Water Quality in the Great Salt Lake Basins

Utah, Idaho, and Wyoming, 1998–2001

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

Circular 1236

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

Great Salt Lake Basins contact and Web site:

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National Assessments

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

Front cover: East shore of Farmington Bay, Great Salt Lake (photograph by Steven Gerner).

Back cover: Left, sampling Little Cottonwood Creek (photograph by Robert Baskin); center, electrofishing in the Weber River near Coalville (photograph by Kidd Waddell); right, Salt Lake City and Wasatch Mountains (photograph courtesy of the Utah Travel Council/ Frank Jensen).

Water Quality in the Great Salt Lake Basins, Utah, Idaho, and Wyoming, 1998–2001

By Kidd M. Waddell, Steven J. Gerner, Susan A. Thiros, Elise M. Giddings,
Robert L. Baskin, Jay R. Cederberg, and Christine M. Albano

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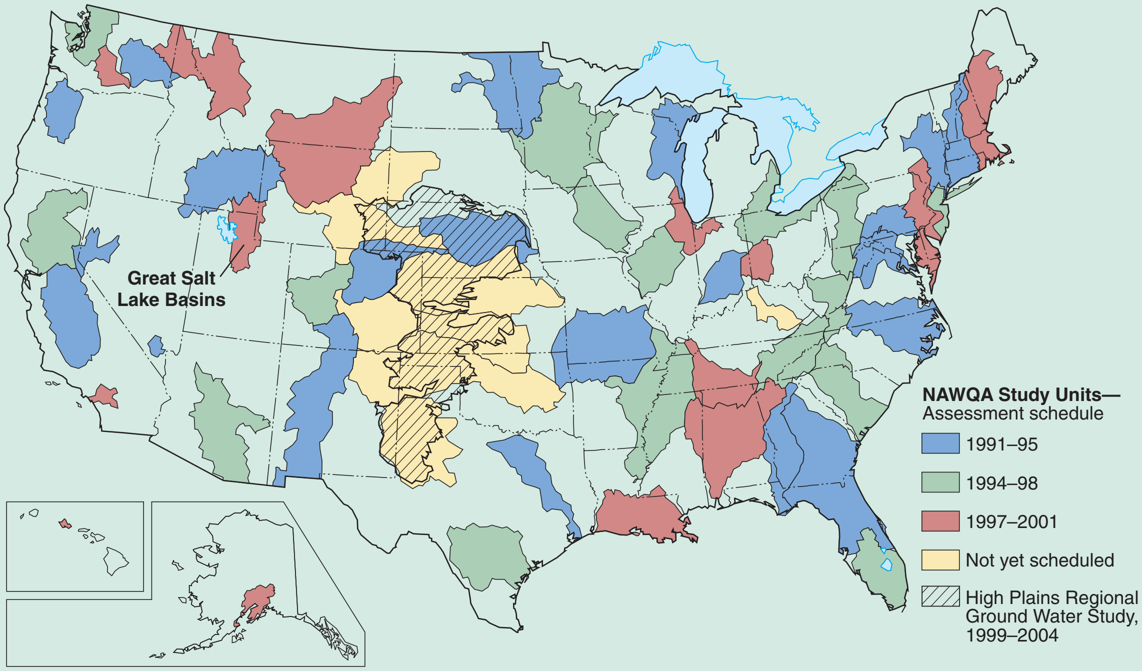
Contents

National Water-Quality Assessment Program

The quality of the Nation's water resources is of great interest because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is 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 Great Salt Lake Basins 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 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 Great Salt Lake Basins 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 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

“Through the city itself flows an unfailing stream of pure, sweet water, which, by an ingenious mode of irrigation, is made to traverse each side of every street, whence it is led into every garden spot, spreading life, verdure, and beauty over what was heretofore a barren waste.”

—Howard Stansbury, 1849, Captain, Corps Topographic Engineers, United States Army, from 1852, Exploration and Survey of the Valley of the Great Salt Lake of Utah.

This report contains the major findings of a 1998–2001 assessment of water quality in the Great Salt Lake Basins. 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.

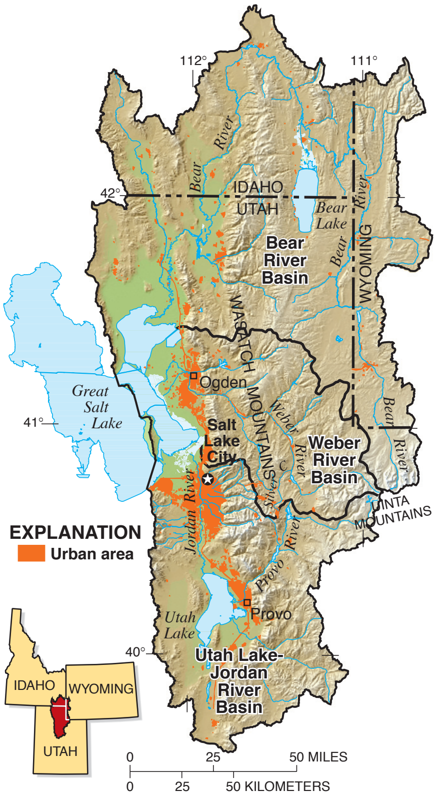
In these reports, water quality is discussed in terms of local, State, and regional issues. Conditions in a particular basin or aquifer system are compared to conditions found elsewhere and to selected national benchmarks, such as those for drinking-water quality and the protection of aquatic organisms.

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, hypoxia 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 water quality in other areas across the Nation.

The water-quality conditions in the Great Salt Lake Basins summarized in this report are discussed in detail in other reports that can be accessed at *http://ut.water.usgs.gov*. 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 at the national NAWQA Web site *http://water.usgs.gov/nawqa*.

Bear River near Corinne, Utah.

Summary of Major Findings

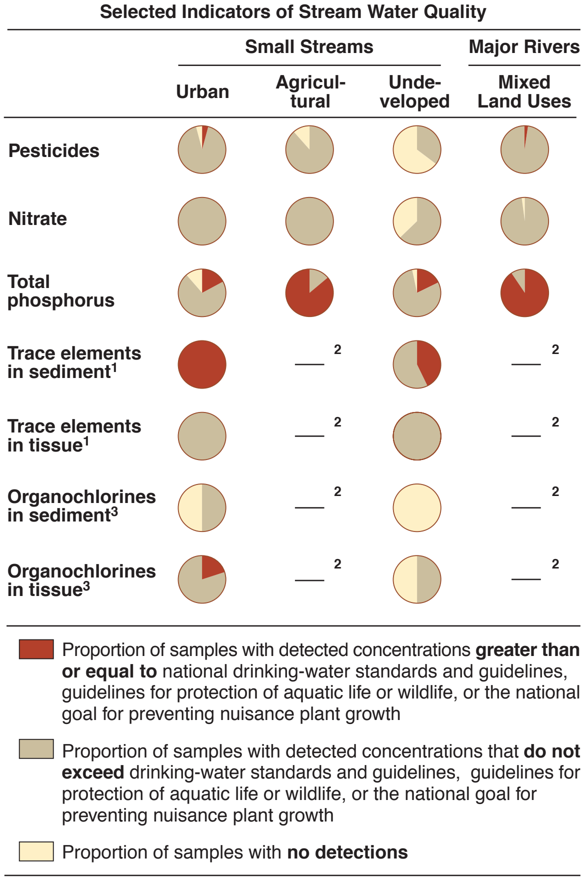


The Great Salt Lake Basins Study Unit encompasses about 14,500 square miles and includes parts of northeastern Utah, southeastern Idaho, and southwestern Wyoming. The Study Unit comprises three major river systems that enter Great Salt Lake: the Bear, Weber, and Utah Lake–Jordan River systems. About 1.7 million people, or about 76 percent of the population in the State of Utah, live along the western flanks of the Wasatch Mountains in the Salt Lake City, Ogden, and Provo metropolitan areas.

Stream and River Highlights

Surface water sampled in the Great Salt Lake Basins Study Unit generally meets existing guidelines for drinking water and protection of aquatic life. Urban, agriculture, and mining land uses have affected water quality, as indicated by elevated concentrations of pesticides, volatile organic compounds (VOCs), nutrients, chloride, and trace elements in basins dominated by these land uses.

- Water development and management have degraded the chemical and biological quality of some streams. Water of good quality in headwater areas often is diverted before reaching lower stream reaches known for poorer quality. Streams with minimal flow have elevated concentrations of nutrients, warm temperatures, and reduced habitat cover, which are difficult conditions for fish and other aquatic organisms to survive. (See pages 6 and 7)



[1] Arsenic, mercury, and metals.

[2] Insufficient data.

[3] Organochlorine compounds, including DDT, PCBs, and chlordane.

- Concentrations of nitrogen were about 3 to 4 times higher in urban, agricultural, and mixed land-use settings than in undeveloped basins. Phosphorus concentrations exceeded the U.S. Environmental Protection Agency (USEPA) desired instream goal of 0.1 *mg/L* (milligram per liter) for preventing nuisance plant growth in 12 of 27 streams sampled. (See page 10)
- Pesticides are widespread, detected in about 95 percent of the streams sampled. Concentrations of carbaryl, diazinon, and malathion exceeded guidelines for protection of aquatic life. Aquatic-life guidelines have been established for only 18 of the 49 pesticides detected. Pesticide concentrations were generally lower in streams in undeveloped and agricultural areas than in streams affected by urban land uses. (See pages 12 and 13)
- Of the 27 organochlorine compounds for which samples were analyzed, 12 were detected in fish tissue and 6 in streambed sediment. Two commonly detected compounds were PCBs and DDT. In fish samples, PCBs were detected at 8 sites, DDT at 13 sites. In sediment, PCBs were detected at two sites, and DDT compounds at four sites. Guidelines for fish-eating wildlife were

exceeded for total DDT (2 sites) and PCBs (4 sites). The use of most of these compounds has been discontinued for decades, but they continue to persist in the environment. (See page 18)

- At 9 of 15 sites sampled for streambed sediment and 11 of 14 sites sampled for fish tissue, concentrations of at least 1 trace element were greater than 90 percent of the samples collected in all NAWQA studies nationally in 1993–2000. Aquatic-life guidelines for arsenic, cadmium, copper, lead, mercury, silver, and zinc were exceeded in bed-sediment samples from stream reaches that were affected by mine tailing deposits and smelters (including some on urbanized streams). (See pages 21 and 24)

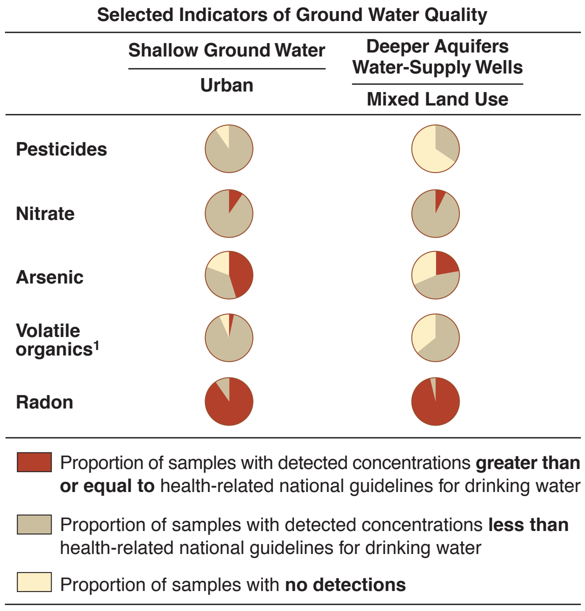
Major Influences on Streams and Rivers

- Urban and agricultural land use
- Historical mining activities
- Water development and management

Ground-Water Highlights

Ground water is a major source of public supply in the Great Salt Lake Basins Study Unit. The basin-fill aquifers receive recharge from precipitation on the mountains through subsurface inflow and from infiltration of precipitation, irrigation, or seepage from streams and canals in the valleys. Shallow ground water in Salt Lake Valley contains elevated concentrations of nitrate; and pesticides and VOCs were detected in many samples from the shallow aquifer, indicating that the shallow aquifer is affected by human activities at the land surface. Water from the deeper underlying basin-fill aquifers generally meets existing Federal and State standards and regulations for drinking water.

- The median nitrate concentration of 6.8 mg/L for shallow water from 30 monitoring wells in recently developed residential and commercial areas in Salt Lake Valley is the highest of 34 studies done across the Nation as part of the NAWQA Program. These wells are in areas with high potential for downward movement of water to the underlying basin-fill aquifer used for public supply. (See page 11)
- Tetrachloroethene (PCE) was detected more frequently in shallow ground water underlying residential and commercial areas in Salt Lake Valley than in most ground water sampled by NAWQA across the Nation. PCE was detected in water from 16 of 30 monitoring wells. Water from one monitoring well exceeded the USEPA drinking-water standard of 5 µg/L (micrograms per liter) for PCE, although water from the shallow aquifer is not used for drinking. (See pages 14 and 15)



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

- VOCs were frequently detected in water from the basin-fill aquifers in both agricultural and urban areas. Chloroform, likely formed as a byproduct of water disinfection, was the most frequently detected VOC, but at concentrations much less than the USEPA drinking-water standard. (See page 15)
- Atrazine was the most frequently detected pesticide (77 percent of samples) in shallow ground water underlying Salt Lake Valley, but mostly at concentrations much less than the USEPA drinking-water standard of 3 µg/L. Atrazine was detected in 23 percent of samples collected from wells in the basin-fill aquifers throughout the Study Unit. (See page 15)
- The age (time since recharge) of water from 31 public-supply wells in Salt Lake Valley ranged from 3 to more than 50 years. Manmade compounds generally were detected in water that was less than 50 years old, but not in water more than 50 years old. (See page 16)
- Concentrations of arsenic in water from about 20 percent of wells (primarily domestic wells) in the basin-fill aquifers underlying recharge areas exceeded the USEPA drinking-water standard of 10 µg/L. Arsenic in basin-fill aquifers likely is derived naturally from geochemical reactions between aquifer minerals and water. (See page 21)

Major Influences on Ground Water

- Urban and agricultural land use
- Aquifer properties and characteristics
- Sources of ground-water recharge

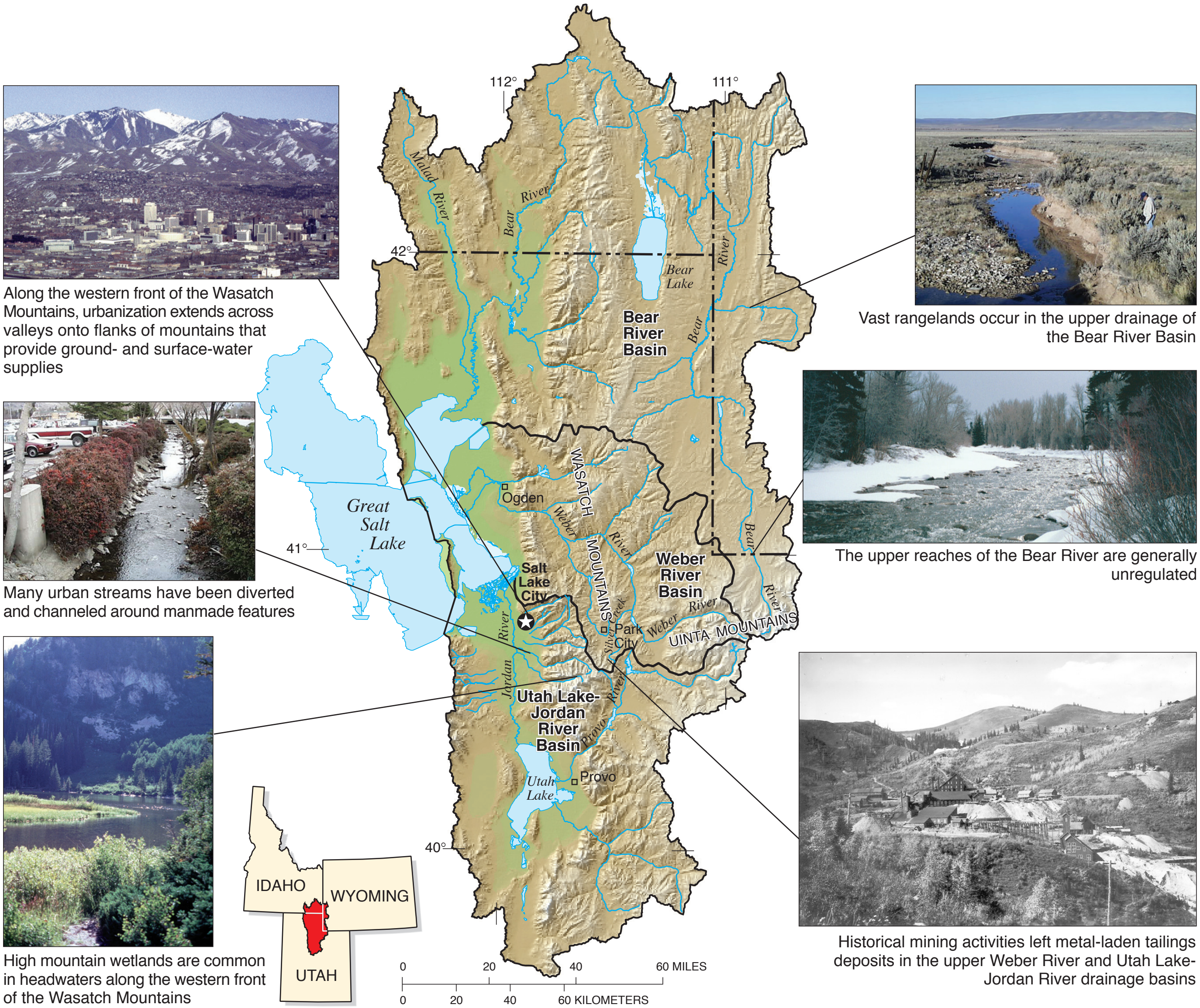
Introduction to the Great Salt Lake Basins

Physical Setting and Climate

The Great Salt Lake Basins *Study Unit* includes about 14,500 square miles of northeastern Utah, southeastern Idaho, and southwestern Wyoming and three major river systems that enter Great Salt Lake: the Bear, Weber, and Utah Lake-Jordan River systems (Baskin and others, 2002). Altitude ranges from about 4,200 feet near Great Salt Lake to more than 12,000 feet in the Uinta Mountains near the eastern edge. About 1.7 million people or about 76 percent of the population in the State of Utah (2000 census) live along the western flanks of the Wasatch Mountains, where Utah's largest cities are located (fig. 1).

The climate in the Study Unit is typical of mountainous areas in the Western United States. Temperature generally fluctuates widely between summer and winter and between day and night. The high mountains have long, cold winters and short, cool summers. The lower valleys are more moderate, with less variance between maximum and minimum temperatures. Average monthly maximum temperature reaches 92ºF in July at the Salt Lake City International Airport, and the average monthly minimum reaches –1.5ºF in January at Sage, Wyoming.

Most of the annual precipitation falls as snow, which provides most of the annual runoff during the spring as snowmelt. Average annual precipitation ranges from less than 16 inches on the valley floors to greater than 70 inches in the high mountain areas.



Along the western front of the Wasatch Mountains, urbanization extends across valleys onto flanks of mountains that provide ground- and surface-water supplies

Many urban streams have been diverted and channeled around manmade features

High mountain wetlands are common in headwaters along the western front of the Wasatch Mountains

Vast rangelands occur in the upper drainage of the Bear River Basin

The upper reaches of the Bear River are generally unregulated

Historical mining activities left metal-laden tailings deposits in the upper Weber River and Utah Lake-Jordan River drainage basins

Figure 1. Large changes in altitude, climate, and land use produce a wide range of hydrologic environments in the Great Salt Lake Basins.

Hydrologic Conditions

Total average annual surface-water discharge from the three river systems during 1931–76 was 2.98 million acre-feet. Of this total, about 62 percent was discharged by the Bear River Basin, 23 percent by the Weber River Basin, and 15 percent by the Utah Lake-Jordan River Basin (fig. 2) (Waddell and Barton, 1980).

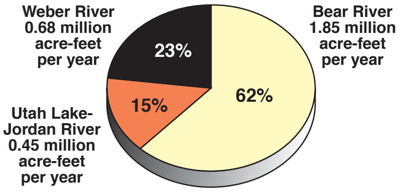


Figure 2. Total average annual surface-water discharge from the three river systems during 1931–76 was 2.98 million acre-feet.

Streamflow variability results from seasonal variations of precipitation, temperature, and evapotranspiration, and human-induced hydrologic modifications resulting from dams and diversions. Flows in most of the major streams and tributaries naturally peak during May to June (fig. 3).

In some watersheds, dams that create major reservoirs control streamflow. The basins have 27 reservoirs with a storage capacity greater than 6,500 acre-feet, resulting in a combined storage capacity of more than 3.5 million acre-feet. This includes Bear Lake, which has a usable storage capacity of about 1.4 million acre-feet, much of which comes from water diverted from the Bear River (fig. 4). Snowmelt is stored in reservoirs (usually during March through June) and is released during the irrigation season (June through September). The regulation alters the basin's natural peak runoff period and affects the physical, chemical, and biological conditions of streams.

Water Use

Irrigation is the primary use of water in the Great Salt Lake Basins study unit. In 1995, irrigation for agriculture accounted for an estimated 92 percent of all water use in the Bear River Basin, 82 percent in the Weber River Basin, and 70 percent in the Utah Lake-Jordan River Basin. Water use for public supply was estimated at 4 percent (of all use) in the Bear River Basin, 16 percent in the Weber River Basin, and 26 percent in the Utah Lake-Jordan River Basin.

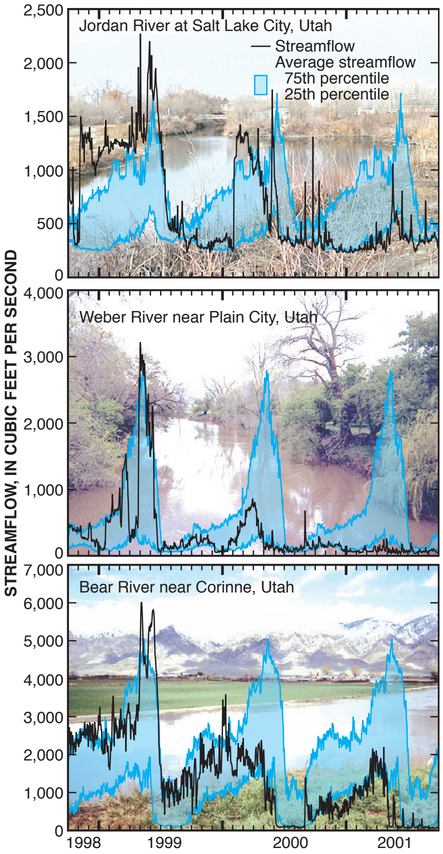


Figure 3. Flow in most streams in the study area was above normal during the 1999 water year, then below normal during water years 2000–01.

Total water use in the Great Salt Lake Basins Study Unit in 1995 was estimated to be 2,797 Mgal/d (million gallons per day) (U.S. Geological Survey, 1995). About 2,379 Mgal/d (85 percent) of this total was supplied by surface-water withdrawals and 418 Mgal/d (15 percent) by ground-water withdrawals. Irrigation accounted for about 2,130 Mgal/d in surface-water withdrawals and 139 Mgal/d in ground-water withdrawals. An estimated 193 Mgal/d of surface water and 240 Mgal/d of ground water were withdrawn for public supply.

Water Quality and Land Use

As the major rivers emerge from the headwater areas and flow through the broad valleys east of the Wasatch Mountains, water quality is similar among the three rivers, controlled primarily by natural factors. At lower altitudes west of the Wasatch Mountains, however, and to a lesser extent in the areas east of and adjacent to the Wasatch Mountains, human and natural factors differ considerably and affect the rivers in different ways.

Natural factors of physiography, geology, soils, climate, and hydrology largely determine the natural background quality of water, and cultural factors of population, land and water use, and water- and waste-management practices define the human influence on water quality. Hydrologic modifications of streams, along with *point* and *nonpoint* sources of contaminants, have had detrimental effects on the quality of ground-water and surface-water

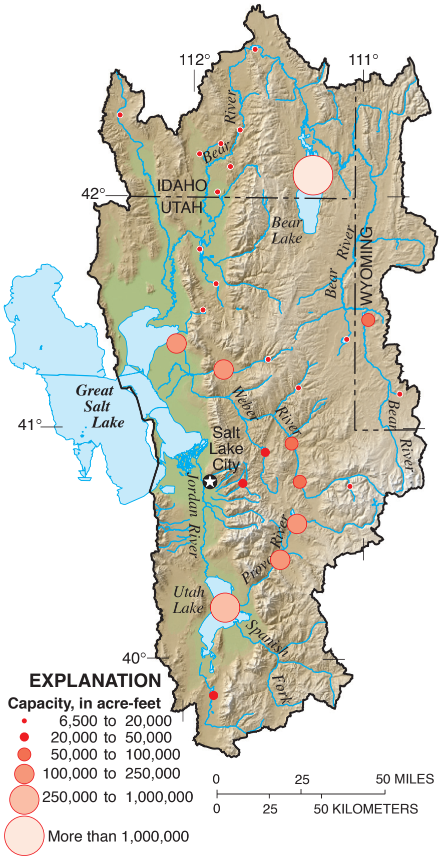


Figure 4. Reservoir capacity in the Great Salt Lake Basins Study Unit exceeds 3.5 million acre-feet.

resources throughout the basins (Utah Department of Natural Resources, 1996).

Rangeland covers about 48 percent of the Study Unit and forest and agricultural land covers 22 and 18 percent, respectively (Hitt, 1994). Urban land accounts for 4 percent of the total land cover, and the remaining 8 percent is distributed between wetlands (4 percent), water (3 percent), and bare ground (1 percent) (fig. 5). Mining occurred in several of the canyons of the Wasatch Mountains within a 30-mile radius of Salt Lake Valley.

Land use and associated human activities alter the natural character of streams by changing water quality, channel shape, and flow characteristics. In headwater areas, logging, mining, and, more recently, recreation and residential construction have increased erosion and changed water quality. In the valleys, agriculture, grazing, and urbanization have removed many of the natural wetlands and *riparian* vegetation; channelized stream reaches in some areas; and contributed nutrients, sediments, and other contaminants to streams.

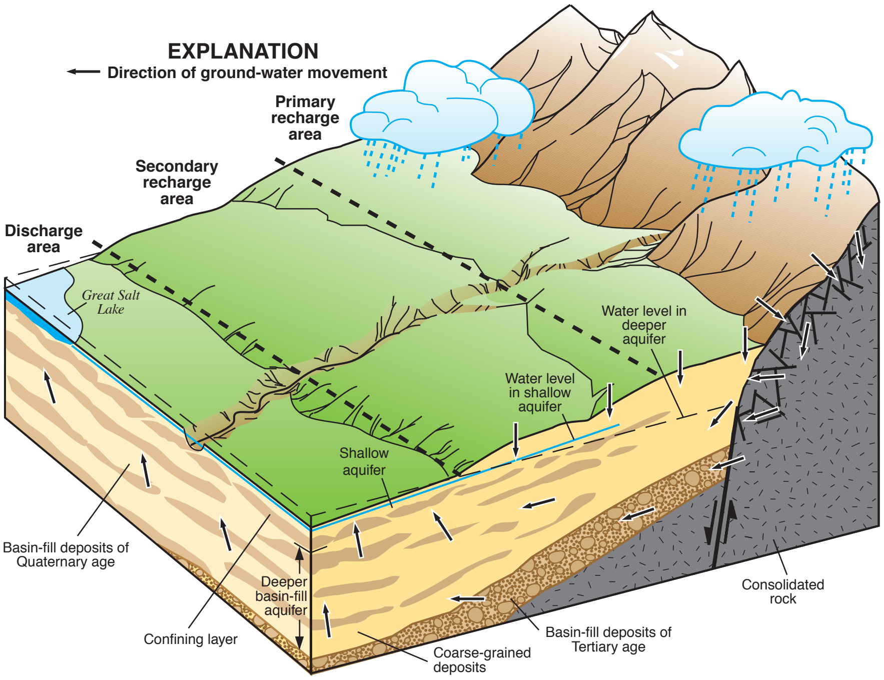


Figure 6. Ground water in the study area generally comes from precipitation on the mountains or on valley benches, where it infiltrates into the soil and moves to the basin-fill aquifers.

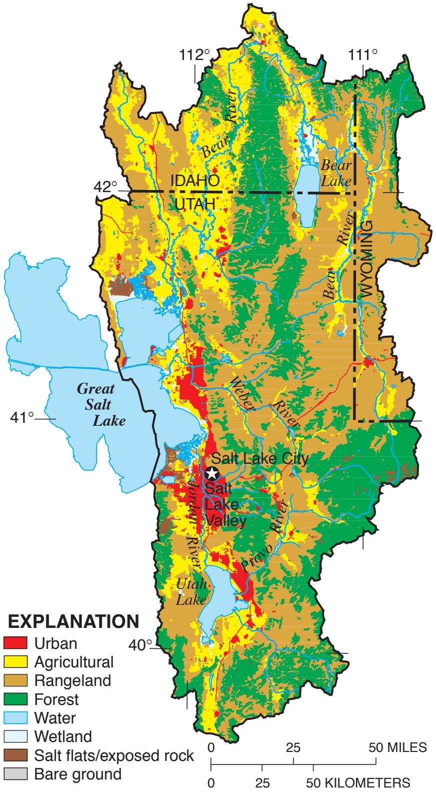


Figure 5. Land-use/land-cover information is useful in assessing human influences on water quality by providing information on the possible causal factors related to water-quality observations.

Aquatic Habitat and Biota

The composition of aquatic *communities* depends on stream environment. The distribution of aquatic invertebrates and *algae* is determined by local habitat characteristics such as substrate size and type, stream velocity, food source availability, and water temperature (Stevenson and others, 1996). In the Study Unit, these physical factors vary considerably between small, steep mountain streams and large, low-gradient streams.

The native fishery of the basin is limited in diversity and has been affected by introductions of nonnative fish. Trout are the dominant *species* in cold waters at higher altitudes, and introduced warm-water fishes dominate in warmer waters at lower altitudes (Holden and others, 1996). At least 20 exotic species are common to streams in the Study Unit.

Ground Water

Ground water is contained within unconsolidated basin-fill deposits in the basins and in consolidated rocks in the mountains (fig. 6). The unconfined part of the basin-fill *aquifer*s, which is the primary *recharge* area, contains the water table (or uppermost saturated zone in the subsurface) and is the most vulnerable to contamination from overlying land-use activities. The lack of *confining layers* near the mountain fronts results in relatively deep unconfined aquifers (water levels generally greater than 100 feet below land surface). Mountain-front areas are becoming increasingly developed for residential and commercial uses. Where confining layers exist in the subsurface, shallow unconfined aquifers (generally about 50 feet below land surface) overlie the *confined aquifers* (Thiros, 2003a). Water from the adjacent and overlying unconfined deposits recharges confined parts of the basin-fill aquifers. Although separated from the land surface by confining layers, the confined aquifers also are susceptible to contamination from the shallow and deeper unconfined aquifers by flow reversals caused by large withdrawals of ground water. The basin-fill aquifers are a major source of water for domestic and municipal supply and for irrigated agriculture.

Major Findings

Water development affects quantity and quality of water resources

Streamflow regulation, such as that in the Bear River Basin, alters daily and seasonal flows

Regulation of streamflow for power generation and irrigation substantially alters daily flow in some streams in the Great Salt Lake Basins Study Unit. For example, streamflow in the Bear River at the Utah/Idaho State line, downstream from the Oneida Narrows hydroelectric dam, fluctuated from about 400 to more than 1,600 ft^3/s (cubic feet per second) over a 7-day period in August 2000. Flow in the Bear River near Cokeville, Wyoming, which is not affected by power generation, remained nearly constant at 180 ft^3/s during the same period (fig. 7).

Seasonal fluctuations in flow in a regulated stream in the basins also are demonstrated in the Bear River. During the winter months, when large amounts of water are not stored in reservoirs or diverted into canals, flow naturally increases in a downstream direction (from about 50 to more than 1,000 ft^3/s) (fig. 8). In the summer months, when water is released from reservoirs and diverted into canals for irrigation, flow changes substantially (from nearly no flow in some stream segments, to more than 1,200 ft^3/s in others) (fig. 8).

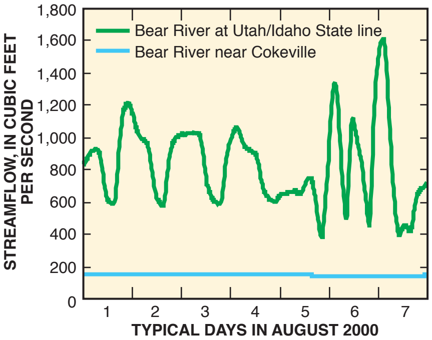


Figure 7. During a typical week in the summer, streamflow at sites below hydroelectric dams (such as Bear River at Utah/Idaho State line) have large daily fluctuations, while sites unaffected by power generation (such as Bear River near Cokeville) have steady flow.

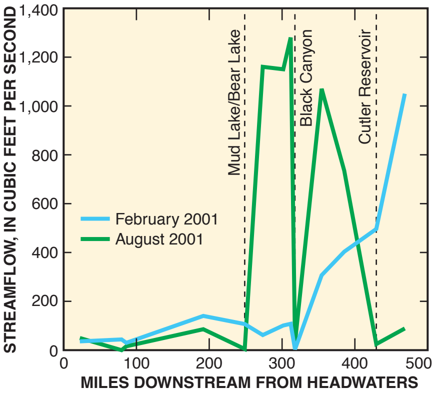


Figure 8. The flow of the Bear River in February approaches that of a natural river, increasing from upstream to downstream. The flow in August is dramatically altered by release and diversion of stored water for downstream irrigators.

Periodic low flow in streams can affect recreation, ground-water recharge, aquatic life, and fish and wildlife *habitat*. To avoid such effects, minimum instream flow requirements, maintained through purchased water rights or legislation, have been established for some streams in the Great Salt Lake Basins. Segments of other streams with no requirements, including some in the Bear River Basin, however, can be completely dewatered by diversions.

Reductions in water quantity also affect water quality in streams

Identifying and understanding daily and seasonal fluctuations in streamflow is important because the amount of water in a stream can directly affect the quality of the water. Specifically, the magnitude and timing in transport of sediment, *nutrients*, and other contaminants is affected. For example, *concentrations* of total phosphorus in the Bear River in March 2001, when flow regulation was minimal, increased downstream from less than 0.004 mg/L at the Utah/Wyoming State line (near the

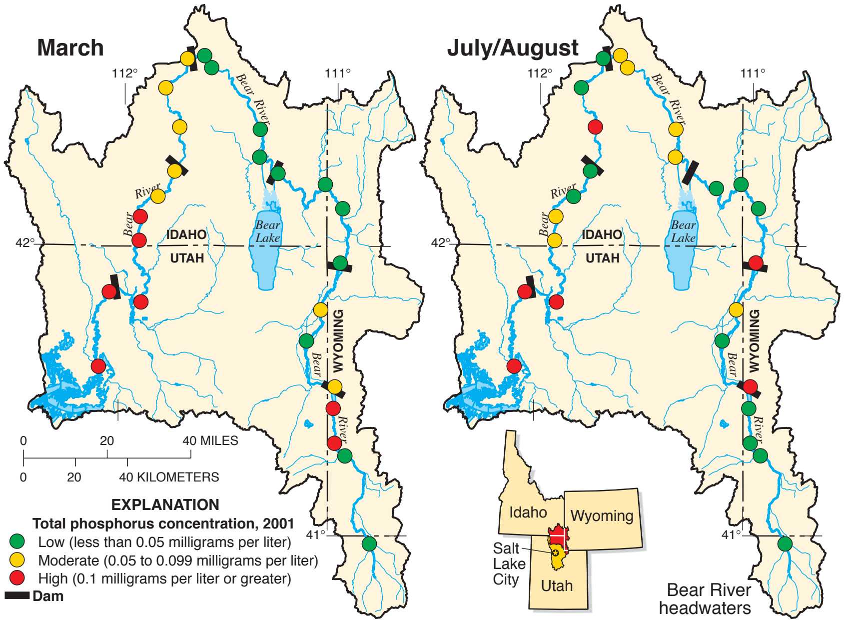


Figure 9. In the Bear River, contributions from tributary streams have a large influence on total phosphorus concentration in March. Reservoir management and canal diversions affect concentrations in July and August.

headwaters) to 0.49 mg/L below Cutler Reservoir (near the mouth) (fig. 9). Concentrations of phosphorus in the contributing tributaries averaged about 0.46 mg/L and were associated primarily with natural phosphorus deposits, manure from animal feeding operations, fertilizers used on farm fields, and wastewater-treatment discharge. In contrast, concentrations of total phosphorus in the Bear River in July/August 2001, when large amounts of water were diverted for irrigation, were highly variable, especially above and below dams. For example, concentrations of total phosphorus generally increased below reservoirs upstream from Bear Lake (possibly due to low water levels in the reservoirs, which allowed resuspension of particulate phosphorus) and decreased below most reservoirs downstream from Bear Lake (due to deposition of particulate phosphorus in the reservoirs). During this period, tributaries generally were diverted upstream from their *confluence* with the Bear River and contributed little flow or contaminants to the Bear River.

Similar patterns in water quality above and below diversions also were noted in other streams (fig. 10). In general, streams above diversions generally drain undeveloped basins and water is of good quality. Below diversions, streamflow consists mainly of agricultural and urban *runoff*, ground-water inflow, and inflow from irrigation canals and wastewater-treatment facilities, which can contain elevated levels of *suspended sediment*, nutrients, organic pollutants, and *dissolved solids*. For example, the concentration of dissolved solids above diversions on Baer Creek, a small stream in the Weber River Basin between Ogden and Salt Lake City, was less than 100 mg/L, whereas the concentration below diversions was greater than 500 mg/L.

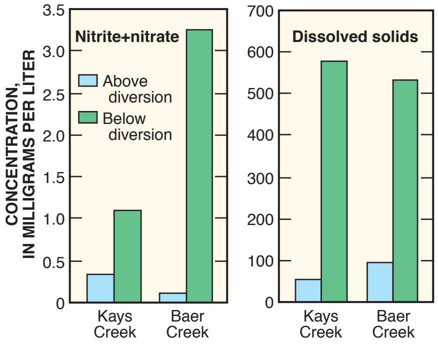


Figure 10. Good quality water from undeveloped basins is diverted at canyon mouths. Agricultural and urban runoff replaces this water, and the quality of water in the stream is degraded.

Fish communities in urban streams respond to changes in water quantity

Water management infrastructure and operation affect fish community composition and the ability of urban streams to support fish. These factors are particularly important in moderate-sized watersheds, such as Little Cottonwood, Big Cottonwood, and Mill Creeks in Salt Lake Valley, Utah. These watersheds are similar in size and environmental setting but have very different fish communities, in large part due to withdrawals of water. Water is withdrawn from Little and Big Cottonwood Creeks before they flow into urban areas, sometimes resulting in complete dewatering of the channel below the withdrawal point in the summer, when natural flows are low (fig. 11). In Mill Creek, smaller diversions remove water, but there is not a large withdrawal that completely dewaters the channel. Water is restored to all three stream channels downstream from diversions through ground-water inflow and additions through canal systems. The additions to Big Cottonwood Creek are more substantial than those to Little Cottonwood Creek, and as a result, flow in Big Cottonwood Creek is more nearly continuous and reliable in the summer.

Figure 11. Segments of many urban streams in the Study Unit, such as the one shown here on Little Cottonwood Creek, are completely or nearly dewatered in the summer when natural flows are low and water use is high.

Fish communities in these streams reflect the differences in flow. For example, in Little Cottonwood Creek, which had the largest diversions and least flow, the fish community consisted of mountain sucker, speckled dace, and fathead minnows. These small-bodied fish are able to survive in low-flow, shallower environments. In Mill Creek, which had the least diversion and most flow, the dominant fish collected was brown trout, a larger species. The fish community of Big Cottonwood Creek was a mix of mountain sucker (the dominant fish species in Little Cottonwood Creek), brown trout, and a variety of other species consisting primarily of sunfishes, minnows, and catfish (fig. 12).

Alterations of natural flow in stream channels can adversely affect water quality and the availability and quality of fish habitat. Consequently,

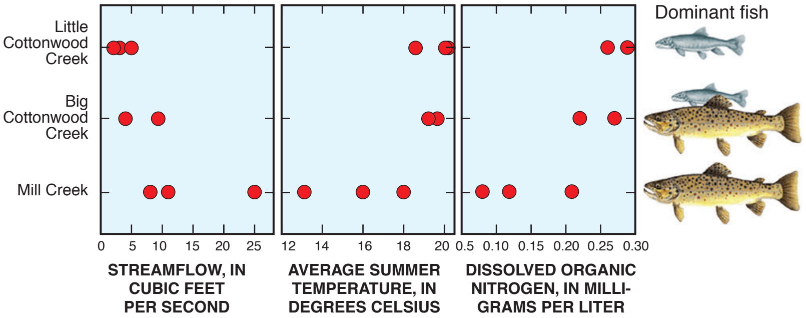


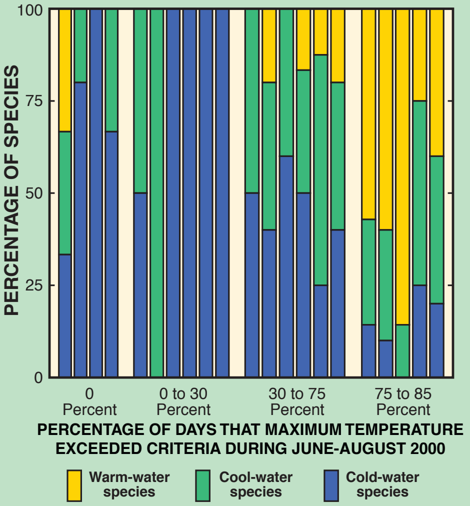
Figure 12. Among three sampled urban streams, the two with lower streamflow (and greater withdrawals) had warmer water temperatures and poorer water quality (shown by higher concentrations of dissolved organic nitrogen) and were dominated by smaller fish species.

Upstream diversions have resulted in increased water temperatures in streams and changed fish communities

In the State of Utah, the criterion for water temperature in stream reaches designated to support cold-water aquatic life is 20 degrees Celsius (ºC). This criterion was selected prior to any continuous monitoring of stream temperature and applies to any point measurement of temperature taken at any time of day. Twenty-one sites on 13 urban streams designated to support cold-water game fisheries were monitored for temperature, and at 17 of these sites the criterion was exceeded at least once during the summer of 2000. Five sites had maximum daily temperatures that exceeded the criterion on more than 75 percent of the days during this time.

Most urban sites are in the valley and are exposed to warmer air temperatures; however, these streams historically supported cold-water salmonid species (Sigler and Sigler, 1996). Thermal pollution in these streams is likely due to upstream diversion of water and subsequent replacement with urban and agricultural runoff. Additionally, the reduction of flow that also results from diversions increases temperatures during the summer due to the loss of thermal mass.

Increased temperatures in urban streams have changed fish communities. Specifically, warm-water species, such as common carp, green sunfish, and channel catfish, which are not native to streams in the Great Salt Lake Basins, have populated streams in which temperatures exceed 20ºC at least 30 percent of the time. These warm-water species have replaced native cold-water species, such as trout and whitefish, and cool-water species, such as sculpin and dace, which cannot tolerate the warmer waters. In fact, in streams where the daily maximum temperature exceeds 20ºC more than 75 percent of the time, cold-water species compose less than 25 percent of the fish community.



changes in natural flow conditions can result in corresponding changes in the number and kinds of fishes found in a stream. For example, streams with more diversions have less available habitat for fish. With decreased water at low flows, deeper water habitats, such as pools, are reduced, which limits larger species, such as brown trout. Smaller species that are adapted to shallow, riffle areas, such as mountain sucker, tend to dominate in streams with severe dewatering. In addition, streams with less flow had higher water temperatures and higher concentrations of nutrients. These conditions tend to favor warm-water fish species more tolerant of high temperatures and degraded water quality, such as sunfish and catfish.

Pumping likely affects the distribution of dissolved solids in the basin-fill aquifer in Salt Lake Valley

Pumping from wells accounts for about one-third of the total estimated discharge from the basin-fill aquifer in Salt Lake Valley, Utah, an urban area in the Study Unit (seepage to streams and evapotranspiration are the other major forms of discharge). Most ground-water withdrawals occur on the eastern side of the valley because of higher well yields (discharge rates) and lower dissolved-solids concentrations. In some areas on the western side, ground water is withdrawn and blended with water from other sources to improve its quality.

Comparison of water in the basin-fill aquifer sampled in 1988–92 and that sampled in 1998–2002, shows an increase in the extent of the aquifer containing water with a dissolved-solids concentration greater than 500 mg/L. Water with less than 500 mg/L dissolved solids extended to the northwest past the Jordan River in 1988–92, but was replaced by water with concentrations of dissolved solids greater than 500 mg/L by 1998–2002 (fig. 13). Concentrations of dissolved solids increased in water from some wells near the center of the valley, where the direction of ground-water movement (gradient) is naturally upward between the basin-fill aquifer and land surface. Withdrawals from the basin-fill aquifer for public supply may have caused gradients to reverse, allowing more mineralized water that was recharged in the valley to move to the aquifer.

Land use influences water quality and aquatic community health

Undeveloped basins show minimal degradation of water quality and biological communities

Water quality and biological conditions are generally better in streams draining forests and rangeland (undeveloped areas) than in streams draining agricultural and urban areas or areas of mixed land use (developed areas).

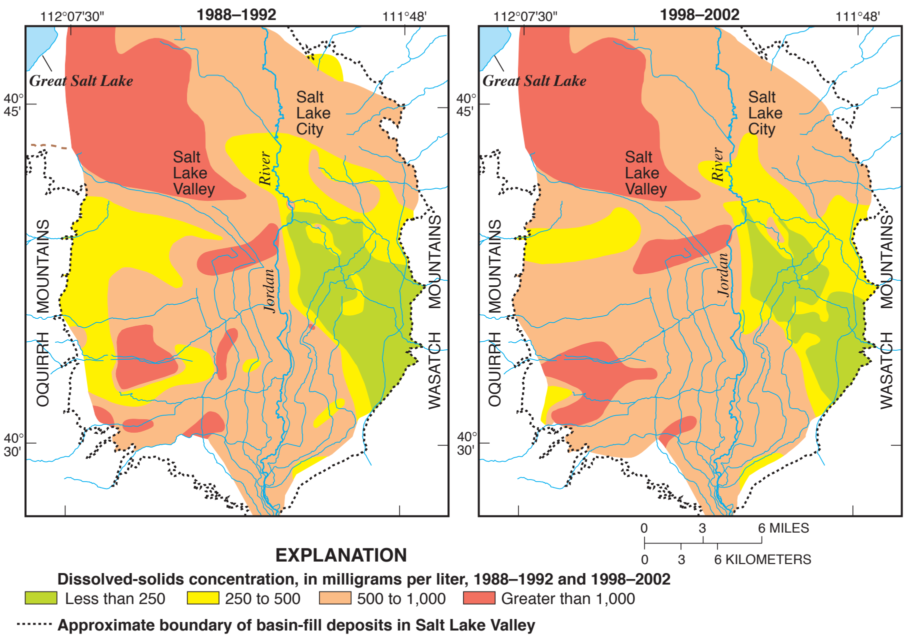


Figure 13. Dissolved-solids concentration in water from parts of the deeper basin-fill aquifer in Salt Lake Valley increased from 1988–92 to 1998–2002.

Forest and rangeland cover approximately 70 percent of the Study Unit. Undeveloped basins are sparsely populated and commonly include high, precipitous mountains with narrow crests and forested valleys or broad intermontane basins dominated by arid grasslands and shrublands. Examples of streams in undeveloped areas include the upper Bear and upper Weber Rivers, and Red Butte Creek (Jordan River Basin). The quality of water and the state of the aquatic community in these streams represents "natural" conditions in the basins (fig. 14).

Figure 14. USGS scientists assess stream habitat at a site on the upper Weber River (a largely undeveloped river basin).

The concentration of dissolved solids in a stream generally indicates the degree of stream development and human influence on water quality. For example, concentrations in undeveloped streams ranged from 176 to 469 mg/L, whereas concentrations in more developed and urbanized streams ranged from 67 to 2,750 mg/L (fig. 15). Elevated concentrations of dissolved solids in the developed streams generally reflect the return of water to the streams after use for human consumption, industrial activities, and irrigation.

Physical habitat, including streambed composition, bank stability, water velocity and depth, amount of sunlight received, and protective structures also indicates the degree of stream development and human influence. Physical habitat features often are integrated into one measure, referred to as Habitat Quality Index Scores, which were higher (better) for undeveloped streams than for developed streams (fig. 15). Streams with dams and diversions sometimes had lower scores regardless of human influences or land-use activities within their basins. For example, the watershed above the Bear River near Pescadero, Idaho, is largely undeveloped; the Habitat Quality Index Score in this stream reach is low, however, because channelization and flow regulation have resulted in little pool variation or stream sinuosity.

Composition of biological communities also indicates degree of stream development and human influence. Specifically, streams in developed basins had aquatic communities that were more tolerant to pollution and habitat disturbances than were aquatic communities in undeveloped basins. Streams in developed basins also had a lower percentage of native fish species such as longnose dace and cutthroat trout, a lower percentage of insect *taxa* preferring good water-quality conditions such as mayflies, stoneflies, and caddisflies, and a higher percentage of pollution-tolerant algal species, such as *Nitzschia inconspicua*.

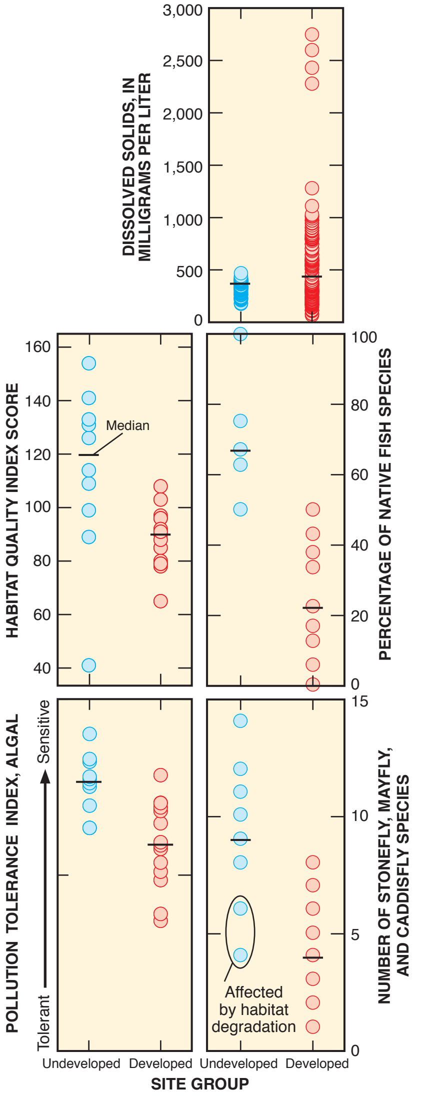


Figure 15. Aquatic communities and water chemistry in streams affected by urban and agricultural land uses are generally degraded compared to streams in largely undeveloped basins with predominantly rangeland and forest land cover.

Phosphorus and nitrogen levels are elevated in streams draining agricultural and urban areas

Streams associated with agricultural, urban, or mixed land uses generally had higher concentrations of phosphorus and nitrogen relative to streams associated with forest or rangeland cover.

Nutrients occur naturally in streams due to mineral weathering and biological activity in the streambed sediment; however, additional nutrients can enter streams in agricultural and urban runoff, *atmospheric deposition*, and wastewater discharge. Elevated nutrients can lead to eutrophic conditions, which include excessive growth of aquatic vegetation, reduced dissolved-oxygen concentrations, imbalance of predator and prey species, and a decline in aesthetic and recreational values.

Concentrations of phosphorus exceeded the USEPA desired goal of 0.1 mg/L to prevent nuisance plant growth in streams in only 15 percent of the samples from undeveloped streams (fig. 16). More than 80 percent of the samples from streams affected by agricultural and mixed land use had phosphorus concentrations exceeding 0.1 mg/L. Total phosphorus concentration in water from urban streams exceeded 0.1 mg/L in only 21 percent of the samples; however, the highest concentrations of total phosphorus were measured in water samples from urban sites on Silver Creek (2.49 mg/L, attributed to treated wastewater outflow) and Little Cottonwood Creek (2.39 mg/L, attributed to storm runoff).

Concentrations of nitrogen were higher in streams in basins with predominately agricultural, urban, or mixed land uses, relative to streams in undeveloped watersheds. The *median* concentration of total nitrogen measured in water samples from undeveloped streams was 0.37 mg/L (fig. 16). This is within the range of total nitrogen concentrations representing naturally occurring (or “reference”) conditions (0.34 – 0.48 mg/L) identified by the USEPA (2000) for the *ecoregions* in which the Study Unit resides. The median concentration of total nitrogen was above the reference range in water samples from urban (1.1 mg/L), agricultural (1.7 mg/L), and mixed-land-use streams (1.8 mg/L).

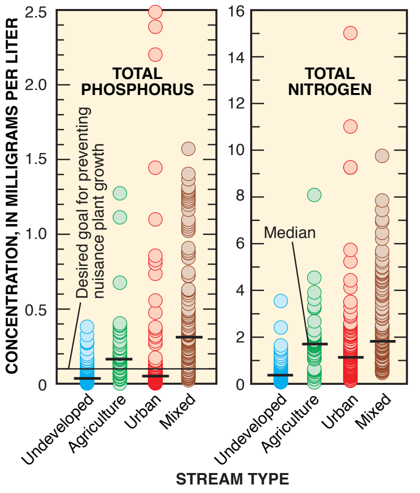


Figure 16. The concentration of phosphorus and nitrogen in undeveloped (forest/rangeland) streams was generally lower than in streams affected by other land uses.

Urban, agricultural, and mixed land-use streams with elevated concentrations of phosphorus and nitrogen are contributing nutrients to lakes and reservoirs in the Study Unit, sometimes resulting in *eutrophication* of these water bodies. For example, Pineview and East Canyon Reservoirs in the Weber River Basin have been shown to have seasonal depletion of dissolved oxygen because of algal blooms associated with excessive amounts of nutrients. Less dissolved oxygen in these reservoirs negatively affects the fish community. These reservoirs and their respective watersheds are being managed to control nutrients, including the amount of nutrients introduced by streams.

Nitrate levels generally are low in the basin-fill aquifers

Concentrations of *nitrate* in water from the basin-fill aquifers used for water supply throughout the Study Unit generally were low—at or less than 2 mg/L—which is considered a naturally occurring or “background” concentration on the basis of available data for undeveloped areas across the Nation (U.S. Geological Survey, 1999). Only four samples exceeded the USEPA *drinking-water standard* for nitrate (10 mg/L). Water from these four wells is used for irrigation and stock watering, and not for drinking. The highest measured concentration of nitrate (27.9 mg/L) was in a sample from a well in an agricultural area (fig. 17).

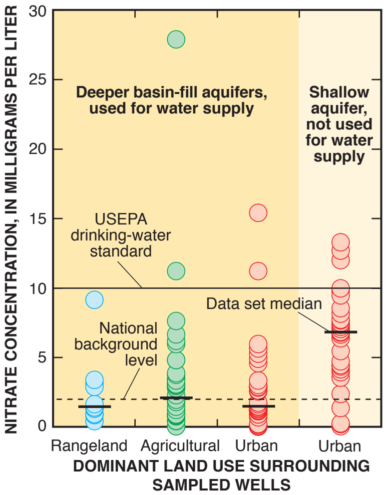
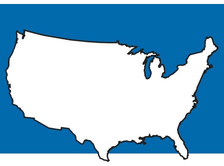


Figure 17. The median nitrate concentration of ground-water samples collected from the deeper aquifers is lower than the median for samples from a shallow aquifer in an urban area. Nitrate in most wells is below the drinking-water standard.

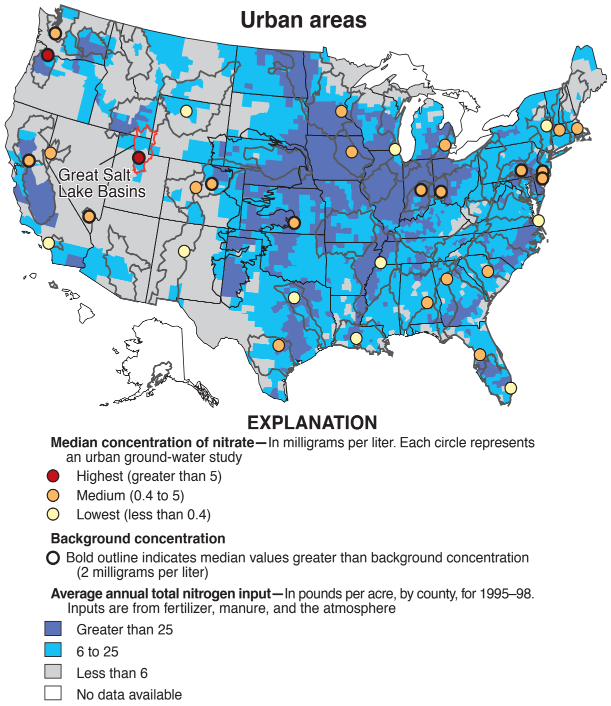
The presence of clay confining layers between the land surface and the basin-fill aquifers impedes the movement of water and any included contaminants to the underlying aquifer. The median concentration of nitrate in water from the confined part of the basin-fill aquifers was 1.5 mg/L. Concentrations of nitrate were highest in wells in the primary recharge areas (fig. 6) of the basin-fill aquifers (relative to wells in the more downgradient, confined parts). Specifically, the median concentration of nitrate was 3.1 mg/L in the primary recharge areas of the aquifers, which was the seventh highest value for 94 major drinking-water aquifers studied by NAWQA across the Nation.



Median nitrate concentration in Salt Lake Valley shallow ground water is the highest for urban areas in the Nation

The median concentration of nitrate in shallow ground water underlying residential and commercial land in Salt Lake Valley (6.8 mg/L) was almost 5 times the national NAWQA median for urban ground-water studies (1.4 mg/L) and was the highest found in 34 NAWQA studies across the Nation. Nitrate concentrations in water from 3 of the 30 monitoring wells in Salt Lake Valley exceeded the USEPA drinking-water standard of 10 mg/L, which was established because concentrations above this level are known to cause a blood disorder in infants, commonly called blue-baby syndrome. Water from the shallow aquifer underlying Salt Lake Valley is not currently used for drinking, but a longer term concern is the potential for contaminated water that might enter the shallow aquifer to move downward to the underlying basin-fill aquifer that is used for public supply. Such downward movement may already be evident, as water from 12 of 31 public-supply wells contained concentrations of nitrate greater than 2 mg/L (the naturally occurring or "background" concentration). The median concentration was 1.3 mg/L. No value exceeded the drinking-water standard, and public suppliers regularly monitor the source water for nitrate.

Although nitrate does occur naturally in ground water, elevated concentrations in urban areas, such as in Salt Lake Valley, are likely caused by human activities related to, for example, fertilizers applied to lawns and gardens and leaking or improperly functioning septic systems and sewer pipes.



Although none of the sampled domestic-supply wells in the basin-fill aquifers contained nitrate at concentrations that exceeded the drinking-water standard, the elevated concentrations (above background) indicate that the basin-fill aquifers are susceptible to human activities at the land surface. A chemical analysis of the water is generally required before a domestic-supply well can be connected to a residence, but subsequent monitoring typically is not required. It may be important for domestic well owners to assess activities around their wells and to monitor nitrate in their wells if concentrations are elevated or changing.

Urban storm runoff affects stream chemistry and temperature

Storm runoff can carry substantial quantities of nutrients, *pesticide*s, and *VOCs* to streams. These contaminants accumulate on impervious surfaces in urban areas of the basins between storms and are transported to streams in storm runoff. For example, mean concentrations of total nitrogen and phosphorus in runoff to Little Cottonwood Creek were 9.6 and 1.8 mg/L, respectively, during a storm in April 2000 (Gerner and Waddell, 2003) (fig. 18). The storm runoff resulted in elevated concentrations in the creek during the storm (6.5 and 1.2 mg/L of total nitrogen and phosphorus, respectively). The phosphorus concentrations greatly exceeded the USEPA recommended goal of 0.1 mg/L to prevent nuisance plant growth in streams.

Storm runoff also carried pesticides, particularly the insecticide carbaryl and the herbicide prometon (which is easily dissolved in and transported by water). Carbaryl can be toxic to fish and aquatic *invertebrate* animals. In fact, the concentration of carbaryl, in storm runoff and in stream samples collected during rainstorms, exceeded the Canadian water-quality guideline for the protection of aquatic life (0.20 *μg/L*)(Canadian Council of Ministers of the Environment, 2002) (fig. 18). These events are intermittent; however, they are important to consider, particularly when they occur during critical life cycles of aquatic organisms.

The concentration of dissolved solids in streams generally is lower during storms because of dilution. Exceptions occur in some study-unit urban streams, such as Little Cottonwood Creek, during and immediately following snowstorms

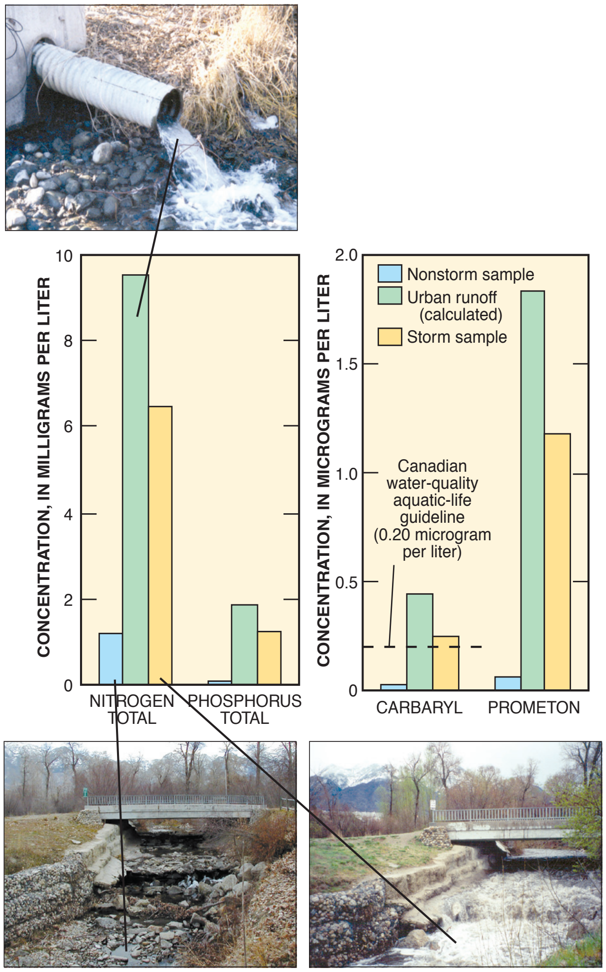


Figure 18. Nutrients and pesticides are transported to Little Cottonwood Creek in urban runoff, substantially increasing the concentration of these contaminants during storms.

because of increased inputs of sodium and chloride from deicing of roadways. For example, the chloride concentration in Little Cottonwood Creek during a 1999 winter storm exceeded 2,900 mg/L (fig. 19); conversely, chloride concentrations in Red Butte Creek (an adjacent, undeveloped basin) remained about 12 mg/L. Chloride concentrations in Little Cottonwood Creek exceeded the acute USEPA aquatic-life criterion for chloride (860 mg/L) (U.S. Environmental Protection Agency, 2002a) in 10 percent of the samples, and the chronic criterion (230 mg/L) in 61 percent of the samples collected during December 1999 through March 2000.

Elevated concentrations of chloride can cause acute and chronic toxicity in aquatic organisms. Even moderate concentrations can affect community structure, diversity, and productivity (Environment Canada and Health Canada, 2001). The effects of chloride are particularly evident in Little Cottonwood Creek, where several types of algae tolerant to saline conditions, such as *Nitzschia inconspicua* and *Navicula veneta*, are most dominant.

Urban storm runoff may be a source of certain VOCs in surface water and ground water. Many of the same VOCs, such as tetrachloroethene (PCE) and trichloroethene (TCE), commonly were detected in both storm runoff and shallow ground water from urban areas across the United States (Lopes and Bender, 1998). In urban Salt Lake Valley, elevated concentrations of gasoline-related compounds (1,2,4-trimethylbenzene, xylene, and toluene), chloroform, and TCE were measured during storm events in water sampled from Little Cottonwood Creek. Chloroform and TCE also were detected in shallow ground water.

Water temperature is another stream characteristic that is altered by storm runoff. During storms, water temperature in urban streams sometimes increased by 3º to 5º Celsius (ºC). Urban streams draining a higher percentage of high-density residential/commercial land had larger and longer alterations in temperature during storms than streams draining other types of land. Rapid or prolonged temperature changes can alter streamwater chemical characteristics considerably and can adversely affect aquatic organisms that are intolerant to these changes. For example, increased stream temperature can reduce the amount of oxygen available for aquatic organisms while at the same time increasing their metabolic rate and oxygen needs.

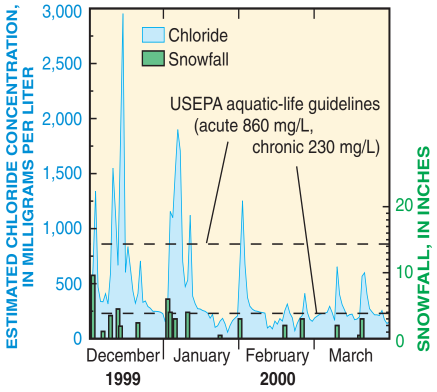
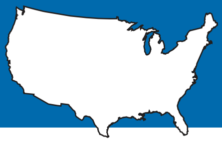


Figure 19. Chloride concentration in Little Cottonwood Creek often exceeded aquatic-life guidelines.

Elevated levels of pesticides are most common in urban streams

Water samples collected from streams were analyzed for 107 pesticides, of which 49 were detected (Gerner, 2003). At least one pesticide was detected in 23 of the 24 streams sampled. Pesticides (herbicides and insecticides) are applied in many agricultural and nonagricultural settings in the Study Unit to control unwanted vegetation and destructive insects. On average, samples from streams in basins with predominantly urban or mixed land cover contained more pesticides than samples from streams in agricultural and undeveloped basins (fig. 20). The number of pesticides detected in individual samples in each stream ranged from none in many samples collected at forest and rangeland sites to 16 in a sample from the Jordan River, a stream whose water quality is influenced by mixed, but predominantly urban, land uses.

The types of pesticides detected also differed by land use. Specifically, insecticides—most commonly carbaryl, diazinon, and malathion—occurred more frequently in urban streams than in agricultural streams. For example, diazinon was detected in about 90 percent of 42 samples from the urbanized Little Cottonwood Creek but in only about 4 percent of 26 samples from the agricultural Cub River.



Some pesticides frequently detected nationally in surface-water samples also are found in the Great Salt Lake Basins Study Unit

The types of pesticides in streams are closely linked to pesticide use. Such relations help to explain why some pesticides are found in streams in the Great Salt Lake Basins and across the Nation, while others are not. For example, atrazine, which was detected in 100 percent of the samples collected from the Jordan River, which drains land with mixed cover types, also was commonly detected (in 88 percent of samples) in 47 rivers across the Nation that drain land with mixed cover types. Similarly, the insecticide diazinon and the herbicide prometon, which were detected in about 90 percent of the samples collected from the urbanized Little Cottonwood Creek near Salt Lake City, were commonly detected in 32 other urban streams across the Nation (65 percent for diazinon and 85 percent for prometon).

The frequency of detection of several pesticides in the Great Salt Lake Basins differed from that of other streams across the Nation. For example, carbaryl, which was detected in 38 percent of samples collected from the agricultural Cub River, was detected in only 9 percent of samples collected from 78 agricultural streams across the Nation. Simazine was frequently detected nationally (61 percent of 154 samples), but was detected in only 17 percent of the samples collected from streams in the Great Salt Lake Basins. Metolachlor was detected infrequently in streams in the Great Salt Lake Basins (only 5 percent of samples) but was detected in 73 percent of 157 samples collected from other streams across the Nation.

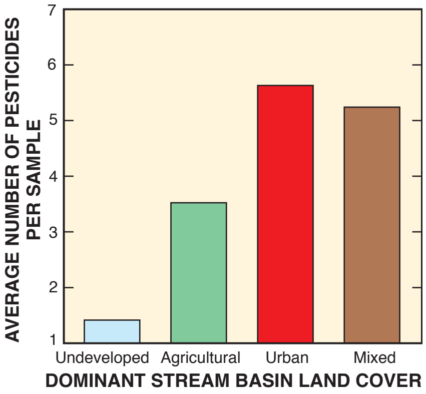


Figure 20. More pesticides were detected in streams affected by urban land use than in agricultural or undeveloped (forest/rangeland) streams.

The median total concentration of pesticides measured in water samples from streams representative of undeveloped and agricultural land uses (0.004 and 0.041 µg/L (*microgram per liter*), respectively) was lower than that measured in samples from streams principally affected by urban land and mixed land uses (0.095 and 0.077 µg/L, respectively) (fig. 21). The concentration of pesticides in surface-water samples from the Study Unit was generally low. Ninety-seven percent of the samples had a total pesticide concentration less than 1 µg/L. The maximum concentration of pesticides (6.54 µg/L) was measured in a sample collected from an urban site near the mouth of Little Cottonwood Creek during a rainstorm (see “Urban storm runoff affects stream chemistry and temperature”).

Eighteen of 49 pesticides detected in stream samples have guidelines for the protection of aquatic communities. Concentrations of carbaryl, diazinon, and malathion exceeded those guidelines (in 5, 19, and 4 samples, respectively), indicating the potential for impairment of some portions of the aquatic community. The implications for aquatic organisms of those pesticides detected that do not have *aquatic-life guidelines* are unknown. None of the pesticides detected in streams exceeded human-health standards for drinking water; however, the USEPA has established standards for only 23 of the 49 pesticides detected.

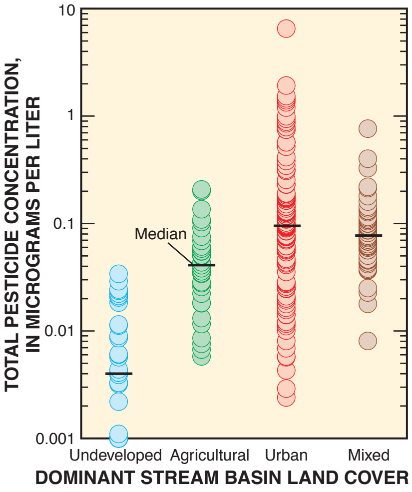


Figure 21. The highest concentrations of pesticides were measured in samples from urban streams.

VOCs are common in urban streams

Water samples from two urban streams, Little Cottonwood Creek and the Jordan River, were analyzed for 86 *volatile organic compounds* (VOCs), 33 of which were detected. Some likely pathways for VOCs to enter urban streams include (1) direct discharge into the stream from accidental spills and industrial or wastewater discharge; (2) industrial and vehicle emissions, scavenged from air by precipitation, deposited directly into the stream, or transported in runoff; and (3) contaminated ground-water inflow.

The number of VOCs detected per sample ranged from 3 to 20. Fuel-related BTEX (benzene, toluene, ethyl benzene, and xylenes) compounds were the most frequently detected group of compounds in Little Cottonwood Creek.

Pesticides and VOCs were detected more frequently in water from streams than from wells

The number and frequency of pesticides and VOCs detected in water from streams was greater than those detected in water from wells (fig. 22). Ground water has a lower incidence of contamination than streams because water infiltrating the land surface moves slowly through soil and rock formations. This contact, along with the slow rate of flow, allows greater opportunity for *sorption*, retardation, degradation, and dispersion of contaminants that can reduce the concentration or remove the compounds from ground water. In addition, because of the slow rate of flow, many compounds in recharged water have not yet reached the sampled wells, but may in the future.

Pesticides that are generally chemically stable and mobile in ground water, including prometon, atrazine, deethylatrazine, and simazine, commonly were detected in streams and wells. Chemically less stable pesticides, including insecticides that are generally applied in lesser quantities, commonly were detected in water from streams but not from wells. VOCs generally had a greater frequency of detection in streams, with the exception of the chlorinated drinking water byproducts, chloroform and bromodichloromethane, which were detected at similar frequencies in surface water and ground water.

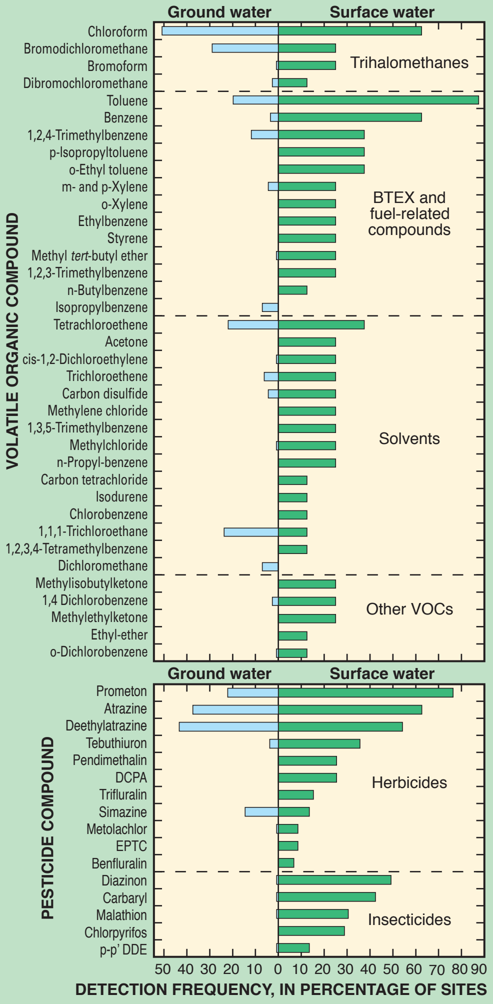
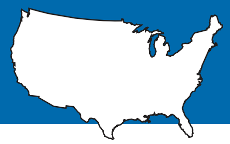
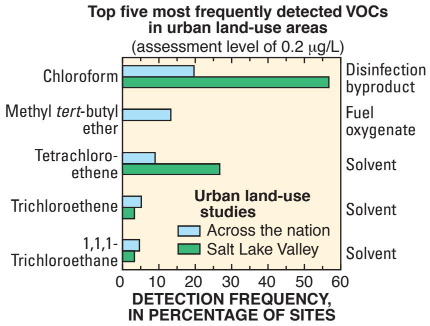


Figure 22. The frequency of detection and number of pesticides and VOCs in water samples were greater for streams than for wells. Pesticides and VOCs that occurred in less than 5 percent of both streams and well samples are not shown.

VOCs are more common in shallow ground water underlying Salt Lake Valley than in most other urban areas sampled across the Nation



VOCs were commonly detected in shallow ground water underlying residential and commercial areas in Salt Lake Valley. Seventeen of 30 wells (almost 60 percent) contained water with at least 1 VOC measured at concentrations equal to or greater than a common national assessment level of 0.2 µg/L. The percentage of VOC detections in Salt Lake Valley ranks 9th out of 33 urban areas assessed by the NAWQA Program. The types of VOCs detected were similar. For example, chloroform, a disinfection byproduct and solvent, was the most frequently detected VOC nationally and in shallow ground water underlying Salt Lake Valley. Tetrachloroethene (PCE), a solvent used for degreasing and dry cleaning, also was common nationally (found at concentrations greater than 0.2 µg/L in about 10 percent of wells), and was even more common in Salt Lake Valley (approximately 25 percent of the wells). The similarity does not extend to methyl *tert*-butyl ether (MTBE), a gasoline additive used to reduce air pollution. MTBE was the second most common VOC nationally, but was not detected above 0.2 µg/L in any well in Salt Lake Valley. MTBE is not commonly used in the area.



Trihalomethanes (THMs, see box below) were the most frequently detected group of compounds in the Jordan River. Treated wastewater was a large component of streamflow at the Jordan River site, which most likely explains why THMs were detected more frequently in water samples from the Jordan River than in samples from Little Cottonwood Creek. Concentrations of most VOCs in water samples were less than 1 µg/L. Eleven percent of the VOC detections were greater than 1 µg/L, with a maximum concentration of 20 µg/L (acetone).

Chloroform, bromodichloromethane, dibromochloromethane, and bromoform form a group of compounds known as trihalomethanes, or THMs. THMs are formed when chlorine, used to disinfect drinking water, reacts with naturally occurring organic materials. THMs are carcinogenic and have a USEPA cumulative drinking-water standard of 80 µg/L.

Pesticides and VOCs are detected in basin-fill aquifers underlying all types of land use

Pesticides in water from the basin-fill aquifers throughout the Study Unit were detected more often and at higher concentrations in samples collected from wells in agricultural areas than in areas dominated by rangeland or urban land uses (fig. 23). Detections of pesticides in water from the aquifers consisted predominantly of the herbicides atrazine and its *degradation product* deethylatrazine (DEA), prometon, and simazine. Atrazine and simazine are selective herbicides commonly used on crops and orchards in agricultural areas and to control vegetation in industrial areas. Prometon is used primarily along road rights-of-way and urban corridors. Atrazine and DEA were detected in 23 and 31 percent, respectively, of samples collected from wells in the basin-fill aquifers. Many of the samples with detections were collected from wells in primary recharge areas that historically have been undeveloped or used for agricultural purposes but have become increasingly urbanized.

VOCs were detected in 63 percent of the ground-water samples collected from the basin-fill aquifers throughout the Study Unit. Wells surrounded by predominantly urban and agricultural land had a slightly higher frequency of detection, 66 and 63 percent respectively, than wells located in rangeland (54 percent) areas (fig. 23). The two most frequently detected VOCs in the basin-fill aquifers were the THMs chloroform and bromodichloromethane, which were detected in 37 and 19 percent of samples, respectively.

The detected pesticide and VOC concentrations were well within USEPA drinking-water standards (U.S. Environmental Protection Agency, 2002b) and are not a known health concern; however, their widespread occurrence in the aquifers indicates the presence of water recharged recently enough to be affected by human activities.

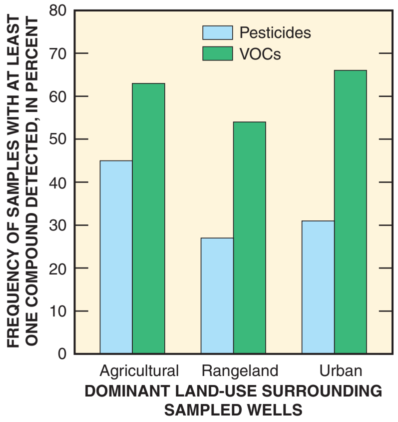


Figure 23. Pesticides were detected more frequently in ground-water samples from the basin-fill aquifers in agricultural areas than in rangeland and urban areas, and VOCs were detected at a higher frequency in agricultural and urban areas than in rangeland areas.

VOCs and pesticides commonly are detected in shallow ground water and in the basin-fill aquifer used for public supply in Salt Lake Valley

At least 1 VOC was detected in water from 27 of 30 monitoring wells completed in the shallow aquifer beneath recently developed residential and commercial areas of Salt Lake Valley (Thiros, 2003b; see inset on page 14). The most frequently detected VOCs were THMs (chloroform and bromodichloromethane) and those used as solvents (PCE and 1,1,1-trichloroethane). The widespread occurrence of THMs at low concentrations in shallow ground water is likely a result of chlorinated public-supply water used to irrigate lawns and gardens in residential areas of Salt Lake Valley that has recharged the aquifer. Water disinfected for public supply also can enter the ground-water system through leaking water lines, sewer lines, and swimming pools. PCE was detected in water from 16 monitoring wells completed in the shallow aquifer at concentrations up to 7.8 µg/L, exceeding the USEPA drinking-water standard of 5 µg/L. PCE is used primarily as a dry-cleaning agent and a solvent.

The herbicides atrazine and its degradation product DEA were the most frequently detected pesticides in water from the shallow aquifer in Salt Lake Valley and were found in 77 and 70 percent of the samples, respectively. Atrazine concentrations in water from the monitoring wells ranged from less than 0.001 to 1.58 µg/L (fig. 24), less than the USEPA drinking-water standard of 3 µg/L. All but one of the water samples from the western side of the valley contained detectable concentrations of atrazine. The high detection frequency of atrazine in shallow ground water underlying primarily residential areas on the western side of the valley may be the result of past application in agricultural or industrial areas that have been converted to residential uses. Also, atrazine applied in nonurban areas may have been transported to urban areas in the Study Unit by ground water. The

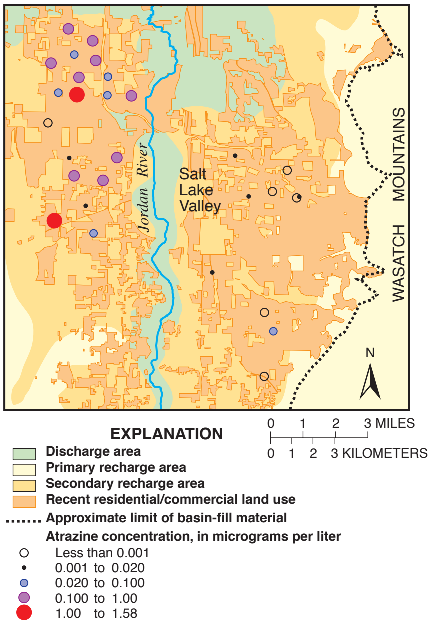


Figure 24. Atrazine was detected more frequently and at higher concentrations in water sampled from monitoring wells on the west side of Salt Lake Valley, Utah.

four wells with the highest concentrations of atrazine and its degradation products also had minimal concentrations of chloroform, which likely comes from watering lawns with chlorinated water. This correlation suggests that the recharge area for these wells includes more agricultural or nonirrigated industrial and vacant land than residential land.

The compounds detected in shallow ground water and used at the land surface have the potential to move to the deeper basin-fill aquifer in Salt Lake Valley, which is used for public supply. VOCs and (or) pesticides were detected, mostly at low concentrations, in water from 23 of 31 public-supply wells sampled in the valley. Although the concentration of these compounds measured in ground water used for public supply is not a known health concern according to current standards, their occurrence in the deeper ground water presents the possibility that water with higher concentrations may enter the aquifer in the future.

Most ground water used for public supply in Salt Lake Valley was recharged in the past 50 years and contains manmade compounds

Elevated nitrate concentrations and the occurrence of pesticides, VOCs, and other manmade compounds in the deeper basin-fill aquifer underlying Salt Lake Valley indicate relatively recent (within the past 50 years) recharge of water to the ground-water system (Thiros and Manning, 2004). The apparent age for water sampled from public-supply wells in the valley ranges from 3 to more than 50 years.[1] Ground water is generally older with distance from the mountain front, the oldest water being in the discharge area toward the center of the valley (fig. 25).

Concentrations of manmade compounds generally decreased with the age of water and were not detected in water older than 50 years from many of the public-supply wells. For example, summed concentration of VOCs and pesticides generally was in the range of 0.1 to 10 µg/L in water younger than 20 years of age and was less than 0.01 µg/L in water about 50 years or more in age (fig. 26). Similarly, nitrate concentrations were lower in the older ground water. Manmade compounds were detected or chlorofluorocarbon (CFC) contamination occurred in water from five wells with shallow, open intervals in ground-water discharge areas within Salt Lake Valley. This indicates that the aquifer in the discharge area can receive modern water recharged in the valley despite the natural upward gradient.

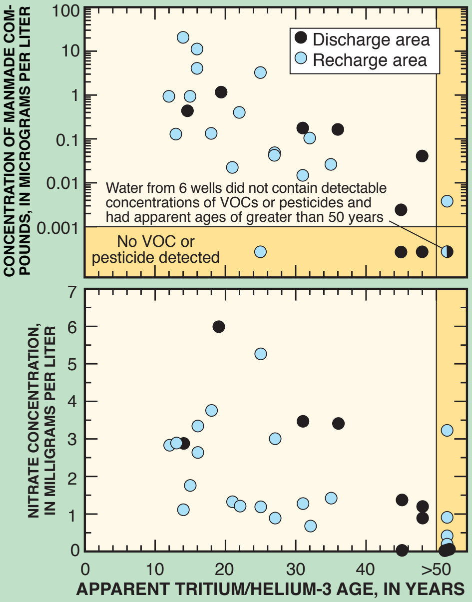


Figure 26. The concentration of manmade compounds and nitrate in water from 31 public-supply wells in Salt Lake Valley generally increased as the apparent tritium/helium-3 age of the water decreased.

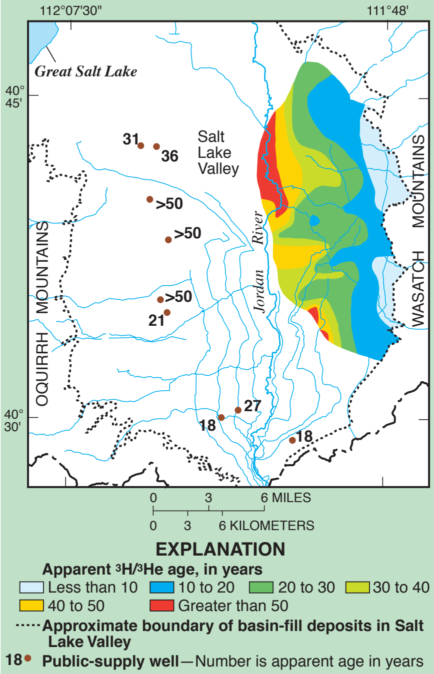


Figure 25. Apparent ages for water sampled from public-supply wells in the basin-fill aquifer range from 3 to more than 50 years.

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[1] Ground-water ages determined from environmental tracers such as tritium, helium-3, and CFCs are interpreted from measured concentrations and can be affected by mixing between waters with different ages, dispersion, and other factors and, therefore, are usually qualified as "apparent ages."

Surface-water contaminants and aquatic communities change as watersheds become urbanized

PAH levels are elevated in streambed sediment in urban basins and in Farmington Bay

Many contaminants, like *trace elements*, *organochlorine compounds*, and polycyclic aromatic hydrocarbons (PAHs), generally sorb to soil and sediment, are chemically stable and persistent, and tend to accumulate in aquatic organisms. Concentrations of PAHs in streambed sediment increase from the most upstream to the most downstream site of major urban areas in the Weber and Utah Lake-Jordan River Basins (fig. 27). PAHs are formed by the incomplete combustion of hydrocarbons—coal, oil, gasoline, and wood—resulting from many urban sources including industrial and powerplant emissions, home heating, refuse and open burning, car and truck exhaust, tires, and asphalt roads and roofs (Edwards, 1983).

PAHs represent the largest class of suspected carcinogens (Björseth and Ramdahl, 1985) and can present a threat to aquatic life (Long and Morgan, 1991).

Samples from a Jordan River site, located downstream from the Salt Lake City metropolitan area (fig. 27), had the highest concentration of total PAHs in streambed sediments in the Study Unit (1,630 µg/kg [micrograms per kilogram]) (Waddell and Giddings, 2003). Contaminants deposited on land can wash into streams and seep into ground water. Soil and debris (and any attached contaminants) carried by runoff or atmospheric deposition can settle to the bottom of reservoirs, lakes, and other impoundments in successive layers over time. USGS analysis of sediment cores (vertical tubes of mud) from lake bottoms across the country document changes in contamination as watersheds become increasingly more urbanized.

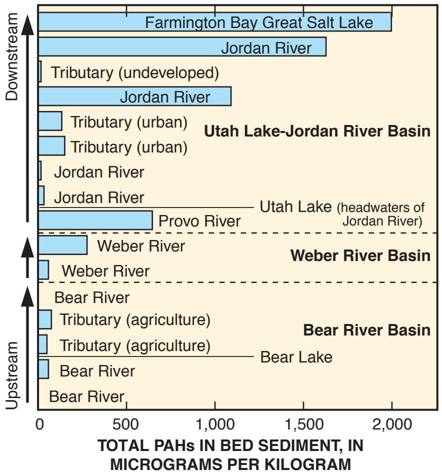


Figure 27. PAHs increase in sediments from upstream to downstream in each basin.

Concentrations of total PAHs in sediment from Farmington Bay of Great Salt Lake, which receives water from the Jordan River, increased from less than 100 µg/kg in sediments deposited before 1940 to more than 2,000 µg/kg after the mid-1980s (Naftz and others, 2000) (fig. 28). During this time, the population in Salt Lake County also increased, causing increased vehicular traffic and human-induced combustion products.

Van Metre and others (2000) documented the pattern of increased PAHs for other cities in the United States and associated it with increased vehicular traffic in their watersheds. PAH concentrations in sediment will probably continue to increase as urbanization and associated vehicular traffic and fossil fuel use increase.

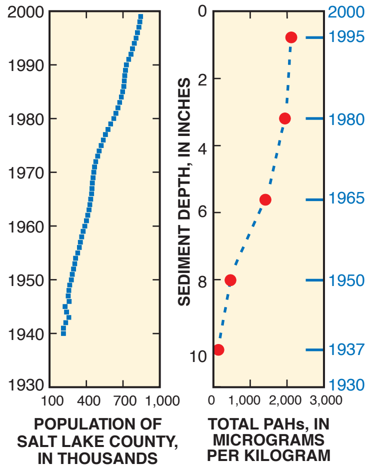


Figure 28. PAHs have increased as the population of Salt Lake County has grown, as evidenced by an increase of these compounds with time in the sediment of Farmington Bay.

Lead concentrations have decreased in Farmington Bay sediments since the 1980s

Unlike other contaminants, lead has shown a recent decline in concentration in Farmington Bay sediments (see inset, page 18). Recent sediments deposited during 1996–98 indicate a 41- to 62-percent reduction in lead concentration since the peak in the mid-1980s. The concentration of lead began to increase after about 1842, made the most marked increase between about 1916 and 1950, and peaked in the 1980s (fig. 29). The early increases have been attributed to atmospheric deposition from historical mining activities associated with smelters in Salt Lake Valley.

Mining and smelter activities had already declined considerably in Salt Lake Valley by the mid-1980s, when the concentration of lead started to decrease

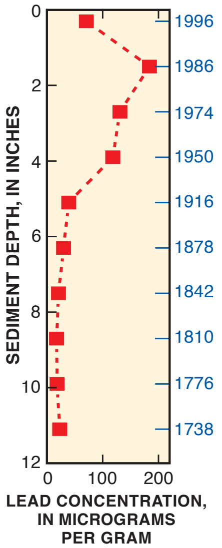


Figure 29. Lead concentration in sediment core from Farmington Bay indicates increasing inputs after about 1842, coinciding with the mining and smelter activities in the region.

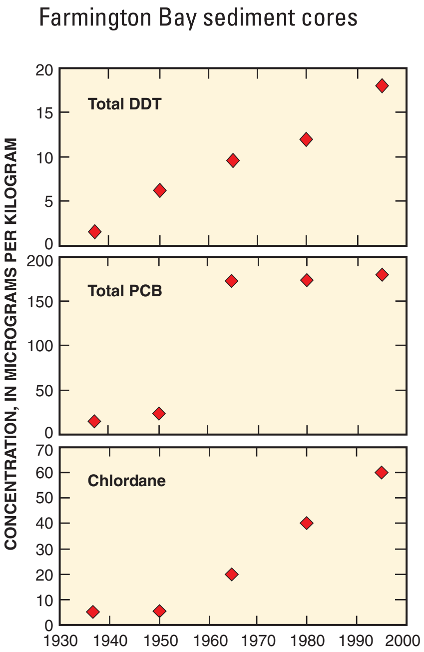
in Farmington Bay sediments. Thus, recent declines in lead concentration in sediments of Farmington Bay probably are mostly due to reduced lead in automobile emissions. Recent declines in lead concentration in sediment have been noted elsewhere and usually are attributed to reduction in lead emissions following passage of the Clean Air Act of 1970 (Callender and Van Metre, 1997).

Trends in DDT, PCBs, and chlordane in Farmington Bay sediment are different from those at other sites nationally

As a part of the NAWQA Program, trends in *polychlorinated biphenyls* (PCBs) and organochlorine compounds were tracked over the last several decades to the mid-to-late 1990s in sediment cores from 10 lakes and reservoirs in 6 U.S. metropolitan areas (Van Metre and others, 2000).

Nationally, total *DDT* concentration generally followed the historical use of DDT (an *organochlorine insecticide*) in the United States, which peaked from the 1950s to the mid-1970s and then declined substantially. DDT use was discontinued in the United States in 1972; however, in Farmington Bay, which receives inflow from the Jordan River after it flows through the metropolitan area of Salt Lake City, the concentration was still increasing in the mid-1990s. Similarly, total PCB concentrations increased substantially between 1950 and 1965, coinciding with peak production, but concentrations in Farmington Bay sediment have not declined as at other sites nationally. Chlordane concentrations in Farmington Bay sediment began increasing significantly after 1950 and were still increasing in 1995, even though chlordane was discontinued from general use in the 1970s.

The reasons for the continued trend of increasing concentrations of DDT, PCBs, and chlordane in the sediment cores from Farmington Bay are not understood at this time and will require further investigation. The relatively low concentrations in the sediments of streams in the Study Unit suggest that the concentrations should decrease in the bay with times.



DDT, PCBs, and other organochlorine compounds occur more commonly in fish than in sediment in area streams

Twenty-seven organochlorine compounds were analyzed in streambed sediment and fish tissues at 15 sites. Twelve compounds were detected in fish tissue, whereas only 6 of the compounds were detected in sediment. All of the compounds detected in the sediment were also detected in tissue at each site (fig. 30). These data illustrate the tendency for these compounds to accumulate in fatty tissue.

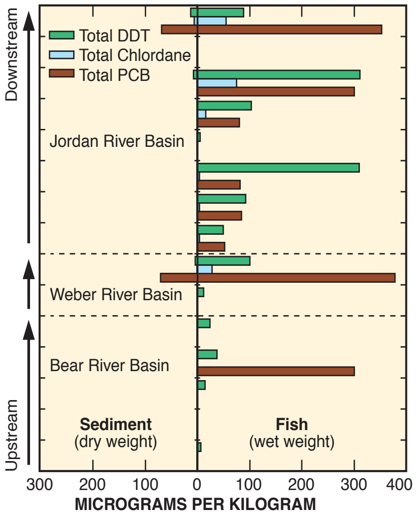


Figure 30. Organic compounds were detected more frequently in fish tissue than in sediment.

Two commonly detected compounds were PCBs and DDT, although the use of these compounds was discontinued in the United States in the 1970s. In 1998, PCBs were detected in whole-fish samples from 8 of 15 sites, and DDT breakdown products were detected at 13 of 15 sites. PCBs were detected in bed-sediment samples at only 2 of 15 sites, and DDT compounds were detected at 4 of 15 sites. In general, concentrations of organic compounds in fish tissue and sediment from the Study Unit were lower than those in other areas studied as part of the NAWQA Program.

The concentrations of DDT compounds in sediment were between the threshold effect level (TEL)[1] and probable effect level (PEL) for aquatic life at three sites. Concentrations between the TEL and PEL indicate possible

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[1] Currently there are no U.S. standards for assessing the potential for adverse biological effects due to contaminated freshwater sediment. The Canadian Council of Ministers of the Environment (CCME) modified an approach by Long and Morgan (1991) to develop guidelines for marine and freshwater sediment. The CCME modified approach uses two assessment levels: (1) the threshold effect level (TEL), representing the concentration below which adverse effects are expected to occur rarely, and (2) the probable effect level (PEL), representing the concentration above which adverse effects are expected to occur frequently (Ecosystem Conservation Directorate Evaluation and Interpretation Branch, 1995).

occasional adverse biological effects are expected. Adverse biological effects are generally defined as effects that are considered to produce a negative response in an organism, such as reduced reproductive success, reduction in growth, or death.

Increased urban land use has altered invertebrate and algal communities

Researchers have shown that as urbanization increases in a watershed, streams typically show a decline in water quality and condition of the physical habitat, which in turn leads to a decline in the quality of biological communities in the streams. (For a review of literature on effects of urban land use, see Paul and Meyer, 2001.) Effects of urbanization on streams along the Wasatch Mountains were examined using a special "urban gradient design" (see inset). Differences in the physical, chemical, and biological characteristics of 30 sites along a gradient of urbanization were compared with the level of urban intensity in each watershed to see if urbanization was having a measurable effect on these characteristics. The area included in the urban-gradient assessment has strong natural gradients, and the hydrology and chemistry of the streams are affected to a large degree by the movement of water across watershed boundaries to meet human water-use needs.

The urban-gradient assessment showed that water quality of the streams declined with increasing levels of urban intensity. Specifically, increasing concentrations of nutrients (nitrogen and phosphorus), warmer water temperatures, a greater number of pesticides, and increasing *specific conductance* were associated with increasing urban intensity (fig. 32). Specific conductance is a measure of dissolved ions in the water, and increasing values most likely indicate increased runoff associated with increasing urban intensity. Urban runoff commonly contains contaminants that are harmful to biological communities. An increase in dissolved

An Urban Gradient Study

The Great Salt Lake Basins Study Unit was one of several NAWQA Study Units that participated in an urban land-use gradient study. This special study was designed to examine the effects of urbanization on streams by sampling physical, chemical, and biological characteristics of 30 sites along a gradient of low to high levels of urbanization (fig. 31) and to compare how urbanization affects streams in different parts of the country. An integrated index of "urban intensity" was used to define urban effects at each site (McMahon and Cuffney, 2000). Each watershed was ranked in urban intensity (ranging from 0 to 100) on the basis of 13 measures of urbanization, including measures of land cover (for example, percentage of land surface covered with vegetation), urban infrastructure (for example, the density of roads), and socio-economic characteristics (for example, the density and type of housing, population density). For reference, an urban index of 50 represents approximately 30 percent land cover that is urbanized and an average road density of approximately 17 kilometers of roads per square kilometer area. A low rating on the urban index means there is very little urban development in the watershed and the land is mostly forested. A high rating on the urban index represents a watershed with a mixture of higher density housing and(or) commercial space. Along the western front of the Wasatch Mountains, the intensity of urbanization tends also to follow the elevation gradient, with the most intensely urbanized areas at the valley bottom.

The characteristics of streams, be they physical, chemical, or biological, also change along the elevational gradient, regardless of differences in urbanization. Because the objective was to measure changes due to urbanization, the study sites were limited to only those on the benchlands of the Wasatch Mountains, and, as a result, the study did not sample the high intensity urban areas at the valley bottoms.

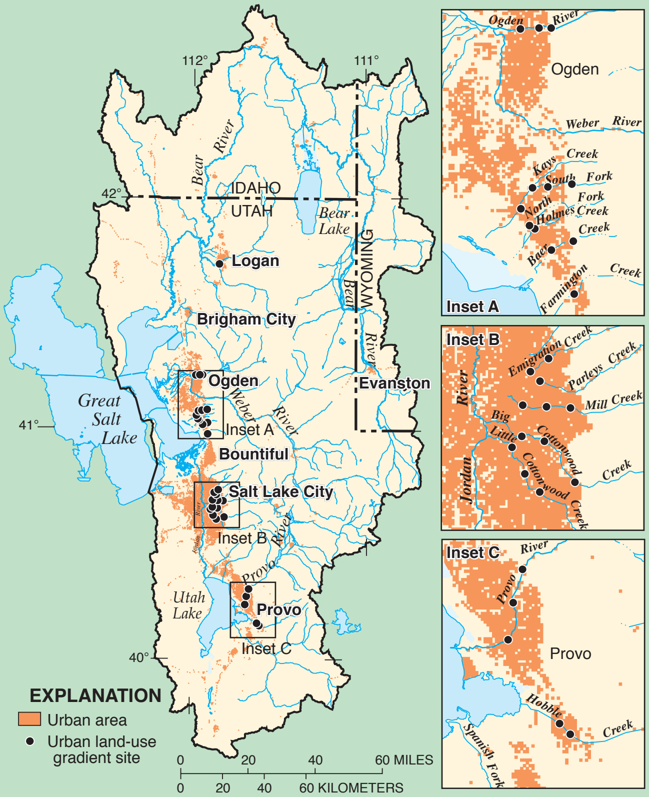


Figure 31. Thirty sites were sampled for fish, macroinvertebrates, algae, water chemistry, and physical habitat along a gradient of urban intensity.

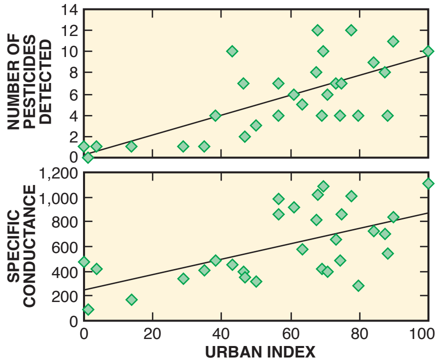


Figure 32. In samples collected in July, the number of pesticides detected and the specific conductance, in microsiemens per centimeter, of the water generally increased with increasing urban index values.

nutrient concentrations and in the number of pesticides detected likely reflects the use of these compounds on lawns, parkways, roadways, and other areas of the urban landscape. High concentrations of nutrients and pesticides can be toxic to many stream organisms, and the presence of these chemicals in stream water can limit the numbers and kinds of organisms found in urban streams. In addition, water temperature can increase in the more highly urbanized areas as the amount of impervious surface area increases. For example, during storms, rainwater falling on hot pavement heats up and then runs into streams, increasing their temperature. Also, the temperature of the land surface in urban areas is often several degrees warmer than in the surrounding countryside. As the temperature of the ground surface in urban areas increases, the temperature of streams flowing through these areas may also increase. Many biological organisms have a limited temperature range in which they survive. An increase in stream temperature favors those organisms able to tolerate higher temperatures, thus altering the biological community.

The quality of physical habitat, while substantially different among sites, did not show a strong correlation with the level of urbanization in the watershed. With the exception of substrate particle size, the differences in physical habitat among sites appeared most strongly related to natural gradients, such as basin size and altitude. The size of substrate (bottom material) in streams decreased as the intensity of urbanization increased. Small particles, such as sand and silt, were more common at more urbanized sites, where they may have been washed into streams from unvegetated areas, such as construction sites. In addition, dirt and silt accumulate on impervious areas (blacktop, rooftops, sidewalks) and can easily be washed into streams during rainstorms. When large amounts of these fine particles enter a stream channel they can clog the spaces between rocks on the stream bottom and reduce the availability of the stable habitat preferred by bottom-dwelling organisms.

Algae and invertebrates living on the bottom of a stream channel are good indicators of changes in water quality and habitat conditions. As physical and chemical conditions change with urbanization, the number and type of organisms in a stream also changes. For example, as the intensity of urbanization increased, the relative abundance (percentage of all individuals collected) of algae that are *tolerant* to organic pollution, salinity, and silt increased, while the relative abundance of algae sensitive to pollution (intolerant algae) decreased (fig. 33). The increase in the abundance of algae tolerant of organic pollution corresponded to an increase in water-column nutrient concentrations. Likewise, the increase in silt-tolerant algae corresponded to a decrease in substrate particle size in the stream channel.

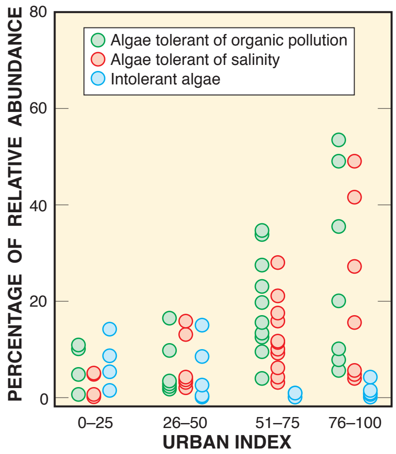


Figure 33. As the level of urbanization increases, the percentage of algae tolerant of salinity (red) and organic pollution (green) increases, while the percentage of algae sensitive to pollution (blue) decreases.

Similarly, as the intensity of urbanization increased, the number of kinds of invertebrates (richness) sensitive to pollution decreased and the number of kinds of invertebrates tolerant of pollution increased (fig. 34). Generally, invertebrate organisms considered intolerant, such as mayflies and stoneflies, prefer lower water temperatures, require more stable substrate and flow regimes, and require good water quality. In contrast, the presence of tolerant invertebrates, such as *midges* and worms, generally increases under conditions of degraded habitat or poor water quality.

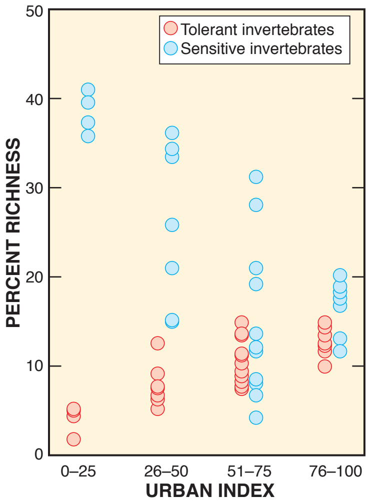
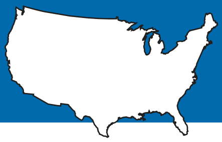


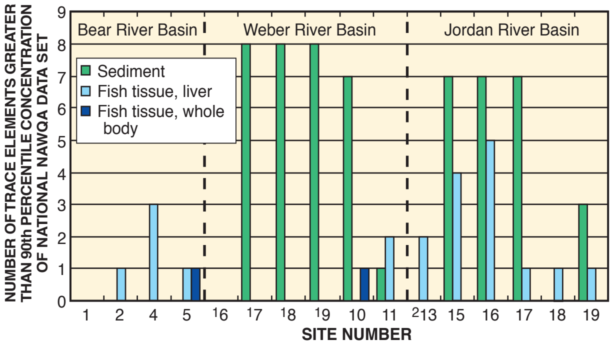
Figure 34. As urban intensity in the watershed increases, the number of invertebrate taxa sensitive to pollution (blue) decreases while the number of invertebrate taxa tolerant to pollution (red) increases.

Although not measured directly in this study, the amount of water diversion and exchange in these streams likely is responsible, in part, for these alterations in biological communities. As discussed in the section "Water development affects quantity and quality of water resources," the quality of water is affected by diversions. For example, stream temperature was substantially lower in urban streams with continuous



Some of the trace element concentrations in sediment and fish tissue at urban sites were greater than concentrations for many urban sites nationwide

Streambed sediment concentrations in Red Butte Creek, a reference site for study unit streams, were greater than the NAWQA national median for cadmium, chromium, selenium, and silver in urban streams. This may indicate that the streams in the Great Salt Lake Basins Study Unit have relatively higher natural *background concentrations* than those found nationally. Trout livers from Red Butte Creek in Jordan River Basin exceeded the national 90th percentile (fig. 35) concentration for nickel and exceeded the national median concentrations for arsenic, cadmium, mercury, and selenium. Concentrations of trace elements at two sites on the Jordan River and two sites on Little Cottonwood Creek, an urban tributary of the Jordan River, greatly exceeded the national median values in both sediment and fish tissue. In Little Cottonwood Creek, 7 of 10 elements in bed sediment were greater than the national 90th percentile concentration. In fish-tissue samples from Little Cottonwood Creek, 5 of 10 elements exceeded the national 90th percentile. Arsenic in particular was substantially elevated above the 90th percentile. These exceedances are believed to be due mostly to historical mining activities before the area became highly urbanized.



[1] No fish tissue sample collected at this site.
[2] No sediment sample collected at this site.

Figure 35. Trace-element concentrations in bed sediment and fish tissue in the Great Salt Lake Basins exceeded the 90th percentile concentration of the NAWQA Program dataset.

flow from their mountainous watersheds (for example, Mill Creek, Provo River) than those without continuous flow (for example, Little Cottonwood Creek, Kays Creek). Stream temperature was identified as an important factor determining the composition of the biological community. Diversions also serve as barriers to migration of stream organisms, which could reduce diversity.

This study identified some of the human-caused factors affecting communities in urban steams along the Wasatch Mountains. It is clear that maintaining flow in the stream channel is essential for the maintenance of biological communities. Reducing water temperatures, improving water quality, and reducing runoff of silt into streams will help maintain the health of the biological community. Such findings may help in the development of useful ecological or other indicators of the effects of urbanization on stream ecosystems, and the uses of these indicators may increase the cost effectiveness of monitoring programs.

Elevated concentrations of trace elements in sediment and water are related to natural sources and past mining activities

Minerals in rocks are sources of arsenic and radon in ground water

Concentrations of arsenic in shallow and basin-fill aquifers in the Great Salt Lake Basins Study Unit were highly variable, ranging from less than 0.4 to 95 µg/L, with a median of 2.1 µg/L (fig. 36). Arsenic, a naturally occurring trace element in ground water within the Study Unit, is derived from geochemical reactions with certain types of minerals. Tertiary volcanic rocks and the Salt Lake Formation exposed near the base of the Oquirrh Mountains may be a source of arsenic on the western side of the Salt Lake Valley that is not present on the eastern side. Water from wells in the western and northwestern parts of the valley generally had higher arsenic concentrations than water from wells in other areas. The median concentration of arsenic in water from relatively shallow monitoring wells, many of which

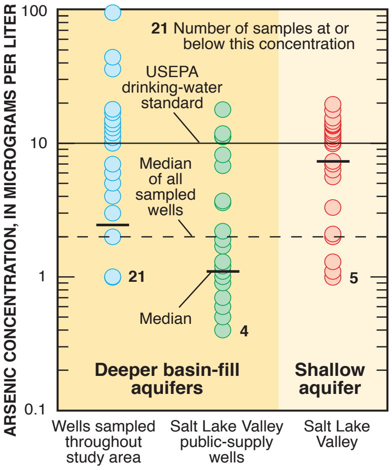


Figure 36. Arsenic concentrations exceeded the USEPA drinking-water standard in about 20 percent of samples collected from the basin-fill aquifers.

are on the western side of the valley, was 7.3 µg/L, with 43 percent of the samples exceeding the USEPA drinking-water standard of 10 µg/L. Concentrations of arsenic were generally lower in water from public-supply wells completed in the basin-fill aquifer underlying the valley (median of 1.1 µg/L with 16 percent exceeding the standard) because many of these wells are on the eastern side of the valley. About 20 percent of the wells sampled in the recharge areas of the basin-fill aquifers throughout the Study Unit exceeded the drinking-water standard. Water from most wells sampled is used for domestic supply (provides drinking water to a small number of families). The Safe Drinking Water Act does not regulate domestic wells and therefore homeowners may not be aware of possible risks associated with elevated arsenic concentrations in their wells.

Radon occurs naturally as a gas that is soluble in ground water and is released through radioactive decay from rocks containing uranium. Higher amounts of radon occur in areas with uranium-rich sources such as granite, metamorphic rocks, and basin-fill deposits weathered from these rocks. Because of a short half-life of 3.8 days, radon is detected only near its source. Radon moves easily through highly permeable material, such as sand, gravel, and fractures; and readily degasses from water exposed to air.

Radon occurred commonly at elevated concentrations in shallow and basin-fill aquifers underlying the Great Salt Lake Basins Study Unit, with a median of 667 pCi/L (*picocuries* per liter). Most samples (95 percent) exceeded the USEPA proposed drinking-water standard of 300 pCi/L, but none exceeded the alternative standard of 4,000 pCi/L. Radon concentrations greater than 2,000 pCi/L measured in three water-supply wells in Davis County are likely the result of their proximity to metamorphic rocks in the Wasatch Mountains. The mountain block and basin-fill deposits in the southeastern part of Salt Lake Valley are composed primarily of uranium-bearing rocks, resulting in radon concentrations greater than 1,000 pCi/L in water from monitoring and public-supply wells in the area.

Breathing radon in indoor air is the second leading cause of lung cancer and is a greater health concern than drinking water that contains radon. Most of the risk from radon in water is from breathing radon released to indoor air from household water uses. The USEPA proposed rule for radon allows States and community water systems to use a higher alternative drinking-water standard if they implement a program to address radon risks in indoor air (U.S. Environmental Protection Agency, 1999).

Past mining activities contribute to elevated levels of trace elements in sediment and water

Trace elements are elevated in sediment and water in Silver Creek, Weber River below Silver Creek, and Echo Reservoir, largely because of historical mining for silver and lead ores in the headwaters of the Silver Creek drainage through the 1970s (fig. 37). Specifically, concentrations of arsenic and lead in bed sediment were more than 10 times higher in the Weber River below Silver Creek than in the Weber River above the creek (fig. 38). Enrichment in Echo Reservoir as well as at sites on the Weber River below Silver Creek is largely due to inflow from the creek. Concentrations of cadmium, copper, selenium, silver, and zinc also were elevated, but concentrations of chromium and nickel in bed

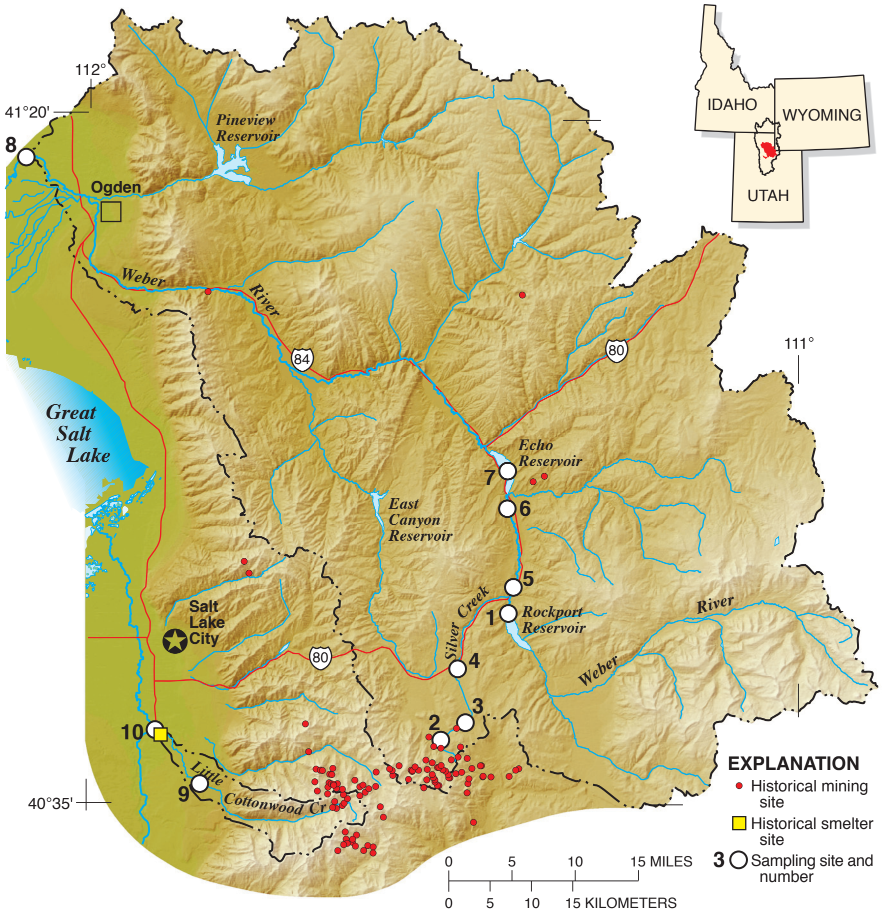


Figure 37. Mining in the Silver Creek and Little Cottonwood Creek watersheds has increased concentrations of arsenic and other trace elements in the water and sediment of these streams.

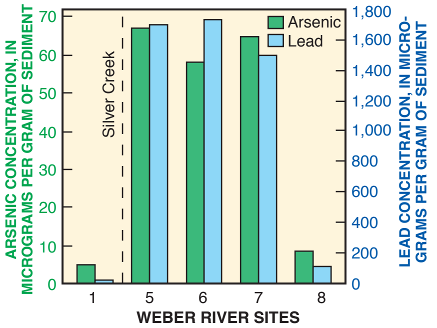


Figure 38. Inflow from Silver Creek greatly enriches the concentration of trace elements in the sediments of Weber River and Echo Reservoir. From the mid-1800s through the 1970s, the headwaters of the Silver Creek drainage were extensively mined for silver and lead ores (see fig. 37 for site locations).

sediments did not appear to be greater downstream from mining-affected areas.

The concentrations of some metals were elevated in the water of streams draining areas with historical mining and ore smelting. For example, zinc concentrations in water samples from Silver Creek ranged from 90 to 1,800 µg/L, exceeding the USEPA aquatic-life criterion (adjusted for hardness) in four of eight samples. Aquatic macroinvertebrate communities at sites in upper Silver Creek with high zinc concentrations were impaired (low species richness and a higher percentage of tolerant taxa) relative to other sites in the area with lower concentrations of zinc (Giddings and others, 2001). Streams draining basins with little or no mining activity, such as those in the Bear River Basin, generally had low concentrations of dissolved metals. For example, zinc concentrations in water samples from Bear River sites ranged from 2 to 7 µg/L.

Mercury, used from the 1880s to early 1900s to process lead and silver ores in the Park City mining district, was detected in water and bed-sediment samples from Silver Creek at concentrations exceeding various aquatic-life guidelines (Giddings and others, 2001). Total mercury concentration in streambed sediment from three sites on Silver Creek (sites 2, 3, and 4, fig. 37) and one site on the Weber River (site 6, fig. 37) ranged from about 1,000 to 27,000 µg/kg, far exceeding the Canadian guideline of 486 µg/kg, designed to protect aquatic life (Canadian Council of Ministers of the Environment, 2002). Although concentrations of total dissolved mercury in water were below the USEPA chronic aquatic-life criterion (770 nanograms per liter), methylmercury concentrations in water exceeded the USEPA chronic criterion for fish-eating wildlife (0.05 nanogram per liter) (National Irrigation Water Quality Program, 1998). Methylmercury is readily available for biological uptake and has been shown to biomagnify in the food chain (Eisler, 1987). Thus, even small amounts of methylmercury in the environment can be harmful to *biota* that feed on aquatic prey.

The concentration of arsenic measured in water samples from lower Little Cottonwood Creek (site 10, fig. 37) ranged from 4.7 to 284 µg/L, exceeding the USEPA aquatic-life criterion of 150 µg/L in 8 of 49 water samples. Sources of arsenic in Little Cottonwood Creek include imported water from the Utah Lake Basin and, most notably, runoff from historical smelter sites. The August 1999 synoptic study of trace elements in lower Little Cottonwood Creek identified the area near the historical Murray smelter site as the major source of arsenic (fig. 39). Reclamation has been done at this site; however, surface and subsurface flow near the site still appears to be contributing dissolved arsenic to the stream.

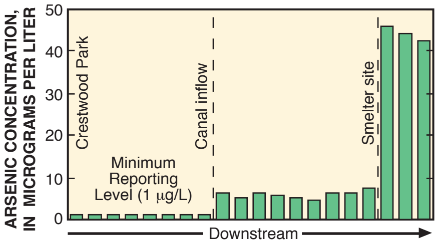


Figure 39. Dissolved arsenic concentration in water samples from Little Cottonwood Creek, August 1999, were greatest at sites adjacent to and downstream from historical ore-smelting sites.

Streams in basins with little or no mining had arsenic concentrations less than 3 µg/L. The metals in the water and sediment of many of the mining-affected streams of the Great Salt Lake Basins Study Unit probably will persist for many years.

Increases in levels of trace elements in sediment since the mid-19th century are related to smelter emissions

Trace-element concentrations first began to increase in sediment deposited in Mirror Lake and Farmington Bay of Great Salt Lake in 1870, with a substantial increase occurring after 1900. Mirror Lake is in the Uinta Mountains, approximately 50 miles east of Salt Lake City. The surface sediments of cores taken from Mirror Lake had higher concentrations of arsenic, cadmium, copper, lead, tin, and zinc, relative to the deeper sediments (fig. 40). Age dating of a core collected in 1998 from Farmington Bay (Naftz and others, 2000) indicated a lead profile (fig. 29) similar to that determined for Mirror Lake (fig. 40). In the Farmington Bay core, the profile indicates that lead contamination began to increase after about 1842 and made the most marked increase between about 1916 and 1950. Due to the remote location of Mirror Lake, it was concluded that the increases in metal concentrations over time are related to atmospheric deposition from smelter activities. Large-scale mining and smelting of nonferrous metal ores began in the Wasatch Mountains and adjacent valleys after 1868, which would have contributed metals to the atmosphere. Industrial and energy-related sources in the Salt Lake City area also would have contributed metals to the atmosphere, and growth of these industries occurred after 1900. These dates coincide with increases in metal concentrations of the cores. In addition, lead concentrations in cores correspond to lead emissions from vehicles and other combustion sources.

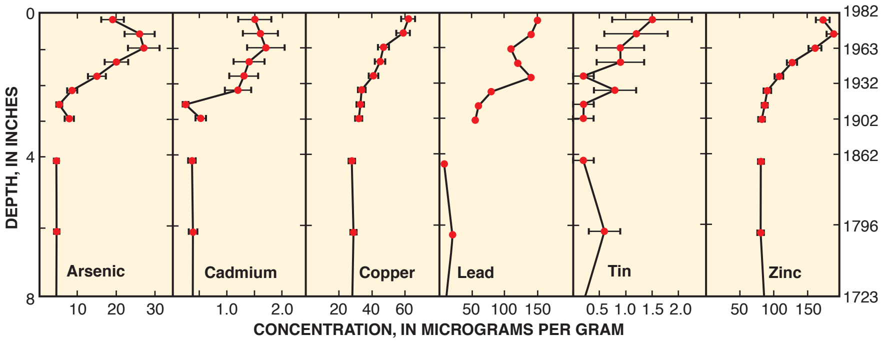


Figure 40. Metals concentration in sediment core from Mirror Lake began increasing after about 1870. Due to the remote location and absence of mining in the watershed upstream from the lake, the metal enrichment is believed to be due to atmospheric deposition from mining-related activities. Data from Kada and others (1994, fig. 7).

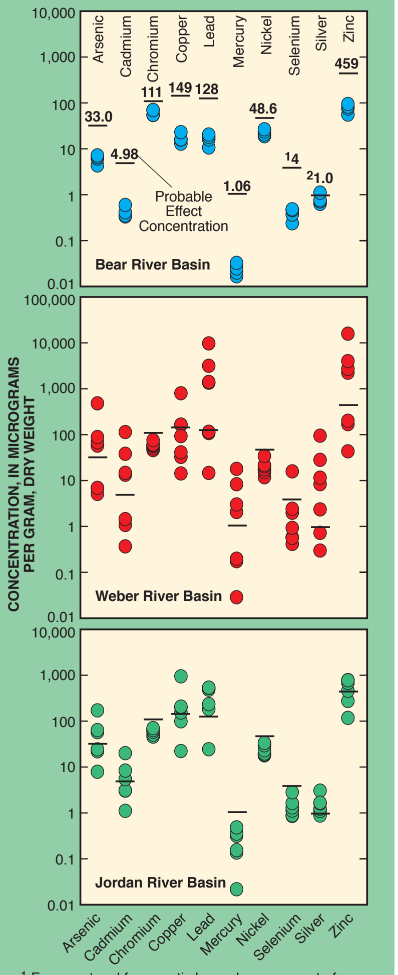
Trace elements in sediments exceed Probable Effect Concentrations only in areas with mining-related activities

In areas with mining-related activities, concentrations of trace elements in sediment often exceeded the Probable Effect Concentration (PEC) values (Waddell and Giddings, 2003). The PEC represents the concentration in bulk sediments above which adverse biological effects are likely to occur (MacDonald and others, 2000). The upper Weber River Basin, and the Utah Lake-Jordan River Basin were the most extensively mined areas and the Bear River Basin the least mined.

The most heavily affected streams sampled were Little Cottonwood Creek, Silver Creek, and the Weber River below the Silver Creek confluence. Concentrations at two sites on Silver Creek and at a site on the Weber River below the confluence with Silver Creek exceeded the PEC levels for arsenic, cadmium, copper, lead, mercury, silver, and zinc. Concentrations at two sites on Little Cottonwood Creek, as well as at a site on the Jordan River below the confluence with Little Cottonwood Creek, exceeded the PEC levels for arsenic, cadmium, copper, lead, silver, and zinc.

In areas with very little mining, no PEC levels were exceeded. None of the concentrations in samples from the 15 sites sampled exceeded the PEC levels for chromium and nickel, and concentrations at only one site on Silver Creek exceeded the PEC for selenium.

NAWQA samples represent the fine-grained fraction of bed sediment only (less than 63 micrometers), which, in general, contains higher concentrations of trace elements than bulk sediment. The guidelines of MacDonald and others (2000) are intended for bulk sediment; thus, results from NAWQA samples may somewhat overstate the problem based on bulk-sediment criteria, and caution should be used in applying the criteria to values close to the PEC.



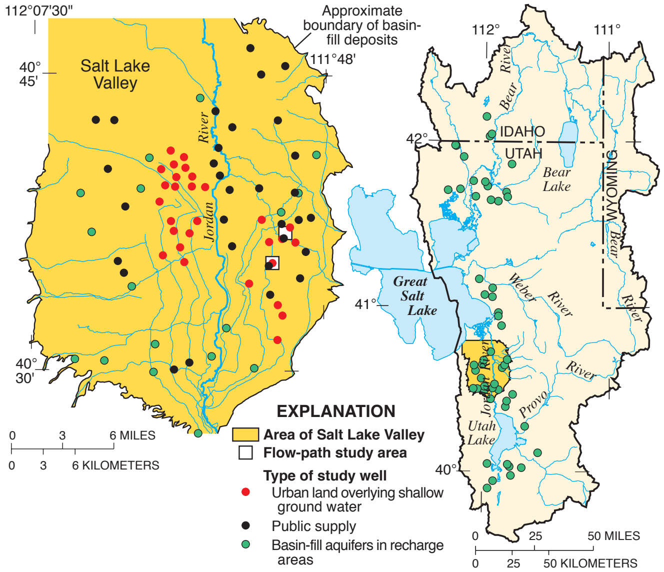
[1] From protocol for aquatic hazard assessment of selenium (Lemly, 1995).

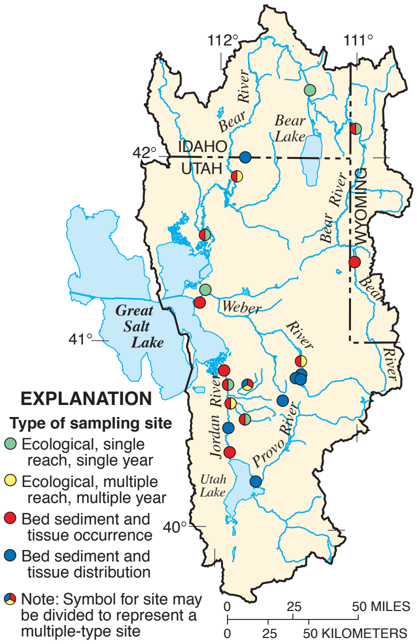
[2] From Long and others, 1995.

Study Unit Design

Ground-Water Chemistry

Ground-water samples were collected from wells in basin-fill aquifers used for drinking-water supply or from wells in the overlying shallow aquifer that has the potential to recharge the deeper aquifers. Water-supply wells were sampled to assess the water quality of the deeper aquifers in recharge areas across the Great Salt Lake Basins. Monitoring wells installed in the shallow ground-water system in Salt Lake Valley (including the flow-path study areas) were sampled to determine the effects of land use on water quality. Public-supply wells in Salt Lake Valley also were sampled to characterize the quality of water in the aquifer used for drinking water in an urban area.



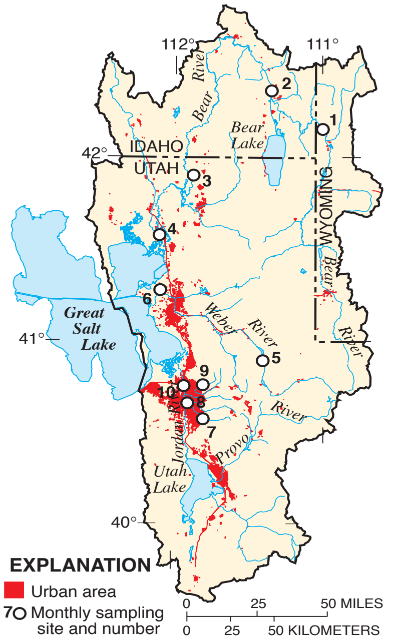


Stream Ecology

Ecological assessments were completed at sites frequently sampled for stream chemistry to define existing biological conditions. Some of the assessments examined multiple reaches of a stream to determine spatial variations in the habitat and community structure. Broad, one-time snapshot assessments (referred to as synoptic studies) were designed to further examine spatial variability in biological communities. Bed sediment and fish tissue were sampled at selected sites.

Stream Chemistry

Surface-water samples were collected monthly from 10 sites on 6 streams to measure quality and to assess the effects of land use and hydrogeologic setting on water quality (Baskin and others, 2002). Sites 3, 8, and 10 were sampled more often to determine seasonal variability and to test for pesticides and volatile organic compounds. About 100 additional sites throughout the Study Unit were sampled once or twice to further assess the occurrence and distribution of nutrients, pesticides, or trace elements in streams.



Site number	Site name	Site type	Basin area (square miles)	Site number	Site name	Site type	Basin area (square miles)
1	Bear River below Smiths Fork, near Cokeville, Wyoming	Rangeland	2,444	6	Weber River near Plain City, Utah	Mixed/Urban	2,072
2	Bear River at Pescadero, Idaho	Rangeland	3,699	7	Little Cottonwood Creek at Crestwood Park, at Salt Lake City, Utah	Urban	36
3	Cub River near Richmond, Utah	Agriculture	222	8	Little Cottonwood Creek at Jordan River, near Salt Lake City, Utah	Urban	45
4	Bear River near Corinne, Utah	Mixed/ Rangeland	7,065	9	Red Butte Creek at Fort Douglas, near Salt Lake City, Utah	Forest	7.21
5	Weber River near Coalville, Utah	Forest	427	10	Jordan River at Salt Lake City, Utah	Mixed/Urban	3,508

Study Component	What data are collected and why	Number and types of sites sampled	Sampling frequency and period
Stream Chemistry			
Streams and Rivers	Physical parameters (streamflow, dissolved oxygen, pH, alkalinity, specific conductance, temperature), nutrients, *major ions*, organic carbon, and suspended sediment. To measure how often and how much of a constituent is found, over time, given seasonal changes or land use.	Ten sites representing urban development, agriculture, forest and rangeland, and mixed land use.	Monthly and during selected runoff events. October 1998 to September 2000
Streams and Rivers, Intensive Sampling	Same as above but sampled more frequently and for pesticides and VOCs. To measure how often and how much of a constituent is found, over time, given seasonal changes or land use.	Includes three of the above sites. One site representing urban development, one site representing agriculture, and one site representing mixed, but predominately urban land use.	Weekly to monthly and during selected runoff events. March 1999 to September 2000
Urban Stream Study	Physical parameters, trace elements, nutrients, and pesticides. Used a bromide tracer to determine streamflow sources. To measure how much a constituent concentration changes over the area due to different land- or chemical-use patterns.	Study done in Little Cottonwood Creek. Bromide tracer was sampled at 97 sites, trace elements were sampled at 24 sites, and nutrients and pesticides were sampled at 4 sites.	Once. August 31 or September 2, 1999
Agricultural Stream Study	Physical parameters, nutrients, major ions (July and August only), sediment, turbidity, and pesticides (not collected at all sites). To measure how much a constituent concentration changes over the area due to different land- or chemical-use patterns.	Study conducted in the Bear River drainage and included the main stem of the Bear River and tributaries of the Bear River. Sixty-five sites were sampled.	Twice. A 2-week period in March 2001 and a 2-week period in July/August 2001
Mining Stream Study	Physical parameters, trace elements in water and sediment, and invertebrate community samples. To measure mining impacts on stream chemistry and the aquatic community.	Study conducted in the Park City/upper Weber River area and included 10 sites.	Twice. March 2000 (dissolved trace elements only) and July/August 2000
Stream Ecology			
Ecological Studies	Physical parameters, fish, macroinvertebrates, and algal communities, and habitat characteristics. To describe the water quality of streams by using species assemblages and to examine how they vary in relation to different physical and chemical conditions.	Ten sites representing urban development, agriculture, forest and rangeland, and mixed land use (same sites as in Streams and Rivers study component).	Six sites were sampled once and four sites were sampled 3 consecutive years, July-August 1999–2001
Flow-Regime Study	Physical parameters and macroinvertebrate communities. To examine effects of hydrologic alterations on macroinvertebrate communities.	Fourteen sites along the main stem of the Bear River.	Sampled in August 2001
Bed-Sediment and Tissue Studies	Physical parameters, pesticides, other synthetic organic compounds, and trace elements in streambed sediment and in fish tissue. To determine occurrence and distribution of potentially toxic compounds in sediment and fish tissue at selected sites.	Study was conducted at 19 sites.	Once. Twelve sites were sampled during August-September 1998. Seven sites were sampled during July 1999
Ground-Water Chemistry			
Shallow Ground Water Underlying Urban Areas in Salt Lake Valley	Physical parameters, major ions, selected trace elements, pesticides, VOCs, nutrients, radon, and stable isotopes. Selected samples to estimate ground-water ages using tritium, helium-3, and CFCs. To examine how land use in an urban area affects the quality of ground water in recently recharged shallow aquifers.	Installed 30 monitoring wells in the shallow ground-water system underlying recently developed (less than 30 years) residential and commercial areas in Salt Lake Valley, Utah.	Sampled once in summer 1999
Basin-Fill Aquifers Study	Physical parameters, major ions, selected trace elements, pesticides, VOCs, nutrients, radon, stable isotopes, and tritium. To characterize the water quality in the basin-fill aquifers that are most important for present and future use in the study area.	Included 55 wells (mostly used for domestic supply) in the recharge areas for the deeper basin-fill aquifers within the Great Salt Lake Basins.	Sampled once during July-November 1998
Ground-Water Flow-Path Study	Physical parameters, major ions, selected trace elements, pesticides, VOCs, nutrients, radon, and stable isotopes. Selected samples to estimate ground-water ages using tritium, helium-3, and CFCs. To characterize shallow ground-water quality in relation to ground-water flow in a residential area.	Installed 11 monitoring wells along 2 hypothetical flow paths in residential areas in Salt Lake Valley, Utah. Sampled the monitoring wells, 6 nearby existing wells (including 3 land-use study wells) and 1 nearby stream.	Sampled 17 sites in spring 2000. Sampled or resampled 13 sites in fall 2000
Public-Supply Well Study	Physical parameters, major ions, selected trace elements, pesticides, VOCs, nutrients, radon, stable isotopes, and methylene blue active substances. Selected samples to estimate ground-water ages using tritium, helium-3, and CFCs. To characterize water quality in the principal aquifer used for public supply in an urban area.	Included 31 public supply wells, 15 of which represent the largest producers in Salt Lake Valley, Utah.	Sampled once during May-June 2001
Special Studies			
Land-Use Gradient Study	Physical parameters, fish, macroinvertebrates, and algal communities, and habitat characteristics, nutrients, major ions (July sample only), and pesticides. To examine relations between varying levels of land-use intensity and water quality using biological, physical, and chemical responses.	Sampled 1 to 3 sites on 13 streams and rivers along the western side of the Wasatch Mountains. A total of 28 sites were sampled.	Twice during 2000, in spring and summer
Trend Analysis from Sediment Cores	Analyzed sediment cores for trace elements, selected organic compounds, and cesium-137 (for age dating). To reconstruct the history of contaminant flux from runoff and atmospheric deposition during the past several decades of urban and industrial growth.	Sampled at three depositional sites along the western side of the Wasatch Mountains. Red Butte Reservoir, representing an undeveloped site, Farmington Bay, representing a mixed site, and Decker Lake, representing an urban site.	Sampled once in 1998

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Glossary

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

Aquatic-life guidelines—Water-quality guidelines for protection of aquatic life. Often refers to U.S. Environmental Protection Agency water-quality criteria for protection of aquatic organisms.

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

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

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

Biota—Living organisms.

Chlorofluorocarbons—A class of volatile compounds consisting of carbon, chlorine, and fluorine. Commonly called freons, which have been used in refrigeration mechanisms, as blowing agents in the fabrication of flexible and rigid foams, and, until several years ago, as propellants in spray cans.

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

Concentration—The amount or mass of a substance present in a given volume or mass of 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.

Confining layer—A layer of sediment or lithologic unit of low permeability that bounds an aquifer.

Confluence—The flowing together of two or more streams; the place where a tributary joins the main stream.

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

Degradation products—Compounds resulting from transformation of an organic substance through chemical, photochemical, and/or biochemical reactions.

Dissolved solids—Amount of minerals, such as salt, that are dissolved in water; amount of dissolved solids is an indicator of salinity or hardness.

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

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

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

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

Invertebrate—An animal having no backbone or spinal column.

Major ions—Constituents commonly present in concentrations exceeding 1.0 milligram per liter. Dissolved cations generally are calcium, magnesium, sodium, and potassium; the major anions are sulfate, chloride, fluoride, nitrate, and those contributing to alkalinity, most generally assumed to be bicarbonate and carbonate.

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

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

Midge—A small fly in the family Chironomidae. The larval (juvenile) life stages are aquatic.

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

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

Organochlorine insecticide—A class of organic insecticides containing a high percentage of chlorine. Includes dichlorodiphenylethanes (such as DDT), chlorinated cyclodienes (such as chlordane), and chlorinated benzenes (such as lindane). Most organochlorine insecticides were banned because of their carcinogenicity, tendency to bioaccumulate, and toxicity to wildlife.

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

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

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

Point source—A source at a discrete location such as a discharge pipe, drainage ditch, tunnel, well, concentrated livestock operation, or floating craft.

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

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.

Sorption—General term for the interaction (binding or association) of a solute ion or molecule with a solid.

Species—Population of organisms that may interbreed and produce fertile offspring having similar structure, habits, and functions.

Specific conductance—A measure of the ability of a liquid to conduct an electrical current.

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

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

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

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

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.

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 Great Salt Lake Basins 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 in the Great Salt Lake Basins are available at our Web site at:

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

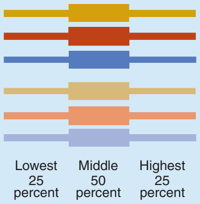
These summaries of chemical concentrations and detection frequencies from the Great Salt Lake Basins are compared to findings from 51 NAWQA Study Units investigated from 1991 to 2001 and to water-quality benchmarks for human health, aquatic life, fish-eating wildlife, or prevention of nuisance plant 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, Great Salt Lake Basins, 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



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

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 in the Great Salt Lake Basins (1) concentrations generally are lower than national findings in streams in all land use areas; (2) concentrations are not in violation of the USEPA drinking-water standard in streams and ground water; and (3) frequency of detection is lower in ground water than in surface water.

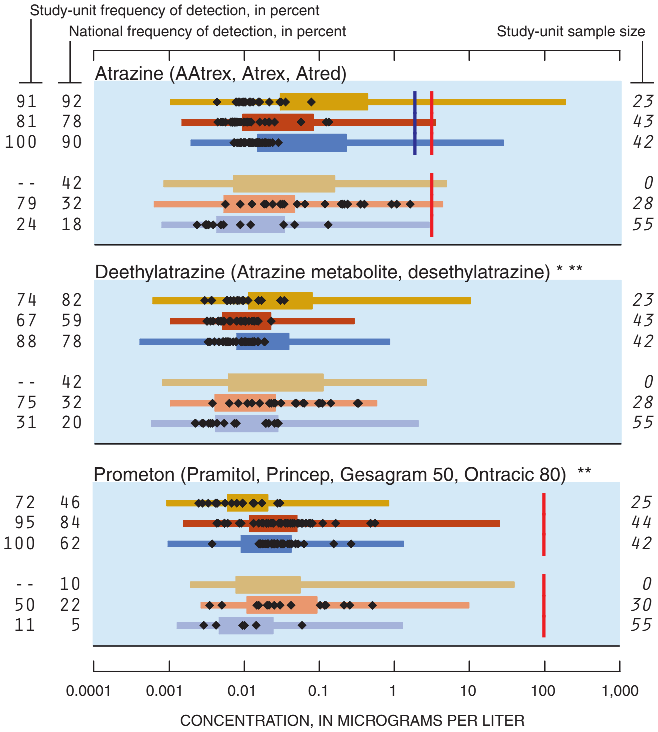
NOTE to users:

- The analytical detection limit varies among the monitored chemicals, thus frequencies of detections are not comparable among chemicals.
- It is important to consider the frequency of detection along with concentration. For example, atrazine was detected more frequently in mixed land use streams in the Great Salt Lake Basins than in mixed land use streams nationwide (100 percent compared to 90 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



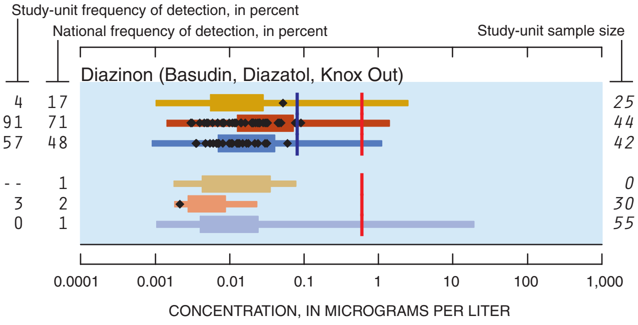
Other herbicides detected

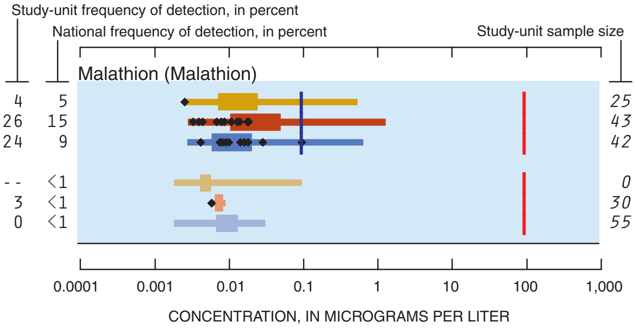
Cyanazine (Bladex, Fortrol)
Alachlor (Lasso, Bronco, Lariat, Bullet) **
Benfluralin (Balan, Benefin, Bonalan, Benefex) * **
Bromacil (Hyvar X, Urox B, Bromax)
2,4-D (Aqua-Kleen, Lawn-Keep, Weed-B-Gone)
2,4-DB (Butyrac, Butoxone, Embutox Plus) *
DCPA (Dacthal, chlorthal-dimethyl) **
Dinoseb (Dinosebe)
Diuron (Crisuron, Karmex, Direx, Diurex) **
EPTC (Eptam, Farmarox, Alirox) * **
Ethalfluralin (Sonalan, Curbit) * **
MCPA (Rhomene, Rhonox, Chiptox)
Metolachlor (Dual, Pennant)
Metribuzin (Lexone, Sencor)
Napropamide (Devrinol) * **
Pendimethalin (Pre-M, Prowl, Weedgrass Control, Stomp, Herbadox) * **
Picloram (Grazon, Tordon)
Propanil (Stam, Stampede, Wham, Surcopur, Prop-Job) * **
Simazine (Princep, Caliber 90, Gesatop, Simazat)
Tebuthiuron (Spike, Tebusan)
Triallate (Far-Go, Avadex BW, Tri-allate) *
Triclopyr (Garlon, Grandstand, Redeem) * **
Trifluralin (Treflan, Gowan, Tri-4, Trific, Trilin)

Herbicides not detected

Chloramben, methyl ester (Amiben methyl ester) * **
Acetochlor (Harness Plus, Surpass) * **
Acifluorfen (Blazer, Tackle 2S) **
Bentazon (Basagran, Bentazone, Bendioxide) **
Bromoxynil (Buctril, Brominal) *
Butylate (Sutan +, Genate Plus, Butilate) **
Clopyralid (Stinger, Lontrel, Reclaim) * **
Dacthal mono-acid (Dacthal metabolite) * **
Dicamba (Banvel, Dianat, Scotts Proturf)
Dichlorprop (2,4-DP, Seritox 50, Kildip) * **
2,6-Diethylaniline (metabolite of Alachlor) * **
Fenuron (Fenulon, Fenidim) * **
Fluometuron (Flo-Met, Cotoran, Cottonex, Meturon) **
Linuron (Lorox, Linex, Sarclex, Linurex, Afalon) *
MCPB (Thistrol) * **
Molinate (Ordram) * **
Neburon (Neburea, Neburyl, Noruben) * **
Norflurazon (Evital, Predict, Solicam) * **
Oryzalin (Surflan, Dirimal) * **
Pebulate (Tillam, PEBC) * **
Pronamide (Kerb, Propyzamid) **
Propachlor (Ramrod, Satecid) **
Propham (Tuberite) **
2,4,5-T
2,4,5-TP (Silvex, Fenoprop)
Terbacil (Sinbar) **
Thiobencarb (Bolero, Saturn, Benthiocarb, Abolish) * **

Pesticides in water—Insecticides





Other insecticides detected

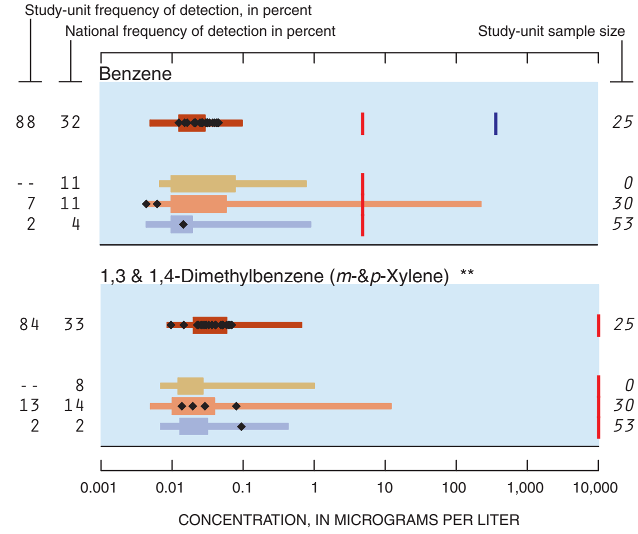
Carbaryl (Carbamine, Denapon, Sevin)
Chlorpyrifos (Brodan, Dursban, Lorsban)
gamma-HCH (Lindane, gamma-BHC, Gammexane)
Methomyl (Lanox, Lannate, Acinate) **

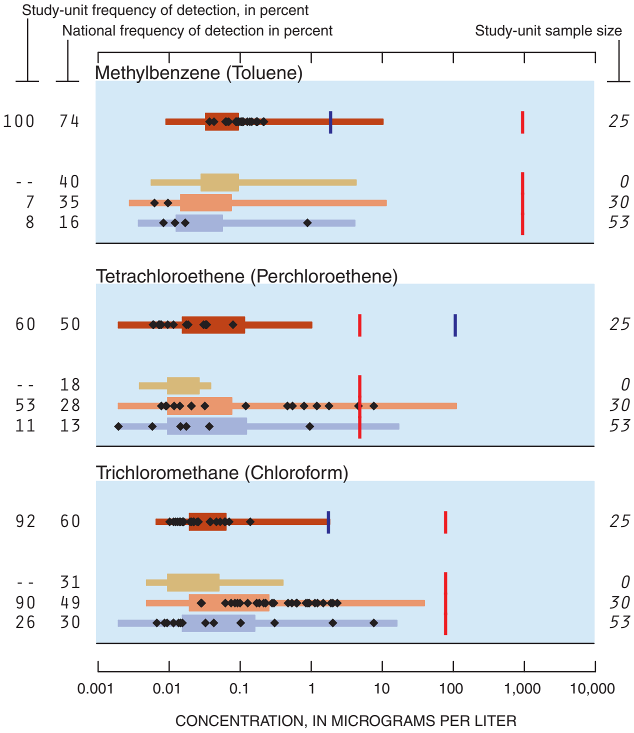
Insecticides not detected

Aldicarb (Temik, Ambush, Pounce)
Aldicarb sulfone (Standak, aldoxycarb)
Aldicarb sulfoxide (Aldicarb metabolite)
Azinphos-methyl (Guthion, Gusathion M) *
Carbofuran (Furadan, Curaterr, Yaltox)
Dieldrin (Panoram D-31, Octalox)
Disulfoton (Disyston, Di-Syston, Frumin AL, Solvirex, Ethylthiodemeton) **
Ethoprop (Mocap, Ethoprophos) * **
Fonofos (Dyfonate, Capfos, Cudgel, Tycap) **
alpha-HCH (alpha-BHC, alpha-lindane) **
3-Hydroxycarbofuran (Carbofuran metabolite) * **
Methiocarb (Slug-Geta, Grandslam, Mesurol) * **
Methyl parathion (Penncap-M, Folidol-M, Metacide, Bladan M) **
Oxamyl (Vydate L, Pratt) **
Parathion (Roethyl-P, Alkron, Panthion) *
cis-Permethrin (Ambush, Astro, Pounce) * **
Phorate (Thimet, Granutox, Geomet, Rampart) * **
Propargite (Comite, Omite, Ornamite) * **
Propoxur (Baygon, Blattanex, Unden, Proprotox) * **
Terbufos (Contraven, Counter, Pilarfox) **

Volatile organic compounds (VOCs) in water

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





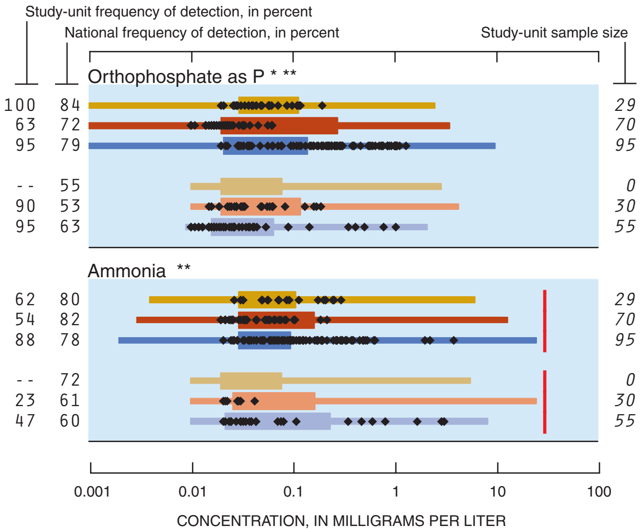
Other VOCs detected

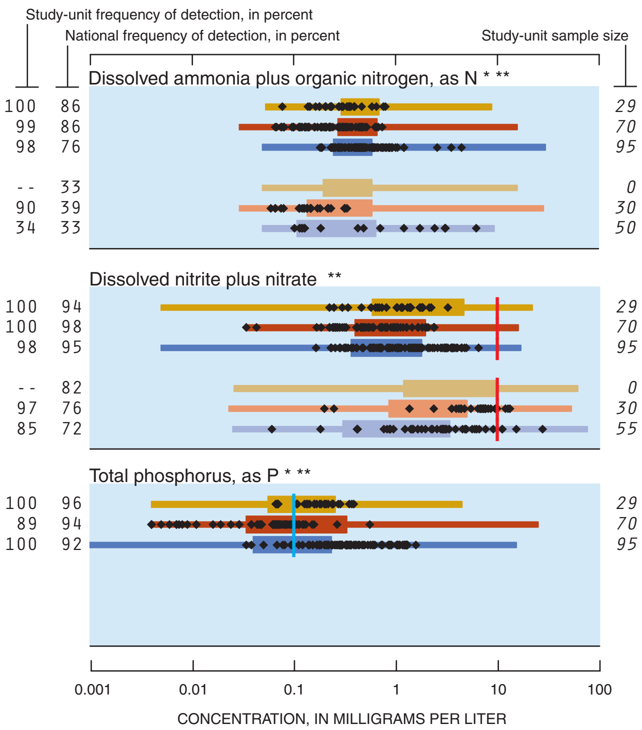
Acetone (Acetone) * **
Bromodichloromethane (Dichlorobromomethane) **
2-Butanone (Methyl ethyl ketone (MEK)) **
Carbon disulfide * **
Chloromethane (Methyl chloride) **
Dibromochloromethane (Chlorodibromomethane) **
1,4-Dichlorobenzene (*p*-Dichlorobenzene, 1,4-DCB)
Dichlorodifluoromethane (CFC 12, Freon 12) **
1,2-Dichloroethane (Ethylene dichloride)
1,1-Dichloroethane (Ethylidene dichloride) * **
1,1-Dichloroethene (Vinylidene chloride) **
cis-1,2-Dichloroethene ((Z)-1,2-Dichloroethene) **
Dichloromethane (Methylene chloride)
1,2-Dimethylbenzene (*o*-Xylene) **
Ethenylbenzene (Styrene) **
Ethylbenzene (Phenylethane)
2-Ethyltoluene (*o*-Ethyltoluene) * **
Isopropylbenzene (Cumene) * **
p-Isopropyltoluene (*p*-Cymene, 1-Isopropyl-4-methylbenzene) * **
Methyl *tert*-butyl ether (MTBE) **
4-Methyl-2-pentanone (Methyl isobutyl ketone (MIBK)) * **
Tetrachloromethane (Carbon tetrachloride)
Tribromomethane (Bromoform) **
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113, CFC 113) * **
1,1,1-Trichloroethane (Methylchloroform) **
Trichloroethene (TCE)
Trichlorofluoromethane (CFC 11, Freon 11) **
1,2,3-Trimethylbenzene (Hemimellitene) * **
1,2,4-Trimethylbenzene (Pseudocumene) * **
1,3,5-Trimethylbenzene (Mesitylene) * **

VOCs not detected

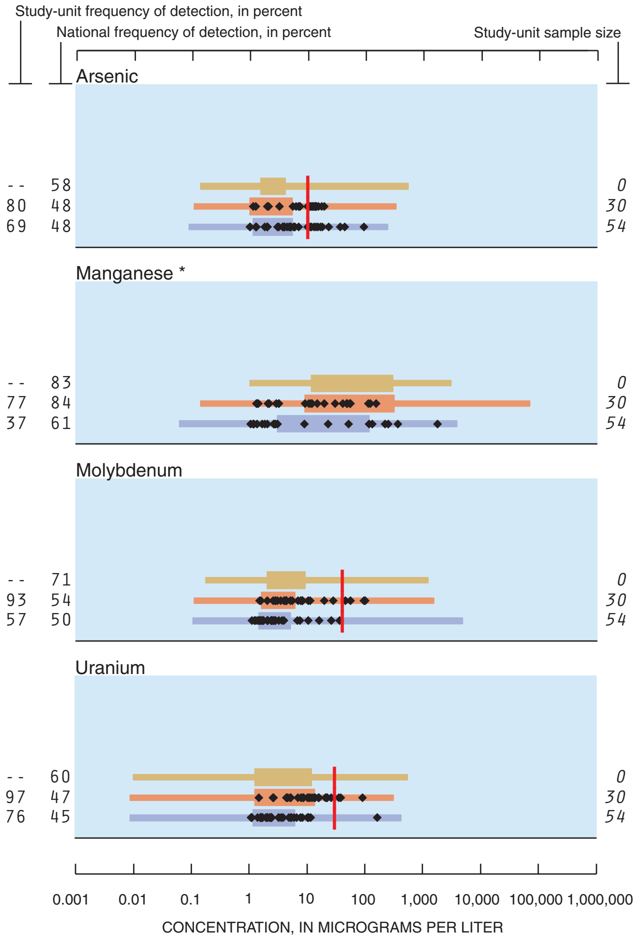
Bromobenzene (Phenyl bromide) * **
Bromochloromethane (Methylene chlorobromide) **
Bromoethene (Vinyl bromide) * **
Bromomethane (Methyl bromide) **
n-Butylbenzene (1-Phenylbutane) * **
sec-Butylbenzene ((1-Methylpropyl)benzene) * **
tert-Butylbenzene ((1,1-Dimethylethyl)benzene) * **
3-Chloro-1-propene (3-Chloropropene) * **
1-Chloro-2-methylbenzene (*o*-Chlorotoluene) **
1-Chloro-4-methylbenzene (*p*-Chlorotoluene) **
Chlorobenzene (Monochlorobenzene)
Chloroethane (Ethyl chloride) * **
Chloroethane (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)
trans-1,2-Dichloroethene ((E)-1,2-Dichlorothene) **
1,2-Dichloropropane (Propylene 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) **
1,1-Dichloropropene * **
Diethyl ether (Ethyl ether) * **
Diisopropyl ether (Diisopropylether (DIPE)) * **
Ethyl methacrylate (Ethyl methacrylate) * **
Ethyl *tert*-butyl ether (Ethyl-t-butyl ether (ETBE)) * **
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) * **
Methyl acrylonitrile (Methacrylonitrile) * **
Methyl methacrylate (Methyl-2-methacrylate) * **
Methyl-2-propenoate (Methyl Acrylate) * **
Naphthalene
2-Propenenitrile (Acrylonitrile) **
n-Propylbenzene (Isocumene) * **
1,1,2,2-Tetrachloroethane **
1,1,1,2-Tetrachloroethane (1,1,1,2-TeCA) **
Tetrahydrofuran (Diethylene oxide) * **
1,2,3,4-Tetramethylbenzene (Prehnitene) * **
1,2,3,5-Tetramethylbenzene (Isodurene) * **
1,2,4-Trichlorobenzene
1,2,3-Trichlorobenzene (1,2,3-TCB) *
1,1,2-Trichloroethane (Vinyl trichloride) **
1,2,3-Trichloropropane (Allyl trichloride) **
tert-Amyl methyl ether (TAME) * **

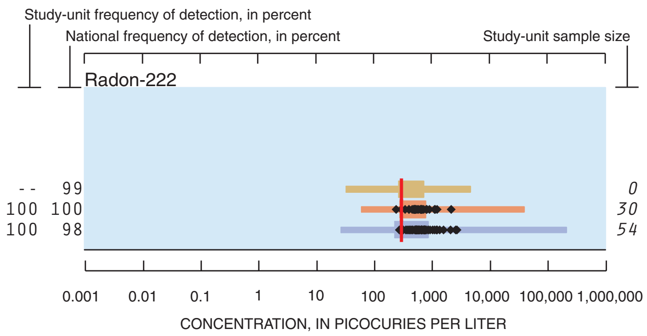
Nutrients in water





Trace elements in ground water





Other trace elements detected

Antimony
Lead
Selenium

Trace elements not detected

Beryllium
Silver

CHEMICALS IN FISH TISSUE AND BED SEDIMENT

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

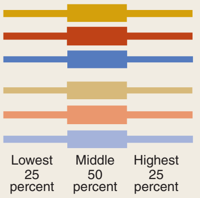
◆ Detected concentration in Study Unit

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



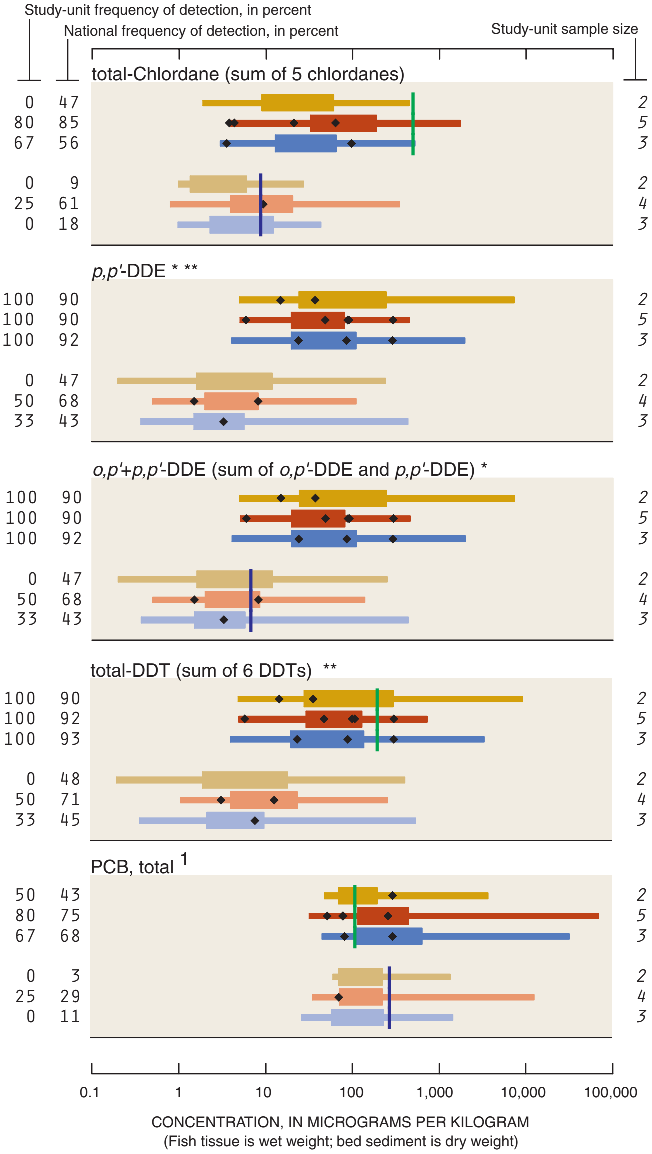
Fish tissue from streams in agricultural areas
Fish tissue from streams in urban areas
Fish tissue from streams draining mixed land uses
Sediment from streams in agricultural areas
Sediment from streams in urban areas
Sediment from streams draining mixed land uses

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

Organochlorines in fish tissue (whole body) and bed sediment



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

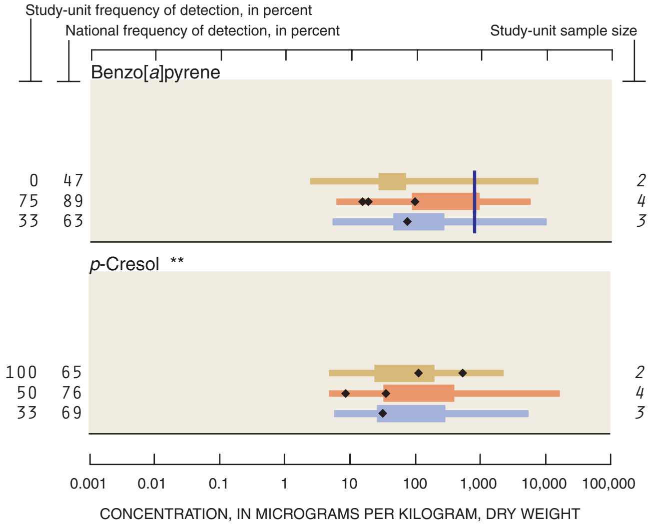
Other organochlorines detected

o,p′+*p,p′*-DDD (sum of *o,p′*-DDD and *p,p′*-DDD) *
o,p′+*p,p′*-DDT (sum of *o,p′*-DDT and *p,p′*-DDT) *
Dieldrin (Panoram D-31, Octalox) *
Dieldrin+aldrin (sum of dieldrin and aldrin) **
Hexachlorobenzene (HCB) **

Organochlorines not detected

Chloroneb (chloronebe, Demosan) * **
DCPA (Dacthal, chlorthal-dimethyl) * **
Endosulfan I (alpha-Endosulfan, Thiodan) * **
Endrin (Endrine)
gamma-HCH (Lindane, gamma-BHC, Gammexane) *
Total HCH (sum of alpha, beta, gamma, and delta-HCH) **
Heptachlor epoxide (Heptachlor metabolite) *
Heptachlor+heptachlor epoxide **
Isodrin (Isodrine, Compound 711) * **
p,p′-Methoxychlor (Marlate, methoxychlore) * **
o,p′-Methoxychlor * **
Mirex (Dechlorane) **
Pentachloroanisole (PCA, pentachlorophenol metabolite) * **
cis-Permethrin (Ambush, Astro, Pounce) * **
trans-Permethrin (Ambush, Astro, Pounce) * **
Toxaphene (Camphechlor, Hercules 3956) * **

Semivolatile organic compounds (SVOCs) in bed sediment



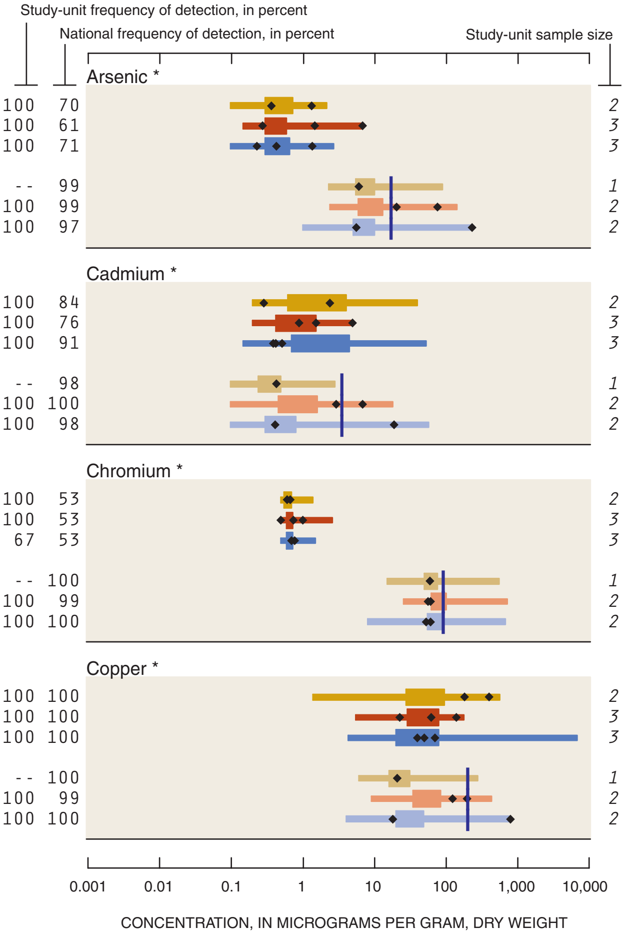
Other SVOCs detected

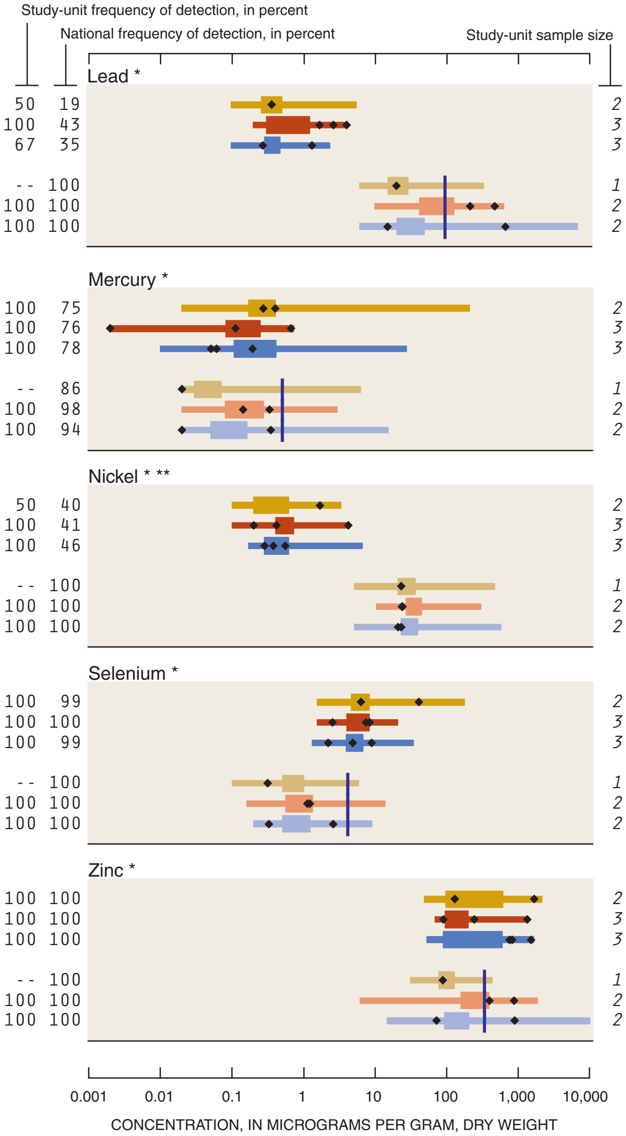
Acenaphthene
Acenaphthylene
Acridine **
Anthracene
Anthraquinone **
Benz[*a*]anthracene
Benzo[*b*]fluoranthene **
Benzo[*g,h,i*]perylene **
Benzo[*k*]fluoranthene **
9*H*-Carbazole **
Chrysene
Di-*n*-octylphthalate **
Dibenz[*a,h*]anthracene
Dibenzothiophene **
1,3-Dichlorobenzene (*m*-Dichlorobenzene) **
1,4-Dichlorobenzene (*p*-Dichlorobenzene, 1,4-DCB) **
1,2-Dimethylnaphthalene **
1,6-Dimethylnaphthalene **
2,6-Dimethylnaphthalene **
Dimethylphthalate **
Fluoranthene
9*H*-Fluorene (Fluorene)
Indeno[1,2,3-*c,d*]pyrene **
1-Methyl-9*H*-fluorene **
2-Methylanthracene **
4,5-Methylenephenanthrene **
1-Methylphenanthrene **
1-Methylpyrene **
Naphthalene
Phenanthrene
Pyrene
2,3,6-Trimethylnaphthalene **

SVOCs not detected

C8-Alkylphenol **
Azobenzene **
Benzo[*c*]cinnoline **
2,2-Biquinoline **
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) **
3,5-Dimethylphenol **
2,4-Dinitrotoluene **
Isophorone **
Isoquinoline **
Nitrobenzene **
N-Nitrosodi-*n*-propylamine **
N-Nitrosodiphenylamine **
Pentachloronitrobenzene **
Phenanthridine **
Quinoline **
1,2,4-Trichlorobenzene **

Trace elements in fish tissue (livers) and bed sediment





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

Federal Agencies
Bureau of Land Management
Bureau of Reclamation
Natural Resources Conservation Service
U.S. Environmental Protection Agency
U.S. Fish and Wildlife Service (USFWS)
U.S. Department of Agriculture, Forest Service

State Agencies
Idaho Department of Environmental Quality
Idaho Department of Fish and Game
Idaho Department of Water Resources
Utah Department of Agriculture
Utah Department of Environmental Quality
Utah Department of Natural Resources
Wyoming Department of Environmental Quality
Wyoming State Engineer's Office

Local Agencies
Central Utah Water Conservancy District
City of Sandy
Jordan Valley Water Conservancy District
Salt Lake City Department of Public Utilities
Salt Lake City Health Department
Salt Lake County
Salt Lake Metropolitan Water District
Weber Basin Water Conservancy District

Universities
University of Utah
Utah State University

Other public and private organizations
Bear Lake Regional Commission
Bear River Commission
Bear River Water Quality Committee
Pacificorp/Utah Power
Utah Climate Center

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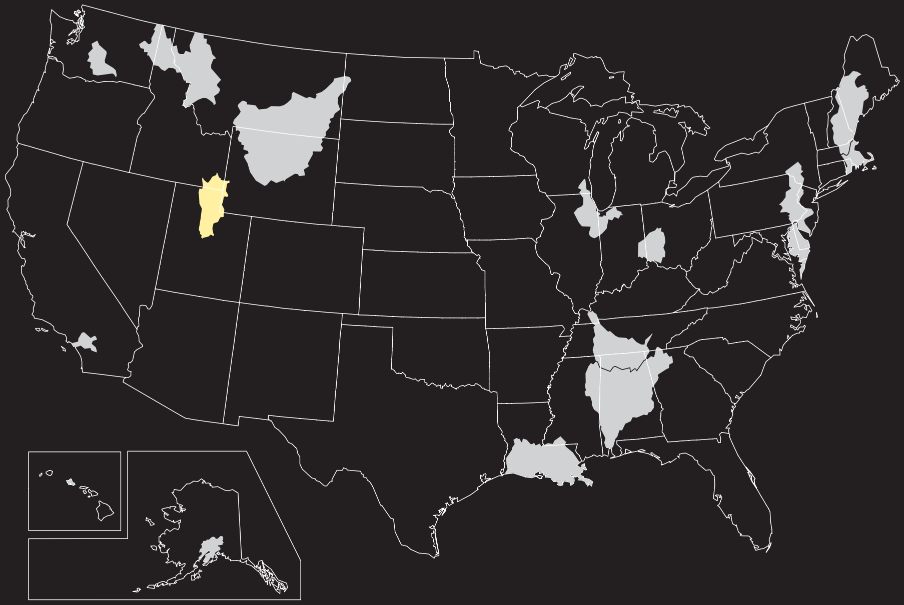
Property owners throughout the Great Salt Lake Basins, for granting permission to access their property and to sample their wells.

NAWQA

National Water-Quality Assessment (NAWQA) Program
Great Salt Lake Basins



Waddell and others—Water Quality in the Great Salt Lake Basins
U.S. Geological Survey Circular 1236

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