Water Quality in the Santa Ana Basin

California, 1999–2001

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

Circular 1238

425

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

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Front cover: State highway 91 runs through the city of Corona, through the gap between the Santa Ana Mountains and Chino Hills, and westward toward the ocean (photograph by Eagle Aerial Imaging, Costa Mesa, California).
Back cover: Left, Prado Dam (Photograph by U.S. Army Corps of Engineers); center, monitoring-well installation in the Coastal Basin (photograph by Scott Hamlin, U.S. Geological Survey); right, flowers, Santa Ana River at Featherly Regional Park (photograph by Carmen Burton, U.S. Geological Survey).

Water Quality in the Santa Ana Basin, California, 1999–2001

By Kenneth Belitz, Scott N. Hamlin, Carmen A. Burton, Robert Kent, Ronald G. Fay, and Tyler Johnson

Circular 1238

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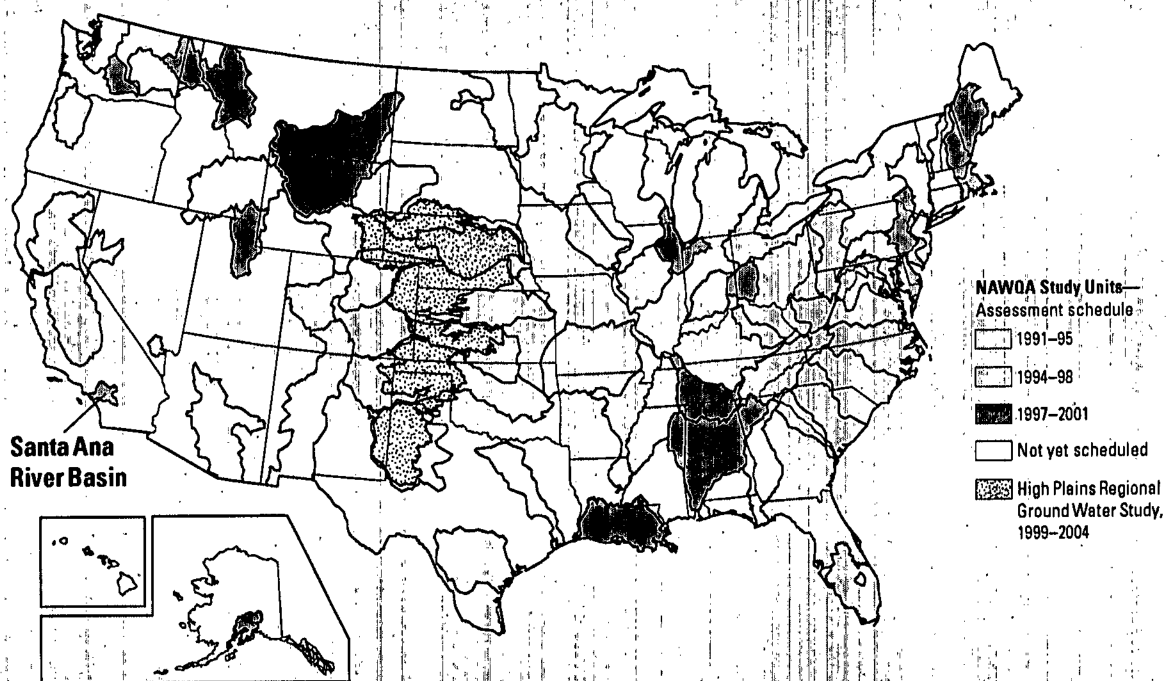
Contents

National Water-Quality Assessment Program

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



The Santa Ana River Basin 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 Santa Ana River Basin is part of the third set of intensive investigations that began in 1997.

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

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

- Total resource assessment—NAWQA assessments are long-term and interdisciplinary, and include information on water chemistry, hydrology, land use, stream habitat, and aquatic life. Assessments are not limited to a specific geographic area or water-resource problem at a specific time. Therefore, the findings describe the general health of the total water resource, as well as emerging water issues, thereby helping managers and decision makers to set priorities.
- Source-water characterization—Assessments focus on the quality of the available, untreated resource and thereby complement (rather than duplicate) Federal, State, and local programs that monitor drinking water. Findings are compared to drinking-water standards and health advisories as a way to characterize the resource.
- Compounds studied—Assessments focus on chemical compounds that have well-established methods of investigation. It is not financially or technically feasible to assess all the contaminants in our Nation's waters. In general, the NAWQA Program investigates those pesticides, nutrients, volatile organic compounds, and metals that have been or are currently used commonly in agricultural and urban areas across the Nation. A complete list of compounds studied is on the NAWQA Web site at *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, multi-scale 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

"California's State Water Resources Control Board (SWRCB) has worked with other State, local and Federal agencies, as well as with representatives of industry and nongovernmental agencies, to develop a $50 million comprehensive monitoring and assessment program for California's groundwater basins. The approach, methods, and results from NAWQA studies are important elements of California's plans to evaluate ground-water quality on a statewide basis. The USGS will work with the SWRCB to implement this program."

Arthur G. Baggett, Jr.,
Chair State Water Resources Control Board

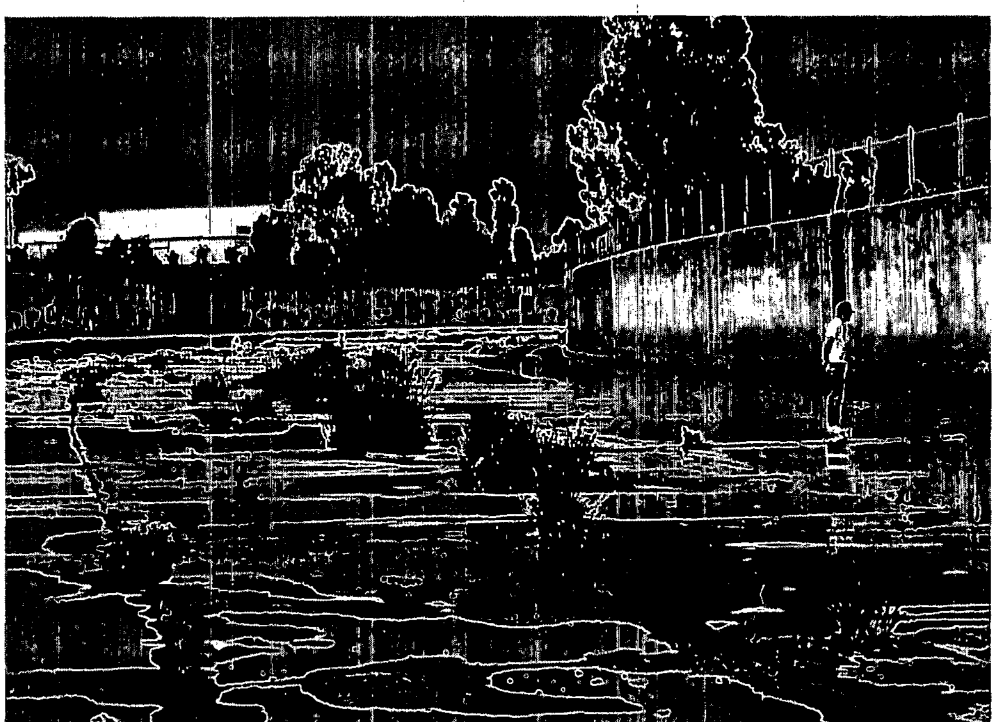
This report contains the major findings of a 1999–2001 assessment of water quality in the Santa Ana River Basin. It is one of a series of reports by the National Water-Quality Assessment (NAWQA) Program that present major findings in 51 major river basins and aquifer systems across the Nation.

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 other areas across the Nation.

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

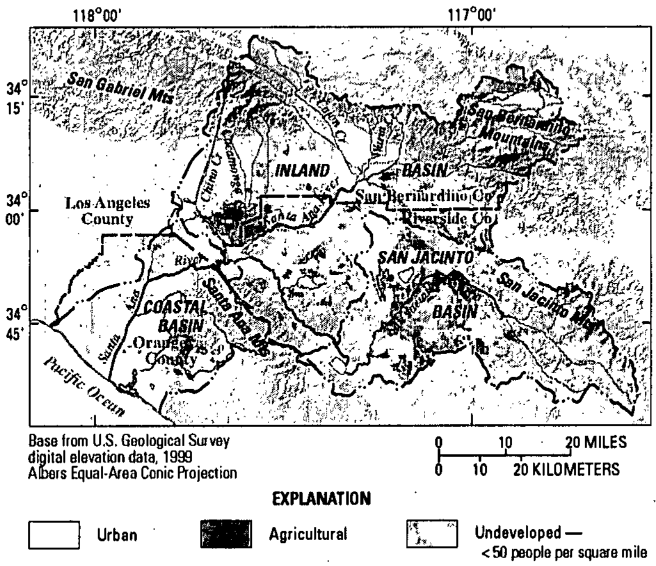
Urbanization has resulted in channelization of streams in the Santa Ana Basin. In many cases channels are concrete lined. Warm Creek, near San Bernardino, is an example. (photograph by Carmen Burton, U.S. Geological Survey)



Summary of Major Findings

Stream and River Highlights

Urbanization in the Santa Ana Basin has resulted in alteration of stream channels and the sources of water reaching those channels. The primary source of base flow in the Santa Ana River, and many of its tributaries, is treated wastewater effluent. Secondary sources include mountain runoff, urban runoff, and ground-water influx. During storms, base flow is supplemented primarily by runoff from urban areas, and secondarily by runoff from undeveloped and agricultural areas. The quality of water in the Santa Ana River and its tributaries reflects the quantity and quality of the different sources of water.



The Santa Ana Basin is highly urbanized, with nearly 5 million people living within the 2,700-square-mile watershed. About one-half of the basin consists of steep mountains that are difficult to develop.

- Concentrations of nitrate were high in the Santa Ana River and Cucamonga Creek, a tributary receiving treated wastewater, with values occasionally higher than the U.S. Environmental Protection Agency (USEPA) drinking-water standard (10 mg/L as nitrogen, p. 6).

- Volatile organic compounds (VOCs) were detected in 100 percent of 106 surface-water samples collected from three sites in urban areas (Warm Creek, Santa Ana River below Prado Dam, and Santa Ana River below Imperial Highway) and in 5 of 8 samples collected from a site in an undeveloped area (Santa Ana River near Mentone)(p. 9). Although the concentrations of these compounds were generally low, the concentration of chloroform, a byproduct of water disinfection, sometimes exceeded the aquatic life guideline (p. 10).

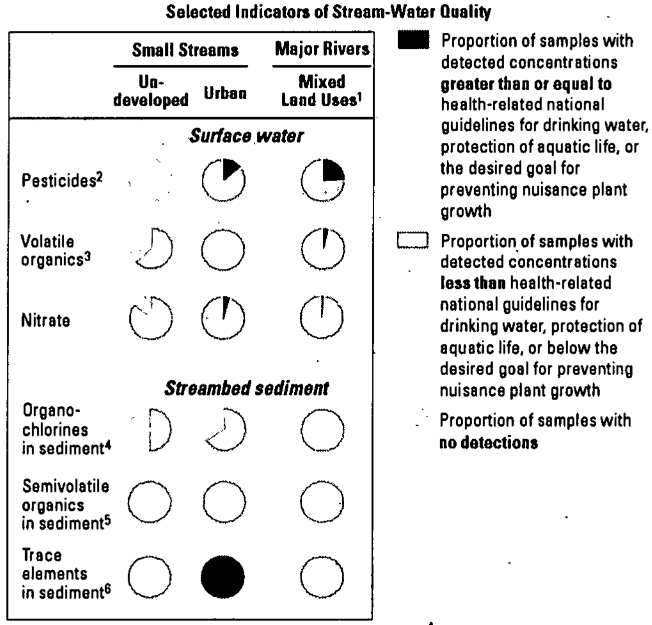
- Pesticides were detected in 104 of 105 surface-water samples collected from three sites in urban areas (p. 9). The concentrations of several pesticides (diuron, diazinon, carbaryl, chlopyrifos, lindane, malathion, and chlorothalonil) were occasionally above either nonenforceable drinking water guidelines or aquatic life criteria. In contrast to their detections at urban sites, pesticides were not detected in samples from a site in an undeveloped area.

- Organochlorine compounds and semivolatile organic compounds (SVOCs) were frequently detected in bed sediment from streams draining urban and undeveloped areas. The number of compounds detected and the concentrations of those compounds were higher for urban sites (p. 17).

- Trace-element concentrations in bed sediment exceeded guidelines for the protection of aquatic life in three streams draining urban areas: Chino Creek, Warm Creek, and the San Jacinto River. Trace elements with concentrations exceeding guidelines were zinc, lead, and arsenic (p. 20).

- Aquatic invertebrate and algal communities were more degraded in streams receiving treated wastewater than in streams receiving either urban runoff or ground-water influx. Aquatic communities were least degraded in streams receiving mountain runoff (p. 21).

Selected Indicators of Stream-Water Quality



[1] The predominant land use is urban at these sites.
[2] Insecticides, herbicides, fungicides, and pesticide metabolites sampled in water.
[3] Disinfection byproducts, solvents, refrigerants, fumigants, and gasoline compounds in water.
[4] Organochlorine compounds including DDT and PCBs sampled in sediment.
[5] Byproducts of fossil-fuel combustion; components of coal and crude oil, in sediment.
[6] Arsenic, mercury, and other metals, sampled in sediment and water.

- Aquatic invertebrate and fish communities were more degraded in concrete-lined channels than in natural channels or channelized streams with natural bottoms. Aquatic communities in channelized streams with natural bottoms were more similar to those in natural channels than those in concrete channels (p. 22).

Trends in Surface-Water Quality

Pesticides and SVOCs can persist in the environment for long periods of time. For example, DDT and chlordane have not been used for 15 to 30 years, yet they are still detected in stream-bed sediment (p. 17). However, analyses of sediment cores obtained from the West Street Basin, located in the Coastal Basin, indicate that concentrations of these compounds are lower in younger sediment than in older sediment (p. 18). Analyses of sediment cores also indicate that the concentrations of lead and zinc in sediment at the West Street Basin have been persistently above aquatic-life guidelines, but are lower in more recent sediment (p. 20). The concentrations of some pesticides, SVOCs, and trace elements fluctuate with climate: higher during wet periods and lower during dry periods (p. 19, 20).

Major Influences on Streams and Rivers

- Routing and rerouting of water through the urban landscape affects water quality
- Channelization and concrete lining of streams degrades aquatic ecosystems

Ground-Water Highlights

Ground-water pumping and artificial recharge have accelerated the movement of water through the aquifers of the Santa Ana Basin. To a large extent, native water in these aquifers has been replaced by water recharged since the early 1950s (p. 8). The quality of younger ground water (recharged since the early 1950s) is generally different from the quality of the older, native ground water. In the Inland and San Jacinto Basins, younger ground water tends to be shallower than older, native ground water. In the Coastal Basin, younger ground water tends to be closer to recharge facilities along the Santa Ana River and Santiago Creek.

- Ground water recharged since the 1950s has higher concentrations of nitrate and dissolved solids than older ground water (p. 8). Nitrate concentrations in younger water from aquifers that provide drinking-water supply exceed the USEPA drinking-water standard of 10 mg/L (as nitrogen) in some areas of the Inland and San Jacinto Basins. Dissolved-solids concentrations in younger water from aquifers used for public supply frequently exceed the USEPA nonenforceable drinking-water guideline (500 mg/L) in the Coastal Basin.
- Pesticides and volatile organic compounds (VOCs) were detected more frequently in younger ground water than in older ground water (p. 14). While the concentrations of these compounds were generally low, the concentrations of three VOCs (PCE, TCE, and DBCP) exceeded USEPA drinking-water standards in four irrigation wells in the Inland Basin (p. 10).
- Pesticides and VOCs were detected more frequently in the aquifers of the Santa Ana Basin than in aquifers assessed by NAWQA nationwide (p. 15). The higher detection frequencies are notable because the supply wells in the Santa Ana Basin are relatively deep, typically drilled to depths of 200 to 1,000 feet.
- Nearly 80 percent of the public supply and irrigation wells sampled in the Santa Ana Basin had concentrations of radon higher than the drinking water standard of 300 picocuries per liter proposed by the USEPA (p. 16).

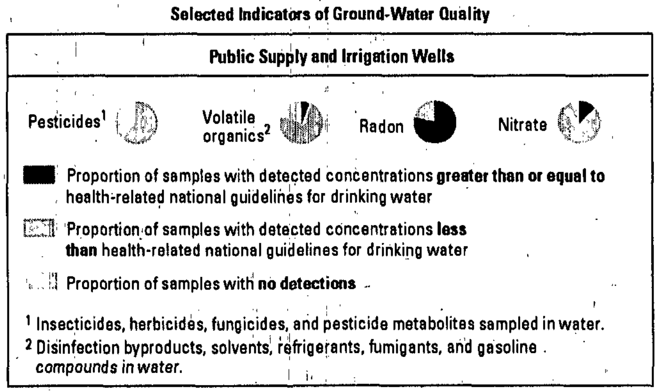
Trends in Ground-Water Quality

Major aquifer systems in the Santa Ana Basin are recharged by the diversion of the Santa Ana River and its tributaries to engineered recharge facilities. Water managers also use water imported from the Colorado River and northern California for recharge. Therefore, the quality of water in aquifers in the Santa Ana Basin reflects the quality of the surface water diverted during the past 50 years. Similarly, the future quality of ground water will be affected by the quality of surface water currently being used to recharge these aquifers (p. 24).

Major Influences on Ground Water

- Artificial recharge and ground-water pumping have accelerated the movement of water and dissolved consituents in aquifers.
- Historical and present-day land uses introduce nitrate, volatile organic compounds, pesticides, and other constituents into ground water.

Selected Indicators of Ground-Water Quality



Introduction to the Santa Ana Basin

The Santa Ana Basin, located in southern California, is characterized by prominent mountains that rise steeply from the relatively flat-lying coastal plain and inland valleys. The tallest peaks in the San Gabriel, San Bernardino, and San Jacinto Mountains exceed 10,000 feet in elevation. These mountain ranges are drained by the Santa Ana River and its tributaries. The drainage area of the Santa Ana River is about 2,700 square miles, making it the largest stream system in southern California.

The Santa Ana Basin includes parts of Orange, San Bernardino, Riverside, and Los Angeles Counties, and is home to nearly 5 million people who rely not only on water resources that originate within the basin but also on water imported from northern California and the Colorado River. The population is expected to increase to about 7 million people by 2025 and to 10 million by 2050 (Santa Ana Water Project Authority, 2003).

Land use in the basin is about 35 percent urban, 10 percent agricultural, and 55 percent undeveloped (fig. 1). Urban and agricultural land uses occur primarily in the relatively flat valleys and coastal plain. The mountains are generally steep and remain undeveloped. Population density for the entire study area is 1,500 people per square mile; excluding the land area that is steep, the population density is about 3,000 per square mile. The most densely populated part of the basin is in the city of Santa Ana, where the population density is as high as 20,000 per square mile.

The Santa Ana Basin can be subdivided into three primary subunits: the San Jacinto, the Inland, and the Coastal Basins (fig. 2). Within these subunits, water-bearing deposits lie within the alluvium-filled valleys and coastal plain, which are bounded by relatively impervious mountains and hills. Ground water pumped from the alluvial deposits is the primary source of municipal water supply. Public supply wells are typically drilled to depths ranging from 200 to 1,000 feet.

The hydrologic cycle in the Santa Ana Basin is dominated by human activities

The climate of the Santa Ana Basin is Mediterranean with hot, dry summers and cool, wet winters. Average annual precipitation ranges from 10 to 24 inches in the coastal plain and inland valleys and from 24 to 48 inches in the San Gabriel and San Bernardino Mountains. As a consequence of the semiarid climate and the water demands of the urban population, the hydrologic cycle is dominated by human activities. Streams and rivers draining the San Gabriel, San Bernardino, and San Jacinto Mountains are diverted to ground-water recharge facilities (fig. 2). In turn, pumped ground water is the major source of water supply in the watershed, providing about two-thirds of the total water demand (1.2 million acre-feet per year acre feet per year, or about 1 billion gallons per day). Water imported from north-

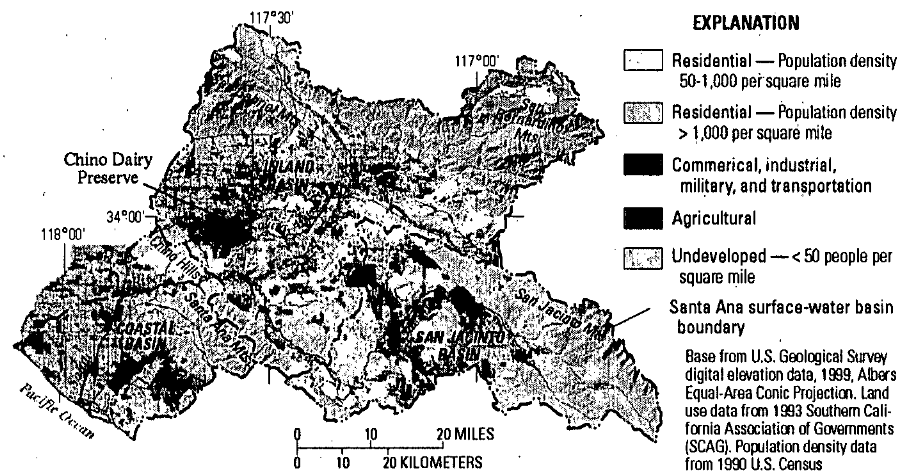


Figure 1. The Santa Ana Basin is characterized by prominent mountains that rise steeply from the flat-lying coastal plain and inland valleys. Almost all of the urban and agricultural land uses occur on the coastal plain and inland valleys.

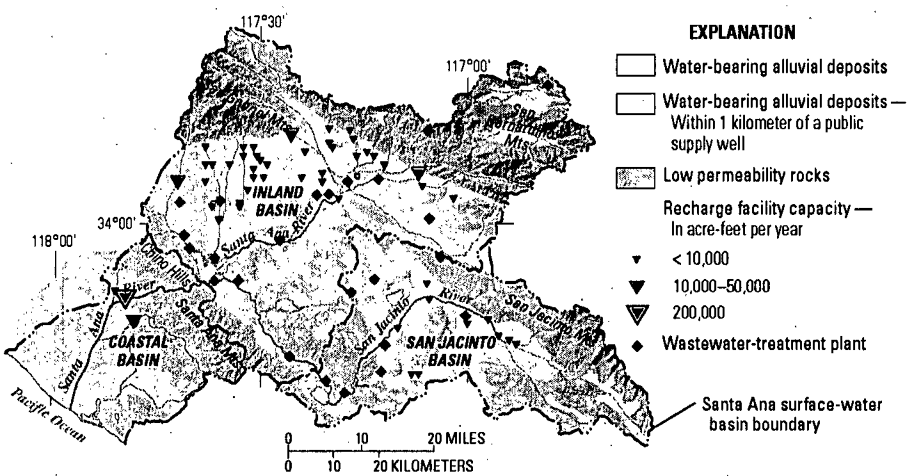


Figure 2. The hydrologic cycle in the Santa Ana Basin is dominated by artificial recharge, ground-water pumping, and discharge of treated wastewater. Water-bearing deposits, used for municipal supply, lie within the alluvium filled valleys and coastal plain.

ern California and the Colorado River accounts for about one-quarter of the total consumptive demand. Imported water is delivered directly to consumers and is also used as a supplementary water source at ground-water recharge facilities.

From a mass-balance perspective, water is cycled twice in the Inland and Coastal Basins before it is discharged to the ocean. In the first cycle, tributaries exiting the San Gabriel and San Bernardino Mountains are diverted to ground-water recharge facilities in the Inland Basin. In turn, ground water is extracted for use and then discharged as treated wastewater to the Santa Ana River. In the second cycle, the Santa Ana River enters the Coastal Basin, where water managers utilize almost all of the base flow and most of the stormflow to recharge the coastal aquifer system. Base flow consists primarily of treated wastewater (Mendez and Belitz, 2002) and stormflow includes runoff from urban and agricultural land. Artificially recharged water accounts for about three-quarters of the ground water pumped from the coastal aquifer system (about 300,000 acre feet per year, or about 270 million gallons per day).

Urban water use exceeds agricultural water use in the Study Unit (75 percent as compared to 25 percent). After delivery to consumers, the water is typically used for landscape irrigation and for indoor purposes. Water used for landscape irrigation can be used by plants, run off into storm drains and then streams, or recharge ground-water aquifers. Water used indoors is routed to wastewater-treatment facilities and then discharged, primarily to surface-water bodies: in the San Jacinto Basin, to constructed ponds; in the Inland Basin, to the Santa Ana River, its tributaries, and ponds; and in the Coastal Basin, to the ocean. In the Coastal Basin, reclaimed wastewater is also injected into aquifers along the coast as a barrier to seawater intrusion.

During the period of this study (October 1998 to September 2001), precipitation was less than the 30-year average. Streamflow in Warm Creek, a small urban watershed in the Inland Basin, was generally near historical lows during base-flow conditions; high flows occurred only during storms (fig. 3). In contrast, streamflow in the Santa Ana River was higher than the 30-year average (fig. 4). The high streamflow resulted from discharges of treated wastewater to the Santa Ana River (Burton and others, 1998). During the past 30 years, increasing urbanization has led to a steady increase in the volume of these discharges.

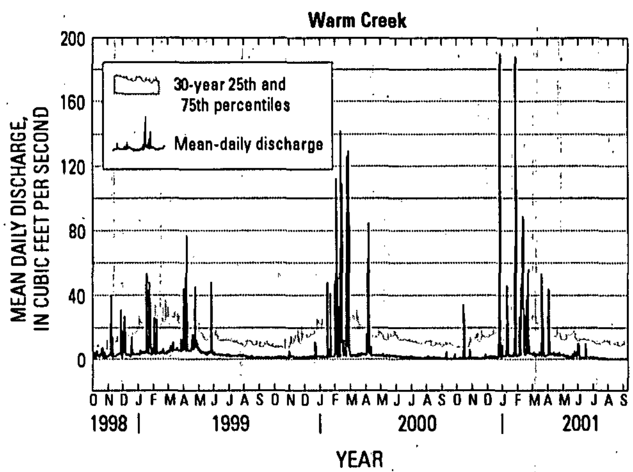


Figure 3. Base flow in Warm Creek was near historical lows during the period of study (October 1998 to September 2001) due to below-average precipitation.

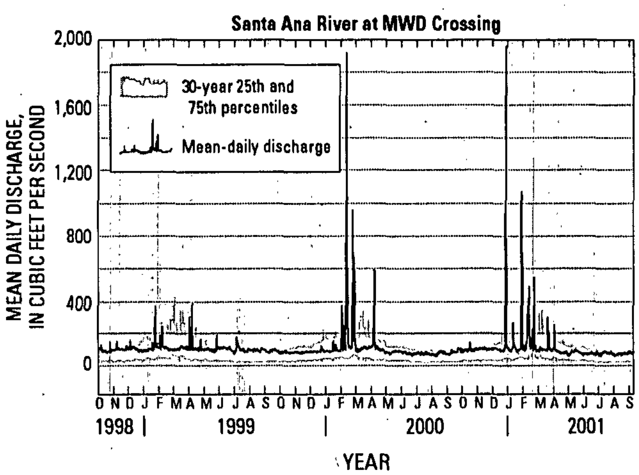


Figure 4. The base flow of the Santa Ana River was high during the period of study (October 1998 to September 2001) due to the steady increase in the volume of treated wastewater discharged to the river.

Water quality in the Santa Ana Basin reflects the influence of urbanization

The best quality water in the Santa Ana watershed occurs in streams flowing from surrounding mountains and in ground water recharged by those streams. As the water flows away from the mountains, either in the surface or subsurface, its quality is affected by mineral dissolution, urban runoff, discharge of treated wastewater, dairy operations in the Chino Dairy preserve (fig. 1), landscape irrigation, and the use of high-salinity imported surface water. Water quality can also be affected by the legacy of previous activities including spills and leaks of industrial solvents, and by agricultural production.

The purpose of the NAWQA study in the Santa Ana Basin was to assess water quality in streams and aquifers. In this report, particular emphasis is placed on understanding the influence of urbanization on water quality. The Santa Ana Basin is the most densely populated of the NAWQA study areas and is among the more arid. The large population places a high demand on the limited water resources. Therefore, the Santa Ana Basin provides an ideal opportunity for assessing the effects of human activities on water quality.

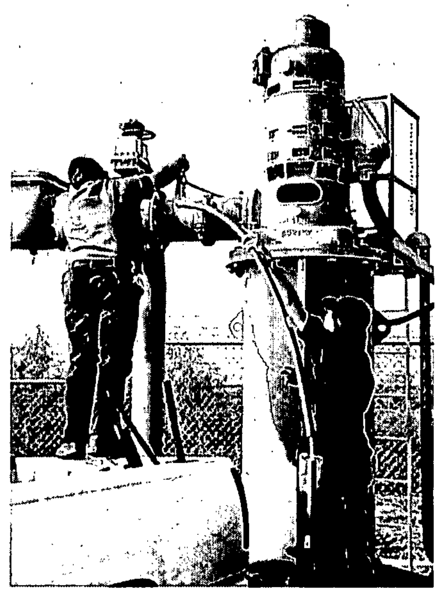
Major Findings

Concentrations of nitrate and dissolved solids are elevated in surface water and ground water in the Santa Ana Basin

Concentrations of nitrate above 10 milligrams per liter (mg/L), the USEPA drinking-water standard, can adversely affect human health, particularly the health of infants. In the Santa Ana River and some of its tributaries (for example Cucamonga Creek and San Timoteo Creek), the concentrations of nitrate can exceed the USEPA drinking-water standard. In some areas of the Inland and San Jacinto Basins, the concentrations of nitrate in ground-water can also exceed the drinking-water standard. For example, water from agricultural wells located in the Chino Dairy Preserve (fig. 1) have nitrate concentrations generally above 25 mg/L (Wildermuth Environmental Inc., 2002).

Concentrations of dissolved solids above 500 mg/L are of secondary concern, affecting mainly the odor, taste, or color of water. In the Santa Ana River and some tributaries (for example, Warm Creek and Little Chino Creek), the concentrations can exceed 500 mg/L. In ground water, concentrations are generally below 500 mg/L but are higher in some areas. For example, dissolved-solids concentrations in ground water from the Chino Dairy Preserve (Wildermuth Environmental Inc., 2000; 2002) and from many areas of the San Jacinto Basin (Kaehler and Belitz, 2003) are generally above 1,000 mg/L.

These findings are supported by the Study-Unit Design described on pages 26–27.



The USGS NAWQA Program works with local water districts and municipalities to sample ground-water supply wells. (photograph by Barbara Dawson, U.S. Geological Survey)

Water samples must be handled carefully to ensure the accuracy of laboratory analyses. (photograph by Carmen Burton, U.S. Geological Survey)

The USGS has been monitoring the Santa Ana River for more than 100 years. Here, at the MWD Crossing site, discharge has been monitored since 1969. The NAWQA Program has been monitoring the Santa Ana River since 1998. (photograph by Carmen Burton, U.S. Geological Survey)

Nitrate and dissolved solids concentrations in streams are related to water source and location

Concentrations of nitrate and dissolved solids in streams in the Santa Ana Basin are controlled to a large extent by the sources of water reaching the streams. During base-flow conditions, these sources include treated wastewater, mountain runoff, urban runoff, and ground-water influx. During stormflow conditions, stream discharge includes additional runoff from mountain and urban areas. Treated wastewater and urban runoff represent the indoor and outdoor use of water delivered to consumers. Delivered water consists of pumped ground water and imported water. The sources of mountain runoff and storm runoff are precipitation. The sources of ground-water influx to streams vary, reflecting the complexities of the hydrologic cycle in the Santa Ana Basin.

The highest concentrations of nitrate were in streams receiving treated wastewater. For example, nitrate concentrations in Cucamonga Creek and the Santa Ana River (sites at MWD Crossing, below Prado Dam, and below Imperial Highway) typically ranged from 4 to 8 mg/L (fig. 5). In contrast, nitrate concentrations in mountain streams and in Warm Creek, which receives urban runoff and ground-water influx, were usually less than 1 mg/L (fig. 5). Nitrate concentrations in samples consisting predominantly of storm runoff typically ranged from 1 to 3 mg/L.

The highest dissolved-solids concentrations were in the Santa Ana River and valley-floor tributaries during base-flow conditions (fig. 6). Concentrations typically ranged from 400 to 600 mg/L. The lowest dissolved-solids concentrations were in mountain streams and storm runoff, with values typically ranging from 100 to 300 mg/L.

The concentrations of dissolved solids in streams receiving treated wastewater were comparable to dissolved-solids concentrations in Warm Creek, which receives urban runoff and ground-water influx. This indicates that the indoor use of delivered water and subsequent treatment of that water do not substantially increase dissolved-solids concentrations.

Concentrations of fluoride, a minor component of dissolved solids, were above the USEPA drinking-water standard (4 mg/L) in four of eight samples collected from East Twin Creek, a small stream located in the San Bernardino Mountains. Over a long period of time, drinking water with elevated concentrations of fluoride can lead to bone disease in some people. The high concentrations likely result from geothermal water discharging to East Twin Creek.

Collecting water samples on the Santa Ana River near Imperial Highway, just upstream from facilities used to recharge aquifers in the coastal plain. (photograph by Carmen Burton, U.S. Geological Survey)

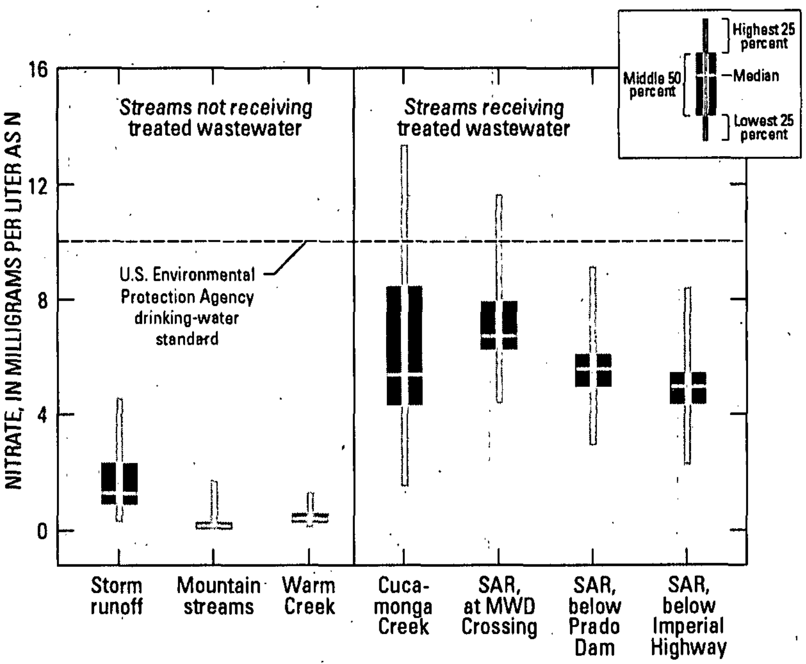


Figure 5. Nitrate concentrations in streams receiving treated wastewater are higher than streams that do not have wastewater inflows. (SAR = Santa Ana River)

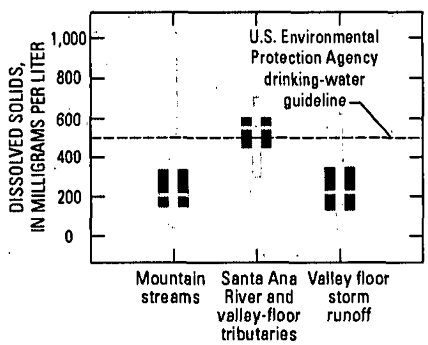
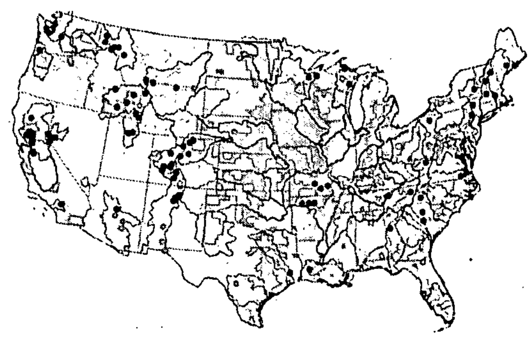


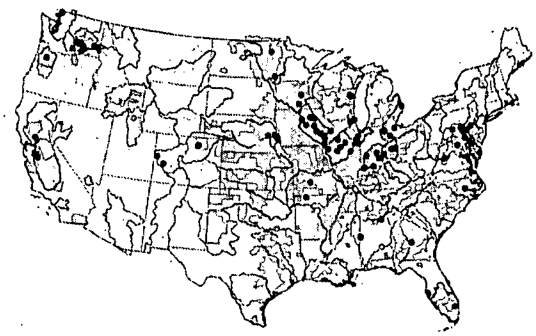
Figure 6. Concentrations of dissolved solids were relatively high in the Santa Ana River and valley floor tributaries (Warm Creek and Cucamonga Creek), and relatively low in mountain streams and in storm runoff. Concentrations of dissolved solids in storm runoff were calculated from records of continuously monitored discharge and conductivity (Kent and Belitz, 2004)

National Perspective—The primary source of elevated nitrogen concentrations in surface water in the Santa Ana Basin differs from most areas sampled by NAWQA in the Nation

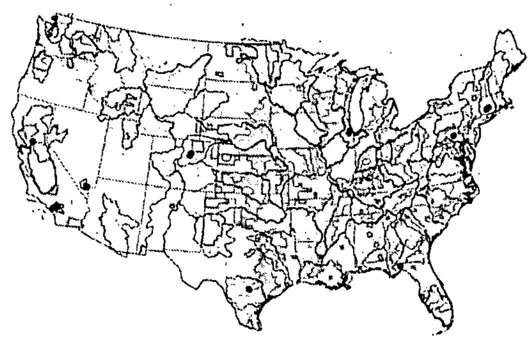
The Santa Ana Basin is one of the few urban areas in the country sampled by NAWQA (60 urban sites) where total nitrogen concentrations in streams commonly exceed 3 mg/L. In most streams sampled by NAWQA (a total of 479 sites), elevated nitrogen concentrations come from applications of fertilizer and manure in agricultural areas (Fuhrer and others, 1999). In contrast, elevated concentrations in the Santa Ana Basin come primarily from wastewater-treatment-plant effluent. In the Santa Ana Basin, all base-flow samples (about 120) collected at four sites downstream from wastewater-treatment plants had total nitrogen concentrations above 3 mg/L, placing these sites in the upper 10 percent of urban sites sampled by NAWQA. In contrast, base-flow samples collected upstream from the wastewater-treatment plants in the Santa Ana Basin had total nitrogen concentrations below 2 mg/L. The predominant form of nitrogen in streams in the Santa Ana Basin is nitrate because modern wastewater-treatment plants convert ammonia to nitrate to protect aquatic life from the toxic effects of un-ionized ammonia.



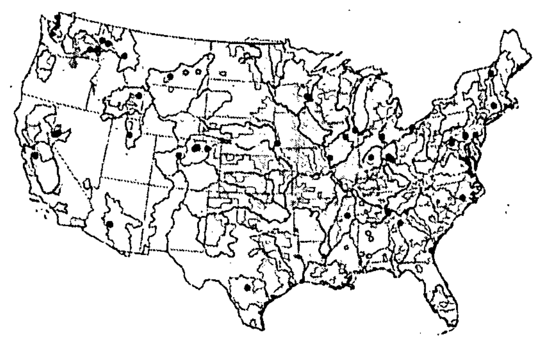
Total nitrogen in streams—1993–2001
(Undeveloped areas)



Total nitrogen in streams—1993–2001
(Agricultural areas)



Total nitrogen in streams—1993–2001
(Urban land-use areas)



Total nitrogen in streams—1993–2001
(Mixed land-use areas)

EXPLANATION

Mean annual concentration – In milligrams per liter
- < 0.6
- 0.6–3.0
- > 3.0

Nitrogen input – In pounds per acre
- < 6
- 6–25
- > 25

In the urbanized Santa Ana Basin, the median concentration of nitrogen in streams is about 6 milligrams per liter, and results from discharge of treated wastewater effluent. Nitrate is the predominant form of nitrogen in the Santa Ana Basin.

Nitrate and dissolved-solids concentrations are higher in ground water recharged since the 1950s than in older ground water

In the Santa Ana Basin, ground water recharged since the early 1950s typically has higher concentrations of nitrate and dissolved solids than ground water recharged before the early 1950s. The water quality of younger ground water has generally been affected by activities such as agriculture, landscape irrigation, and wastewater generation and disposal. These activities typically increase the concentrations of nitrate and dissolved solids. As aquifers are recharged with water associated with these activities, the concentrations of nitrate and dissolved solids increase in ground water.

In the Santa Ana Basin, the concentration of nitrate in younger ground water typically ranges from 2 to 10 mg/L (fig. 7). In general, nitrate concentrations greater than 2 mg/L in ground water are indicative of contamination by human activities (Mueller and Helsel, 1996). In the San Jacinto and Coastal Basins, concentrations of nitrate in older ground water typically range from less than 0.05 mg/L to about 3 mg/L, with most less than 0.1 mg/L (fig. 7). In the Inland Basin, only three wells tap older ground water; the nitrate concentrations range from 0.8 to 8 mg/L.

Of the 52 public supply and irrigation wells sampled in the San Jacinto and Inland Basins, 6 public supply wells and 3 irrigation wells produced water with nitrate concentrations that exceeded the USEPA drinking-water standard (10 mg/L as nitrogen). Ground water from eight of those nine wells is young. Water from the public supply wells with high nitrate concentrations is blended with other water sources with lower nitrate concentrations to comply with drinking-water standards.

Concentrations of dissolved solids are generally higher in ground water recharged since the early 1950s than in older ground water in the Coastal and Inland Basins (fig. 8). In the Coastal Basin, the median concentration of dissolved solids in younger ground water exceeded 500 mg/L (the USEPA nonenforceable drinking-water guideline). In contrast, the median concentration in older ground water was less than 300 mg/L. In the Inland Basin, the concentrations of dissolved solids in younger ground water ranged from 200 to 800 mg/L, whereas the samples of older water had concentrations less than 300 mg/L. The higher concentrations in younger ground water in both basins are primarily due to human activity, including the importation of high-salinity water from the Colorado River. The Colorado River has been an important source of engineered recharge in the Coastal Basin since the 1950s.

In the San Jacinto Basin, the difference in the concentrations of dissolved solids between younger and older ground water is not as apparent as that observed in the two other ground-water basins. This difference is due to several factors including less human activity, higher concentrations of dissolved solids in the native ground water, and greater variability in concentrations in the native ground water. In many parts of the San Jacinto Basin, the native ground water has dissolved-solids concentrations exceeding 1,000 mg/L (Burton and others, 1996; Kaehler and others, 1998; Kaehler and Belitz, 2003); there are relatively few water-supply wells in these areas.

Additional Information

Additional information and data on nitrate, dissolved solids, and sampling protocols in the Santa Ana Basin are provided by Kent and Belitz (2004) and Hamlin and others (2002). Additional data are also available at http://water.usgs.gov/pubs/wri/wri02-4243/text.html

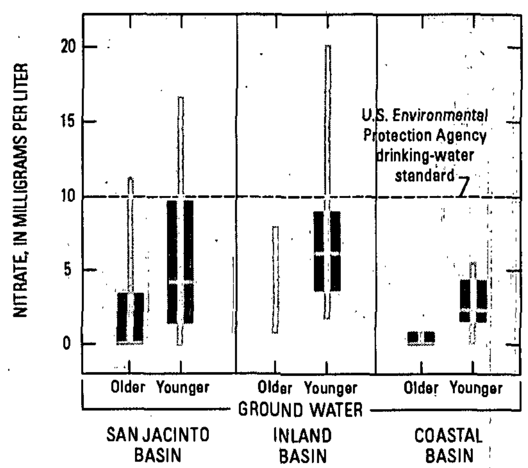


Figure 7. Concentrations of nitrate are higher in ground water recharged during the past 50 years (younger ground water) than in older ground water in many areas of the Santa Ana Basin.

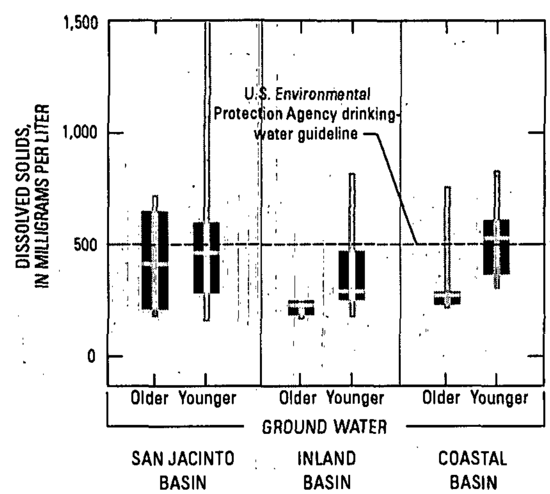
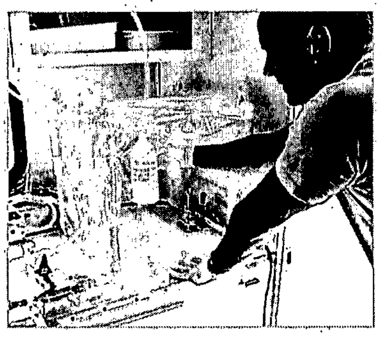


Figure 8. Concentrations of dissolved solids are higher in younger ground water than older ground water in the Inland and Coastal Basins.



Processing of ground-water samples in a mobile laboratory, including samples for analysis of tritium. (photograph by Carmen Burton, U.S. Geological Survey)

Tritium analyses are used to assess whether ground water has been recharged since the early 1950s

Tritium, a radioactive isotope of hydrogen that is incorporated into molecules of water, is generated by natural and human activities. The primary natural source is the interaction of cosmic rays with water in the Earth's atmosphere (Thatcher, 1962). The primary human source was the testing of nuclear weapons in the atmosphere from 1952 until 1963; atmospheric testing elevated the concentration of tritium by several orders of magnitude in the Northern Hemisphere. Since the ban on atmospheric testing in 1963, the amount of tritium in the atmosphere and in rainfall has been decreasing due to radioactive decay. Presently (2003), the amount of tritium in the atmosphere is approaching natural concentrations, and as a consequence, concentrations of tritium in precipitation and modern recharge are also approaching background levels. Concentrations of tritium above background levels generally indicate the presence of water recharged since the early 1950s. NAWQA studies routinely include the analysis of tritium concentrations in ground water. These analyses provide a basis for identifying the presence of "young" (recharged since the early 1950s) water in aquifers.

Pesticides and volatile organic compounds are commonly present in surface water and ground water

Pesticides—including herbicides, insecticides, and fungicides—are synthetic organic compounds used throughout the Nation to control weeds, insects, fungi, and other pests. Volatile organic compounds (VOCs) — present in paints, solvents, fuels, fuel additives, refrigerants, fumigants, and disinfected water – tend to evaporate under normal environmental conditions. Both classes of compounds were frequently detected in surface and ground water in the Santa Ana Basin (fig. 9). VOCs were detected in 100 percent of 106 samples collected at three stream sites located in urban areas: Warm Creek, Santa Ana River below Prado Dam, and Santa Ana River below Imperial Highway. Pesticides were detected in 104 of the 105 samples. In contrast, VOCs were detected in 5 of 8 samples collected at a stream site draining an undeveloped area (Santa Ana River near Mentone); pesticides were not detected there (fig. 9).

Pesticides and VOCs were detected less frequently in ground water than in urban streams (fig. 9). However, at least one pesticide or one VOC was detected in about 85 percent of the wells sampled in the San Jacinto, Inland, and Coastal Basins. VOCs were detected more frequently (80 percent) than pesticides (60 percent). Fewer pesticides were detected than VOCs because many pesticides do not have the chemical stability or mobility that allows them to move and persist in the ground-water flow system long enough to reach a well. Of the 72 wells sampled as part of the aquifer system studies, 57 were used for public supply.

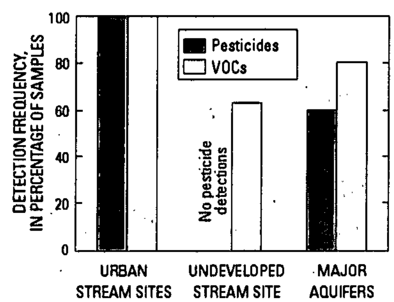


Figure 9. Pesticides and volatile organic compounds (VOCs) were detected frequently in urbanized streams (Warm Creek, Santa Ana River below Prado Dam, and Santa Ana River below Imperial Highway) and in ground water (72 wells in the San Jacinto, Inland, and Coastal Basins).

A large number of different pesticides and VOCs were detected in surface and ground-water samples from the Santa Ana Basin. Of the 103 pesticides and pesticide degradates routinely analyzed for in both surface water and ground water, 58 were detected. Of the 85 VOCs routinely analyzed for, 49 were detected.

Pesticide concentrations are generally low

All detections of pesticides were at concentrations less than USEPA drinking-water standards (enforceable) and almost all were less than USEPA drinking-water guidelines (nonenforceable). Diuron, a herbicide, and diazinon, an insecticide, were detected at concentrations above their USEPA health advisory limits (10 and 0.6 μg/L [micrograms per liter], respectively) in a few samples. These exceedances occurred at four streams; water from these streams is not directly used for drinking-water supply.

Six pesticides were detected at concentrations above aquatic life criteria. Four of these (carbaryl, chlorpyrifos, malathion, and chlorathalonil) were only in exceedance in stormflow samples collected at three stream sites located in urban areas, suggesting that aquatic organisms are not chronically exposed at concentrations of concern at these locations. Two compounds (diazinon and lindane) were detected at concentrations above aquatic life criteria in base-flow samples from eight stream sites located in urban areas, suggesting that aquatic organisms may be chronically exposed at concentrations of concern at these locations. Diazinon was also detected in storm samples above aquatic life criteria at three stream sites located in urban areas. At one site (Santa Ana River below Imperial Highway), diazinon was detected at concentrations above these levels in all storm samples.

VOC concentrations are also generally low

Like pesticides, most detections of VOCs were at low concentrations relative to drinking water standards, drinking-water guidelines, and aquatic life criteria. Two solvents, tetrachloroethylene (PCE) and trichloroethylene (TCE), and a soil fumigant, dibromochloropropane (DBCP), were detected in ground water at concentrations exceeding USEPA drinking-water standards (5 µg/L, 5 µg/L, and 0.2 µg/L respectively). These exceedances occurred in samples from four irrigation wells in the Inland Basin. Chloroform, a byproduct of the disinfection of water, was detected at concentrations higher than its aquatic life criterion (1.8 µg/L) in 2 of 14 samples collected from the Santa Ana River below Prado Dam.

A comprehensive analysis of possible risks implied by findings in the Santa Ana River Basin is not possible because many of the compounds do not have established standards, guidelines, or criteria. Of the 58 pesticides detected in water samples from the Santa Ana Basin, the USEPA has established drinking-water standards (enforceable) or guidelines (nonenforceable) for only 30 compounds; only 23 of the 58 have established aquatic life criteria. Similarly, of the 49 VOCS detected, the USEPA has established standards or guidelines for 34; only 13 of the 49 have established aquatic life criteria. Moreover, existing standards, guidelines, and criteria do not account for the possible synergistic effects of exposure to mixtures of pesticides and VOCs. A detailed listing of detected and nondetected compounds, along with selected graphical summaries, is provided in the Appendix.

Some pesticides are detected more frequently in streams, and at higher concentrations, during and after storms than during dry periods

Pesticide concentrations in Santa Ana Basin streams can increase during storms (Izbicki and others, 2000), and elevated concentrations can persist for several days or weeks after the storm. The elevated concentrations of pesticides persist even though the stream discharge has returned to base-flow conditions. Because it rains more during the winter than during the other seasons, pesticides were detected more frequently during the winter. However, extended dry periods are common throughout the year. It is therefore more appropriate to characterize samples on the basis of how long it has been since a storm rather than by the season.

The influence of storms was evaluated by grouping samples into four categories: samples collected during and within 1 day of a storm (or peak flow); samples collected 1 to 7 days after; samples collected more than 7 and up to 14 days after; and samples collected more than 14 days after. The period within 1 day of storms can be defined as wet conditions and the period more than 14 days after can be defined as dry conditions.

Warm Creek is a concrete-lined channel that drains a small urban area. As a result, discharge in Warm Creek increases rapidly in response to storms, and decreases rapidly after the storms pass. During the period of this study (October 1998 to September 2001), few storms lasted more than a few hours, and the discharge at Warm Creek usually returned to prestorm conditions within a few hours after the rain stopped. In contrast, some pesticide compounds persisted at elevated concentrations for nearly 2 weeks after the rain stopped. For example, the insecticide diazinon (fig. 10*A*) was detected in more than 90 percent of samples collected within 1 day of storms (wet conditions) and in less than 40 percent of samples collected more than 14 days after storms (dry conditions); detection frequencies for samples collected in the two intermediate time categories were transitional between wet and dry conditions. The herbicide simazine (fig. 10*B*) behaved similarly. The systematic decrease in detection frequency suggests that these pesticides are washed off the landscape by storms and that concentrations in the stream can persist for weeks afterward.

The Santa Ana River drains a large watershed with mixed land use. Many pesticides were detected in the Santa Ana River below Imperial Highway during both base-flow and storm conditions. For example, diazinon and simazine were detected in all samples collected at this site (figs. 10*A*, *B*). However, the concentration of these compounds is higher during wet conditions than during dry conditions (figs. 11*A*, *B*).

The discharge of the Santa Ana River increases after storms. Photograph taken below Prado Dam. (photograph by Michael Wright, California State University Sacramento Foundation)

Figure 10. At Warm Creek, diazinon (*A*) and simazine (*B*) are washed into the stream by storms, and detections can persist for days or weeks after storms.

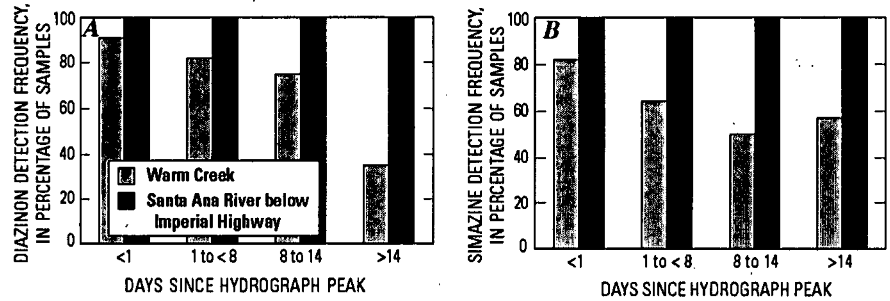
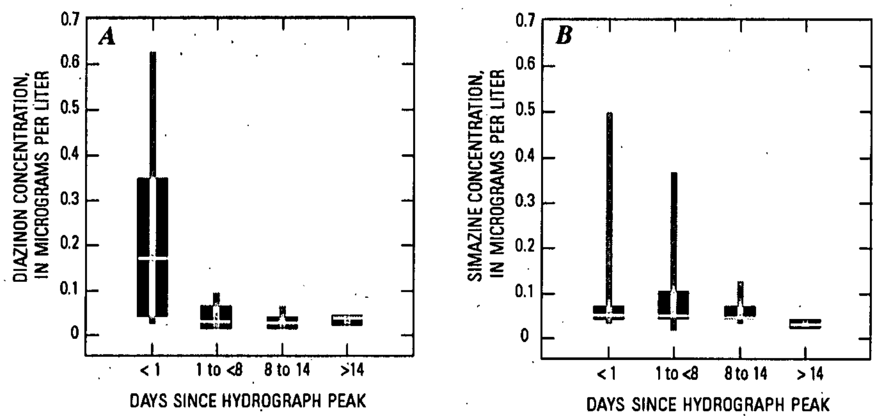


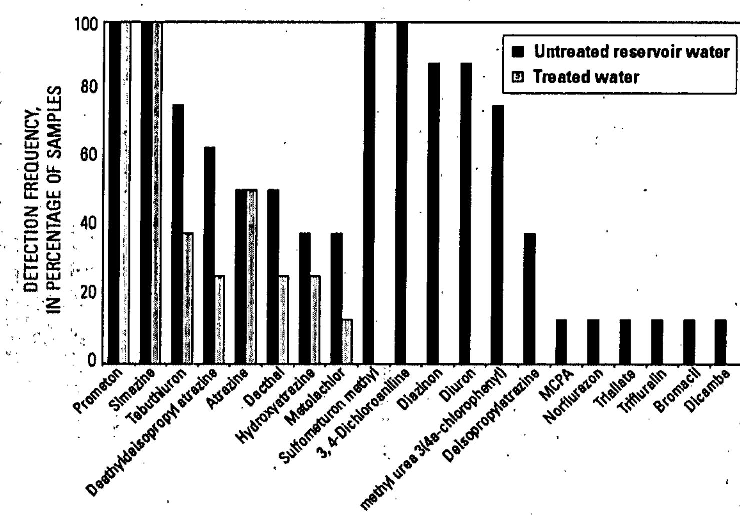
Figure 11. Diazinon (*A*) and simazine (*B*) concentrations decrease with time after storms in the Santa Ana River below Imperial Highway.



Drinking-water treatment can reduce concentrations of many pesticides

In 1999, NAWQA and the USEPA initiated a 2-year pilot monitoring program to assess human exposure to pesticides in drinking water derived from surface-water reservoirs (Blomquist and others, 2001). Reservoirs were sampled because they are important sources of drinking water and because they integrate pesticide loadings within their watersheds. Canyon Lake in Elsinore Valley, Calif., was 1 of 12 reservoirs sampled in the national assessment. From July to December 1999, water samples were collected from a drinking-water treatment facility both before (8 samples) and after treatment (8 samples). The water samples were analyzed for 186 pesticides and pesticide degradation products: 20 were detected (see figure). All 20 compounds were detected in untreated water, whereas only 8 were detected in treated water. Five of the eight were detected less frequently in the treated water than in the untreated water. The remaining three compounds—prometon, simazine, and atrazine (all herbicides)—were detected just as frequently in the treated water as in the untreated water.

Of the 20 compounds detected in the reservoir water samples, drinking-water standards (enforceable) or guidelines (nonenforceable) have been established for only 12. Concentrations of these 12 compounds were less than the applicable standards or guidelines. Concentrations of the other 8 compounds were similar to the concentrations of the 12 with standards or guidelines.



Analyses of water samples, collected before and after drinking-water treatment at Canyon Lake in Elsinore Valley, show that the treatment process reduces the concentrations of many pesticides below laboratory detection levels.

Volatile organic compounds in Santa Ana Basin streams can come from the air, treated wastewater, or ground water or can be washed in by storms

Volatile organic compounds (VOCs) can enter streams in a variety of ways. MTBE (Methyl *tert*-butyl ether), chloroform, and TCE (trichloroethylene) were among the most frequently detected VOCs in surface water in the Santa Ana Basin, but each comes primarily from a different source. MTBE and other gasoline components are present in the atmosphere in the Santa Ana Basin and can enter streams due to exchange between air and water. Chloroform and other byproducts of the disinfection of water are present in streams receiving treated wastewater and in streams receiving runoff of chlorinated tapwater used outdoors. TCE and other solvents are present in ground water in many parts of the Santa Ana Basin due to improper disposal or to inadvertent leaks and spills and can enter streams through ground-water influx. To a large extent, the frequency of occurrence and concentrations of MTBE, chloroform, and TCE in the Santa Ana River and in Warm Creek reflect the sources of these compounds.

Discharge of treated municipal wastewater is the single largest source of base flow to the Santa Ana River. Photograph looking down toward the point of discharge from a large treatment facility. (photograph by Carmen Burton, U.S. Geological Survey)

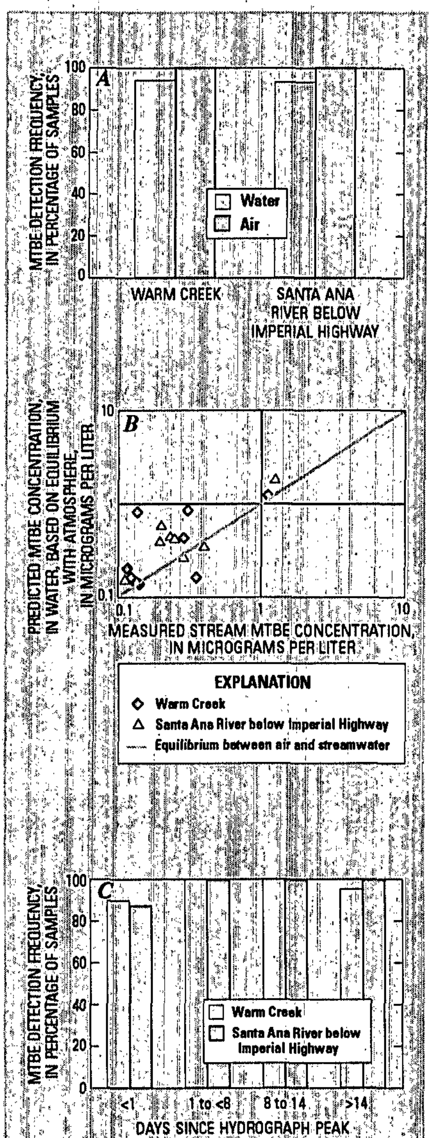


Figure 12. The atmosphere is the primary source of MTBE detected in surface water at Warm Creek and the Santa Ana River below Imperial Highway. (*A*) MTBE is detected frequently in surface water and the atmosphere at both sites. (*B*) Concentrations of MTBE measured in water are less than or equal to concentrations predicted by equilibrium with the atmosphere; predicted values in water are based on concentrations of MTBE measured in air samples collected at the same time as stream samples. (*C*) MTBE is detected less frequently during storms than during other time periods.

MTBE was detected frequently in surface-water samples collected from Warm Creek (94 percent of 49 samples, fig. 12*A*) and from the Santa Ana River below Imperial Highway (93 percent of 43 samples, fig. 12*A*), and in all air samples collected at both sites (9 samples at each site, fig. 12*A*). At both sites, the concentrations in surface water were generally less than or equal to the concentrations predicted for a water sample in equilibrium with the atmosphere (fig. 12*B*), indicating the likely transfer of MTBE from the atmosphere to the streams. In addition, the concentrations (fig. 12*B*) and detection frequencies (fig. 12*C*) of MTBE in water samples from Warm Creek were similar to those from the Imperial Highway site, providing additional evidence that the atmosphere is the likely source of MTBE in surface water at the two sites.

Chloroform primarily enters the Santa Ana River and some tributaries with discharges of treated wastewater. At the Santa Ana River below Imperial Highway, streamflow consists primarily of treated wastewater (Mendez and Belitz, 2002), and chloroform was detected in all samples collected there (fig. 13*A*). The concentrations of chloroform in samples collected from the Imperial Highway site were higher than concentrations predicted by equilibrium with the atmosphere. (fig. 13*B*), indicating the likely transfer of chloroform from the water to the air.

At the Warm Creek site, streamflow does not contain treated wastewater, and chloroform was detected less frequently than at the Imperial Highway site (fig. 13*A*). Chloroform in Warm Creek was detected more frequently in samples collected during and shortly after storms than during dry conditions (more than 14 days after storms, fig. 13*C*), suggesting that chloroform is associated with storm runoff from this urbanized basin. Although chloroform was detected in all nine air samples collected at Warm Creek (fig. 13*B*), it was detected in water in only two of the water samples collected at the same time.

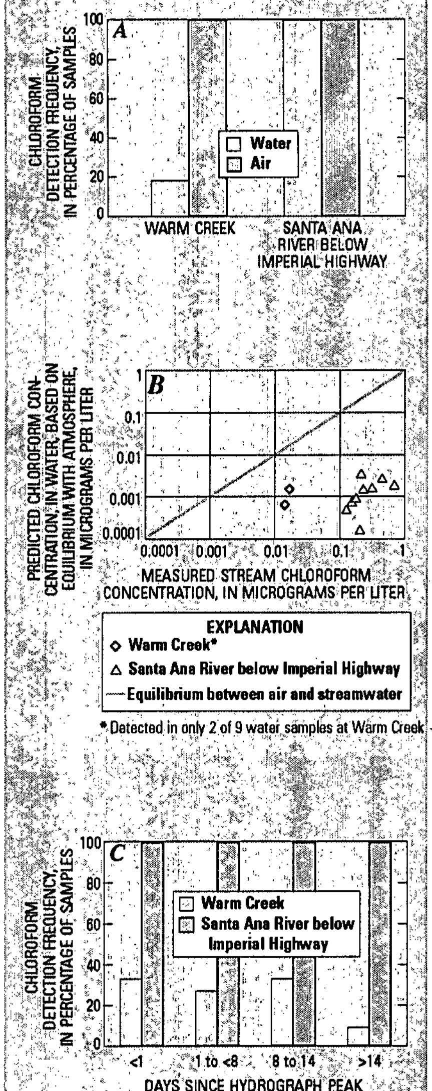
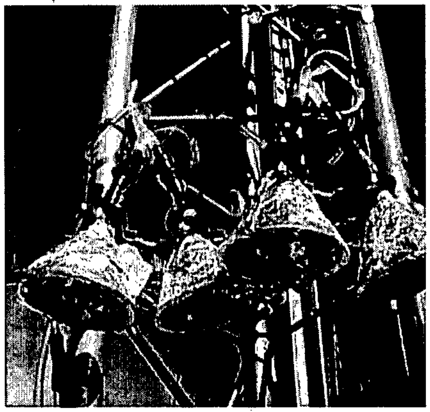


Figure 13. Treated wastewater is the primary source of chloroform in the Santa Ana River. Urban runoff can also contribute chloroform to streams. (*A*) Chloroform was detected in surface water more frequently in water samples from the Santa Ana River below Imperial Highway than from Warm Creek. (*B*) Chloroform was detected in water samples from the Imperial Highway and Warm Creek sites at concentrations higher than would be expected if the atmosphere were the source of chloroform. (*C*) Chloroform was detected more frequently in Warm Creek during wet conditions than during dry conditions.



Low-volume air samplers are used to monitor VOCs in the atmosphere. (photograph by Greg Mendez, U.S. Geological Survey)

Large TCE plumes are present in ground water in many areas of the Santa Ana basin, including areas near Warm Creek (Hamlin and others, 2002). At Warm Creek, ground-water influx is a major source of base flow, and TCE was present in all samples collected more than 1 day after storms (fig. 14*C*). In contrast, detection frequency was only 63 percent during storms (fig. 14*C*), suggesting dilution of concentrations in ground-water influx by storm runoff. The concentrations of TCE in samples collected from Warm Creek were higher than concentrations predicted by equilibrium with the atmosphere (fig. 14*B*), indicating that the atmosphere is not a likely source of TCE at Warm Creek.

At the Imperial Highway site, ground water is not a major source of base flow, and TCE is detected less frequently than at Warm Creek (fig. 14*A*). In fact, TCE was never detected during dry conditions (>14 days) at Imperial Highway (fig. 14*C*), suggesting that TCE in the Santa Ana River may come from storm runoff. Although TCE was detected in all nine air samples collected at Imperial Highway (fig. 14*B*), it was detected in only one of the water samples collected at the same time.

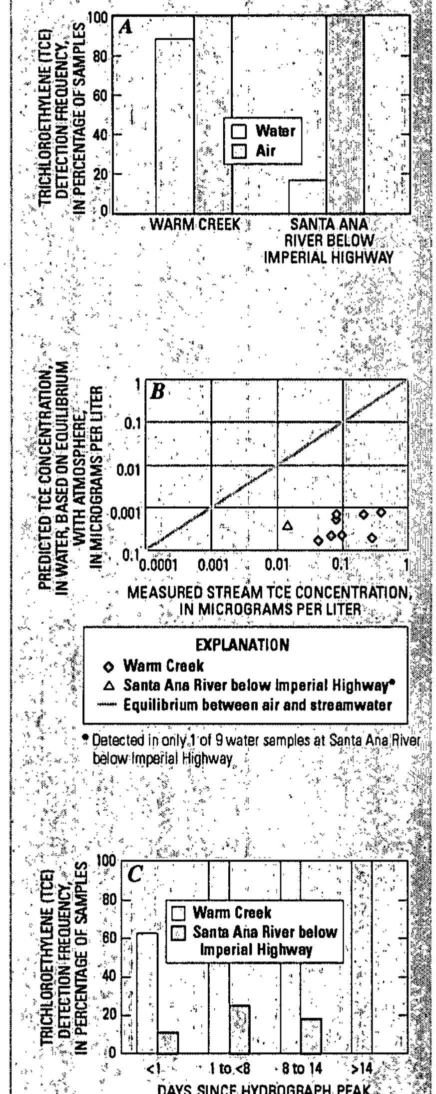


Figure 14. Ground water is the primary source of TCE in streams during base-flow conditions. (*A*) TCE is detected frequently in water samples from Warm Creek, but not in water samples from Santa Ana River below Imperial Highway. (*B*) TCE was detected in water samples from Warm Creek at concentrations higher than would be expected if the atmosphere were the source of TCE. (*C*) At Warm Creek TCE is detected less frequently during wet periods because of dilution from storm runoff.

Pesticides and volatile organic compounds are more frequently detected in ground water recharged since the 1950s than in older ground water

In the Santa Ana Basin, pesticides and VOCs are detected more frequently in ground water recharged during the past 50 years than in older ground water (fig. 15). In the San Jacinto Basin, pesticides and VOCs were detected in more than 70 percent of the younger samples but were detected in only 20 percent of the older samples. In the Inland Basin, these compounds were detected in more than 80 percent of the younger samples and in only one of the three older samples. In the Coastal Basin, pesticides were detected in almost 40 percent of the younger samples but in none of the older samples; VOCs were detected in more than 90 percent of the younger samples but in only 50 percent of the older samples.

The age of ground water reflects proximity to sources of recharge. In the San Jacinto and Inland Basins, shallower ground water is younger than deeper ground water, indicating the predominance of recharge from the overlying land surface rather than by lateral flow from more distant areas. In the Coastal Basin, ground water in the unconfined area, located closer to the Santa Ana Mountains, is younger than ground water in the confined area, located farther from the mountains. The age distribution is consistent with the dynamics of the flow system: recharge in the unconfined area and lateral flow toward the confined areas. The detection frequencies of pesticides and VOCs reflect these age distributions.

In the San Jacinto Basin, pesticides and VOCs were detected more frequently in water from shallower wells than in water from deeper wells (fig. 16*A*). In this basin, wells are typically drilled to depths ranging from about 300 to more than 1,500 feet. The top one-third of a typical well is solid casing, and the bottom two-thirds is usually screened (open to the aquifer). Pesticides and VOCs were detected more frequently in wells in which the top of the well screen is within 250 feet of land surface than in deeper wells (fig. 16*A*). The differences in detection frequency based on depth are comparable to the differences based on age.

In the Inland Basin, as in the San Jacinto Basin, pesticides and VOCs were detected more frequently in the shallower wells (fig. 16*B*). These compounds were detected in all wells (100 percent) in which the top of the screen is within 150 feet of land surface, but in less than two-thirds of the wells in which the top of the screen is more than 350 feet deep. As in the San Jacinto Basin, the differences in detection frequency are consistent with recharge from the overlying land surface. The detection frequencies for pesticides and VOCs were higher in the Inland Basin than in the San Jacinto Basin and reflect more intensive land use, more pumping of ground water, and higher rates of recharge in the Inland Basin. In addition, the Inland Basin has been developed for a longer period of time.

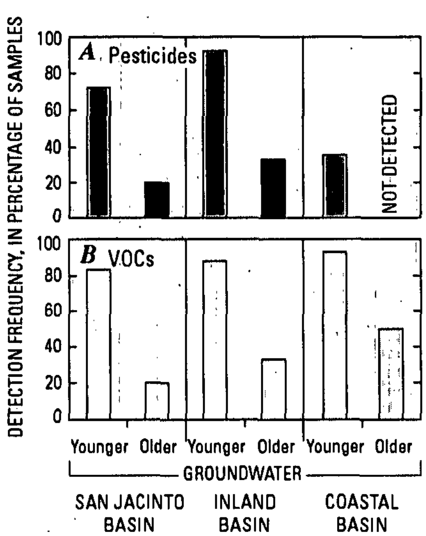


Figure 15. Pesticides (*A*) and VOCs (*B*) are detected more frequently in ground water recharged during the past 50 years than in older ground water.

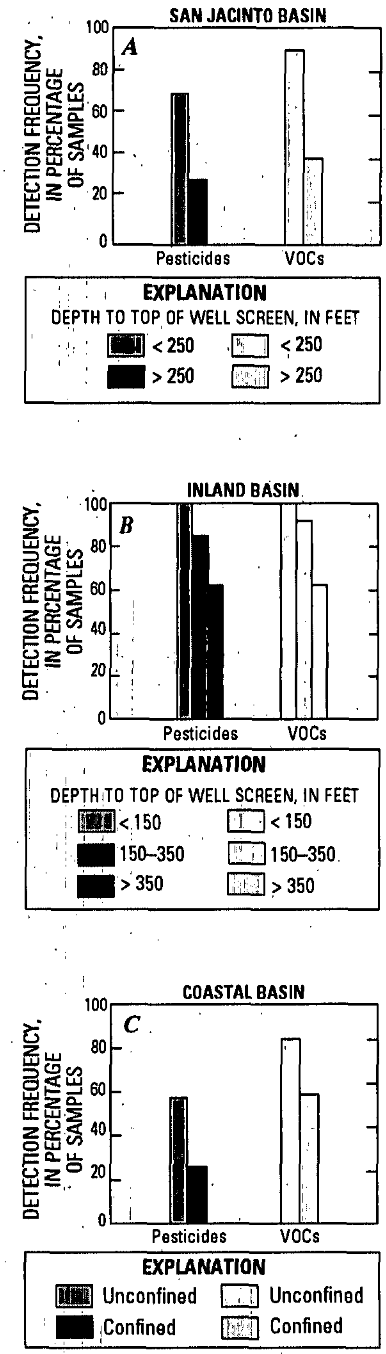
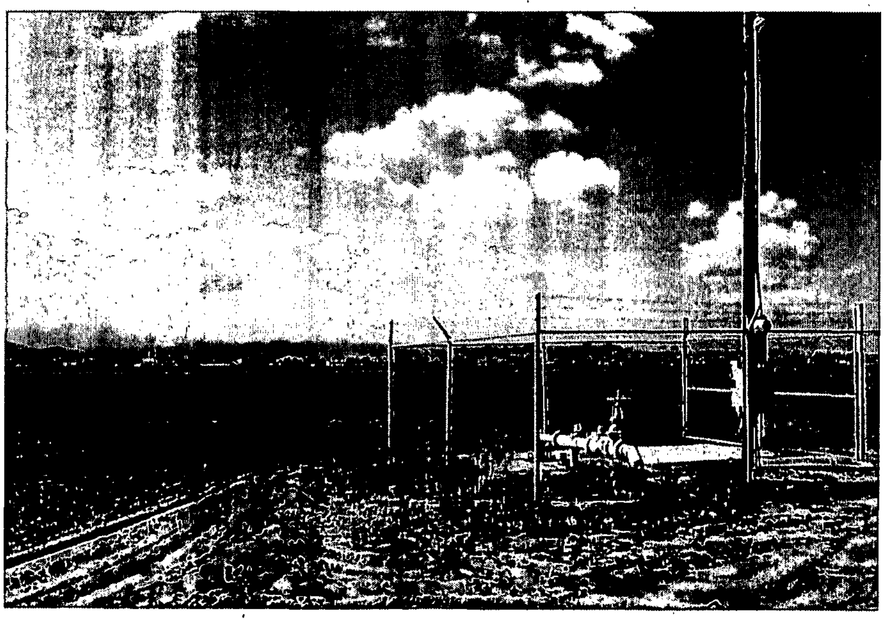


Figure 16. Detection frequency for pesticides and volatile organic compounds is related to proximity to recharge sources. (*A*) Shallow and deep ground water in the San Jacinto Basin; recharge is from the overlying land surface. (*B*) Shallow, intermediate-depth, and deep ground water in the Inland Basin; recharge is from the overlying land surface. (*C*) Unconfined and confined areas of the Coastal Basin; recharge is in the unconfined area.

In the Coastal Basin, pesticides and VOCs were detected more frequently in ground water in the unconfined area than in the confined area (fig. 16*C*). The differences in detection frequencies based on location are similar to the differences based on age, and reflect the fact that ground water is recharged in the unconfined area and moves laterally into the confined area.

Additional Information

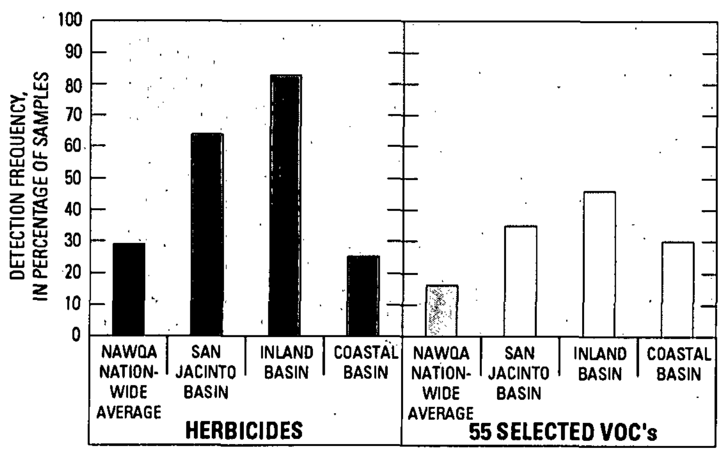
Additional information and data on pesticides and volatile organic compounds in the Santa Ana Basin, are provided by Hamlin and others (2002). Additional data are also available at http://water.usgs.gov/pubs/wri/wri02-4243/text.html



The USGS NAWQA Program sampled public supply and irrigation wells in the Santa Ana Basin. Photograph of an irrigation well in the San Jacinto Basin. (photograph by Sarah Kraja, California State University Sacramento Foundation)

National Perspective—Herbicides and volatile organic compounds occur more frequently in the deep aquifers of the Santa Ana Basin than in other aquifers sampled by NAWQA nationwide

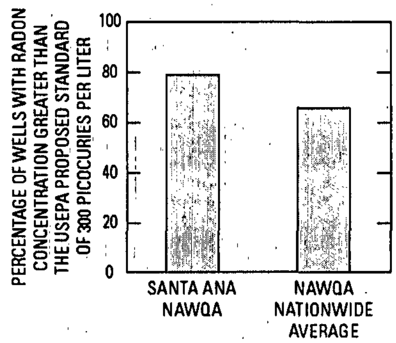
Herbicides and VOCs were detected in aquifers of the Santa Ana Basin more frequently than in other aquifers sampled by NAWQA across the Nation (84 aquifer studies). The higher detection frequencies are notable because the supply wells in the Santa Ana Basin are relatively deep, typically drilled to depths of 200 to 1,000 feet. Detection frequencies of herbicides in the San Jacinto and Inland Basins ranked in the upper 10 percent of all aquifers sampled by NAWQA from 1991 to 2001. Detections of 55 selected VOCs (at concentrations above 0.2 μg/L) in the Inland ground-water basin ranked in the upper 5 percent of all aquifers sampled, and detections in the San Jacinto and Coastal Basins ranked in the upper 20 percent. All of the aquifers sampled in the Santa Ana Basin are used for public supply. The high detection frequencies of herbicides and VOCs in aquifers of the Santa Ana Basin reflect the intensive land use and management of ground water. Engineered recharge, ground-water pumping, and incidental recharge from landscape and agricultural irrigation act to accelerate the movement of water through the aquifer system and to widely distribute anthropogenic compounds.



National Perspective—Radon and arsenic concentrations in ground water may be of concern as drinking-water regulations change

Radon is a colorless, odorless, radioactive gas that enters air and water from the decay of uranium that occurs naturally in rocks and soils. Of the estimated 160,100 lung cancer deaths in the United States in 1998, an estimated 19,000 were attributed to radon in air and to the combination of radon and smoking (National Research Council, 1999). In response, the U.S. Environmental Protection Agency (USEPA) has proposed drinking water standards to address radon levels in indoor air. In communities with programs to mitigate radon in air, the proposed drinking-water standard is 4,000 pCi/L (picocurie per liter). In communities without such programs, the proposed standard is 300 pCi/L. In the Santa Ana Basin, 50 of 63 wells sampled by NAWQA had concentrations of radon exceeding the proposed 300 pCi/L standard (samples from 9 wells were not analyzed for radon); one well had a concentration exceeding the proposed 4,000-pCi/L standard. Nationwide, two-thirds of the wells sampled by NAWQA had concentrations of radon exceeding the proposed 300 pCi/L standard.

Arsenic is a trace element derived from naturally occurring minerals. Arsenic can occur naturally in soils and rocks, can be used as a component in pesticides, and has been detected in some fertilizers. The USEPA drinking-water standard for arsenic is 10 micrograms per liter; nationwide, 7 percent of the wells sampled by NAWQA had concentrations higher than the standard. In the Santa Ana Basin, 3 percent of the 72 wells sampled had concentrations of arsenic exceeding the USEPA drinking-water standard.



In the Santa Ana Basin, about 80 percent of the public supply wells sampled by NAWQA had radon concentrations above 300 pCi/L, a drinking-water standard proposed by the USEPA. Nationwide, about 65 percent of the wells sampled had concentrations exceeding the proposed standard.

USGS scientists work with colleagues from other institutions to sample fish in the Santa Ana River below Prado Dam. (photograph by Carmen Burton, U.S. Geological Survey)

Organochlorine and semivolatile organic compounds are detected more frequently in bed sediment and fish tissue at urban sites than at undeveloped sites

Organochlorine compounds have been used historically as insecticides on crops and to control termites and insect-borne diseases. These compounds can be detrimental to the health of aquatic organisms. Some compounds, such as DDT and chlordane, are no longer used but continue to be present in bed sediment and fish tissue (Wong and others, 2000). More organochlorine compounds were detected in bed sediment and fish tissue, and at higher concentrations at urban sites in the Santa Ana Basin (8 sites) than at undeveloped sites (4 sites)(figs. 17 and 18).

Semivolatile organic compounds (SVOCs) include polycyclic aromatic hydrocarbons (PAHs), phenols, and phthalates, and have a variety of sources including vehicle exhaust, petroleum refining, forest fires, asphalt, solvents, and plasticizers. The number of SVOCs detected and the concentrations of SVOCs were greater at urban sites than at undeveloped sites. (figs. 17 and 18).

DDT (*p,p'*-DDT) and one of its breakdown products (*p,p'*-DDE) and chlordane, a pesticide used for termite control, were detected in bed sediment at concentrations exceeding guidelines established to protect aquatic life (probable-effect level, Canadian Council of Ministers of the Environment, 1999) (fig. 18*A*). These elevated concentrations occurred at urban sites on the Santa Ana River (4 sites) but not at an undeveloped site on the Santa Ana River nor at any tributary sites (4 urban and 3 undeveloped sites). Other organochlorine compounds detected in bed sediment were present at concentrations lower than the guidelines. SVOCs were not detected in bed sediment at concentrations exceeding guidelines; however, guidelines have been established for only 13 of the 77 SVOCs analyzed. In addition, all detections of organochlorine compounds in fish tissue were at concentrations lower than guidelines developed for fish-eating wildlife (Newell and others, 1987).

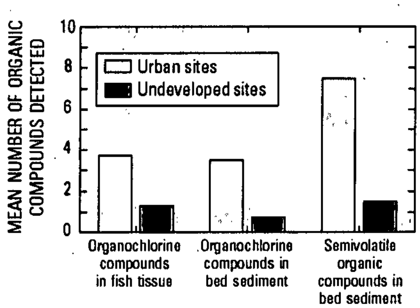


Figure 17. Organochlorine compounds and semivolatile organic compounds (SVOCs) were detected more frequently in bed sediment and fish tissue at urban sites than at undeveloped sites.

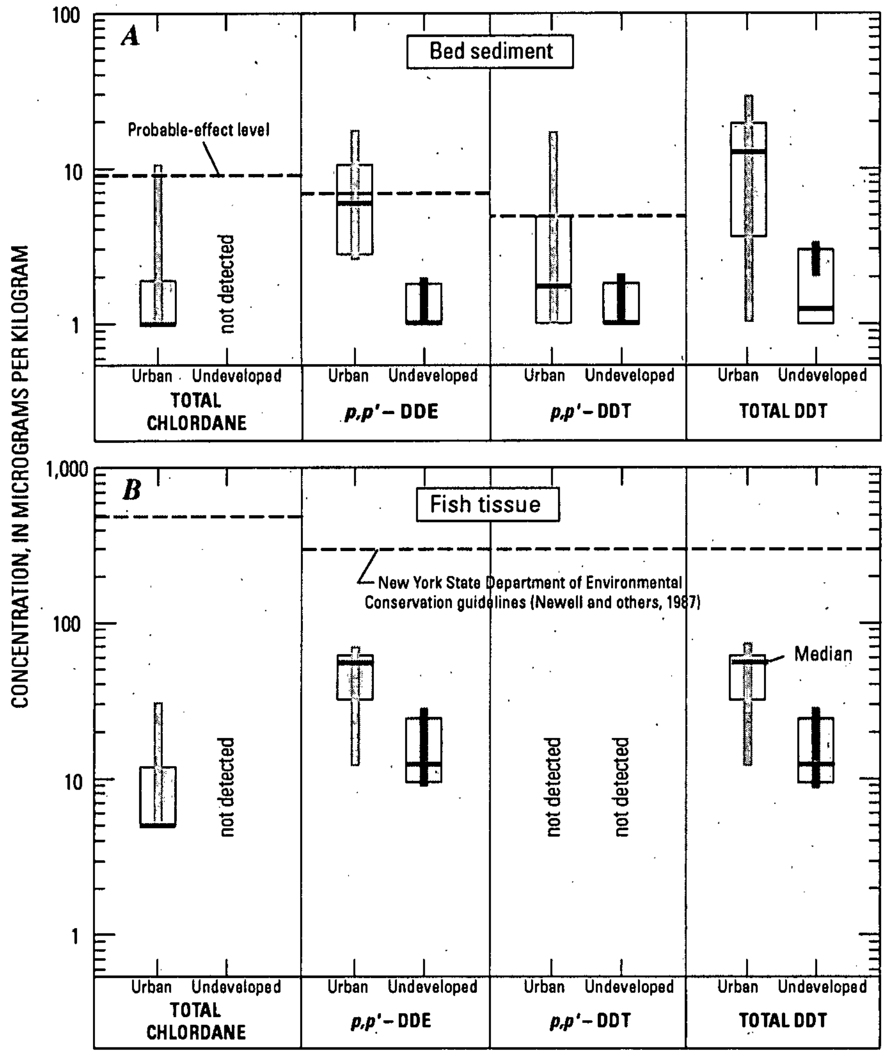


Figure 18. Organochlorine compounds were detected at higher concentrations at urban sites (8 sites) than at undeveloped sites (4 sites) in both bed sediment (*A*) and fish tissue (*B*). Concentrations of chlordane, p,p'-DDE, and p,p'-DDT in bed sediment occasionally exceeded guidelines for the protection of aquatic life (probable-effect level, Canadian Council of Ministers of the Environment, 1999). Concentrations in fish tissue were lower than guidelines developed for protection of fish-eating wildlife (Newell and others, 1987).

Detection frequencies of organic compounds at Santa Ana River sites are different than detection frequencies at tributary sites

More organochlorine compounds were detected in bed sediment and fish tissue collected at urban sites on the Santa Ana River than at urban sites on tributaries. At the Santa Ana River sites, the number of compounds detected in bed sediment ranged from four to nine at any single site, compared to zero to three compounds detected at any single tributary site (fig. 19*A*). The total number of compounds detected in bed sediment at all Santa Ana River sites was also higher than the total number for tributary sites: 12 compared to 4. The occurrence of organochlorine compounds in fish tissue showed a similar pattern. The greater occurrence of organochlorine compounds in bed sediment and fish tissue in the Santa Ana River may have resulted from the persistent nature of these compounds, which facilitates transport to and accumulation in the Santa Ana River.

In contrast to organochlorine compounds, generally fewer SVOCs were detected in bed-sediment samples from urban sites on the Santa Ana River than from urban sites on tributaries (fig. 19*B*). Nine compounds were detected at Santa Ana River sites as compared to 19 compounds at tributary sites. The number of compounds detected at any single site showed a similar pattern: 2 to 5 at Santa Ana River sites compared to 1 to 19 at tributary sites. The less frequent occurrence in the Santa Ana River may be due to a greater distance of the Santa Ana River sites from sources of SVOCs, thus allowing more time for degradation to nondetectable levels.

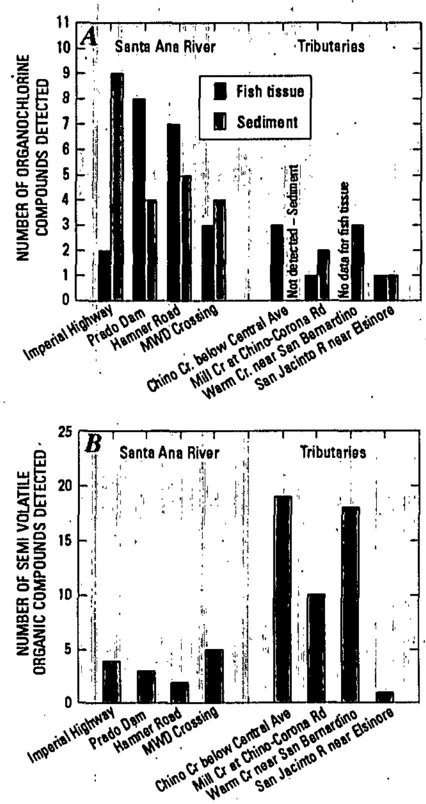
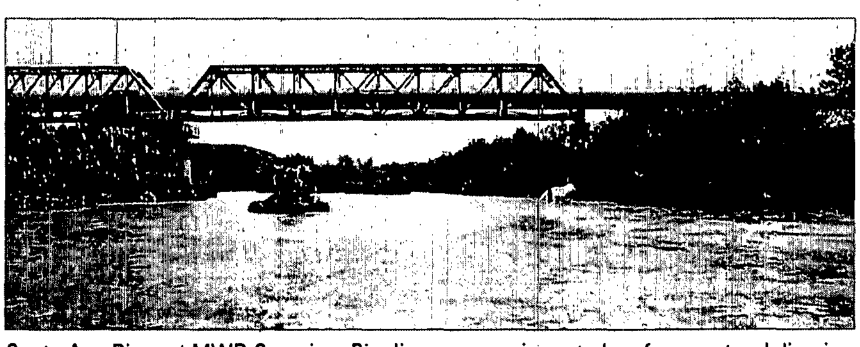


Figure 19. (*A*) More organochlorine compounds were detected in bed sediment and fish tissue from the Santa Ana River than from its tributaries. (*B*) In contrast, generally more semivolatile organic compounds were detected in samples from the tributaries.



Santa Ana River at MWD Crossing. Pipeline conveys imported surface-water deliveries. (photograph by Carmen Burton, U.S. Geological Survey)

Sediment cores from reservoir and retention basins provide a historical record of pesticides and semivolatile organic compounds

Cores of sediment that accumulates at the bottom of reservoirs and stormflow retention basins were collected at three locations in the Santa Ana Basin to assess historical concentrations of selected pesticides and SVOCs. West Street Basin is a small stormflow-retention basin located in an area that began urban development after World War II and was fully urbanized by the middle of the 1960s. Canyon Lake is located in an area that has been undergoing active urbanization since the 1970s. Hemet Lake is located in a relatively undeveloped mountain area. Chemical analyses of age-dated sediment cores (Van Metre and others, 1997) from the West Street Basin and Canyon Lake define historical trends (early 1950s to 1998) in the presence and concentrations of selected organic compounds, which are related to factors such as land use, traffic density, and chemical use.

Analyses of sediment cores indicate that concentrations of DDT, used to control mosquitoes and other insects, decreased significantly in Canyon Lake and West Street Basin after discontinuation of its use in 1972 (fig. 20). For example, concentrations decreased in West Street Basin from its peak of about 500 micrograms per kilogram (μg/kg) in the late 1960s to less than 100 μg/kg in 1975. However, DDT continues to be present in sediment deposited since 1975, indicating that the compound is still being transported with sediment. Similar results have been found elsewhere in the Nation (Ging and others, 1999; Van Metre and others, 1997).

Sediment cores also show that concentrations of chlordane, used to control termites and other insects, decreased significantly in West Street Basin since its partial termination in 1978 (fig. 20). Chlordane use was completely terminated in the United States in 1988. However, chlordane concentrations at West Street Basin remain above 100 μg/kg, which is more than 10 times greater than the sediment guideline for

Collection of sediment cores from Hemet Lake. (photograph by Jennifer Wilson, U.S. Geological Survey)

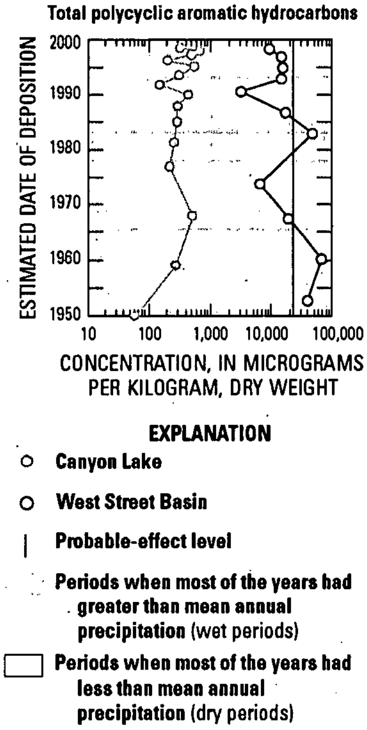


Figure 21. Concentrations of polycyclic aromatic hydrocarbons (PAHs) are decreasing at West Street Basin, located in a well-established urban area, but are increasing at Canyon Lake, in an area of active urban development.

protection of aquatic life (probable-effect level, Canadian Council of Ministers of the Environment, 1999). Concentrations are lower at Canyon Lake than at West Street Basin but are near the guideline.

The concentrations of polycyclic aromatic hydrocarbons (PAHs) have decreased at West Street Basin and increased at Canyon Lake since the 1950s (fig. 21). These trends correlate with historical land use: West Street Basin is in an area that has long been urbanized, whereas Canyon Lake is in an area of active urbanization. This correlation in the Santa Ana Basin suggests that PAHs may be decreasing with time in well-established urbanized areas and increasing with time in areas of active urban development. One possible explanation is that controls on industrial and automobile emissions have resulted in a decrease in PAHs in well-established urban areas, but these reductions at the source can be offset by an increased number of cars and increased road density in more recently urbanizing areas.

Sediment cores also show that the concentrations of pesticides and SVOCs can fluctuate with climate (Burton, 2002). Some pesticides, such as chlordane and DDT, are present at higher concentrations in reservoir sediment deposited during wet periods than sediment deposited during dry periods (fig. 20). Similarly, some SVOCs (for example, total PAHs) also have higher concentrations in sediment deposited during wet periods than that deposited during dry periods (fig. 21). These results suggest that some pesticides and SVOCs accumulate and persist on the landscape during dry periods and are subsequently mobilized and transported to receiving waters during wet periods.

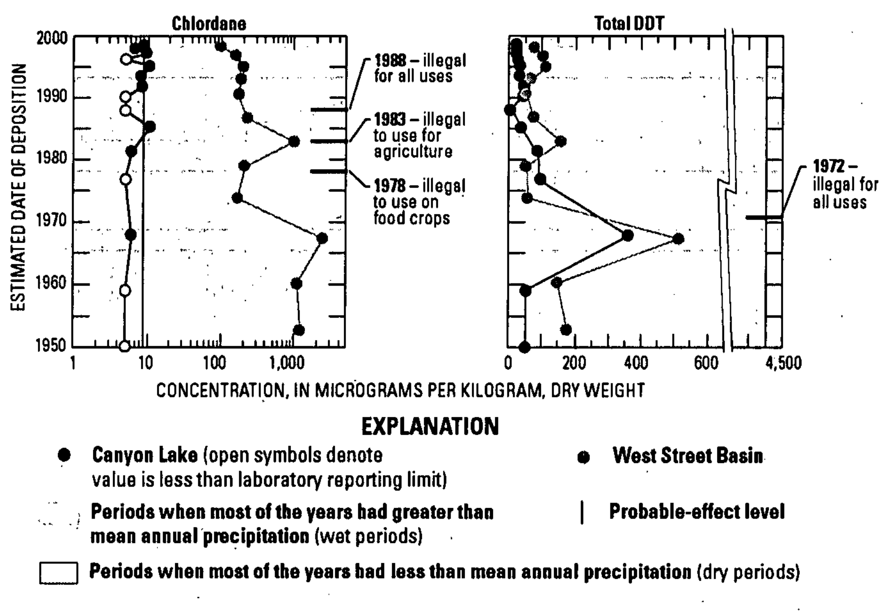


Figure 20. Chlordane and DDT are decreasing in concentration but continue to be detected in sediment decades after the use of these compounds was discontinued. The concentrations of these pesticides tend to be higher during wet periods and lower during dry periods (Burton, 2002).

Trace-element concentrations sometimes exceed aquatic-life guidelines in bed sediment and reservoir-sediment cores

Table 1. Guidelines for trace-element concentrations in sediment, established to protect *aquatic life, were exceeded at three stream sites in the Santa Ana Basin.*

Trace element	Median (micrograms per gram)	Maximum (micrograms per gram)	Probable-effect level (micrograms per gram)[1]	Location of exceedances
Arsenic	4.8	45	17	San Jacinto River
Cadmium	0.35	2.8	3.5	no exceedances
Chromium	55	72	90	no exceedances
Copper	52.5	86	197	no exceedances
Lead	28.5	100	91.3	Warm Creek
Mercury	0.055	0.20	0.486	no exceedances
Selenium	0.4	2.7	4.02[2]	no exceedances
Zinc	160	550	315	Chino Creek, Warm Creek

[1]Sediment-quality guideline from Canadian Interim Sediment Quality Guidelines, Freshwater (Canadian Council of Ministers of the Environment, 1999).
[2]Toxicity threshold obtained from the National Irrigation Water Quality Program Information Report (U.S. Department of the Interior, 1998).

In the Santa Ana Basin, trace element concentrations exceeded guidelines established for the protection of aquatic life (probable-effect levels, Canadian Council of Ministers of the Environment, 1999) at three sites, all of which are urban. At Warm Creek, the concentrations of two trace elements (lead and zinc) exceeded guidelines (table 1). At Chino Creek, the concentration of one trace element (zinc) exceeded a guideline (table 1). Sediment from the San Jacinto River also had one trace element (arsenic) with a concentration higher than a guideline (table 1). Thirty-eight of the 46 trace elements, for which samples were analyzed, do not have guidelines established to protect aquatic life. Sediment samples analyzed for trace element concentrations by the NAWQA Program are sieved and are relatively fine-grained (less than 63 micrometers); therefore, the detected concentrations may be higher than concentrations in a whole-sediment sample.

Sediment cores collected from West Street Basin and Canyon Lake provide a historical record of trace-element concentrations (fig. 22). At West Street Basin, concentrations of lead and zinc equaled or exceeded guidelines throughout the historical record (fig. 22). The concentrations of four of the six other trace elements with established guidelines also exceeded guidelines at some point during the historical record; concentrations of cadmium, chromium, copper, and mercury exceeded guidelines at least once, but concentrations of arsenic and selenium did not (Burton, 2002). Concentrations of trace elements in the sediment core from Canyon Lake were generally lower than those in the core from West Street Basin, and with the exception of copper (fig. 22), were lower than established guidelines (Burton, 2002).

The concentrations of lead in sediment at West Street Basin decreased from older to younger sediment (fig. 22). Similar trends have been observed in sediment cores obtained from reservoirs in urban areas elsewhere in the Nation (Burton, 2002; Ging and others, 1999; Van Metre and others, 1997). At West Street Basin, other trace elements, including zinc (fig. 22), show a decrease in concentration from 1952 to about 1970. The decrease in concentration during that time period may reflect changes in land use in the surrounding area (Van Metre and others, 2003).

Concentrations of some trace elements (for example, arsenic, cadmium, copper, and zinc) in sediment cores tend to be higher during wet periods and lower during dry periods (Burton, 2002). One possible explanation is that these trace elements behave similarly to pesticides and many SVOCs: accumulating on the landscape during dry periods and washing off into receiving waters during wet periods.

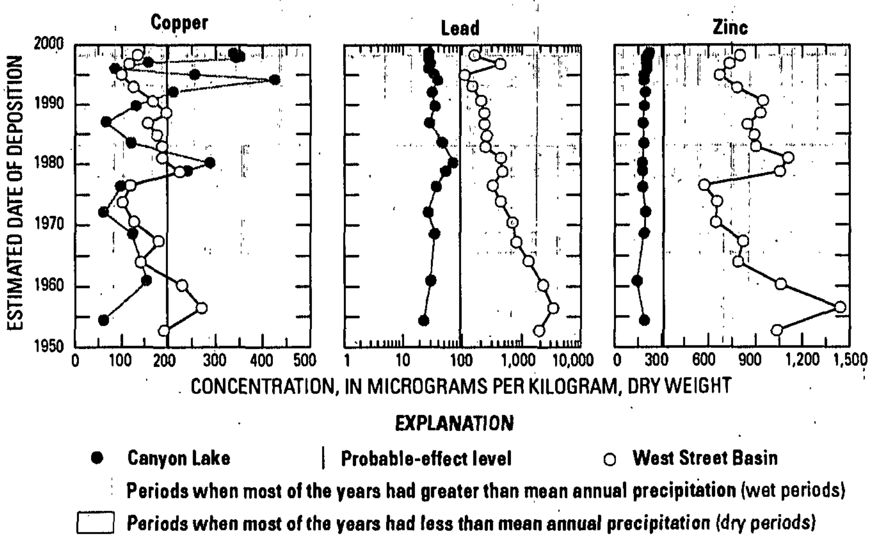


Figure 22. Trace-element concentrations in reservoir-sediment cores often exceeded guidelines established for protecting aquatic life at West Street Basin. Concentrations of lead and zinc in sediment core at Canyon Lake are lower than at West Street Basin.

Additional Information

A detailed description of trace elements in bed sediment and reservoir cores is given by Burton (2002).

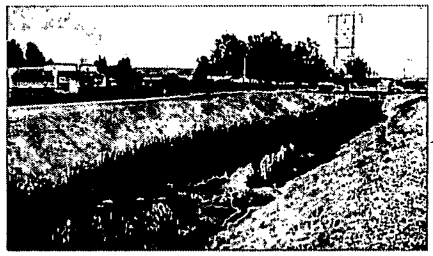
Urbanization has altered stream channels and the sources of water reaching stream channels; these changes have degraded aquatic ecosystems

Urbanization has resulted in channelization of streams in the Santa Ana Basin and, in many cases, channels are concrete lined. The water in these channels also reflects a hydrologic system that is highly engineered. Streamflow from the mountains is typically diverted for ground-water recharge, and streamflow is reestablished on the valley floor by discharge from wastewater-treatment plants, urban runoff, and ground-water influx. The health of aquatic ecosystems has been affected by these changes.

Some organisms thrive in undisturbed ecosystems, whereas others thrive in degraded systems. The richness (number of species or other taxa) and relative abundance of the different types of organisms (invertebrates, algae, and fish) were used as a measure of ecosystem health. In the summer of 2000, ecological assessments were conducted at 19 sites that included a range of water sources and channel types. Four sources of water were sampled: mountain runoff, ground water, urban runoff, and treated wastewater. Three channel types were sampled: natural channels, channelized streams with natural bottoms, and concrete-lined channels. Artificial substrates were used to collect invertebrates and algae.

Water source affects the health of aquatic ecosystems

The source of water to a stream channel affects water chemistry and many of the physical characteristics of the aquatic ecosystem. Stream sites receiving treated wastewater have higher concentrations of dissolved solids, nutrients, iron, and suspended sediment than do other stream sites. In addition, streams receiving treated wastewater have relatively high and stable discharge and low variability in other physical characteristics, such as temperature,



Little Chino Creek is one of many tributaries that have been channelized for flood control. (photograph by Carmen Burton, U.S. Geological Survey)

stream depth, and stream width. Aquatic communities at these sites are more degraded than in streams receiving other sources of water. Stream sites receiving urban runoff or ground water have more dissolved solids and higher water temperatures than do streams receiving mountain runoff; aquatic communities in these streams are degraded relative to streams receiving mountain runoff.

Richness (number) of invertebrate taxa (fig. 23*A*) is lowest in streams receiving treated wastewater and highest in streams receiving mountain runoff. The median number of taxa was 9 in streams receiving wastewater, 14 in streams receiving urban runoff or ground-water influx, and 19 in streams receiving mountain runoff. Moreover, the abundance of pollution-tolerant diatom species (a group of alga, fig. 23*B*) is highest in streams receiving treated wastewater, intermediate in streams receiving urban runoff or ground-water influx, and lowest in streams receiving mountain runoff.

The results of the ecosystem assessment indicate that aquatic ecosystems are most degraded in streams receiving treated wastewater and least degraded in streams receiving mountain runoff. Aquatic ecosystems in streams receiving urban runoff or ground water are intermediate between these two extremes; aquatic ecosystems are less degraded in streams receiving ground water than in streams receiving urban runoff.

The drainage basins of streams receiving mountain runoff are less urbanized than those of streams receiving other sources of water (table 2). This partly explains why aquatic ecosystems were least degraded in streams receiving mountain runoff. However, the percentage of urbanization did not vary among the drainage basins of streams receiving water from the other sources. One can therefore conclude that the observed differences in aquatic communities are related more to water source than to percentage of urbanization.

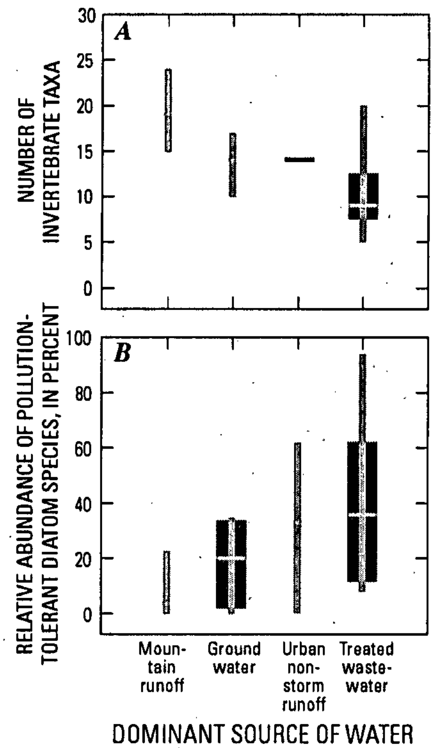


Figure 23. (*A*) Larger numbers of invertebrate taxa indicate healthier ecosystems. (*B*) Larger percentages of pollution-tolerant diatom species indicate ecosystem degradation.

Table 2. Percentage of urbanization in relation to stream sites studied during the summer of 2000.

Water source	Percentage of urbanization		
	Minimum	Maximum	Median
Mountain runoff	0	65	20
Ground water	45	95	55
Urban runoff	50	100	80
Treated wastewater	45	100	69

Aquatic ecosystems are more degraded in concrete channels than in either channelized streams or natural channels

Physical habitat for aquatic communities differs substantially among natural channels, channelized streams with natural bottoms, and concrete-lined channels. In the Santa Ana Basin, natural streams have the most bank shading, allowing the least penetration of sunlight and coolest temperatures. Concrete-lined channels have minimal to no bank shading and are generally wide and shallow, resulting in the most exposure to sunlight and highest water temperatures. Bank shading in channelized streams encompasses the extremes, ranging from complete canopy cover to minimal shading. Streambed substrates in natural channels and channelized streams are composed of sand, gravel, and (or) cobbles, along with leaf litter and woody debris. These substrates provide habitat for invertebrates and other aquatic life. In contrast, suitable habitat is minimal to absent in smooth concrete-lined channels.

Aquatic communities were most degraded at sites located in concrete-lined channels and least degraded at sites located in natural channels. The median number of insect taxa sensitive to pollution and habitat degradation (caddisfly and mayfly, fig. 24*A*) is highest in natural channels and lowest in concrete-lined channels; the number in channelized streams (four taxa) is more similar to that in natural channels (five taxa) than in concrete-lined channels (two taxa). Moreover, the abundance of noninsect invertebrates (such as snails and worms) was highest in concrete-lined channels; the abundance in channelized streams was similar to the abundance in natural channels (fig. 24*B*). These noninsect taxa tend to thrive in degraded ecosystems. Similarly, the percentage of native fish species was highest in natural channels and lowest in concrete-lined channels (fig. 25), with the percentage in channelized streams intermediate between the two.

In this study, the health of aquatic ecosystems appears to be related more to streambed substrate materials than to stream-channel shape or percentage of urbanization. Channelized streams have aquatic ecosystems that are more similar to those in natural channels than to those in concrete-lined channels. Similarly, channelized streams have streambed substrate materials that are more similar to those in natural channels than to those in concrete-lined channels. In contrast, channelized streams are more similar to concrete-lined channels in terms of shape and percentage of urbanization (table 3). These results suggest that lining of channels with concrete has a greater effect on ecosystem health than does channelization of streams in the urbanized Santa Ana Basin.

Cajon Creek is located in the pass between the San Gabriel and San Bernardino Mountains. (photograph by Carmen Burton, U.S. Geological Survey)

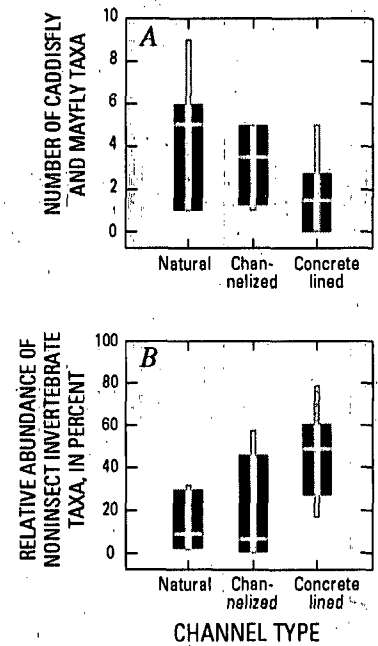


Figure 24. The richness (*A*) and relative abundance (*B*) of different types of organisms indicate that concrete-lined channels are the most degraded. Streams with natural banks are the least degraded. Channelized streams are slightly more degraded than natural streams.

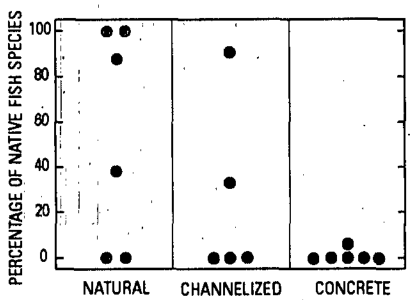


Figure 25. The percentage of native fish is highest in streams with natural channels and lowest in concrete channels.

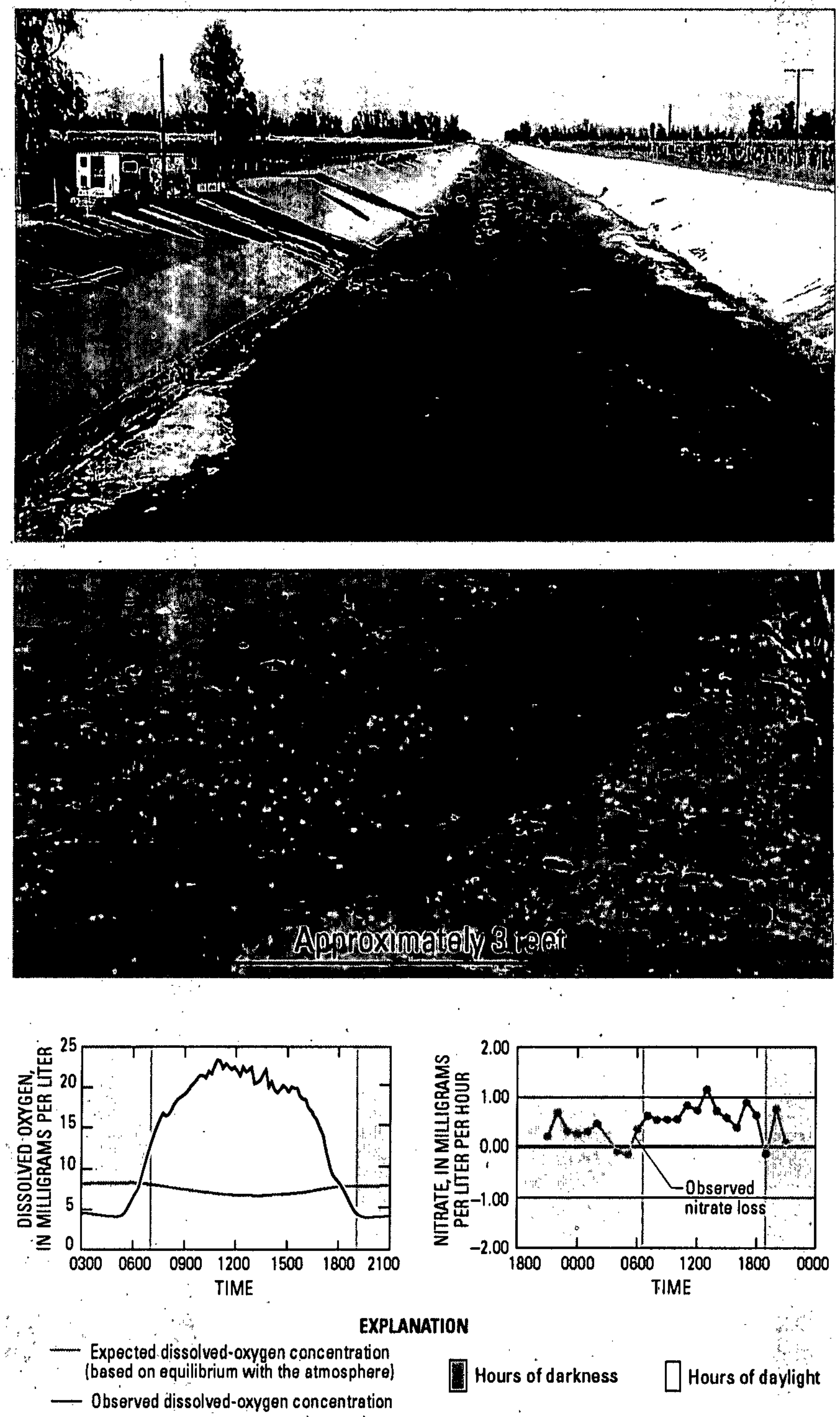
Table 3. Percentage of urbanization in relation to stream sites studied during the summer of 2000.

Channel type	Percentage of urbanization		
	Minimum	Maximum	Median
Natural channels	0	65	20
Channelized streams with natural bottoms	45	95	55
Concrete-lined channels	50	100	80

Shallow water depth and high nitrate concentrations in Cucamonga Creek support a highly productive ecosystem

Cucamonga Creek in Ontario, Calif. is a wide, concrete-lined flood control channel receiving effluent from a wastewater-treatment plant. The treated effluent has high concentrations of nitrate, typically ranging from 5 to 10 mg/L. During nonstorm conditions, the stream is shallow (typically less than 4 inches), exposed to direct sunlight most of the day, and relatively warm. Such conditions promote the growth of algae, which blanket the channel bottom throughout the year. These algae assimilate nitrate as a consequence of their productivity. The productivity and assimilative capacity of the algae were evaluated during a 24-hour study conducted in August 2001.

Algal photosynthesis during the day produced concentrations of dissolved oxygen (DO) three times greater than concentrations predicted by equilibrium with the atmosphere. This magnitude of DO production is rare in natural streams. During the night, concentrations of DO in Cucamonga Creek were not as low as might be expected in a stream with abundant algal growth (Caduto, 1985) because the shallow stream depth permits replenishment of oxygen from the atmosphere. The high levels of algal productivity were accompanied by nitrate assimilation, which resulted in the lowering of stream-nitrate concentrations by about 1 mg/L per hour during daylight hours. The lowering of nitrate concentrations by algal assimilation is an important factor affecting nitrate concentrations in Cucamonga Creek where the discharge consists primarily of treated-wastewater effluent.



Abundant algae in Cucamonga Creek produce high levels of oxygen during the day. The high levels are not followed by correspondingly low concentrations at night due to the shallow stream depth, which facilitates replenishment of oxygen from the atmosphere. The algae assimilate nitrate as a consequence of their high productivity. (photograph by Carmen Burton, U.S. Geological Survey)

Today's surface water is tomorrow's ground water

In many parts of the Nation, an important source of surface water is ground water. In the Santa Ana Basin and elsewhere in the Western United States, the converse is often true: surface water is the primary source of ground-water recharge. For example, in the Santa Ana Basin, ground-water recharge facilities are located along rivers and streams draining the San Gabriel, San Bernardino, and San Jacinto Mountains. In addition, large-scale recharge facilities are located along and adjacent to the Santa Ana River in the Coastal Basin. Recharge facilities throughout the Santa Ana Basin are used to enhance replenishment of aquifers used for public supply.

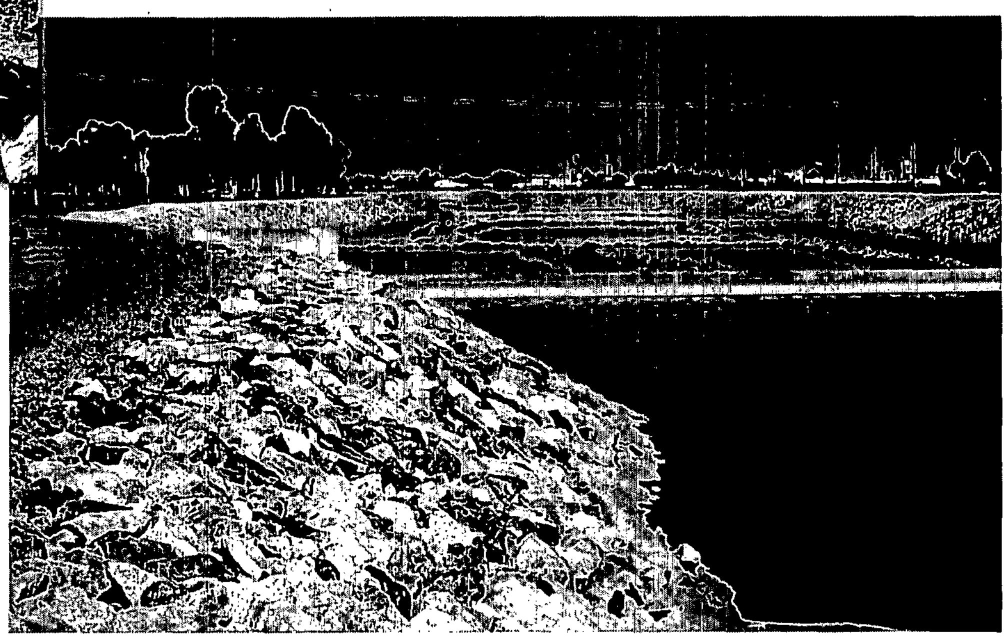
Lake Elsinore in the spring. (photograph by Mark Dennis, City of Lake Elsinore)

At the large-scale recharge facilities in the Coastal Basin, water managers capture almost all of the base flow and most of the stormflow of the Santa Ana River. This engineered or artificial recharge, averaging about 225,000 acre-feet per year (about 200 million gallons per day), helps balance the total amount of ground water pumped from the aquifer system and used for public supply. These facilities have been used since the late 1940s.

The distribution of anthropogenic compounds in ground water in the Coastal Basin illustrates the extent to which native ground water has been replaced by artificial recharge (fig. 26). Tritium, an isotope of hydrogen that is incorporated into the water molecule, is an indicator of ground water recharged since the early 1950s (see sidebar, p. 9). Tritium is widespread in the aquifer system, indicating widespread replacement of older, native ground water with water recharged during the past 50 years. Chloroform, a byproduct of water disinfection, is also widely distributed in the aquifer system, although it is not as widespread as is tritium. MTBE, a compound added to gasoline to reduce air pollution, has been used extensively since the early 1990s (Squillace and Moran, 2000). MTBE is not as widespread in the aquifer system as is chloroform, which has been generated for a longer period of time. The concentrations of chloroform and MTBE are below USEPA drinking-water standards.

These results indicate that yesterday's surface water is today's ground water and therefore remind us of the importance of protecting surface-water quality. Protection of today's surface water will ensure the future quality of the ground-water resource.

Surface-water drain, Riverside, California. (photograph by Phil Contreras, U.S. Geological Survey)



Water managers utilize the flow of the Santa Ana River for recharging the ground-water basin. An inflatable rubber dam across the Santa Ana River impounds water to facilitate diversion into recharge ponds. (photograph by Carmen Burton, U.S. Geological Survey)

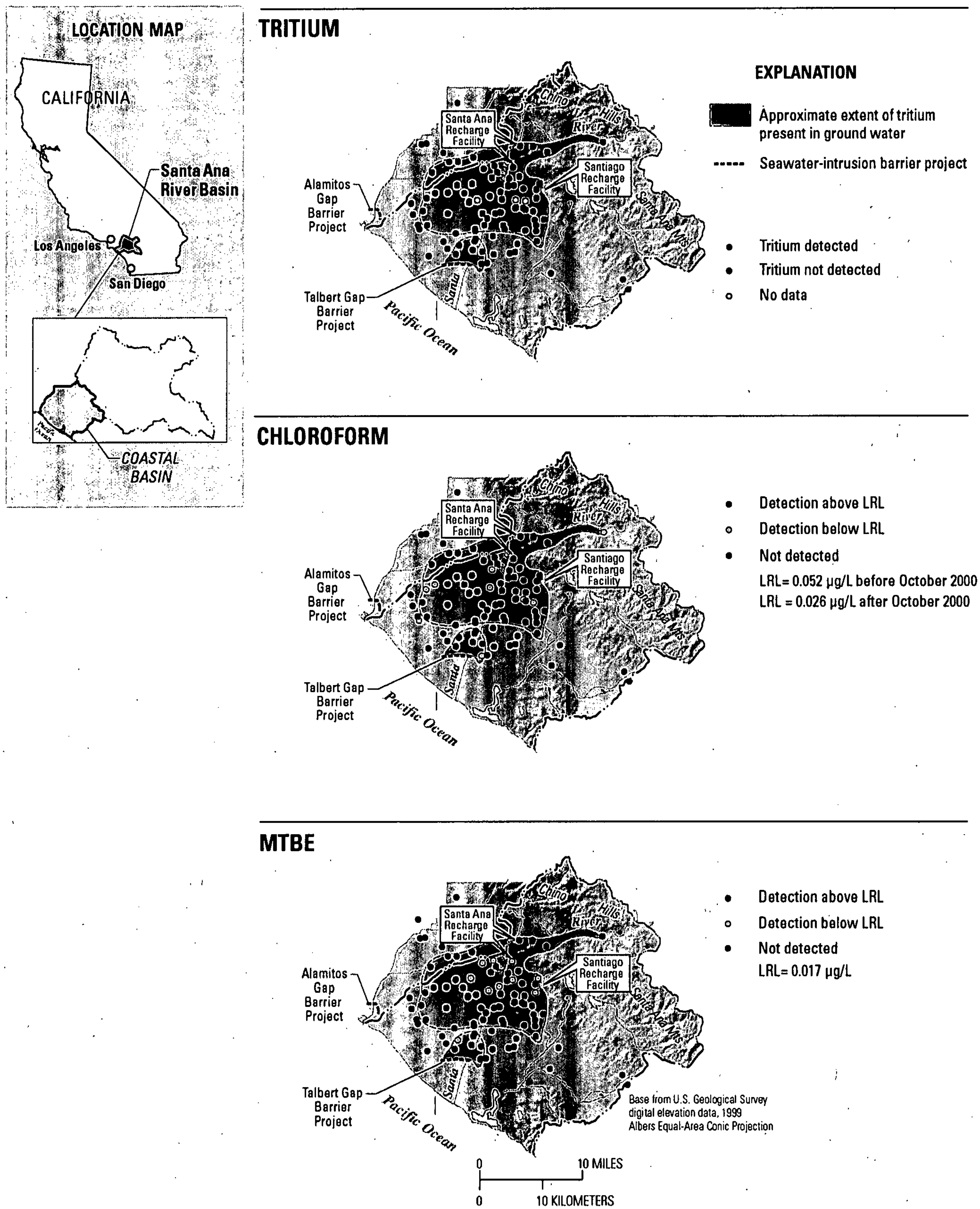


Figure 26. The areal distribution of anthropogenic compounds in the Coastal ground-water basin illustrates the displacement of native ground water by artificial recharge. (LRL, laboratory reporting level)

Study Unit Design

Stream Chemistry

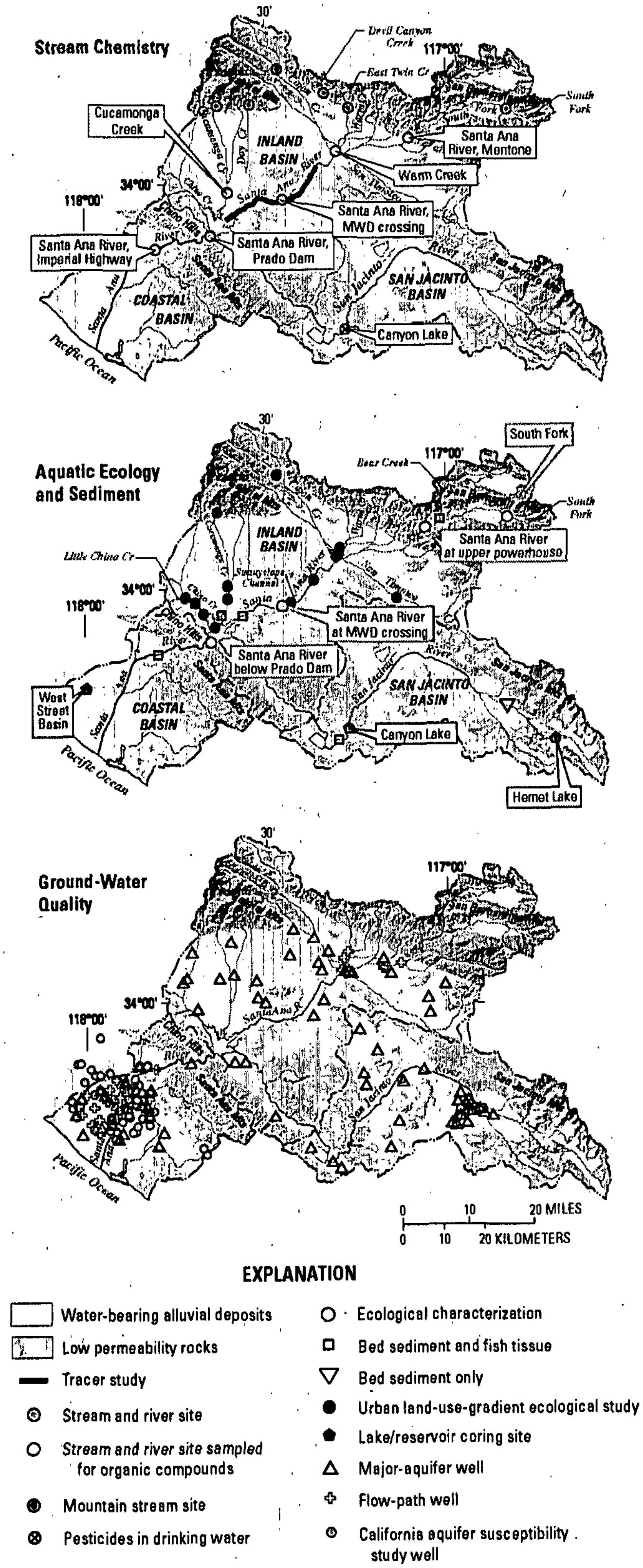
In the Santa Ana Basin, stream-chemistry studies were designed to broadly assess water quality using a nationally consistent approach (Gilliom and others, 1995; Wilde and Radtke, 1998) and to assess the effects of urbanization. Sampling sites were established on streams that receive a variety of water sources, including mountain runoff, urban runoff, ground water, and treated wastewater. Two of the sites were sampled more frequently than the other sites to assess the influence of seasonality on water quality; samples from these sites were also analyzed for pesticides and volatile organic compounds (VOCs). Air samples were also collected and analyzed for VOCs; these data helped to identify the sources of VOCs in streams. In addition to the regularly scheduled sampling, a tracer test was conducted along the Santa Ana River; the tracer study was designed to determine how much of the base flow is from treated wastewater and how much is from other sources. Sampling for pesticides was also conducted at a drinking-water treatment facility as part of a national study conducted by NAWQA in collaboration with the U.S. Environmental Protection Agency (Blomquist and others, 2001).

Aquatic Ecology and Sediment

Surface-water studies also included characterization of ecological conditions and sampling of bed sediment and fish tissue. These studies were implemented to provide a nationally consistent assessment of conditions. In addition to these broad-scale assessments, an intensive study of algae and invertebrates was conducted at 19 sites to assess the effect of urbanization on ecosystem health. The sites were selected on the basis of channel type and water source. Two additional studies were also implemented. One was a study of the role of algae in the lowering of nitrate concentrations along a 2-mile reach of Cucamonga Creek. The other study, conducted as part of a national study (http://tx.usgs.gov/coring/), was of sediment cores obtained from two lakes and a storm-retention basin; these cores provide a historical record of the concentrations of organochlorine compounds, semivolatile organic compounds, and trace elements.

Ground-Water Quality

The quality of ground water in deep aquifers used for public supply in the Santa Ana Basin was assessed using nationally consistent approaches. Broad-scale assessments of major aquifers were conducted in the San Jacinto, Inland, and Coastal Basins. These assessments were supplemented by two flowpath studies that were designed to evaluate changes in water quality as water moves through the aquifer system. The flowpath studies, as well as additional sampling, were done in collaboration with the California State Water Resources Control Board as part of their California Aquifer Susceptibility program.



Study component	What data were collected and why	Types and number of sites sampled	Sampling frequency and period
Stream chemistry			
Streams and rivers	Streamflow, dissolved oxygen, pH, alkalinity, specific conductance, temperature, nutrients, major ions, organic carbon, and suspended sediment; to determine concentration and variability of a constituent over seasons or time.	4 sites—Santa Ana River (SAR) at Mentone (reference); Cucamonga Creek (urban, treated wastewater); SAR at MWD Crossing and SAR below Prado Dam (mixed urban, predominantly treated wastewater).	Monthly plus 6 storms, October 1998–September 2001.
Organic compounds in streams and rivers	Same as streams and rivers plus pesticides and volatile organic compounds (VOC); to determine the occurrence, concentration over time, and seasonality of organic compounds. VOCs collected in air.	2 sites—Warm Creek (urban, ground water); and SAR below Imperial Highway (mixed urban, predominantly treated wastewater) discontinued, April 2001. (Prado added July 2000, Mentone added February 2001)	Semimonthly to monthly plus 6 storms, October 1998–September 2001.
Mountain streams	Same as streams and rivers; to determine if SAR at Mentone is representative of mountain runoff.	5 sites located at the base of the mountains and 1 alpine site.	Quarterly, January 2000–July 2001
Drinking-water reservoirs	Pesticides; to assess pesticide occurrence from drinking-water reservoirs before and after treatment as part of a nationwide study.	2 sites—at a drinking-water treatment plant located near Canyon Reservoir, one site before treatment and one site after.	16 samples, July–December 1999
Tracer study	Same as stream and rivers plus bromide, isotopes, and rhodamine dye; to assess how much of the base flow is from treated wastewater and how much is from other sources.	9 sites on the Santa Ana River from the Rapid Infiltration/Extraction treatment facility to the wetlands behind Prado Dam, and 7 sites on other water sources to the river.	Hydrograph sampling in May 2001
Stream ecology, streambed sediment and fish tissue, and reservoir sediment			
Ecology in streams and rivers	Invertebrate, algal, and fish communities and stream habitat conditions; to assess the temporal variability in contrasting stream environments.	4 sites—2 collocated with the 2 mixed urban river sites. 1 site located upstream from dam construction and 1 site located in the mountains.	Annually, single reach, 1999–2000; 3 reaches, 2001
Urban land-use study	Same as ecology and streams and rivers, but used artificial substrates for algal and invertebrate communities; to assess water source and channel type as factors affecting biological communities.	19 sites—3 reference, 16 urban, representing 4 sources of water and 3 channel types. Sites were collocated with stream and river sites or bed-sediment sites when possible.	July—September 2001
Cucamonga Creek study	Streamflow, nutrients, organic carbon, pH, temperature, dissolved oxygen, specific conductance, alkalinity, carbon dioxide, bicarbonate and carbonate; to assess nitrate uptake by algae.	2 sites in the concrete-lined Cucamonga Creek located below treated-wastewater outfall.	25 samples in a diel study, August 2001
Streambed sediment and fish tissue	Organochlorine compounds, semivolatile-organic compounds and trace elements in sediment and fish tissue to determine occurrence and distribution and to compare urban and undeveloped land use.	12 sediment and 10 fish tissue sites—8 urban sites located on the basin floor and 4 undeveloped sites.	Once, September 1998
Reservoir-sediment coring sites	Same as for streambed sediment but at multiple depths in sediment cores to evaluate changes in concentration in relation to time and historical land- and chemical-use patterns.	3 reservoirs representing 3 types of land use; undeveloped, actively urbanizing, and a well-established urban area.	Once, November 1998
National mercury study	Mercury, methylmercury, and acid-volatile sulfides in bed sediment and fish fillets; to evaluate factors for mercury occurrence and methylation potential.	4 urban and 1 undeveloped sites as part of a larger national mercury study.	Once, September 1998
Ground-water quality			
Major aquifer survey	Major ions, nutrients, pesticides, volatile organic compounds, trace elements, stable isotopes, tritium, and radon analyzed to assess occurrence in the Coastal, Inland, and San Jacinto Basins.	Spatially distributed randomized deep public supply, irrigation, and domestic wells in the Coastal (20 wells), Inland (29 wells), and San Jacinto (23 wells) ground-water basins.	Coastal—spring 1999 Inland—Spring 2000 San Jacinto — winter 2001
Urban land-use study	Same constituents as above, to assess shallow ground-water quality in the Coastal Basin.	Monitoring wells installed at 30 randomly chosen sites in commercial and residential areas.	Summer 2000
Flow-path study	Same constituents as for the major aquifer survey, to assess replacement of ground water by engineered recharge.	23 deep production wells. 20 deep monitoring wells and 1 production well.	Summer 2000

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Glossary

Acre-foot

A volume of water equal to 1 foot in depth and covering 1 acre; equivalent to 43,560 cubic feet or 325,851 gallons.

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.

Alluvium

Deposits of clay, silt, sand, gravel or other particulate rock material left by a river in a streambed, on a flood plain, in a delta, or at the base of a mountain.

Aquatic-life guidelines

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

Aquifer

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

Base flow

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

Bed sediment

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

Channelization

Modification of a stream, typically by straightening the channel, to provide more uniform flow; often done for flood control or for improved agricultural drainage or irrigation.

Confined area

That part of an aquifer that is overlain by material that restricts the movement of water.

Degradation products

Compounds resulting from transformation of an organic substance through chemical, photochemical, and (or) biochemical reactions.

Diatoms

Single-celled, colonial, or filamentous algae with siliceous cell walls constructed of two overlapping parts.

Discharge

Rate of fluid flow passing a given point at a given moment in time, expressed as volume per unit of time.

Dissolved solids

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

Diversion

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

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.

Ecosystem

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

Effluent

Outflow from a particular source, such as a stream that flows from a lake or liquid waste that flows from a factory or sewage-treatment plant.

Engineered recharge

Augmentation of natural replenishment of ground-water storage by some method of construction, by spreading of water, or by pumping water directly into an aquifer.

Flow path

An underground route for ground-water movement, extending from a recharge (intake) zone to a discharge (output) zone such as a shallow stream or public supply well.

Fumigant

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

Habitat

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

Hydrograph

Graph showing variation of water elevation, velocity, streamflow, or other property of water with respect to time.

Hydrologic cycle

The circulation of water from the sea, through the atmosphere, to the land, and thence back to the sea by overland and subterranean routes.

Invertebrate

An animal having no backbone or spinal column, including insects, mollusks, crustaceans, and worms.

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.

Nitrate

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

Phenols

A class of organic compounds containing phenol (C_6H_5OH) and its derivatives. Used to make resins or weed killers, and as a solvent, disinfectant, and chemical intermediate. Some phenols occur naturally in the environment.

Phthalates

A class of organic compounds containing phthalic acid esters [$C_6H_4(COOR)_2$] and derivatives. Used as plasticizers in plastics. Also used in many other products (such as detergents and cosmetics) and industrial processes (such as defoaming agents during paper and paperboard manufacture, and dielectrics in capacitors).

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 3.7×10^{10} radioactive disintegrations per second (dps). A picocurie yields 2.22 disintegrations per minute (dpm) or 0.037 dps.

Polycyclic aromatic hydrocarbon (PAH)

A class of organic compounds with a fused-ring aromatic structure. PAHs result from incomplete combustion of organic carbon (including wood), municipal solid waste, and fossil fuels, as well as from natural or anthropogenic introduction of uncombusted coal and oil. PAHs include benzo(a)pyrene, fluoranthene, and pyrene.

Recharge

Water that infiltrates the ground and reaches the saturated zone.

Relative abundance

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

Semivolatile organic compound (SVOC)

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

Synoptic sites

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

Taxon (plural taxa)

Any identifiable group of taxonomically related organisms.

Total DDT

The sum of DDT and its breakdown products, including DDD and DDE.

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.

Tributary

A river or stream flowing into a larger river, stream, or lake.

Unconfined area

That part of an aquifer whose upper surface is a water table.

Volatile Organic Compounds (VOCs)

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

Water table

The point below the land surface where ground water is first encountered and below which the earth is saturated. Depth to the water table varies widely across the country.

Appendix—Water-Quality Data from the Santa Ana Basin in a National Context

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

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

These summaries of chemical concentrations and detection frequencies from the Santa Ana Basin are compared to findings from 51 NAWQA Study Units investigated from 1991 to 2001 and to water-quality benchmarks for human health, aquatic life, fish-eating wildlife, or prevention of nuisance plant growth. These graphical summaries provide a comparison of chemical concentrations and detection frequencies 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.

For example, the graph for trichloromethane shows that detections and concentrations in the Santa Ana Basin generally are (1) lower than national findings in urban streams; (2) not in violation of the USEPA drinking-water standard in urban streams; and (3) lower in streams than in ground 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, simazine was detected more frequently in urban ground-water areas in the Santa Ana Basin than in urban ground-water areas nationwide (23 percent compared to 18 percent), but generally was detected at lower concentrations.

CHEMICALS IN WATER

Concentrations and detection frequencies, Santa Ana Basin, 1999–2001

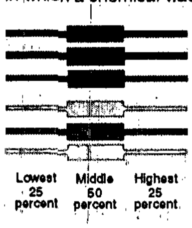
◆ Detected concentration in Study Unit

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

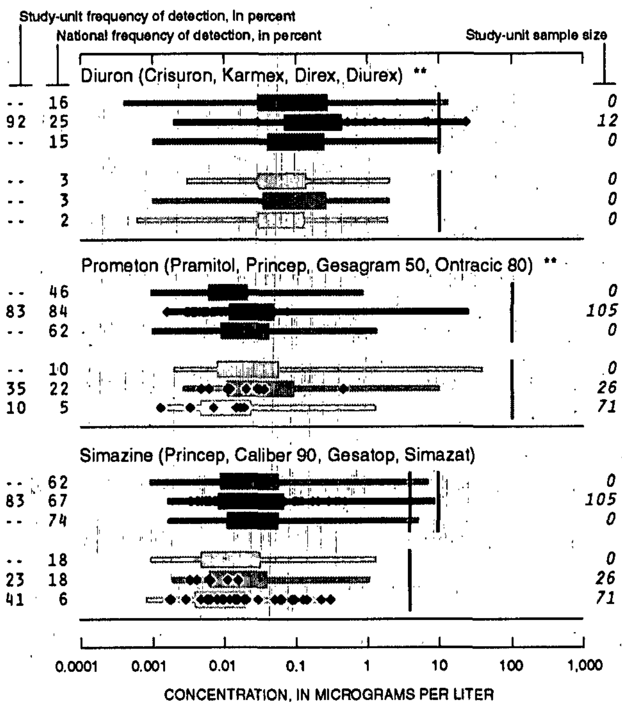
* No benchmark for drinking-water quality

** No benchmark for protection of aquatic life

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



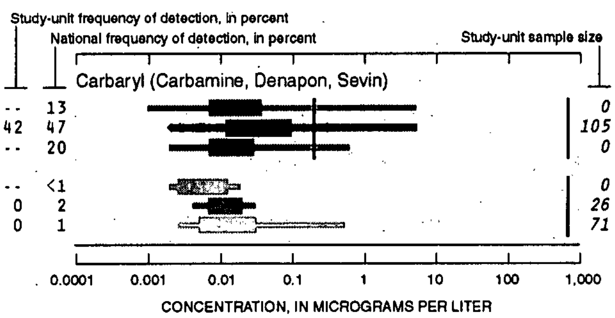
Other herbicides detected

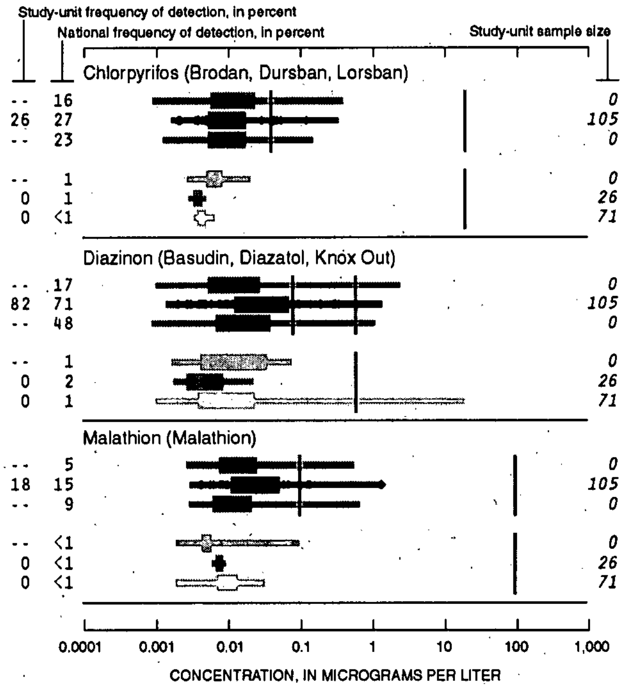
Atrazine (AAtrex, Atrex, Atred)
DCPA (Dacthal, chlorthal-dimethyl) **
Deethylatrazine (Atrazine metabolite, desethylatrazine) * **
EPTC (Eptam, Farmarox, Alirox) * **
Metolachlor (Dual, Pennant)
Molinate (Ordram) * **
Oryzalin (Surflan, Dirimal) * **
Pendimethalin (Pre-M, Prowl, Weedgrass Control, Stomp, Herbadox) * **
Propanil (Stam, Stampede, Wham, Surcopur, Prop-Job) * **
Tebuthiuron (Spike, Tebusan)
Terbacil (Sinbar) **

Herbicides not detected

Chloramben, methyl ester (Amiben methyl ester) * **
Acetochlor (Harness Plus, Surpass) * **
Acifluorfen (Blazer, Tackle 2S) **
Alachlor (Lasso, Bronco, Lariat, Bullet) **
Benfluralin (Balan, Benefin, Bonalan, Benefex) * **
Bentazon (Basagran, Bentazone, Bendioxide) **
Bromacil (Hyvar X, Urox B, Bromax)
Bromoxynil (Buctril, Brominal) *
Butylate (Sutan +, Genate Plus, Butilate) **
Clopyralid (Stinger, Lontrel, Reclaim) * **
Cyanazine (Bladex, Fortrol)
2,4-D (Aqua-Kleen, Lawn-Keep, Weed-B-Gone)
2,4-DB (Butyrac, Butoxone, Embutox Plus) *
Dacthal mono-acid (Dacthal metabolite) * **
Dicamba (Banvel, Dianat, Scotts Proturf)
Dichlorprop (2,4-DP, Seritox 50, Kildip) * **
2,6-Diethylaniline (metabolite of Alachlor) * **
Dinoseb (Dinosebe)
Ethalfluralin (Sonalan, Curbit) * **
Fenuron (Fenulon, Fenidim) * **
Fluometuron (Flo-Met, Cotoran, Cottonex, Meturon) **
Linuron (Lorox, Linex, Sarclex, Linurex, Afalon) *
MCPA (Rhomene, Rhonox, Chiptox)
MCPB (Thistrol) * **
Metribuzin (Lexone, Sencor)
Napropamide (Devrinol) * **
Neburon (Neburea, Neburyl, Noruben) * **
Norflurazon (Evital, Predict, Solicam) * **
Pebulate (Tillam, PEBC) * **
Picloram (Grazon, Tordon)
Pronamide (Kerb, Propyzamid) **
Propachlor (Ramrod, Satecid) **
Propham (Tuberite) **
2,4,5-T
2,4,5-TP (Silvex, Fenoprop)
Thiobencarb (Bolero, Saturn, Benthiocarb, Abolish) * **
Triallate (Far-Go, Avadex BW, Tri-allate) *
Triclopyr (Garlon, Grandstand, Redeem) * **
Trifluralin (Treflan, Gowan, Tri-4, Trific, Trilin)

Pesticides in water—Insecticides





Other insecticides detected

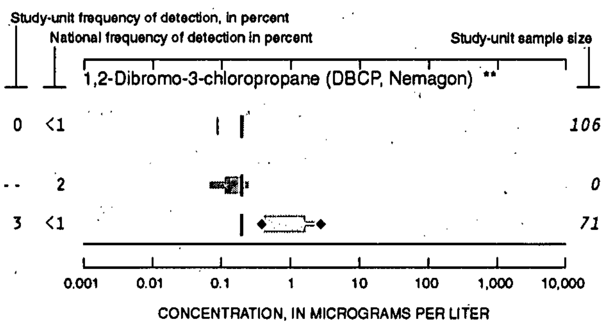
Aldicarb sulfone (Standak, aldoxycarb)
Carbofuran (Furadan, Curaterr, Yaltox)
p,p'-DDE
gamma-HCH (Lindane, gamma-BHC, Gammexane)
Methyl parathion (Penncap-M, Folidol-M, Metacide, Bladan M) **
Propoxur (Baygon, Blattanex, Unden, Proprotox) * **

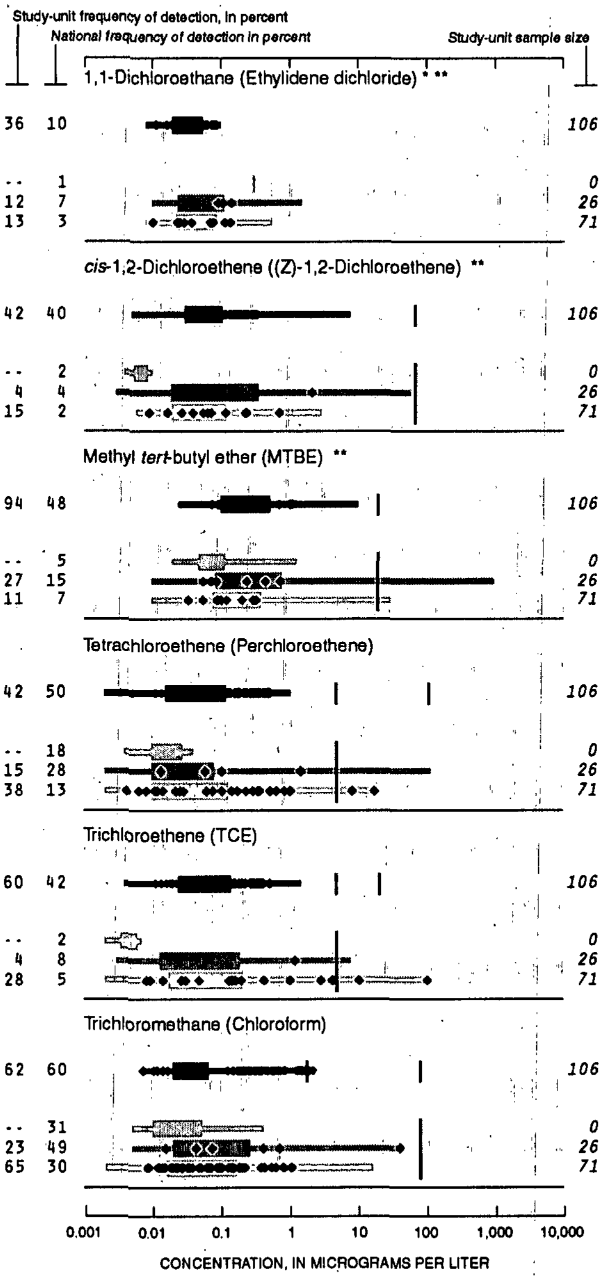
Insecticides not detected

Aldicarb (Temik, Ambush, Pounce)
Aldicarb sulfoxide (Aldicarb metabolite)
Azinphos-methyl (Guthion, Gusathion M) *
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) * **
Methomyl (Lanox, Lannate, Acinate) **
Oxamyl (Vydate L, Pratt) **
Parathion (Roethyl-P, Alkron, Panthion) *
cis-Permethrin (Ambush, Astro, Pounce) * **
Phorate (Thimet, Granutox, Geomet, Rampart) * **
Propargite (Comite, Omite, Ornamite) * **
Terbufos (Contraven, Counter, Pilarfox) **

Volatile organic compounds (VOCs) in water

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





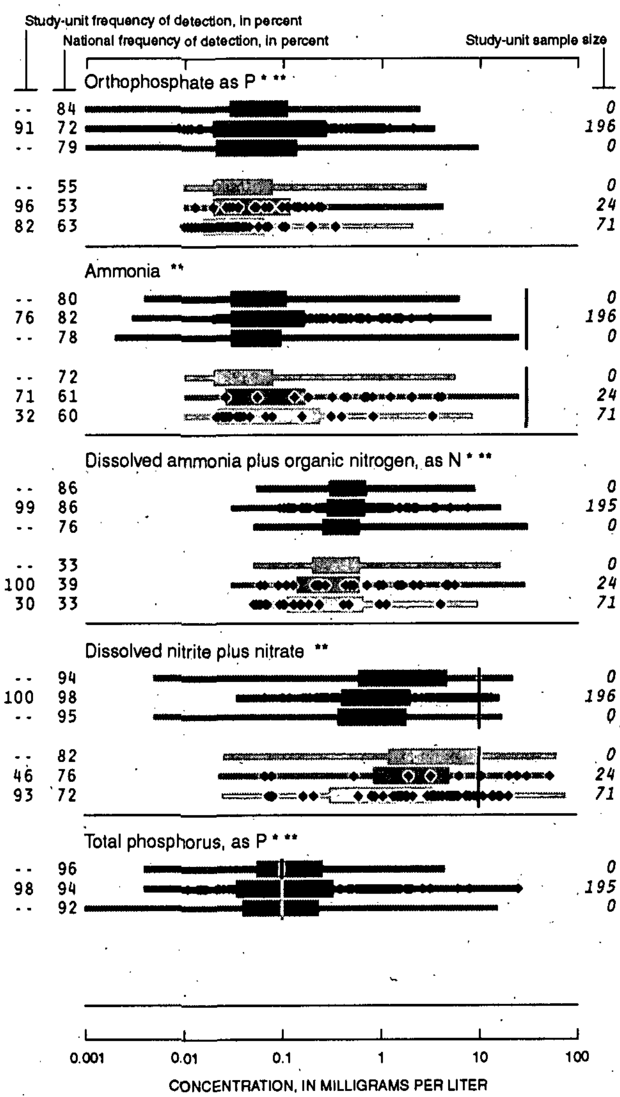
Other VOCs detected

Acetone (Acetone) * **
Benzene
Bromochloromethane (Methylene chlorobromide) **
Bromodichloromethane (Dichlorobromomethane) **
2-Butanone (Methyl ethyl ketone (MEK)) **
Carbon disulfide * **
1-Chloro-2-methylbenzene (*o*-Chlorotoluene) **
Chlorobenzene (Monochlorobenzene)
Chloromethane (Methyl chloride) **
Dibromochloromethane (Chlorodibromomethane) **
Dibromomethane (Methylene dibromide) * **
1,3-Dichlorobenzene (*m*-Dichlorobenzene)
1,4-Dichlorobenzene (*p*-Dichlorobenzene, 1,4-DCB)
Dichlorodifluoromethane (CFC 12, Freon 12) **
1,2-Dichloroethane (Ethylene dichloride)
1,1-Dichloroethene (Vinylidene chloride) **
trans-1,2-Dichloroethene ((E)-1,2-Dichlorothene) **
Dichloromethane (Methylene chloride)
1,2-Dichloropropane (Propylene dichloride) **
Diethyl ether (Ethyl ether) * **
Diisopropyl ether (Diisopropylether (DIPE)) * **
1,2-Dimethylbenzene (*o*-Xylene) **
1,3 & 1,4-Dimethylbenzene (*m*-&*p*-Xylene) **
Ethenylbenzene (Styrene) **
Ethylbenzene (Phenylethane)
2-Ethyltoluene (*o*-Ethyltoluene) * **
Isopropylbenzene (Cumene) * **
p-Isopropyltoluene (*p*-Cymene, 1-Isopropyl-4-methylbenzene) * **
4-Methyl-2-pentanone (Methyl isobutyl ketone (MIBK)) * **
Methylbenzene (Toluene)
Naphthalene
Tetrachloromethane (Carbon tetrachloride)
1,2,3,4-Tetramethylbenzene (Prehnitene) * **
1,2,3,5-Tetramethylbenzene (Isodurene) * **
Tetrahydrofuran (Diethylene oxide) * **
Tribromomethane (Bromoform) **
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113, CFC 113) * **
1,1,1-Trichloroethane (Methylchloroform) **
Trichlorofluoromethane (CFC 11, Freon 11) **
1,2,3-Trimethylbenzene (Hemimellitene) * **
1,2,4-Trimethylbenzene (Pseudocumene) * **
1,3,5-Trimethylbenzene (Mesitylene) * **

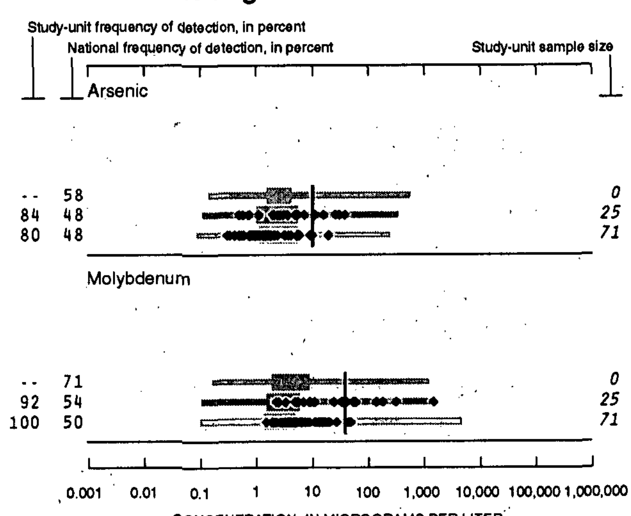
VOCs not detected

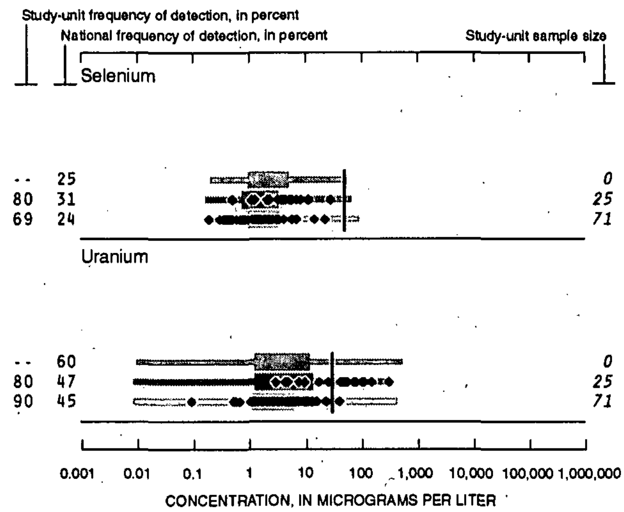
Bromobenzene (Phenyl bromide) * **
Bromoethene (Vinyl bromide) * **
Bromomethane (Methyl bromide) **
n-Butylbenzene (1-Phenylbutane) * **
sec-Butylbenzene ((1-Methylpropyl)benzene) * **
tert-Butylbenzene ((1,1-Dimethylethyl)benzene) * **
3-Chloro-1-propene (3-Chloropropene) * **
1-Chloro-4-methylbenzene (*p*-Chlorotoluene) **
Chloroethane (Ethyl chloride) * **
Chloroethene (Vinyl chloride) **
1,2-Dibromoethane (Ethylene dibromide, EDB) **
trans-1,4-Dichloro-2-butene ((Z)-1,4-Dichloro-2-butene) * **
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 * **
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) * **
2-Propenenitrile (Acrylonitrile) **
n-Propylbenzene (Isocumene) * **
1,1,2,2-Tetrachloroethane **
1,1,1,2-Tetrachloroethane (1,1,1,2-TeCA) **
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) * **

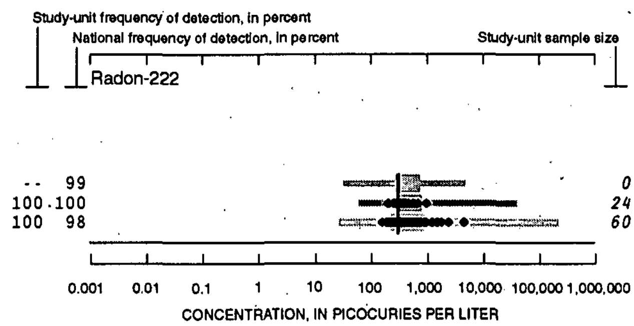
Nutrients in water



Trace elements in ground water







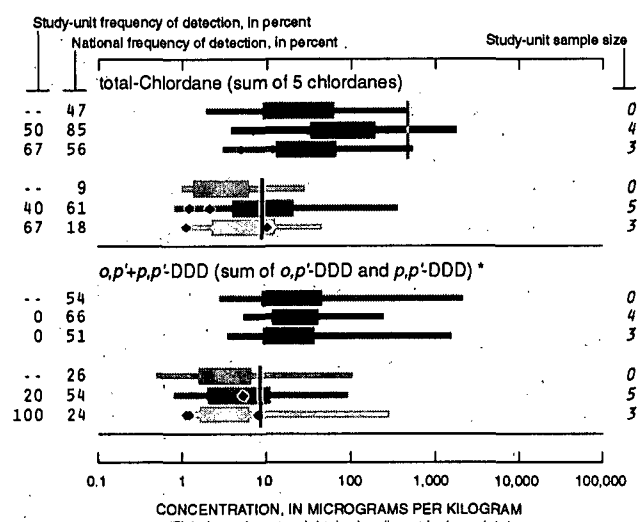
Other trace elements detected

Antimony
Lead
Manganese *
Thallium
Vanadium *

Trace elements not detected

Beryllium
Silver

Organochlorines in fish tissue (whole body) and bed sediment

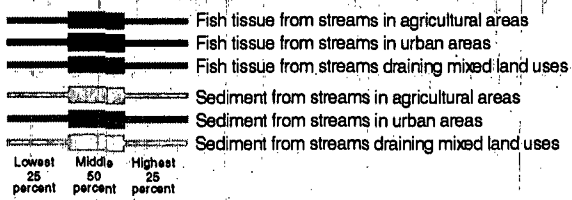


CHEMICALS IN FISH TISSUE AND BED SEDIMENT

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

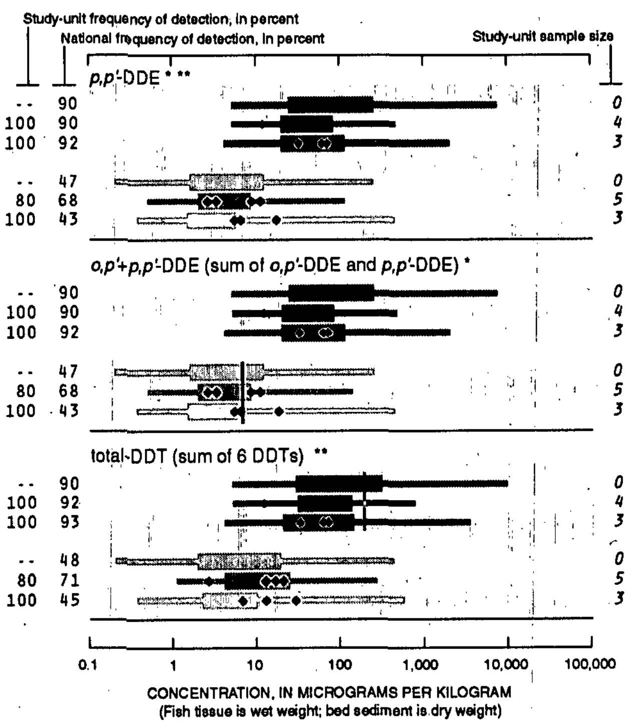
- ◆ Detected concentration in Study Unit
- 66 38 Frequencies of detection, in percent. Detection frequencies were not censored at any common reporting limit. The left-hand column is the study-unit frequency and the right-hand column is the national frequency
- -- Not measured or sample size less than two
- *12* Study-unit sample size

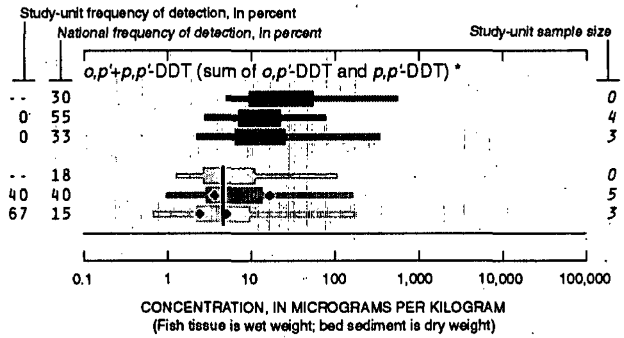
National ranges of concentrations detected, by land use, in 51 NAWQA Study Units, 1991–2001—Ranges include only samples in which a chemical was detected



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





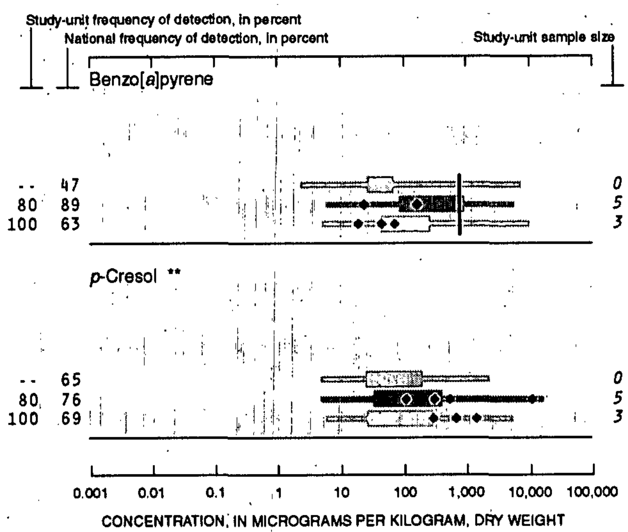
Other organochlorines detected

DCPA (Dacthal, chlorthal-dimethyl) * **
Dieldrin (Panoram D-31, Octalox) *
Dieldrin+aldrin (sum of dieldrin and aldrin) **
gamma-HCH (Lindane, gamma-BHC, Gammexane) *
PCB, total

Organochlorines not detected

Chloroneb (chloronebe, Demosan) * **
Endosulfan I (alpha-Endosulfan, Thiodan) * **
Endrin (Endrine)
Heptachlor epoxide (Heptachlor metabolite) *
Heptachlor+heptachlor epoxide **
Hexachlorobenzene (HCB) **
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



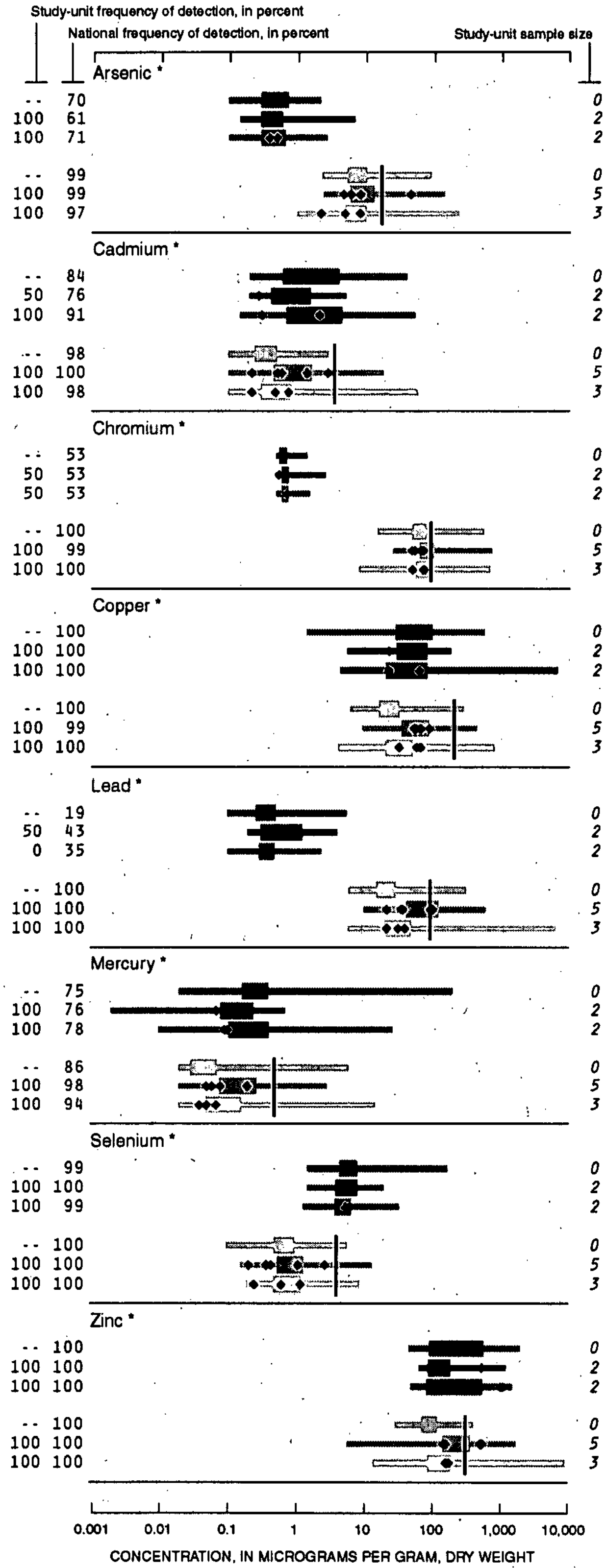
Other SVOCs detected

Acenaphthene
Acenaphthylene
Anthracene
Anthraquinone **
Benz[*a*]anthracene
Benzo[*b*]fluoranthene **
Benzo[*g,h,i*]perylene **
Benzo[*k*]fluoranthene **
9*H*-Carbazole **
bis (2-Chloroethyl)ether **
Chrysene
Di-*n*-octylphthalate **
Dibenz[*a,h*]anthracene
1,6-Dimethylnaphthalene **
2,6-Dimethylnaphthalene **
Dimethylphthalate **
Fluoranthene
9*H*-Fluorene (Fluorene)
Indeno[1,2,3-*c,d*]pyrene **
4,5-Methylenephenanthrene **
1-Methylphenanthrene **
1-Methylpyrene **
Naphthalene
Phenanthrene
Pyrene

SVOCs not detected

Acridine **
C8-Alkylphenol **
Azobenzene **
Benzo[*c*]cinnoline **
2,2-Biquinoline **
4-Bromophenyl-phenylether **
4-Chloro-3-methylphenol **
bis (2-Chloroethoxy)methane **
2-Chloronaphthalene **
2-Chlorophenol **
4-Chlorophenyl-phenylether **
Dibenzothiophene **
1,2-Dichlorobenzene (*o*-Dichlorobenzene, 1,2-DCB) **
1,3-Dichlorobenzene (*m*-Dichlorobenzene) **
1,4-Dichlorobenzene (*p*-Dichlorobenzene, 1,4-DCB) **
1,2-Dimethylnaphthalene **
3,5-Dimethylphenol **
2,4-Dinitrotoluene **
Isophorone **
Isoquinoline **
1-Methyl-9*H*-fluorene **
2-Methylanthracene **
Nitrobenzene **
N-Nitrosodi-*n*-propylamine **
N-Nitrosodiphenylamine **
Pentachloronitrobenzene **
Phenanthridine **
Quinoline **
1,2,4-Trichlorobenzene **
2,3,6-Trimethylnaphthalene **

Trace elements in fish tissue (livers) and bed sediment



Other trace element detected

Nickel * **

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

Federal Agencies
Bureau of Indian Affairs, Southern California Agency
Bureau of Reclamation

State Agencies
California Department of Water Resources
California State Water Resources Control Board
Santa Ana Regional Water Quality Control Board

Local Agencies
City of Lake Elsinore
City of Riverside
City of San Bernardino
Eastern Municipal Water District
Inland Empire Utilities Agency
Metropolitan Water District of Southern California
Orange County Sanitation District
Orange County Water District
San Bernardino Valley Municipal Water District
Santa Ana Watershed Project Authority
Southern California Coastal Water Research Project
Western Municipal Water District
Yucaipa Valley Water District

Native American Tribes and Nations
San Manuel Indian Reservation

Universities
University of California at Riverside

Other public and private organizations
Environmental Systems Research Institute (ESRI)
Wildermuth Environmental

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- Andrea Altmann (USGS, San Diego CA), prepared supplies and equipment for field work and assisted in the collection of ecology and surface-water samples.
- Larry Brown (USGS, Sacramento CA), participated in the design of aquatic ecology studies and in field activities associated with these studies.
- Ted Callender (USGS, Austin TX), collected, processed, and analyzed reservoir core samples.
- Dennis Clark (USGS, San Diego CA), assisted in logging and installation of monitoring wells for a land-use study.
- Robert Fisher (USGS, San Diego CA), assisted in the collection and field identification of fish.
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- Larry Shelton (USGS, Sacramento CA), assisted in the collection of streambed sediment and fish-tissue samples.
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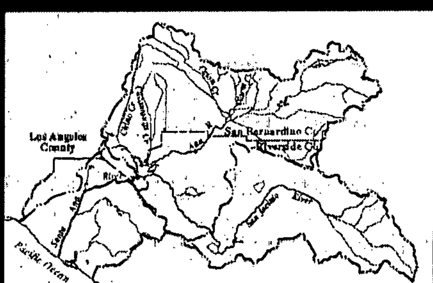
NAWQA

National Water-Quality Assessment (NAWQA) Program
Santa Ana Basin



Belitz and others—Water Quality in the Santa Ana Basin
U.S. Geological Survey Circular 1238

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