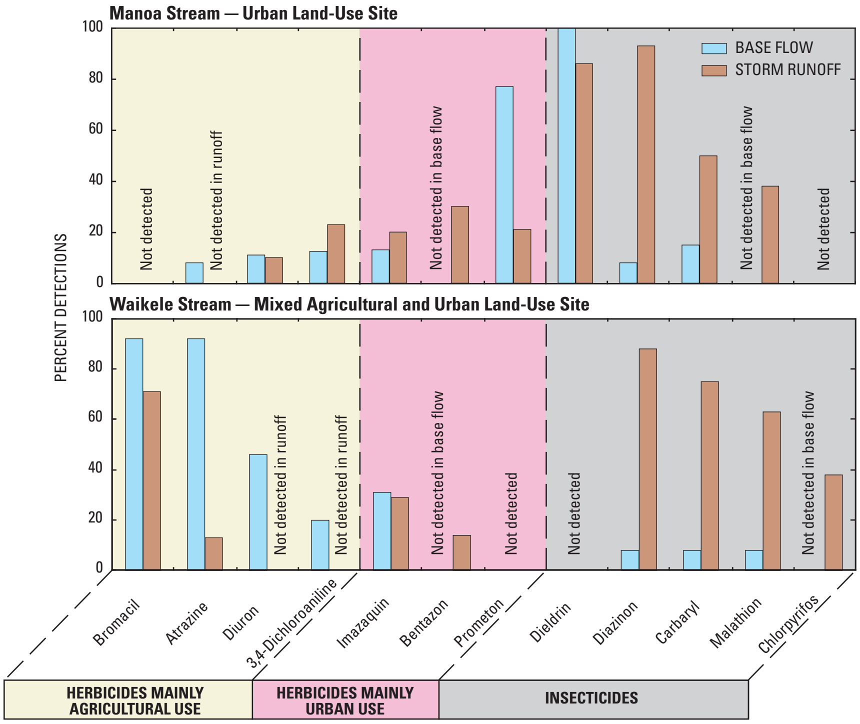


Figure 13. In general, herbicides were detected more frequently in stream base flow (supplied by ground water) and insecticides were detected more frequently in storm runoff. Dieldrin was detected at both high and low flow in Manoa Stream.

Table 2. Concentrations of four insecticides sometimes exceeded aquatic-life guidelines in urban Manoa Stream and agricultural-urban Waikele Stream.

[E, estimated]

Pesticide	Aquatic life guideline (micrograms per liter)	Percentage of samples that exceeded guideline (in parentheses)	Range of concentrations detected at the site (micrograms per liter)
Dieldrin	[1]0.056	Manoa (26)	0.015 – 0.077
Malathion	[1]0.1	Waikele (5)	E0.004 – 0.184
Diazinon	[2]0.08	Manoa (4) Waikele (14)	0.003 – 0.083 0.004 – 0.293
Carbaryl	[3]0.2	Manoa (11) Waikele (10)	E0.007 – E0.37 E0.01 – E0.294

[1] USEPA chronic water-quality criteria for protection of aquatic organisms (U.S. Environmental Protection Agency, 2002b).

[2] Great Lakes water-quality objectives (International Joint Commission United States and Canada, 1989).

[3] Canadian water-quality guidelines (Canadian Council of Ministers of the Environment, 1999).

lines in Manoa and Waikele Streams (table 2). Dieldrin exceeded its USEPA aquatic-life guideline in 26 percent of samples from Manoa Stream, and by extrapolating from continuous flow data it is estimated that dieldrin might exceed the guideline about 47 percent of the time. Aquatic-life guidelines have been established for only 13 of the 47 pesticides detected in Oahu streamwater.

Dieldrin persists in urban streams

The organochlorine insecticides dieldrin, aldrin (which breaks down to dieldrin), chlordane, and heptachlor were used for decades in Hawaii to control termites but were phased out by about 1988 in favor of less persistent compounds (Brasher and Anthony, 2000; Brasher and Wolff, 2004). Dieldrin was detected more often in urban Manoa Stream water than any other insecticide. Concentrations of dieldrin in Manoa Stream were highest in base flow (reaching a maximum of 0.077 microgram per liter) but also remained elevated during storms. In fact, concentrations of dieldrin during storms were still one-half to one-third the concentration in base flow, despite as much as a hundredfold dilution of base flow by storm runoff. This suggests that dieldrin originates from several sources in the Manoa Stream drainage (fig. 14): it may be flushed from soil and carried to the stream by rainfall runoff, it may be supplied by ground-water inflow, and it may dissolve into the water column from stream sediments (Larson and others, 1997).

More frequent detection of dieldrin than other insecticides probably is due to its being one of the more long-lived compounds within the historically used organochlorine group, resulting in great persistence in soils (Fuhrer and others, 1999). Soils and stream sediments in urban Honolulu likely serve as long-term reservoirs of dieldrin. The valley-fill aquifer system immediately beneath the stream may also act as a persistent reservoir of dieldrin. The valley-fill aquifer system is not used for drinking-water supply, but it does contribute base flow to Manoa Stream. Although dieldrin was detected in the deep volcanic aquifer in Honolulu (the drinking-water aquifer), this probably is not a source of dieldrin to Manoa Stream. Concentrations of dieldrin in water from the deep aquifer were 2 to 10 times lower than concentrations in stream base flow (0.003–0.015 compared to 0.032–0.077 microgram per liter), and ground-water levels are not high enough to force seepage from the deep aquifer into the stream at the sampling site.

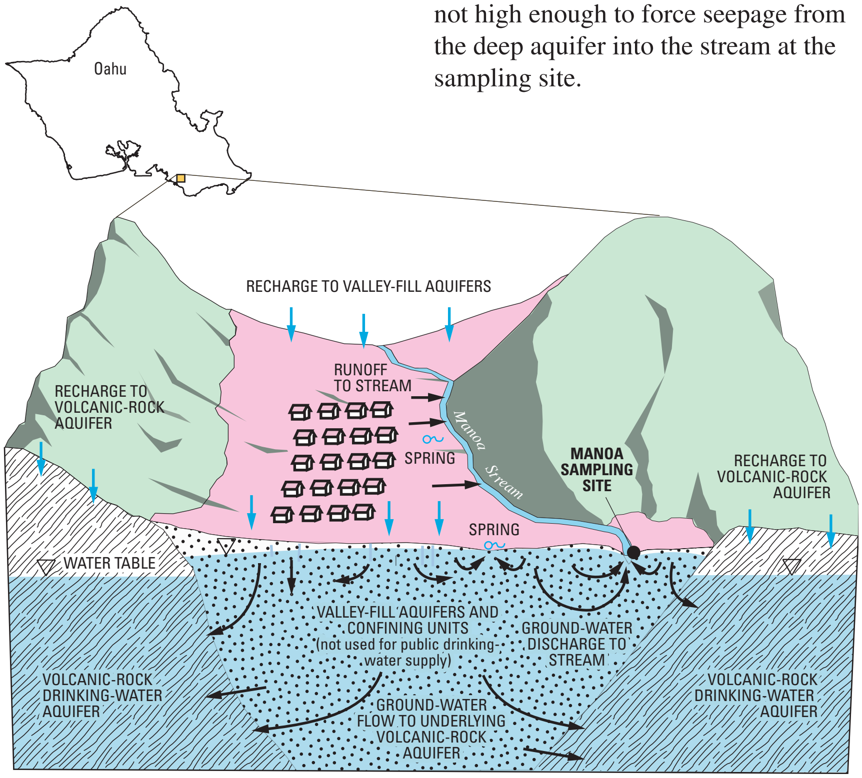


Figure 14. Possible sources of dieldrin in Manoa Stream include surface runoff of water and soil, transfer from stream sediments to the water column, and ground-water inflow from the valley-fill aquifer system. The volcanic-rock aquifer probably is not a source because water levels in that aquifer are lower than the stream. (Modified from block diagram provided by Scot Izuka, U.S. Geological Survey.)

Excess nutrients may adversely affect stream and coastal ecosystems

Concentrations of nutrients in Oahu streams were moderate to high in comparison to streams studied by NAWQA across the Nation. Flow-weighted mean concentrations of total nitrogen in Manoa and Waikele Streams ranked in the middle 50 percent of 497 streams sampled nationwide, and mean concentrations of total phosphorus ranked in the highest 25 percent of streams. Nutrient concentrations consistently exceeded State water-quality guidelines (State of Hawaii, 2002) and may be of concern locally because of nutrient-sensitive coral reefs along the coast.

Agricultural fertilizers are a source of nutrients

Agricultural-urban Waikele Stream had dissolved nitrate concentrations more than 10 times greater (median value 1.2 milligrams per liter as N) than those in urban Manoa Stream or forested Waihee Stream (fig. 15). Dissolved phosphorus at Waikele (median concentration 0.14 milligram per liter as P) was about 4 to 6 times higher than at Manoa or Waihee. High concentrations of nutrients in Waikele Stream likely result from large amounts of fertilizers applied to agricultural land in the Waikele basin.

Ground water contributes nutrients to gaining streams

Nutrient contamination in streams is commonly attributed to agricultural runoff or to effluent discharged from wastewater-treatment plants. However, ground water largely controls nutrient concentrations in Waikele Stream, which more closely resemble ground-water concentrations than concentrations in Manoa or Waihee Streams (fig. 15).

The influence of ground water was studied by sampling two sites along Waikele Stream (fig. 4). Nitrate and phosphorus concentrations were much lower at the upper Waikele site than at the lower Waikele site a short distance downstream (fig. 16). The increased concentrations are directly attributable to ground-water inflow to the stream. The regional water table lies beneath the streambed at the upper site but intersects it at the lower site, causing a gaining reach of stream where streamflow is augmented by ground-water discharge. Despite the ground-water contribution, nutrient concentrations at the lower Waikele site were not as high as in nearby ground water (median concentration from five nearest wells). Possible reasons include spatial variability of nutrients in ground water (concentrations right at the streambed may differ from concentrations at nearby wells), natural removal processes such as plant uptake or **denitrification** that could reduce nutrient concentrations, and dilution by the upstream component of streamflow arriving at the lower Waikele site. Dilution alone cannot explain the differences between ground-water and stream concentrations, however. Flow at lower Waikele in figure 16 was about 88 percent ground-water-derived, yet median stream concentrations were less than one-half the median ground-water concentrations instead of the approximately nine-tenths proportion that would be expected from simple dilution by upper Waikele streamwater.

Dilution is most distinct during storms, as can be seen by segregating the lower Waikele data into base-flow and storm events (fig. 17). Lower nutrient concentrations during storms reflect dilution of ground-water-fed base flow at the lower Waikele site by large amounts of storm runoff from upstream.

Ground-water contributions of nutrients and other contaminants are significant to water-resource programs such as those that establish **Total Maximum Daily Loads** (TMDLs) in streams. If ground-water contributions are not adequately defined, this would prevent a full accounting of all contributing sources and limit the effectiveness that TMDLs would have in future stream restoration and protection.

Nutrients and suspended sediments exceeded state standards for streamwater quality and may affect coastal ecosystems

More than 30 streams on Oahu have been identified by the State as water-quality impaired, primarily for exceeding standards for nutrients and **suspended** sediment (Henderson and Harrigan, 2002). As a consequence, the State is coordinating with stakeholders and government agencies to reduce **non-point-source** pollution and is studying

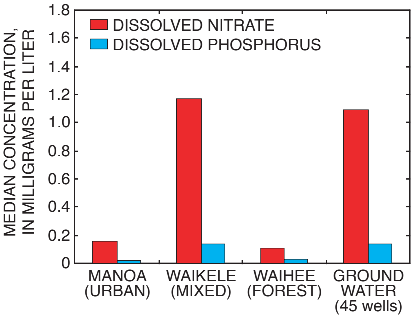


Figure 15. Agricultural fertilizers cause elevated nutrient concentrations in Waikele Stream and in ground water.

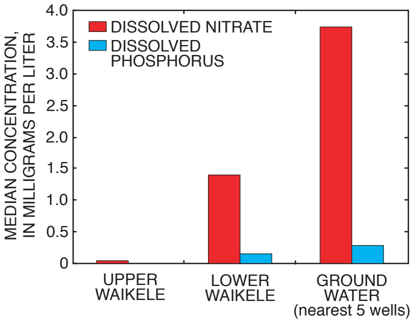


Figure 16. Nutrient concentrations at Waikele increase downstream because of nutrient-laden ground-water inflow.

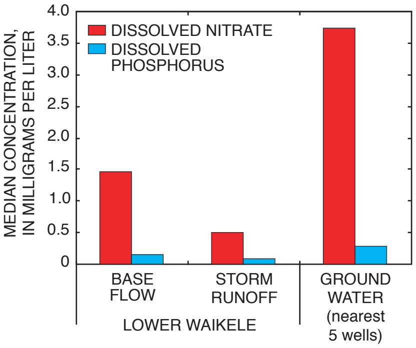


Figure 17. Ground-water inflow (base flow) containing substantial nutrients is diluted by runoff during storms.

selected streams under the USEPA Total Maximum Daily Load (TMDL) program of the Clean Water Act.

NAWQA sampling showed that concentrations of nutrients in urban Manoa Stream and agricultural-urban Waikele Stream consistently exceeded State water-quality standards by a factor of 3 or 4 (State of Hawaii, 2002). Even undeveloped, forested Waihee Stream consistently exceeded State standards for total nitrogen, total phosphorus, and dissolved nitrogen. Standards for suspended solids were consistently exceeded at urban Manoa Stream and sometimes exceeded at agricultural-urban Waikele Stream and forested Waihee Stream.

Annual amounts (or loads) of nutrients and suspended sediment carried from the Waikele Stream basin to coastal waters were estimated at about 28 tons of dissolved nitrogen, 3.5 tons of dissolved phosphorus, and 4,300 tons of suspended sediment, respectively (fig. 18; Tomlinson and Miller, in press). Nutrients also enter Hawaiian coastal waters from numerous other streams, as well as from ground-water discharge. In fact, submarine discharge of nutrients to the ocean may far exceed nutrients delivered by stream runoff, as indicated by elevated concentrations of nutrients in Oahu ground water. Nutrients and suspended sediment are a management concern for Hawaiian coastal waters because of potential effects on nearshore coral reefs, which are an important biological resource and an integral part of Hawaii's economically important tourist industry. Reefs and associated estuaries are susceptible to nutrient and sediment loading above natural background levels (U.S. Coral Reef Task Force, 1999; Clark, 1995). Nutrient concentrations in streams and ground water are 100 to 1,000 times the nutrient guidelines for coral reefs.

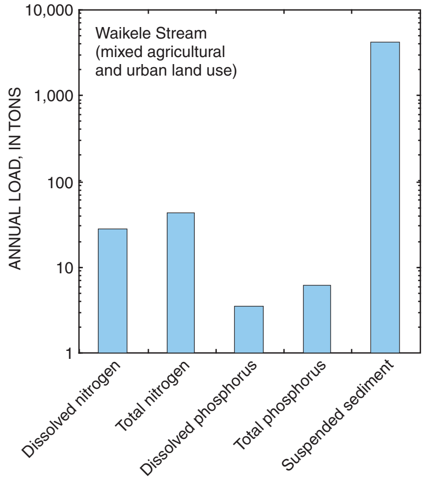


Figure 18. Tons of nutrients and suspended sediment are delivered to coastal waters by a single Oahu stream. Dissolved nitrogen and phosphorus account for the bulk of the nutrient load, much of it originating from ground-water inflow to the stream.

Additional Information

Oahu NAWQA surface water: *http://hi.water.usgs.gov/nawqa/sw.html*

USEPA surface-water standards: *http://epa.gov/waterscience/standards*

Hawaii water quality standards: *http://www.state.hi.us/doh/rules/11-54.pdf*

Streambed Sediment and Fish Tissue

Aquatic habitat is degraded by nonpoint-source pollution

Traditionally, water-quality monitoring has focused on surface-water sampling. There are compelling reasons why contaminants in streambed sediment and fish tissue also were analyzed in the Oahu NAWQA study. Different types of compounds are more readily detected in sediment and tissue (hydrophobic compounds) than in water (hydrophilic, or water-soluble, compounds). Furthermore, analyses of sediment and fish provided measures of these contaminants that are integrated over time. A joint approach of sampling water, sediment, and fish provides the best means of detecting chemicals in the hydrologic system and the most information for management decisions.

Nonpoint-source pollution is an urban as well as an agricultural problem. Some of the greatest nonpoint-source effects on stream quality on Oahu are in urban watersheds, where contaminants such as organochlorine compounds and semivolatile organic compounds (SVOCs) were detected at greater frequencies and concentrations than in other land-use settings. Improvements in water quality will therefore depend not only on managing point sources of pollution, but also on managing various diffuse, nonpoint contributions from lawns, gardens, cars, and developed land.

Discontinued organochlorine pesticides persist in the environment

The organic compounds of greatest concern in Oahu streams are organochlorine insecticides used for termite control: dieldrin and chlordane. Chlordane and aldrin (which breaks down to dieldrin) were used heavily in urban settings until discontinued in the mid-1980s (Takahashi, 1982) and persist today in streambed sediment and fish at concentrations well above aquatic-life and wildlife guidelines (Appendix, p. 29). DDT, another organochlorine insecticide, was used in both agricultural and urban settings on Oahu (Honolulu Star Bulletin, 1944) before being discontinued from use in the United States in 1972. Although environmental concentrations have decreased substantially since the 1970s, DDT and its breakdown products still are present at elevated levels in Oahu streams (Appendix, p. 29).

The persistence of organochlorine compounds in Oahu streams likely reflects slow breakdown of the compounds, persistent reservoirs of the compounds in soils, and continual delivery to streams. Organochlorine compounds are hydrophobic: they do not dissolve well in water but instead bind strongly to soil particles and are carried with eroded soils to streams by runoff. Once in streams, the soil-bound compounds dissolve in water to a slight degree but mostly remain suspended or settle to the streambed. From the water column or sediment, the compounds may be absorbed by plants or ingested by invertebrates and fish. Streams can transport significant amounts of dissolved or sediment-bound chemicals to nearshore coastal waters, a major concern in island ecosystems. Although little can be done about present-day concentrations in soils, controlling soil erosion could reduce the quantities of contaminated sediment entering streams and, ultimately, estuaries and nearshore marine waters.

Organochlorine compounds and SVOCs in sediment were strongly associated with urban land use

Land use largely determines what compounds are used in a given area, as well as the concentrations at which they are detected in the environment. For example, more organochlorine compounds (as many as 15) were detected in streambed sediments and fish tissue at urban and mixed land-use sites than at agricultural or forested sites (fig. 19). This is because organochlorine pesticides and polychlorinated biphenyls (PCBs) are primarily urban-use chemicals. Chlordane compounds were the most frequently detected organochlorine compounds at urban sites (present in 100 percent of sediment and fish samples), followed by dieldrin, DDT compounds, and total PCBs (Appendix, p. 29–30). Chlordane and dieldrin were not detected at agricultural or forested sites, again because they are used in Hawaii as urban termiticides. DDT compounds were detected in fish tissue and streambed sediments at agricultural sites (Brasher and Wolff, 2004).

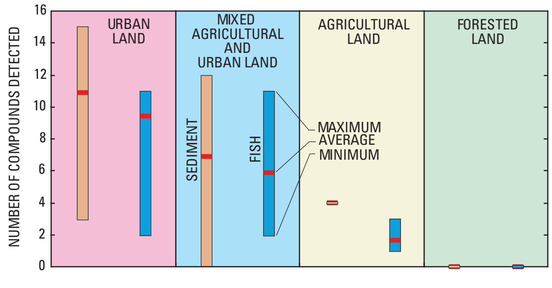


Figure 19. Streambed sediment and fish tissue from urban streams contained the greatest numbers of organochlorine compounds (including PCBs).

Semivolatile organic compounds (SVOCs) were detected in streambed sediment at nearly every urban and mixed land-use site (Appendix, p. 30). SVOCs are used for a wide variety of functions, and some are nearly ubiquitous in the environment (Lopes and Furlong, 2001; Van Metre and others, 2000). Urban and agricultural-urban sites had the highest number of SVOCs detected, as many as 30 of the 65 compounds analyzed (Brasher and Wolff, 2004). Only one SVOC was detected at an agricultural site, and between zero and four at forested sites. Of the SVOC subclasses, phthalates were most commonly found in areas of residential land use. Phthalates have been used in paint, construction materials, wood preservatives, disinfectants, and as plasticizers in a variety of household items including appliances, furnishings, and food containers and wrappings (Smith and others, 1988). Polyaromatic hydrocarbons (PAHs) mainly occurred in areas of industrial and commercial land use. PAHs are associated with incomplete combustion, such as from vehicle exhaust, waste incinerators, and—notably in Hawaii—burning sugarcane. PAHs also are present in mothballs, pesticides, dyes, synthetic resins, solvents, and lubricants.

Organochlorine compounds accumulate in fish and may be transferred to fish-eating birds and wildlife

Chemicals in water and sediment can be taken up and accumulate in tissues of invertebrates and fish. Chemical concentrations tended to be higher in fish tissue than in sediment on Oahu. For example, certain organochlorine contaminants—DDT, chlordane, and dieldrin—were as much as ten- or a hundredfold more concentrated in fish than in sediment (Appendix, p. 29). Contaminated fish can pose risks to fish-eating birds and wildlife and ordinarily might present a human-health risk. However, stream fish generally are not consumed on Oahu, and warnings against consumption are posted at contaminated streams.

Organochlorine compounds and SVOCs exceeded aquatic-life and wildlife guidelines in streambed sediment and fish

Chemical concentrations in many sediment and fish samples exceeded guidelines designed to protect aquatic life (Canadian Council of Ministers of the Environment, 1999) and fish-eating wildlife (Newell and others, 1987). Of the organochlorine compounds, chlordane, dieldrin, and heptachlor epoxide consistently exceeded guidelines in urban streams (appendix, p. 29–30; Brasher and Wolff, 2004). Total DDT (*o,p'*- and *p,p'*-DDT, and breakdown products DDD and DDE) exceeded wildlife guidelines in fish at 33 percent of agricultural sites and 10 percent of agricultural-urban sites. DDE exceeded the aquatic-life guideline in sediment at the only agricultural site sampled for sediment, at 43 percent of agricultural-urban sites, and at 17 percent of urban sites. Total PCBs exceeded the wildlife guideline in fish at 12 percent of urban sites and 20 percent of agricultural-urban sites and exceeded the aquatic-life guideline in sediment at 17 percent of urban sites. Very few SVOCs have established aquatic-life guidelines. The PAHs benzo(a)anthracene, phenanthrene, and pyrene exceeded aquatic-life guidelines in sediment at one urban and one agricultural-urban site, and anthracene and chrysene exceeded guidelines at one urban site (Appendix, p. 30).

It is difficult to assess what effects the observed chemical concentrations in sediment and fish might have on local aquatic life. One might attribute a paucity of certain types of fish or invertebrates to chemical contamination, but other factors such as temperature, flow volume and depth, or predation could have equal or greater importance. Investigation of physical abnormalities and reproductive-cycle disturbances would be needed to define chemical influences on aquatic life, whereas ecological surveys would be needed to better define effects of physical habitat disturbances and interspecies competition.

Human activities elevate trace elements in stream sediments

Concentrations of some trace elements in streambed sediments were higher in developed basins than in undeveloped forested basins, suggesting human sources of those elements. Contamination was greatest at urban sites for barium, cadmium, lead, tin, and zinc; arsenic contamination was greatest at agricultural sites (fig. 20). The mean concentration of lead in urban sediment samples was 35 times higher than the mean concentration at forested sites. Possible urban sources of trace elements include vehicular traffic (lead from leaded gasoline; barium, cadmium, and zinc from tire wear), batteries and paint (lead), and galvanized metal (zinc). A possible source of arsenic is fertilizer, in which arsenic is a common impurity. Probable Effect Level (PEL) aquatic-life guidelines for sediment were exceeded by lead and zinc at urban sites and arsenic at agricultural sites (fig. 21).

Leaded gasoline and lead-based paint were phased out in the 1970s, but lead persists in soils and will continue to enter Oahu's streams with sediment in runoff (DeCarlo and Anthony, 2002).

Chromium, cobalt, copper, nickel, and vanadium varied little by land use; their presence in sediments is due to natural abundance in volcanic rocks and soil and not to human contamination. Concentrations of chromium, copper, and nickel in all Oahu sediment samples were in the upper 25 percent of concentrations from 1,297 NAWQA samples nationwide. Chromium concentrations exceeded aquatic-life guidelines for sediments in all Oahu samples, ranging from 3 to 7 times the PEL guideline. Copper concentrations exceeded the PEL guideline in more than two-thirds of Oahu samples.

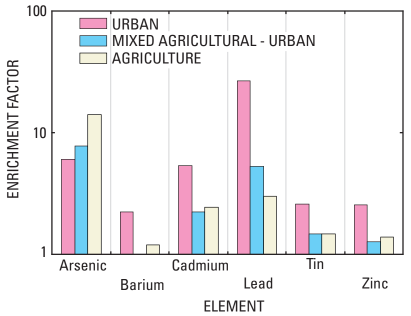


Figure 20. Concentrations of several trace elements in streambed sediment were elevated in comparison to forested sites (where the enrichment factor equals 1). Cadmium and lead were highest at urban sites, arsenic at agricultural sites.

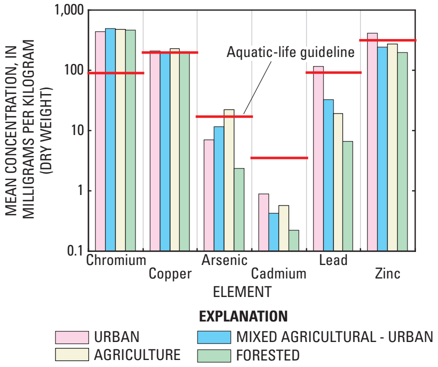


Figure 21. Arsenic, lead, and zinc exceed aquatic-life guidelines in streambed sediments because of agricultural and urban contamination. Chromium and copper exceed guidelines because of high natural abundance in rocks and soil.

Guidelines for Protection of Aquatic Life and Wildlife

Contaminant concentrations in streambed sediment were compared with the Canadian Sediment Quality Guidelines (CSQG) for the protection of aquatic life (Canadian Council of Ministers of the Environment, 1999). The Probable Effect Level (PEL) defines the level above which adverse effects to biota are expected to occur frequently. The guidelines are based on chronic (long-term) effects of individual contaminants on aquatic invertebrates. Contaminants in fish were compared with the New York State Department of Environmental Conservation (NYSDEC) guidelines for the protection of birds and wildlife such as mammals that consume fish (Newell and others, 1987). The NYSDEC guidelines are based on analyses of whole fish, not fillets.

Although similar standards have not been established nationally or in Hawaii, the Canadian and New York guidelines have been adopted in the NAWQA Program to flag cautionary concentrations of trace elements, organochlorine pesticides, and SVOCs that may adversely affect aquatic organisms or wildlife. Limitations of these guidelines are that they have been established only for a small number of constituents, the toxicities of compound mixtures and breakdown products generally are not considered, and effects such as endocrine disruption and unique responses of sensitive individuals have not been assessed.

Additional Information

Oahu NAWQA bed sediment and fish tissue: *http://hi.water.usgs.gov/nawqa/bst.html*

Stream Ecology

Urban alteration of stream habitat has adversely affected native aquatic species

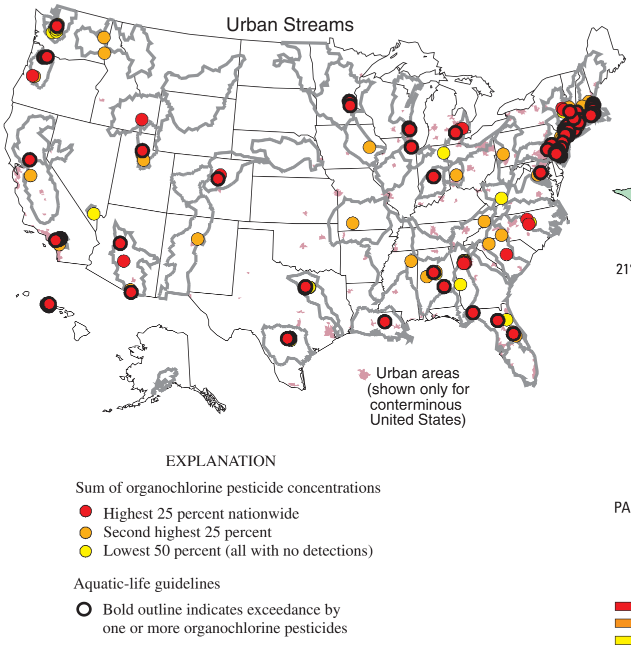
Evidence of degradation in biological communities—aquatic invertebrates and fish—includes the elevated abundance of nonnative and pollution-tolerant taxa. Physical habitat disturbance has affected Oahu watersheds as much as, or more than, chemical degradation. Improvements to stream quality will require management of physical alterations to landscapes and stream habitats, in addition to management of nonpoint-source pollution runoff.

Stream ecology differed substantially among Oahu streams, judging from assessments of instream and riparian habitat conditions, and species composition and abundance of invertebrates, fish, and algae (see map, p. 20).

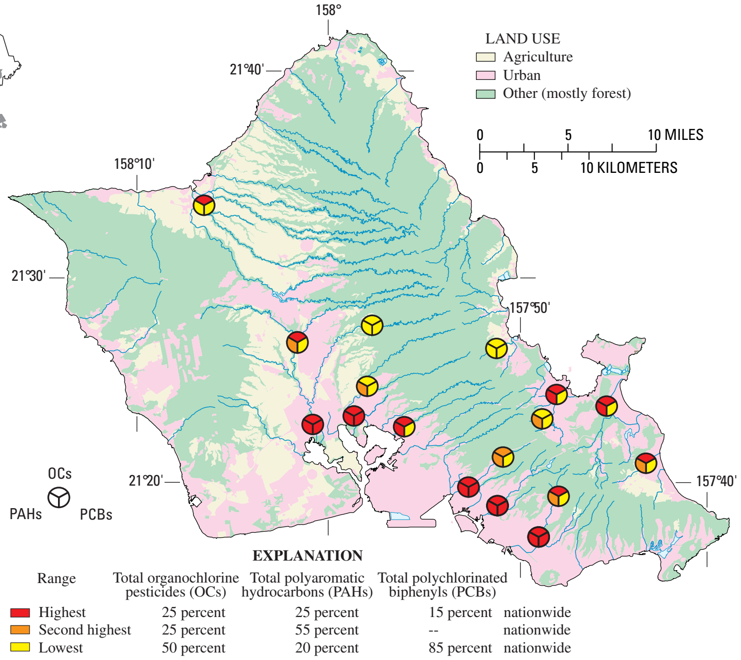
Concentrations of organic compounds in sediment and fish were among the highest in the nation

Concentrations of organic compounds in streambed sediment and fish tissue on Oahu were mostly in the upper one-half of the national range for more than a thousand NAWQA stream sites sampled nationwide. Total organochlorine compounds in sediment and fish from urban and mixed land-use sites typically were in the highest 25 percent of the national range. Total PCBs in sediment were in the highest 15 percent at five sites (three urban and two agricultural-urban), but were not detected at any other sites. Total PAH concentrations in sediment were in the highest 25 percent of the national range at eight sites and in the middle half at six other sites. At undeveloped forested sites, organochlorine pesticides, PCBs, and PAHs were not detected in most samples, placing Oahu in the lowest part of the national concentration range for undeveloped stream basins.

Of the organochlorine pesticides, concentrations of the termiticides dieldrin and chlordane were in the highest 5 percent nationally in sediment at urban Oahu sites and were highest in the Nation at one site (dieldrin in sediment and total chlordane in sediment and fish at Nuuanu Stream). Total DDT concentrations in sediment also were in the highest 5 percent of the national range at two agricultural-urban sites and an agricultural site, where it was the only organochlorine pesticide detected.



Concentrations of organochlorine compounds in streambed sediment were high on Oahu and in other urban areas.



Organic compounds in streambed sediment at urban Oahu stream sites were in the highest 25 percent of the national range.

Concentrations of organochlorine pesticides in fish over time

Following a trend that has been observed across the country (Schmitt and others, 1990; Nowell and others, 1999; Wong and others, 2000), concentrations of organochlorine compounds in stream fish on Oahu declined substantially from maximum values in the 1970s to 1998–2000 values observed by NAWQA sampling (Brasher and Anthony, 2000; Brasher and Wolff, 2004). Although early studies used different analytical methods and slightly different fish species than the NAWQA study, the data are useful for looking at trends over time. At urban Manoa Stream, total DDT in fish declined 62-fold from 1,870 to 30 µg/kg (micrograms per kilogram), total chlordane declined sevenfold (6,360 to 885 µg/kg), and dieldrin declined eightfold (9,100 to 885 µg/kg). Despite an initial decline, dieldrin concentrations in fish from Manoa Stream are still similar to those measured in the 1980s. At agricultural-urban Waikele Stream, total DDT in fish declined almost 200-fold (2,510 to 43 µg/kg), total chlordane declined 67-fold (470 to 7 µg/kg), and dieldrin declined 77-fold (770 to 10 µg/kg). Although total PCBs were present in fish from Manoa and Waikele Streams in the 1970s (1,700 and 1,200 µg/kg, respectively) and 1980s, no PCBs were detected in 1998–2000. However, PCBs were detected in fish from other freshwater bodies on Oahu: Nuuanu Stream, South Fork Kaukonahua Stream, Ala Wai Canal, and Wahiawa Reservoir (Lake Wilson).

Compared to forested streams (fig. 22), urban and mixed agricultural-urban sites typically were channelized (fig. 23) and had less riparian vegetation, less large-boulder habitat, and siltier substrates). High proportions of impervious surfaces in urban areas can increase runoff, and land clearing for construction can promote soil erosion and siltation. Lack of overhanging trees reduces shade, warming streamwater and causing large temperature fluctuations. At urban Kaneohe Stream, the average water temperature was about 9 degrees Celsius higher than at forested Punaluu Stream, and the seasonal temperature range was about 10 degrees as compared to only 4 degrees at Punaluu (fig. 24).

Few native fish were collected

Only two of five stream fishes native to Hawaii were found in considerable numbers on Oahu: oopu akupa (Hawaiian name), or *Eleotris sandwicensis* (latin name); and oopu naniha *(Stenogobius hawaiiensis)* (fig. 25). These species are relatively tolerant to large variations in environmental conditions such as temperature, turbidity, and siltation. Native fishes least tolerant of habitat degradation—oopu alamoo *(Lentipes concolor)* and oopu nopili *(Sicyopterus stimpsoni)*—were not found in the streams sampled, and the fifth native species, oopu nakea (*Awaous guamensis*), was occasionally found. Two native and four introduced species of crustaceans were found. Two species were present primarily at forested sites: the native atyid shrimp opae kalaole *(Atyoida bisulcata)* and the introduced Tahitian prawn *(Macrobrachium lar)*. The other native crustacean, *Macrobrachium grandimanus*, is an estuarine species and was found only near stream mouths.

Introduced fishes are more tolerant of altered, degraded habitat than native fishes

Surveys on the islands of Oahu, Kauai, and Hawaii show that urban land use is associated with the highest abundances of nonnative species, such as green swordtails, mollies, and jewel cichlids, which have been introduced for mosquito control or have been released from home aquariums (Devick, 1991). Habitat characteristics associated with urbanization favor nonnative species that tend to be tolerant generalists (Brown and others, 1999). Forested stream basins on Kauai had the greatest **relative abundance** of native fishes, whereas heavily urbanized stream basins on Oahu had the least.

Figure 22. Measuring habitat characteristics in a forested stream. (Photograph by Anne Brasher, U.S. Geological Survey.)

Figure 23. A channelized urban stream. (Photograph by Anne Brasher, U.S. Geological Survey.)

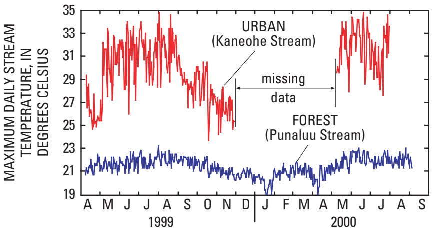


Figure 24. Urban streams are shallower and less shaded than forested streams, causing higher water temperatures and larger temperature fluctuations.

Figure 25. Native fish were rarely found in streams on Oahu. Those found tended to be of the more tolerant species such as oopu naniha (*Stenogobius hawaiiensis*). (Photograph by Eric Nishibayashi.)

Habitat alteration inhibits upstream migration and downstream dispersal of native fish, shrimp, and snails

Native fish, shrimp, and snails in Hawaii are primarily amphidromous (they have a marine larval life-stage). Adults lay eggs in streams, the eggs hatch, and the larvae drift to the ocean where they mature for 4 to 7 months before returning to a stream. Distribution of these animals in streams is affected by spatial and year-to-year variability in recruitment (their ability to return from ocean to stream mouth) and by their ability to migrate upstream unimpeded (Kinzie, 1988, 1990).

The more urbanized streams, such as Manoa, produced the fewest drifting fish and shrimp larvae, whereas forested streams, such as Punaluu, produced the most larvae (Luton and Brasher, 2001). The most frequently collected native larval species, oopu akupa (*Eleotris sandwicensis)* and the crustaceans *Macrobrachium sp.*, are tolerant of a wide range of environmental conditions.

Stream channels have been altered most near their mouths for flood control. Lower stream reaches are essential pathways for native amphidromous species requiring downstream dispersal of larvae and upstream migration of post-larval juveniles or adults. Diversions and channelization may block these pathways and inhibit migrations required for completion of the life cycle. Native species also are subject to substantial predation (commonly by introduced species) as they attempt to settle in altered habitat or migrate through to upstream reaches of streams (Brown and others, 1999).

Benthic invertebrates reflect degraded stream quality

Urban and agricultural activities can degrade habitat quality, alter natural streamflows, and increase contaminants and temperatures, all of which are reflected in invertebrate community structure. Smaller numbers of invertebrates but greater numbers of invertebrate species were found at urban and mixed agricultural-urban stream sites on Oahu than at undeveloped forested sites (Brasher and others, in press). This pattern reflects the naturally low diversity of native invertebrate species that would be expected in unaltered Hawaiian streams and the proliferation of nonnative species that are more tolerant of physically and chemically degraded environments in the more heavily developed and urbanized basins.

Distinct assemblages of invertebrates were found in streams with different amounts of habitat degradation and consequently can be used to indicate stream quality (by equating assemblages at undeveloped forested sites with good quality). At forested sites, insects typically made up more than 80 percent of the invertebrates present, and molluscs (clams and snails) were few (fig. 26). At urban and agricultural-urban sites with degraded environmental quality, invertebrate communities typically contained about 50 percent insects and 30 percent molluscs. True flies (Diptera) and caddisflies (Trichoptera; fig. 27) were the most common insects at all sites, with forested sites dominated by caddisflies and urban and agricultural-urban sites dominated by true flies.

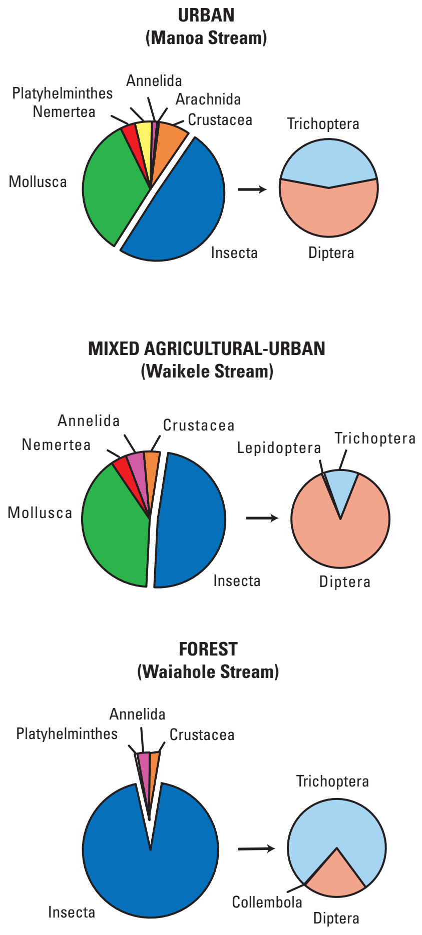


Figure 26. Stream-habitat quality can be inferred from ratios of less-tolerant to more-tolerant invertebrates, for example insect-to-mollusc and caddisfly-to-true-fly (Trichoptera-to-Diptera) ratios. Higher proportions of insects or caddisflies were associated with less-degraded streams, whereas lower proportions reflect degradation of the stream environment.

Most identified invertebrates were nonnative

Hawaiian streams have far fewer native species than continental streams, even under undisturbed conditions. A total of 75 invertebrate species were identified at 10 sites on Oahu. Of these, 5 percent were native, 48 percent were introduced, and the remaining 47 percent were undetermined (for a species list see Brasher and others, in press). Common, widespread orders of insects such as mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera) are absent from native biota in Hawaii (Howarth and Polhemus, 1991). Historically, the geographic isolation of Hawaii prevented large-scale colonization by aquatic invertebrates, and most native stream species probably originated from marine ancestors.

Figure 27. Many invertebrates, such as caddisflies (Trichoptera), live in the stream as larvae, but the adults are terrestrial (flying insects in this case). (Photograph by Mark Vinson.)

Mollusc abundance was strongly associated with urban land use. Although a number of native freshwater molluscs are known in Hawaii (including neritid limpets and lymnaeid snails), they tend to inhabit the less disturbed streams, and none were found during this study. The most abundant molluscs collected were the pan-tropical thiarid snails, the introduced clam *Corbicula fluminea*, and the limpet *Ferrissia sharpi*, whose status as native or nonnative is uncertain.

Three nonnative crustaceans were collected primarily at urban and agricultural-urban sites: a recently introduced shrimp *Neocaridina denticulata*, an amphipod *Hyalella azteca*, and a crayfish *Procambarus clarkii*. The native shrimp *Atyoida bisulcata* was found only at undeveloped forested sites.

Additional Information

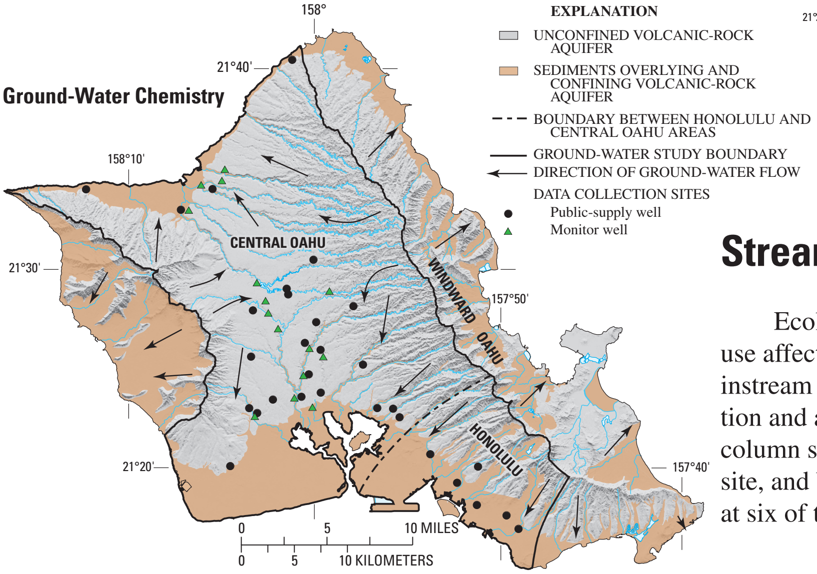
Oahu NAWQA aquatic ecology: *http://hi.water.usgs.gov/nawqa/eco.html*

Study Unit Design

The Oahu NAWQA study was designed to assess physical, chemical, and biological characteristics of surface and ground water by means of nationally consistent protocols and methods (Gilliom and others, 1995). Thus, findings from the Oahu Study Unit can be compared to findings in other Study Units and placed in a national context.

Ground-Water Chemistry

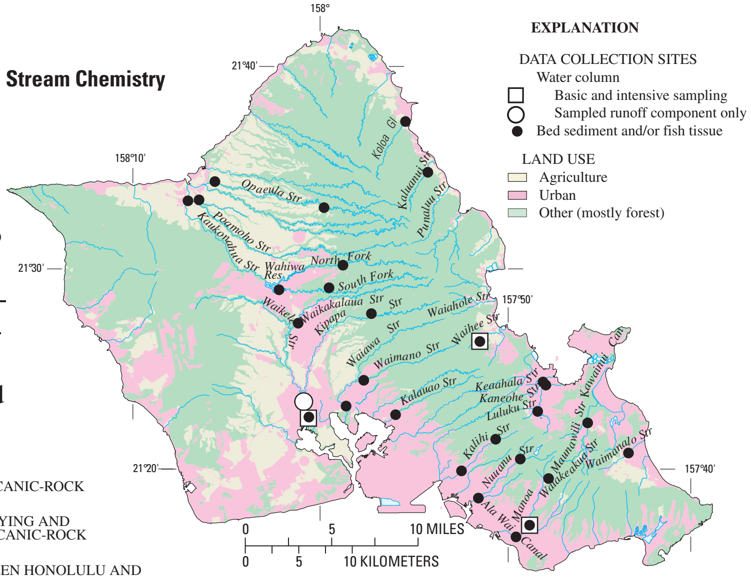
Randomly selected public-supply wells were sampled to characterize water quality in major drinking-water aquifers (volcanic-rock aquifers) in central Oahu and Honolulu. Monitor wells also were sampled to assess effects of human activities on recently recharged ground water; for example, effects from recent conversion of sugarcane plantations to diversified crops and residential areas.



Stream Chemistry

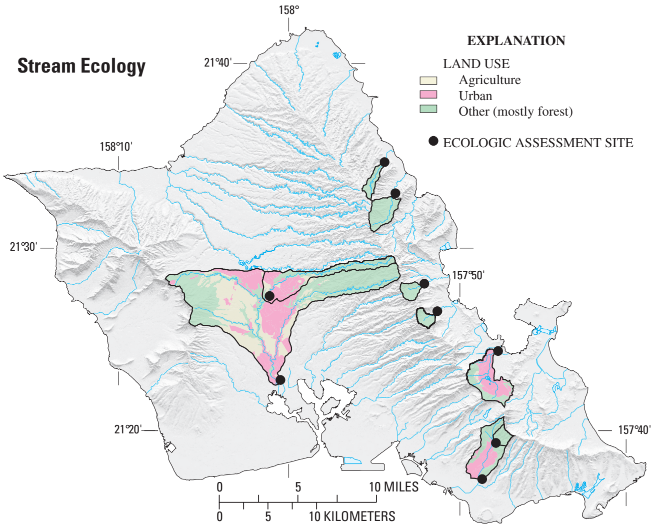
Sampling was concentrated in three representative areas: central Oahu with varied land uses (agricultural, residential urban, military, and forested), windward Oahu (mostly forested, with some residential urban and agricultural use), and Honolulu (high-density urban).

Assessments focused on how water quality varies in relation to land use and the natural setting. Contaminants were analyzed in samples from the water column, bed sediment, and whole fish collected at 3 agricultural sites, 8 urban sites, 12 mixed land-use (agricultural-urban) sites, and 11 forested sites. Frequent water samples were collected (monthly and during storms) at three stream sites (Manoa, Waikele, and Waihee). At most other sites, one water sample was collected to coincide with sediment samples, fish samples, or ecologic assessments.



Stream Ecology

Ecologic assessments focused on describing how land use affects biological communities. Assessments measured instream and riparian habitat conditions and species composition and abundance of invertebrates, fish, and algae. Water-column samples also were collected at each stream ecology site, and bed-sediment and fish-tissue samples were collected at six of the sites.



Summary of data collection on the island of Oahu

Study component	What data are collected and why	Types of sites sampled	Number of sites sampled	Sampling frequency and period
Ground-Water Chemistry				
Major aquifer study	Nutrients, major ions, pesticides, volatile organic compounds, trace elements, and radon in deep, unconfined, volcanic-rock aquifer to assess the quality of Oahu's main drinking-water aquifer.	Existing public-supply wells widely distributed throughout the central Oahu ground-water flow system.	30	Once; 2000
Special study	Nutrients, major ions, pesticides, volatile organic compounds, and trace elements in deep, unconfined, volcanic-rock aquifer to assess **anthropogenic** effects on central Oahu ground water.	Existing monitor wells that sample young, newly recharged ground water in central Oahu.	15	Once; 2001
Stream Chemistry				
Water column sites, basic	Streamflow and general water-quality properties and constituents (dissolved oxygen, pH, alkalinity, specific conductance, temperature, nutrients, major ions, organic carbon, and suspended sediment) to assess occurrence and concentration.	Forested site in windward Oahu (Waihee Stream).	1	Monthly plus storms March 1999 – June 2001
Water column sites, intensive	Streamflow and general water-quality properties and constituents as above plus trace elements and pesticides at Waikele and Manoa, and volatile organic compounds at Manoa only to assess occurrence and concentration.	Urban land-use site in Honolulu (Manoa Stream), and a mixed agricultural-urban land-use site in central Oahu (Waikele Stream).	2	Monthly plus storms March 1999 – June 2001
Water column site, runoff component only	Streamflow and general water-quality properties and constituents plus pesticides and VOCs to characterize stream water before it enters the downstream gaining reach at Waikele Stream site.	Mixed land-use site upstream from the Waikele intensive site, which gains from ground-water inflow.	1	Three times during fair-weather base flow and one storm in 2001
Contaminants in bed sediment	Trace elements and (or) organic compounds to determine occurrence and distribution related to land use.	Depositional zones of all three water-column basic and intensive sites and 22 additional sites.	25	Once; 1998 and 2000
Contaminants in whole fish	Trace elements and (or) organic compounds to assess occurrence and distribution related to land use.	All but one of the bed-sediment sites and three additional sites.	27	Once; 1998, and 2000–2001
Stream Ecology				
Ecologic assessments	Invertebrate, algae, and fish communities, streamflow, water chemistry, and instream and riparian habitat conditions to assess land-use effects on aquatic communities. Algae data were not available for inclusion in this report.	All three water-column basic and intensive sites, three of the bed-sediment sites, and four additional forested sites.	10	One reach at each site in 1999; and, at Waihee Stream, three reaches in 2000 and one reach in 2001.

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Glossary

Anthropogenic–A condition that is the result of, or is influenced by, human activity.

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

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

Background concentration–A concentration of a substance in a particular environment that is indicative of minimal influence by human (anthropogenic) sources.

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

Bed sediment–The material that temporarily is stationary in the bottom of a stream or other watercourse.

Benthic–Refers to plants or animals that live on the bottom of lakes, streams, or oceans.

Concentration–The amount or mass of a substance present in a given volume or mass of sample. Usually expressed as micrograms/liter (water sample) or micrograms/kilogram (sediment or tissue sample).

Confined aquifer (artesian aquifer)–An aquifer that is completely filled with water under pressure and that is overlain by material that restricts the movement of water.

Contamination–Degradation of water quality, caused by human activity, compared to original or natural conditions.

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

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

Dissolved constituent–Operationally defined as a constituent that passes through a 0.45-micrometer filter.

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

Drinking-water standard or guideline–A threshold concentration in a public drinking-water supply, designed to protect human health. Standards are enforceable maximum contaminant levels (MCLs) for public water systems designed to protect the public welfare. Guidelines have no regulatory status and are issued in an unenforceable advisory capacity only.

Ecosystem–The interacting populations of plants, animals, and microorganisms occupying an area, plus their physical environment.

Eutrophication–The process by which water becomes enriched with plant nutrients, most commonly phosphorus and nitrogen.

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

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

Herbicide–A chemical or other agent applied for the purpose of killing undesirable plants. See also Pesticide.

Insecticide–A substance or mixture of substances intended to destroy or repel insects. See also Pesticide.

Intermittent stream–A stream that flows only when it receives water from rainfall runoff or springs, or from some surface source such as melting snow.

Invertebrate–An animal having no backbone or spinal column.

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.

Nitrate–An ion consisting of nitrogen and oxygen (NO_3^-). Nitrate is a plant nutrient and is very mobile in soils.

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

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

Organochlorine compound–Synthetic organic compounds containing chlorine. Examples include organochlorine insecticides, polychlorinated biphenyls, and some solvents containing chlorine.

Perennial stream–A stream that normally has water in its channel at all times.

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

Phosphorus–A nutrient essential for growth that can play a key role in stimulating aquatic growth in lakes and streams.

Reach–A continuous part of a stream between two specified points along its length.

Recharge–Water that infiltrates the ground and reaches the saturated zone.

Relative abundance–The number of organisms of a particular kind present in a sample relative to the total number of organisms in the sample.

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

Runoff–Excess rainwater or snowmelt that is transported to streams by overland flow, tile drains, or ground water.

Semivolatile organic compound (SVOC)–Operationally defined as a group of synthetic organic compounds that are solvent-extractable and can be measured by gas chromatography/mass spectrometry. SVOCs include phenols, phthalates, and polycyclic aromatic hydrocarbons (PAHs).

Sole-source aquifer–A ground-water system that supplies at least 50 percent of the drinking water to a particular human population; the term is used to denote special protection requirements under the Safe Drinking Water Act and may be used only by approval of the U.S. Environmental Protection Agency.

Suspended (as used in tables of chemical analyses)–The amount (concentration) of undissolved material in a water-sediment mixture. It is associated with the material retained on a 0.45-micrometer filter.

Total Maximum Daily Load (TMDL) –The maximum amount of a pollutant that a water body can receive and still meet water-quality standards, and an allocation of that amount to the pollutant's sources.

Trace element–An element found in only minor amounts (concentrations less than 1.0 milligram per liter) in water or sediment; includes arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc.

Unconfined aquifer–An aquifer whose upper surface is a water table; an aquifer containing unconfined ground water.

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

Appendix—Water-Quality Data from the Island of Oahu, Hawaii, 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, nutrients, VOCs, and trace elements assessed on the island of Oahu, Hawaii, are available at our Web site at:

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

These summaries of chemical concentrations and detection frequencies from the island of Oahu, Hawaii, 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 between (1) surface- and ground-water resources, (2) agricultural, urban, and mixed land uses, and (3) shallow ground water and aquifers commonly used as a source of drinking water.

CHEMICALS IN WATER

Concentrations and detection frequencies, island of Oahu Hawaii, 1999–2001

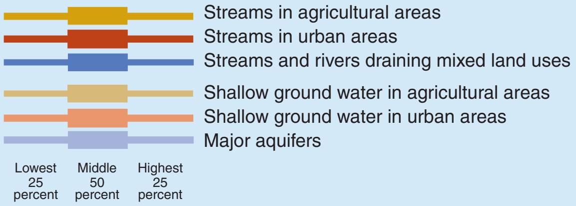
◆ Detected concentration in Study Unit

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

For example, the graph for atrazine shows that detections and concentrations on the island of Oahu Hawaii generally are (1) lower than national findings in urban streams and streams in areas of mixed land use; (2) greater in streams draining areas of mixed land use than in those draining urban areas; and (3) greater in concentration in ground water than in streams.

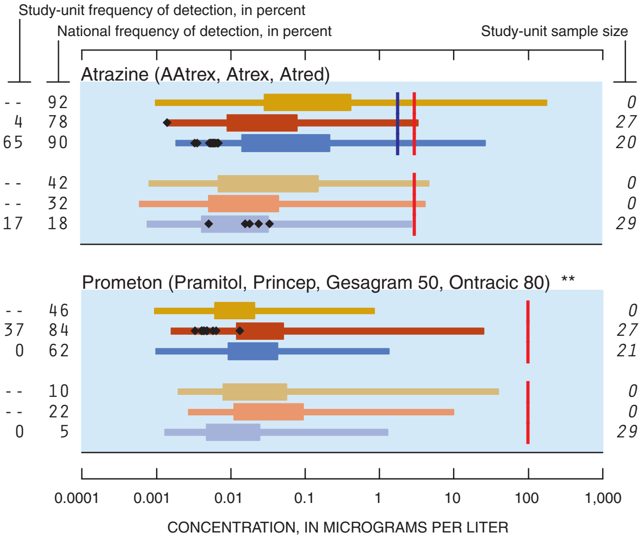
NOTE to users:

- 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, methylbenzene was detected more frequently in urban streams on the island of Oahu, Hawaii, than in urban streams nationwide (94 percent compared to 74 percent) but generally was detected at lower concentrations.

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.

Trace elements in ground water: aluminum, barium, boron, cadmium, chromium, cobalt, copper, lithium, nickel, strontium, zinc
SVOCs in bed sediment: phenol, bis(2-ethylhexyl)phthalate, butylbenzylphthalate, di-*n*-butylphthalate, diethylphthalate
Insecticides in water: *p,p'*-DDE

Pesticides in water—Herbicides



Other herbicides detected

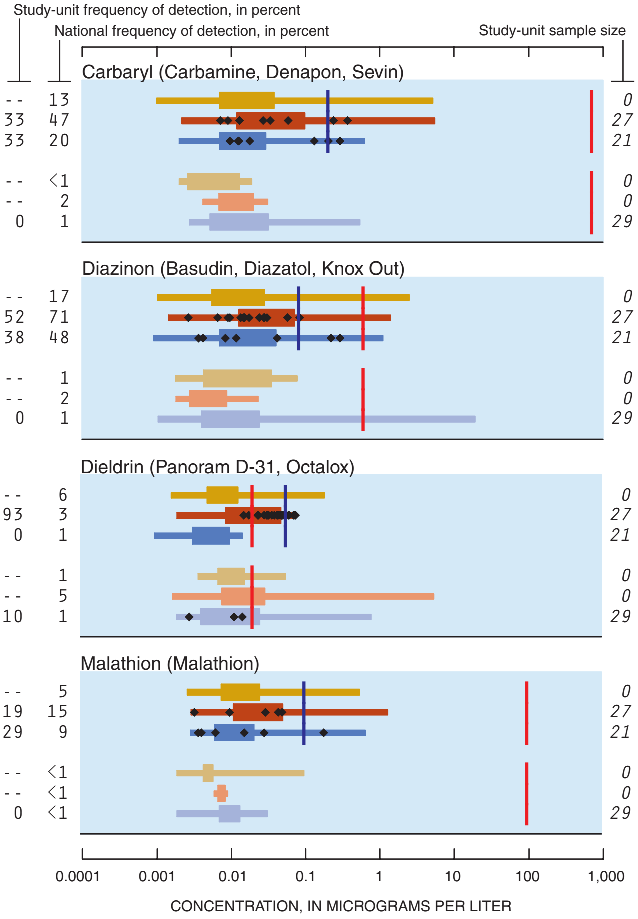
Alachlor (Lasso, Bronco, Lariat, Bullet) **
Cyanazine (Bladex, Fortrol)
Deethylatrazine (Atrazine metabolite, desethylatrazine) * **
Metribuzin (Lexone, Sencor)
Pendimethalin (Pre-M, Prowl, Weedgrass Control, Stomp, Herbadox) * **

Simazine (Princep, Caliber 90, Gesatop, Simazat)
Trifluralin (Treflan, Gowan, Tri-4, Trific, Trilin)

Herbicides not detected

Acetochlor (Harness Plus, Surpass) * **
Benfluralin (Balan, Benefin, Bonalan, Benefex) * **
Butylate (Sutan +, Genate Plus, Butilate) **
DCPA (Dacthal, chlorthal-dimethyl) **
2,6-Diethylaniline (metabolite of Alachlor) * **
EPTC (Eptam, Farmarox, Alirox) * **
Ethalfluralin (Sonalan, Curbit) * **
Linuron (Lorox, Linex, Sarclex, Linurex, Afalon) *
Metolachlor (Dual, Pennant)
Molinate (Ordram) * **
Napropamide (Devrinol) * **
Pebulate (Tillam, PEBC) * **
Pronamide (Kerb, Propyzamid) **
Propachlor (Ramrod, Satecid) **
Propanil (Stam, Stampede, Wham, Surcopur, Prop-Job) * **
Tebuthiuron (Spike, Tebusan)
Terbacil (Sinbar) **
Thiobencarb (Bolero, Saturn, Benthiocarb, Abolish) * **
Triallate (Far-Go, Avadex BW, Tri-allate) *

Pesticides in water—Insecticides



Other insecticides detected

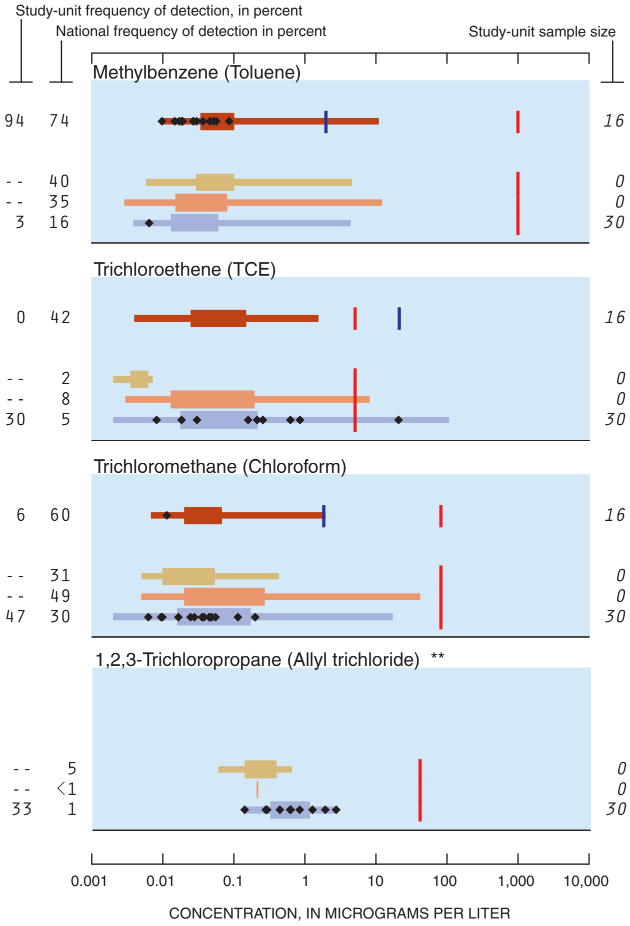
Chlorpyrifos (Brodan, Dursban, Lorsban)

Insecticides not detected

Azinphos-methyl (Guthion, Gusathion M) *
Carbofuran (Furadan, Curaterr, Yaltox)
Disulfoton (Disyston, Di-Syston, Frumin AL, Solvirex, Ethylthiodemeton) **
Ethoprop (Mocap, Ethoprophos) * **
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) * **
Propargite (Comite, Omite, Ornamite) * **
Terbufos (Contraven, Counter, Pilarfox) **

Volatile organic compounds (VOCs) in water

These graphs represent data from 32 Study Units, sampled from 1994 to 2001



Other VOCs detected

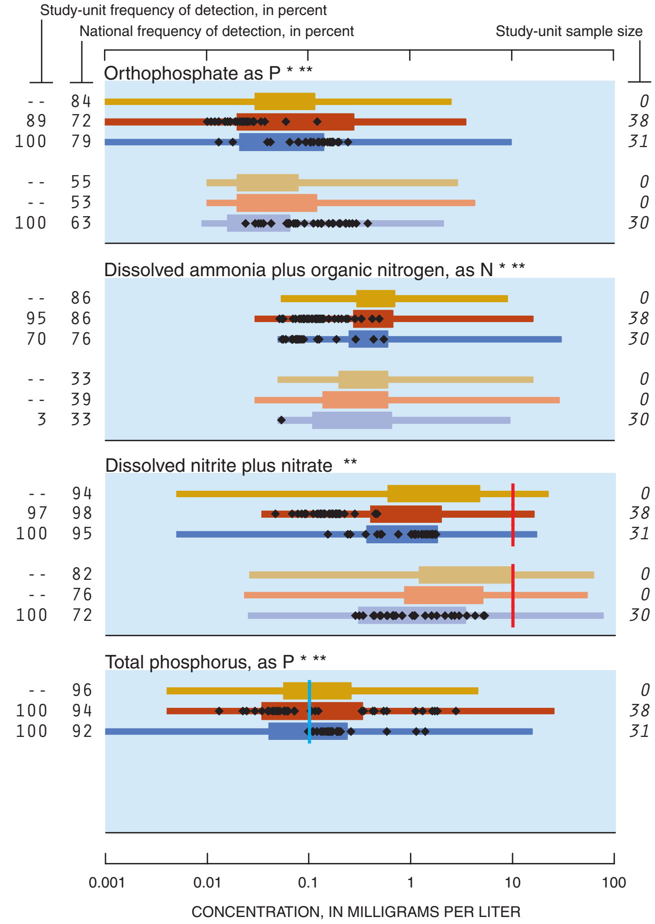
Acetone (Acetone) * **
Benzene
Bromodichloromethane (Dichlorobromomethane) **
Chlorobenzene (Monochlorobenzene)
Chloromethane (Methyl chloride) **
Dibromochloromethane (Chlorodibromomethane) **
1,1-Dichloroethene (Vinylidene chloride) **
trans-1,2-Dichloroethene ((E)-1,2-Dichlorothene) **
cis-1,2-Dichloroethene ((Z)-1,2-Dichloroethene) **
Dichloromethane (Methylene chloride)
1,1-Dichloropropene * **
1,3 & 1,4-Dimethylbenzene (*m*-&*p*-Xylene) **

Ethenylbenzene (Styrene) **
Ethyl *tert*-butyl ether (Ethyl-t-butyl ether (ETBE)) * **
p-Isopropyltoluene (*p*-Cymene, 1-Isopropyl-4-methylbenzene) * **
1,1,1,2-Tetrachloroethane (1,1,1,2-TeCA) **
Tribromomethane (Bromoform) **
1,1,2-Trichloroethane (Vinyl trichloride) **
1,2,4-Trimethylbenzene (Pseudocumene) * **

VOCs not detected

Bromobenzene (Phenyl bromide) * **
Bromochloromethane (Methylene chlorobromide) **
Bromoethene (Vinyl bromide) * **
Bromomethane (Methyl bromide) **
2-Butanone (Methyl ethyl ketone (MEK)) **
n-Butylbenzene (1-Phenylbutane) * **
sec-Butylbenzene ((1-Methylpropyl)benzene) * **
tert-Butylbenzene ((1,1-Dimethylethyl)benzene) * **
Carbon disulfide * **
3-Chloro-1-propene (3-Chloropropene) * **
1-Chloro-2-methylbenzene (*o*-Chlorotoluene) **
1-Chloro-4-methylbenzene (*p*-Chlorotoluene) **
Chloroethane (Ethyl chloride) * **
Chloroethene (Vinyl chloride) **
1,2-Dibromo-3-chloropropane (DBCP, Nemagon) **
1,2-Dibromoethane (Ethylene dibromide, EDB) **
Dibromomethane (Methylene dibromide) * **
trans-1,4-Dichloro-2-butene ((Z)-1,4-Dichloro-2-butene) * **
1,3-Dichlorobenzene (*m*-Dichlorobenzene)
1,4-Dichlorobenzene (*p*-Dichlorobenzene, 1,4-DCB)
Dichlorodifluoromethane (CFC 12, Freon 12) **
1,2-Dichloroethane (Ethylene dichloride)
1,1-Dichloroethane (Ethylidene dichloride) * **
2,2-Dichloropropane * **
1,3-Dichloropropane (Trimethylene dichloride) * **
trans-1,3-Dichloropropene ((E)-1,3-Dichloropropene) **
cis-1,3-Dichloropropene ((Z)-1,3-Dichloropropene) **
Diethyl ether (Ethyl ether) * **
Diisopropyl ether (Diisopropylether (DIPE)) * **
1,2-Dimethylbenzene (*o*-Xylene) **
Ethyl methacrylate (Ethyl methacrylate) * **
Ethylbenzene (Phenylethane)
2-Ethyltoluene (*o*-Ethyltoluene) * **
1,1,2,3,4,4-Hexachloro-1,3-butadiene (Hexachlorobutadiene)
1,1,1,2,2,2-Hexachloroethane (Hexachloroethane) **
2-Hexanone (Methyl butyl ketone (MBK)) * **
Iodomethane (Methyl iodide) * **
Isopropylbenzene (Cumene) * **
Methyl acrylonitrile (Methacrylonitrile) * **
Methyl methacrylate (Methyl-2-methacrylate) * **
Methyl *tert*-butyl ether (MTBE) **
4-Methyl-2-pentanone (Methyl isobutyl ketone (MIBK)) * **
Methyl-2-propenoate (Methyl acrylate) * **
Naphthalene
2-Propenenitrile (Acrylonitrile) **
n-Propylbenzene (Isocumene) * **
1,1,2,2-Tetrachloroethane **
Tetrahydrofuran (Diethylene oxide) * **
1,2,3,4-Tetramethylbenzene (Prehnitene) * **
1,2,3,5-Tetramethylbenzene (Isodurene) * **
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113, CFC 113) * **
1,2,4-Trichlorobenzene
1,2,3-Trichlorobenzene (1,2,3-TCB) *
1,1,1-Trichloroethane (Methylchloroform) **
Trichlorofluoromethane (CFC 11, Freon 11) **
1,2,3-Trimethylbenzene (Hemimellitene) * **
1,3,5-Trimethylbenzene (Mesitylene) * **
tert-Amyl methyl ether (TAME) * **

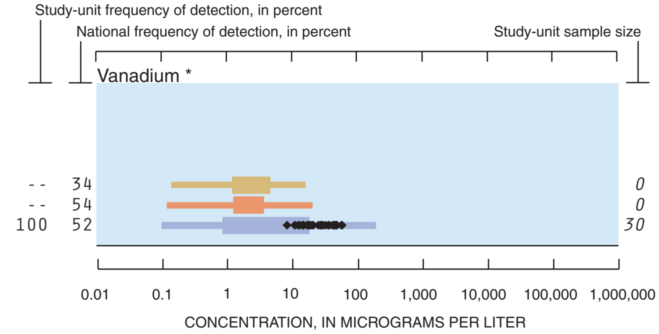
Nutrients in water

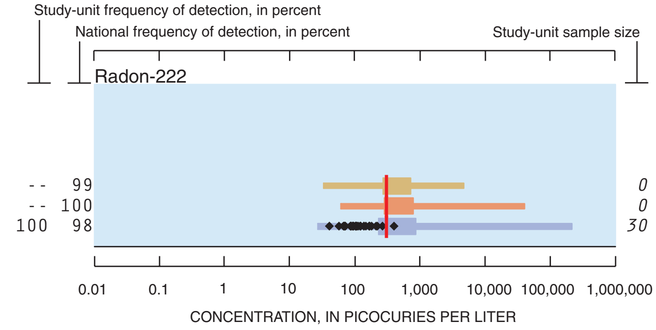


Other nutrient detected

Ammonia **

Trace elements in ground water





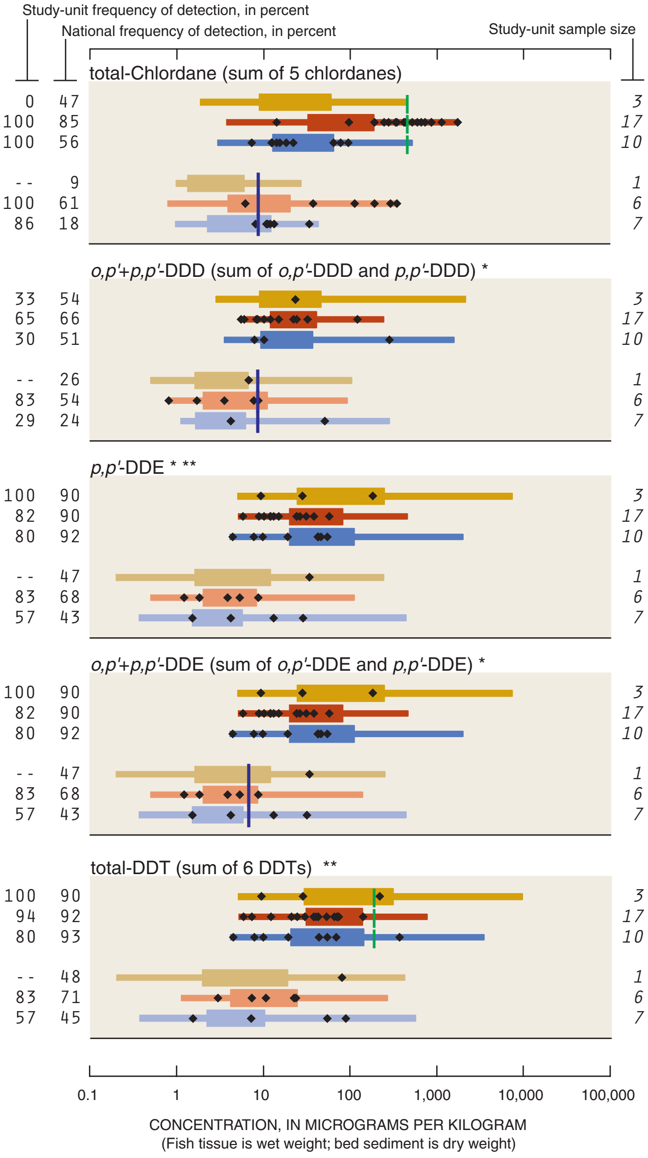
Other trace elements detected

Lead
Selenium

Trace elements not detected

Antimony
Arsenic
Beryllium
Manganese *
Molybdenum
Silver
Thallium
Uranium

Organochlorines in fish tissue (whole body) and bed sediment



CHEMICALS IN FISH TISSUE AND BED SEDIMENT

Concentrations and detection frequencies, the island of Oahu Hawaii, 1999–2001—Study-unit frequencies of detection are based on small sample sizes; the applicable sample size is specified in each graph

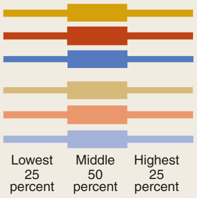
◆ Detected concentration in Study Unit

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

-- Not measured or sample size less than two

12 Study-unit sample size

National ranges of concentrations detected, by land use, in 51 NAWQA Study Units, 1991–2001—Ranges include only samples in which a chemical was detected



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

National benchmarks for fish tissue and bed sediment

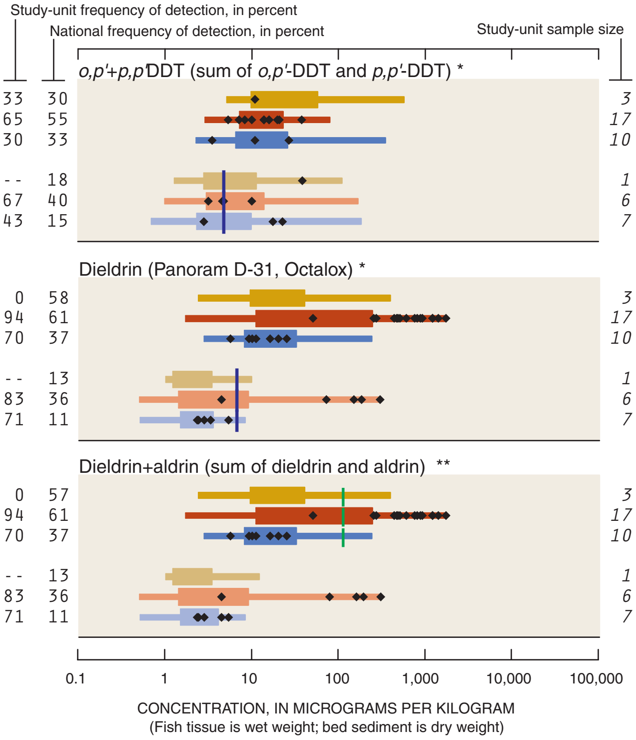
National benchmarks include standards and guidelines related to criteria for protection of the health of fish-eating wildlife and aquatic organisms. Sources include the U.S. Environmental Protection Agency, other Federal and State agencies, and the Canadian Council of Ministers of the Environment.

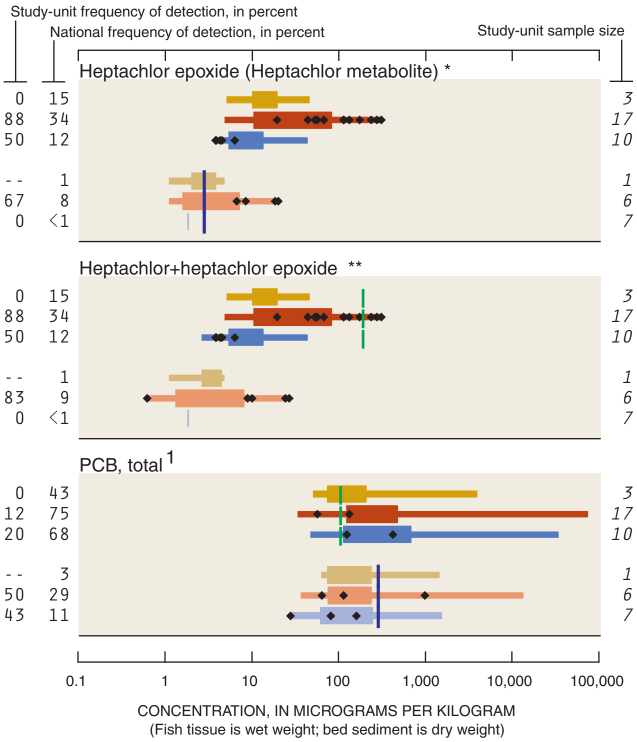
| Protection of fish-eating wildlife (applies to fish tissue)

| Protection of aquatic life (applies to bed sediment)

* No benchmark for protection of fish-eating wildlife

** No benchmark for protection of aquatic life





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

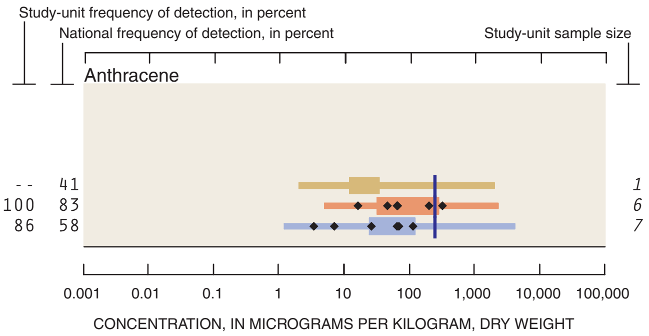
Other organochlorines detected

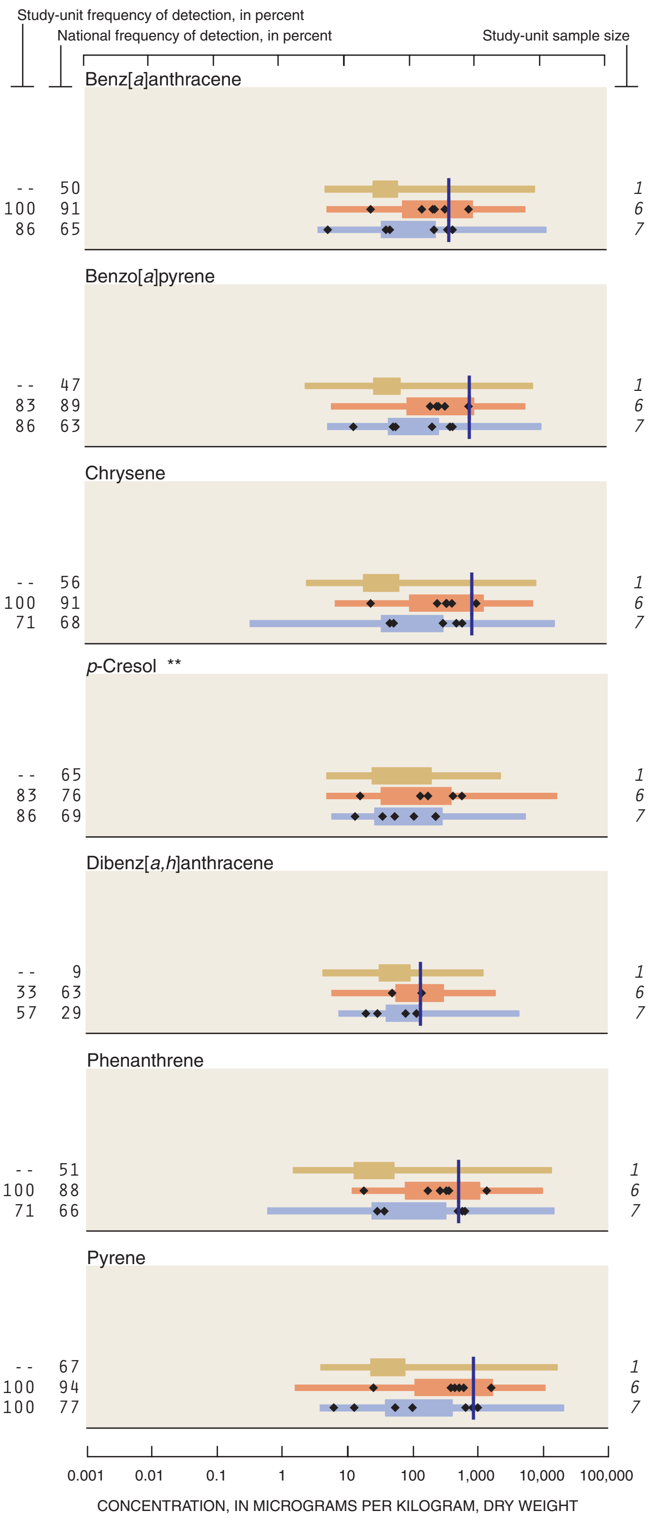
Endrin (Endrine)
Hexachlorobenzene (HCB) **
Pentachloroanisole (PCA, pentachlorophenol metabolite) * **
cis-Permethrin (Ambush, Astro, Pounce) * **
trans-Permethrin (Ambush, Astro, Pounce) * **

Organochlorines not detected

Chloroneb (chloronebe, Demosan) * **
DCPA (Dacthal, chlorthal-dimethyl) * **
Endosulfan I (alpha-Endosulfan, Thiodan) * **
gamma-HCH (Lindane, gamma-BHC, Gammexane) *
Total HCH (sum of alpha, beta, gamma, and delta-HCH) **
Isodrin (Isodrine, Compound 711) * **
p,p'-Methoxychlor (Marlate, methoxychlore) * **
o,p'-Methoxychlor * **
Mirex (Dechlorane) **
Toxaphene (Camphechlor, Hercules 3956) * **

Semivolatile organic compounds (SVOCs) in bed sediment





Other SVOCs detected

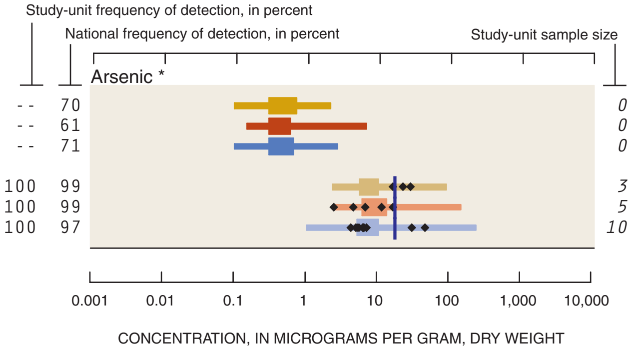
Acenaphthene
Acenaphthylene
Acridine **
Anthraquinone **
Benzo[*b*]fluoranthene **
Benzo[*g,h,i*]perylene **
Benzo[*k*]fluoranthene **

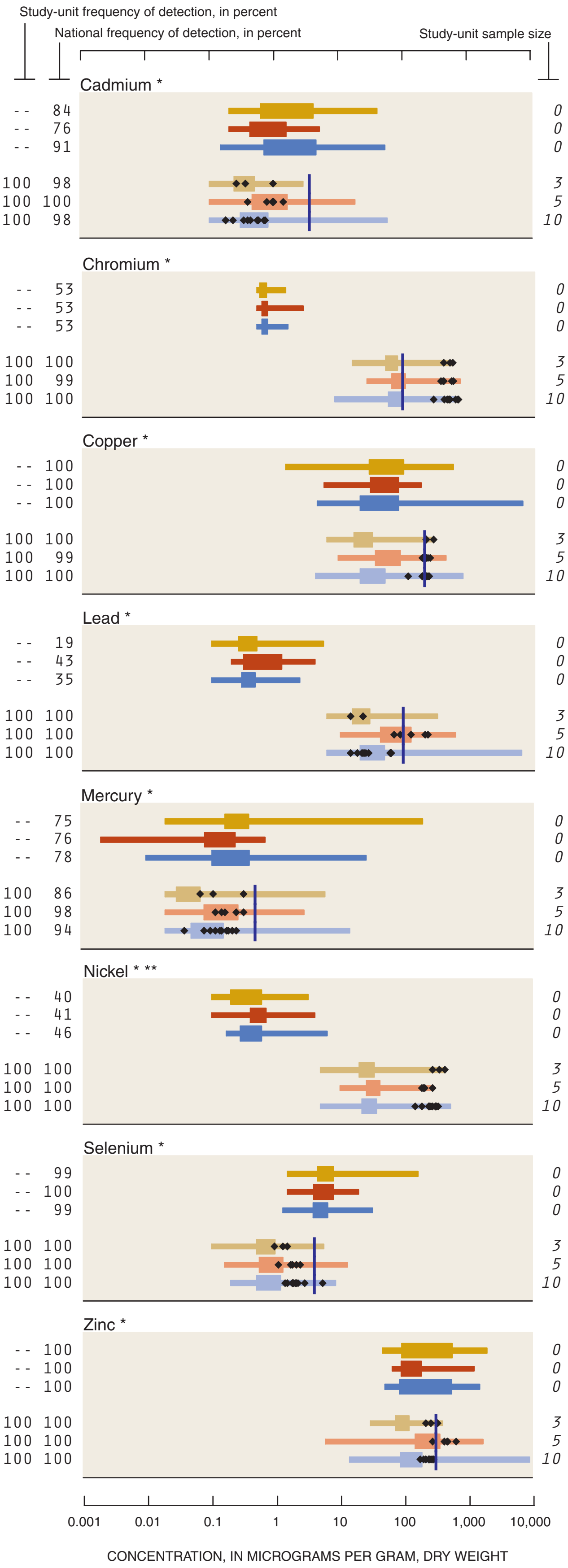
2,2-Biquinoline **
9*H*-Carbazole **
Di-*n*-octylphthalate **
Dibenzothiophene **
1,6-Dimethylnaphthalene **
2,6-Dimethylnaphthalene **
Dimethylphthalate **
Fluoranthene
9*H*-Fluorene (Fluorene)
Indeno[1,2,3-*c,d*]pyrene **
Isophorone **
Isoquinoline **
1-Methyl-9*H*-fluorene **
2-Methylanthracene **
4,5-Methylenephenanthrene **
1-Methylphenanthrene **
1-Methylpyrene **
Naphthalene
Phenanthridine **
2,3,6-Trimethylnaphthalene **

SVOCs not detected

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

Trace elements in fish tissue (livers) and bed sediment





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U.S. Navy, Pearl Harbor
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Natural Resources Conservation Service
U.S. Environmental Protection Agency
U.S. Geological Survey, Pacific Island Ecosystem Research Center

State agencies
Hawaii Department of Agriculture
Hawaii Department of Business, Economic Development, and Tourism
Hawaii Department of Health
Hawaii Department of Land and Natural Resources
Office of Hawaiian Affairs

Local agencies
Honolulu Board of Water Supply
Honolulu Department of Environmental Services
Honolulu Department of Planning and Permitting

Universities
University of Hawaii

Other public and private organizations
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Hawaii Agriculture Research Center
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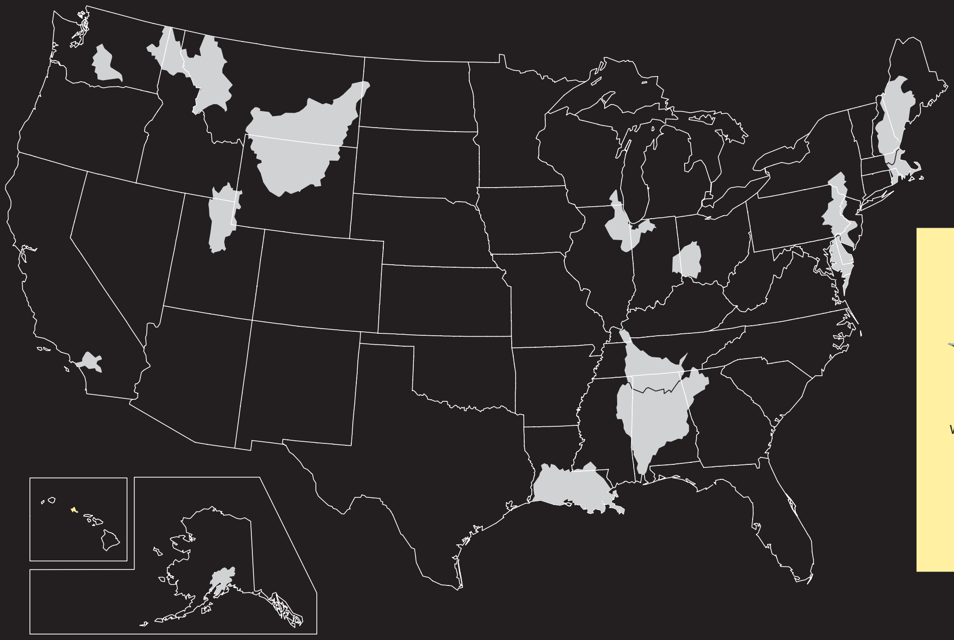
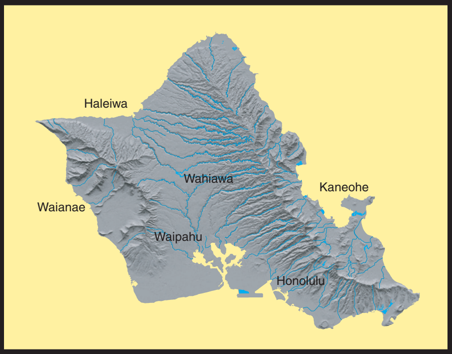
NAWQA

National Water-Quality Assessment (NAWQA) Program
Island of Oahu





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