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Water Quality in Southern Florida

Florida, 1996–98

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

Circular 1207

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Front cover: Everglades National Park *(photograph by Benjamin F. McPherson)*.

Back cover: Left, Southern Everglades C-111 agricultural basin, irrigation of crops*;* center, Northern Everglades, slough and tree islands; right, areal view of Miami *(photographs by Benjamin F. McPherson)*.

Water Quality in Southern Florida
Florida,1996–98

By Benjamin F. McPherson, Ronald L. Miller, Kim H. Haag, *and* Anne Bradner

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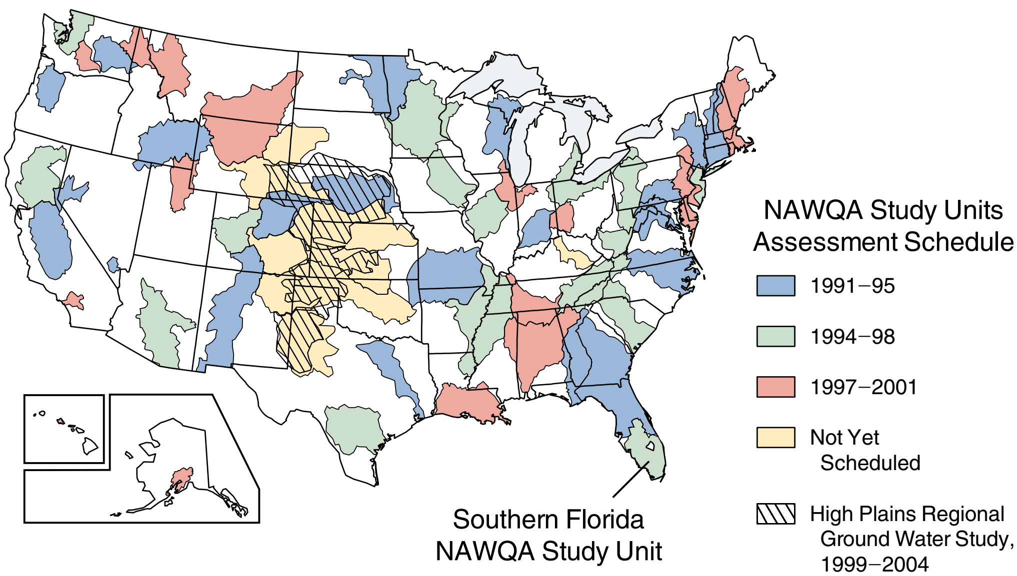
CONTENTS

THIS REPORT summarizes major findings about water quality in the southern Florida area studied by the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program between 1996 and 1998. 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 stream 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 Southern Florida assessment. Basin 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.

The southern Florida area 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.

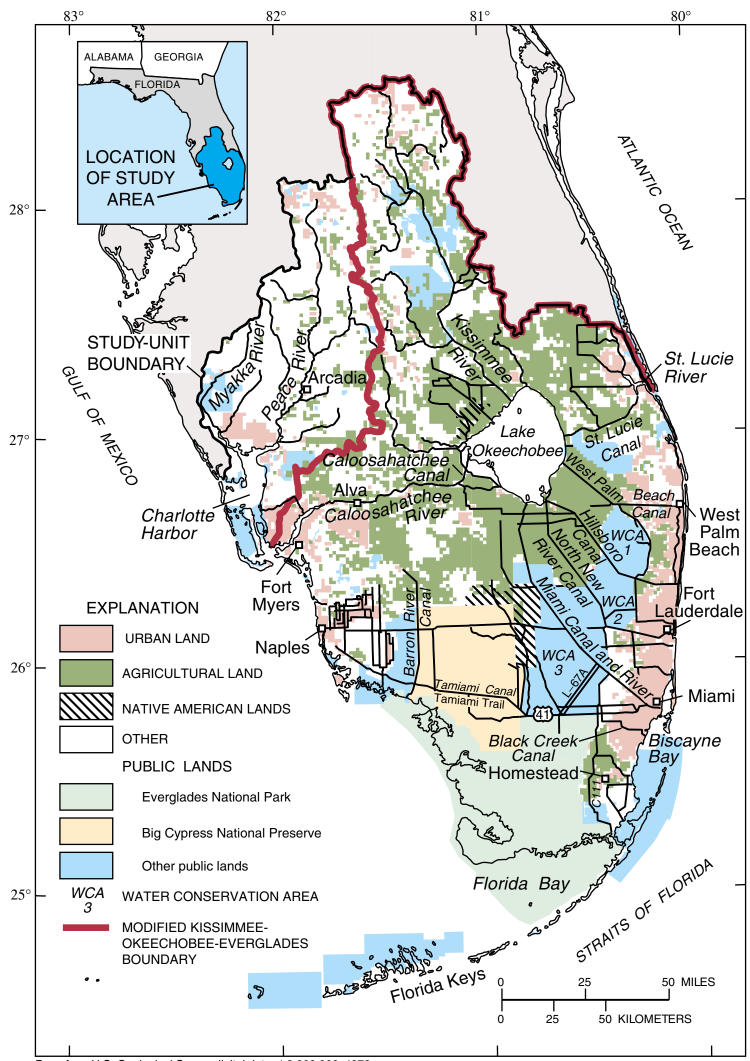
Surface-Water Highlights

The environment in southern Florida is being degraded by human activities. Native biota have been reduced greatly in abundance and diversity by drainage, development, alteration of water flows, degradation of water quality, and by continuing invasions of exotic species.The Everglades ecosystem, which is adapted to water that has an extremely low phosphorus concentration, is being altered by agricultural activities that produce high levels of phosphorus in water. Nutrient loading in the major rivers is contributing to over-enrichment of Lake Okeechobee and estuaries such as Charlotte Harbor. Mercury has accumulated in Everglades game fish, and consumption of the fish poses a potential human health risk. Mercury has accumulated in the Everglades food web because natural conditions and human influences enhance methylation of mercury to its organic form and because high atmospheric mercury deposition rates (among the highest in the Nation) sustain mercury methylation.

Federal and State agencies and environmental groups agree that parts of southern Florida should be restored to predevelopment conditions. Restoration will require massive changes in the water-management system to restore predevelopment drainage patterns, improve water quality, and protect native biota.

Major findings on water quality and biology from this study:

- Concentrations of total phosphorus (TP) at the Southern Florida (SOFL) National Water-Quality Assessment (NAWQA) Program sites were above Everglades background levels and exceeded the U.S. Environmental Protection Agency's (USEPA) Everglades water-quality standard of 0.01 milligram per liter (mg/L). A major source of the high TP is fertilizer from agriculture.
- Concentrations of dissolved organic carbon (DOC) in southern Florida water were relatively high compared with those in other waters of the Nation. High DOC concentrations provide food for bacteria to grow, reduce light penetration in the water, and enhance transport and cycling of pesticides and trace elements such as mercury.
- Pesticides were detected in almost all SOFL samples. Most concentrations were below aquatic-life criteria; however, the criteria do not address potential effects of mixtures of pesticides and their degradation products, which were common in the samples.
- Organochlorine pesticides, such as DDT and its degradation products, are still prevalent in bottom sediment and fish tissue at the SOFL sites, even though most uses of these compounds have been discontinued in recent decades. The mobilization of these pesticides by the reflooding of Everglades farm lands could lead to food-web contamination.
- Of 21 NAWQA basins nationwide, the Everglades has the second highest ratio of methylmercury to mercury in sediment.This enrichment in methylmercury enhances mercury uptake by the biota.
- The frequency of external anomalies (lesions, ulcers, and tumors) on fish collected at two SOFL agricultural canal sites was in the top 25 percent of



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Albers Equal-Area Conic projection
Standard Parallels 29°30′ and 45°30′, central meridian -83°00′

Urban, agricultural, Native American, public lands and other important features in the Southern Florida NAWQA Study Unit (McPherson and Halley, 1996).

144 NAWQA sites sampled nationwide. Anomalies can be indications that fish are stressed by contamination.

- Exotic animals and plants are a threat to native biota. Ten of the 54 exotic fish species established in the region were collected at the SOFL sites. Several herbicides used to control exotic plants were detected in surface water.

Major Influences on Surface Water and Ecology

- Drainage modifications and wetland destruction.
- Runoff from agricultural and urban areas.
- High concentrations of DOC and its effects on the transport of mercury and the attenuation of light.
- Deliberate or accidental release of exotic species.

Ground-Water Highlights

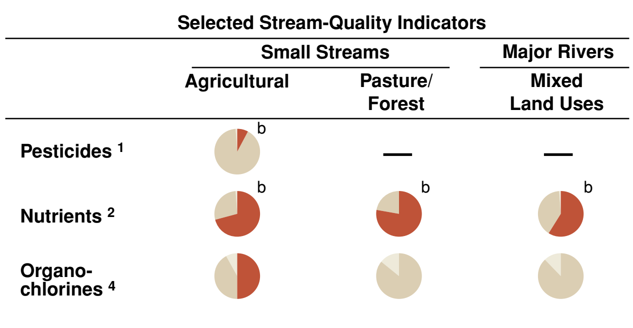
In much of the SOFL region, ground water in the surficial aquifers, such as the Biscayne aquifer, is of good quality and usually meets Federal and State drinking-water quality standards. Contaminants are usually in low concentrations, presumably because of rapid flushing and recharge as a result of high annual rainfall (about 55 inches) and shallow aquifers and porous limestone that allow the easy interchange of surface and ground water. However, because of the shallow aquifers and porous limestone, ground water is vulnerable to surface contamination and to saltwater intrusion.

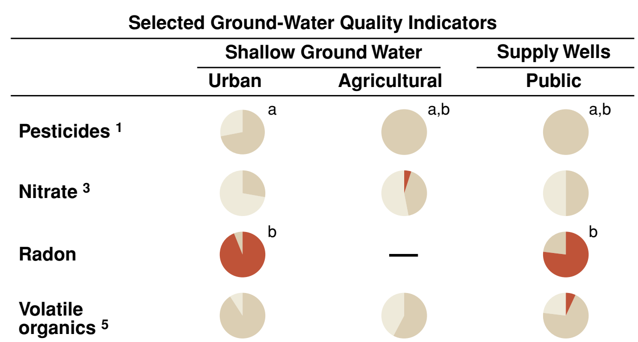
Major findings on ground-water quality from this study include the following:

- Nitrate concentrations were below the drinking-water standard (10 mg/L) in 108 SOFL wells (Biscayne and other surfical aquifers), except for two shallow wells in the unnamed surficial aquifer of the citrus area.
- Pesticides were detected in more than 85 percent of the SOFL wells and beneath every type of land use studied, but no concentrations exceeded any USEPA or State of Florida drinking-water standard.
- Pesticides detected in shallow ground water were associated with specific land uses. For example, the herbicides bromacil and norflurazon were detected almost exclusively in citrus areas. Metolachlor and simazine were common in mixed agricultural areas near the southern Everglades.
- Volatile organic carbon compounds (VOCs) commonly were detected in water from shallow and deep wells in the Biscayne aquifer. Concentrations of one industrial VOC, vinyl chloride, exceeded the USEPA maximum contaminant level (MCL) of 2 micrograms per liter (µg/L) for drinking water in two samples.
- Radon-222 radioactivity exceeded the proposed MCL (300 picocuries per liter ([pCi/L]) in the majority of samples from the Biscayne aquifer, including untreated water from the public-supply wells.

Major Influences on Ground Water

- Porous, shallow limestone aquifers overlain by thin layers of sandy, permeable soils.
- Water-management practices involving canals, pumps, gates, locks, and saltwater-control structures.
- Agricultural and urban land-use practices and aquatic-weed control.





Percentage of samples with concentrations **equal to or greater than** a health-related national guideline for drinking water, aquatic life, or water-contact recreation; or above a national goal for preventing excess algal growth ([a] Percentage is 1 or less and may not be clearly visible)

Percentage of samples with concentrations **less than** a health-related national guideline for drinking water, aquatic life, or water-contact recreation; or below a national goal for preventing excess algal growth

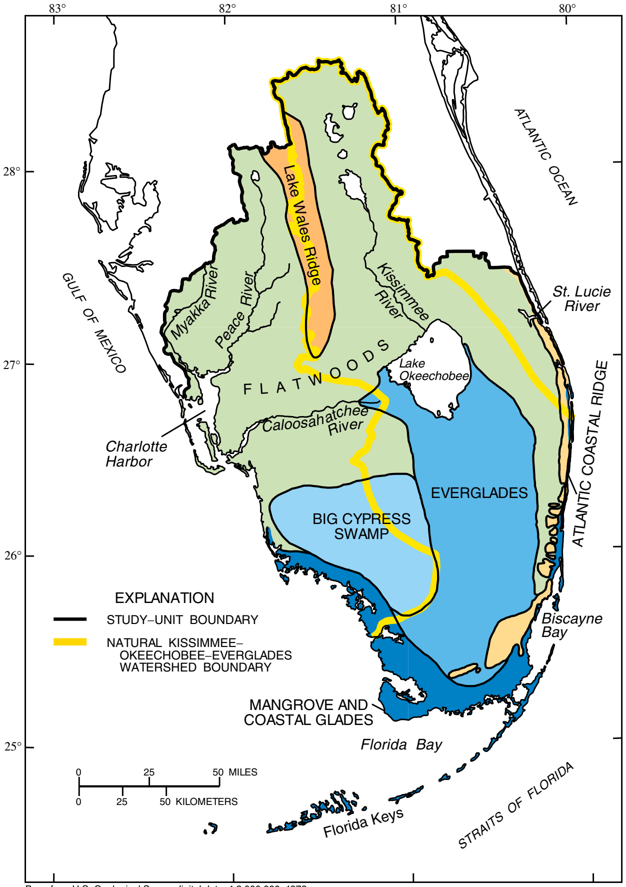
Percentage of samples with **no detection** ([b] Percentage is 1 or less and may not be clearly visible)

— Not assessed

[1] Insecticides, herbicides, and pesticide metabolites, sampled in water.
[2] Total phosphorus (TP) sampled in water. Aquatic-life guidelines based on USEPA Everglades standard of 0.01 mg/L TP for small Everglades streams and on USEPA national goal of 0.1 mg/L TP for major rivers.
[3] Nitrate (as nitrogen), sampled in water.
[4] Organochlorine compounds including DDT and PCBs, sampled in fish tissue.
[5] Solvents, refrigerants, fumigants, and gasoline compounds, sampled in water.

***The Everglades are remarkable for....the absolute purity of the water there, which contrary to popular idea, is clear as crystal....*—Alanso Skinner, *Bird Lore,* XIII, no. 6, Nov.-Dec. 1911.**

***Both these glade rivers (Miami and New Rivers) are singularly beautiful. Their waters, clear and limpid, are fringed on either shore by all the wild growths of the hammock...pine and prairie, reflecting every change of scene like mirrors.*—J.N. MacGonigle, 1896, *The geography of the southern peninsula of the United States: National Geographic Magazine,* v. 7, no. 12, p. 381–394.**



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Albers Equal-Area Conic projection
Standard Parallels 29°30′ and 45°30′, central meridian -83°00′

Figure 1. Physiographic provinces of southern Florida. (Modified from Davis, 1943; Parker and others, 1955.)

In the mid-1800s southern Florida was a lush, subtropical wilderness of pine forest, hardwood hammocks, swamps, marshes, estuaries, and bays. Wetlands dominated the landscape. The region contained one of the largest wetlands in the continental United States, the Everglades, which was part of a larger watershed—the Kissimmee-Okeechobee-Everglades—which extended more than half the length of the Florida peninsula (fig. 1). Wetlands of the Everglades, Big Cypress Swamp, and Mangrove and Coastal Glades stretched continuously across much of the southern part of the peninsula south of Lake Okeechobee (fig. 1). To the north, much of the Flatwoods physiographic province also was wetlands; upland habitats were primarily on the narrow Lake Wales and Atlantic Coastal Ridges.

Freshwater in the Everglades and other wetlands generally moved as sheetflow in marshes, sloughs, and cypress strands. Numerous small streams and rivers near the coast, such as the Miami River, drained into mangrove forests and tidal waters and provided the freshwater that sustained the highly productive and abundant coastal fisheries around the southern end of the peninsula (McIvor and others, 1994).

The wetlands of southern Florida made much of the region inhospitable for human habitation. Settlers and developers in the late 1800s and early 1900s began to drain the wetlands for commercial and safety reasons. Loss of lives as a result of hurricane flooding in the 1920s accelerated drainage projects. Today, many of the region's original wetlands have been drained. Water in the region is now intensively managed, with more that 1,400 miles of primary canals and more

The Southern Florida (SOFL) National Water-Quality Assessment study encompasses about 19,500 square miles. It is part of a regional ecosystem that includes coastal waters between Charlotte Harbor on the Gulf of Mexico and the St. Lucie River on the Atlantic Ocean and the lands that drain into these waters. The elevation in the study area ranges from about 300 feet above sea level to sea level along the coast. It includes a large and rapidly growing urban population (about 5 million people) along the Atlantic coast and a less rapidly growing population (over a million people) along the gulf coast, areas of intense agricultural development around Lake Okeechobee and along the southeastern edge of the Everglades, and vast regions of wetlands, including the Everglades National Park (ENP), Big Cypress National Preserve, and other parks, preserves, and conservation areas that are mostly in public ownership. Ground water from the shallow, highly porous Biscayne aquifer is the source of most of the drinking water for the densely populated southeast coast.

Complex canal system in northern Everglades.

Northern Big Cypress Swamp.

than 100 water-control structures. The larger rivers, such as the Kissimmee and Caloosahatchee Rivers, have been canalized and controlled to enhance their ability to move water. About half the Everglades have been lost to drainage and development since the early 1900s; the remaining Everglades, included in the Everglades National Park (ENP), conservation areas, and the Loxahatchee National Wildlife Refuge, are protected from physical destruction, but it has been degraded by altered quantity, quality, and timing of freshwater inflows.

Drainage and development of wetlands have adversely affected water quality and ecology throughout southern Florida. Water pumped into canals from agricultural lands commonly has high concentrations of nutrients and pesticides. The high nutrient concentrations and loads entering Lake Okeechobee and the Everglades from farms and cattle lands have degraded water quality. Phosphorus concentrations in Lake Okeechobee have increased two and one-half times since the 1970s, and massive algal blooms have become more frequent and persistent. The increased nutrient loading to the Everglades is stressing native vegetative communities. Sawgrass, which is adapted to a low-nutrient environment, is being replaced by cattails in parts of the northern Everglades where nutrient loading has been excessive. Drainage and development also has resulted in loss of peat soils, contamination by pesticides, saltwater intrusion into aquifers near the coast, mercury buildup in the biota, fragmentation of landscape, loss of wetland functions, widespread invasion by exotic species, increased algal blooming, seagrass die-off, and declines in fishing resources in coastal waters.

***Everywhere and at all seasons of the year, the water in the glades is clear, pure, and though sometimes warm, palatable, without the least staleness or stagnancy.*—Edwin Asa Dix and Rev. John N. MacGonigle, *Century Magazine*, February 1905.**

An abundant and uncontaminated supply of freshwater was a primary environmental characteristic of southern Florida in predevelopment times. Increased human population and activity have brought not only increased need for water but also a decrease in water supply and deterioration in water quality. These changes in the hydrologic system, wrought by growth and development, are thought to be the major causes of the substantial declines in the health of the remaining natural ecosystem.

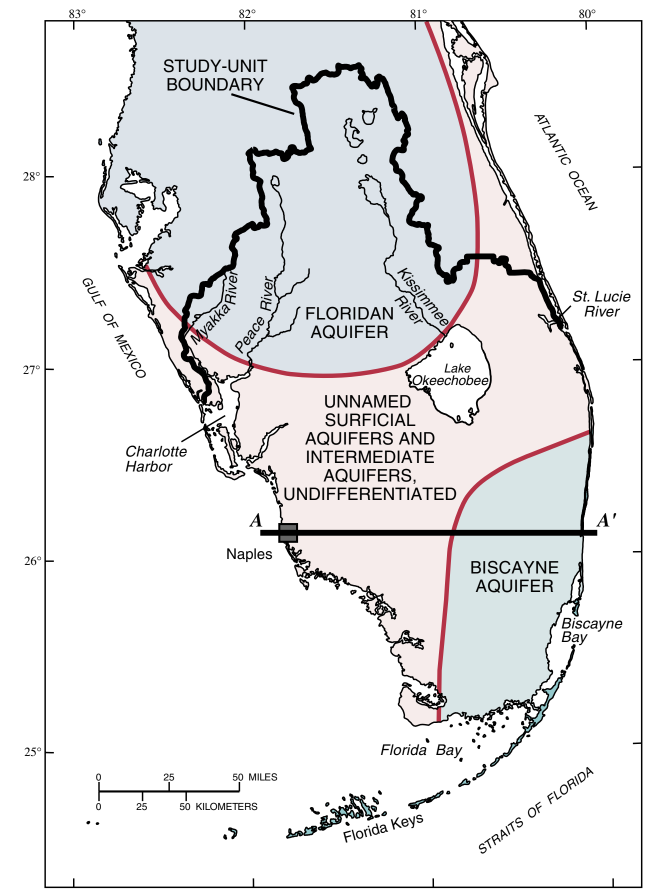
A consensus has begun to emerge among environmental groups and Federal and State agencies that southern Florida, and particularly the Everglades, should be restored to the extent possible to the predevelopment ecosystem. A first and primary step in this undertaking is the restoration of predevelopment hydrologic conditions to the remaining natural system. Plans are to change the manmade water-conveyance system and restore the natural hydrologic cycle of the predevelopment Everglades as a means of contributing to overall ecosystem restoration.

Aquifers and Water Use

Southern Florida, which is underlain by shallow marine carbonate sediments to depths of 20,000 feet, contains three major aquifer systems: the Floridan, the intermediate, and the surficial aquifer systems (figs. 2a,b). The confined Floridan aquifer system is the principal source of water for human use in the northern part of the south Florida area, but water from this aquifer is too mineralized for most uses in the southern part of the area. The semiconfining layers of the intermediate aquifer system, which overlies the Floridan, serves as the confining unit for the Floridan and is a source of freshwater for public supply along the gulf coast. The surficial aquifer system includes the highly permeable Biscayne aquifer, which is the principal source of potable water for the more than 5 million people in southeastern Florida. The Biscayne aquifer has been designated as a “sole-source” drinking-water supply by the USEPA.

Most of the potable water supply in southern Florida is withdrawn from shallow aquifers, generally from wells less than 250 feet deep. Ground water supplied 94 percent (872 million gallons per day [Mgal/d]) of the water used by most of the 5.8 million people in the SOFL Study Unit in 1990. Water used for agriculture in 1990 (2,735 Mgal/d) was nearly evenly divided between ground-water and surface-water sources (Richard L. Marella, U.S. Geological Survey, written commun., 1990).

Agricultural irrigation, eastern Everglades area.



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
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Figure 2a. The three main aquifer systems of southern Florida.

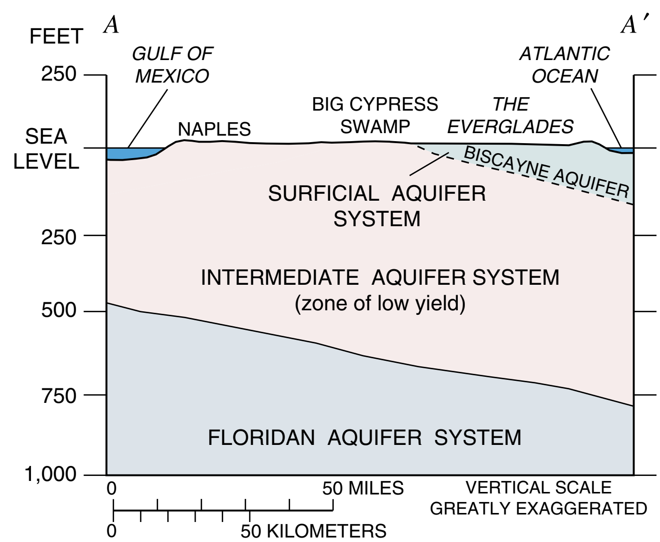


Figure 2b. Generalized subsurface section *A–A′* showing aquifers of southern Florida (Klein and others, 1975).

Rainfall

Annual rainfall in southern Florida ranges from about 40 to 65 inches. The east coast usually receives the greatest amount of rainfall, whereas the Florida Keys and areas near Lake Okeechobee and Charlotte Harbor usually receive the least. More than half the rainfall occurs from June through September and is associated with thunderstorms and tropical cyclones. Rainfall during the remainder of the year usually is the result of large frontal systems and is broadly distributed rather than localized. April and May typically have the least rainfall. Annual and seasonal rainfalls vary from year to year (fig. 3).

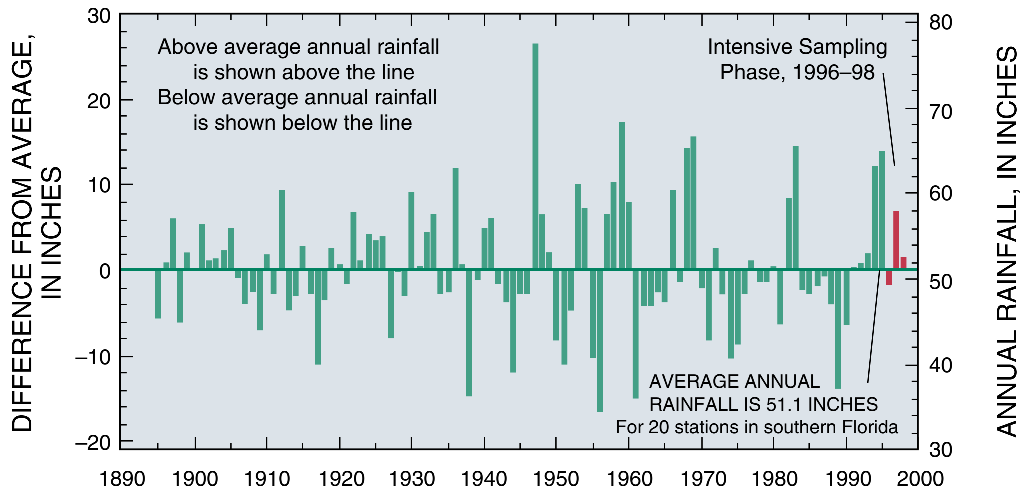


Figure 3. Annual rainfall was above average during the 1996–98 sampling period. (Data from the National Oceanic and Atmospheric Administration's National Climate Center.)

HOW IS THE SOUTHERN FLORIDA NAWQA DIFFERENT FROM OTHER NAWQA STUDY UNITS?

- **Drainage basins are poorly defined.**
- **Surface and ground water are closely connected.**
- **Sheetflow is common through the "River of Grass" and other wetlands.**
- **Surface-water flow in canals and rivers is highly managed and regulated.**
- **Organic soils (peats) are abundant, but much has been lost to oxidation.**
- **The farming season is in winter.**
- **Coastal meteorological effects often dominate.**
- **Tropical storms are common.**
- **Nutrient concentrations are naturally low in the Everglades and other pristine wetlands.**
- **Dissolved organic carbon concentrations are high.**
- **Water color is dark in some rivers and wetlands.**
- **There are extensive subtropical wetlands and public lands, including four national parks, preserves, or refuges.**
- **Many exotic species thrive in the subtropical climate.**

Nutrient enrichment is prevalent in surface water

Water quality has been degraded in large parts of southern Florida by human activities that result in high nutrient concentrations and over-enrichment. Nutrient concentrations at the SOFL NAWQA sites are elevated when compared with Everglades background concentrations (see box below). The high nutrient concentrations, primarily from agricultural runoff, have contributed to overenrichment of surface water, including Lake Okeechobee, estuaries such as Charlotte Harbor, and the northern Everglades. The high phosphorus concentrations in agricultural runoff entering the northern Everglades are a significant cause of ecosystem degradation.

The USEPA recently (May 26, 1999) approved a new water-quality standard of 0.01 mg/L or less for phosphorus in the Miccosukee Federal Indian reservation lands of the Everglades. The State of Florida is reviewing additional scientific information and plans to adopt a numerical phosphorus standard for other parts of the Everglades.

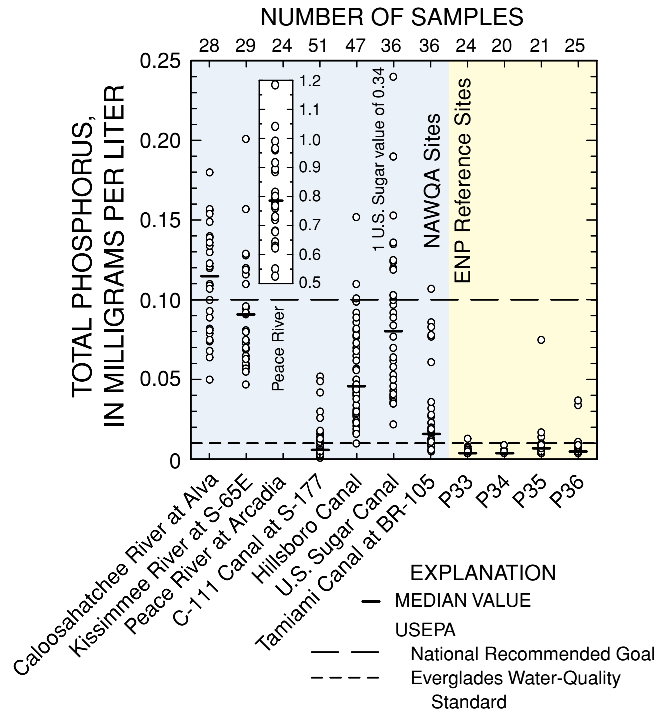


Figure 4. Concentrations of total phosphorus (TP) at SOFL NAWQA sites during 1996–98 frequently exceeded the USEPA recommended goal of 0.1 mg/L and Everglades standard of 0.01 mg/L. Concentrations of TP at Everglades National Park reference sites were near or below 0.01 mg/L.

NUTRIENT CONCENTRATIONS VARY WIDELY IN SOUTHERN FLORIDA AND THE NATION

Concentrations of nutrients in surface water at the SOFL sites vary widely compared with national NAWQA median concentrations. Generally, the high nutrient concentrations in southern Florida are at canal and river sites north of the Tamiami Trail and are associated with agricultural activities. Concentrations of phosphorus in surface water of the more pristine Everglades (south of the Tamiami Trail) are more than an order of magnitude lower than national background concentrations. The Everglades ecosystem is adapted to water that has extremely low phosphorus concentrations and is being adversely affected by agricultural runoff with high concentrations of phosphorus. Concentrations of phosphorus in southern Florida are highest in the Peace River (fig. 4) and are well above national median concentrations. The high concentrations in the Peace River are associated with natural sources (phosphatic deposits) as well as mining and agricultural activities in the basin.

Concentrations of nutrients in shallow ground water at SOFL wells generally are lower than or comparable with the national background concentrations. Median concentrations of nitrate in the southern Florida wells are one-fourth the national background concentration, and median concentrations of orthophosphate are comparable to the national background concentration. Concentrations of nutrients at the SOFL sites are plotted against corresponding national nutrient ranges for different land uses in Appendix A.

Nutrient concentrations of the national NAWQA and the SOFL NAWQA study areas, national background, and Everglades background sites in mg/L

[SW, surface water; GW, shallow ground water; <, less than; --, no data]

Nutrient	NAWQA		Background	
	National, 1993–98, median[2]	SOFL, range of medians[3], 05/96–09/98	National[1] (undeveloped areas)	Everglades[4] 05/96–09/98
Total phosphorus (SW)	0.12	0.006–0.79	0.1	<0.004
Total nitrogen (SW)	1.3	0.7–2.6	1.0	1.1
Nitrite plus nitrate (SW)	0.71	0.006–0.59	0.6	0.005
Ammonia (SW)	0.046	0.017–0.25	0.1	<0.015
Ammonia (GW)	0.02	0.24–0.438	--	--
Nitrite plus nitrate (GW)	1.85	<0.05–0.44	2.0	--
Orthophosphate (GW)	0.11	0.013–0.028	0.02	--

[1]U.S. Geological Survey, 1999.
[2]Flow-weighted concentrations.
[3]Medians for routinely sampled (BFS) sites (SW) and for land-use categories (GW).
[4]Everglades National Park, site P–34, medians; data from South Florida Water Management District (1992).

Ground-water sampling, eastern Everglades C-111 agricultural basin.

All routinely sampled SOFL sites (BFS sites, see Glossary) had phosphorus concentrations that exceeded the USEPA Everglades standard of 0.01 mg/L, but the two southern sites, Canal C-111 and Tamiami Canal at bridge 105, had median concentrations near the 0.01-mg/L Everglades standard (fig. 4). The ENP reference sites had median phosphorus concentrations below 0.01 mg/L and are characteristic of pristine Everglades water.

Seasonal changes in total phosphorus concentrations often are related to changes in water levels and flows. Generally, concentrations were below 0.02 milligram per liter (mg/L) at the Big Cypress Swamp reference site (Br 105) during 1996–98, but increased to more than 0.10 mg/L as water flows and levels declined during the dry season (fig. 5). The increase in phosphorus concentrations occurs when fish, wading birds, and other aquatic organisms congregate in ponded waters and their wastes contribute nutrients to the remaining inundated areas. The relatively greater ground-water contributions to surface water during the dry season also may increase nutrient concentrations. The background marsh sites in the ENP had very low concentrations of phosphorus (less than 0.01 mg/L) throughout the 1996–98 sampling period, and effects of seasonal low water levels on nutrients were not evident.

The dominant source of phosphorus loading in southern Florida is fertilizer (fig. 6). Manure and atmospheric sources are also important in some subbasins. Annual phosphorus loads estimated for selected canals and rivers were highest in the Peace River and lowest in the eastern Big Cypress Swamp. Much more phosphorus has been transported seaward from the northern Everglades and Okeechobee basins by the Caloosahatchee River, St. Lucie Canal, and major canals of Palm Beach County than is transported seaward in the southern Everglades (Haag and others, 1996).

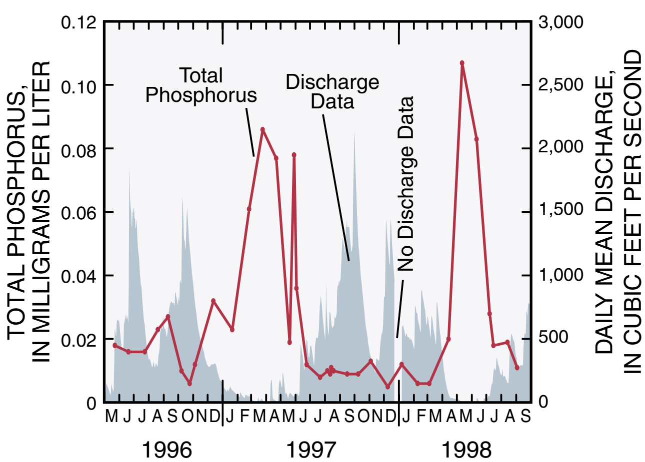


Figure 5. Total phosphorus concentrations increased as discharge and water levels declined at Tamiami Canal at Bridge 105, Big Cypress National Preserve.

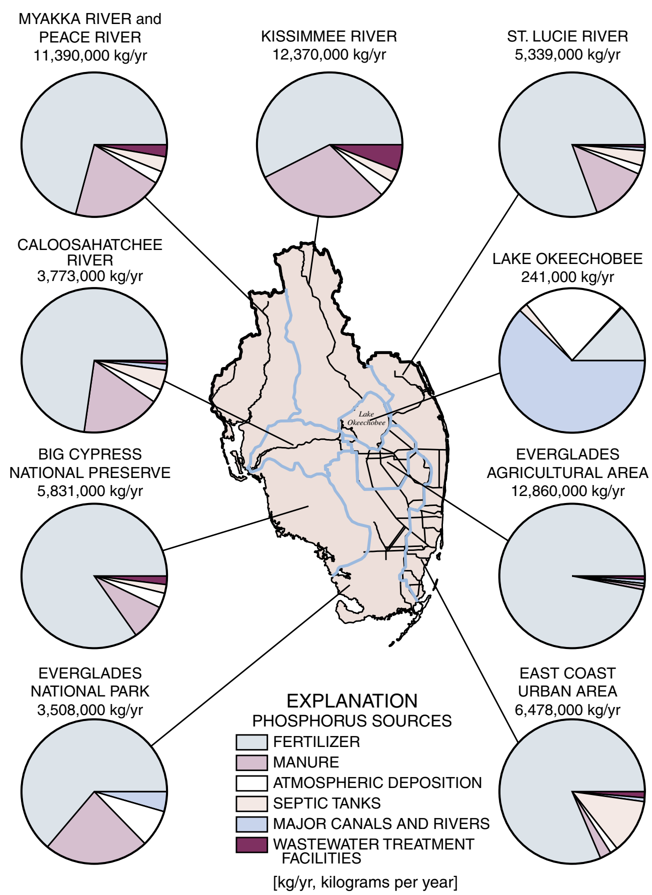


Figure 6. Estimated phosphorus loading from point and nonpoint sources in surface-water basins in southern Florida (Haag and others, 1996).

Nutrient concentrations in ground water are highly variable

High nitrate concentrations (greater than 10 mg/L) in drinking water can cause a life-threatening illness in infants known as “blue-baby syndrome.” Nitrate concentrations in ground water were low (commonly not detected) in most of the 108 wells sampled in the SOFL Study Unit, but a few occasionally were elevated in areas with agricultural land use. Wells located in or near the mixed-agricultural land-use area (including public-supply wells) tended to yield water with detectable concentrations of nitrate, but no nitrate concentrations exceeded the drinking-water standard of 10 mg/L. More than half of the wells located in citrus groves yielded water with no detectable nitrate concentrations, but two wells had nitrate concentrations above the drinking-water standard. With a few exceptions, shallow Biscayne aquifer wells in the urban land-use area contained water with relatively low concentrations of nitrate.

Ammonia concentrations in ground water in the SOFL Study Unit were relatively high compared with concentrations in other NAWQA Study Units across the Nation. The median ammonia concentration (0.396 mg/L) in the SOFL citrus land-use survey was the highest of 47 NAWQA agricultural surveys nationwide. Median concentrations of ammonia in the SOFL urban and study-unit survey (public water supply) ranked second and fifth highest, respectively, in these categories nationally.

Dissolved phosphorus concentrations in SOFL wells ranged from 0.001 to 0.79 mg/L; most land-use areas had median concentrations less than 0.01 mg/L (table 1). Concentrations above 0.05 mg/L occurred in some wells in all land-use and public-supply surveys, but highest concentrations generally were in the deeper public-supply wells of the Biscayne aquifer and in the citrus land-use area. The source of the relatively high concentrations of phosphorus in ground water may be fertilizers or naturally occurring phosphatic materials associated with silt and clays.

Dissolved organic carbon concentrations are commonly high

Dissolved organic carbon (DOC) originates from natural sources, such as living and decaying plants, and from human sources. DOC represents about half the dissolved organic matter (DOM) in natural waters (Hem, 1985). In southern Florida, DOC concentrations commonly are high compared with other natural waters in the Nation and may constitute, as DOM, a significant fraction of the dissolved solids (table 2).

Concentrations of DOC ranged from 4.8 to 52.0 mg/L at the SOFL surface-water sites, and from 0.6 to 80 mg/L at the ground-water sites (table 4). The highest DOC concentrations (median of 34.0 mg/L) occurred at Hillsboro Canal at S-6 in the northern Everglades downgradient from the Everglades Agricultural Area, which has highly organic muck soils that are thought to be a source of DOC. In contrast, the Big Cypress Swamp reference site at Tamiami Trail Bridge 105 had the lowest concentrations (median of 9.5 mg/L) of the routinely sampled sites. This site is characterized by natural swamp vegetation and thin carbonate soils and rock. Concentrations of DOC at sites along the Tamiami Trail (1996–97) ranged from 4.8 to 26.9 mg/L (table 2), and tended to be low in the central and eastern Big Cypress Swamp and higher in the western Big Cypress and to the east in the Everglades (Miller and others, 1999).

The amount of DOC in water is significant. It can (1) contribute to water color, which absorbs sunlight and reduces the amount of light available for use by submerged aquatic plants and phytoplankton;

Table 1. Dissolved phosphorus concentrations varied widely in shallow wells in southern Florida during 1997–98. (Different detection levels were reported for different survey types during the period)

[B, Biscayne aquifer; S, unnamed surficial aquifer; <, less than]

Survey type	Number of wells and samples	Range, mg/L	Median mg/L
Urban/residential (B)	32	<0.01–0.30	<0.01
Urban background (B)	3	<0.01–0.07	<0.01
Citrus (S)	31	<0.01–0.79	0.023
Citrus background (S)	5	<0.004–0.036	<0.01
Mixed agricultural (Canal C-111) (B)	7	0.001–0.019	0.003
Public supply (B)	30	<0.01–0.34	<0.01

Citrus groves north of Big Cypress Swamp.

Table 2. Concentrations of dissolved organic carbon, in milligrams per liter, at surface- and ground-water sites in southern Florida, 1996–98

[Dissolved organic carbon (DOC) in natural water typically is 45 to 55 percent of the dissolved organic matter (DOM; Robert Wershaw and Jerry Leenheer, oral commun., 1997) and averages about 50 percent of the DOM that also includes other elements such as oxygen, hydrogen, nitrogen, phosphorus; --, no data]

Sampling site	Range	Median	Number of DOC samples	DOM as a percentage of dissolved solids
Surface Water				
Kissimmee River at S-65E	13.0–22.0	16.0	29	20–39
Peace River Arcadia	8.6–26.0	15.0	30	6–36
Caloosahatchee River at Alva	13.0–22.0	16.0	27	5–15
Hillsboro Canal at S-6	15.0–52.0	34.0	48	7–13
U.S. Sugar	17.0–30.0	20.0	37	11–16
Tamiami Canal at Bridge 105	7.1–14.0	9.5	35	5–18
Canal C-111 at S-177	5.0–18.0	6.6	51	4–9
All 7 Basic Fixed Sites	5.0–52.0	16.0	257	4–39
Tamiami Trail, SOFL data (1996–97)	4.8–26.9	12.5	43	--
Ground Water				
Urban/residential land-use wells	1.9–36	11.5	32	--
Citrus wells	2.7–80	24	29	--
Public-supply wells	0.6–22	9.4	30	--

(2) serve as a source of carbon for bacterial growth; (3) form complexes with trace elements, such as mercury, and make them more soluble and mobile in water (Reddy and others, 1999); (4) reduce bioavailability of nonionic organic compounds through sorption, entrapment, or sequestering the compounds (Nowell and others, 1999, p. 296); (5) increase the solubilities of relatively insoluble compounds, such as p,p′-DDT, PCBs, and lindane (Chiou and others, 1986); and (6) react with chemicals used to disinfect public water supplies and produce undesirable by-products, such as chloroform and other trihalomethanes, that may have harmful effects on human health.

Pesticides are present in most surface-water samples

Pesticides are widely used in southern Florida to control insects, fungi, weeds, and other undesirable organisms. These compounds vary in their toxicity, persistence, and transport. Some of the more persistent pesticides, such as DDT, chlordane, dieldrin, and aldrin, have been discontinued for use in Florida, but their residues persist in the environment. Although pesticides usually are applied to specific areas and directed at specific organisms, these compounds often become widely distributed and pose potential hazards to nontarget organisms.

Pesticide application in vegetable farming area.

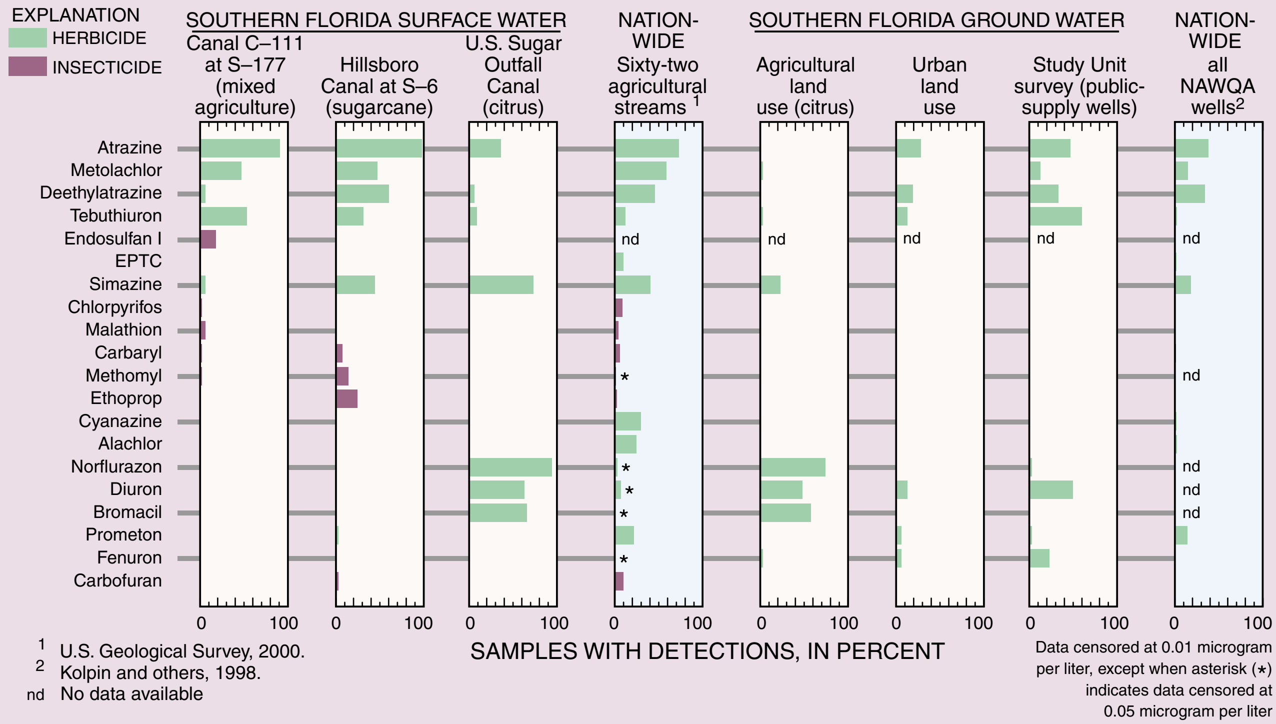
Intensive pesticide sampling (up to weekly sampling) was conducted at three SOFL sites (IFS sites, see Glossary) that represented three different agricultural land uses — mixed vegetable crops (C-111 basin), sugarcane (S-6), and citrus (U.S. Sugar). Pesticides were detected in all but one sample from the three intensive-sampling sites during 1996–98. The most frequently detected pesticides included those with highest annual application rates, such as the herbicides atrazine, bromacil, simazine, 2-4-D, and diuron. Atrazine, the most frequently detected pesticide overall, was detected in about 90 percent of all samples. The other most frequently detected pesticides overall were metachlor, simazine, tebuthiuron, norflurazon, bromacil, and diuron.

Naturally occurring dissolved organic matter (DOM) causes the tea-colored water in many of Florida's rivers and swamps. Water color can have significant ecological effects by decreasing available light in the water column and reducing algal and aquatic plant productivity and growth. In the Peace River and upper Charlotte Harbor, for example, color can contribute up to about half of the total light attenuation in the water column, and this high attenuation limits algal phytoplankton and seagrass growth (McPherson and Miller, 1987). The range in color for southern Florida water, including the NAWQA sites, is shown in table 3.

Table 3. Water color for southern Florida surface-water sites, 1913–1999 (Color is reported in platinum-cobalt units. Data from U.S. Geological Survey data bases)

Sampling site	Range	Median	Number of samples	Period of record
Kissimmee River, S-65E	25–240	85	51	1959–75
Peace River, Arcadia	0–320	82.5	414	1930–99
Caloosahatchee River at S-79	5–500	62.5	144	1953–88
Hillsboro Canal at S-6	30–560	120	89	1945–84
Tamiami Canal at Bridge 105	10–100	30	56	1967–99
Canal, C-111 at S-18-C	0–40	5	40	1970–83
Everglades P-33	10–120	45	82	1959–85
878 southern Florida sites in Miami USGS data base	0–640	55	11,457	1913–99

PESTICIDE DETECTIONS VARY WITH LAND USE IN SOUTHERN FLORIDA AND THE NATION



Different patterns of pesticide detections were evident in surface and ground water of the different land-use areas of southern Florida. For example, norflurazon and bromacil frequently were detected in citrus land-use areas but seldom detected in other agricultural and urban areas. Detections of prometon and fenuron were relatively high in the public-supply wells of the Biscayne aquifer but were much lower in other areas. Many of the same pesticides were detected in surface and ground water nationwide, but a few such as alachlor, cyanazine, and carbofuran were mostly absent in southern Florida. The most commonly detected pesticides, such as atrazine, simazine, and metolachlor, were more common in surface water than in ground water in both southern Florida and the Nation. Concentrations of selected herbicides at SOFL sites are plotted against corresponding national herbicide ranges for different land uses in Appendix A.

Concentrations of pesticides in water were seasonal and related to land use. Concentrations of atrazine peaked at all three sites in late winter and spring (fig. 7). Concentrations were highest at the S-6 site, where some samples had atrazine concentrations that exceeded the Canadian aquatic-life criterion of 2 µg/L and the USEPA MCL of 3 µg/L. Concentrations at the other two sites were significantly lower, with maximum values less than 1 µg/L.

A pesticide of particular concern, endosulfan, was detected mainly at the Canal C-111 site (fig. 8). Endosulfan was detected by the South Florida Water Management

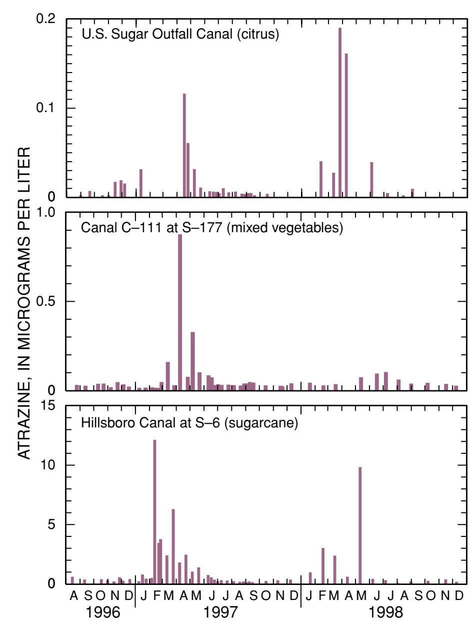


Figure 7. Concentrations of atrazine at the Intensive Fixed Sites, August 1996–December 1998, showing similar seasonal occurrence patterns but different concentrations.

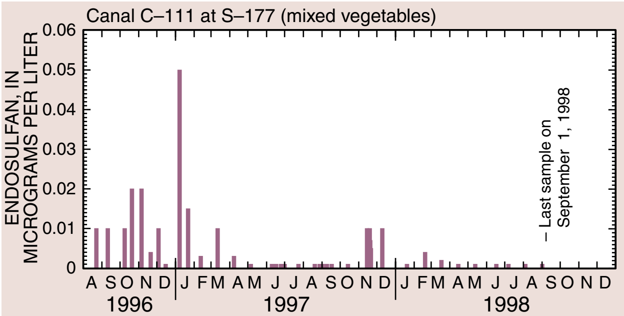


Figure 8. Concentrations of endosulfan at Canal C-111 at S-177, August 1996-September 1998.

Residential land near Fort Lauderdale.

District (SFWMD) over a number of years in the C-111 basin at levels considered to be a threat to aquatic life in the basin and in nearby Florida Bay (Miles and Pfeuffer, 1997). During the intensive sampling period of the SOFL study (1996–98), endosulfan concentrations were 0.05 µg/L or less (fig. 8), which is just below the Florida Department of Environmental Protection criterion (0.056 mg/L) for Class III (recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife) freshwater. Detections of endosulfan were frequent in 1996 but became less frequent in the following 2 years, as the use of this pesticide was discouraged and an alternate, imidacloprid, was introduced.

Mixtures of pesticides were common in samples from SOFL and other national NAWQA sites (see figure on page 13). The effects of pesticide mixtures on biota or humans are not included in criteria, which are based on the results of single-species, single-chemical toxicity tests conducted in the laboratory. As a result, analyses of individual pesticides may underestimate potential adverse effects of contaminants on biota (Nowell and others, 1999).

Regional patterns of pesticides, VOCs, and trace elements are evident in ground water

Pesticides were detected in ground water from more than 85 percent of the 108 SOFL wells and beneath every type of land use studied. No pesticide concentration exceeded USEPA or State of Florida drinking-water standards or health advisories.

VOCs commonly were detected in water from shallow, residential land-use wells and deeper public-supply (study-unit survey) wells in the Biscayne aquifer (fig. 9). Vinyl chloride, trichloroethylene, *tetra*-chloroethylene, *cis*-1,2-dichloroethene, and methyl *tert*-butyl ether (MTBE) were detected more commonly in the older residential and industrial areas and in public-supply wells near mixed agricultural lands. Toluene, p-isopropyltoluene, and 1,2,4-trimethyl-benzene commonly were detected in the newer residential areas and in public-supply wells near mixed agricultural lands. Two samples from public-supply wells in more industrial-

The NAWQA Program uses Federal drinking-water standards and guidelines to assess the quality of drinking water in potential surface- or ground-water sources prior to treatment and distribution. This complements many ongoing Federal, State, and local monitoring programs that assess drinking water after treatment and distribution.

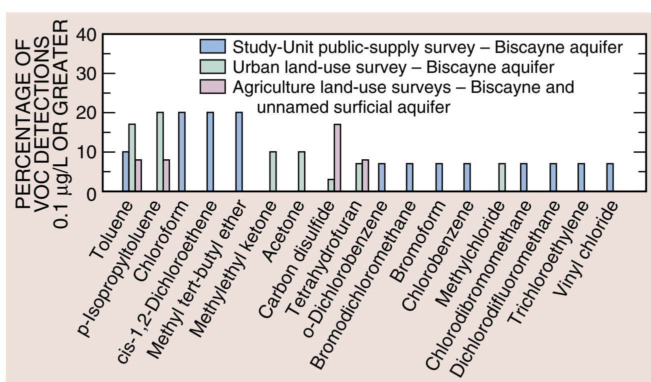


Figure 9. Percentages of common volatile organic carbons (VOCs) detected in water from shallow urban (residential) and agricultural wells and from deeper public-supply wells (see Study Unit Design on page 22 for locations).

ized areas had vinyl chloride concentrations (4.68 and 3.18 µg/L) slightly above the USEPA MCL of 2 µg/L.

Urban and agricultural activities are sources of trace-element contamination in ground water. Arsenic and copper are used as fungicides in citrus groves. Arsenic (in the herbicide monosodium meth-anearsonate) is used in turfgrass maintenance on golf courses, and concentrations of arsenic in shallow ground water are sometimes elevated (Swancar, 1996). Arsenic has been implicated as causing several cancers. Because of this health concern, the USEPA is considering lowering the MCL for arsenic from 50 to about 5 µg/L. Concentrations of arsenic in shallow ground water exceeded 5 µg/L in some of the urban and citrus land-use SOFL wells. Concentrations of copper in the SOFL ground-water samples reached 19 µg/L, which is well below the drinking-water MCL of 1,300 µg/L.

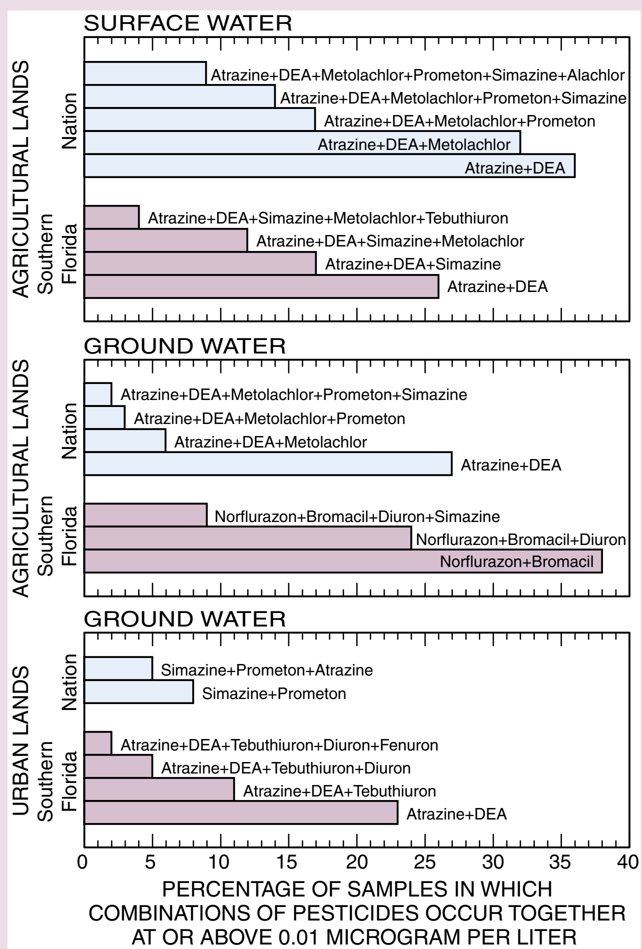
Uranium and radon-222, two naturally occurring radioactive elements that are potential carcinogens, exceeded drinking-water standards in some shallow ground water in the SOFL Study Unit. Uranium exceeded the MCL in 5 of 116 samples. Radon-222, a gaseous radionuclide that, when released to the air and inhaled is a significant cause of lung cancer, exceeded the proposed MCL of 300 picocuries per liter (piC/L) in more than 75 percent of the samples from the Biscayne aquifer.

WHAT COMBINATIONS OF PESTICIDES OCCUR MOST FREQUENTLY IN SOUTHERN FLORIDA AND THE NATION?

The composition of the most common pesticide mixtures in surface water of agricultural areas in the SOFL Study Unit is similar to, but generally lower than, that of mixtures in agricultural areas nationwide. Atrazine, deethylatrazine (DEA), simazine, and metolachlor are found together most frequently in both southern Florida and the Nation.

Ground water in the SOFL Study Unit, however, has a different composition of pesticide mixtures than is found in ground water in other areas of the Nation. Norflurazon and bromacil were found together most frequently as mixtures in the SOFL Study Unit; these pesticides commonly are used on citrus crops.

The composition of the most common pesticide mixtures in ground water in urban areas in the SOFL Study Unit also differs from that throughout the rest of the Nation: the most common pesticides in mixtures were atrazine and DEA in the SOFL Study Unit compared with simazine and prometon nationwide. The atrazine and DEA in shallow ground water of the southern Florida urban study area may originate from local residential lawn herbicide applications or may be transported from nearby agricultural lands, either through the atmosphere or in canals. Canals that drain agricultural lands recharge shallow ground water in this urban area.



DEA is deethylatrazine.
National data from U.S. Geological Survey, 1999.

Transport of Herbicides and their Breakdown Products

To evaluate the geochemical transport of herbicides, water and bed-sediment samples were collected in May 1997 and February 1998 from six SOFL sites (fig. 10) representing different land uses. The samples were analyzed after the methods of Thurman and others (1990) and Meyer and others (1993) for a suite of herbicides and breakdown products. Low levels (0.05 to 2.5 μg/L) of one or more herbicides were detected in water at all sites, including atrazine at every site. Other herbicides detected include ametryn, prometryn, and metolachlor at the sugarcane site, simazine and metolachlor at a mixed-agricultural (vegetable) site, and ametryn, simazine, and terbutryn at a citrus site. Atrazine (at trace levels) and ametryn (exceeding 40 micrograms per kilogram (μg/kg)) were detected in the sediment samples from the sugarcane site (S-6) in both years. The only other herbicides detected in sediments were trace levels of ametryn and alachlor at the mixed-agricultural (vegetable) site (Canal C-111). A breakdown product of alachlor, 2,6-diethylaniline, was detected in water at the same site. At the sugarcane site, S-6, the ratio of sediment-to-water concentration for ametryn was 240 (1997) and 580 (1998) and was zero for atrazine both years, which indicates that ametryn is transported primarily in sediment and atrazine is transported primarily in water.

The ratio of the concentration of deethylatrazine to the parent herbicide atrazine (DAR) has been used as an indicator of herbicide transport and surface- and ground-water interaction in the Midwestern States. Generally, a ratio greater than 1.0 indicates slow unsaturated zone transport and ground-water contributions to surface water (Adams and Thurman, 1991; Thurman and others, 1991; 1992). An elevated ratio also can be caused by photodecomposition of atrazine to deethylatrazine during atmospheric transport of herbicides (Goolsby and others, 1997). A ratio less than 0.1 indicates rapid overland-flow transport to surface water shortly after herbicide application. In southern Florida, DAR values were less than 0.1 at the sugarcane site (S-6), suggesting rapid transport of the herbicide into canal water shortly after herbicide application. The DAR at three other sites was between 0.1 and 1.0, which suggests post-application runoff. The DAR value of 1.0 at the background site (Br-105) presumably is from low-level atmospheric transport and photodecomposition because this site is remote from any farm runoff or ground-water sources of atrazine. The higher values above 1.0 at the citrus site (U.S. Sugar) and Canal C-111 at S-178 could indicate ground-water contributions (as in the Midwest) or more rapid photodegradation of atrazine in southern Florida because of higher temperatures, stronger sunlight, or greater soil organic carbon content and soil moisture than in the Midwest.

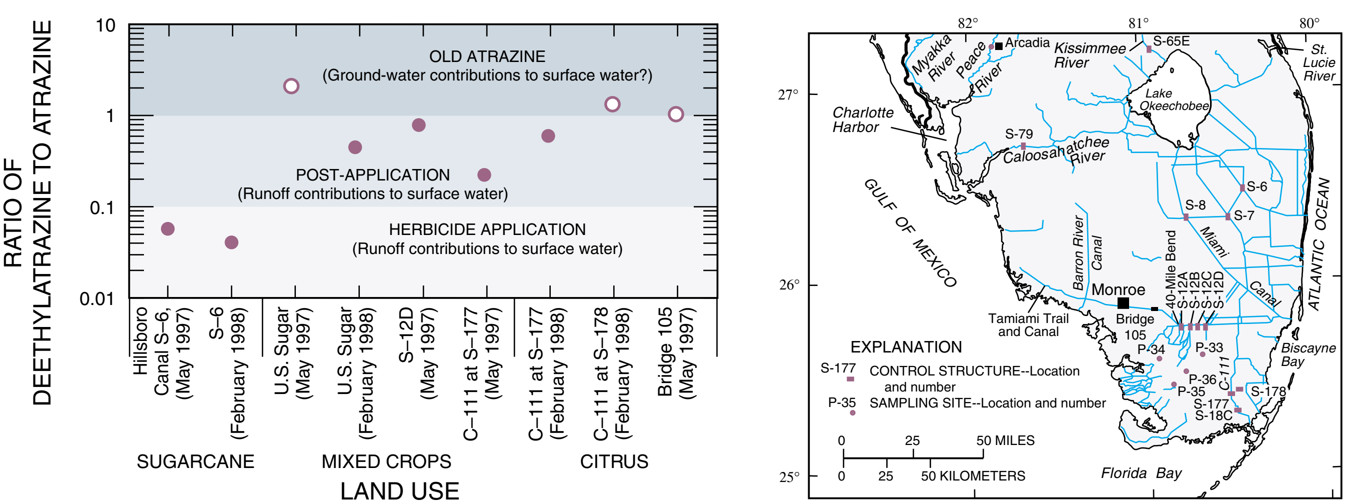


Figure 10. Ratio of deethylatrazine to atrazine (DAR) in surface water at selected sites, 1997–98 (M.T. Meyer, U.S. Geological Survey, written commun., 1998).

Pesticides, PCBs, other organics, and trace elements have accumulated in bottom sediment and fish

Many pesticides, other trace organic compounds, and trace elements are hydrophobic; that is, in aquatic environments they tend to be associated with sediment particles and biological tissues rather than dissolved in water. For this reason, sampling bottom sediment and fish is an effective way to assess the occurrence of these contaminants in the aquatic environment.

The most frequently detected pesticides in bottom sediment at the SOFL sites during 1996–98 were DDT and its breakdown products DDE and DDD, ranging from 2.4 to 670 micrograms per kilogram (µg/kg). DDE exceeded the Canadian sediment quality guidelines probable effects level (PEL) of 6.75 µg/kg (Environment Canada, 1999) at four of the seven fixed sites, including the Hillsboro Canal at S-6 (308 µg/kg) and the Kissimmee River at S-65E (670 µg/kg). More than 40 organic compounds were detected in bed-sediment from the Hillsboro Canal at S-6, including ametryn, chlordane, DDT compounds, dieldrin, endosulfan, and other semivolatile organic compounds, including polycyclic aromatic hydrocarbons (PAHs).

Fish sampling in Big Cypress Swamp as part of the southern Florida NAWQA study.

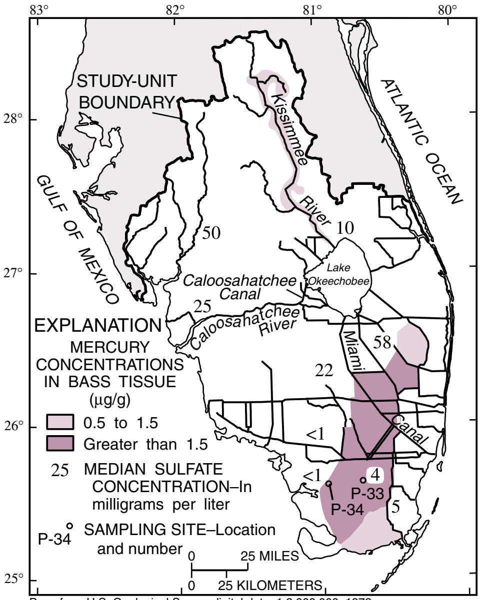
The most frequently detected pesticides in fish at 15 SOFL sites also were DDT and its breakdown products. Largemouth bass and (or) Florida gar were collected at each site, and one or more samples (5–8 whole fish) were analyzed for pesticides. DDT compounds were detected in 25 of the 27 composited fish samples. Concentrations of total DDT ranged from less than 5 to 1,170 µg/kg in Florida gar and from less than 5 to 610 µg/kg in largemouth bass. The most commonly detected and abundant DDT product was *p,p′*-DDE. Total DDT concentrations exceeded the 200-µg/kg guidelines (Newell and others, 1987) for the protection of fish-eating wildlife in 4 of 27 fish samples. Highest concentrations of total DDT were in canals of the northern Everglades near agricultural lands. For comparison, during 1970–73 concentrations of total DDT in 49 composite fish samples from 12 sites in southern Florida ranged from 6 to 800 µg/kg. In 1978, total DDT concentrations in 23 fish samples ranged from 3 to 1,650 µg/kg (Haag and McPherson, 1997).

Row crops, C-111 basin, southern Florida.

Other organochlorine compounds and PCBs detected in the composite whole-fish samples collected during 1995–96 include polychlorinated biphenyls (PCBs) and the pesticides dieldrin, mirex, and various compounds of chlordane (*cis*-chlordane, *oxy*-chlordane, *trans*-chlordane, *trans*-nonachlor, and *cis*-nonachlor). Maximum concentrations of pesticides occurred primarily in fish collected in Hillsboro Canal at S-6. PCBs were detected in three separate fish samples; the maximum concentration (140 µg/kg) was in fish collected from Black Creek Canal. Dieldrin and toxaphene were two other pesticides commonly detected in composite fish samples from the Everglades in the early 1970s. Concentrations of dieldrin in largemouth bass were as high as 130 µg/kg, and concentrations of toxaphene were as high as 5,000 µg/kg. In 1995, dieldrin concentrations ranged from less than 5 to 18 µg/kg, and 5 of 27 fish samples had detectable dieldrin. Toxaphene was not detected in fish collected during 1995–96, but the analytical method was not very sensitive for toxaphene (only levels greater than 200 µg/kg could be detected).

The types and amounts of pesticides used in Florida have changed over the years because of new technology, land use, and State and Federal regulations. One of the most frequently detected herbicides in bed sediment in southern Florida, ametryn, is used in relatively small amounts on sugarcane crops (6 tons per year [tons/y]) (Miles and Pfeuffer, 1997). By far, the greatest frequency of insecticide detection was the organochlorine insecticides, such as DDD, DDE, DDT, dieldrin, and heptachlor. DDT was banned for most uses in the Nation in 1973. These insecticides also are the most frequently detected pesticides in bottom sediments (Shahane, 1994). Although most organochlorine pesticides such as DDT and chlordane are no longer sold in the United States, they persist in the environment and continue to pose potential threats to wildlife and humans. Persistent organochlorine pesticides were detected beginning in the late 1960s and early 1970s (Kolipinski and Higer, 1969; McPherson, 1973) in bottom sediment and fish that are a part of the food chain in the Everglades. Reflooding of farm lands for Everglades restoration potentially could lead to mobilization of persistent organochlorine pesticides and foodweb contamination, as occurred in Lake Apoka just north of the study area. Many organochlorine pesticides and PCBs also have been linked to hormone disruption and reproductive problems in aquatic animals (Colborn and others, 1993).

Polynuclear aromatic hydrocarbons (PAHs) are contaminants in soils and sediments and originate from such sources as crude oil and tar and from forest fires and incomplete combustion of fossil fuels. Bottom-sediment samples were collected at 10 sites in a survey of the Barron River Canal in 1998 to evaluate the occurrence of PAHs and other semivolatile organic compounds in the vicinity of the Big Cypress National Preserve (Miller and McPherson, U.S. Geological Survey, in press). PAHs normalized to organic carbon had patterns of distribution that indicated sources to be roads, vehicles, or an old creosote wood-treatment facility. Concentrations of phthalate esters and the trace elements arsenic, cadmium, and zinc in the Barron River Canal appear to have a nonpoint source and to be influenced by local bed-sediment properties, such as sediment particle size and organic content. At some Barron River Canal sites, lead, copper, and zinc, normalized to aluminum, exceeded background levels and may be enriched by human activities. Trace elements in bottom-sediment samples from the Barron River Canal sites did not exceed the Canadian PEL for freshwater sediment.



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-Area Conic projection
Standard Parallels 29°30' and 45°30', central meridan -83°00'

Figure 11. Mercury concentrations in largemouth bass tissue equaled or exceeded 0.5 µg/g in an area in southern Florida. (Lambou and others, 1991). Median sulfate concentrations at SOFL sites, P-33 and P-34, in mg/L, 1996-98 (P-site data from South Florida Water Management District).

Mercury is a contaminant in the Southern Florida Study Unit

Game fish in the Everglades have concentrations of mercury that exceed recommended levels (1.5 micrograms per gram, µg/g) for human consumption (Ware and others, 1990; fig. 11). The maximum concentrations of mercury found in edible portions of largemouth bass (4.4 µg/g) collected from the Everglades exceeded mercury concentrations in game fish from all other parts of the State (Stober and others, 1995). The NAWQA Program specifies that trace elements (including mercury) be determined for fish livers. Thus, the data are not directly comparable to data from studies analyzing fish fillets (the edible portion of the fish). Mercury concentrations in composite samples of largemouth bass livers from the SOFL sites ranged from 0.4 µg/g in Black Creek Canal to 42 µg/g in Miami Canal at S-8. Mercury concentrations in Florida gar livers ranged from 2.1 µg/g in the Caloosahatchee River at Alva to 190 µg/g in the Miami Canal at S-8. Largemouth bass and gar are top predators; on average, mercury concentrations in gar livers were about four times higher than mercury concentrations in largemouth bass livers.

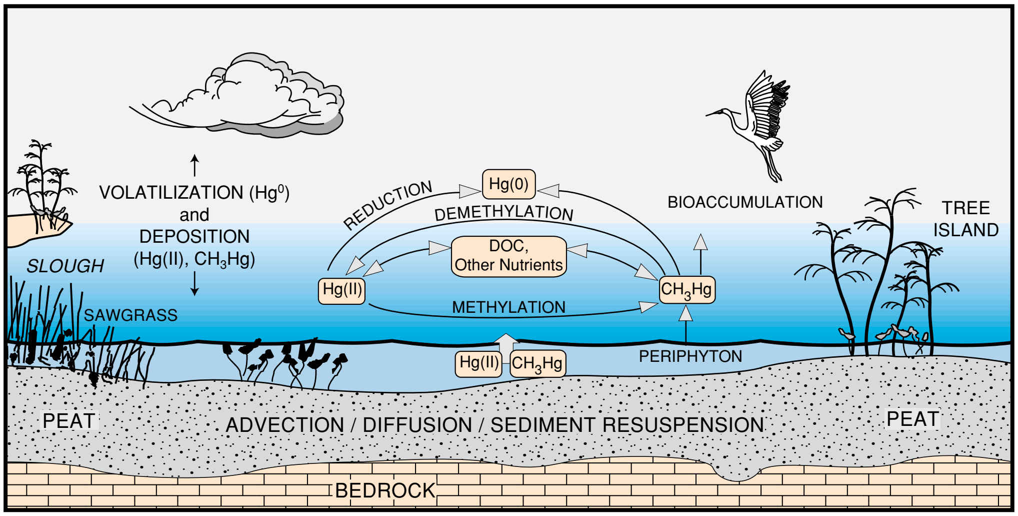


Figure 12. High concentrations of mercury in Everglades fish, birds, and other organisms is a result of food web bioaccumulation of methylmercury, which originates primarily at the sediment and periphyton-water interface (modified from Krabbenhoft, 1996).

The high concentrations of mercury in fish result from food-web bioaccumulation of methylmercury, the most biologically available form of mercury in the environment (fig. 12). Buildup in the Everglades food web begins with high rates of bacterial mercury methylation at the sediment-water interface and subsequent transport of methylmercury from this interface into the water column. The Everglades region had one of the highest methylmercury to mercury ratios in sediment of the 21 NAWQA basins sampled in 1998 (Krabbenhoft and others, 1999a).

Mercury methylation rates in the Everglades are affected by complex physical-chemical-biological processes that vary widely from day to night, from season to season, and along spatial gradients. Two of the most important controls on mercury methylation are availability of sulfur and bacterial cycling of sulfur. Sulfur inputs to the Everglades have increased over background levels during the 20th century as a result of runoff containing agricultural fertilizers. Large inputs of sulfur in parts of the northern Everglades have stimulated sulfate reduction that would normally favor methylation, but very high levels of sulfide in the eutrophic areas have an inhibitory effect on methylation rates. Lower levels of sulfur contamination in the central Everglades (fig. 11) have increased sulfate reduction and mercury methylation without the inhibitory effects of excess sulfide on methylation rates (Benoit and others, 1999; Orem and others, 1999, p. 79). Concentrations of mercury are higher in fish and other organisms in the more remote and low-nutrient waters of the central and southern Everglades than in the high-nutrient waters of the northern Everglades (Cleckner and others, 1998; Gilmour and others, 1998; Hurley and others, 1998).

Degradation of methylmercury also is a dynamic process that varies from day to night and spatially across the Everglades. Microbial demethylation rates in the sediments do not show strong spatial patterns, whereas photodemethylation rates in the water column do show a strong north to south upward trend, ranging from 2 to 15 percent per day, as a result of decreasing DOM in the water column from north to south and the resulting increase in light penetration in the south (Krabbenhoft and others, 1999b).

Atmospheric sources supply mercury that sustains methylation and food-web biomagnification in the Everglades. The southern Florida area has one of the highest atmospheric mercury deposition rates (25 micrograms per square meter per year, $\mu g/m^2/y$) in the United States (Krabbenhoft and others, 1999a). Atmospheric inputs have local sources, such as medical, municipal, and industrial incinerators, landfills, power plants, and other urban activities, and global sources. Local sources are considered by most investigators to be primarily responsible for the relatively high atmospheric mercury inputs in southern Florida.

Biological communities are influenced by water quality

The distribution of fish, invertebrates, and algae within a river or canal is influenced by natural conditions and human activities that affect water quality and available habitat. Generally, a diverse aquatic community composed of a variety of species and dominated by no single species or group of species is an indicator of favorable biotic conditions and an absence of contaminants and other environmental stresses. Although human activities have caused significant changes in many southern Florida freshwater habitats, it is important to understand how unique natural conditions in southern Florida influence the composition of aquatic communities there.

Sixty-three species of fish in 26 families were collected in the seven canals and rivers sampled in the SOFL Study Unit during 1996–98. The fish community included 43 native species and 10 exotic or non-native species. Additionally, 10 species of marine fish that periodically inhabit portions of canals and rivers in southern Florida also were collected. The chemical composition of freshwater in southern Florida, in particular the concentrations of sodium, chloride, and calcium, facilitates the invasion and occasional establishment of fishes with broad salinity tolerance (Loftus and Kushlan, 1987). No fish species listed as threatened or endangered in the United States or Florida were collected in southern Florida during the NAWQA study.

Florida rivers have smaller drainage basins and fewer fish species than rivers in the adjacent Southeastern United States (Swift and others, 1986). Natural conditions, in this case the repeated rise and fall of sea level over geologic time, have reduced the number of freshwater fish species in the Florida peninsula. The present fish community represents the most recent reinvasion following sea-level withdrawal (Bass, 1990). The most important natural factors limiting the diversity of the fish community are unsuitability of habitat and climate for temperate species (Loftus and Kushlan, 1987).

The rivers in southern Florida have very low gradients, typically only a few inches per mile (McPherson and Halley, 1996), as well as slow current velocities, high water temperatures, and low dissolved-oxygen concentrations. Fish and invertebrate communities are characterized by species that prefer these conditions and by the absence of related species that are found only in cool, swiftly flowing, well-oxygenated streams. The number of fish species collected at SOFL sites, or the species richness of the community, tended to increase with increasing mean annual dissolved-oxygen concentrations. Some game-fish species, such as bass, were absent at sites with the lowest dissolved-oxygen concentrations. One entire group of invertebrates (Plecoptera: stoneflies), which prefer cool running waters, usually are not found anywhere in the waters of southern Florida. Diptera (true flies) was the dominant insect group at all sites (fig. 13). Many of the Diptera were species in the family Chironomidae (midges), which are adapted to aquatic environments with sandy substrates and very low dissolved-oxygen concentrations, such as those prevalent in southern Florida surface waters. Species in this family are also tolerant of nutrient enrichment and contaminants.

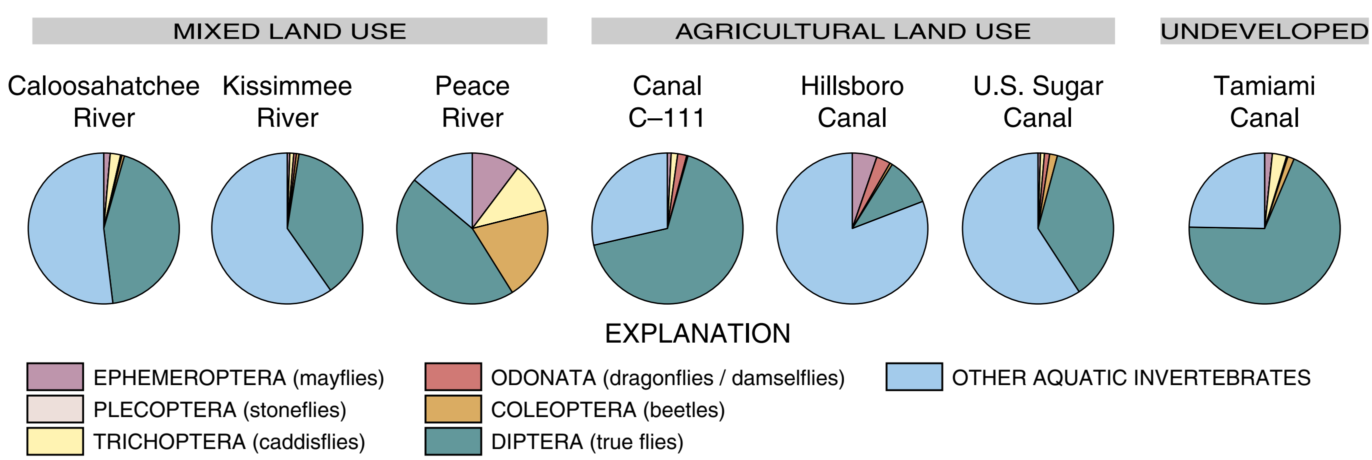


Figure 13. Diptera (true flies) dominated the insect community at the Southern Florida National Water-Quality Assessment Study Unit Sites, 1996–98.

In the canals and some of the rivers of southern Florida, habitat alteration is significant. The canal channels are rectangular in cross-section, and they have been channelized and are routinely dredged to facilitate navigation and the movement of water. There are few areas of shallow water (littoral zone) to provide sufficient light for attached algae (periphyton) and suitable spawning areas for fish. Moreover, aquatic vegetation is periodically removed for water-management purposes, further reducing habitat for small fish and invertebrates that serve as food for fish. The species richness of fish and the total numbers of fish collected generally were lowest in the canals of southern Florida in basins with agricultural land use (fig. 14). The canals and channelized rivers have little suitable habitat of any kind for many aquatic insects that prefer hard substrate, such as caddisflies (Trichoptera) and some mayflies (Ephemeroptera); snags (woody debris) are scarce because bankside vegetation is usually cleared, and hard surfaces, such as rock, are limited to porous limestone outcroppings.

Fish can be categorized on the basis of their ability to tolerate a range of environmental conditions. There were no intolerant fish species collected in any of the canals in southern Florida (fig. 14). The presence of intolerant species in the Peace River during the SOFL study, as well as in earlier studies (Champeau, 1990), indicates favorable biotic conditions. The Peace River is unique among the rivers sampled in southern Florida because it has not been channelized, and the main channel is connected to the flood plain during periods of high water. The flood plain provides a refuge for fish during high flow, perhaps enhancing survival and reproduction. Also, periodic flooding results in input of particulate organic matter and dissolved organic carbon from the flood plain, which increases the productivity of the river and increases its ability to support a diverse fish community.

The environmental conditions in the Peace River also supported a diverse aquatic insect community compared to most other SOFL sites (fig. 13). For example, the Peace River had the highest mean dissolved-oxygen concentration of any southern Florida site. Hard substrates, such as the woody snags preferred by many aquatic insects, were abundant. Seasonal input of leaf debris (particulate organic matter) from the flood plain provides a valuable food source for many aquatic invertebrates. In contrast, Hillsboro Canal, a relatively degraded SOFL site, had insects from a number of different groups, but few of the pollution-sensitive insects, including caddisflies, were present.

In many parts of the United States, the abundance of a group of invertebrate taxa referred to as the EPT taxa (Ephemeroptera, Plecoptera, Trichoptera) is used to assess the biotic condition of streams and rivers. Species in these insect groups generally thrive in conditions of flowing water, moderate to high dissolved oxygen, and low suspended sediment and are intolerant of contaminants and habitat disturbance. The relative abundance of EPT taxa compared to the more tolerant Diptera taxa can be used to assess and compare sites. However, this metric must be used with caution because Plecoptera usually are not found in southern Florida. The Peace River had the highest EPT/Diptera ratio compared to the other SOFL sites. The Peace River also supported a diverse algae community with the greatest species richness (220 species) of all the SOFL sites. Total phosphorus and nitrogen concentrations were high in the Peace River compared to other SOFL sites because of natural conditions and human activities. The availability of these essential nutrients, combined with an unmodified habitat and more shallow-water areas, may contribute to a more diverse algal community.

The Tamiami Canal is unique among the SOFL canal sites because land within its basin is mostly undeveloped, limiting the input of contaminants. However, the environmental conditions are stressful because the shallow canal has almost no flow, the water is warm, and dissolved-oxygen concentra-

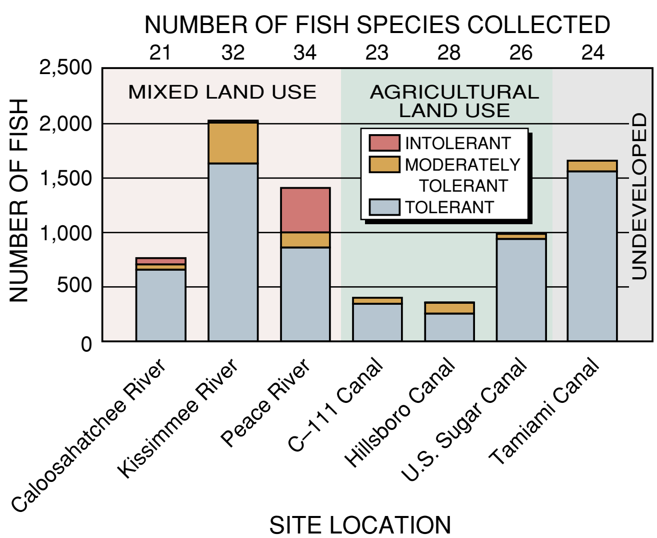
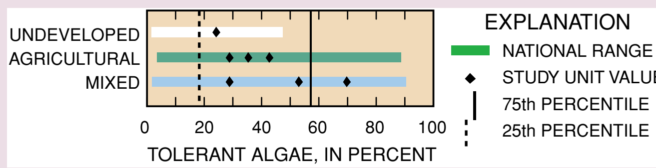


Figure 14. Environmentally tolerant fish are common in southern Florida canals and rivers.

tions typically are very low. Nutrient concentrations were among the lowest of the SOFL sites. The insect community was dominated by Diptera, although some Trichoptera that are adapted to still or slow-flowing conditions were collected. Bluegreen algae were relatively abundant. The fish community showed little similarity to any of the other sites and was characterized by an abundance of minnows and Florida gar. The Tamiami Canal had the smallest proportion (5 percent) of fish with external anomalies. External anomalies, such as eroded fins, lesions, ulcers, tumors, and external parasites, can be an indication that fish are stressed by environmental conditions or contaminants. The highest percentages of fish with external anomalies were from the Hillsboro (32 percent) and C-111 Canals (22 percent). Anomalies at these two sites were primarily external parasites, eroded fins, and anatomical deformities. These two sites were in the top 25 percent of 144 NAWQA sites sampled nationwide.

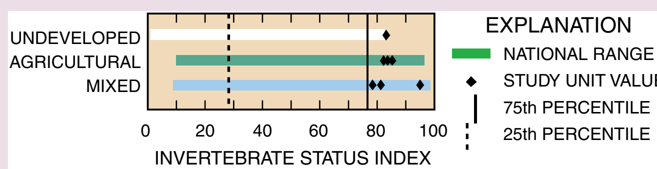
SOUTHERN FLORIDA AQUATIC COMMUNITIES IN A NATIONAL CONTEXT

Algae Siltation Index



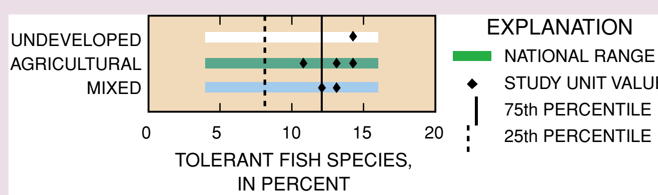
Algae collected at the seven southern Florida NAWQA sites were compared to algae at 140 national NAWQA sites by using the Siltation Index (Bahls and others, 1992). This index is the relative abundance of the motile diatoms *Navicula*, *Nitzschia*, *Cylindrotheca*, and *Surirella* in a diatom count. These diatoms are able to move through silt particles, and because they are able to avoid being buried, they are considered more tolerant of sedimentation than other diatoms. The values for this index are higher for streams in agricultural basins. Based on the relative abundance of these diatoms, the undeveloped Southern Florida site (Tamiami Trail Canal) falls into the less degraded stream category, whereas the agricultural sites are between the 25th and 50th percentile, and two of the three major river sites in the mixed land-use category are near or above the 75th percentile. See pages 18–20 for how algae communities compare at sites within the SOFL Study Unit.

Invertebrate Community Status Index (ICSI)



Invertebrate communities at the seven southern Florida NAWQA sites were compared to invertebrate communities at NAWQA sites nationwide by using a multimetric index. The index combines 11 metrics, including ones that assess taxa richness and diversity, taxa richness of mayflies, stoneflies, and caddisflies, and various measures of environmental tolerance. Using the ICSI, all seven of the Southern Florida sites ranked above the 75th percentile, indicating that they are among the most degraded sites in the Nation. Use of the ICSI in southern Florida must be approached with caution because background environmental conditions prevalent at all sites, including slow water velocities and low dissolved-oxygen concentrations, probably contribute to the high index values and may obscure differences in invertebrate communities because of other factors, such as land use or changes in habitat. The dominance of Diptera (true flies), insects that are tolerant of degraded environmental conditions, and low diversity of insects overall contribute to the high ICSI scores for Southern Florida. See pages 18–20 for how insect communities compare at sites within the SOFL Study Unit.

Fish Status Index



To facilitate comparisons, fish collected at NAWQA sites across the Nation were classified based on four fish metrics (percentage of tolerant, ominvorous, non-native individuals, and percentage of individuals with external anomalies). Nationwide, higher values suggest a more degraded stream site. Six of the SOFL sites, including the reference site, ranked in the highest 25th percentile cataegory for the Nation. Environmental conditions mentioned above for invertebrates also may contribute to stress in the fish community at sites including the reference site. This environmental stress can lead to dominance of tolerant fish, favorable conditions for exotic species, and increased external anomalies at some sites in the SOFL Study Unit, leading to higher values compared with other sites nationwide. See pages 18–20 for a discussion of how fish communities compare at sites within the SOFL Study Unit.

Exotic species are a threat to native biota

Exotic or non-native species of fish, as well as other animals and plants, represent a major threat to native biota in southern Florida. Exotic fish compete with native species for food and habitat. Exotic plants crowd out native species and can form dense monocultures that alter habitat for birds, fish, and other native biota. Ten exotic fish species were collected at the SOFL sites during 1996–98 (fig. 15). Cichlids were the most numerous and widespread exotic species, including the black acara, Mayan cichlid, peacock cichlid, blue tilapia, spotted tilapia, and the oscar. The other exotic species collected (pike killifish, grass carp, walking catfish, and sailfin catfish) were all rare and found at only one or two sites each. Fifty-four exotic fish species have been recorded in southern Florida, and the total statewide exceeded 125 species by 1998 (Fuller and others, 1999). Nearly all the exotic fish species were originally imported for the aquarium trade and either escaped from fish farms or were released by individuals with home aquariums. Exotic fish usually are most abundant in streams that have been altered by human activity (Moyle, 1986). Generally, the canal sites in southern Florida had more exotic species than the major rivers. The number of species of exotic fish at SOFL sites ranked in the top one-third of NAWQA sites nationwide.

The swamp eel (*Monopterus albus),* recently introduced from Southeast Asia, is a potentially dangerous invader. The swamp eel can breathe air for extended periods of time, enabling it to inhabit stagnant water and even live out of water. This characteristic also enhances its ability to disperse widely. It is a voracious general predator, making it a threat to native fishes, amphibians, and aquatic invertebrates. The swamp eel was not collected at any of the SOFL sites during 1996–98. However, this species has affected regional water-management practices. Selected water-control structures in the vicinity of established populations are not being opened to prevent or at least retard dispersal, particularly into waters of ENP.

In addition to fish, other exotic species are of great concern in Florida. At least 25 percent of all plant species in the State are exotic (Langeland, 1998). Melaleuca, a wetland tree, covers almost 400,000 acres in the State and is particularly troublesome in the Water Conservation Areas (Laroche, 1994). Brazilian pepper, a wetland shrub, has infested more than 100,000 acres in the ENP (Ferriter, 1997). Hydrilla, water hyacinth, water milfoil, and water lettuce are the most abundant exotic aquatic plant species infesting canals throughout southern Florida. Efforts to control or eradicate exotic plant species involve the use of mechanical, chemical, and biological control methods. Numerous herbicides are applied, including 2,4-D, copper sulfate, diquat, endothall, fluridone, glyphosate, imazapyr, triclopyr, and others. At least two of these compounds (2,4-D and triclopyr) have been detected in surface water at the SOFL sites.

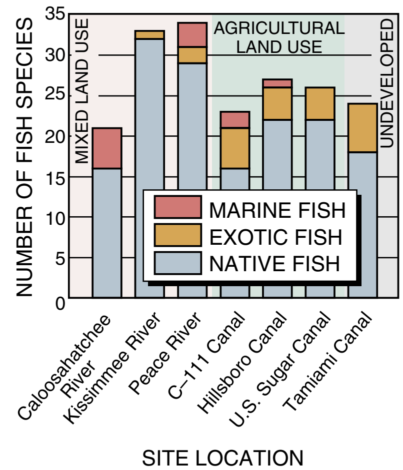
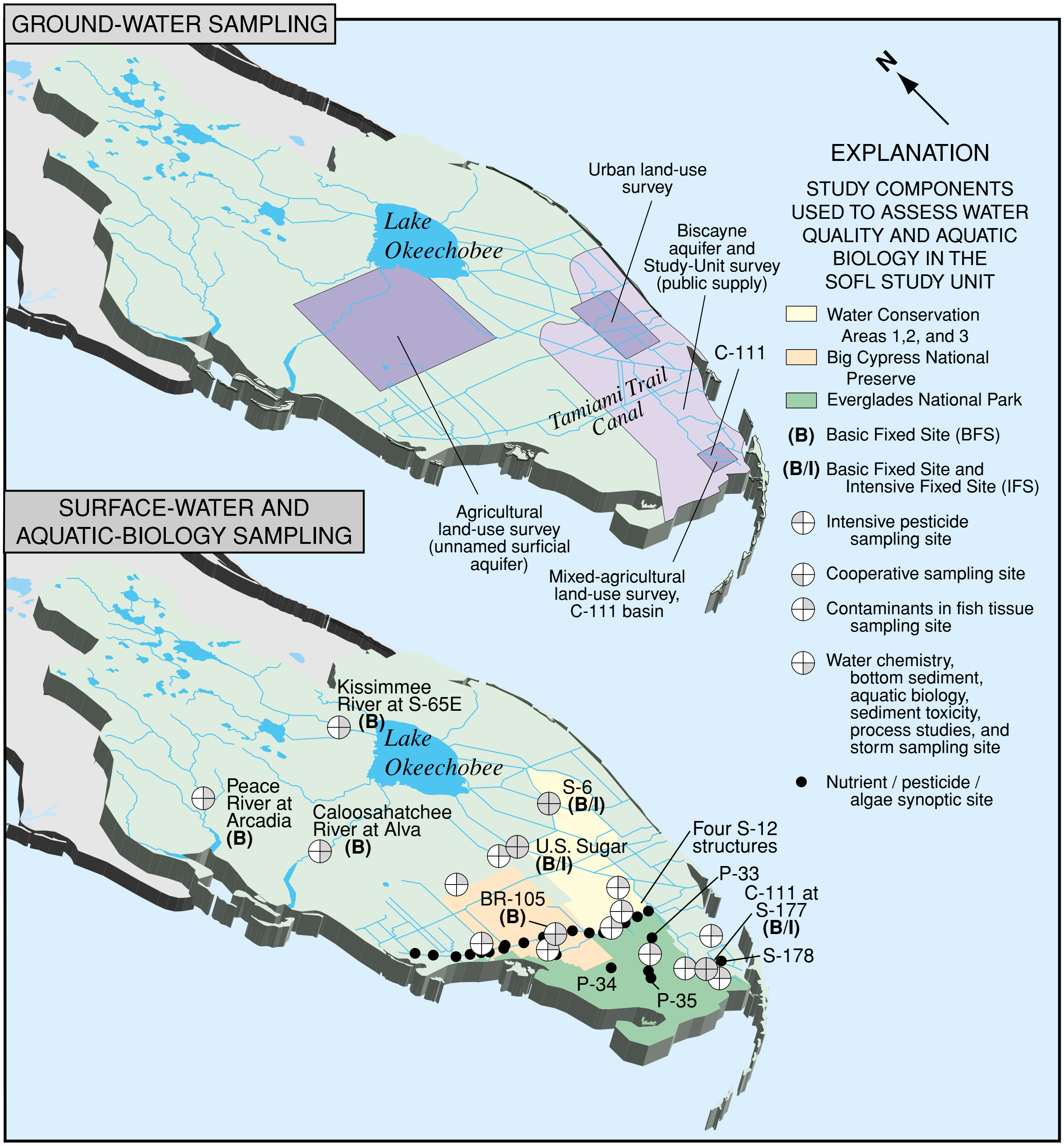


Figure 15. Exotic fish species were collected at all SOFL sites, 1996-98.

The exotic sailfin catfish, *Pterygoplichthys disjunctivus*, is a South American invader.

The Asian swamp eel, *Monopterus albus*, continues to spread.


GROUND-WATER SAMPLING
Lake Okeechobee
Urban land-use survey
Biscayne aquifer and Study-Unit survey (public supply)
C-111
Tamiami Trail Canal
Agricultural land-use survey (unnamed surficial aquifer)
Mixed-agricultural land-use survey, C-111 basin
SURFACE-WATER AND AQUATIC-BIOLOGY SAMPLING
Kissimmee River at S-65E (B)
Lake Okeechobee
Peace River at Arcadia (B)
Caloosahatchee River at Alva (B)
S-6 (B/I)
U.S. Sugar (B/I)
Four S-12 structures
BR-105 (B)
P-33
C-111 at S-177 (B/I)
S-178
P-34
P-35
N
EXPLANATION
STUDY COMPONENTS USED TO ASSESS WATER QUALITY AND AQUATIC BIOLOGY IN THE SOFL STUDY UNIT
Water Conservation Areas 1,2, and 3
Big Cypress National Preserve
Everglades National Park
(B) Basic Fixed Site (BFS)
(B/I) Basic Fixed Site and Intensive Fixed Site (IFS)
Intensive pesticide sampling site
Cooperative sampling site
Contaminants in fish tissue sampling site
Water chemistry, bottom sediment, aquatic biology, sediment toxicity, process studies, and storm sampling site
Nutrient / pesticide / algae synoptic site

Study component (Type of site)	Objectives	Brief description and water-quality parameters	Number of sites	Sampling frequency during water year	Historical data available
SURFACE WATER					
Bottom-sediment survey (BFS)	Determine presence of potentially toxic compounds in sediment at selected sites	Sample the depositional zone for pesticides, other synthetic organic compounds, and trace elements at water-chemistry sites	7	1 (1996)	some
Water-chemistry sites (BFS)	Describe concentrations and loads of major ions and nutrients at selected sites	Sample near-continuous streamflow sites for major ions, nutrients, organic carbon, and suspended sediment	7	2–6 in 1996 12–31 in 1997 12 in 1998	data at some sites
Cooperative sampling program (BFS)	Assess the influence of sampling method and location on water-quality data	Sample water-chemistry sites on the same day as the SFWMD using both USGS methods and SFWMD methods	5	2–6 in 1996 12–31 in 1997 12 in 1998	none
Storm sampling (BFS)	Assess effects of runoff during high-flow conditions on surface-water quality	Sample water-chemistry sites during high-flow conditions for major ions, nutrients, organic carbon, and suspended sediment	variable	variable (1997 and 1998)	some
Nutrient/ pesticide synoptic studies	Determine the concentration of nutrients and pesticides across southern end of Study Unit during high and low flow	Sample sites along the Tamiami Trail Canal during low flow (June) and high flow (August) for major ions, mercury, nutrients, organic carbon, and pesticides	30	3 (Aug. 1996, June and August 1997)	limited
Process studies	Describe processes controlling the degradation and biological availability of pesticides	Deploy and collect semipermeable membrane devices at selected sites. Collect water and bottom-sediment samples	variable	4 (1997–98)	undeter-mined
Intensive pesticide sampling (IFS)	Determine seasonal variation in the occurrence and concentrations of nutrients and pesticides at water-chemistry sites	Sample water-chemistry sites that are located in specified agricultural land-use areas (citrus, sugarcane, and vegetables) for nutrients and pesticides	3	2 in 1996; weekly/biweekly in 1997; monthly in 1998	some
GROUND WATER					
Urban land-use survey	Describe water quality in a residential and light commercial land-use area in a shallow aquifer susceptible to contamination	Sample monitoring wells for major ions, nutrients, organic carbon, pesticides, radionuclides, trace elements, and volatile organic compounds (VOCs)	38 wells	1 (1997)	some
Ground-water and surface-water synoptic survey	Determine which water-quality constituents are transported through shallow ground water into surface water in an agricultural land-use area	Sample shallow wells and surface-water sites for major ions, nutrients, pesticides, and VOCs before and during a surface-water release in a canal that drains agricultural land	7 wells; 9 surface-water sites	1–5 (1997)	none
Agricultural land-use survey	Describe the effects of citrus land use on water quality in a shallow aquifer.	Sample new wells for major ions, nutrients, pesticides, radionuclides, and trace elements	30 wells	1 (1998)	some
Study-unit survey (public supply)	Describe overall water quality in the Biscayne aquifer, which is used for drinking-water supply	Sample existing wells for major ions, nutrients, organic carbon, pesticides, radionuclides, trace elements, and VOCs	30 wells	1 (1998)	some
AQUATIC BIOLOGY					
Contaminants in fish tissue	Determine the presence of contaminants that can accumulate in fish tissue	Collect largemouth bass and Florida gar at a large number of sites. Sample composites of whole fish for organic compounds and fish livers for trace elements	15	1 (1996)	limited
Sediment toxicity testing	Evaluate potential toxicity of bed sediment at the water-chemistry sites	Collect bed-sediment samples and evaluate their potential toxicity by using ASTM methods and *Hyallela azteca*	7	1 (1996)	none
Aquatic biology	Assess biological communities and stream habitat at the Basic Fixed Sites	Quantitatively sample fish, macroinvertebrates, and algae near water-chemistry sites. Quantitatively describe stream habitat for these organisms	7	3 (1 per year during 1996–98)	limited
Algae synoptic studies	Determine the influence of nutrients on the algal community along a nutrient gradient in the southern part of the basin	Collect algae using artificial substrate samplers at sites across the Tamiami Trail Canal	10–13	3 (June, August, November, 1997)	none

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

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

Basic Fixed Sites (BFS) - Sites on streams or canals at which streamflow is measured and samples are routinely collected for temperature, salinity, major ions, nutrients, and organic carbon. Samples may also be periodically collected for contaminants in bottom sediment, biota, storm effects, or other constituents.

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

DDT - Dichloro-diphenyl-trichloroethane. An organochlorine insecticide no longer registered for use in the United States. DDT degradation products include DDE and DDD.

Drinking-water standard or guideline - A threshold concentration in a public drinking-water supply, designed to protect human health.

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

Intensive Fixed Sites (IFS) - Basic Fixed Sites with increased sampling frequency during selected seasonal periods and analysis of dissolved pesticides for 1 year.

Load - General term that refers to a material or constituent in solution, in suspension, or in transport; usually expressed in terms of mass or volume.

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.

Methylation - The addition of a methyl group ($–CH_3$) to a molecule or atom through a chemical reaction.

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

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

Organochlorine insecticide - A class of organic insecticides containing a high percentage of chlorine. Includes dichlorodiphenylethanes (such as DDT), chlorinated cyclodienes (such as chlordane), and chlorinated benzenes (such as lindane).

Periphyton - Organisms that grow on underwater surfaces; periphyton include algae, bacteria, fungi, protozoa, and other organisms.

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

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

Phthalates - A class of organic compounds containing phthalic acid esters [C6H4(COOR)2] and derivatives. Used as plasticizers in plastics. Also used in many other products (such as detergents, cosmetics) and industrial processes (such as defoaming agents during paper and paperboard manufacture, and dielectrics in capacitors).

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

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.

Reference site - A sampling site selected for its relatively undisturbed conditions.

Trace element - An element found in only minor amounts (concentrations less than 1.0 mg/L) in water or sediment; includes arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc.

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

Water-quality criteria - Specific levels of water quality which, if reached, are expected to render a body of water unsuitable for its designated use.

Water-quality standards - State-adopted and U.S. Environmental Protection Agency-approved ambient standards 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.

Water year - The 12-month period October 1 through September 30, designated by the calendar year in which it ends.

REFERENCES

Adams, C.D., and Thurman, E.M., 1991, Formation and transport of deethylatrazine in the soil and vadose zone: Journal of Environmental Quality, v. 20, no. 3, p. 540–547.

Bahls, L.R., Burkantis, R., and Tralles, S., 1992, Benchmark biology of Montana reference streams: Helena, Montana, Department of Health and Environmental Science, Water Quality Bureau, 47 p.

Bass, D.G., Jr., 1990, Monitoring Florida's riverine fish communities: Florida Science, v. 53, no. 1, p. 1–10.

Benoit, J.M., Gilmour, C.C., Mason, R.P., and Heyes, A., 1999, Sulfide controls on mercury speciation and bioavailability to methylating bacteria in sediment and pore waters: Environmental Science and Technology, v. 33, p. 951–957.

Champeau, T.R., 1990, Ichthyofaunal evaluation of the Peace River, Florida: Florida Scientist, v. 53, p. 302–311.

Chiou, C.T., Malcolm, R.L., Brinton, T.I., and Kile, D.E., 1986, Water solubility enhancement of some organic pollutants and pesticides by dissolved humic and fulvic acids: Environmental Science and Technology, v. 20, p. 502–508.

Cleckner, L.A., Garrison, P.J., Hurley, J.P., Olson, M.O., and Krabbenhoft, D.P., 1998, Trophic transfer of methyl mercury in the northern Florida Everglades: Biogeochemistry, v. 40, p. 347–361.

Colborn, T., vom Saal, F.S., and Sota, A.M., 1993, Developmental effects of endocrine-disrupting chemicals in wildlife and humans: Environmental Health Perspectives, v. 101, p. 378–384.

Davis, J.H., Jr., 1943, The natural features of southern Florida, especially the vegetation, and the Everglades: Florida Geological Survey Bulletin 25, 311 p.

Environment Canada, 1999, Canadian sediment quality guidelines for the protection of aquatic life, Summary tables: accessed September 17, 1999 at http://www.ec.gc.ca/ceqg-rcqe/sediment.htm.

Ferriter, A.P., 1997, Brazilian pepper management plan for Florida: West Palm Beach, Fla., Florida Exotic Pest Plant Council, 38 p.

Fuller, P.L., Nico, L.G., and Williams, J.D., 1999, Nonindigenous fishes introduced into inland waters of the United States: Bethesda, Md., American Fisheries Society, Special Publication, v. 27, 613 p.

Gilmour, C.C., Riedel, G.S., Ederington, M.C., Bell, J.T., Benoit, J.M., Gill, G.A., and Stordal, M.C., 1998, Mercury methylation and sulfur cycling across a trophic gradient in the northern Everglades: Biogeochemistry, v. 40, p. 327–345.

Goolsby, D.A., Thurman, E.M., Pomes, M.L., Meyer, M.T., and Battaglin, W.A., 1997, Herbicides and their metabolites in rainfall: Origin, transport, and deposition patterns across the Midwestern and Northeastern United States, 1990–1991: Environmental Science and Technology, v. 31, p. 1325–1333.

Haag, K.H., and McPherson, B.F., 1997, Organochlorine pesticides and PCBs in southern Florida fishes—Then and Now: U.S. Geological Survey Fact Sheet FS–110–97, 4 p.

Haag, K.H., Miller, R.L., Bradner, L.A., and McCulloch, D.S., 1996, Water-quality assessment of southern Florida—An overview of available information on surface and ground water and ecology: U.S. Geological Survey Water-Resources Investigations Report 96–4177, 42 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hurley, J.P., Krabbenhoft, D.P., Cleckner, L.B., Olson, M.L., Aiken, G., and Rawlik, P.S., Jr., 1998, System controls on aqueous mercury distribution in the northern Everglades: Biogeochemistry 40, p. 293–311.

Klein, Howard, Armbruster, J.T., McPherson, B.F., and Freiberger, H.J., 1975, Water and the south Florida environment: U.S. Geological Survey Water-Resources Investigation 24–75, 165 p.

Kolipinski, M.C., and Higer, A.L., 1969, Some aspects of the effects of the quantity and quality of water on biological communities in Everglades National Park: U.S. Geological Survey Open-File Report, 97 p.

Kolpin, D.W., Barbash, J.E., and Gilliom, R.J., 1998, Occurrence of pesticides in shallow ground water of the United States—Initial results from the National Water-Quality Assessment Program: Environmental Science and Technology, v. 32, 558–566 p.

Krabbenhoft, D.P., 1996, Mercury studies in the Florida Everglades: U.S. Geological Survey Fact Sheet FS–166–96, 4 p.

Krabbenhoft, D.P., Wiener, J.G., Brumbaugh, W.G., Olson, M.L., DeWild, J.F., and Sabin, T.J., 1999a, A national pilot study of mercury contamination of aquatic ecosystems along multiple gradients, *in* Morganwalp, D.W., and Buxton, H.T., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the Technical Meeting, Charleston, SC, March 8–12, 1999—Contamination of hydrologic systems and related ecosystems: U.S. Geological Survey Water-Resources Investigations Report 99–4018B, v. 2, p. 147–160.

Krabbenhoft, D.P., Hurley, J.P., Marvin-DiPasquale, M., Orem, W.H., Aiken, G.R., Schuster, P.J., Gilmour, C.C., and Harris, R., 1999b, The aquatic cycling of mercury in the Everglades (ACME) project: A process-based investigation of mercury biogeochemistry in a complex environmental setting, *in* Gerould, Sarah, and Higer, Aaron, compilers, U.S. Geological Survey, Program on the South Florida Ecosystem—Proceedings of South Florida Restoration Science Forum, May 17–19, 1999, Boca Raton, Florida: U.S. Geological Survey Open-File Report 99–181, p. 54–56.

Lambou, V.W., Barkay, T., Braman, R.S., Delfino, J.J., Jansen, J.J., Nimmo, D., Parks, J.W., Porcella, D.B., Rudd, J., Schultz, D., Stober, J., Watras, C., Wiener, J.G., Gill, G., Huckabee, J., and Rood, B.E., 1991, Mercury technical advisory committee interim report to the Florida Governor's Mercury in Fish and Wildlife Taskforce and the Department of Environmental Regulation: Tallahassee, Fla., Center for Biomedical and Toxicological Research and Waste Management, 60 p.

Langeland, K.A., 1998, Help protect Florida's natural areas from non-native invasive plants: Gainesville, University of Florida, Cooperative Extension Service, Institute of Food and Agricultural Sciences, Circular 1204, 6 p.

Laroche, F.B., ed., 1994, Melaleuca management plan for Florida: West Palm Beach, Florida Exotic Pest Plant Council, 88 p.

Loftus, W.F., and Kushlan, J.A., 1987, Freshwater fishes of southern Florida: Gainesville, Fla., Bulletin of the Florida State Museum of Biological Sciences, v. 31, no. 4, 344 p.

McIvor, C.C., Ley, J.A., and Bjork, R.D., 1994, Changes in freshwater inflow from the Everglades to Florida Bay including effects on biota and biotic processes—A review, *in* Davis, S.M., and Ogden, J.C., eds., Everglades—The ecosystem and its restoration: Delray Beach, Fla., St. Lucie Press, p. 117–146.

McPherson, B.F., 1973, Water quality in the conservation areas of the central and southern Florida Flood Control District, 1970–72: U.S. Geological Survey Open-File Report 73–014, 39 p.

McPherson, B.F., and Halley, Robert, 1996, The south Florida environment—A region under stress: U.S. Geological Survey Circular 1134, 61 p.

McPherson, B.F., and Miller, R.L., 1987, The vertical attenuation of light in Charlotte Harbor, a shallow, subtropical estuary, southwestern Florida: Estuarine, Coastal, and Shelf Science, v. 25, p. 721–737.

Meyer, M.T., Mills, M.S., and Thurman, E.M., 1993, Automated solid-phase extraction of herbicides from water for gas chromatographic-mass spectrometric analysis: Journal of Chromatography, v. 629, p. 55–59.

Miles, C.J., and Pfeuffer, R.J., 1997, Pesticides in canals of south Florida: Archives of Environmental Contamination and Toxicology, v. 32, p. 337–345.

Miller, R.L., and McPherson, B.F., in press, Occurrence and distribution of contaminants in bottom sediment and water of the Barron River Canal, Big Cypress National Preserve, Florida, October 1998: Florida Scientist, v. 64, no. 1.

Miller, R.L., McPherson, B.F., and Haag, K.L., 1999, Water quality in the southern Everglades and Big Cypress Swamp in the vicinity of the Tamiami Trail, 1996–97: U.S. Geological Survey Water-Resources Investigations Report 99–4062, 16 p.

Moyle, P.B., 1986, Fish introductions into North America—Patterns and ecological impact, *in* Mooney, H.A., and Drake, J.A., eds., Ecology of biological invasions of North America and Hawaii: New York, Springer-Verlag, p. 27–43.

Newell, A.J., Johnson, D.W., and Allen, L.K., 1987, Niagara River Project—Fish flesh criteria for piscivorous wildlife: New York State Department of Environmental Conservation Technical Report 87–3.

Nowell, L.H., Capel, P.D., and Dileanis, P.D., 1999, Pesticides in stream sediment and aquatic biota—Distribution, trends, and governing factors: Boca Raton, Fla., Lewis Publishers, 1001 p.

Orem, W.H., Bates, A.L., Lerch, H.E., Corum, Margo, and Boylan, Ann, 1999, Sulfur contamination in the Everglades and its relation to mercury methylation, *in* Gerould, Sarah, and Higer, Aaron, comps., U.S. Geological Survey Program on the South Florida Ecosystem—Proceedings of South Florida Restoration Science Forum, May 17–19, 1999, Boca Raton, Florida: U.S. Geological Survey Open-File Report 99–181, 121 p.

Parker, G.G., Ferguson, G.E., Love, S.K., and others, 1955, Water resources of southeastern Florida, with special reference to geology and ground water of the Miami area: U.S. Geological Survey Water-Supply Paper 1255, 965 p.

Reddy, M.M., Aiken, G.R., and Schuster, P.F., 1999, Mercury-dissolved organic carbon interactions in the Florida Everglades—A field and laboratory investigation, *in* U.S. Geological Survey, Program on the south Florida ecosystem, Proceedings of South Florida Restoration Science Forum, May 17–19, 1999, Boca Raton, Fla.: U.S. Geological Survey Open-File Report 99–181, p. 86–87.

Shahane, A.N.,1994, Pesticide detections in surface waters of Florida—Toxic substances and the hydrologic sciences: American Institute of Hydrology, p. 408–416.

Stober, Q.J., Jones, R.D., and Scheidt, D.J., 1995, Ultra trace level mercury in the Everglades ecosystem, a multi-media canal pilot study: Water, Air, and Soil Pollution, v. 80, p. 991–1001.

Swancar, Amy, 1996, Water quality, pesticide occurrence, and effects of irrigation with reclaimed water at golf courses in Florida: U.S. Geological Survey Water-Resources Investigations Report 95–4250, 85 p.

Swift, C.C., Gilbert, C.R., Bortone, S.A., Burgess, G.H., and Yerger, R.W., 1986, Zoogeography of the freshwater fishes of the southeastern United States—Savannah River to Lake Pontchartrain, *in* Hocutt, C.H. and Wiley, E.O., eds., The zoogeography of northern American freshwater fishes: New York, John Wiley and Sons, p. 213–265.

Thurman, E.M., Goolsby, D.A., Meyer, M.T., and Kolpin, D.W., 1991, Herbicides in surface waters of the Midwestern United States—The effect of the spring flush: Environmental Science and Technology, v. 25, p. 1794–1796.

Thurman, E.M., Goolsby, D.A., Meyer, M.T., Mills, M.S., Pomes, M.L., and Koplin, D.W., 1992, A reconnaissance study of herbicides and their metabolites in surface water of the Midwestern United States using immunoassay and gas chromatography/mass spectrometry: Environmental Science and Technology, v. 26, p. 2440–2447.

Thurman, E.M., Meyer, M.T., Pomes, M.L., Perry, C.A., and Schwab, P., 1990, Comparison of an enzyme-linked immunosorbent assay and gas chromatography/mass spectrometry for the analysis of herbicides in water: Analytical Chemistry, v. 62, p. 2043–2048.

U.S. Geological Survey, 2000, Pesticides in surface and ground water of the United States: Summary of results of the National Water-Quality Assessment Program (NAWQA): accessed Aug. 18, 2000, at http://wwwd-cascr.wr.usgs.gov/pnsp/allsum_sw.html.

———1999, The quality of our Nation's waters: U.S. Geological Survey Circular 1225, 82 p.

Ware, F. J., Royals, H., and Lange, T., 1990, Mercury contamination in Florida largemouth bass: Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies, no. 44, p. 5–12.

APPENDIX—WATER-QUALITY DATA FROM SOUTHERN FLORIDA IN A NATIONAL CONTEXT

For a complete view of Southern Florida 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://water.usgs.gov/nawqa/data.

This appendix is a summary of chemical concentrations and biological indicators assessed in Southern Florida. 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 Southern Florida 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, norflurazon concentrations in Southern Florida ground water in agricultural areas were similar to the national distribution, but the detection frequency was much higher (72 percent compared to 2 percent).

CHEMICALS IN WATER

Concentrations and detection frequencies, Southern Florida, 1996–98—Detection sensitivity varies among chemicals and, thus, frequencies are not directly comparable among chemicals

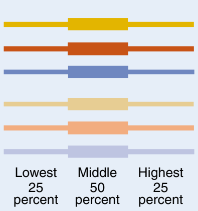
◆ Detected concentration in Study Unit

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



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)

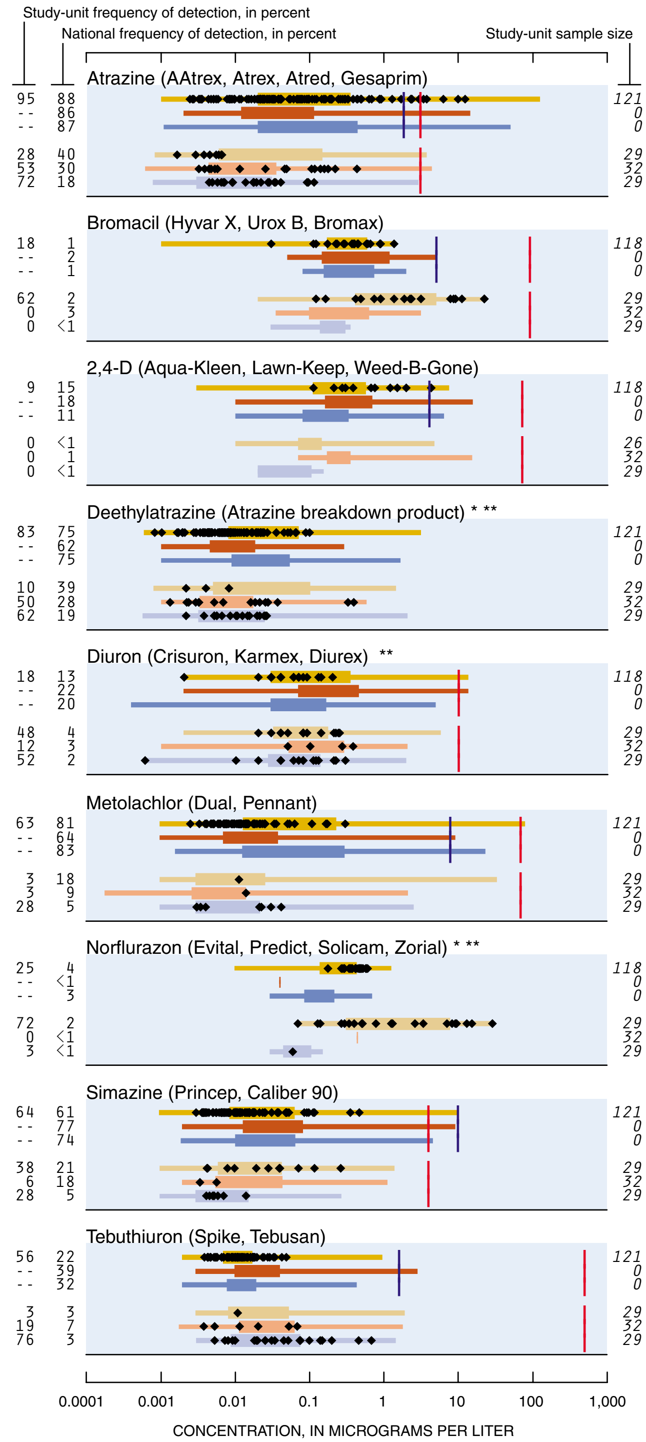
| Protection of aquatic life (applies to surface water only)

| 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

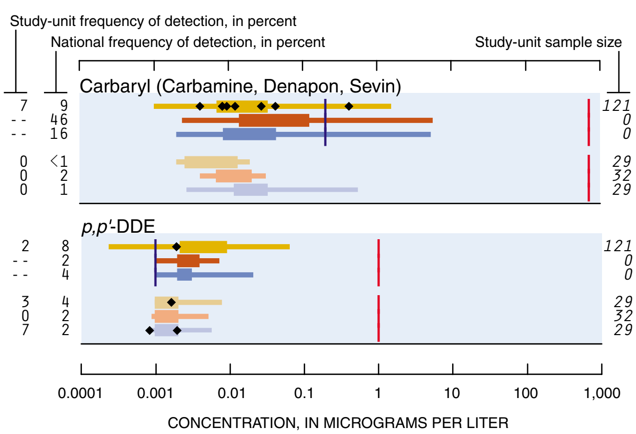


Other herbicides detected
Alachlor (Lasso, Bronco, Lariat, Bullet) **
Benfluralin (Balan, Benefin, Bonalan) * **
Bentazon (Basagran, Bentazone) **
Butylate (Sutan +, Genate Plus, Butilate) **
Cyanazine (Bladex, Fortrol)

DCPA (Dacthal, chlorthal-dimethyl) * **
Dicamba (Banvel, Dianat, Scotts Proturf)
2,6-Diethylaniline (Alachlor breakdown product) * **
EPTC (Eptam, Farmarox, Alirox) * **
Fenuron (Fenulon, Fenidim) * **
Linuron (Lorox, Linex, Sarclex, Linurex, Afalon) *
Metribuzin (Lexone, Sencor)
Napropamide (Devrinol) * **
Prometon (Pramitol, Princep) **
Pronamide (Kerb, Propyzamid) **
Propanil (Stam, Stampede, Wham) * **
Terbacil (Sinbar) **
Triclopyr (Garlon, Grandstand, Redeem, Remedy) * **

Herbicides not detected
Acetochlor (Harness Plus, Surpass) * **
Acifluorfen (Blazer, Tackle 2S) **
Bromoxynil (Buctril, Brominal) *
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) * **
Dinoseb (Dinosebe)
Ethalfluralin (Sonalan, Curbit) * **
Fluometuron (Flo-Met, Cotoran) **
MCPA (Rhomene, Rhonox, Chiptox)
MCPB (Thistrol) * **
Molinate (Ordram) * **
Neburon (Neburea, Neburyl, Noruben) * **
Oryzalin (Surflan, Dirimal) * **
Pebulate (Tillam, PEBC) * **
Pendimethalin (Pre-M, Prowl, Stomp) * **
Picloram (Grazon, Tordon)
Propachlor (Ramrod, Satecid) **
Propham (Tuberite) **
2,4,5-T **
2,4,5-TP (Silvex, Fenoprop) **
Thiobencarb (Bolero, Saturn, Benthiocarb) * **
Triallate (Far-Go, Avadex BW, Tri-allate) *
Trifluralin (Treflan, Gowan, Tri-4, Trific)

Pesticides in water—Insecticides

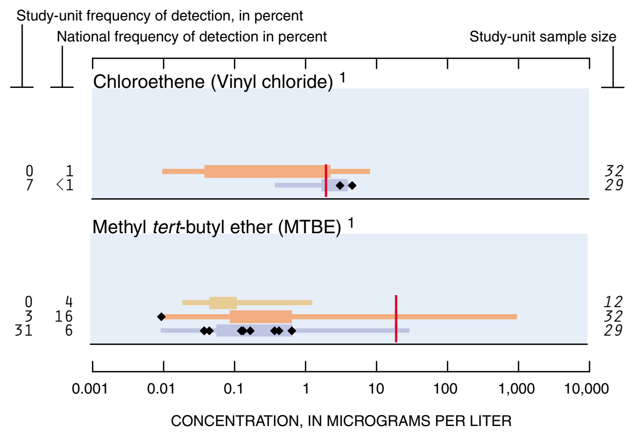


Other insecticides detected
Carbofuran (Furadan, Curaterr, Yaltox)
Chlorpyrifos (Brodan, Dursban, Lorsban)
Dieldrin (Panoram D-31, Octalox, Compound 497)
Ethoprop (Mocap, Ethoprophos) * **
Malathion (Malathion)
Methomyl (Lanox, Lannate, Acinate) **
Methyl parathion (Penncap-M, Folidol-M) **
Propoxur (Baygon, Blattanex, Unden, Proprotox) * **

Insecticides not detected
Aldicarb (Temik, Ambush, Pounce)
Aldicarb sulfone (Standak, aldoxycarb)
Aldicarb sulfoxide (Aldicarb breakdown product)
Azinphos-methyl (Guthion, Gusathion M) *
Diazinon (Basudin, Diazatol, Neocidol, Knox Out)
Disulfoton (Disyston, Di-Syston) **
Fonofos (Dyfonate, Capfos, Cudgel, Tycap) **
alpha-HCH (alpha-BHC, alpha-lindane) **
gamma-HCH (Lindane, gamma-BHC)
3-Hydroxycarbofuran (Carbofuran breakdown product) * **
Methiocarb (Slug-Geta, Grandslam, Mesurol) * **
Oxamyl (Vydate L, Pratt) **
Parathion (Roethyl-P, Alkron, Panthion, Phoskil) *
cis-Permethrin (Ambush, Astro, Pounce) * **
Phorate (Thimet, Granutox, Geomet, Rampart) * **
Propargite (Comite, Omite, Ornamite) * **
Terbufos (Contraven, Counter, Pilarfox) **

Volatile organic compounds (VOCs) in ground water

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

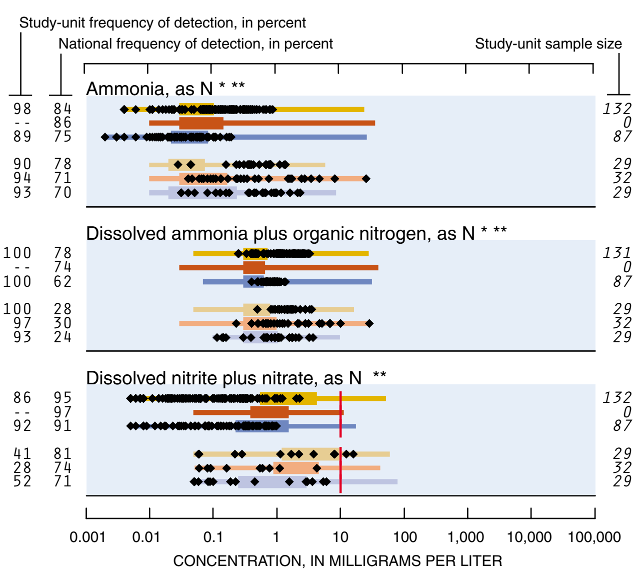


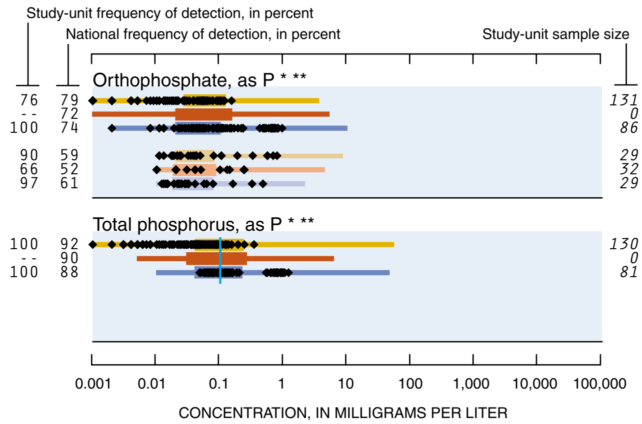
[1] Many of the samples in this study were diluted prior to laboratory analysis and therefore the actual detection frequency may be larger than the value listed.

Other VOCs detected
tert-Amylmethylether (*tert*-amyl methyl ether (TAME)) *
Benzene
Bromochloromethane (Methylene chlorobromide)
Bromodichloromethane (Dichlorobromomethane)
2-Butanone (Methyl ethyl ketone (MEK)) *
Carbon disulfide *
1-Chloro-2-methylbenzene (*o*-Chlorotoluene)
Chlorobenzene (Monochlorobenzene)
Chlorodibromomethane (Dibromochloromethane)
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) *
1,1-Dichloroethene (Vinylidene chloride)
trans-1,2-Dichloroethene ((E)-1,2-Dichlorothene)
cis-1,2-Dichloroethene ((Z)-1,2-Dichloroethene)
Dichloromethane (Methylene chloride)
1,2-Dichloropropane (Propylene dichloride)
Diethyl ether (Ethyl ether) *
1,2-Dimethylbenzene (*o*-Xylene)
1,3 & 1,4-Dimethylbenzene (*m*-&*p*-Xylene)
1-4-Epoxy butane (Tetrahydrofuran, Diethylene oxide) *
Ethylbenzene (Phenylethane)
p-Isopropyltoluene (*p*-Cymene) *
4-Methyl-2-pentanone (Methyl isobutyl ketone (MIBK)) *
Methylbenzene (Toluene)
Naphthalene
2-Propanone (Acetone) *
Tetrachloroethene (Perchloroethene)
Tribromomethane (Bromoform)
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113) *
Trichloroethene (TCE)
Trichloromethane (Chloroform)
1,2,4-Trimethylbenzene (Pseudocumene) *

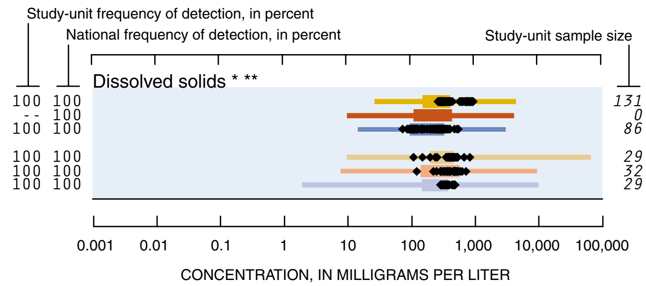
VOCs not detected
Bromobenzene (Phenyl bromide) *
Bromoethene (Vinyl bromide) *
Bromomethane (Methyl bromide)
n-Butylbenzene (1-Phenylbutane) *
sec-Butylbenzene *
tert-Butylbenzene *
3-Chloro-1-propene (3-Chloropropene) *
1-Chloro-4-methylbenzene (*p*-Chlorotoluene)
Chloroethane (Ethyl chloride) *
1,2-Dibromo-3-chloropropane (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)
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 *
Diisopropyl ether (Diisopropylether (DIPE)) *
Ethenylbenzene (Styrene)
Ethyl methacrylate *
Ethyl *tert*-butyl ether (Ethyl-*t*-butyl ether (ETBE)) *
1-Ethyl-2-methylbenzene (2-Ethyltoluene) *
Hexachlorobutadiene
1,1,1,2,2,2-Hexachloroethane (Hexachloroethane)
2-Hexanone (Methyl butyl ketone (MBK)) *
Iodomethane (Methyl iodide) *
Isopropylbenzene (Cumene) *
Methyl acrylonitrile *
Methyl-2-methacrylate (Methyl methacrylate) *
Methyl-2-propenoate (Methyl acrylate) *
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 *
1,1,1-Trichloroethane (Methylchloroform)
1,1,2-Trichloroethane (Vinyl trichloride)
Trichlorofluoromethane (CFC 11, Freon 11)
1,2,3-Trichloropropane (Allyl trichloride)
1,2,3-Trimethylbenzene (Hemimellitene) *
1,3,5-Trimethylbenzene (Mesitylene) *

Nutrients in water

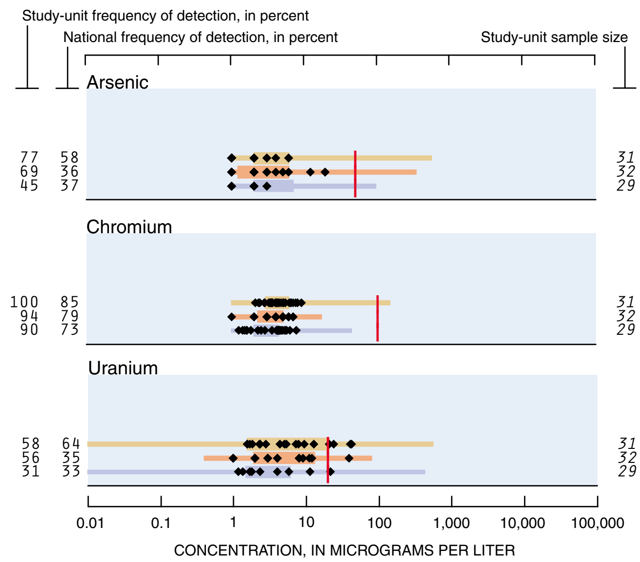


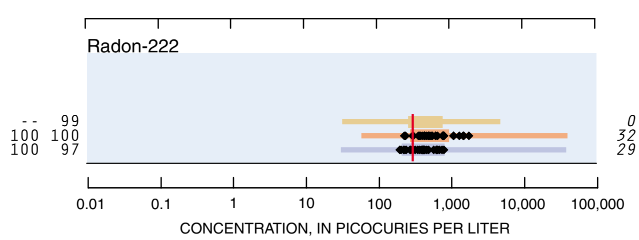


Dissolved solids in water



Trace elements in ground water





Other trace elements detected
Lead
Selenium
Zinc

Trace elements not detected
Cadmium

CHEMICALS IN FISH TISSUE AND BED SEDIMENT

Concentrations and detection frequencies, Southern Florida, 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

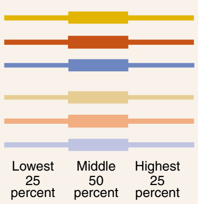
◆ Detected concentration in Study Unit

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



National benchmarks for fish tissue and bed sediment

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

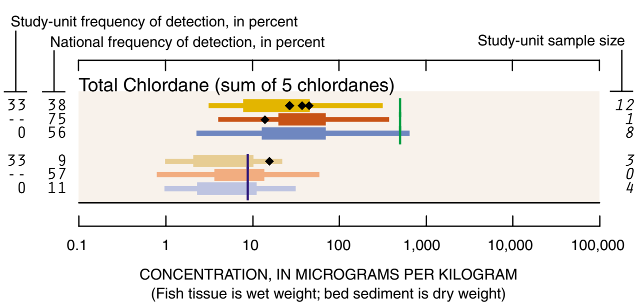
| Protection of fish-eating wildlife (applies to fish tissue)

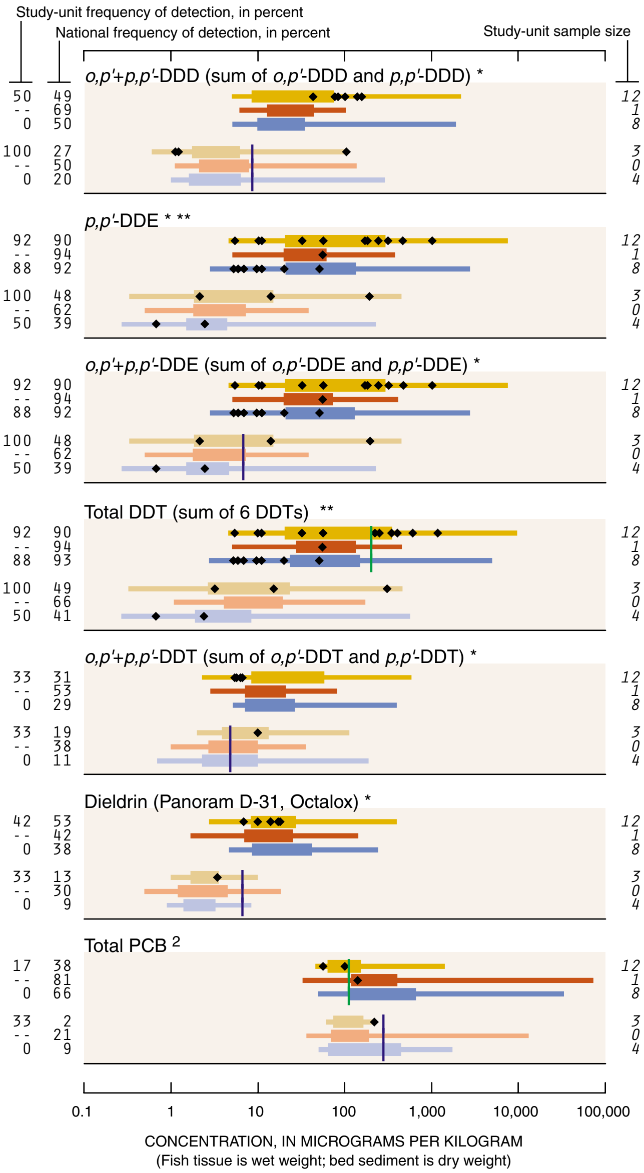
| Protection of aquatic life (applies to bed sediment)

* No benchmark for protection of fish-eating wildlife

** No benchmark for protection of aquatic life

Organochlorines in fish tissue (whole body) and bed sediment



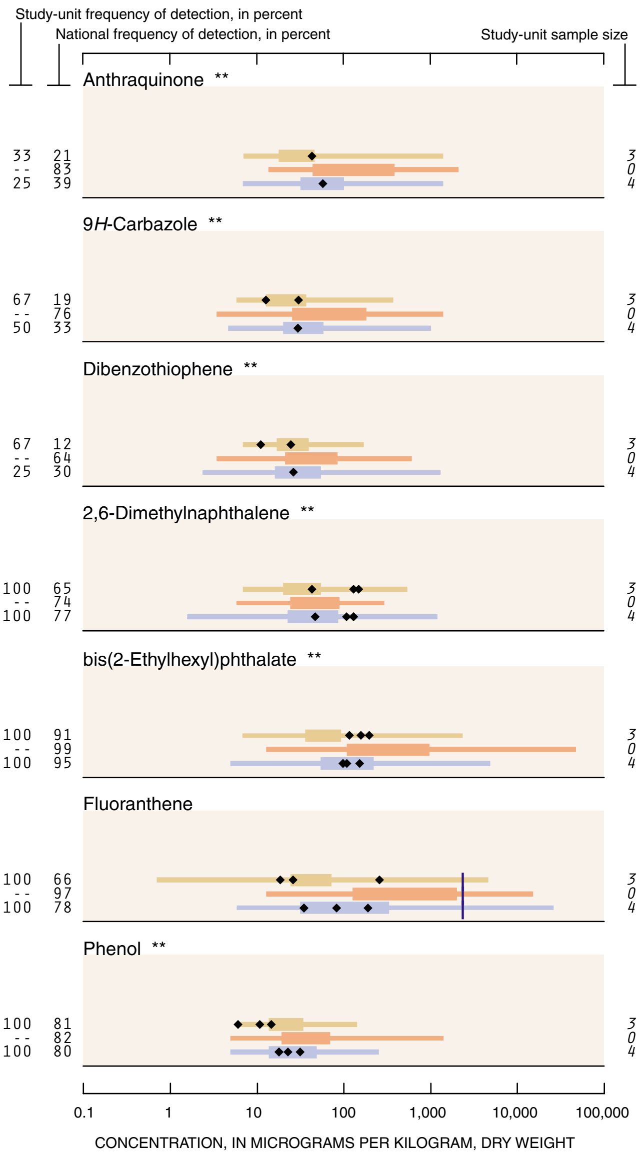


[2] The national detection frequencies for total PCB in sediment are biased low because about 30 percent of samples nationally had elevated detection levels compared to this Study Unit. See http://water.usgs.gov/nawqa/ for additional information.

Other organochlorines detected
Dieldrin+aldrin (sum of dieldrin and aldrin) **
Endosulfan I (alpha-Endosulfan, Thiodan) * **
Mirex (Dechlorane) **

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

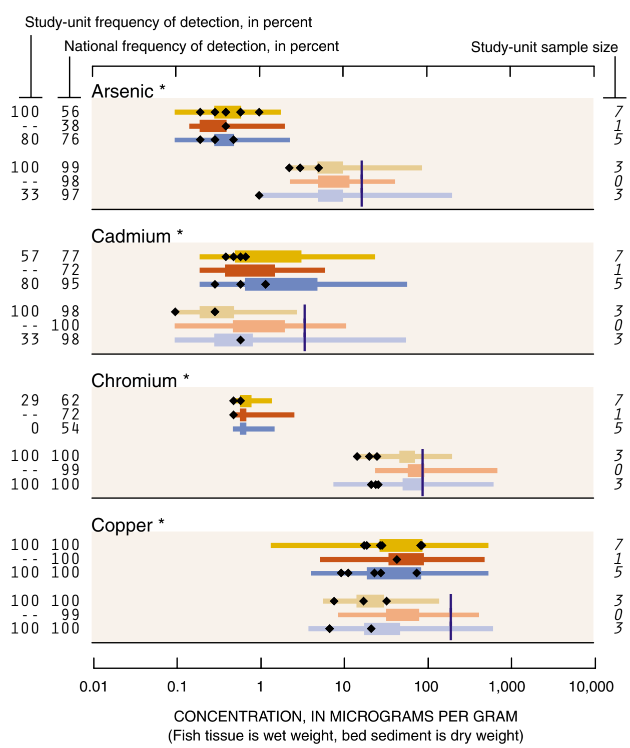
Semivolatile organic compounds (SVOCs) in bed sediment

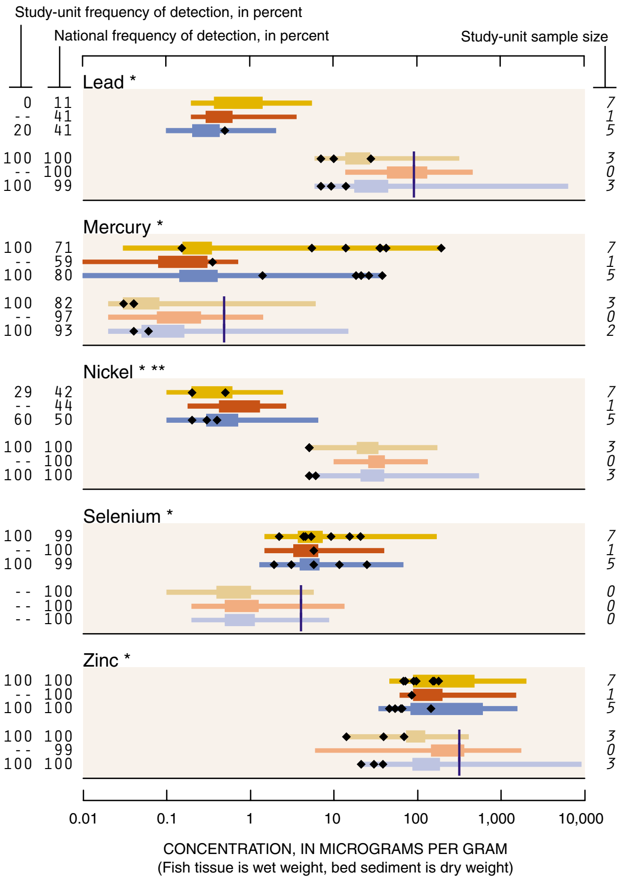


Other SVOCs detected
Acenaphthene
Acenaphthylene
Acridine **
Anthracene
Benz[*a*]anthracene
Benzo[*a*]pyrene
Benzo[*b*]fluoranthene **
Benzo[*ghi*]perylene **
Benzo[*k*]fluoranthene **
Butylbenzylphthalate **
Chrysene
p-Cresol **
Di-*n*-butylphthalate **
Di-*n*-octylphthalate **
Dibenz[*a,h*]anthracene
Diethylphthalate **
1,6-Dimethylnaphthalene **
Dimethylphthalate **
9*H*-Fluorene (Fluorene)
Indeno[1,2,3-*cd*]pyrene **
1-Methyl-9*H*-fluorene **
2-Methylanthracene **
4,5-Methylenephenanthrene **
1-Methylphenanthrene **
1-Methylpyrene **
Naphthalene
Phenanthrene
Phenanthridine **
Pyrene
2,3,6-Trimethylnaphthalene **

SVOCs not detected
C8-Alkylphenol **
Azobenzene **
Benzo[*c*]cinnoline **
2,2-Biquinoline **
4-Bromophenyl-phenylether **
4-Chloro-3-methylphenol **
bis(2-Chloroethoxy)methane **
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 **
3,5-Dimethylphenol **
2,4-Dinitrotoluene **
2-Ethylnaphthalene **
Isophorone **
Isoquinoline **
Nitrobenzene **
N-Nitrosodi-*n*-propylamine **
N-Nitrosodiphenylamine **
Pentachloronitrobenzene **
Quinoline **
1,2,4-Trichlorobenzene **

Trace elements in fish tissue (livers) and bed sediment





BIOLOGICAL INDICATORS

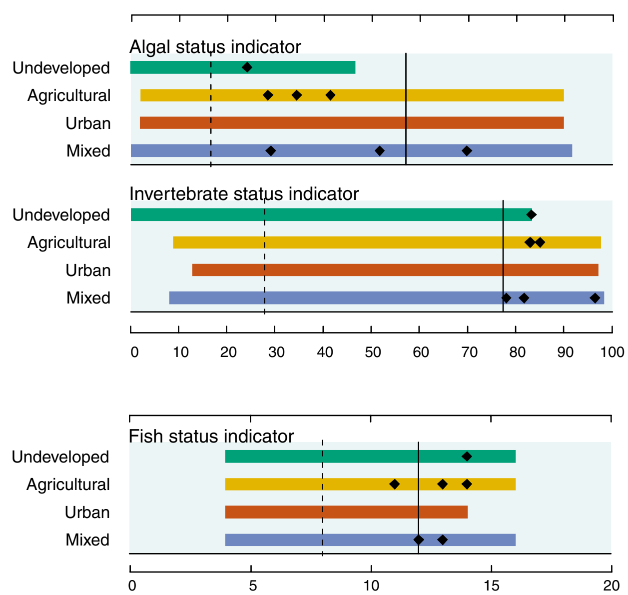
Higher national scores suggest habitat disturbance, water-quality degradation, or naturally harsh conditions. The status of algae, invertebrates (insects, worms, and clams), and fish provide a record of water-quality and stream conditions that water-chemistry indicators may not reveal. **Algal status** 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, Southern Florida, by land use, 1996–98

◆ 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

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Federal Organizations
- National Park Service
- National Oceanic and Atmospheric Administration
- U.S. Army Corps of Engineers
- U.S. Department of Agriculture
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service
- National Marine Fisheries Service

State Agencies
- Florida Marine Research Institute
- Florida Department of Agriculture and Consumer Services
- Florida Department of Environmental Protection
- Florida Game and Freshwater Fish Commission
- Florida Geological Survey
- Florida Park Service
- South Florida Water Management District
- Southwest Florida Water Management District

Private Organizations
- Nature Conservancy

Native American
- Miccosukee Tribe of Indians of Florida
- Seminole Tribe of Florida

Universities
- University of Miami
- University of Florida
- Florida International University

Local Agencies
- City of Naples
- Metropolitan Dade County
- Palm Beach County
- Broward County
- Collier County

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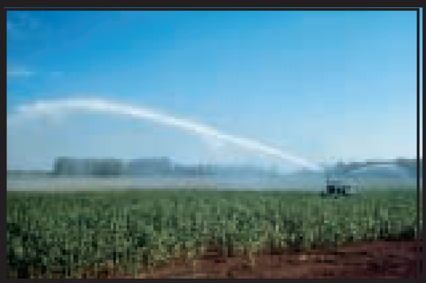
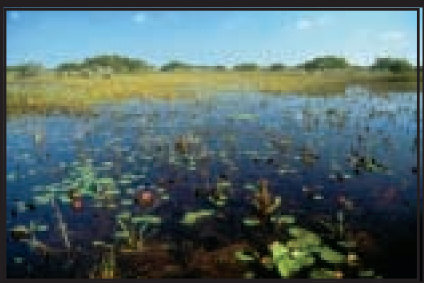
NAWQA

National Water-Quality Assessment (NAWQA) Program
Southern Florida

McPherson and others—Water Quality in Southern Florida
U.S. Geological Survey Circular 1207





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