Water Quality in South-Central Texas

Texas, 1996–98

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

Circular 1212

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South-Central Texas contact and web site:

USGS State Representative
U.S. Geological Survey
Water Resources Division
8027 Exchange Dr.
Austin, TX 78754
e-mail: dc_tx@usgs.gov
http://tx.usgs.gov/sctx/

National NAWQA Program:

Chief, NAWQA Program
U.S. Geological Survey
Water Resources Division
12201 Sunrise Valley Drive, M.S. 413
Reston, VA 20192
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Front cover: Horsecollar Bend on the Frio River north of Leakey, Real County *(photograph courtesy of TEXAS HIGHWAYS Magazine)*.

Back cover: Left, Guadalupe River in the Hill Country; center, San Antonio Riverwalk *(photographs courtesy of TEXAS HIGHWAYS Magazine)*; right, hay field near Utopia, Uvalde County *(photograph by Clarence E. Ranzau, U.S. Geological Survey)*.

Water Quality in South-Central Texas, Texas, 1996–98

By Peter W. Bush, Ann F. Ardis, Lynne Fahlquist, Patricia B. Ging,
C. Evan Hornig, *and* Jennifer Lanning-Rush

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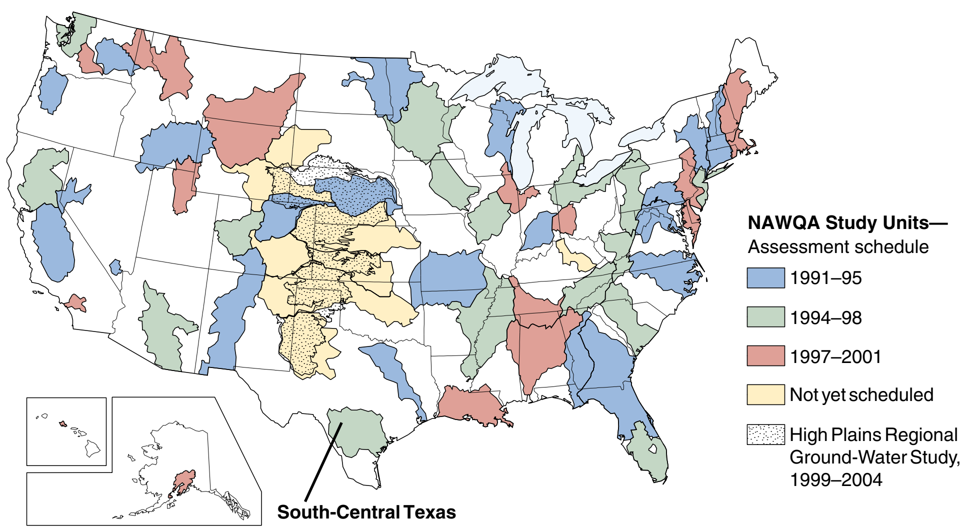
CONTENTS

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

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

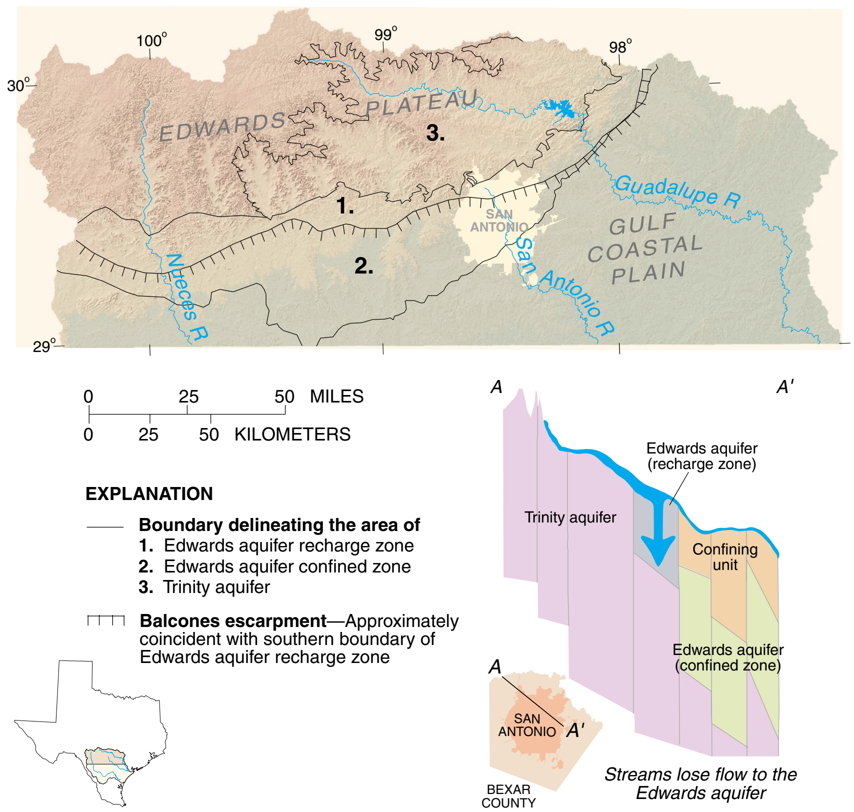


THE NAWQA PROGRAM seeks to improve scientific and public understanding of water quality in the Nation's major river basins and ground-water systems. Better understanding facilitates effective resource management, accurate identification of water-quality priorities, and successful development of strategies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

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

Stream and River Highlights

Numerous organic chemicals and trace elements were detected in streams and rivers in the upper part of the South-Central Texas Study Unit—in part because of high detection sensitivities (fractions of a part per billion) of laboratory analytical methods. Most concentrations of organic chemicals and trace elements were extremely low and many times less than levels of concern for human health or aquatic life. No concentrations of sampled chemical constituents except those of dissolved nitrite plus nitrate nitrogen (hereinafter, nitrate) downstream from wastewater treatment plants exceeded drinking-water standards or guidelines. Although surface water historically has not been a source of drinking water, streams and rivers are the major source of replenishment (recharge) to the Edwards aquifer, the principal water supply for much of the region. Surface water provides habitat for a wide variety of aquatic organisms and recreational opportunities for many people.



The South-Central Texas Study Unit encompasses the Nueces, San Antonio, and Guadalupe River Basins. The 1996–98 assessment involved only the upper part of the Study Unit. Streams and rivers that originate in the rugged hills of the Edwards Plateau generally gain water as they flow southeastward toward the Edwards aquifer outcrop (recharge zone). As they flow across the highly permeable, faulted, and fractured rocks of the recharge zone, most lose substantial amounts of flow directly into the aquifer.

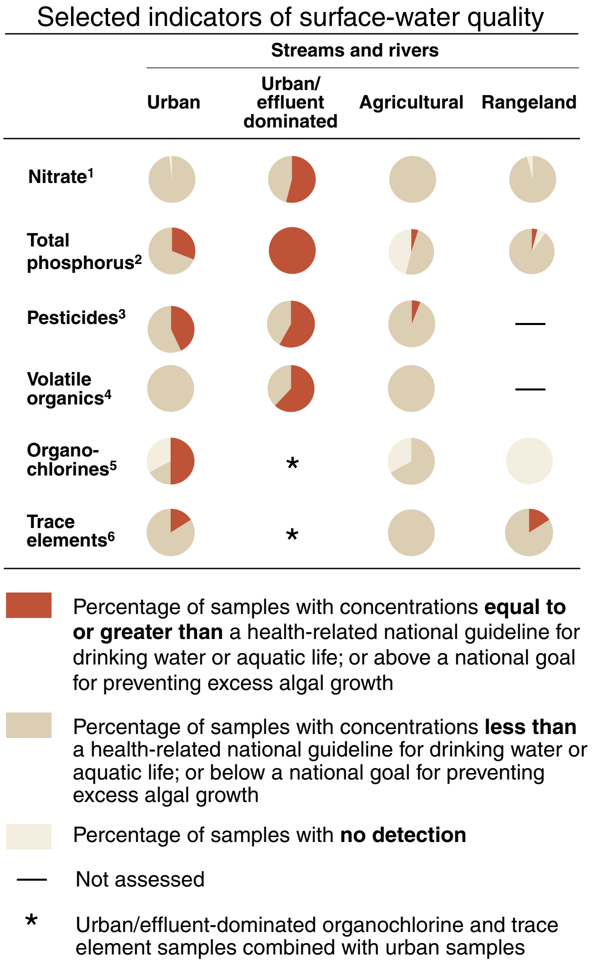
- Nitrate concentrations downstream from wastewater treatment plants consistently were about 5 times greater than those downstream from agricultural land and about 20 times greater than those downstream from rangeland. All total phosphorus concentrations downstream from wastewater treatment plants exceeded a goal for controlling nuisance algae and aquatic plant growth.
- More pesticides and volatile organic compounds (VOC) at generally higher concentrations were detected in urban stream water than in agricultural stream water. Concentrations of each of six pesticides and one VOC exceeded aquatic-life guidelines in several (mostly urban) stream samples. The herbicide atrazine was detected in all urban and agricultural stream samples.
- Generally higher concentrations of organochlorine compounds and trace elements were detected in urban stream-sediment and fish-tissue samples than in agricultural and rangeland samples. Concentrations of several samples exceeded sediment guidelines for the protection of aquatic life or fish-tissue guidelines for the protection of fish-eating wildlife; most were from urban streams.
- Biological community status is related to watershed development. The most degraded algal, invertebrate, and fish communities were in urban streams, and the healthiest were in rangeland streams.

Major Influences on Streams and Rivers

- Wastewater-treatment plant effluent
- Runoff from urban areas
- Pesticide use in urban watersheds
- High flow caused by storms

Ground-Water Highlights

Ground water, primarily from the Edwards aquifer and also from the Trinity aquifer, is the principal source of water supply in the upper part of the Study Unit. In general, the quality of water in the Edwards and Trinity aquifers reflects little evidence of human activities—despite major urban development and agricultural land in places overlying the Edwards aquifer and increasing urban development in places overlying the Trinity aquifer. Numerous organic chemicals were detected in the Edwards aquifer, fewer in the Trinity aquifer, but most concentrations were extremely low. Concentrations of nutrients, organic chemicals, and trace elements generally were very low relative to

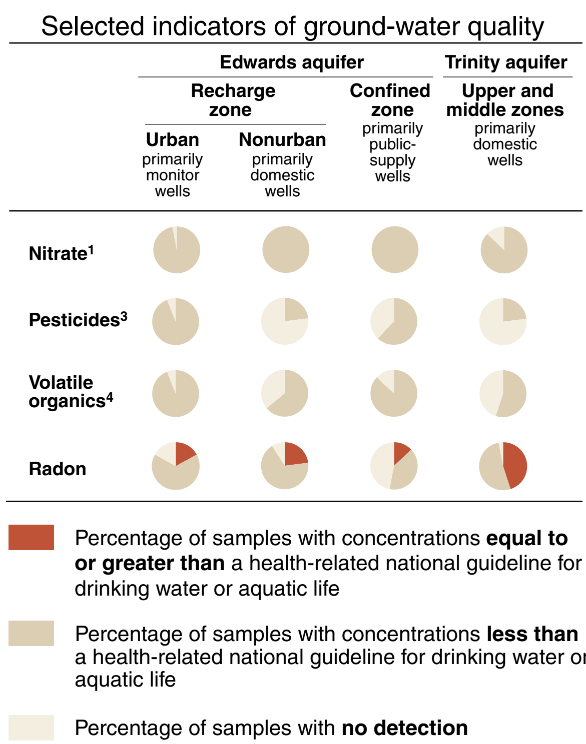


drinking-water standards and guidelines. Some radon concentrations exceeded a proposed drinking-water standard, but radon concentrations were among the lowest of NAWQA Study Units nationwide.

- The median nitrate concentration among primarily public-supply wells sampled in the confined zone of the Edwards aquifer was about six times less than the maximum contaminant level for nitrate in drinking water; nevertheless, the median was in the top 10 percent of median nitrate concentrations of major aquifers sampled by NAWQA nationwide. Median nitrate concentration in the Trinity aquifer was more than 10 times less than that in the Edwards aquifer.
- The greatest frequencies of detection of pesticides and VOCs in the Edwards aquifer were in urban (northern San Antonio) recharge-zone samples. The outcropping fractured and faulted limestone of the recharge zone allows unrestricted downward movement of water, which can contain contaminants, into the ground-water-flow system.
- Four of the 5 most frequently detected pesticides in water from urban recharge-zone wells in the Edwards aquifer were the same as 4 of the 5 most frequently detected pesticides in surface water at urban sites in the San Antonio area. This finding illustrates the correlation between the quality of recently recharged ground water in an urban setting and the quality of urban stream and river water.
- The quality of water in the Trinity aquifer remains influenced primarily by the natural processes of water-rock interaction. Concentrations of dissolved solids, sulfate, iron, and strontium exceeded drinking-water standards or guidelines in some samples. Fewer pesticides and VOCs were detected in Trinity aquifer samples than in Edwards aquifer samples, possibly because of low permeability of the Trinity aquifer and little urban development.

Major Influences on Ground Water

- Urban development in the Edwards aquifer recharge zone
- The quality of stream and river water that recharges the Edwards aquifer
- The natural processes of water-rock interaction in the Trinity aquifer



[1] Nitrate (as nitrogen), sampled in water.
[2] Total phosphorus, sampled in water.
[3] Insecticides, herbicides, and pesticide breakdown products, sampled in water.
[4] Solvents, refrigerants, fumigants, and gasoline compounds, sampled in water.
[5] Organochlorine compounds including DDT and PCBs, sampled in sediment.
[6] Arsenic, mercury, and metals, sampled in sediment.

INTRODUCTION TO THE UPPER PART OF THE SOUTH-CENTRAL TEXAS STUDY UNIT

The upper part of the South-Central Texas Study Unit (hereinafter, Study Unit) encompasses parts of the topographically rugged and picturesque Edwards Plateau and the comparatively flat, gently coastward-sloping Gulf Coastal Plain physiographic regions. An abrupt topographic break, the Balcones escarpment, separates the two landforms (fig. 1).

San Antonio is the principal urban area in the Study Unit. The agricultural areas of primary interest are west of San Antonio. Rangeland predominates in the Edwards Plateau.

The Study Unit contains the Edwards aquifer in the Balcones fault zone, a zone of northeastward-trending parallel faults that straddles the Balcones escarpment. The Study Unit also contains the Trinity aquifer (fig. 2) in the “Hill Country,” the local name for the eastern part of the Edwards Plateau in the region.

An Unusual Physical System

Surface water and ground water in the Study Unit are uniquely interrelated. Rainfall reaches streams deeply incised into the marl, shale, and limestone of the Edwards Plateau as springflow and surface runoff. The streams generally gain water as they flow south-southeastward from headwaters in the higher elevations of the plateau. As the major streams flow across the faulted and fractured carbonate rocks of the Edwards aquifer outcrop (recharge zone), they lose substantial amounts of flow directly into the highly permeable aquifer.

Ground Water Predominates

Ground water accounts for nearly all of the water supply in the Study Unit (fig. 3), and the Edwards aquifer, one of the most productive aquifers in the world, is the principal source. Withdrawals from the Edwards aquifer meet the water-supply needs of more

Rangeland streams near the Balcones escarpment often go dry.

Corn is among the top agricultural commodities in the region.

Upgrading roads goes hand in hand with increasing development north of San Antonio.

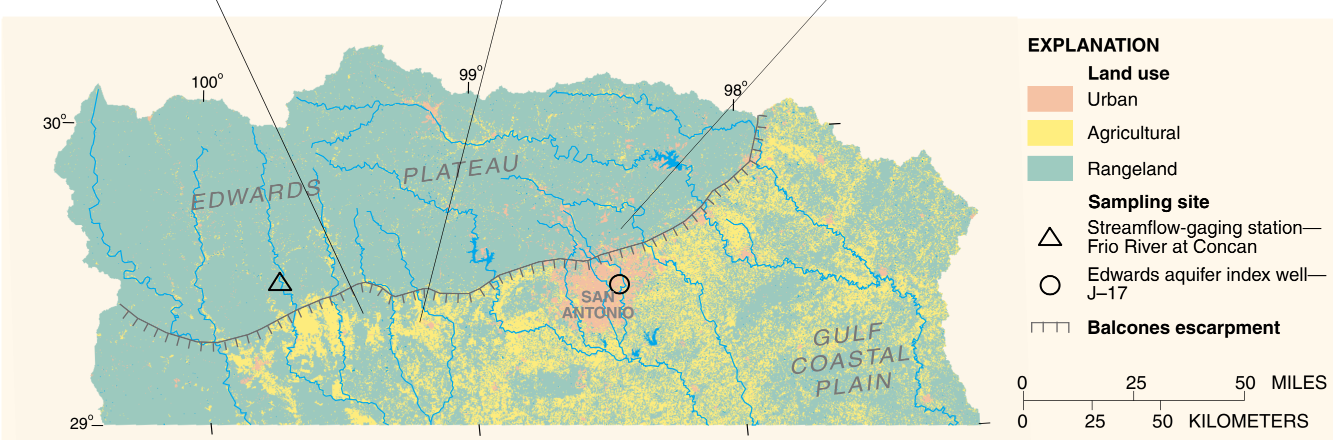


Figure 1. Land use in the Study Unit correlates with physiography. The rugged, thin-soiled terrain of the Edwards Plateau is largely undeveloped. The flatter, thicker-soiled terrain of the Gulf Coastal Plain is better suited to growing crops—primarily hay, sorghum, wheat, corn, and oats. (Land use from Landsat thematic mapper scenes acquired in 1991–93 [1].)

Figure 2. Areal extent of the Edwards and Trinity aquifers sampled during 1996–98 (modified from [4]). The outcrop of the Edwards aquifer essentially is the recharge zone; the subcrop essentially is the confined zone. The outcrop of the Trinity aquifer is approximately coincident with the Hill Country. The subcrop of the Trinity aquifer (not shown), which extends beneath the Edwards aquifer, is not a source of water supply in the region and was not sampled.

than 1.5 million people in the greater San Antonio region and support farming and ranching west of San Antonio. The aquifer sustains the flows of Comal and San Marcos Springs, which attract tourists to the region, yield base flow to the Guadalupe River to meet downstream water requirements, and provide habitat for several threatened and endangered species. The Edwards aquifer harbors diverse aquatic communities above and below land surface; at least 90 described species, one-half of which are subterranean, are unique to the region.

The Trinity aquifer, although much less productive than the Edwards aquifer, is the most commonly used and reliable source of water supply in the Hill Country.

Development is Increasing

The watersheds of major streams in the Edwards Plateau that recharge the Edwards aquifer were largely undeveloped rangeland in the late 1990s—but that is changing. A common sight in the area is the construction of new subdivisions on land that for generations has been devoted to ranching. Edwards, Bandera, and Kendall Counties were among the top 10 statewide and the top 50 nationally in percentage of population increase during 1990–98. Urban development in the Edwards aquifer recharge zone, particularly in Bexar County (San Antonio), also is increasing. Bexar County ranked fourth among counties statewide and 15th nationally in numeric population increase during 1990–98. Continued development on a scale suggested by those U.S. Census Bureau statistics has the potential to affect surface- and ground-water quality in the Study Unit.

The Edwards Aquifer Is Particularly Vulnerable to Contamination

The highly permeable rocks that compose the Edwards aquifer recharge zone, and development in the watersheds of major streams in

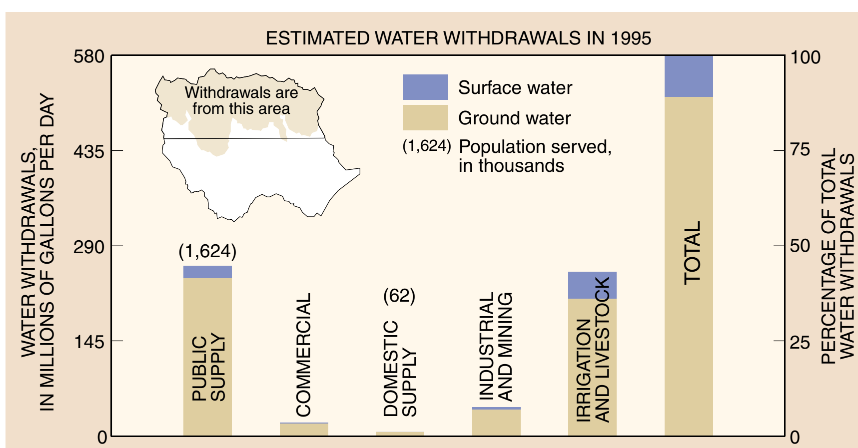


Figure 3. Nearly all the withdrawals from the Study Unit were ground water. About 70 percent of the ground-water withdrawals were from the Edwards aquifer.

the Edwards Plateau and in the recharge zone, make the Edwards aquifer particularly vulnerable to contamination. That vulnerability and the dependence of so many people on the aquifer combine to make the water quality of the Edwards aquifer and the streams that recharge it a critical issue for the future of the region.

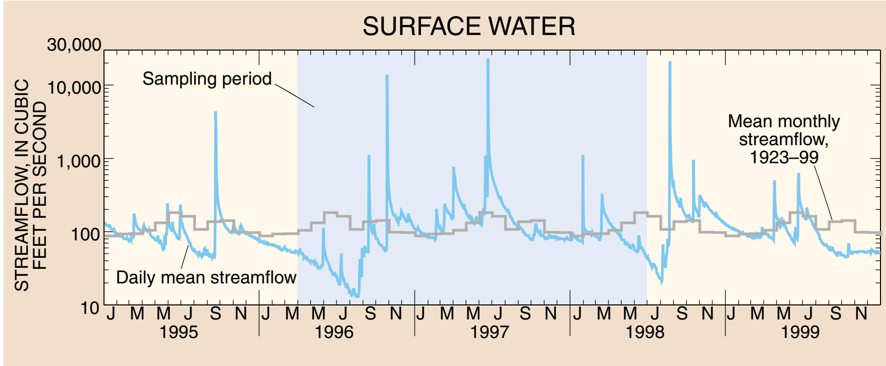


Figure 4. Daily mean streamflow of the Frio River at Concan, a basic site for sampling, reflects the regional droughts of 1996 and 1998 and the subsequent wet periods. Streamflow at the site can increase almost instantly by a factor of 100 or more for short periods in response to intense rainfall. The region near the Balcones escarpment is more prone to flash floods than anywhere else in the Nation [5, p. 63].

Climate and Hydrologic Conditions Can Affect Water Quality

Hydrologic conditions in the Study Unit often are extreme. Months-long droughts that strain water supplies and produce widespread crop failure commonly are followed by wet periods that include torrential rains and flash floods. Such was the pattern during the 1996–98 period of intensive sampling (figs. 4, 5).

Whether hydrologic conditions are wet or dry can affect water quality. For example, during wet conditions, proportionately more of the streamflow is surface runoff. Runoff that contains excessive nutrients, pesticides, or other contaminants washed off land surfaces can degrade stream quality. During dry conditions, stream quality is more strongly influenced by the quality of the base flow (and wastewater-treatment plant discharge, if present).

The Study is a Benchmark for Changes to Come

This study is more of a benchmark from which to measure future water-quality changes than a documentation of problems. Population growth and development bring changes in land use, and land use can have a strong influence on water quality. Accordingly, part of the study design focuses on land use. Surface-water sampling was done to assess the effects of urban, agricultural, and rangeland use on stream quality during stormflows and during normal and low flows. Ground-water sampling was done to assess the overall quality of ground water in the Edwards and Trinity aquifers and to assess the relation between ground-water quality and urban land use in the recharge zone in San Antonio. Synoptic samples were collected primarily from domestic and monitor wells in the Edwards aquifer recharge zone, public-supply wells in the Edwards aquifer confined zone, and domestic wells in the upper and middle zones of the Trinity aquifer. (See “Study Unit Design,” p. 22.)

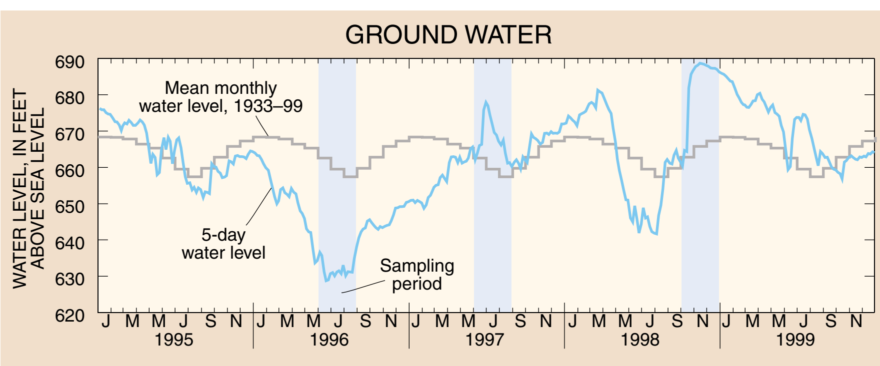


Figure 5. The water level in Edwards aquifer index well J–17 in Bexar County rose substantially during wet periods following the regional droughts of 1996 and 1998; and reflects the effects of pumpage at San Antonio as well as natural fluctuations in recharge and discharge. Although pumpage at San Antonio has increased fivefold since the 1930s, Edwards aquifer water levels show no long-term declines because the aquifer readily accepts recharge when rainfall is plentiful.

Stream Quality Is Affected Most by Urban Activities

Chemical and biological indicators in monitored streams in key land-use settings in the Study Unit (fig. 6) show that stream-quality degradation tends to be associated with urban land to a greater degree than with agricultural land or rangeland. With a few exceptions, pesticides, VOCs, and trace elements were either not detected or detected at concentrations below levels of concern for human health or aquatic life in all monitored streams.

Nutrient Concentrations Increased as a Result of Wastewater-Treatment Plant Discharges

Discharges from wastewater treatment plants had the greatest effect on nutrient concentrations of any identifiable source in the Study Unit [6]. Nitrate concentrations were appreciably higher in an urban stream downstream from four wastewater treatment plants (San Antonio River at Elmendorf) than in streams in other land-use settings (fig. 7). Nitrate concentrations in the San Antonio River at Elmendorf generally increased as the percentage of wastewater-treatment plant discharge (effluent) in streamflow increased (fig. 8). Although the San Antonio River historically has not been a source of drinking water, the median nitrate concentration at Elmendorf (11 milligrams per liter [mg/L]) exceeded the U.S. Environmental Protection Agency (USEPA) maximum contaminant level (MCL) for drinking water (10 mg/L). No aquatic-life guideline for nitrate has been established. The flow-weighted mean nitrate concentration at Elmendorf, 5.8 mg/L, was about the 90th percentile among 372 NAWQA stream sites nationwide.

Ammonia at sufficient concentrations, which vary with water temperature and acidity [7], can be toxic to fish. Median ammonia concentration at Elmendorf was 0.1 mg/L, the same as the

Nutrients in Water

Nitrogen (primarily dissolved nitrate) and phosphorus (primarily dissolved phosphates and organic phosphorus in streams and orthophosphate in ground water) are essential to the health of plants and animals. Elevated concentrations of these nutrients in water, however, can cause problems. Too much nitrate in drinking water can reduce oxygen concentrations in the blood of infants to dangerously low levels. Excessive nitrate and phosphorus concentrations in surface water can cause nuisance algae and plant growth, which in turn can adversely affect aquatic ecosystems and water-related recreational activities.

Nitrogen and phosphorus occur naturally in water, but natural concentrations are increased by the introduction of fertilizers, manure, or treated sewage effluent into the water.

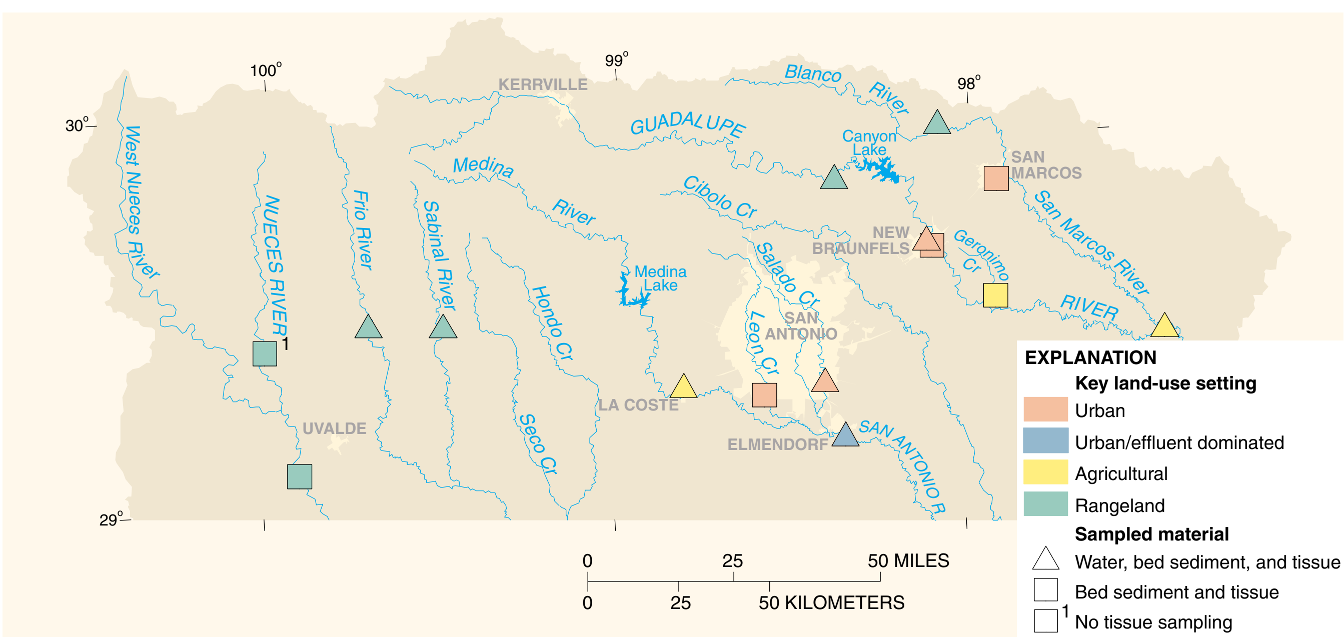


Figure 6. Stream-water sampling in key land-use settings in the Study Unit was done at 9 sites, bed-sediment sampling at 15 sites, and fish-tissue sampling at 14 sites.

estimated national background concentration in streams essentially unaffected by human activities [8]. Modern treatment plants effectively remove ammonia from wastewater by converting it to nitrate.

Land use had less effect on nutrient concentrations than proximity to wastewater treatment plants. The median nitrate concentration in an urban stream not affected by wastewater-treatment plant discharge (Salado Creek at San Antonio) was 0.56 mg/L, about the same as the estimated national background nitrate concentration (0.6 mg/L) in streams essentially unaffected by human activities [8]. The median nitrate concentration in an agricultural (cropland) stream (Medina River at La Coste) was 2.0 mg/L, higher than that of Salado Creek and showing the effect of runoff containing nitrate from fertilizers. The median is typical of median nitrate concentrations in surface water draining agricultural areas in selected NAWQA Study Units nationwide [8]. Median nitrate concentrations in four rangeland streams (Frio, Sabinal, Guadalupe, and Blanco Rivers) were near background levels (0.34 to 0.77 mg/L).

Nitrate concentrations vary over time in response to hydrologic conditions, wastewater-treatment plant discharges, plant and algal uptake, and timing of fertilizer application. However, no seasonal pattern in concentrations associated with any land-use setting was evident (fig. 7).

Total phosphorus concentrations also were highest in the San Antonio River at Elmendorf. The median total phosphorus concentration was 1.6 mg/L, and all concentrations were greater than the USEPA goal of 0.1 mg/L to control nuisance algae and aquatic plant growth. The flow-weighted mean total phosphorus concentration at Elmendorf, 1.2 mg/L, was about the 98th percentile among 372 NAWQA stream sites nationwide. The median total phosphorus concentration in Salado Creek at San Antonio, the urban stream not affected by wastewater-treatment plant discharge, was 0.066 mg/L, and individual concentrations commonly exceeded the USEPA goal of 0.1 mg/L. The median total phosphorus concentration for the Medina River at

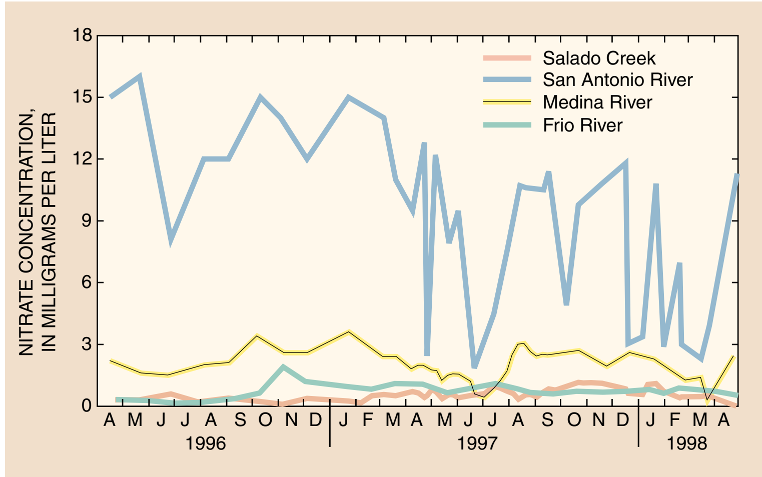


Figure 7. Nutrient concentrations were consistently higher in streams influenced by urban wastewater-treatment plant discharge (San Antonio River) and agricultural runoff (Medina River) than in an urban stream (Salado Creek) or a rangeland stream (Frio River). Greater rainfall and streamflow during 1997 and early 1998 diluted nitrate concentrations associated with wastewater-treatment plant discharge in the San Antonio River at Elmendorf.

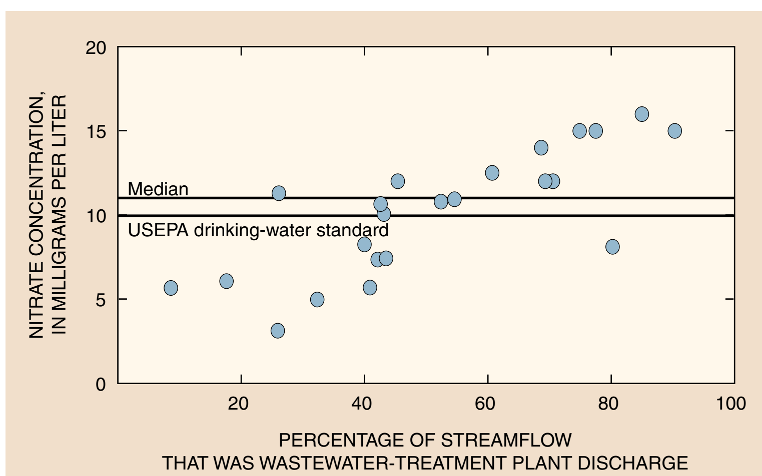


Figure 8. Differences in rainfall-runoff relations with flow in the San Antonio River at Elmendorf account for variability in the dilution of wastewater-treatment plant discharge. Concentrations of nitrate in the river increased appreciably with the percentage of wastewater-treatment plant discharge in the streamflow.

La Coste, the agricultural stream, was 0.030 mg/L; and the median concentration for each of the four rangeland streams was less than 0.010 mg/L, the minimum reporting level. Total phosphorus concentrations in all streams exceeded the USEPA goal during stormflows. Higher phosphorus concentrations during stormflows is consistent with the adherence of phosphorus to sediment particles and the increase in suspended sediment concentrations during stormflows.

More Pesticides—at Generally Higher Concentrations—Were Associated with Urban Land Use

More pesticides and their breakdown products (hereinafter, pesticides) were detected in Salado Creek at San Antonio (25 of 83 analyzed) than in the San Antonio River at Elmendorf downstream from the wastewater treatment plants (18 of 83) and the Medina River at La Coste (15 of 83) [6]. Samples from rangeland streams were not analyzed for pesticides. The maximum concentrations of 7 of the 10 pesticides detected in all three streams occurred in Salado Creek at San Antonio. In all three streams, some pesticide concentrations increased in the spring, which is consistent with the time of year for application.

No concentration of a pesticide for which a drinking-water standard has been established (25 of 31 pesticides detected) exceeded that standard in any of the three streams. However, aquatic-life guidelines (established for 17 of 31 pesticides detected) were exceeded in at least one sample for 5 pesticides in Salado Creek at San Antonio, 3 insecticides in the San Antonio River at Elmendorf, and 1 insecticide in the Medina River at La Coste (table 1).

The most frequently detected pesticides in all three streams were atrazine, deethylatrazine, and prometon (fig. 9). Atrazine was detected in all of the samples from each of the three streams.

The number of pesticides and the most frequently detected pesticides in each stream change when frequency of detection is based on a common concentration of 0.05 microgram per liter (µg/L). (See box, p. 9.) In Salado Creek at San Antonio, 13 pesticides were detected on the basis of the

Pesticides in Streams—How Toxic to Aquatic Life?

According to the Extension Toxicology Network [9], the insecticide carbaryl, a general-use pesticide, is moderately toxic to aquatic organisms. The insecticide diazinon, some formulations of which are classified as restricted use (use by certified applicators only), is highly toxic to fish. The insecticide gamma-HCH, some formulations of which are classified as restricted use, is highly to very highly toxic to aquatic organisms. The insecticide malathion, a general-use pesticide, has a wide range of toxicities to aquatic organisms. DDE is a breakdown product of the insecticide DDT, which was banned for use in the United States in 1972. DDE has similar chemical and physical properties to DDT, which is very highly toxic to fish and to many aquatic invertebrate species. The herbicide tebuthiuron, a general-use pesticide, is slightly toxic to practically non-toxic to aquatic organisms.

Atrazine is a restricted-use pesticide (home use exempted from restrictions) commonly used to kill broadleaf weeds. Atrazine is the most widely used herbicide in Texas corn and grain sorghum production [10] and the most widely used pesticide in the United States [11]. The Extension Toxicology Network [9] classifies atrazine as slightly toxic to aquatic organisms. No aquatic-life guideline has been established for the atrazine breakdown product deethylatrazine.

The herbicide prometon, a general-use pesticide, has been shown in toxicological studies on selected fish species to have very low toxicity [12]. The herbicide simazine, also a general-use pesticide, is slightly toxic to practically non-toxic to aquatic organisms [9]; and the herbicide diuron, another general-use pesticide, is moderately toxic to fish and highly toxic to aquatic invertebrates [9].

Table 1. Pesticides and VOCs in stream water for which at least one sample exceeded an aquatic-life guideline

[I, insecticide; H, herbicide; VOC, volatile organic compound]

Compound	Type	Number of exceedances / samples		
		Salado Creek urban	San Antonio River urban/effluent dominated	Medina River agricultural
Carbaryl	I	1 / 35	2 / 26	0 / 32
Diazinon	I	11 / 35	3 / 26	0 / 32
Gamma-HCH	I	0 / 35	12 / 26	0 / 32
Malathion	I	1 / 35	0 / 26	0 / 32
p,p′-DDE	I	4 / 35	0 / 26	2 / 32
Tebuthiuron	H	1 / 35	0 / 26	0 / 32
Trichloromethane	VOC	0 / 22	8 / 13	0 / 7

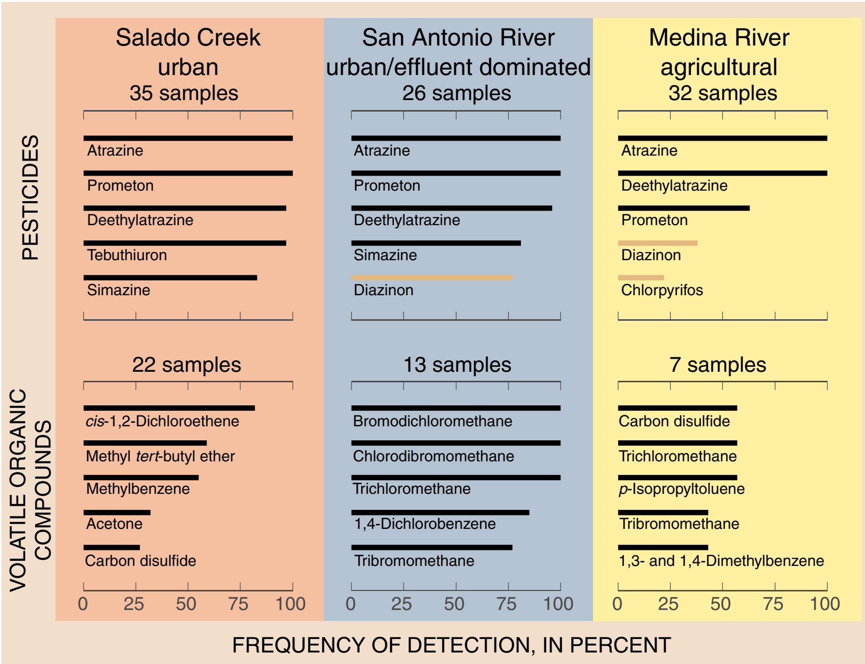


Figure 9. Pesticides and VOCs were detected more frequently in urban streams than agricultural streams. The five pesticides and VOCs most frequently detected in stream water are shown. More herbicides than insecticides (shaded brown) were detected.

common concentration (compared with 25 detected without regard to a common concentration). The five most frequently detected pesticides and their detection frequencies based on the common concentration were

Tebuthiuron	91 percent
Atrazine	46 percent
Diazinon	46 percent
Diuron	37 percent
Carbaryl	31 percent.

In the San Antonio River at Elmendorf, only 5 pesticides were detected on the basis of the common concentration (compared with 18). The five detected and their detection frequencies were

Atrazine	46 percent
Diazinon	27 percent
Carbaryl	19 percent
Tebuthiuron	19 percent
Diuron	12 percent.

In the Medina River at La Coste, 5 pesticides also were detected on the basis of the common concentration (compared with 15). Detection frequencies of all 5 pesticides based on the common concentration were less than 10 percent.

The number of pesticides detected and, in general, the frequencies of detection based on a common concentration of 0.05 µg/L are substantially less than those not based on a common concentration. This result underscores the fact that the majority of pesticide detections in stream water represent extremely low concentrations. Less than 0.05 µg/L means less than 1 part contaminant per 20 billion parts water, which is about the same concentration as an aspirin tablet dissolved in an olympic-size swimming pool.

All of the surface-water samples contained more than one pesticide, which is consistent with national NAWQA findings that show pesticides commonly occur in mixtures of several compounds [13]. Drinking-water standards for combinations of pesticides have not been established, and very little is known about the effects of mixtures of pesticides on aquatic life.

Most Volatile Organic Compound Concentrations Were Low Relative to Standards and Guidelines

The most VOCs (33 of 86 analyzed) were detected in the

About Frequencies of Detection

The minimum reporting level (MRL) is the smallest measured concentration of a constituent that may be reliably reported using a given analytical method; the MRL varies among constituents and analytical methods.Thus, the frequency at which a constituent is detected depends in part on its MRL. In general, the frequency of detection of a constituent increases as the MRL decreases. For example, atrazine was detected in 100 percent of the surface-water samples in this study on the basis of an MRL of 0.001 µg/L. The detection frequency would have been 38 percent if the MRL for atrazine was 0.05 µg/L.

Detection frequencies for pesticides and VOCs in water are reported in two ways in this report. The first is based on the MRLs of the methods used by the laboratory. The second is based on a common concentration for each group of constituents, which eliminates the effect of different MRLs for different constituents. The common concentration was selected as 0.05 µg/L for pesticides and 0.1 µg/L for VOCs.

San Antonio River at Elmendorf. Twenty-one VOCs were detected in Salado Creek at San Antonio. As was the case with pesticide detections, the fewest VOC detections (15) were in the Medina River at La Coste [6]. The maximum concentrations of 7 of the 10 VOCs detected in all three streams were from the San Antonio River at Elmendorf. No samples from rangeland streams were analyzed for VOCs. Of the 20 VOCs detected for which drinking-water standards and (or) aquatic-life guidelines have been established, one VOC—trichloromethane—exceeded the Canadian water-quality guideline for the protection of aquatic life [14] in 8 of 13 samples in the San Antonio River at Elmendorf (table 1). Trichloromethane is moderately toxic to aquatic life [15], but it is not persistent in surface water; one-half of it will have evaporated after several days. No other VOC concentrations in any of the three streams approached the levels of concern for the protection of human health or aquatic life.

Four of the 5 VOCs most frequently detected in the San Antonio River at Elmendorf (bromodichloromethane, chlorodibromomethane, trichloromethane, and tribromomethane) (fig. 9), are by-products of water chlorination. The presence of these trihalomethane compounds is consistent with the fact that a major part of the flow of the river was wastewater-treatment plant discharge. On the basis of a common concentration of 0.1 µg/L, only 5 VOCs were detected (compared with 33 detected without regard to a common concentration). The same four trihalomethanes were detected at essentially the same frequencies as those detected without regard to a common concentration (fig. 9). The fifth, methylbenzene, was detected in 31 percent of the samples.

Four of the 5 VOCs most frequently detected in Salado Creek at San Antonio (*cis*-1,2-dichloroethene, methylbenzene, acetone, and carbon disulfide) (fig. 9) are industrial chemicals with a variety of uses. They probably entered the stream in urban runoff. The fifth VOC most frequently detected (methyl *tert*-butyl ether [MTBE]) was 1 of 3 VOCs detected on the basis of a common concentration of 0.1 µg/L. MTBE was the only one of the three with a detection frequency (50 percent) greater than 10 percent. MTBE is a gasoline additive used primarily to reduce air pollution and has received recent publicity because of its potential to contaminate ground water. Although the use of MTBE in gasoline in the area has not been mandatory, it likely has been in some of the gasoline supplied to service stations and subsequently entered the environment during refueling at service stations or from engine exhaust, leaking storage tanks, or spills.

The five VOCs most frequently detected in the Medina River at La Coste (fig. 9) are hard to associate with a specific agricultural use. None of the five were detected on the basis of a common concentration of 0.1 µg/L. Two other VOCs, benzene and methylbenzene, were detected on the basis of the common concentration (compared with 15). The frequency of detection for both was 14 percent.

As with pesticides in stream water, the substantially smaller number of VOCs detected and, in general, the reduced frequencies of detection based on a common concentration show that the majority of VOC concentrations were extremely low—less than 1 part contaminant per 10 billion parts water.

Persistent Contaminants That Accumulate in Sediment and Fish Tissue Were Most Prevalent in Urban Streams

The occurrence of environmentally persistent organochlorine compounds (organochlorine insecticides and polychlorinated biphenols [PCB]), semivolatile organic compounds (SVOC) including polycyclic aromatic

Fish for tissue analysis and community status assessment were collected by seining (shown above in the Blanco River near Wimberley) and by electrofishing.

hydrocarbons (PAH), and trace elements (primarily metals) was assessed by measuring their concentrations in stream sediment and fish and clam tissue in key land-use settings. (Urban and urban/effluent dominated samples were grouped together as urban.)

Sediment samples from 15 sites (fig. 6) were analyzed for 32 organochlorine pesticides, total PCBs, and 63 SVOCs. The greatest number of contaminants detected, and generally the highest concentrations (table 2), occurred in urban stream sediment. An average of 26 contaminants per site were found at 6 urban sites. An average of 10 contaminants per site were found at 3 agricultural sites; and an average of 8 contaminants per site were found at 6 rangeland sites.

The total organochlorine pesticide concentrations (sum of concentrations of all pesticides detected at each site) in some urban sediment samples were among the highest of 836 NAWQA stream sites nationwide. Total concentrations at 3 of the 6 urban sites ranked in the top 12 percent. In contrast, no pesticides were detected in sediment from 2 of the 3 agricultural streams, and none were detected in sediment from any of the 6 rangeland sites. PCBs were not detected in any stream-sediment samples.

The stream-sediment samples also were analyzed for 44 trace elements. Although the frequencies of detection were similar among urban, agricultural, and rangeland sites (23 to 28 per site), the concentrations generally were highest in urban sediment (table 2).

For the 27 organochlorine pesticides and total PCBs analyzed in wholebody and carcass (wholebody without liver) fish tissue

Table 2. Concentrations of contaminants in urban, agricultural, and rangeland stream sediment and fish and clam tissue

[Concentrations are average of samples from number of streams listed]

Selected organochlorine pesticides and PAHs in sediment
[Concentrations in micrograms per kilogram, dry weight; <, less than]

	Urban 6 sites	Agri-cultural 3 sites	Range-land 6 sites
Chlordane	7.1	<1.0	<1.0
Total DDT	6.3	.64	<1.0
Total PAHs	1,327	150	90

Selected trace elements in sediment
[Concentrations in micrograms per gram, dry weight]

	Urban 6 sites	Agri-cultural 3 sites	Range-land 6 sites
Arsenic	6.1	4.0	1.7
Cadmium	.5	.2	.3
Chromium	49.5	40.3	17.5
Copper	17.7	9.3	4.5
Lead	40.8	15.7	8.2
Mercury	.1	.01	.1
Selenium	.6	.8	.9
Zinc	93.5	60.3	74.2

Selected organochlorine compounds in wholebody and carcass fish tissue
[Concentrations in micrograms per kilogram, wet weight]

	Urban 4 sites	Agri-cultural 3 sites	Range-land 2 sites
Chlordane	43	7	4
Total DDT	110	26	28
Total PCBs	286	60	16

Selected trace elements in clam tissue
[Concentrations in micrograms per gram, wet weight]

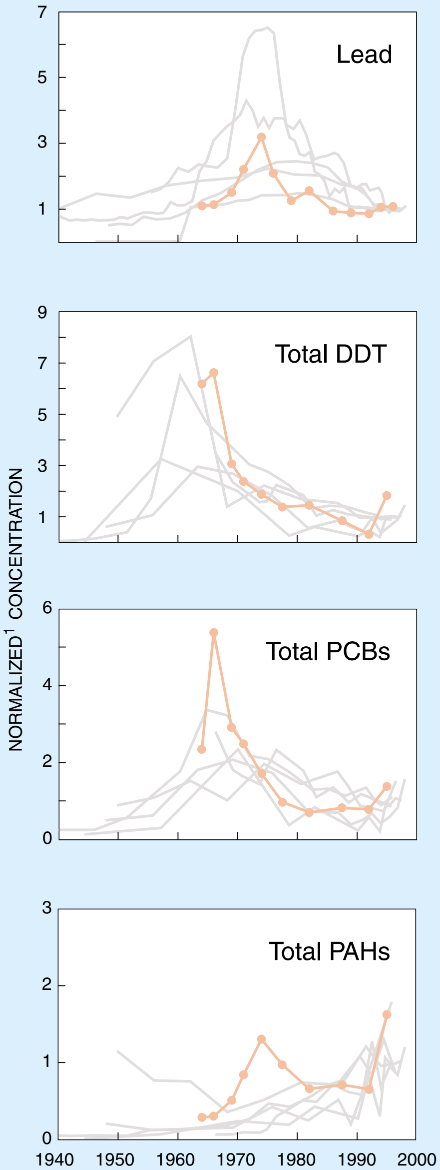
	Urban 4 sites	Agri-cultural 3 sites	Range-land 5 sites
Arsenic	5.9	5.5	4.4
Cadmium	3.8	.5	.4
Chromium	3.9	2.6	1.8
Copper	60	31.0	21.8
Lead	3.3	1.7	.5
Mercury	.2	.03	.1
Selenium	5.4	7.3	6.7
Zinc	277	143	164

from nine sites, the greatest number of contaminants, and generally the highest concentrations (table 2), also were found in urban samples. An average of 5 contaminants per sample were found in 7 urban fish-tissue samples; an average of 2 contaminants per sample were found in 10 agricultural fish-tissue samples; and an average of 2 contaminants per sample were found in 4 rangeland fish-tissue samples. The fish-tissue samples were composites from 3 to 9 fish of the same species, typically common carp (*Cyprinus carpio*).

The total organochlorine pesticide concentrations in urban wholebody and carcass fish-tissue samples ranked in the middle-to-high range among concentrations in wholebody tissue from 505 NAWQA sites nationwide. Three of the 7 urban sample concentrations were in the top 25 percent. As with total organochlorine pesticide concentrations in sediment, concentrations in agricultural and rangeland fish-tissue samples generally were lower than those in urban samples. Only 2 of the 10 agricultural samples and none of the 4 rangeland samples contained total organochlorine pesticide concentrations in the upper 50 percent of concentrations nationwide.

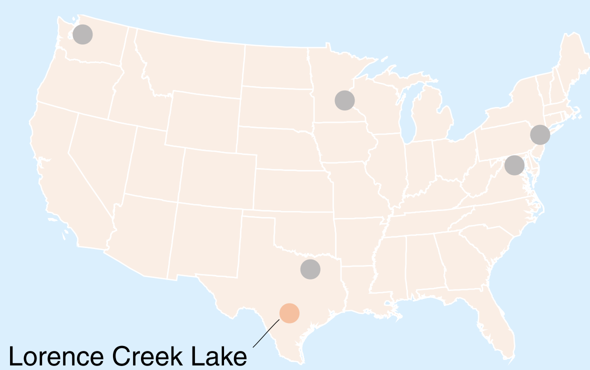
Total PCB concentrations in wholebody and carcass fish-tissue samples generally followed the same pattern. Concentrations were in the top 15 percent of wholebody PCB concentrations nationwide in 4 of the 7 urban samples, 1 of the 10 agricultural samples, and none of the 4 rangeland samples.

Trends in Water Quality Associated With Urban Development, as Reflected in Bottom Sediment of Lakes and Reservoirs, Are Not Unique to San Antonio



The NAWQA Program began a national study of water-quality trends using age-dated bottom-sediment cores in 1992. Ages of core sediment are dated using a combination of physical and chemical markers, specifically the amount of cesium-137 (a radioactive by-product of nuclear weapons testing) at selected depths in the core.

Urban development in watersheds is leaving similar marks on water quality nationwide. Changes in water quality over time as watersheds become more urban are recorded in the successive layers of bottom sediment in lakes and reservoirs (hereinafter, lakes). Soil and debris, and any attached contaminants, carried by runoff to the lakes settle to the bottom. By analyzing short sections of sediment cores (vertical tubes of mud) extracted from lake bottoms across the country, the USGS has been documenting changes in water quality as the watersheds become more developed. Lorence Creek Lake, a small suburban lake in a rapidly urbanizing area in northern San Antonio, fits the pattern observed nationally. Trends in selected contaminants from Lorence Creek Lake sediment [16] generally match those from other lakes in watersheds in different parts of the country that have undergone rapid urban development in recent years. Lead concentrations generally peaked in the mid-1970s and declined appreciably as unleaded gasoline and lower lead content in other products became widespread. Total DDT concentrations generally followed the historical use of DDT in the United States, which peaked from the late 1950s to the mid-1960s and then declined substantially. DDT was banned in 1972. Total PCB concentrations generally peaked in the mid-1960s and declined in the 1970s, reflecting peak production and subsequent regulation of PCBs in the United States. Total PAH concentrations generally have increased substantially since about 1970. PAHs result from the burning of hydrocarbons and other organic material. The lower concentrations in Lorence Creek Lake sediment in the 1980s are thought to be due to washed-in soil from subsurface layers (older and thus low in PAH concentration) associated with major highway construction adjacent to the lake.



Locations of the five lakes in addition to Lorence Creek Lake for which water-quality trends from sediment cores are graphed.

[1] The graphed contaminant concentrations are "normalized" values. That is, the concentrations down each core were divided by the mean concentration of the top three samples in each core. This allows very different concentrations to be graphed together to show similarity in trends.

Nationally and Locally, Biological Community Status Is Related to Watershed Development

Selected biological community status indicators of stream quality nationwide show that stream quality is more likely to be degraded in watersheds dominated by urban and agricultural activities than those that are predominantly undeveloped. Biological community status indicators in the Study Unit generally were consistent with the national results. The algal status at the urban site on the San Antonio River was the highest of all NAWQA biological sites and is a reflection of the high nitrate and phosphorus conditions at the site. The fish status at the site was among the highest 25 percent of NAWQA biological sites. Degraded habitat conditions (mostly unstable sands and muds) likely contributed to the degraded condition of algal and fish communities. These results are consistent with the finding that the quality of water, bed sediment, and fish tissue in the San Antonio River has been affected by proximity to development.

The agricultural streams Medina River, Geronimo Creek, and lower Guadalupe River generally had lower indicator scores than the urban streams, except those for algal status.

The rangeland Sabinal and Frio Rivers had national scores among the lowest 25 percent of NAWQA biological sites. Among biological sites in the Study Unit, these two streams are least affected by urban or agricultural development.

Selected biological indicators[1] of water quality—comparison of upper South-Central Texas Study Unit sites with NAWQA sites[2] nationwide

Stream	Watershed land use[3]	Algal status	Invertebrate status	Fish status
Sabinal River	Rangeland	Lowest 25	Lowest 25	Lowest 25
Frio River	Rangeland	Lowest 25	Lowest 25	Lowest 25
Blanco River	Rangeland	Middle 50	Lowest 25	Middle 50
Guadalupe River (upper)	Mixed (rangeland)	Middle 50	Lowest 25	Middle 50
Medina River	Agricultural	Middle 50	Lowest 25	Lowest 25
Geronimo Creek[4]	Agricultural	Highest 25	Lowest 25	Middle 50
Guadalupe River (lower)	Mixed (agricultural)	Highest 25	Middle 50	Lowest 25
Salado Creek	Urban	Middle 50	Middle 50	Highest 25
San Antonio River	Mixed (urban)	Highest 25	Middle 50	Highest 25

- Lowest 25 percent nationally (least degraded)
- Middle 50 percent nationally
- Highest 25 percent nationally (most degraded)

[1] See Glossary.

[2] Represents 140 sites in the NAWQA national basic- and intensive-site network that have algal, invertebrate, and fish data.

[3] Watershed land use was categorized on the basis of national and local (study-unit) criteria. Where national and study-unit criteria yielded different land-use settings, the study-unit land-use setting is in parentheses.

[4] Not one of the NAWQA national sites.

In clam (*Corbicula*) tissue from 12 sites, the concentrations of trace elements generally were highest in the samples from urban sites (table 2). In fish-liver tissue from nine sites, however, no clear association between trace element concentration and watershed land use was evident.

At some sites, concentrations of some sediment contaminants exceeded the Canadian sediment guidelines for the protection of aquatic life [17]. The guidelines are termed "probable effects levels" (PEL). The PEL is the concentration above which adverse effects on aquatic life are predicted to occur frequently. PELs have been established for 18 of the 43 organochlorine compounds and SVOCs and 8 of the 28 trace elements detected in sediment. In one each of 4 urban sediment samples, DDT, DDE, chlordane, and lead concentrations exceeded the respective PEL; in 1 rangeland sediment sample, the mercury concentration exceeded the PEL.

Guidelines to protect fish-eating wildlife (for the State of New York) [18] have been established for 8 of the 10 organochlorine compounds detected in wholebody and carcass fish tissue but not for the 19 trace elements detected in clam and fish-liver tissue. Total PCB concentrations in 6 of the 7 urban fish-tissue samples and 2 of the 10 agricultural fish-tissue samples exceeded the guideline for PCBs. The guideline for total DDT was exceeded in 1 of the 7 urban fish-tissue samples.

Floodflows, Non-Native Species Can Affect Biological Community Status

Intense rainstorms on terrain conducive to rapid runoff result in frequent floodflows in the Study Unit. In June 1997, about a month before biological samples were collected, severe flooding on the Frio and Sabinal Rivers affected the biological communities, particularly the invertebrates. Estimated recurrence intervals for the peak floodflows at the sampling sites on the Frio and Sabinal Rivers were 15 and 90 years, respectively [19]. For both rivers, the invertebrate communities were more degraded in 1997 than in 1996 and 1998 during considerably drier conditions. Changes in the percentages of certain algae reflected less siltation and reduced nutrient concentrations after scouring floodflows. The fish communities were not noticeably affected by the flooding.

More than 30 non-native aquatic species, many of tropical origin, are known to exist in the Study Unit [20, table 5]. Non-native aquatic species are considered a threat to native species [21]. However, the findings of this study show that native fish species remain dominant at the locations sampled. The redbreast sunfish (*Lepomis auritus*), originally introduced in Texas as a game fish, was the most common non-native fish species, particularly in the Blanco River where clear-flowing water favors this species.

Edwards Aquifer Water Quality Remains Excellent

The quality of water in the Edwards aquifer is “excellent” according to the Edwards Aquifer Authority (EAA), the State agency charged with managing, conserving, preserving, and protecting the aquifer [22]. Comprehensive analyses of water samples from 88 wells (fig. 10) (one sample per well) in the Edwards aquifer in urban, agricultural, and rangeland areas of the recharge and confined zones support that characterization. However, the fact that water samples contained detectable concentrations of pesticides and VOCs, even though the levels were well below allowable maximums in drinking water, shows that human activities can affect the aquifer.

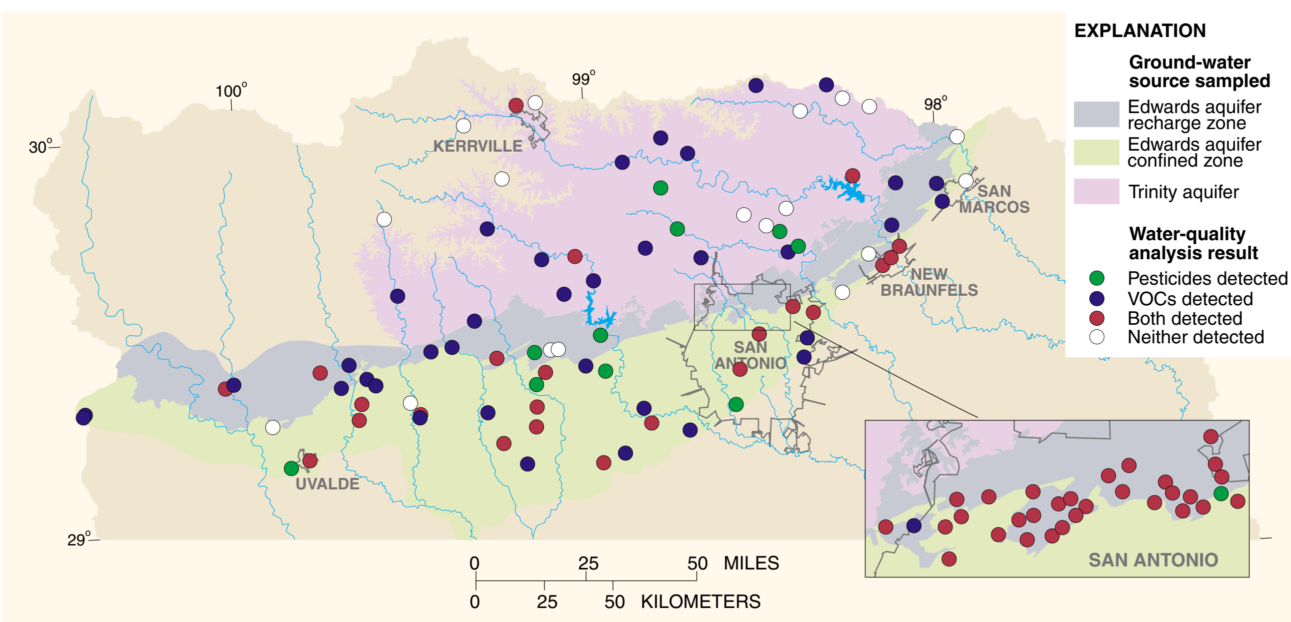


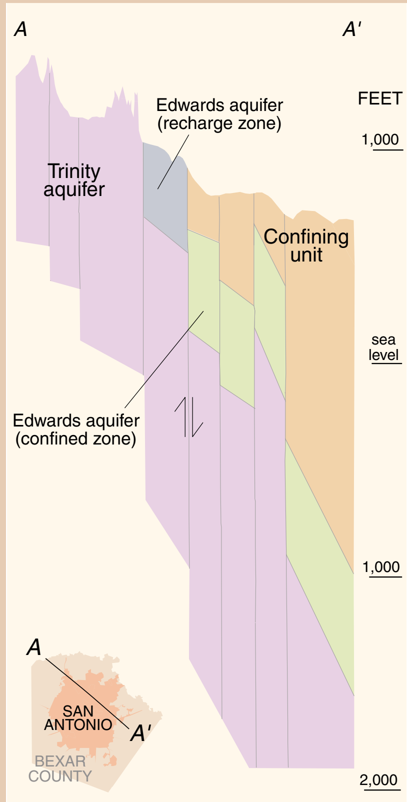
Figure 10. Fifty-eight of the Edwards aquifer wells sampled were in the recharge zone, and 30 were in the confined zone. Most of the recharge-zone wells were for domestic supply or monitoring, and nearly all of the confined-zone wells were for public supply. Almost all of the urban recharge-zone samples contained both pesticides and VOCs. Most of the 31 sampled wells from the upper and middle zones of the Trinity aquifer were for domestic supply. About one-third of the Trinity aquifer samples contained no pesticides or VOCs, and only three samples contained both.

Hydrogeology and Land-Use Distribution—Good for Edwards Aquifer Water Quality

A fortuitous combination of hydrogeology and land-use distribution has helped to maintain the quality of water in the Edwards aquifer. Nearly all agricultural areas and much of San Antonio, the only urban area large enough to affect water quality regionally, overlie the confined zone rather than the recharge zone. In the confined zone, the Navarro-Del Rio confining unit [23], which comprises hundreds of feet of low-permeability rocks, overlies the Edwards aquifer and forms a regional barrier to vertical ground-water flow. The confining unit insulates to a large extent the part of the Edwards aquifer beneath it from the effects of land-use activities.

Additionally, the streams that provide much of the recharge to the aquifer originate in and flow through what is now mostly undeveloped rangeland before reaching the recharge zone of the aquifer; thus, the streams are not carrying urban or agricultural runoff in the recharge water.

Finally, the quality of Edwards aquifer water generally is enhanced by the dynamic nature of the ground-water-flow system. Since the mid-1930s, the annual flow through the system has averaged about 680,000 acre-feet [24, table 1]. One estimate of regional ground-water velocity in the aquifer is 27 feet/day [25, p. 82]. Under those conditions, contaminants tend to be diluted and have less chance of remaining stationary and accumulating than they would in a less dynamic system.



Modified from [23, pl. 3].

The occurrence of contaminants in the Edwards aquifer is influenced by hydrogeology and land use. The faulted and fractured limestone of the Edwards aquifer recharge zone allows unrestricted downward movement of water containing contaminants into the ground-water-flow system, whereas the confined zone has a buffer (confining unit) between land surface and the aquifer that restricts the downward movement of water and contaminants. (See box above.) Thus, within the recharge zone, land use noticeably influences water quality; but in the confined zone, land use has much less effect.

Nutrient Concentrations Were Low

Nitrate, which dissolves readily in water, is widespread in the Edwards aquifer. It was detected in all but 1 of 88 samples. The median nitrate concentration was 1.4 mg/L in the recharge zone and 1.7 mg/L in the confined zone.

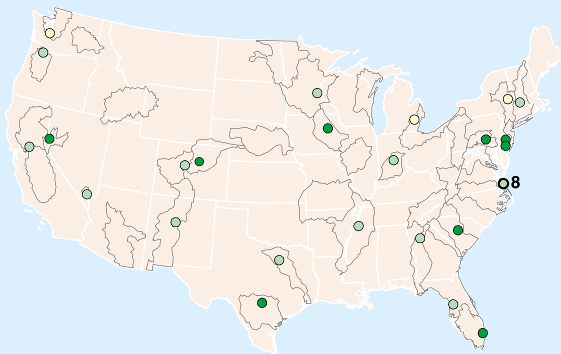
Primarily public-supply wells were sampled in the confined zone. The median concentration of 1.7 mg/L in that zone, although well below the USEPA MCL for drinking water (10 mg/L), was in the top 10 percent of median nitrate concentrations of major aquifers sampled by NAWQA nationwide. The highly permeable, faulted and fractured rocks of the recharge zone readily allow infiltration of water that contains nitrate and dissolved oxygen. Nitrate is more stable under aerobic conditions. Nitrate commonly migrates large distances from recharge areas in fractured-rock aquifers that contain considerable dissolved oxygen [26]. The median dissolved oxygen concentration in the confined zone was 6.0 mg/L.

Orthophosphate, which accounts for nearly all the dissolved phosphorus, was less prevalent than nitrate. Orthophosphate was detected in 49 of 88 well-water samples. Concentrations throughout the aquifer were low; the median concentration was 0.015 mg/L.

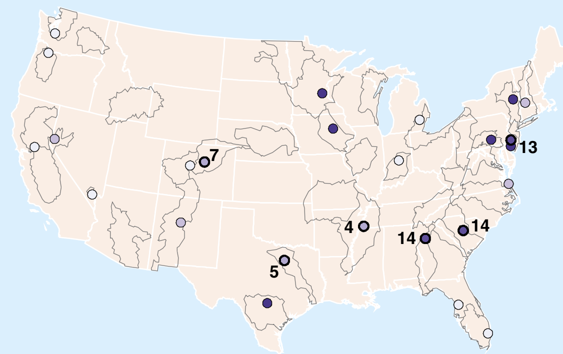
Pesticide Concentrations Were Substantially Less Than Drinking-Water Standards and Guidelines, and Detections Were Most Frequent in Urban Recharge-Zone Wells

Seventeen of the 83 pesticides analyzed in recharge-zone samples and 18 of the 47 pesticides analyzed in confined-zone samples were detected (fig. 10); 17 of 18 were the same in both zones. At least one-half of the water samples with a pesticide detection contained two or more pesticides. The concentration of each of the

The Frequencies of Pesticide Detection in Ground Water Vary in Comparison With Those in Ground Water Nationally—Compounds Detected Were the Same

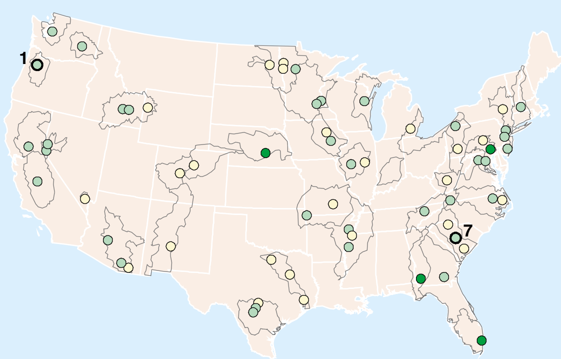


Herbicides in shallow ground water in urban areas

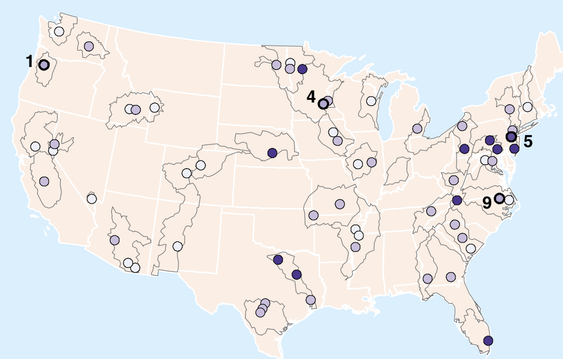


Insecticides in shallow ground water in urban areas

The maps are based on data from 25 urban ground-water land-use studies and 63 major aquifer surveys from NAWQA Study Units across the country. Most samples for land-use studies were collected from monitor wells. Most samples for major aquifer surveys were collected from domestic and public-supply wells.



Herbicides in major aquifers



Insecticides in major aquifers

The frequencies of detection of herbicides and insecticides in recently recharged urban ground water in northern San Antonio (Edwards aquifer recharge zone) ranked among the highest 25 and 30 percent, respectively, of frequencies of detection in urban shallow ground water across the country. The same four pesticides—the herbicides atrazine, deethylatrazine, prometon, and simazine—were the most frequently detected in both northern San Antonio ground water and urban shallow ground water nationwide.

The frequency of detection of herbicides in the Edwards aquifer was in the middle 50 percent of major aquifers nationally, and the frequency of detection of herbicides in the Trinity aquifer was in the lowest 25 percent. For insecticides, Edwards and Trinity aquifer water ranked in the middle 45 percent of frequencies of detection in major aquifers nationally. Atrazine, deethylatrazine, prometon, and *p,p′*-DDE were the pesticides most frequently detected in major aquifers both locally and nationally.

Locally, herbicides were detected at a much greater frequency than insecticides. As the map explanation indicates, national ground-water data show the same finding.

EXPLANATION

Study-unit boundary

Herbicide detection frequency

- Highest 25 percent (greater than 62.10 percent detection)
- Middle 50 percent (19.40–62.10 percent detection)
- Lowest 25 percent (less than 19.40 percent detection–no detections)

Insecticide detection frequency

- Highest 30 percent (greater than 10.70 percent detection)
- Middle 45 percent (2.60–10.70 percent detection)
- Lowest 25 percent (less than 2.60 percent detection–no detections)

7 **Drinking-water standards or guidelines—** Bold outline indicates exceedance by one or more pesticide concentrations. Number is percentage of well-water sample concentrations that exceeded a standard or guideline.

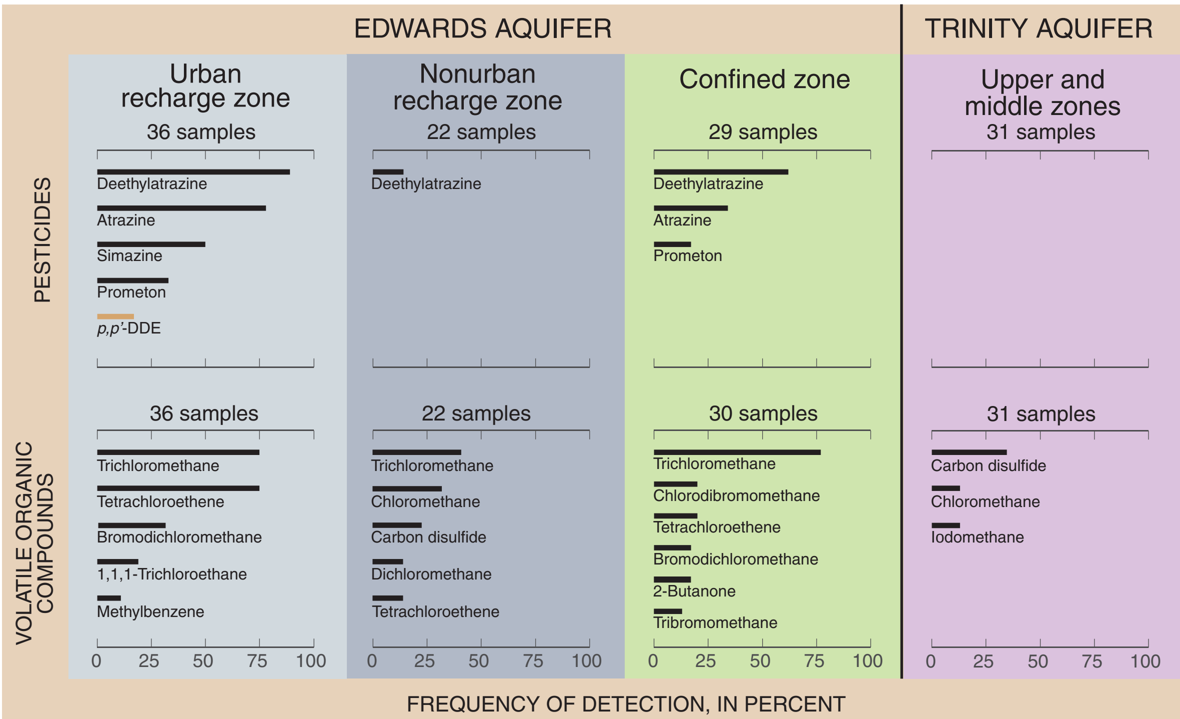


Figure 11. Pesticides and VOCs in the Edwards aquifer were most frequently detected in urban recharge-zone wells. Shown are those pesticides and VOCs detected in more than 10 percent of samples. Only one insecticide, *p,p′*-DDE (shaded brown), a breakdown product of DDT, was detected in more than 10 percent of samples; the other pesticides shown here are herbicides.

13 pesticides detected for which drinking-water standards or guidelines have been established was substantially less than the respective allowable maximum [27]. However, standards for combinations of pesticides have not been established, and very little is known about the effects of mixtures of pesticides on human health.

More pesticides were detected and frequencies of detection were greater in urban recharge-zone samples than in nonurban recharge-zone or confined-zone samples (fig. 11). Pesticide usage in urban areas likely is higher than in nonurban areas in the recharge zone. Nonurban areas in the recharge zone primarily are rangeland where usage is nonexistent or very low. Little if any direct (downward) recharge occurs in the confined zone compared with the recharge zone. Although pesticide usage in urban and agricultural areas overlying the confined zone could be greater, fewer pesticides will reach the aquifer because of the lack of direct recharge.

As was the case for stream water, the pesticide detection picture changes considerably when detection frequency is based on a common concentration of 0.05 µg/L. Among urban recharge-zone samples, only five pesticides were detected (compared with 17 without regard to a common concentration). Atrazine was the most frequently detected but only in 5.6 percent of the samples. On the basis of the common concentration, no pesticides were detected in any nonurban recharge-zone or confined-zone samples (compared with 5 and 6, respectively, without regard to a common concentration). As in stream water, the majority of pesticide detections thus represent concentrations of less than 1 part contaminant per 20 billion parts water.

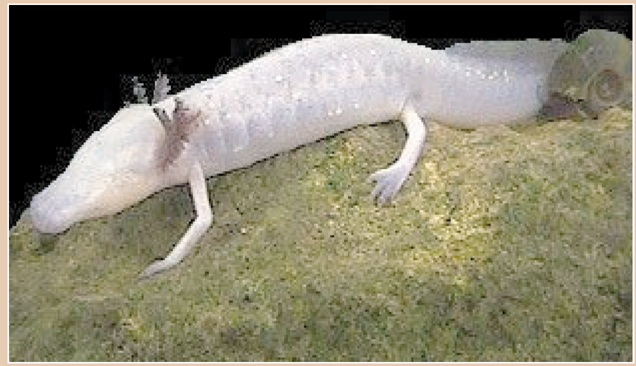
The Most Frequently Detected Pesticides Were the Same in Ground Water and Surface Water

Four of the 5 pesticides most frequently detected in ground water from urban recharge-zone wells—the herbicides deethylatrazine, atrazine, simazine, and prometon (fig. 11)—were the same as 4 of the 5 pesticides most frequently detected in urban streams (Salado Creek at San Antonio and San Antonio River at Elmendorf) (fig. 9). Although both sites are

The Edwards Aquifer Harbors Diverse Subterranean and Unique Spring-Dependent Aquatic Species

The Edwards aquifer contains one of the most diverse subterranean biological communities in the world. At least 43 species of underground aquatic animals can be found [21], including two species of blind catfish (a predator and a forager) living several hundred feet below the surface at San Antonio [28]. The blind catfishes' highly modified adaptations to cave life, including degree of eye reduction, are evidence that these animals are among the oldest of cave fish, having entered the ground-water system as long as 20 million years ago. Organic matter brought in from distant recharge areas would not be sufficient to support these fish and the other animals living in the deep parts of the aquifer. Rather, the aquifer is sustaining an ancient self-contained community, with hydrogen-sulfide-fixing bacteria possibly the primary food source.

An additional 47 surface-water species are found only in the aquifer's associated springs and spring runs. With this high diversity of unique, geographically restricted organisms, it is not surprising that 13 of the subterranean and spring-dwelling species—5 salamanders, 4 fish, 3 invertebrates, and 1 plant—are federally or State-listed as endangered or threatened. The spring-dwelling species are dependent on the consistent quantity and quality of flow from Comal and San Marcos Springs for their survival.



The colorless, eyeless, and gilled Texas blind salamander (*Tyhlomolge rathbuni*) is an endangered species that lives in the subterranean waters below San Marcos. (Photograph by J.N. Fries, U.S. Fish and Wildlife Service.)

downstream from the recharge zone, the contaminants detected at the sites likely are typical of contaminants in urban runoff in northern San Antonio, which is in the recharge zone.

Atrazine and deethylatrazine were the most frequently detected pesticides in Edwards aquifer water and were among the top three most frequently detected pesticides in stream water. Although atrazine was detected in more than three-fourths of urban recharge-zone wells, the maximum measured concentration was about 23 times less than the drinking-water MCL, 3 µg/L. No drinking-water standard or guideline has been established for deethylatrazine.

Two Volatile Organic Compounds Were Frequently Detected at Low Concentrations

Thirty-four of 86 VOCs analyzed were detected in samples from Edwards aquifer wells. Unlike pesticides, the fewest VOCs (12) were detected in urban recharge-zone samples. Sixteen were detected in nonurban recharge-zone samples, and 27 were detected in confined-zone samples. In general, however, frequencies of detection were greatest in urban recharge-zone samples.

Trichloromethane, the most frequently detected VOC, was detected in three-fourths of the urban recharge-zone and confined-zone samples (fig. 11). Measured concentrations of trichloromethane were very low; the largest was about 80 times less than the drinking-water MCL, 100 µg/L.

Tetrachloroethene also was frequently detected. It was detected in three-fourths of the urban recharge-zone samples. The largest measured concentration of tetrachloroethene was about 12 times less than the drinking-water MCL, 5 µg/L.

When detection frequency is based on a common concentration of 0.1 µg/L, only 7 VOCs were detected—5 in urban recharge-zone samples, 3 in nonurban recharge-zone samples, and 5 in confined-zone samples. Trichloromethane remained the most frequently detected VOC, but it was detected only in about 20 percent of urban and nonurban recharge-zone samples. No other VOC was detected in more than 10 percent of recharge-zone or confined-zone samples.

MTBE, a gasoline additive of recent concern because of its potential to contaminate ground water, was detected in 2 samples, 1 from the urban recharge zone and 1 from the confined zone. Concentrations were more than 200 times less than the lifetime health advisory, 20 µg/L.

Analyses Show Very Low Concentrations of Arsenic—Detections of Lead Could Be Related to Well Construction

Arsenic, ranked first on the Agency for Toxic Substances and Disease Registry (ATSDR) and USEPA 1999 list of priority hazardous substances [29], was detected at concentrations many times less than the current (2000) drinking-water MCL of 50 µg/L (fig. 12). The median concentration of this naturally occurring element was about 1 µg/L, still less than a proposed new standard of 5 µg/L that is being considered for adoption by the USEPA in 2001.

Lead, ranked second on the ATSDR and USEPA 1999 list of priority hazardous substances, also was detected in Edwards aquifer samples. Lead concentrations ranged from 1 to 9 µg/L with a median of about 2 µg/L (fig. 12), well below the drinking-water action level for lead, 15 µg/L. Lead was detected only in previously existing domestic and public-supply wells and not in any of 30 PVC monitor wells. The monitor wells were constructed in the urban recharge zone in cooperation with the Edwards Aquifer Authority as a part of the 1996–98 assessment. This finding indicates that detections of lead could be related to metal parts of the wells or pumps.

Radon Was Prevalent in the Edwards Aquifer, But Concentrations Were Low Compared With Other Study Units

Radon is a colorless, odorless, radioactive gas that forms naturally from uranium in rocks. Ground water in contact with some rock types—for example, light-colored volcanic rocks, granites, and dark-colored shales—can contain elevated concentrations of radon [30].

Radon was detected in 41 of 58 wells in the Edwards aquifer. (Radon was not analyzed in samples from the 30 monitor wells constructed in the urban recharge zone.) Concentrations ranged from 80 to 780 picocuries per liter (pCi/L), with a median concentration of 150 pCi/L. The 75th-percentile radon concentration in samples from wells completed in the Edwards and Trinity aquifers ranked 32 among 35 NAWQA Study Units nationwide.

Radon dissolved in water generally poses a smaller health risk than radon in indoor air, which has been linked to lung cancer in humans [31]. The USEPA has proposed an MCL for radon in drinking water of 300 pCi/L and an alternative MCL of 4,000 pCi/L, the higher level applicable when accompanied by a

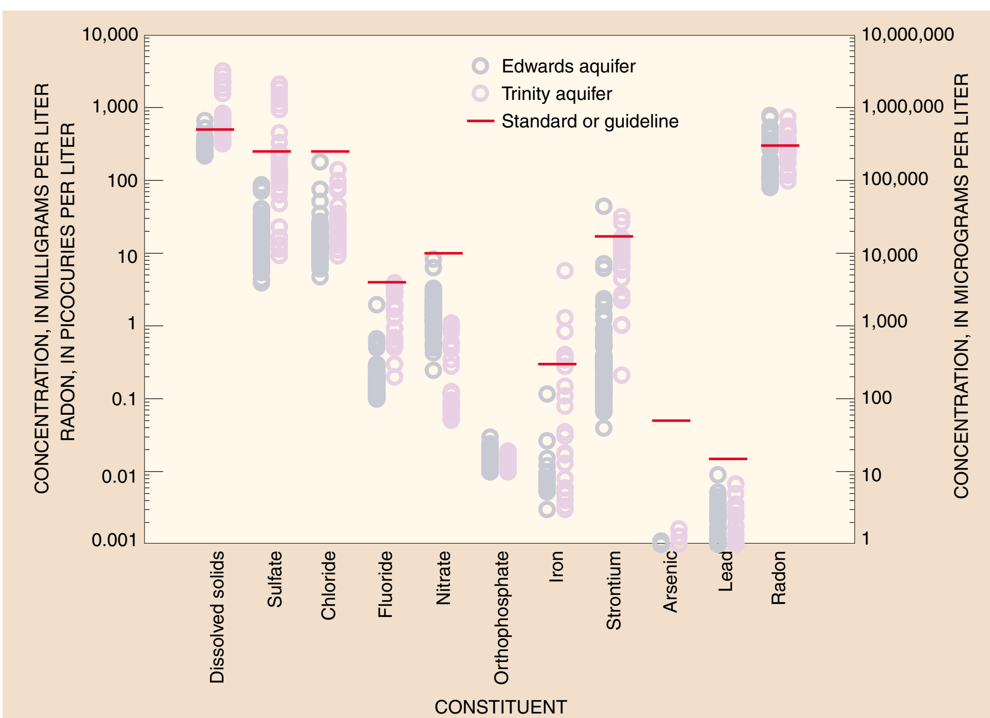


Figure 12. A comparison of concentrations in samples from wells completed in the Edwards and Trinity aquifers shows that, in general, the Trinity aquifer contains higher concentrations of dissolved constituents than the Edwards aquifer.

mitigation program to address radon risks in indoor air. About 25 percent of the sample concentrations from the Edwards aquifer exceeded the proposed MCL of 300 pCi/L.

Trinity Aquifer Water Quality Is Mostly Unaffected by Human Activities

As in the Edwards aquifer, the presence of pesticides and VOCs in ground water of the upper and middle zones of the Trinity aquifer is evidence that human activities can affect the aquifer; but as of the late 1990s, the effects of human activities were minimal. The concentrations of these contaminants were well below drinking-water standards and guidelines, and the water quality of the aquifer remains influenced primarily by the natural processes of water interacting with surrounding rock. Concentrations of some of the products of these natural processes—dissolved solids, sulfate, and iron—exceeded nonenforceable guidelines related to esthetic effects in drinking water in some samples; some concentrations of strontium and radon exceeded a lifetime health advisory (strontium) and a proposed drinking-water standard (radon).

In the largely undeveloped Hill Country, 28 of 31 mostly domestic wells sampled were in rangeland settings, 2 were in urban settings, and 1 was in an agricultural setting. Because of the predominance of rangeland, the hydrogeologic characteristics of the aquifer, and the depth to water—the median depth to water in sampled wells was 209 feet—land use probably has not been a major influence regionally on aquifer water quality.

Although Both the Trinity and Edwards Aquifers Predominantly are Limestone, Hydrogeologic Differences Contribute to Differences in Water Quality

Trinity aquifer water generally is more mineralized than Edwards aquifer water (fig. 12); Edwards aquifer water tends to contain higher nitrate concentrations and more pesticides and VOCs.

Some of the hydrogeologic characteristics that result in natural mineralization of Trinity aquifer water—low permeability and a sluggish flow system—tend to slow the downward movement of water that could contain contaminants. Trinity aquifer rocks are less permeable than those of the Edwards aquifer, with fewer faults and fractures to provide pathways for water movement. Water flows more slowly in the Trinity aquifer than in the Edwards aquifer, which allows more time for minerals in the Trinity aquifer rocks to dissolve. Tritium concentrations from more than one-half the Trinity aquifer water samples indicate that the water is older (at least 50 years) than most of the Edwards aquifer water. Most of the Edwards aquifer water samples had tritium concentrations that indicate recharge within the last decade. (Tritium is a radioactive isotope of hydrogen that is particularly suited for recharge studies because it enters the hydrologic cycle as part of the water molecules, and its concentrations in precipitation were increased substantially by atmospheric nuclear testing during the 1950s and early 1960s.)

Sluggish flow associated with low permeability implies that the downward movement of water, and potentially the downward movement of contaminants, is much slower in the Trinity aquifer than in the Edwards aquifer recharge zone. Downward flow in the Trinity aquifer is further restricted, and diverted laterally to incised streams, by resistant beds of shale, marl, and limestone, particularly in the upper zone; similar impediments to downward flow are not present in the Edwards aquifer recharge zone.

A typical Edwards aquifer sample—more permeable than the Trinity aquifer, even without faults or fractures.

A typical Trinity aquifer sample—conspicuously lacking the permeability of the Edwards aquifer.

Natural Water Chemistry Affects Water Quality

The 31 Trinity aquifer wells yielded hard water that generally was high (greater than 500 mg/L) in dissolved solids and rich in calcium, bicarbonate, magnesium, and sometimes sulfate. The concentrations of some common constituents (fig. 12) illustrate the chemical variability of Trinity aquifer water and, in large part, reflect the mineral composition of the rocks that compose the aquifer. Dissolved solids concentrations in 19 of 31 samples were greater than the USEPA nonenforceable drinking-water guideline of 500 mg/L. Five of 31 sulfate sample concentrations exceeded a similar nonenforceable guideline of 250 mg/L. Iron was detected in 23 of 31 samples, and concentrations exceeded the nonenforceable guideline of 0.3 mg/L in 7 of the samples. Strontium, which was detected in each of 29 samples, exceeded the USEPA lifetime health advisory level of 17 mg/L in 2 of the 29 samples.

Nutrient Concentrations Were Very Low

Nitrate was detected in 27 of the 31 well-water samples but generally at very low concentrations. The median concentration was 0.12 mg/L. Although the water that recharges the Trinity aquifer and much of the water that recharges the Edwards aquifer originate in the same region—the Edwards Plateau—the median nitrate concentration in Trinity aquifer samples was about 14 times less than that in Edwards aquifer recharge-zone samples. The difference largely is attributable to the ease with which water flows vertically to the subsurface in the Edwards aquifer recharge zone relative to that in the Trinity aquifer.

Orthophosphate was detected in 16 of the 31 well-water samples. As with nitrate, concentrations were very low. The median concentration was 0.015 mg/L.

Few Pesticides Were Detected—And Concentrations Were Very Low

Only 4 of 83 pesticides analyzed were detected in 7 of the 31 Trinity aquifer well-water samples (fig. 10). Atrazine was detected in 3 samples, prometon in 2 samples, and chlorpyrifos and diazinon in 1 sample each. Unlike Edwards aquifer and national NAWQA findings that show that pesticides commonly occur in mixtures of several compounds [13], none of the samples contained more than one pesticide.

The pesticide concentration in each sample was very low—at or near the minimum reporting level—and tens of times less than the applicable drinking-water standard or guideline. When detection frequency is based on a common concentration of 0.05 µg/L, no pesticides were detected in any Trinity aquifer water sample.

VOCs Were Detected More Frequently Than Pesticides—Also at Very Low Concentrations

Analyses of water samples from 31 Trinity aquifer wells detected 16 VOCs of the 86 analyzed. Carbon disulfide was the VOC most frequently detected (fig. 11); it was detected in 11 of 31 samples.

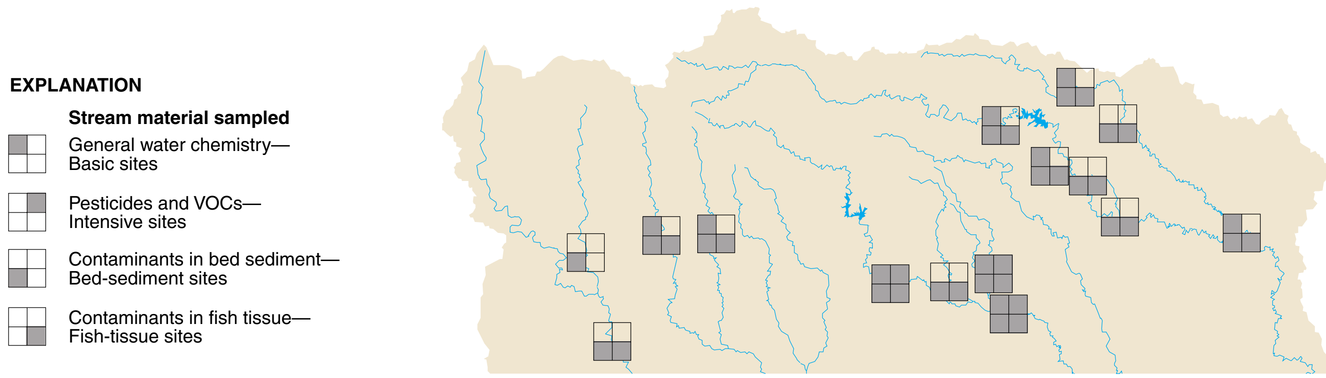
NAWQA sampling protocols and procedures are detailed, exacting, and identical nationwide to reduce inconsistencies and enhance the quality of data for use in spatial and trend analysis. Here, a hydrologist is ensuring that the chemistry of the water is stable and representative of the aquifer before actual sampling of a domestic well begins.

None of the eight VOCs detected for which drinking-water standards or guidelines have been established had concentrations near those standards or guidelines. MTBE was not detected in any sample. On the basis of a common concentration of 0.1 µg/L, the number of VOCs detected dropped from 16 to 3, which reiterates the fact that VOC concentrations were very low. The three VOCs were detected in only one sample each.

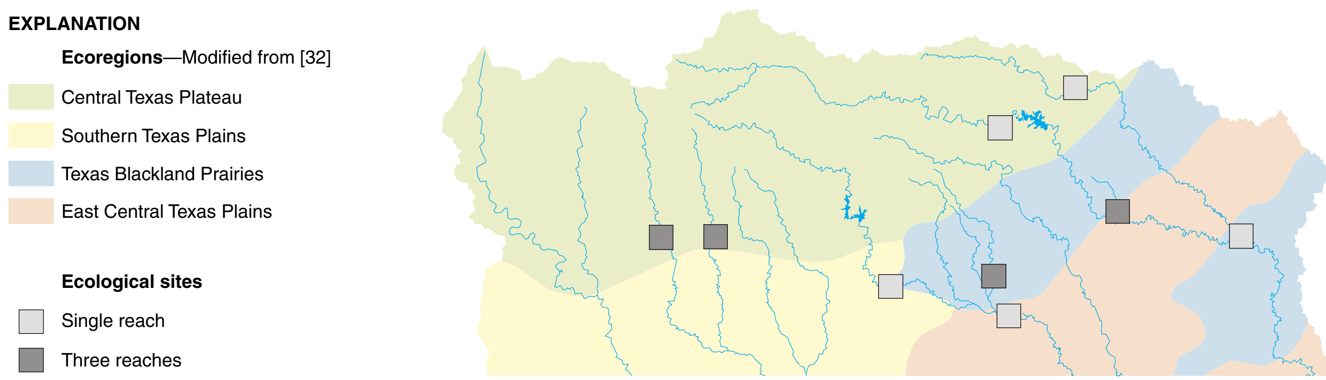
Arsenic and Lead Concentrations Were Low; Radon Concentrations Were Higher Than in Edwards Aquifer

As in the Edwards aquifer, arsenic and lead were detected in the Trinity aquifer at low concentrations relative to current (2000) or proposed drinking-water standards. All arsenic concentrations were less than 2 µg/L (fig. 12); the median lead concentration was 2.1 µg/L. Whether lead is actually in the aquifer or was introduced by metal parts associated with the wells is unknown.

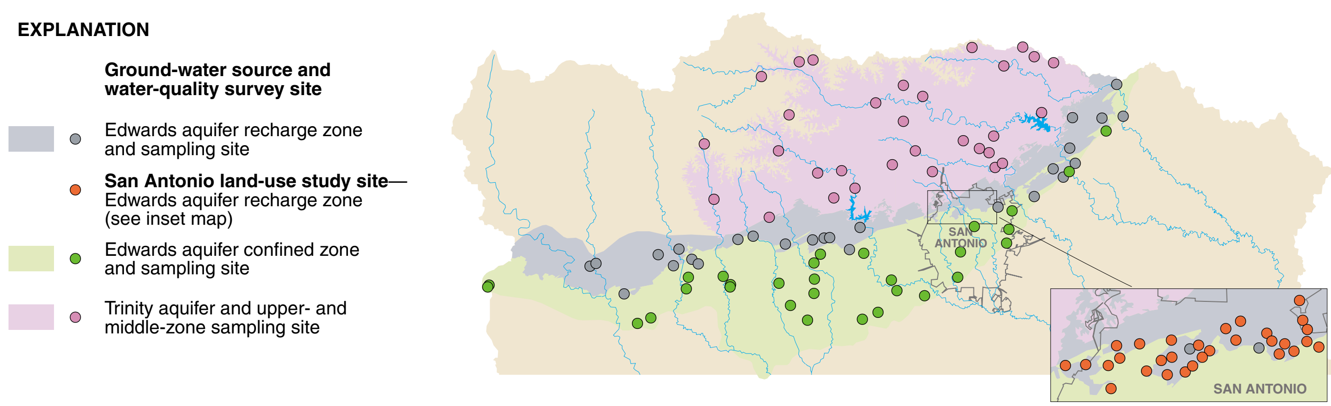
Radon was detected in 30 of 31 Trinity aquifer water samples in concentrations throughout a range similar to that in Edwards aquifer samples (fig. 12). The median concentration, 295 pCi/L, was about twice that in Edwards aquifer samples and about the same as the USEPA-proposed MCL of 300 pCi/L. The median radon concentration of Trinity aquifer samples is greater than that of Edwards aquifer samples probably because granitic rocks north of the Hill Country, the likely source of the radon, are closer to the Trinity aquifer than to the Edwards aquifer.



Stream Chemistry—Basic and intensive sites were selected primarily to assess the occurrence and distribution of dissolved compounds in stream water. Basic sites were sampled less frequently and for fewer compounds than intensive sites. Intensive sites were sampled to evaluate the seasonal effects of land use on water quality and to determine the occurrence of pesticides and VOCs. Sampling of streambed sediments and fish tissue was done to assess the occurrence and distribution of organic compounds and trace elements.



Stream Ecology—The primary objective of the stream ecology component was to assess surface-water quality by integrating physical, chemical, and biological factors. Therefore, the ecological sites were primarily the same as the basic sites. Ecological sites, some with one reach and some with three reaches, were distributed among different land uses and ecological regions.



Ground-Water Chemistry—Aquifer surveys were done to provide a broad assessment of water quality in the Edwards aquifer (recharge and confined zones) and the Trinity aquifer (upper and middle zones). The aquifer surveys involved sampling primarily existing domestic and public-supply wells. The primary objective of the land-use study was to characterize the effects of urban land use on the quality of recently recharged ground water in the Edwards aquifer. A second objective was to learn more about the human and natural factors that affect ground-water quality.

SUMMARY OF DATA COLLECTION IN THE UPPER PART OF THE SOUTH-CENTRAL TEXAS STUDY UNIT, 1996–98

Study component	What data were collected and why	Types of sites sampled	Number of sites	Sampling frequency and period
Stream Chemistry				
Basic sites—General water chemistry	Streamflow, field parameters,[1] major ions, nutrients, organic carbon, and suspended sediment to determine concentrations and seasonal variations	Streams draining basins ranging in size from 130 to 3,500 square miles and representing urban, agricultural, and rangeland use	9	Monthly plus storms; April 1996–June 1998
Intensive sites—Pesticides and VOCs	Constituents for basic sites plus 83 pesticides and 86 VOCs to determine concentrations and seasonal variations	A subset of basic sites draining urban and agricultural land-use areas	3	Weekly to monthly plus storms; January 1997–March 1998
Bed-sediment sites—Contaminants in bed sediment	Total PCBs, 32 organochlorine pesticides, 63 SVOCs, and 44 trace elements to determine occurrence and spatial distribution	Depositional zones of all basic and intensive sites, and six additional similar sites for increased spatial distribution	15	Once; August 1995,[2] November 1996, November 1997, or February 1998
Fish-tissue sites—Contaminants in fish tissue	Total PCBs, 27 organochlorine pesticides, and 22 trace elements in fish and clam tissue to determine occurrence	All basic and intensive sites, and five additional similar sites for increased spatial distribution	14	Once at 8 sites, 2–3 times at 6 sites; selected months August 1995[2]–February 1998
Stream Ecology				
Single-reach assessment	Fish, macroinvertebrates, algae, and aquatic and riparian habitat surveys to assess ecological conditions at a single stream reach	Stream reaches collocated with basic sites draining urban, agricultural, and rangeland areas	9	Yearly for 3 years; July–August 1996, 1997, 1998
Multiple-reach assessment	Fish, macroinvertebrates, algae, and aquatic and riparian habitat surveys to assess ecological conditions at three stream reaches	Stream reaches collocated with a subset of basic sites draining urban, agricultural, and rangeland areas	4	Once; July–August 1996
Ground-Water Chemistry				
Aquifer survey—Edwards aquifer recharge zone	Field parameters,[1] turbidity, major ions, nutrients, organic carbon, trace elements, 83 pesticides, 86 VOCs, radon, and tritium to describe the spatial distribution of ground-water quality	Primarily existing open-hole domestic wells less than 600 feet deep, selected using a statistically based random process	28	Once; June–August 1996
Aquifer survey—Edwards aquifer confined zone	Field parameters,[1] turbidity, major ions, nutrients, organic carbon, trace elements, 47 pesticides, 86 VOCs, radon, and tritium to describe the spatial distribution of ground-water quality	Primarily existing open-hole public-supply wells 400–2,700 feet deep, selected using a statistically based random process	30	Once; June–August 1997
Aquifer survey—Trinity aquifer upper and middle zones (undifferentiated)	Field parameters,[1] turbidity, major ions, nutrients, organic carbon, trace elements, 83 pesticides, 86 VOCs, radon, and tritium to describe the spatial distribution of ground-water quality	Primarily existing open-hole domestic wells less than 800 feet deep, selected using a statistically based random process	31	Once; June–August 1996
Land-use study—Edwards aquifer recharge zone in San Antonio	Field parameters,[1] turbidity, major ions, nutrients, organic carbon, trace elements, 83 pesticides, 86 VOCs, and chlorofluorocarbons to assess effects of urban land use on the quality of recently recharged ground water	Monitor wells 180–320 feet deep, constructed in light-commercial and residential land-use areas in metropolitan San Antonio at sites selected using a statistically based random process	30	Once; October–December 1998
Special Studies				
Paired watershed study in the Edwards aquifer recharge zone	Streamflow, specific conductance, alkalinity, pH, major ions, nutrients, suspended sediment, trace elements, and 83 pesticides to compare quality of stormwater runoff from an urbanizing watershed and a rangeland watershed	Two small (less than 2 square miles) watersheds in the Edwards aquifer recharge zone: one an urbanizing watershed in northern San Antonio and the other a rangeland watershed in Uvalde County	2	Eight storms; August 1996–February 1998
Lorence Creek Lake bottom-sediment core study	Selected trace elements, organochlorine compounds, and PAHs to determine historical occurrence of contaminants in the watershed of a small (4 acres) lake in suburban San Antonio	Two cores collected at the center of the lake (deepest part)	1	Once; August 1996
Guadalupe River Basin study	Streamflow, field parameters,[1] major ions, nutrients, organic carbon, suspended sediment, trace elements, bacteria, and 83 pesticides to assess possible effects of recreation, urbanization, and agriculture in the basin	Selected reaches upstream and downstream from cities and tributaries	21	Twice; December 1996–January 1997, and June 1997 (some sites) and June 1998 (remaining sites)

[1] Field parameters are water temperature, specific conductance, dissolved oxygen, alkalinity, and pH.
[2] A few data were collected before the 1996–98 sampling period.

Action level—A concentration that, when reached, triggers public water systems to take treatment steps if the action level is exceeded in more than 10 percent of tap-water samples.

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

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

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

Biological indicator—A quantitative measure of biological conditions that may reflect habitat disturbance, chemical contamination, or naturally harsh conditions. The status of algae, invertebrates (insects, worms, and clams), or fish provides a record of water quality and stream conditions that water-chemistry indicators might not reveal. Algal status focuses on changes in the percentage of certain algae in response to increasing siltation and higher nutrient concentrations in many regions. Invertebrate status averages 11 metrics that summarize changes in richness (number of taxa), tolerance, trophic conditions, and dominance associated with water-quality degradation. Fish status sums the scores of four metrics (percentages of tolerant, omnivorous, and non-native individuals, and percentage of individuals with anomalies) that increase in response to water-quality degradation. Indicator scores increase as habitat disturbance, chemical contamination, or harsh conditions increase.

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

Carbonate rocks—Rocks (such as limestone or dolostone) that are composed primarily of minerals (such as calcite and dolomite) containing the carbonate ion (CO_3^{2-}).

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

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

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

Constituent—A chemical or biological substance in water, sediment, or biota that can be measured by an analytical method.

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

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

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

Lifetime health advisory—An advisory guideline for drinking-water exposure over a 70-year lifetime, considering noncarcinogenic adverse health effects.

Maximum contaminant level (MCL)—Maximum permissible level of a contaminant in water that is delivered to any user of a public water system. MCLs are enforceable standards established by the U.S. Environmental Protection Agency.

Minimum reporting level—The smallest measured concentration of a constituent that may be reliably reported using a given analytical method.

Monitor well—A well designed for measuring water levels and testing ground-water quality.

Outcrop—That part of a geologic formation that is exposed at land surface.

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

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

Permeability—A measure of the relative ease of fluid flow in porous rocks.

Picocurie (pCi)—One trillionth (1×10^{-12}) of the amount of a radioactive nuclide represented by a curie (Ci). A curie is the quantity of any radioactive nuclide that yields 3.7×10^{10} radioactive disintegrations per second (dps). A picocurie yields 0.037 dps, or 2.22 disintegrations per minute.

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

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.

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.

Species (taxa) richness—The number of species (taxa) present in a defined area or sampling unit.

Subcrop—That part of a geologic formation that is buried; that is, not exposed at land surface.

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

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

Volatile organic compound (VOC)—An organic chemical that has a high vapor pressure relative to its water solubility. VOCs include components of gasoline, fuel oils, and lubricants, as well as organic solvents, fumigants, some inert ingredients in pesticides, and some by-products of chlorine disinfection.

Water-quality guideline—Specific level of water quality which, if reached, might adversely affect human health or aquatic life. Water-quality guidelines are nonenforceable and are issued by a governmental agency or other institution.

Water-quality standard—State-adopted and U.S. Environmental Protection Agency-approved ambient standard for water bodies. Standards include the use of the water body and the water-quality criteria that must be met to protect the designated use or uses.

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APPENDIX—WATER-QUALITY DATA FROM SOUTH-CENTRAL TEXAS IN A NATIONAL CONTEXT

For a complete view of South-Central Texas data and for additional information about specific benchmarks used, visit our Web site at http://water.usgs.gov/nawqa/. Also visit the NAWQA Data Warehouse for access to NAWQA data sets at http://infotrek.er.usgs.gov/wdbctx/nawqa/nawqa.home.

This appendix is a summary of chemical concentrations and biological indicators assessed in South-Central Texas. Selected results for this Study Unit are graphically compared to results from as many as 36 NAWQA Study Units investigated from 1991 to 1998 and to national water-quality benchmarks for human health, aquatic life, or fish-eating wildlife. The chemical and biological indicators shown were selected on the basis of frequent detection, detection at concentrations above a national benchmark, or regulatory or scientific importance. The graphs illustrate how conditions associated with each land use sampled in South-Central Texas compare to results from across the Nation and how conditions compare among the several land uses. Graphs for chemicals show only detected concentrations and, thus, care must be taken to evaluate detection frequencies in addition to concentrations when comparing study-unit and national results. For example, simazine concentrations for monitor-well samples of ground water in urban areas were similar to the national distribution, but the detection frequency was much higher (57 percent compared with 18 percent).

CHEMICALS IN WATER

Concentrations and detection frequencies, South-Central Texas, 1996–98—Detection sensitivity varies among chemicals and, thus, frequencies are not directly comparable among chemicals. Surface-water graphs do not include data from storm composite samples collected in the South-Central Texas Study Unit

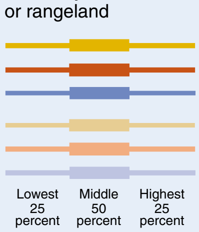
◆ Detected concentration in Study Unit

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

-- Not measured or sample size less than two

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

National ranges of detected concentrations, by land use, in 36 NAWQA Study Units, 1991–98—Ranges include only samples in which a chemical was detected. Land-use areas categorized nationally as mixed were categorized locally as agricultural, urban, or rangeland



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

Lowest 25 percent — Middle 50 percent — Highest 25 percent

National water-quality benchmarks

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

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

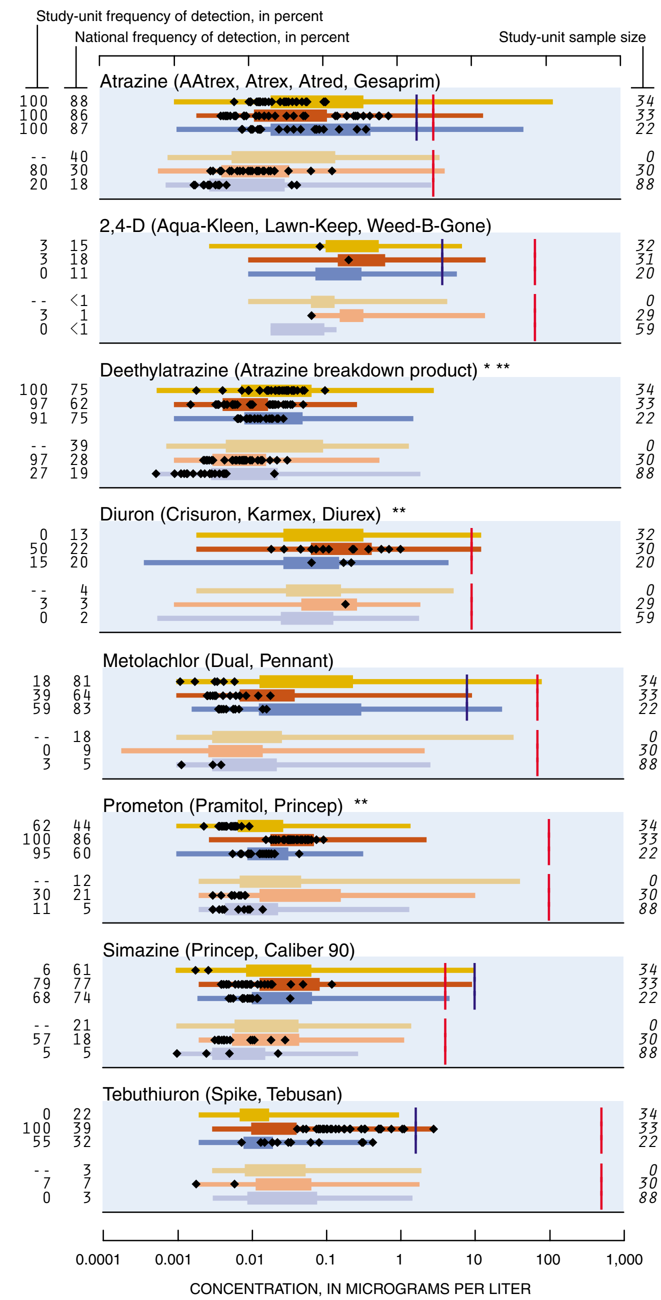
| Protection of aquatic life (applies to surface water only)

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

* No benchmark for drinking-water quality

** No benchmark for protection of aquatic life

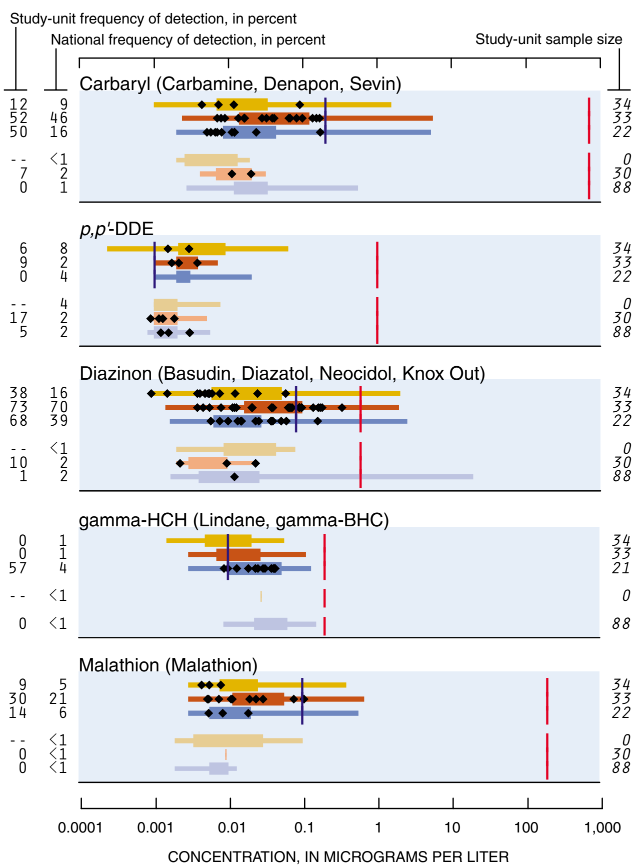
Pesticides in water—Herbicides



Other herbicides detected
Alachlor (Lasso, Bronco, Lariat, Bullet) **
Benfluralin (Balan, Benefin, Bonalan) * **
Bentazon (Basagran, Bentazone) **
Bromacil (Hyvar X, Urox B, Bromax)
Cyanazine (Bladex, Fortrol)
DCPA (Dacthal, chlorthal-dimethyl) * **
Dicamba (Banvel, Dianat, Scotts Proturf)
Metribuzin (Lexone, Sencor)
Oryzalin (Surflan, Dirimal) * **
Pronamide (Kerb, Propyzamid) **
Triclopyr (Garlon, Grandstand, Redeem, Remedy) * **
Trifluralin (Treflan, Gowan, Tri-4, Trific)

Herbicides not detected
Acetochlor (Harness Plus, Surpass) * **
Acifluorfen (Blazer, Tackle 2S) **
Bromoxynil (Buctril, Brominal) *
Butylate (Sutan +, Genate Plus, Butilate) **
Chloramben (Amiben, Amilon-WP, Vegiben) **
Clopyralid (Stinger, Lontrel, Transline) * **
2,4-DB (Butyrac, Butoxone, Embutox Plus, Embutone) * **
Dacthal mono-acid (Dacthal breakdown product) * **
Dichlorprop (2,4-DP, Seritox 50, Lentemul) * **
2,6-Diethylaniline (Alachlor breakdown product) * **
Dinoseb (Dinosebe)
EPTC (Eptam, Farmarox, Alirox) * **
Ethalfluralin (Sonalan, Curbit) * **
Fenuron (Fenulon, Fenidim) * **
Fluometuron (Flo-Met, Cotoran) **
Linuron (Lorox, Linex, Sarclex, Linurex, Afalon) *
MCPA (Rhomene, Rhonox, Chiptox)
MCPB (Thistrol) * **
Molinate (Ordram) * **
Napropamide (Devrinol) * **
Neburon (Neburea, Neburyl, Noruben) * **
Norflurazon (Evital, Predict, Solicam, Zorial) * **
Pebulate (Tillam, PEBC) * **
Pendimethalin (Pre-M, Prowl, Stomp) * **
Picloram (Grazon, Tordon)
Propachlor (Ramrod, Satecid) **
Propanil (Stam, Stampede, Wham) * **
Propham (Tuberite) **
2,4,5-T **
2,4,5-TP (Silvex, Fenoprop) **
Terbacil (Sinbar) **
Thiobencarb (Bolero, Saturn, Benthiocarb) * **
Triallate (Far-Go, Avadex BW, Tri-allate) *

Pesticides in water—Insecticides

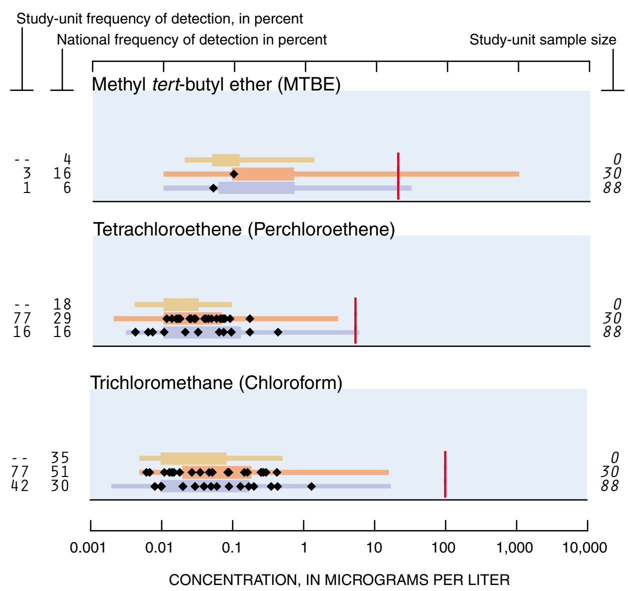


Other insecticides detected
Carbofuran (Furadan, Curaterr, Yaltox)
Chlorpyrifos (Brodan, Dursban, Lorsban)
Terbufos (Contraven, Counter, Pilarfox) **

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

Volatile organic compounds (VOCs) in ground water

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

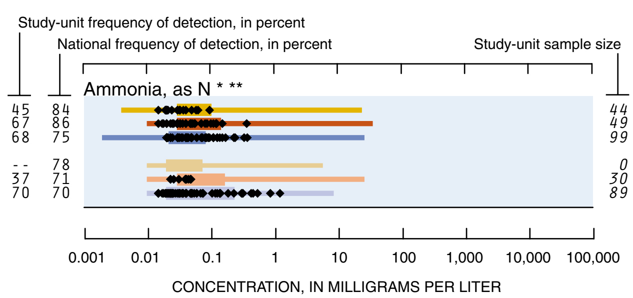


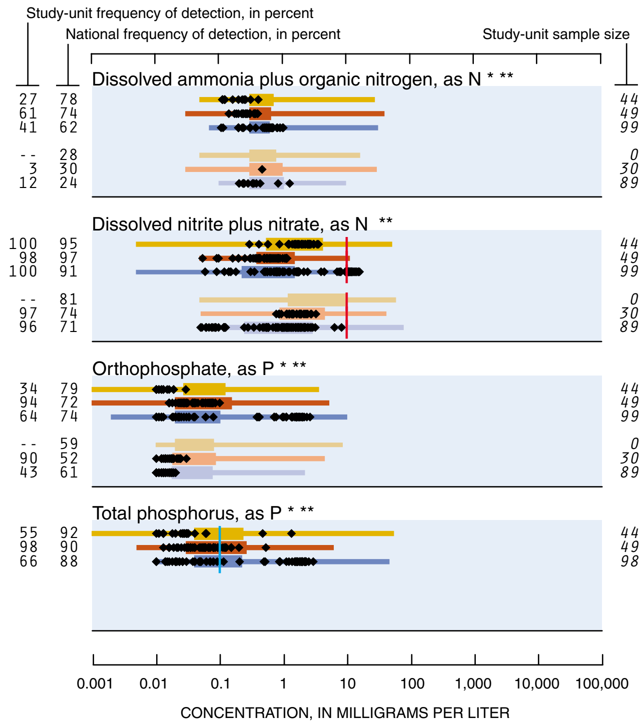
Other VOCs detected
Benzene
Bromobenzene (Phenyl bromide) *
Bromodichloromethane (Dichlorobromomethane)
2-Butanone (Methyl ethyl ketone (MEK)) *
Carbon disulfide *
Chlorobenzene (Monochlorobenzene)
Chlorodibromomethane (Dibromochloromethane)
Chloroethane (Ethyl chloride) *
Chloromethane (Methyl chloride)
Dibromomethane (Methylene dibromide) *
1,3-Dichlorobenzene (*m*-Dichlorobenzene)
1,4-Dichlorobenzene (*p*-Dichlorobenzene)
Dichlorodifluoromethane (CFC 12, Freon 12)
1,1-Dichloroethane (Ethylidene dichloride) *
cis-1,2-Dichloroethene ((Z)-1,2-Dichloroethene)
Dichloromethane (Methylene chloride)
1,2-Dichloropropane (Propylene dichloride)
1,2-Dimethylbenzene (*o*-Xylene)
1,3 & 1,4-Dimethylbenzene (*m*-&*p*-Xylene)
1-4-Epoxy butane (Tetrahydrofuran, Diethylene oxide) *

Ethyl *tert*-butyl ether (Ethyl-*t*-butyl ether (ETBE)) *
Ethylbenzene (Phenylethane)
Iodomethane (Methyl iodide) *
Isopropylbenzene (Cumene) *
4-Methyl-2-pentanone (Methyl isobutyl ketone (MIBK)) *
Methylbenzene (Toluene)
2-Propanone (Acetone) *
Tribromomethane (Bromoform)
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113) *
1,1,1-Trichloroethane (Methylchloroform)
Trichloroethene (TCE)
Trichlorofluoromethane (CFC 11, Freon 11)
1,2,4-Trimethylbenzene (Pseudocumene) *

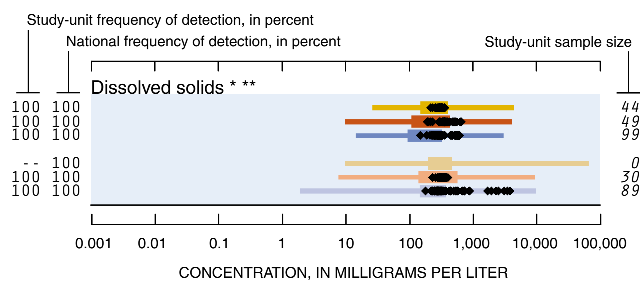
VOCs not detected
tert-Amylmethylether (*tert*-amyl methyl ether (TAME)) *
Bromochloromethane (Methylene chlorobromide)
Bromoethene (Vinyl bromide) *
Bromomethane (Methyl bromide)
n-Butylbenzene (1-Phenylbutane) *
sec-Butylbenzene *
tert-Butylbenzene *
3-Chloro-1-propene (3-Chloropropene) *
1-Chloro-2-methylbenzene (*o*-Chlorotoluene)
1-Chloro-4-methylbenzene (*p*-Chlorotoluene)
Chloroethene (Vinyl chloride)
1,2-Dibromo-3-chloropropane (DBCP, Nemagon)
1,2-Dibromoethane (Ethylene dibromide, EDB)
trans-1,4-Dichloro-2-butene ((Z)-1,4-Dichloro-2-butene) *
1,2-Dichlorobenzene (*o*-Dichlorobenzene)
1,2-Dichloroethane (Ethylene dichloride)
1,1-Dichloroethene (Vinylidene chloride)
trans-1,2-Dichloroethene ((E)-1,2-Dichlorothene)
2,2-Dichloropropane *
1,3-Dichloropropane (Trimethylene dichloride) *
trans-1,3-Dichloropropene ((E)-1,3-Dichloropropene)
cis-1,3-Dichloropropene ((Z)-1,3-Dichloropropene)
1,1-Dichloropropene *
Diethyl ether (Ethyl ether) *
Diisopropyl ether (Diisopropylether (DIPE)) *
Ethenylbenzene (Styrene)
Ethyl methacrylate *
1-Ethyl-2-methylbenzene (2-Ethyltoluene) *
Hexachlorobutadiene
1,1,1,2,2,2-Hexachloroethane (Hexachloroethane)
2-Hexanone (Methyl butyl ketone (MBK)) *
p-Isopropyltoluene (*p*-Cymene) *
Methyl acrylonitrile *
Methyl-2-methacrylate (Methyl methacrylate) *
Methyl-2-propenoate (Methyl acrylate) *
Naphthalene
2-Propenenitrile (Acrylonitrile)
n-Propylbenzene (Isocumene) *
1,1,2,2-Tetrachloroethane *
1,1,1,2-Tetrachloroethane
Tetrachloromethane (Carbon tetrachloride)
1,2,3,4-Tetramethylbenzene (Prehnitene) *
1,2,3,5-Tetramethylbenzene (Isodurene) *
1,2,4-Trichlorobenzene
1,2,3-Trichlorobenzene *
1,1,2-Trichloroethane (Vinyl trichloride)
1,2,3-Trichloropropane (Allyl trichloride)
1,2,3-Trimethylbenzene (Hemimellitene) *
1,3,5-Trimethylbenzene (Mesitylene) *

Nutrients in water

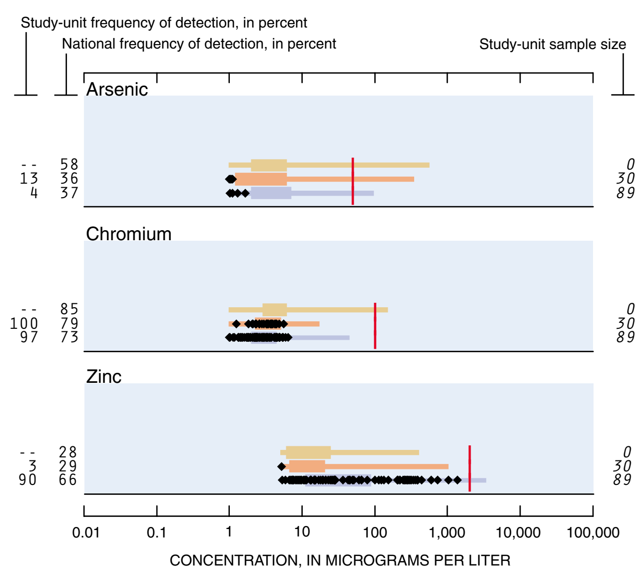


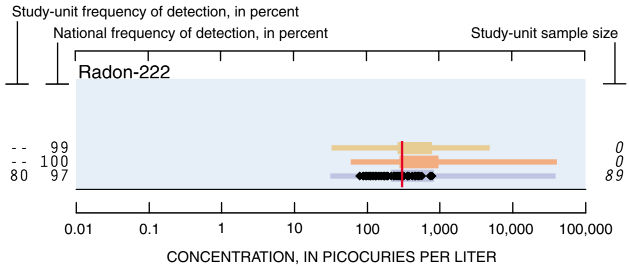


Dissolved solids in water



Trace elements in ground water





Other trace elements detected
Lead
Selenium
Uranium

Trace elements not detected
Cadmium

CHEMICALS IN FISH TISSUE AND BED SEDIMENT

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

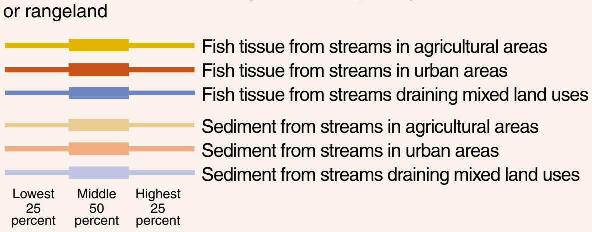
◆ Detected concentration in Study Unit

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

-- Not measured or sample size less than two

12 Study-unit sample size

National ranges of concentrations detected, by land use, in 36 NAWQA Study Units, 1991–98—Ranges include only samples in which a chemical was detected. Land-use areas categorized nationally as mixed were categorized locally as agricultural, urban, or rangeland



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

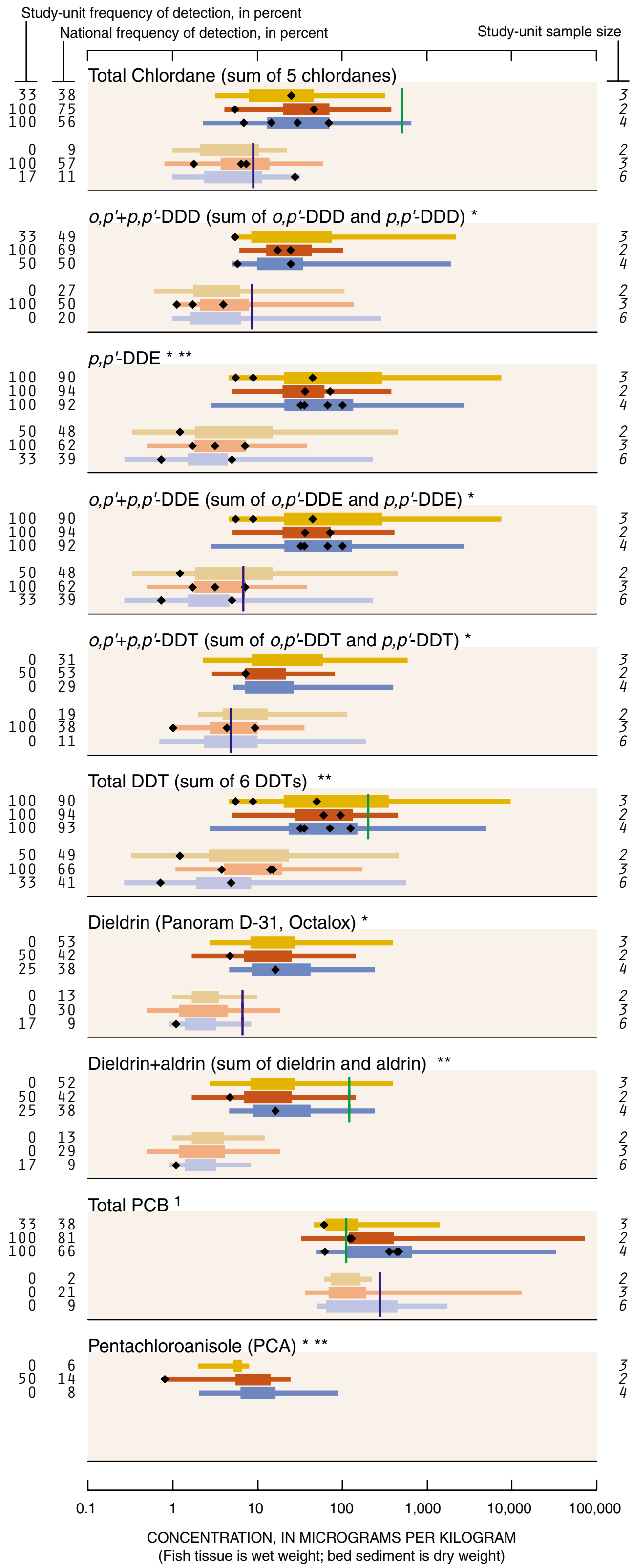
| Protection of fish-eating wildlife (applies to fish tissue) (green line)

| Protection of aquatic life (applies to bed sediment) (purple line)

* No benchmark for protection of fish-eating wildlife

** No benchmark for protection of aquatic life

Organochlorines in fish tissue (whole body) and bed sediment

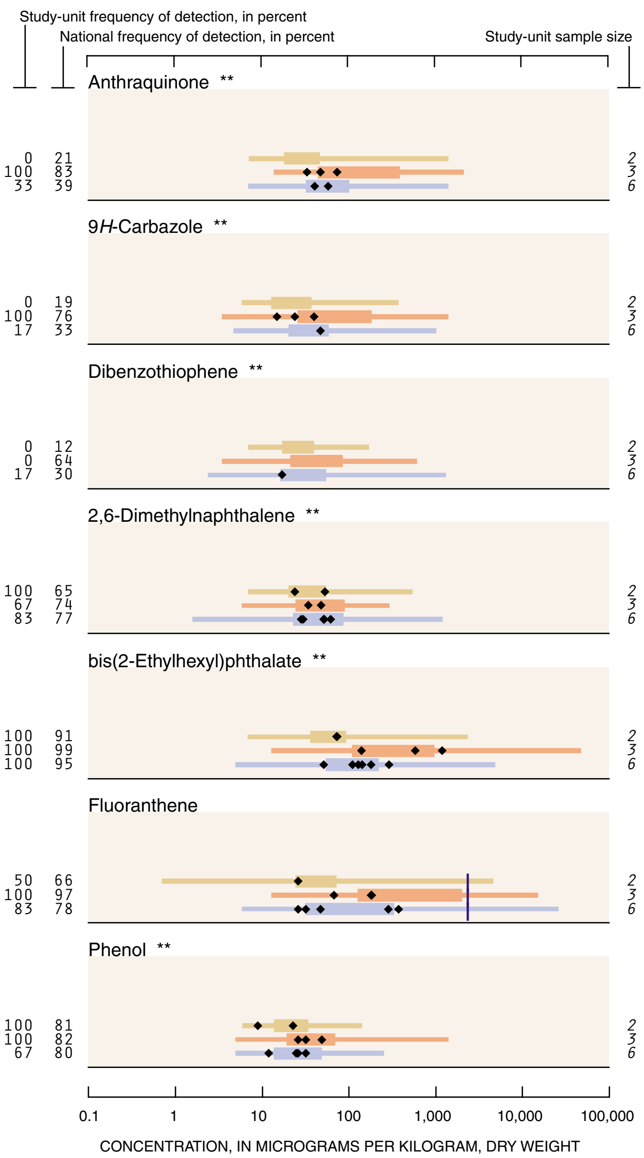


[1] The national detection frequencies for total PCB in sediment are biased low because about 30 percent of samples nationally had elevated detection levels compared to this Study Unit. See http://water.usgs.gov/nawqa/ for additional information.

Other organochlorines detected
Total-HCH (sum of alpha-HCH, beta-HCH, gamma-HCH, and delta-HCH) **
Heptachlor epoxide (Heptachlor breakdown product) *
Heptachlor+heptachlor epoxide (sum of heptachlor and heptachlor epoxide) **
Mirex (Dechlorane) **

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

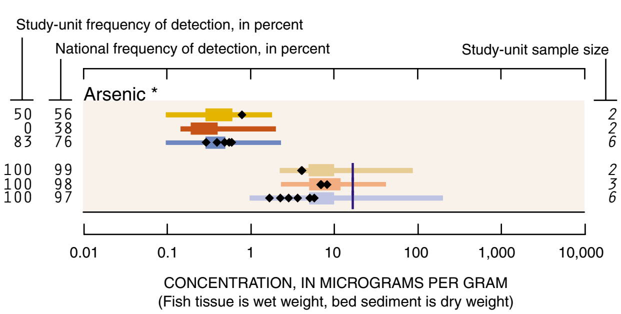
Semivolatile organic compounds (SVOCs) in bed sediment

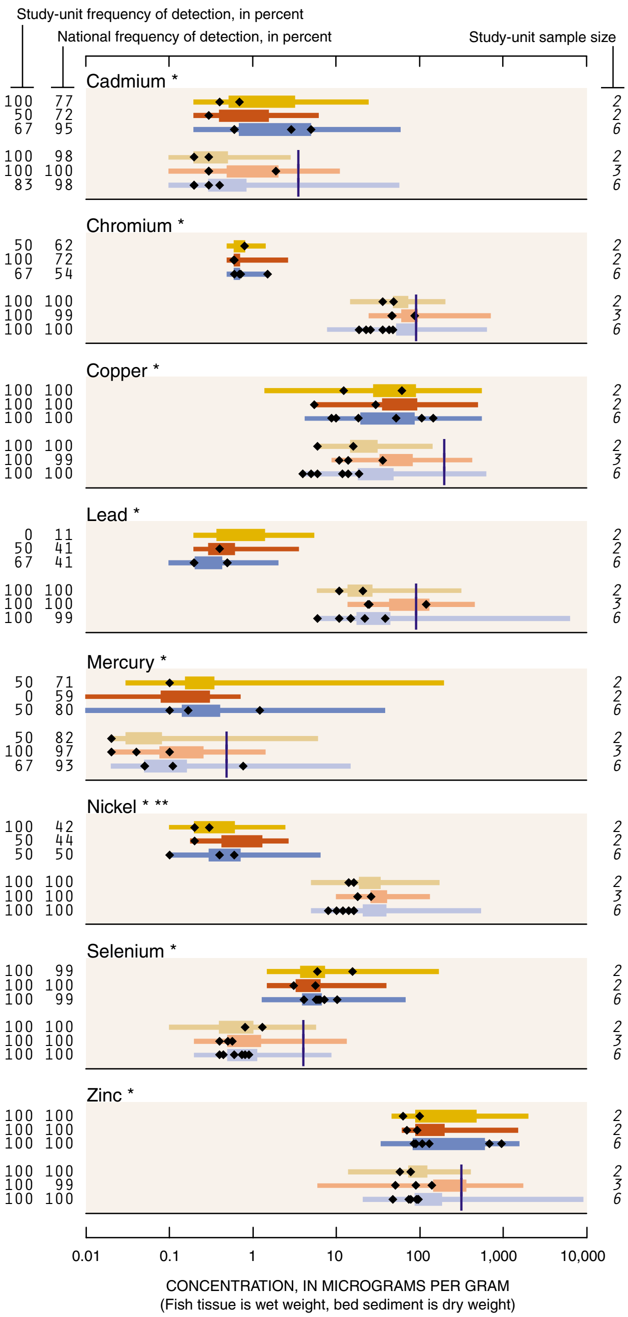


Other SVOCs detected
Acenaphthene
Acenaphthylene
Acridine **
Anthracene
Benz[*a*]anthracene
Benzo[*a*]pyrene
Benzo[*b*]fluoranthene **
Benzo[*ghi*]perylene **
Benzo[*k*]fluoranthene **
Butylbenzylphthalate **
Chrysene
p-Cresol **
Di-*n*-butylphthalate **
Di-*n*-octylphthalate **
Dibenz[*a,h*]anthracene
Diethylphthalate **
Dimethylphthalate **
9*H*-Fluorene (Fluorene)
Indeno[1,2,3-*cd*]pyrene **
Isoquinoline **
1-Methyl-9*H*-fluorene **
2-Methylanthracene **
4,5-Methylenephenanthrene **
1-Methylphenanthrene **
1-Methylpyrene **
Naphthalene
Phenanthrene
Pyrene

SVOCs not detected
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 **
1,2-Dichlorobenzene (*o*-Dichlorobenzene) **
1,3-Dichlorobenzene (*m*-Dichlorobenzene) **
1,4-Dichlorobenzene (*p*-Dichlorobenzene) **
1,2-Dimethylnaphthalene **
1,6-Dimethylnaphthalene **
3,5-Dimethylphenol **
2,4-Dinitrotoluene **
2-Ethylnaphthalene **
Isophorone **
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





BIOLOGICAL INDICATORS

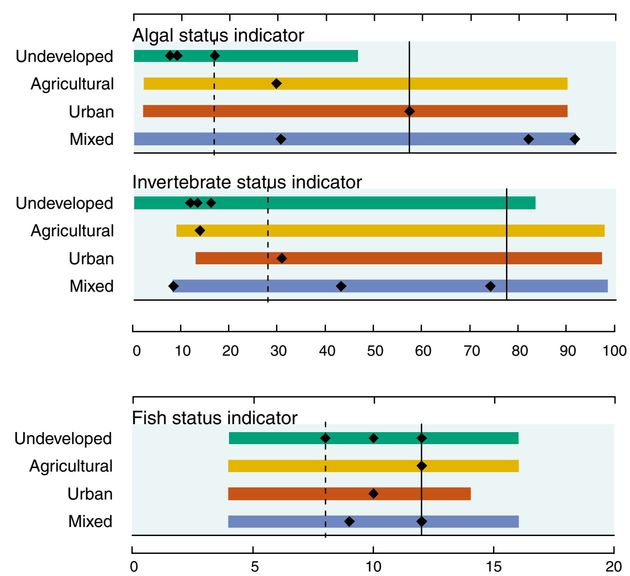
Higher national scores suggest habitat disturbance, water-quality degradation, or naturally harsh conditions. The status of algae, invertebrates (insects, worms, and clams), and fish provide a record of water-quality and stream conditions that water-chemistry indicators may not reveal. **Algal status**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

Biological indicator value, South-Central Texas, by land use, 1996–98—Land-use areas categorized nationally as mixed were categorized locally as agricultural, urban, or rangeland

◆ Biological status assessed at a site

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

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



A COORDINATED EFFORT

Coordination with agencies and organizations in the South-Central Texas Study Unit was integral to the success of this water-quality assessment. We thank those who served as members of our liaison committee and those who contributed in other ways.

Federal Agencies
U.S. Department of Agriculture—Natural Resources Conservation Service, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, U.S. Postal Service

State Agencies
Texas Natural Resource Conservation Commission, Texas Parks and Wildlife Department, Texas Water Development Board

Local Agencies
Bexar-Medina-Atascosa Counties Water Control and Improvement District No. 1, Bexar Metropolitan Water District, Edwards Aquifer Authority, Guadalupe-Blanco River Authority, Headwaters Underground Water Conservation District, Medina County Groundwater Conservation District, Nueces River Authority, San Antonio River Authority, San Antonio Water System, Springhills Water Management District, Upper Guadalupe River Authority, Uvalde County Underground Water Conservation District

Universities
Texas Water Resources Institute—Texas A&M University, Bureau of Economic Geology—University of Texas at Austin, University of Texas at San Antonio, Edwards Aquifer Research and Data Center—Southwest Texas State University

Other public and private organizations
City of San Antonio, City of Shavano Park, Encino Park Homeowners Association, Fort Clark Springs Association, Parkwood Maintenance Association, Texas Center for Policy Studies, The Club at Sonterra, The Nature Conservancy of Texas, Town of Hollywood Park

In addition to the numerous landowners who allowed us to collect water-quality samples on their property, we thank the following individuals for contributing to this effort.

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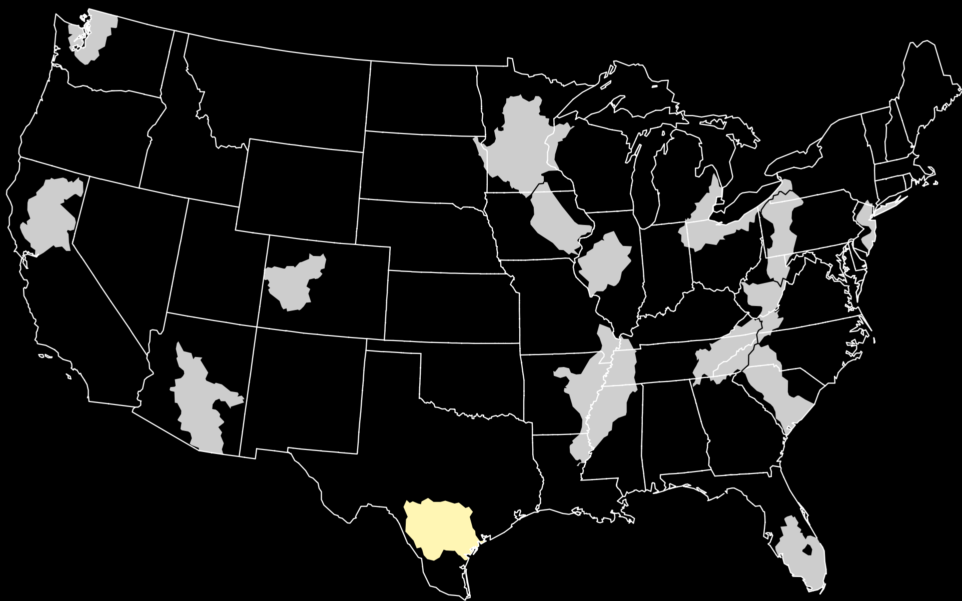
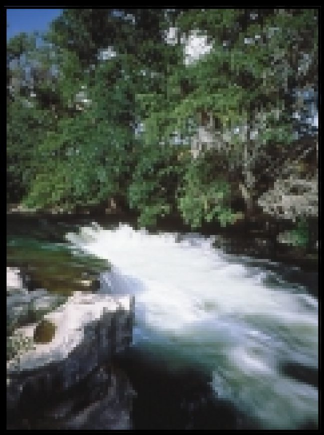
Rob Esquilin
Tommy Fisk
John Flager
T. James Fries
Mike Gonzales
Tom Gonzales
Elisa Graffy
Charles Hartmann
Vic Hildebran
Sue Hovorka
Ivan James
Marshall Jennings
Susan Kemper
Mary Kidd
Gayle Kipp
Glenn Longley
Chiquita Lopez
Mike Lopez
Cecilio Martinez
Mark Mathews
Vidal Mendoza
Buddy Miller
Jesse Mireles
Keith Muhlestein
Venezia Muniz
Kirk Nixon
Phil Nordstrom
Mike Nyman
Jim O'Connor
Bob Olmstead
Dane Ohe
Cassi Otero
Michelle Othon
Robert Ourso
George Ozuna
Jody Palmer
Brian Petri
Stephen Porter
Phil Redman
Dave Reutter
Maurice Rimkus
John Rosendale
Lana Ruiseco
Valarie Schmidt
Larry Shelton
Scott Sherrill
Allison Shipp
Gail Sladek
Ted Small
Gloria Smith
Grant Snyder
Milton Sunvison
Ed Swibas
Lu Tan
Gene Taylor
Chad Thompson
John Tumlinson
Peter Van Metre
James Waclawczyk
John Waugh
Craig Weiss
George Wissmann
Jennifer Wilson
Phillip Wright

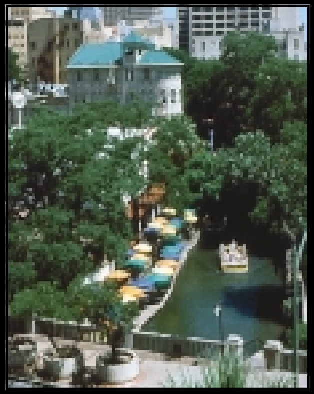
NAWQA

National Water-Quality Assessment (NAWQA) Program
South-Central Texas



Bush and others— Water Quality in South-Central Texas
U.S. Geological Survey Circular 1212





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