Water Quality of the Boca Raton Canal System and Effects of the Hillsboro Canal Inflow, Southeastern Florida, 1990-91

By DONALD J. McKENZIE

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 94-4128

Prepared in cooperation with the
City of Boca Raton

Tallahassee, Florida
1995

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CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot squared per day (ft^2/d)	0.09290	meter squared per day

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

The standard unit for aquifer transmissivity is cubic foot per day per square foot times foot of aquifer thickness. This mathematical expression reduces to foot squared per day and is used in this report.

In this report, chemical concentration in water is expressed in milligrams per liter or micrograms per liter. Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water; 1,000 micrograms per liter is equivalent to 1 milligram per liter.

Additional Abbreviations

BOD = biochemical oxygen demand
FDEP = Florida Department of Environmental Protection
GC/FID = gas chromatograph/flame ionization detection
GC/MS = gas chromatograph/mass spectrometer
MCL = maximum contaminant level
μg/L = micrograms per liter
mg/L = milligrams per liter
SMCL = secondary maximum contaminant level
USGS = U.S. Geological Survey
WATSTORE = National Water Data Storage and Retrieval System

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Abstract

The City of Boca Raton in southeastern Palm Beach County, Florida, is an urban residential area that has sustained a constant population growth with subsequent increase in water use. The Boca Raton network of canals is controlled to provide for drainage of excess water, to maintain proper coastal ground-water levels to prevent saltwater intrusion, and to recharge the surficial aquifer system from which the city withdraws potable water.

Most of the water supplied to the Boca Raton canal system and the surficial aquifer system, other than rainfall and runoff, is pumped from the Hillsboro Canal. The Biscayne aquifer, principal hydrogeologic unit of the surficial aquifer system, is highly permeable and there is a close relation between water levels in the canals and the aquifer. The amount of water supplied by seepage from the conservation areas is unknown. Because the Hillsboro Canal flows from Lake Okeechobee and Water Conservation Areas 1 and 2, which are places of more highly mineralized ground water and surface water, the canal is a possible source of contamination.

Water samples were collected at 10 canal sites during wet and dry seasons and analyzed for major inorganic ions and related characteristics, nutrients, and trace elements. All concentrations were generally within or less than the drinking-water standards established by the Florida Department of Environmental Protection. The high concentrations of sodium and chloride that were detected in samples from the Boca Raton canal system are probably from the more mineralized water of the Hillsboro Canal.

Other water-quality data, gathered from various sources from 1982 through 1991, are limited and do not indicate any significant changes nor trends. The data include pesticide and metal analyses of water samples and bottom sediments collected at four canal sites in the Boca Raton study area by the U.S. Geological Survey during 1982-84.

The effects of the Hillsboro Canal on the water quality of the Boca Raton canal system are indicated by increased concentrations of sodium, chloride, dissolved solids, and total organic carbon. Concentrations of the constituents in the canal water generally decrease with distance from the Hillsboro Canal pumping station and are the result of dilution by receiving canal waters.

INTRODUCTION

The city of Boca Raton is located in the southeastern corner of Palm Beach County (fig. 1) in southeastern Florida. The study area, about 48 mi^2, extends from Florida’s Turnpike east to the Intracoastal Waterway and is bounded on the north by the C-15 Canal (Lateral 39) and on the south by the Hillsboro Canal (fig. 1). This mostly suburban area is characterized by spacious lawns and many golf courses. The dense residential, commercial, and light industrial development is generally limited to the coastal ridge area. Agriculture has been displaced as residential construction has spread westward to Florida’s Turnpike and beyond.

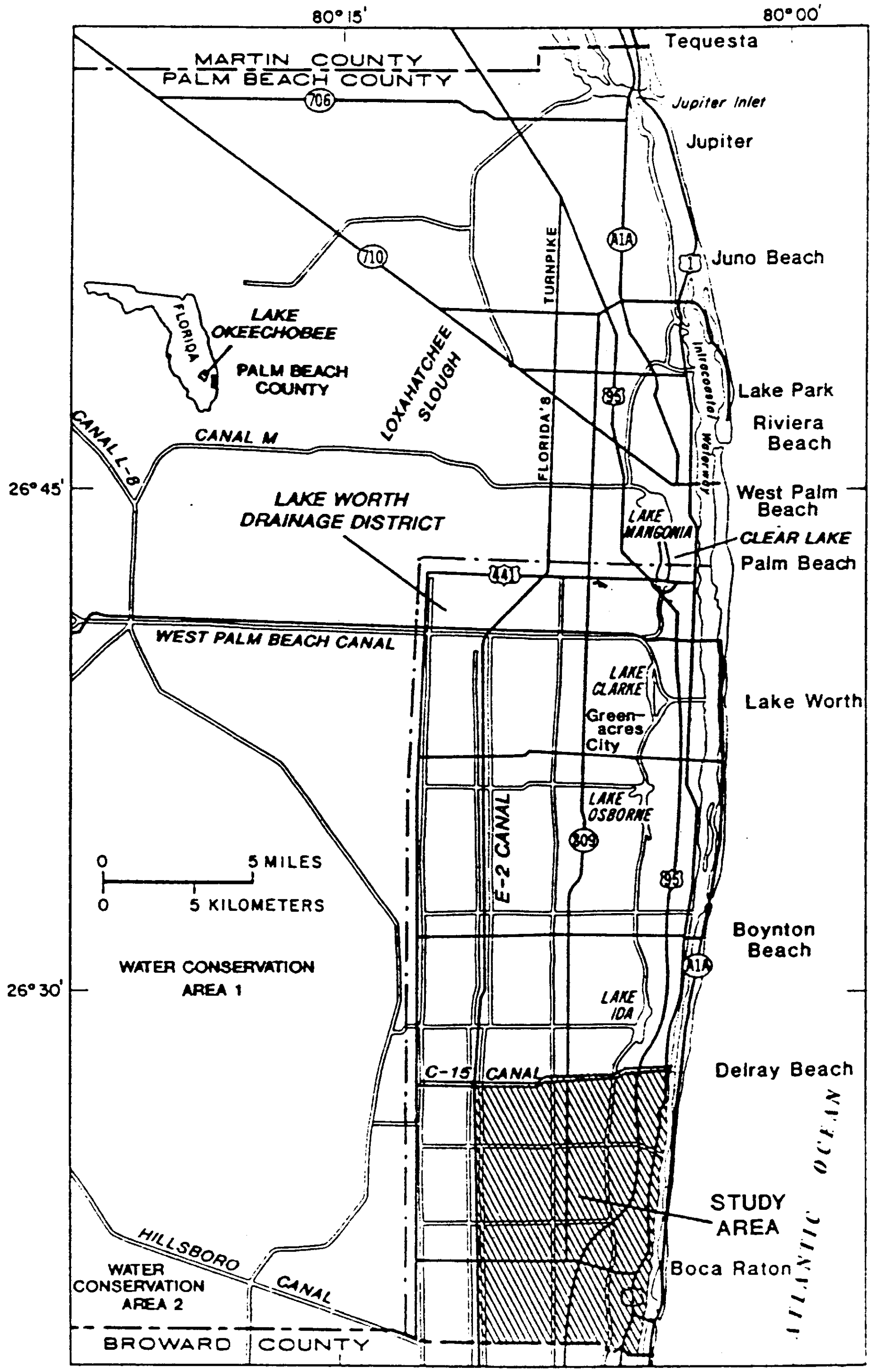

Figure 1. Location of the Boca Raton study area in Palm Beach County, southeastern Florida.

The population of Boca Raton in 1990 was about 83,000, an increase of almost 16 percent from 1985. The population is expected to grow almost another 10 percent in the next 5 years. The population of Palm Beach County is also increasing rapidly. In 1990, there were almost 1,000,000 people; the population is projected to reach 1,216,600 by 1995. The increased demand for potable water required greater pumpage from the Hillsboro Canal, which is the major source of recharge for Boca Raton's canal and well-field system within the Lake Worth Drainage District network.

Boca Raton officials became concerned that the water quality of the canals that recharge the city's well fields could be degraded by water from the Hillsboro Canal, which originates at Lake Okeechobee and flows through an area of organic soils, intensive agriculture, and highly mineralized ground water. There have been sporadic water-quality analyses of the Boca Raton canals in recent years, but because of varying sampling sites and infrequent sampling, appraisal of water-quality conditions and trends has not been feasible. As a result, the U.S. Geological Survey (USGS), in cooperation with the City of Boca Raton, conducted a water-quality study of the canals from October 1989 to September 1992.

Purpose and Scope

The purpose of this report is to characterize the water quality of the Boca Raton canal system. Specifically, the report provides baseline water-quality data for 1990-91 from which future trends can be delineated, and it describes some of the effects of the Hillsboro Canal on the water quality of the Boca Raton canal waters, the principal source of surficial aquifer system recharge.

Canal sampling sites were selected according to the movement of water, volume, direction, and distance from the Hillsboro Canal. Water samples were collected and analyzed for major inorganic ions and related characteristics, nutrients, and trace elements. Additionally, gas chromatograph/flame ionization detection (GC/FID) reconnaissance sampling was conducted to qualitatively detect organic compounds. Data were evaluated and analyzed using summary statistics for selected constituents. Special consideration was given to constituent trends and the seasonal effects of rainfall with subsequent flow from the Hillsboro Canal.

Water-quality data from the Boca Raton canal system were collected by several agencies prior to this study. Agencies that furnished data for the review include the USGS, Florida Department of Environmental Protection (FDEP), South Florida Water Management District, Lake Worth Drainage District, and the City of Boca Raton.

Water Supply and Canal System

The water that flows from the Hillsboro Canal into the Boca Raton area is the principal recharge, other than rainfall and runoff, for the Boca Raton canal system and the surficial aquifer system, which is the source of the potable water supply. There is a close relation between water levels in the canals and in the surficial aquifer system (Swayze and Miller, 1984, p. 2).

Average annual rainfall in southeastern Florida ranges from 58 to 64 in. (Klein and Hull, 1978, p. 15). About 75 percent of the total annual rainfall generally occurs during the wet season, from June to October (Klein and others, 1975, p. 22). The amount of total rainfall that recharges the surficial aquifer system, after evapotranspiration and runoff, annually averages 37 or 38 in. (Schroeder and others, 1958, p. 37; Fish, 1988, p. 66).

Rapidly increasing water demands in the Boca Raton area have required that larger amounts of water be pumped from the Hillsboro Canal into the Boca Raton canal system to recharge the surficial aquifer system. The water supply for Boca Raton consists principally of 26 wells that closely parallel the E-3 Canal, about 12 wells that are 0.5 mi east of the E-4 canal, and about 11 wells that closely parallel the E-4 Canal (fig. 2). New wells are planned for northwestern Boca Raton.

The Boca Raton canal system lies south of the C-15 Canal and north of the Hillsboro Canal in the southern part of the Lake Worth Drainage District (fig. 1). This canal system is part of a larger network of canals operated and controlled by the Lake Worth Drainage District. Water is distributed by large equalizer canals that allow water to flow north and south and by small lateral canals spaced about 0.5 mi apart that allow flow east and west (fig. 2). Water levels are regulated by pumps and control structures. Generally, the control structures allow water to drain in stages from 15.5 ft above sea level in the western area near Florida's Turnpike to 8.5 ft above sea level in the E-4 Canal system near the coast, which is a barrier to saltwater intrusion.

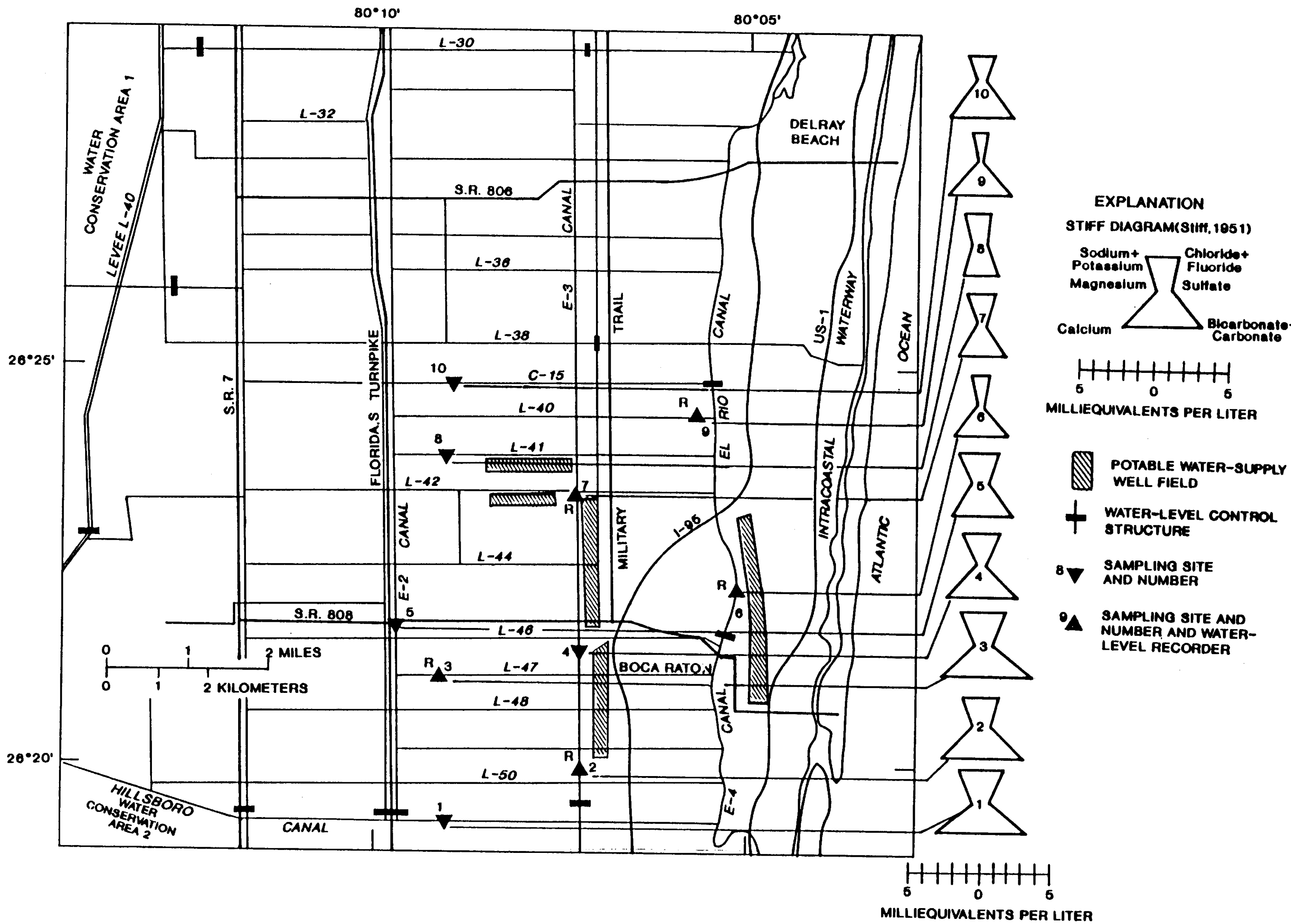

Figure 2. Location of sampling sites, the general area of potable water-supply wells, and the average major-ion composition of water samples from the sampling sites in the Boca Raton canal system.

During seasonal rainfall, the canal network channels water to storage areas, such as Lake Okeechobee and Water Conservation Area 1 (fig. 1), and to the sea to avoid flooding. During rainfall shortages, the water is conveyed from the storage areas back to coastal areas for aquifer recharge and prevention of saltwater intrusion. The sole pumping structure used to withdraw water from the Hillsboro Canal is located at the juncture with the E-2 canal (fig. 2).

Surficial Aquifer System

The surficial aquifer system is the primary source of freshwater for Boca Raton and all of coastal Palm Beach County. Most well fields are located in a discontinuous zone of high permeability in the surficial aquifer system that extends from the Juno Beach area south to Broward County (fig. 1). This is the northernmost extension of the Biscayne aquifer (Swayze and Miller, 1984, p. 1).

The unconfined Biscayne aquifer is the principal hydrogeologic unit of the surficial aquifer system and is composed of highly porous interbedded sandstone and limestone. The high permeability is caused largely by extensive carbonate dissolution. The Biscayne aquifer is wedge shaped and ranges in thickness from about 20 ft on the western edge of Palm Beach County to more than 300 ft in areas along the eastern coast. The aquifer becomes more sandy and somewhat less permeable in southeastern Palm Beach County (Klein and Hull, 1978, p. 3; Klein and Causaras, 1982; and Fish, 1988, p. 61). However, transmissivities are high, ranging from 1,000 ft^2/d along the flanks to 100,000 ft^2/d along the axis. The high transmissivity promotes a quick response between surface-water and ground-water levels.

Sampling Procedures and Analytical Methods

The sampling sites used for this study (which were also used prior to this study) were selected for representative areal coverage of the Boca Raton canal system, year-round flow conditions, and the presence of a bridge to provide proper access for sampling (fig. 2). Standard USGS procedures were applied during sample collection. Water samples representing the overall composition of the canals were obtained by compositing several depth integrated samples of equal volume taken from the bridges at places of estimated equal flow. A stainless steel basket sampler was raised and lowered from the bridge at 5- to 6-ft intervals and the individual depth-integrated samples combined in a churn-splitter.

The composited water samples for major inorganic ions, total nutrient concentrations, total trace-element concentrations, and physical constituents were placed in polyethylene bottles for analysis by the USGS Quality of Water Service Unit in Ocala, Fla. Analytical methods used are described by Fishman and Friedman (1989).

Quality assurance practices included field split samples for each sampling event and standard reference samples for inorganic analyses. Data were stored in the National Water Data Storage and Retrieval System (WATSTORE).

Whole-water samples for analyses of synthetic organic compounds were placed in glass containers (supplied by the Quality of Water Service Unit in Ocala) and preserved with mercuric chloride as a bactericide, then packed in ice and shipped for overnight delivery to the USGS Laboratory in Ocala. Samples were analyzed by the GC/FID method for reconnaissance and the gas chromatograph/mass spectrometer (GC/MS) method for specific compound identification by laboratories of the USGS. The GC/FID analysis, or FID scan, is a screening technique for the determination of synthetic organic compounds in water. The FID scan analysis provides semiquantitative data without identification of specific compounds. When the FID scan analysis indicates a significant amount of a certain synthetic organic compounds is present, the GC/MS analytical method is used to confirm the presence of the particular constituent. The analytical methods for determination of organic substances are described by Wershaw and others (1983). Analyses by mass spectrometer were made by the USGS National Water Quality Laboratory in Denver, Colo.

WATER QUALITY OF THE BOCA RATON CANAL SYSTEM AND EFFECTS OF HILLSBORO CANAL INFLOW

Various physical characteristics and chemical constituents, naturally occurring and those introduced by man’s activities, were monitored in the Boca Raton canal system to assess its present water quality and determine the effects of the Hillsboro Canal inflow. Assessment of present constituent concentrations is important for management of water resources as a measure of baseline conditions and as a reference to determine any future changes. For example, some of the constituents, such as nitrogen and phosphorus in different chemical forms, are used as indicators of agricultural or urban runoff. These constituents have been extensively sampled in southern Florida, and comparison of concentrations from developed and undeveloped areas can be made. Additionally, increases in concentrations of selected constituents, such as trace elements and synthetic organic compounds, might cause the water in the Boca Raton canal system to be less desirable for public use and cause degradation of the conservation storage areas when backpumping occurs.

Historical Water-Quality Data

The surficial aquifer system in Palm Beach County has been the subject of many geologic, hydrologic, and water-quality studies, some with direct application to the Boca Raton study area. The earliest and most comprehensive report about the hydrology, geology, and water quality was provided by Parker and others (1955). Countywide studies by Land (1972), Klein and Hull (1978), Fischer (1980), and Causaras (1982) offer comprehensive overviews of ground-water and surface-water quality, aquifer hydraulics, and geology. Studies more specific to the Boca Raton area include McCoy and Hardee (1970), Land and others (1973), and Miller and Lietz (1976).

The Lake Worth Drainage District conducted a sampling program at two canal sites in the Boca Raton canal system. Sampling on the E-3 Canal at site 2 and on the El Rio Canal at site 6 was conducted monthly from 1983 through 1991 (fig. 2). The characteristics determined included biochemical oxygen demand (BOD), specific conductance, dissolved calcium, dissolved magnesium, dissolved oxygen, sodium, and dissolved solids.

Concentrations of BOD indicate the amounts of oxygen-consuming material in the water. BOD concentrations greater than 3.0 mg/L (milligrams per liter) indicate a level of oxygen-demanding materials that commonly result from sewage effluent or contaminant-laden runoff. The average BOD concentrations in water samples at sites 2 and 6 were 2.1 and 2.6 mg/L, respectively, indicating that the sites did not receive excessive oxygen-demanding materials. The average dissolved-oxygen concentration for the 9-year period was 7.1 mg/L at site 2 and 6.3 mg/L at site 6.

Analysis of dissolved solids measures the amount of dissolved material in a water sample and is used to evaluate the overall inorganic chemical composition. The annual average dissolved-solids concentrations for sites 2 and 6 from 1983 through 1991 are shown in figure 3. The data from 1983 through 1989 are from the Lake Worth Drainage District sampling program, and the 1990-91 data are from the USGS study. The same sites were used in both sampling programs. The dissolved-solids concentrations ranged from 209 to 316 mg/L at site 2 and from 169 to 230 mg/L at site 6. The low range of concentrations and the slight decrease that occurred during the period of record (1983-91) might be due to increased dilution by rainfall or distance from the Hillsboro Canal.

The USGS analyzed whole-water samples for trace elements on five occasions from May 1982 to April 1984 at canal sites 2, 3, 4, and 9. The sampling sites, protocols, and analytical methods were the same as those used for this study. Results of the water sample analyses are given in table 1, which includes the maximum contaminant levels (MCL's) and secondary maximum contaminant levels (SMCL's) established by the Florida Department of Environmental Protection (1993) for drinking-water requirements. None of the constituents, except for iron, exceeded the levels.

Water samples and bottom sediments were also collected from 1982 through 1984 for the analyses of chlorophenoxy acid herbicides and organochlorine insecticides at sites 2, 3, 4, and 9 (fig. 2). Water samples were also analyzed for organophosphorus insecticides. No concentrations exceeded the MCL's for primary drinking-water standards of the Florida Department of Environmental Protection (1993).

Major Inorganic Ions and Related Characteristics

From July 1990 to July 1991, canal water samples were collected at least 5 times during wet and dry seasons (fig. 4) at 10 sites (fig. 2) in the Boca Raton study area and analyzed for major ions, color, pH, hardness, dissolved solids, specific conductance, and alkalinity. Major-ion chemistry and related data were used as a general indicator of water quality and to: (1) identify some of the physical-chemical processes that affect the composition of natural waters, and (2) assess differences in the Boca Raton canal system water quality and changes in quality with time.

The areal distribution of major ions in the canal water was evaluated using polygonal Stiff diagrams (Stiff, 1951) as shown in figure 2. The average concentrations of major cations and anions for each site were converted to milliequivalents per liter and are plotted on their respective axis. The respective points are connected to form an irregular polygonal shape that provides visual

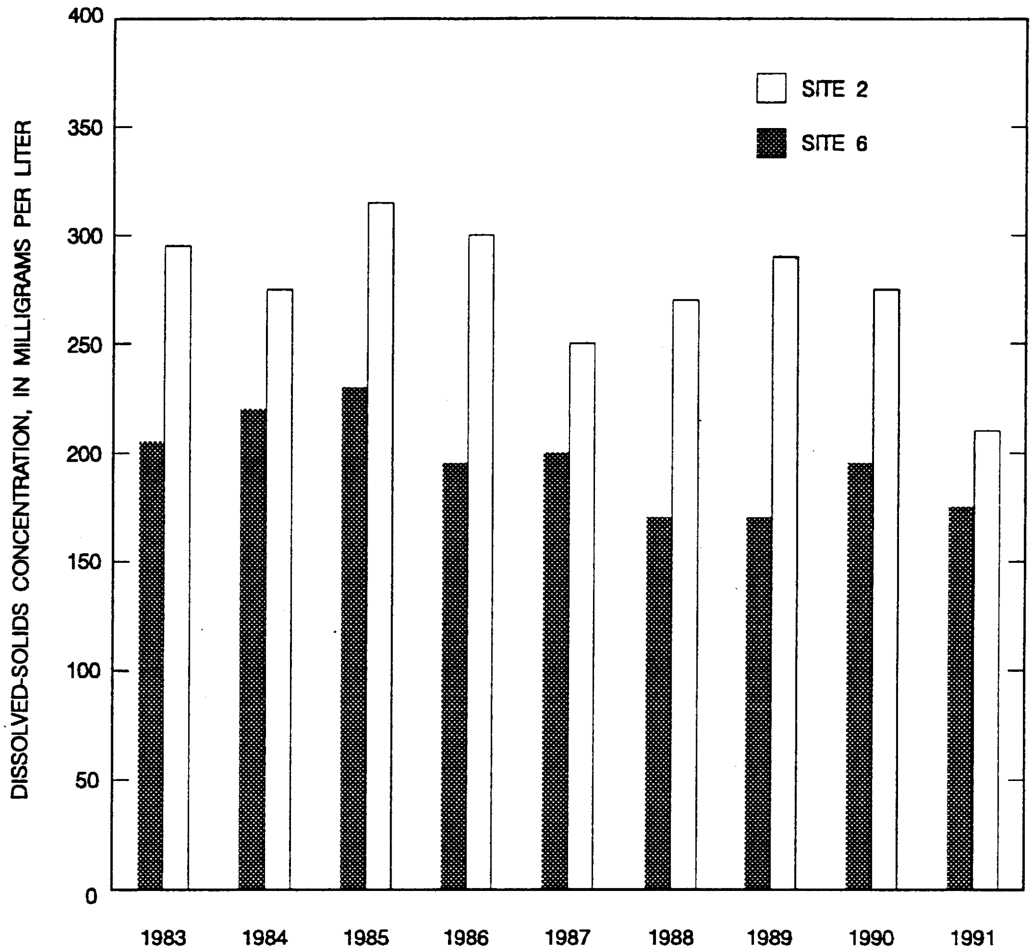

Figure 3. Annual average concentrations of dissolved solids at two sites in the Boca Raton canal system. (1983-89, Lake Worth Drainage District data; 1990-91, U.S. Geological Survey data. Site locations shown in figure 2.)

Table 1. Summary of concentrations of total recoverable trace elements for four sampling sites in the Boca Raton canal system, 1982-84

[Total concentrations in micrograms per liter; FDEP standard, Florida Department of Environmental Protection (1993) drinking water regulations standard; <, less than the value]

Trace element	No. of samples	Minimum	Maximum	Mean	FDEP standard
Arsenic	26	1	9	2	[1]50
Barium	26	<100	<100	<100	[1]2,000
Cadmium	26	<1	1	<1	[1]50
Chromium	26	<10	20	10	[1]100
Copper	26	4	84	10	[2]1,000
Iron	21	110	590	338	[2]300
Lead	17	1	7	3	[1]15
Manganese	21	<10	50	16	[2]50
Mercury	21	< .1	1.7	<1.0	[1]2
Selenium	21	<1	<1.0	<1	[1]50
Silver	21	<1	<1.0	<1	[2]100
Zinc	21	10	150	32	[2]5,000

[1]Maximum contaminant level (MCL): The maximum permissible level of a contaminant in water, which is delivered to any user of a public-water system.

[2]Secondary maximum contaminant level (SMCL): Contaminants that affect the esthetic quality of drinking water. At high concentrations or values, health implications as well as esthetic degradation can also exist.

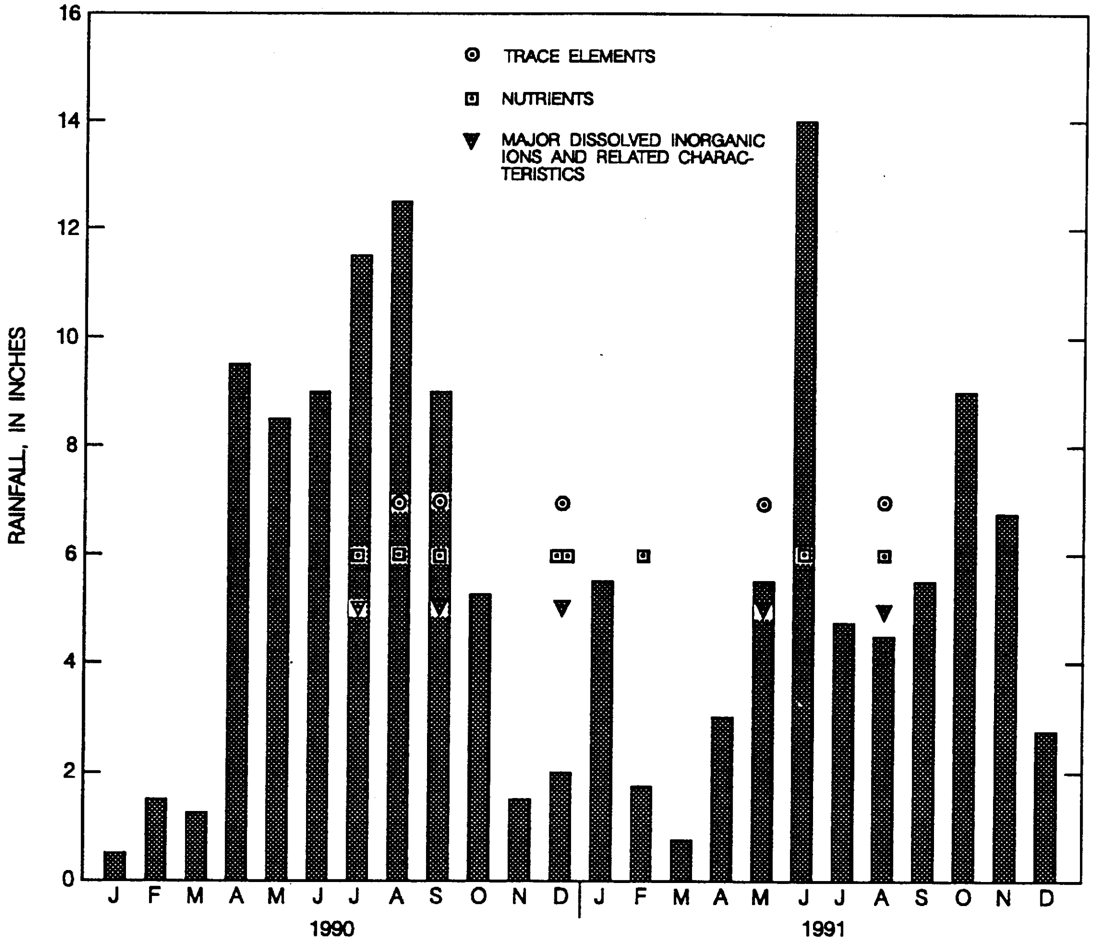

Figure 4. Monthly average rainfall and month when canal water-quality sampling occurred, 1990-91.

on their respective axis. The respective points are connected to form an irregular polygonal shape that provides visual representation of the water's composition. The diagram widens as milliequivalent concentrations increase for individual constituents. Differences or similarities in water quality with respect to major ions can be recognized by comparing the polygonal diagrams.

A summary of the concentrations of selected major inorganic ions and related characteristics indicates that the dominant ions are calcium and bicarbonate, which are products of limestone dissolution (table 2). Concentrations of sodium and chloride are also relatively high. Concentrations reported as less than minimum determination levels for analytical results were treated as 0.0 concentrations for the summary statistics in table 2.

The concentrations of major ions (calcium, sodium, bicarbonate, and chloride) were greater in and near the Hillsboro Canal (fig. 2, sites 1-5). Water in this part of the Boca Raton canal system is affected by the Hillsboro Canal water channeled from conservation and agricultural areas to the west. Water from these lands typically is high in sodium and chloride concentrations derived from ground water used for irrigation and from connate seawater (Parker and others, 1955; Waller and Earle, 1975). During low-flow conditions, highly mineralized ground water (greater than 500 mg/L of dissolved-solids concentration) is discharged into the Hillsboro Canal with only slight dilution by surface water. This results in average concentrations of major ions which are above the overall average of other canals that discharge from the conservation area (Waller and Miller, 1982, p. 13). Water in the eastern and northern parts of the Boca Raton canal system is less affected by water from the Hillsboro Canal, thus, sodium and chloride concentrations are smaller.

The effects of Hillsboro Canal on the water quality of the Boca Raton canal system is demonstrated by the dissolved-solids concentrations. Canal water at sites nearest to the Hillsboro Canal (within a 3.5-mi radius) had the highest dissolved-solids concentrations, from an average of 424 mg/L at site 1 on the Hillsboro Canal to an average of 325 mg/L at site 4 (3.5 mi from the pumping station). At other sampling sites, located 5.5 to 7.0 mi from the Hillsboro Canal, canal water had dissolved-solids concentrations ranging from 229 to 282 mg/L. The dissolved-solids concentrations

Table 2. Summary of concentrations of major inorganic ions and related characteristics, nutrients, and total recoverable trace elements for all sampling sites in the Boca Raton canal system, July 1990 to July 1991

[FDEP standard, Florida Department of Environmental Protection (1993) drinking water regulations standard; --, no standard; mg/L, milligrams per liter; Pt-Co, platinum-cobalt units; µS/cm, microsiemens per centimeter; <, less than the value]

Variable	No. of samples	Minimum	Maximum	Mean	FDEP standard
Major dissolved inorganic ions and related characteristics					
Color, in Pt-Co units	51	40	100	74	[2]15
pH, in standard units	51	7.2	8.5	7.8	[2]6.5–8.5
Hardness, in mg/L	51	97	280	189	--
Dissolved solids, residue at 180 degrees Celsius	60	180	486	308	[2]500
Specific conductance, in µS/cm	51	295	786	504	--
Bicarbonate, in mg/L	51	79	286	190	--
Alkalinity, as $CaCO_3$	51	65	235	156	--
Calcium, in mg/L	51	29	100	65	--
Magnesium, in mg/L	51	2.6	8.4	5.9	--
Sodium, in mg/L	51	11	65	28	[1]160
Potassium, in mg/L	51	2.3	14	7.1	--
Chloride, in mg/L	51	23	100	46	[2]250
Sulfate, in mg/L	51	11	44	27	[2]250
Fluoride, in mg/L	51	.1	.4	.2	[2]2
Silica, in mg/L	51	1.5	11	5.5	--
Nutrients (in milligrams per liter)					
Organic nitrogen, total	92	0.70	2.5	1.08	--
Ammonia nitrogen, total	92	.01	.34	.11	--
Nitrite nitrogen, total	92	< .01	.04	.02	[1]1
Nitrate nitrogen, total	92	< .01	.50	.15	[1]10
Phosphorus, total	92	.03	.54	.13	--
Orthophosphorus, total	92	.01	.29	.08	--
Organic carbon, total	59	9.8	23	14	--
Trace elements (in micrograms per liter)					
Arsenic	23	<1	4	2	[1]50
Barium	31	<100	160	<100	[1]2,000
Boron	21	40	120	80	--
Cadmium	51	<1	1	<1	[1]50
Chromium	51	<1	4	1	[1]100
Copper	51	2	38	7	[2]1,000
Iron	51	40	920	204	[2]300
Lead	51	<1	3	<1	[1]15
Manganese	31	10	<10	18	[2]50
Mercury	31	<1	1	<1	[1]2
Selenium	21	<1	<1	<1	[1]50
Silver	31	<1	1	<1	[2]100
Zinc	51	<10	20	<10	[2]5,000

[1]Maximum contaminant level (MCL): The maximum permissible level of a contaminant in water, which is delivered to any user of a public-water system.

[2]Secondary maximum contaminant level (SMCL): Contaminants that affect the esthetic quality of drinking water. At high concentrations or values, health implications as well as esthetic degradation can also exist.

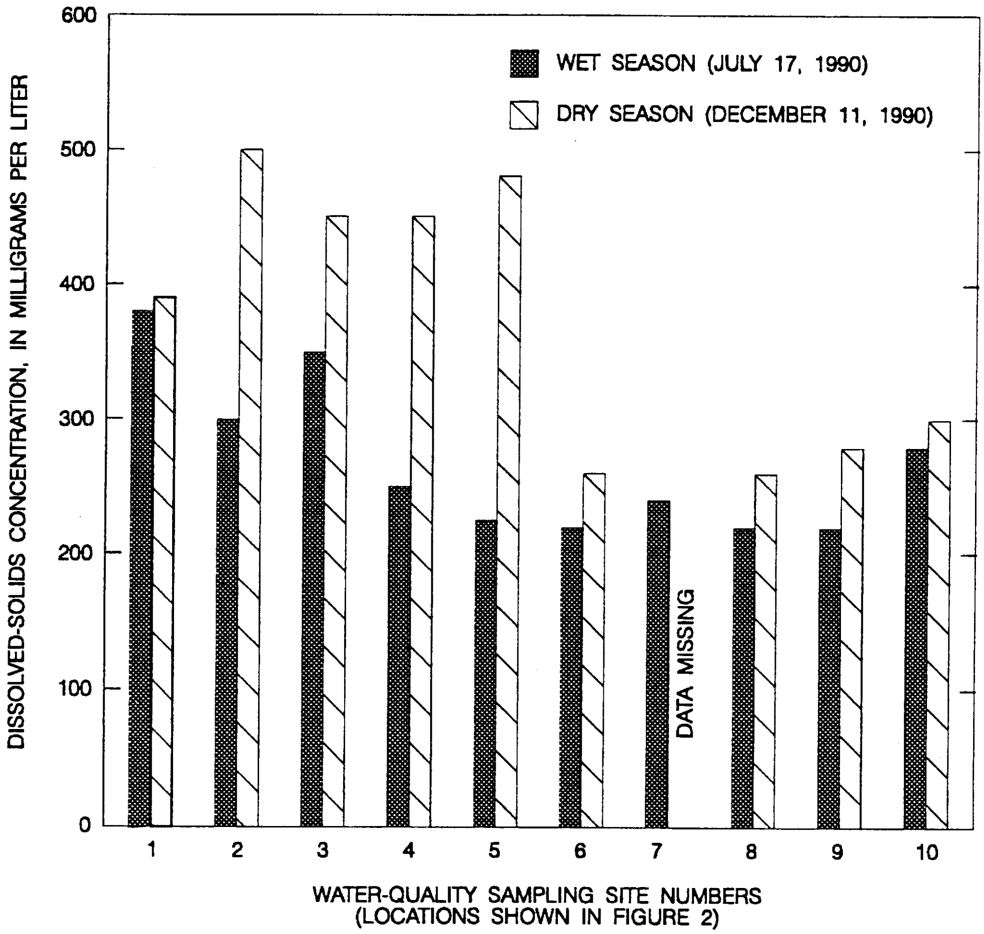

Figure 5. Dissolved-solids concentrations for each water-quality sampling site, July 17, 1990, and December 11, 1990.

analyzed during this study are similar to those concentrations analyzed in previous studies at canal sites 2 and 6 shown in figure 3.

The Boca Raton canal system receives the more highly mineralized water from the Hillsboro Canal during the dry season. Dissolved-solids concentrations were highest in December 1990 when low precipitation occurred (fig. 4). Conversely, concentrations generally were lowest in July 1990 when precipitation was greater. This relation is illustrated by comparison of dissolved-solids concentrations at each canal sampling site during these months (fig. 5). Sites 2 to 5, closest to Hillsboro Canal (fig. 2), also show the greatest concentrations of dissolved solids, which indicate a direct relation with proximity to Hillsboro Canal.

The color of water samples is generally the product of the leaching of decaying vegetation in the surface environment. The color values of the Boca Raton canal water system exceeded the secondary drinking-water standard established by the Florida Department of Environmental Protection (1993) for all the samples during this study (table 2). This is attributed to the organic soils through which the Hillsboro Canal flows from Lake Okeechobee and the Everglades to Boca Raton.

Nutrients

The nutrients analyzed from the Boca Raton canal system were nitrogen and phosphorus compounds and organic carbon compounds. The source of the nutrients in the Boca Raton canals is mostly plant detritus, living plants, and nutrient-laden runoff (fertilizers applied to golf courses and lawns). Additionally, water in contact with the peat and muck soils of the conservation area characteristically has high concentrations of organic carbon and organic nitrogen (Waller and Earle, 1975). Waller and Miller (1982, p. 24) indicated that 6-year average concentrations of total organic carbon were 25 mg/L in the conservation area water and 22 mg/L in the Hillsboro Canal.

Organic nitrogen was the dominant form of total nitrogen in the canal waters. The mean concentration at site 1 on the Hillsboro Canal was 1.21 mg/L, which was slightly greater than the 1.08 mg/L mean total concentration at all of the sites (table 2). Nitrate nitrogen concentrations ranged from less than 0.01 mg/L to 0.50 mg/L, well below the MCL drinking-water standard established by the Florida Department of Environmental Protection (1993). The mean nitrate nitrogen concentration at site 1 was 0.23 mg/L, which was greater than the 0.15 mg/L nitrate nitrogen mean total concentrations at all of the sites (table 2).

Total orthophosphorus concentrations varied slightly with time or sampling location, ranging from 0.01 to 0.29 mg/L; the mean concentration of 92 samples was 0.08 mg/L. The FDEP has not established MCL or SMCL standards for total orthophosphorus concentration in drinking water.

Total organic carbon concentrations ranged from 9.8 to 23 mg/L in the Boca Raton canal system. There was little variation spatially and temporally, except for the sampling event of December 1990, a period of low precipitation (fig. 4). Sites 1 to 5 had a mean total organic carbon concentration of 20 mg/L for December 1990. The other sites, farther from the Hillsboro Canal, had a mean concentration of about 14 mg/L for the December sampling. The higher total organic carbon concentrations for the sampling indicate a greater flow of water to the Hillsboro Canal from the conservation area during the time of low rainfall.

Trace Elements

Samples for trace-element analysis were collected at all study sites on the Hillsboro Canal and in the Boca Raton canal system. The mean concentrations for most of the trace elements were lower than established MCL's or SMCL's (table 2); no MCL or SMCL has been established for boron. The individual concentrations of lead, mercury, selenium, and silver were generally less than or very close to analytical detection limits. Only total iron in some analyses exceeded the SMCL of 300 μg/L. The concentrations of total iron vary widely in southern Florida waters and are commonly high because of ferriferous lithology (Parker and others, 1955, p. 371). There were no significant differences in trace-element concentrations at the sampling sites, and there was no apparent influence from the Hillsboro Canal.

Comparison of the previous data from May 1982 through April 1984 (table 1) and the data for this study (table 2) indicates a similar water chemistry of trace elements for the two periods. Total recoverable chromium is reported at a different level of analytical detection in the two sets of analyses (10 μg/L for the historical data and 1 μg/L for this study), but the data did not indicate notable changes between the two periods.

Pesticides

Pesticides (herbicides and insecticides) can be introduced to the canals in runoff and by direct spraying of: (1) insecticides for control of insects, and (2) herbicides for control of terrestrial and aquatic weeds. Water samples were collected on two different occasions at all of the canal sampling sites for a GC/FID scan analysis. Results of GC/FID scans from the first sampling on August 8, 1990, indicated that only one site contained a detectable but very low level of organic compounds. The second series of samples taken on October 3, 1990, indicated measurable, but very low, concentrations of organic compounds at 7 of 10 sites.

To confirm the absence of significant pesticide concentration in canal water, four of the water-quality sites used in this study were selected for GC/MS analysis. The four sites correspond to sites sampled for pesticide analysis by the USGS in 1982-84. The pesticide analyses made for the two sampling periods (1982-84 and 1990) were the same and included chlorophenoxy acid herbicide and organochlorine insecticide analyses of water and bottom sediments and organophosphorus insecticide analyses of the water samples. The same collection methods and analytical laboratory as described in the "Methods" section were used for the two sampling periods (1982-84 and 1990).

Organochlorine insecticides include the DDT family (DDT, DDE, and DDD), dieldrin, endrin, chlordane, and toxaphene; organophosphates include parathion, malathion, and diazinon; and chlorophenoxy acid herbicides include silvex and 2,4-D. Many of the pesticides are relatively insoluble in water and are more common in bottom sediments. The effects of such accumulation are not well defined and recommended limits have not been established.

The analytical results of this study are similar to the data previously collected by the USGS in 1982-84. No water samples contained pesticide concentrations that exceeded potable water standards established by the Florida Department of Environmental Protection

(1993). Most of the compounds were absent or less than analytical detection limits. Results for bottom sediments were similar. DDT and its metabolites were detected at the four sites, but in low concentrations.

SUMMARY AND CONCLUSIONS

The Boca Raton network of canals is a highly controlled water-management system that provides for drainage of excess water, maintains proper coastal ground-water levels to prevent saltwater intrusion, and recharges the surficial aquifer system from which the city of Boca Raton withdraws potable water. Control structures allow water to drain in stages from 15.5 ft above sea level in the western area near Florida's Turnpike to 8.5 ft above sea level in the E-4 Canal system near the coast (a barrier to saltwater intrusion). Most of the water supplied to the Boca Raton canal system and the surficial aquifer system, other than rainfall and runoff, is pumped from the Hillsboro Canal.

The Biscayne aquifer, principal hydrogeologic unit of the surficial aquifer system, is highly permeable, and there is a close relation between water levels in the canals and the aquifer. The city of Boca Raton has become concerned that the water quality of the canals that recharge the city's well fields could be degraded by water from the Hillsboro Canal, which originates at Lake Okeechobee and flows through an area of organic soils, intensive agriculture, and highly mineralized ground water.

The Lake Worth Drainage District conducted a sampling program at two canal sites in the Boca Raton canal system from 1983 through 1991. Concentrations of BOD and dissolved solids were determined at site 2 on the E-3 Canal and site 6 on the El Rio Canal. BOD concentrations greater than 3.0 mg/L indicate a level of oxygen-demanding materials that commonly result from sewage effluent or contaminant-laden runoff. The monthly average BOD concentrations at sites 2 and 6 were 2.1 and 2.6 mg/L, respectively, indicating that the sites did not receive excessive oxygen-demanding materials. The annual average dissolved-solids concentrations ranged from 209 to 316 mg/L at site 2 and from 169 to 230 mg/L at site 6. The low range of concentrations and the slight decrease that occurred during the period of record (1983-91) might be due to increased dilution by rainfall or distance from the Hillsboro Canal.

From July 1990 through July 1991, the USGS collected water samples from 10 canal sites during wet and dry seasons to determine concentrations of major inorganic ions and related characteristics, nutrients, and trace elements. Standard USGS procedures were used during sample collection. Collected composited water samples were placed in polyethylene bottles for analysis by the USGS Quality of Service Unit in Ocala, Fla. Quality assurance practices included field split samples for each sampling event and standard reference samples for inorganic analyses. Additionally water samples for analyses of synthetic organic compounds were collected from the 10 canal sites on two occasions (August 8, 1990 and October 3, 1990). Whole-water samples for these analyses were placed in glass containers preserved with mercuric chloride, packed in ice, and shipped overnight to the USGS Laboratory in Ocala. Samples were analyzed by the GS/FID method for reconnaissance and the GC/MS method for specific compound identification by USGS laboratories.

Results indicate that the dominant ions are calcium and bicarbonate, which are products of limestone dissolution. Concentrations of sodium and chloride are also relatively high. The concentrations of calcium, bicarbonate, sodium, and chloride were greater at sites in and near the Hillsboro Canal than at sites farther from Hillsboro Canal. The quality of water in the southern part of the Boca Raton canal system is affected by the Hillsboro Canal water channeled from conservation and agricultural areas to the west. Water from these lands is typically high in sodium and chloride concentrations. Water in the eastern and northern parts of the Boca Raton canal system is less affected by water from the Hillsboro Canal, thus, sodium and chloride concentrations are smaller. Canal water at sites nearest to the Hillsboro Canal also had the highest dissolved-solids concentrations, and color values exceeded the drinking-water standard established by the FDEP for all the water samples. The high color values are attributed to the organic soils through which the Hillsboro Canal flows from Lake Okeechobee and the Everglades to Boca Raton.

The nutrients analyzed from the Boca Raton canal system were nitrogen and phosphorus compounds and organic compounds. Nutrients were generally uniform, spatially and temporally, among the canal sites. Total organic nitrogen was the dominant form of total nitrogen in the canal waters with concentrations ranging from 0.70 to 2.5 mg/L. No nutrient concentrations exceeded the MCL drinking-water standard established by the FDEP.

None of the trace elements analyzed in the Boca Raton canal system, except for iron, had concentrations that exceeded the drinking-water standards established by the FDEP. The individual concentrations of lead, mercury, selenium, and silver were generally less than or very close to analytical detection limits. In some individual analyses, iron concentrations exceeded the SMCL of 300 μg/L. This is not uncommon in southern Florida waters where iron concentrations are high and vary widely because of ferriferous lithology. There was no significant differences in trace-element concentrations at the sampling sites, and there was no apparent influence from the Hillsboro Canal. Comparison of previous data collected from 1982 through 1984 indicates a similar water chemistry of trace elements.

Chlorophenoxy acid herbicide and organochlorine insecticide analyses of water and bottom sediments and organophosphorus insecticide analyses of the water samples were made to detect pesticides at four canals sites in 1982-84 and 1990. No water samples contained pesticide concentrations that exceeded the drinking-water standards established by the FDEP. Most of the compounds were absent or less than analytical detection limits. Results for bottom sediments were similar. DDT and its metabolites were detected at the four sites, but in low concentrations.

The chemistry of the water in the Boca Raton canal system was affected by discharge from the Hillsboro Canal, even though concentrations of constituents were generally within drinking-water standards established by the FDEP. During the dry season, more highly mineralized water from the conservation areas was transported by the Hillsboro Canal and added to the Boca Raton canal system. This resulted in higher concentrations of sodium, chloride, dissolved solids, and total organic carbon at sampling sites nearest to the Hillsboro Canal pumping station. Concentrations of these constituents generally decrease with distance from the Hillsboro Canal. Comparison of previous water-quality data (1982-84) and data collected for this study (1990-91) did not indicate any notable changes nor trends for the Boca Raton canal system.

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