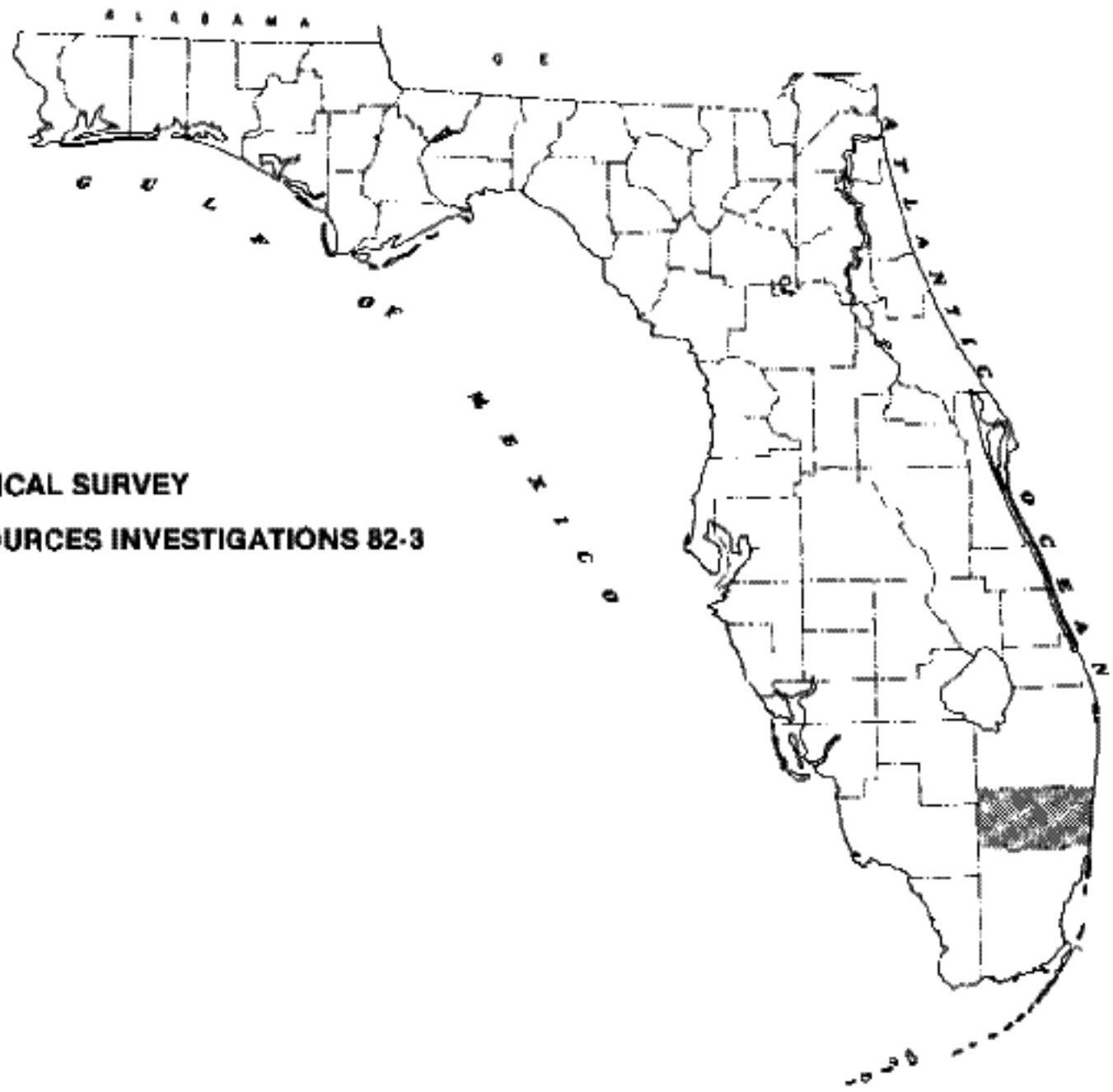
ASSESSMENT OF WATER QUALITY IN CANALS OF EASTERN BROWARD COUNTY, FLORIDA, 1969-74



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WATER-RESOURCES INVESTIGATIONS 82-3

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BROWARD COUNTY ENVIRONMENTAL
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1982

UNITED STATES DEPARTMENT OF THE INTERIOR

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ABBREVIATIONS AND CONVERSION FACTORS

Factors for converting inch-pound units to International System (SI) metric units and abbreviation of units

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
	0.02832	cubic meter per second (m^3/s)

ASSESSMENT OF WATER QUALITY IN CANALS OF EASTERN BROWARD COUNTY, FLORIDA, 1969-74

By Bradley G. Waller and Wesley L. Miller

ABSTRACT

An intensive water-quality monitoring program was started in 1969 to determine the effects of man-induced contaminants on the water quality in the primary canal system of eastern Broward County, Florida. This report covers the first 6 years of the program, providing a data base for comparison with future water-quality conditions.

Most data indicate that beyond the small seasonal fluctuation in constituent level, the greatest adverse effect on the quality of water is caused by sewage effluent. The areas affected by sewage have increased concentrations of macronutrients, trace metals, and pesticides. Major ion concentrations were affected only by season and local lithology.

During the 6-year study, a gradual decrease in macronutrient concentration and an increase in dissolved oxygen have occurred. This improvement in water quality is attributed to decreased sewage discharge into canals and better treatment of sewage effluents.

INTRODUCTION

Broward County is on the southeastern coast of Florida (fig. 1). The population increased from 28,000 in 1940 to about 1 million in 1975. Along with expanding population and urbanization came the problems of supplying services to the community. Two of the major problems are related to water: (1) Provision of water in sufficient quality and quantity throughout the county; and (2) disposal of large quantities of manmade waste. In recent years the effect of contaminants, related to urban and agricultural development activities and rapidly increasing population, on the water quality in the Broward County canal system has been of growing concern.

The primary canal system is managed by the South Florida Water Management District (SFWMD). Although the canals are used primarily for flood control and flow augmentation, other recognized uses include fish and wildlife propagation, recreation, navigation, and transport of urban and agricultural runoff and sewage. These

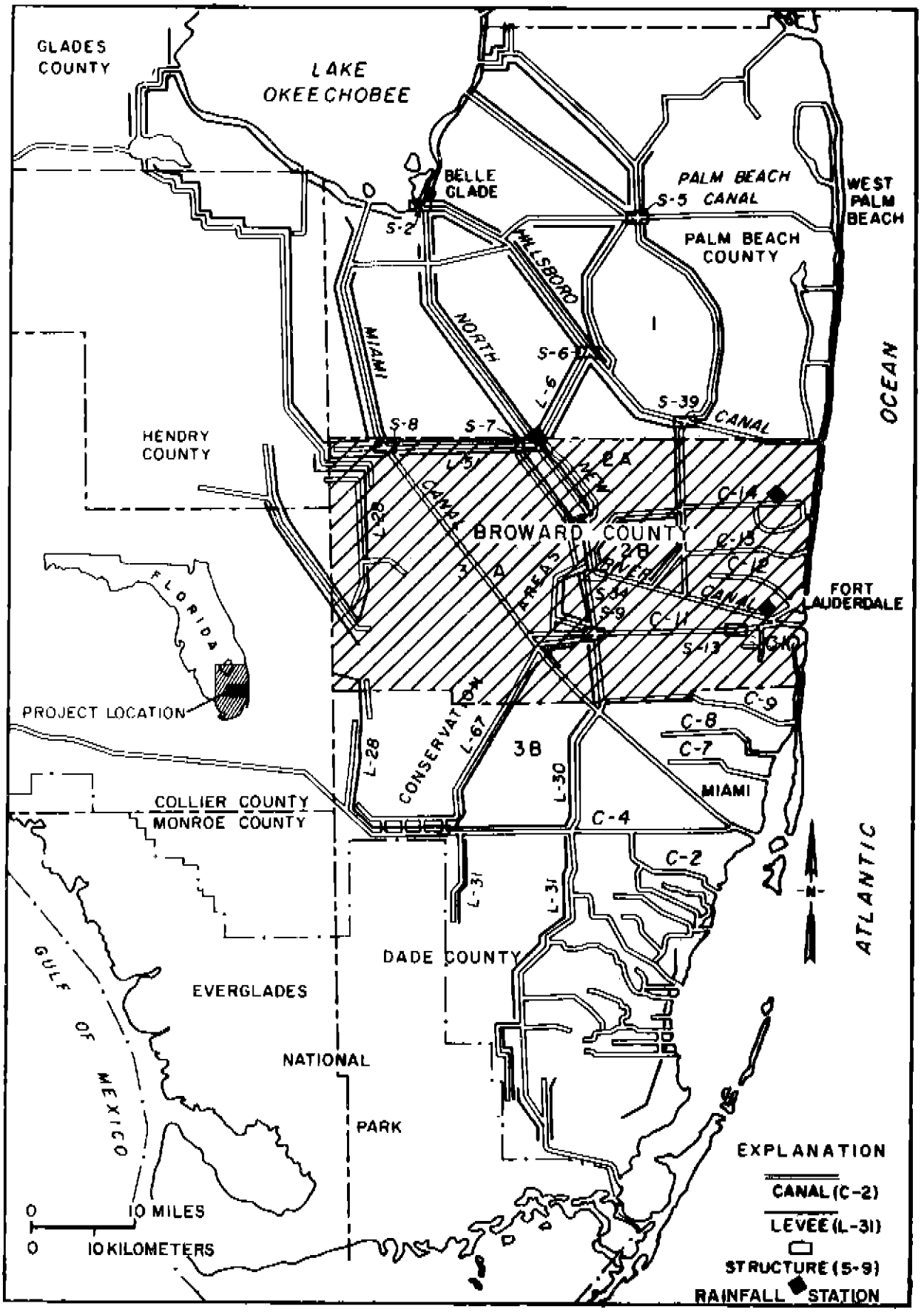

Figure 1.--Location of Broward County.

canals also provide recharge to the Biscayne aquifer, the primary source of municipal and agricultural water supplies. The current need is for a sufficient supply of good quality surface water for varied uses. Along the primary and secondary canals, two water-management problems--flooding of developed low-lying areas during the wet season and saltwater intrusion caused by overdrainage and droughts--have required the construction of controls and pumps.

Contamination of the canal system is a pressing, current water problem. The problem is aggravated by the controlled flow in the canal system, high infiltration rate into the permeable surficial aquifer, and ever-increasing quantities of manmade waste from domestic sewage and agricultural practices. Since the early 1950's and throughout this study, land-use patterns have changed considerably. Agricultural land has given way to urban development, causing problems related to conveyance of urban runoff and deposition of sewage and industrial wastes. Many contaminants associated with urbanization eventually enter the primary canal system, though some are disposed of by deep-well injection and through ocean outfalls.

Water quality in the canal system has been monitored by the U.S. Geological Survey, in cooperation with Broward County and with the SFWMD since 1969, as part of a continuing investigation to determine the effect of man-induced contaminants on the chemical and physical properties of water resources.

Purpose and Scope

The purpose of this report is to present and interpret information on water-quality conditions in the Broward County canal system from 1969-74 for use by agencies involved with water management and other interested concerns or individuals.

This investigation included the periodic collection of surface water and bottom sediment from a monitoring network consisting of 27 sites in five areas (table 1). Twenty-four sites are along seven primary canals (fig. 2), one site (42) is on a secondary canal (Davie Road), and two sites (24 and 41) are on estuarine canals (Hollywood and Dania-Cutoff). Surface-water samples were analyzed for concentrations of major ions, macronutrients, physical characteristics, trace metals, pesticides, and bacteria. Bottom sediment samples were analyzed for pesticide concentrations. Results of these analyses and discussion of methods of collection have been published by Waller and others (1975).

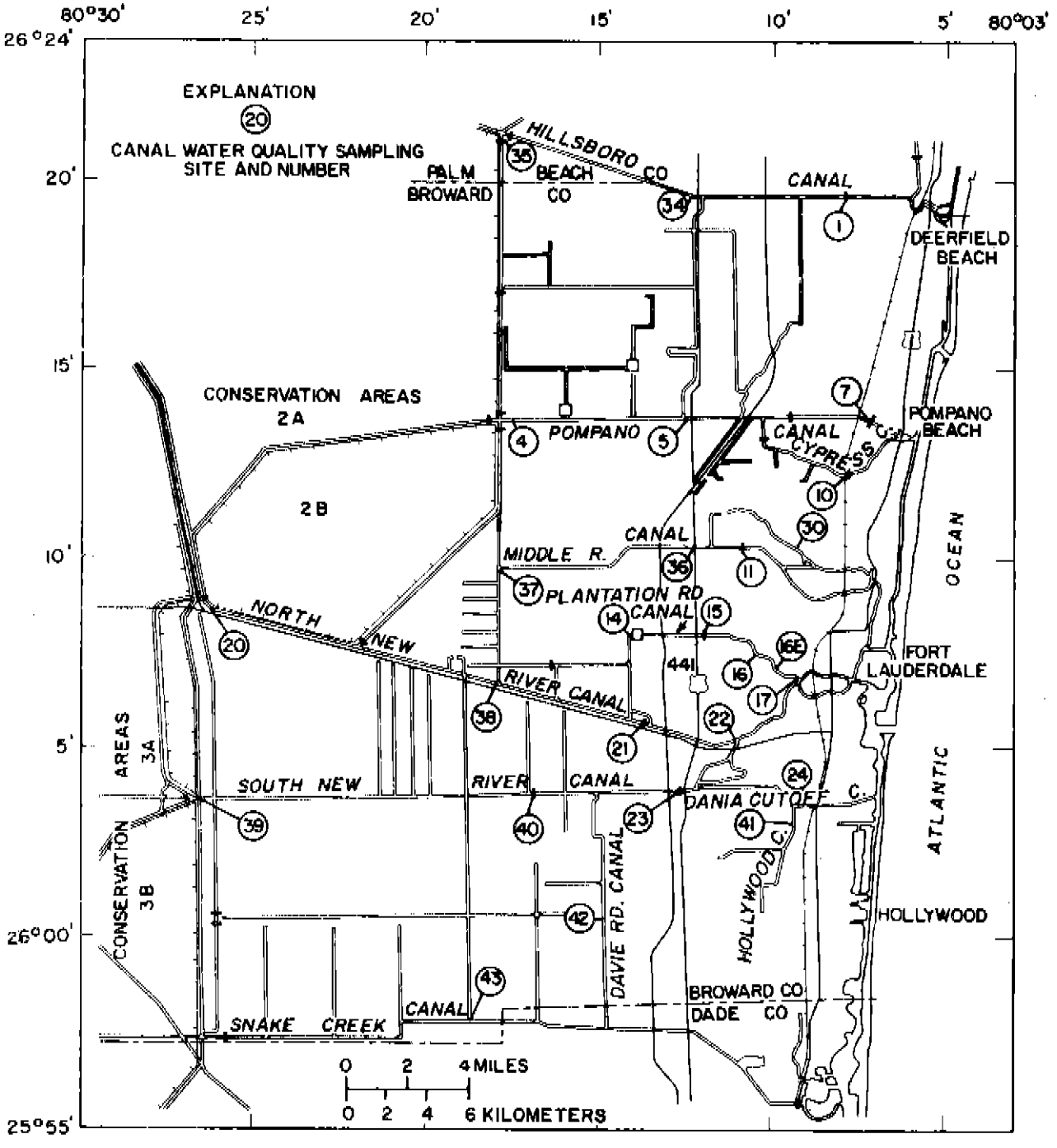

Figure 2.—Location of surface-water sampling sites.

Table 1.--Surface-water sampling sites, identification numbers, and date record began

Site[1]/	Site name	Identification number	Beginning of record
1	Hillsboro Canal near Deerfield Beach.	02281500	2/69
4	Pompano Canal at S-38 near Pompano Beach.	02281700	3/69
5	Pompano Canal at State Road 7 at Margate.	261349080121700	2/69
7	Pompano Canal at Pompano Beach.	02282000	2/69
10	Cypress Creek Canal at S-37A near Pompano.	02282100	2/69
11	Middle River Canal at S-36 near Fort Lauderdale.	02282700	2/69
14	Plantation Canal at N.W. 65th Avenue, Plantation.	260807080140200	2/69
15	Plantation Canal at S-33 near Fort Lauderdale.	02283200	2/69
16	North Fork New River at Fort Lauderdale.	260743080103100	2/69
16E	North Fork New River, Broward Boulevard at Fort Lauderdale.	260717080044700	8/73
17	New River at S.W. 4th and 7th Avenues, Fort Lauderdale.	260702080085800	2/69
20	North New River Canal at 20-Mile Bend.	02284700	3/69
21	North New River near Fort Lauderdale.	02285000	2/69
22	North New River at S.W. 31st Avenue, Fort Lauderdale.	260514080110800	2/69

1/ Locations shown in figure 2.

Table 1.—Surface-water sampling sites, identification numbers, and date record began--Continued

Site[1]/	Site name	Identification number	Beginning of record
23	South New River Canal at S-13 near Davie.	02286100	2/69
24	Dania Cutoff Canal west of Florida East Coast Railroad Bridge at Dania.	260333080084300	2/69
30	CA-13 Feeder Canal at 10th Avenue, Fort Lauderdale.	261034080093500	2/70
34	Hillsboro Canal at Rangeline Road near Deerfield Beach.	02281415	9/70
35	Hillsboro Canal below S-39 near Deerfield Beach.	02281301	9/70
36	Middle River Canal at S-36 at Lauderhill.	261030080131400	9/70
37	Middle River Canal at C-42 near Lauderhill.	260919080172300	9/70
38	North New River Canal above Holloway Lateral near Fort Lauderdale.	02284800	9/70
39	South New River Canal at S-9 near Davie.	02285400	2/70
40	South New River Canal above S-13A near Davie.	02285900	4/70
41	Hollywood Canal at Dania.	02286150	9/70
42	Davie Road Canal at Pembroke Pines.	260031080145300	9/70
43	Snake Creek Canal at N.W. 67th Avenue near Hialeah.	02286200	9/70

1/ Locations shown in figure 2.

Previous Investigations

Collins and Howard (1928), Black and Brown (1951), and Parker and others (1955) present data on major ion concentrations and physical parameters of surface water in Broward County canals prior to the massive increase in development. A report on the chemical quality of ground and surface water of Broward County by Grantham and Sherwood (1968) included data on nutrients and trace metals as well as on major ions. Russo (1974) described the effects of high BOD (biochemical oxygen demand) and nutrient concentrations in Plantation Road Canal. Water-quality conditions in Broward County canals since 1971 have been summarized yearly by Bearden (1972; 1974a; 1974b; 1975). Ground-water quality in various segments of Broward County has been discussed by Schroeder and others (1958), Tarver (1964), McCoy and Hardee (1970), and Bearden (1972 and 1974a). Water resources of the county were described by Sherwood and others (1973).

Acknowledgments

Many individuals and agencies aided in the collection of the water-quality information included in this report. Special thanks are extended to Victor Howard, Broward County Pollution Control Officer, and members of his staff for their cooperation and assistance. Information on flow and water-quality conditions in the primary canals and conservation areas was provided by the South Florida Water Management District. The selection of sampling sites was expedited by historical data provided by the Broward County Health Department. Edward German of the U.S. Geological Survey, Orlando, added much to this report in the technical review of the manuscript.

GENERAL HYDROLOGY

The water in the primary canals of Broward County is derived chiefly from five sources: (1) Rainfall; (2) releases from the conservation areas to the west by controlled surface-water release and seepage through the levees; (3) ground-water inflow; (4) inflow from secondary canals and runoff; and (5) in some canals, sewage effluent.

During the investigation, yearly rainfall averaged 55.37 inches at the three long-term weather stations in the county (fig. 3). Only during 1969 was the rainfall significantly greater than the 30-year average (1940-70) of 58.30 inches. Years of near average rainfall were 1970, 1972, and 1973. During 1971 and 1974, rainfall was well below the long-term average. Approximately 75 percent of the rainfall in south Florida occurs during the wet season, May through October; November through April is considered to be the dry season (fig. 4).

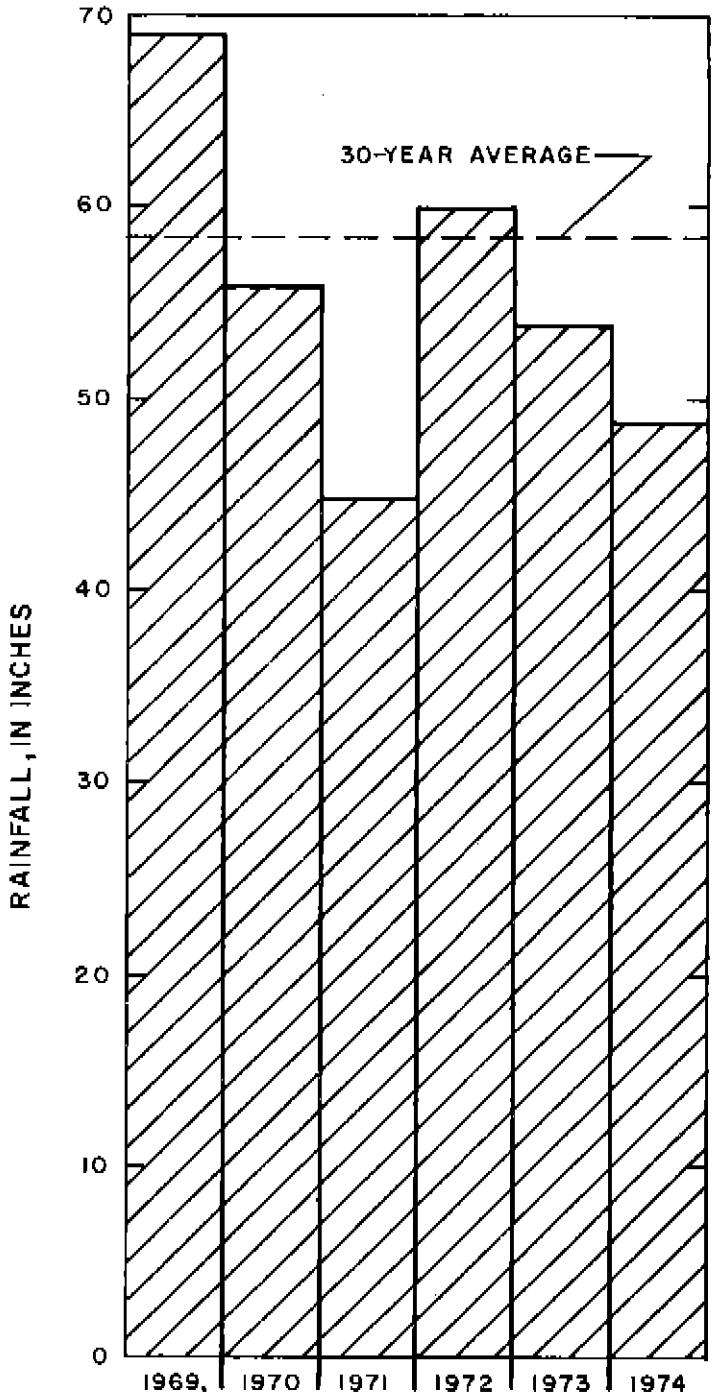

Figure 3.--Average yearly rainfall of the Fort Lauderdale, Pompano Beach, and North New River Canal (S-7) stations.

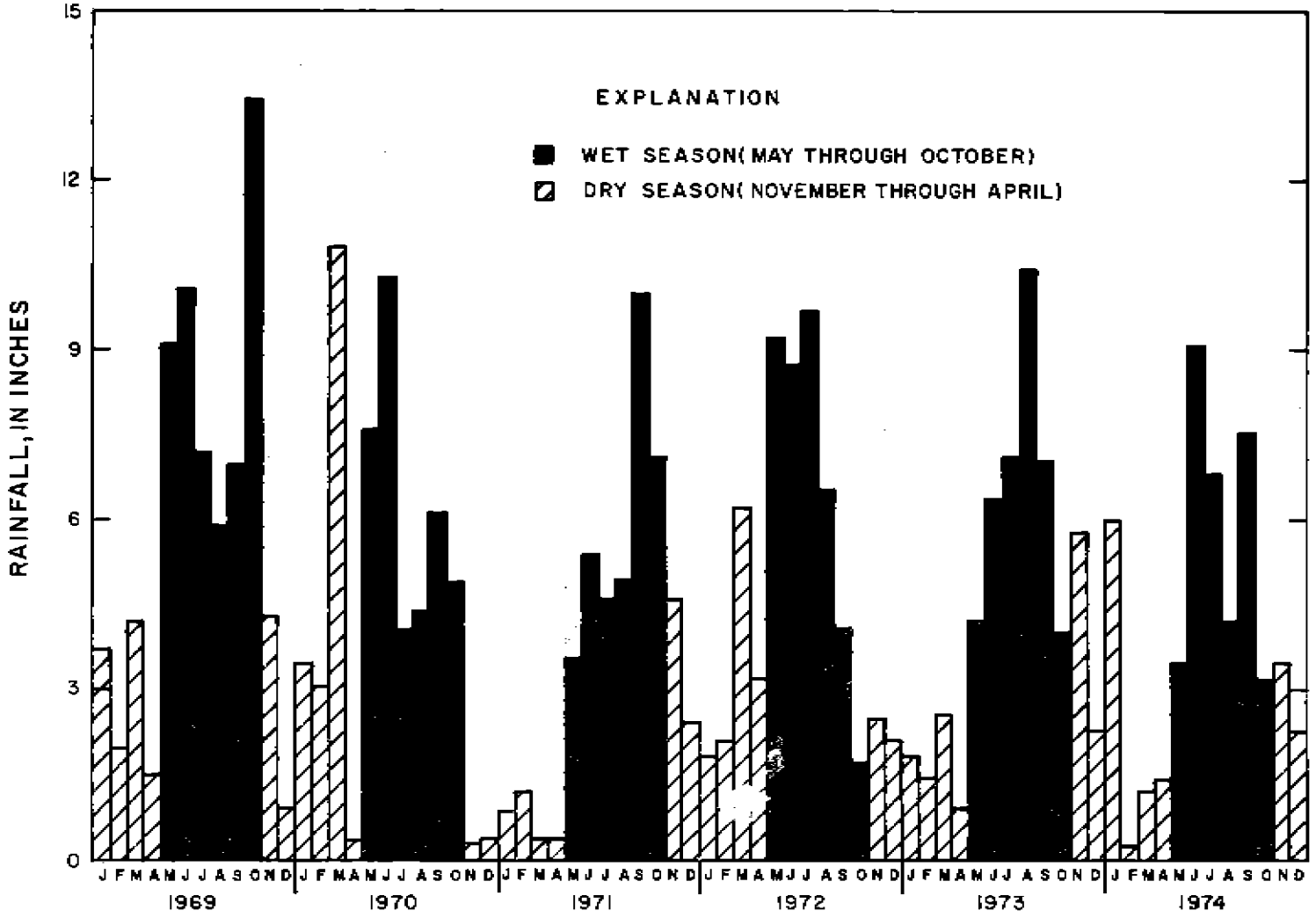

Figure 4.--Average monthly rainfall of the Fort Lauderdale, Pompano Beach, and North New River Canal (S-7) stations.

Water levels in the primary canals of Broward County are controlled to prevent extremes. Salinity-control structures (fig. 5) at the eastern terminus of each canal maintain freshwater head to prevent saltwater intrusion and provide discharge of excess water. Controls, both fixed and mechanically adjustable, on numerous secondary canals throughout the county also regulate water levels. Small drainage districts in the county can discharge excess water to the primary canal system.

The primary and secondary canal systems in Broward County are hydraulically connected to the ground-water system. Fluctuations in canal levels greatly affect ground-water levels in adjacent areas (Sherwood and others, 1973). During the dry season, canals receive considerable amounts of ground-water inflow when back-pumping and controlled discharge occurs.

During the investigation, improvements to the Broward County canal system included new secondary canals for supplemental drainage, extension of primary canals to improve hydraulic connection and channel flow, and construction of a pump station at the headwaters of the Plantation Road Canal to augment flow and improve water quality.

CANAL-WATER QUALITY CHARACTERISTICS

The Broward County primary canals are managed primarily to regulate water level and flow rather than to maintain optimum water-quality conditions. The flow regime and water quality within these canals change seasonally with rainfall.

Chemical, physical, and biological stratification occurs when there is little or no flow in the canals, and stages are maintained by the water-control structures. The canals assume characteristics of long, shallow lakes during the dry season. During periods of rainfall, the coastal water-control structures are opened to release excess water to the ocean to prevent flooding. The resulting flow in the canals initiates three hydrologic changes, which in turn, affect water-quality characteristics. First, the lowering of water levels induces inflow of ground water which is chemically different from surface water in the canals. Second, the secondary canals are flushed of contaminants accumulated during the dry season, increasing the load in the primary canals. Third, stratification, existing under no flow conditions, is displaced by the flow and there is mixing of the canal water.

Environmental factors that influenced chemical and biological properties of the primary canals during data collection are: (1) Surface-water inflow from the water conservation areas (fig. 1); (2) land-use patterns and the urban and agricultural runoff associated with them; (3) discharge of domestic and industrial waste into the canals; (4) inflow of saltwater from the ocean; and (5) morphometry of each canal.

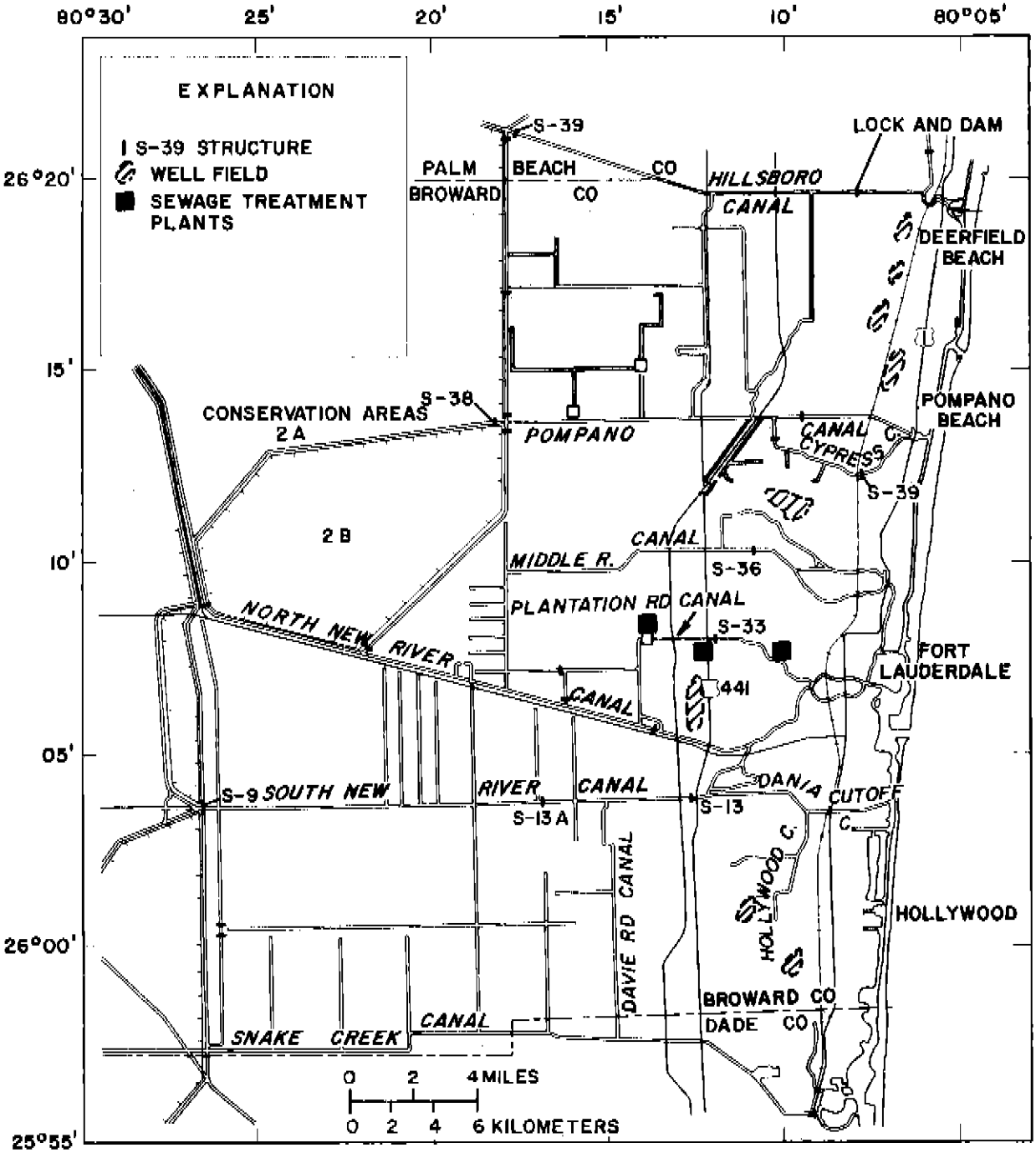

Figure 5.--Salinity-control structures, major sewage-treatment plants, and principal well fields in Eastern Broward County.

The effects of environmental factors on water quality were evaluated by analyzing the chemical and physical data for groups of sites in similar environments. Seasonal variations in water quality were evaluated by segregating the data by wet and dry season collection. The sites and their groupings based on adjacent land use are (see fig. 2 for site locations):

1. Canal sites adjacent to the conservation areas--
   sites 4, 20, 35, 37 39, and 43 (conservation area).

2. Canal sites affected by agricultural drainage--
   sites 34, 36, 38, and 40 (agricultural).

3. Urban canals not directly affected by sewage--
   sites 1, 7, 10, 21, 23, and 30 (urban).

4. Urban canal sites directly affected by domestic sewage discharge--
   sites 5, 11, 14, 15, and 42 (sewage-affected).

5. Estuarine canals--
   sites 16, 16E, 17, 22, 24, and 41 (estuarine).

To determine relations between water-quality parameters, correlation coefficients were calculated for all parameters and are cited where significant. These coefficients indicate which parameters are related and the degree of the relations. The nearer to 1.00 the correlation coefficient, the stonger the direct relation of two parameters. Negative correlation coefficients approaching -1.00 indicate an increasingly strong inverse relation between parameters. Statistical analyses were calculated for all sites by 2-year periods, canal systems, and the foregoing site groupings.

Major Ions

Surface waters commonly contain numerous ions in solution. The major dissolved cations (positively charged ions) include calcium, magnesium, sodium, and potassium; the major anions (negatively charged ions) are sulfate, chloride, fluoride, and those ions, generally assumed to be carbonate and bicarbonate (Hem, 1970), contributing to alkalinity. Silicon in the water is usually nonionic and is reported as an equivalent concentration of the oxide silica (SiO_2). The alkaline earth metals, such as strontium, and the nonmetals, bromine and iodine, are included in many analyses and contribute slightly to the dissolved-solid concentration.

From 1969-74, canal-water samples were collected quarterly at all sites in Broward County and analyzed for major ions, dissolved solids, and hardness (Waller and others, 1975). Results of the analyses indicate that in the freshwater reaches of the canals, concentrations of calcium, magnesium, sodium, chloride, bicarbonate, and hardness are closely correlated. The correlations are consistent by canal system and by individual sites. Correlation coefficients of dissolved solids (residue at 180°C and the sum of constituents) and the major ions range from 0.25 to 0.89.

The dominant ions in the canal water of Broward County are calcium and bicarbonate, the principal products of the solution of limestone (table 2). Sodium and chloride are also found as codominant ions in many of the canals. There are two primary sources of sodium and chloride--one is from saltwater and the other is from the northern Everglades which has ground water typically greater in sodium and chloride (Parker and others, 1955). In terms of ionic character, most Broward County canal water can be classified as mixed having a codominance of calcium bicarbonate and sodium chloride.

When the data are arranged by individual canal or land-use classifications, average, maximum, and minimum constituent concentrations (tables 3 and 4) can be compared with average values for the entire county. Constituents vary depending on the surrounding land-use and canal location as water entering the canals from various sources affects the ion concentrations.

Hillsboro Canal flows through an area in which the ground water is more highly mineralized than in other parts of Broward County. During low-flow conditions, highly mineralized (greater than 500 mg/L [milligrams per liter] of dissolved solids) ground water is discharged into the canal with only slight dilution by surface water. This results in average concentrations of major ions which are above the overall county average (table 3, fig. 6). The same pattern is true of the other canals, such as Pompano and North New River that discharge from the conservation areas (table 4, fig. 7).

In developed areas of Broward County, the canal system becomes more complex, and greater mixing of water sources occurs. Inflow from secondary canals, increased urban runoff from impervious areas, and ground-water inflow reduce the ion concentrations as in the Middle River Canal (Waller and others, 1975, p. 20-23). In some canals such as Plantation Road Canal, secondary-treated sewage is discharged, and further mixing of water sources occurs.

The analyses from estuarine sites on the canals reflect mixing of freshwater and saltwater caused by tides, seawater intrusion, freshwater flow, and rainfall. During the investigation, variations in mixing caused large ranges in the waters' constituent concentrations (table 5). A complete listing of water analyses from estuarine sampling sites in Broward County is presented by Waller and others (1975).

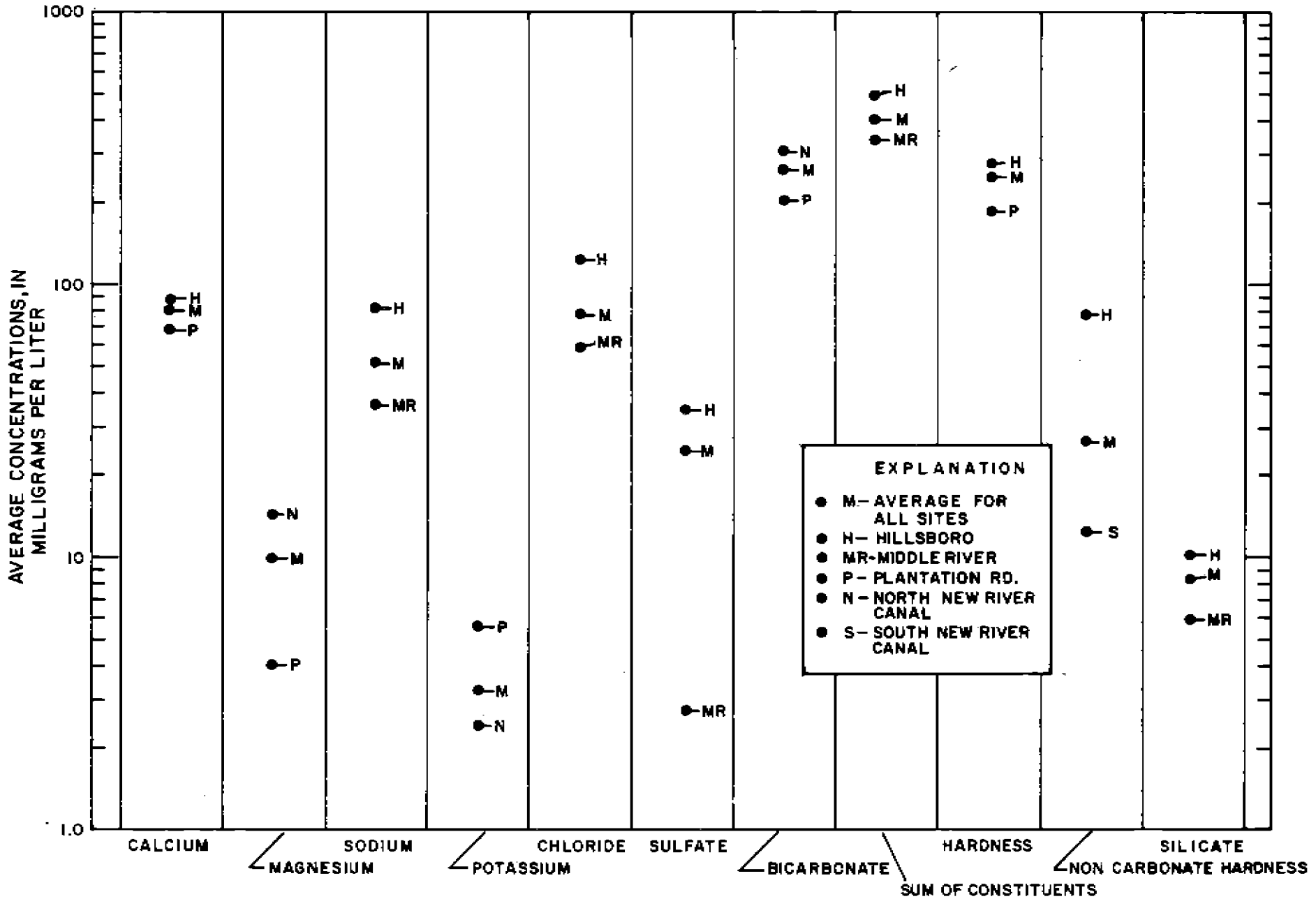

Figure 6.--Maximum and minimum average concentrations and countywide average concentrations of major ions by primary canal.

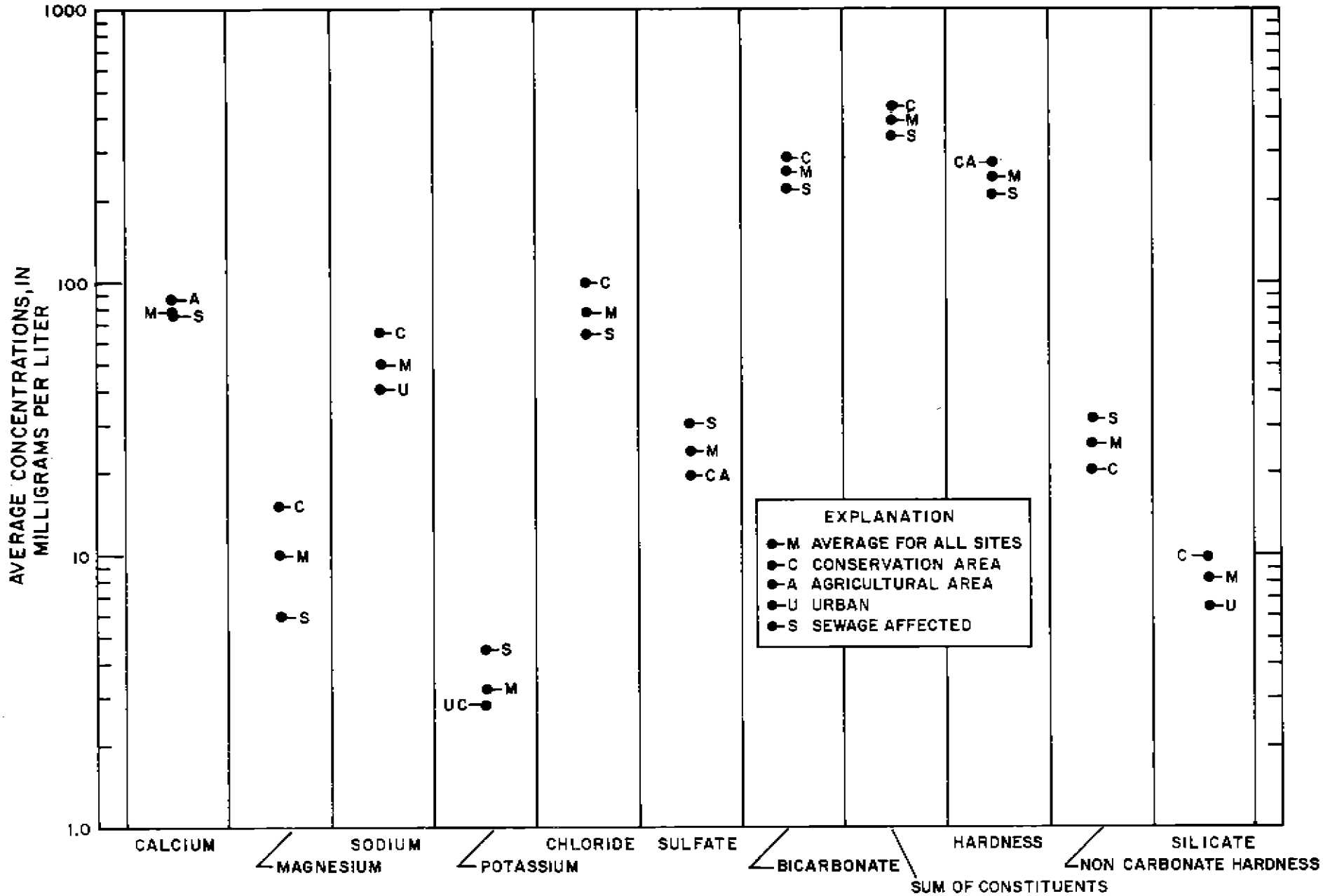

Figure 7.—Maximum and minimum average concentrations and countywide average concentrations of major ions by freshwater site grouping.

Table 2.—Basic statistics for major ion, dissolved-solid, and hardness concentrations in surface water for all freshwater sites

[Concentrations in milligrams per liter]

Constituent	Number of samples	Average	Standard deviation	Minimum	Maximum	Range
Calcium.	272	79	15.4	33.0	110	77
Magnesium.	272	9.8	5.9	1.9	37	35
Sodium.	272	50	24.5	6.8	170	163
Potassium.	272	3.3	2.3	.5	22	21
Chloride.	272	76	34.6	17	230	213
Sulfate.	272	24	15.8	0	98	98
Bicarbonate.	287	260	60.6	70	380	310
Dissolved solids (residue at 180°C).	262	427	94.7	154	848	694
Dissolved solids (sum of constituents).	272	383	88	120	740	620
Hardness.	272	240	44.5	52	350	298
Noncarbonate hardness.	272	26	19.2	0	120	120
Silica.	282	8.1	3.2	.9	25	24

Table 3.--Average, maximum, and minimum concentrations for selected major ions, dissolved solids, and hardness in freshwater reaches

[Concentrations in milligrams per liter]

Constituent	All sites1/			Hillsboro2/			Pompano-Cypress3/		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
Calcium.	33	110	79	45	110	86	33	100	81
Magnesium.	1.9	37	9.8	6.2	37	13	2.1	30	8.8
Sodium.	6.8	170	50	39	150	80	15	170	50
Potassium.	.5	22	3.3	2.7	7.4	4.8	1.2	12	3.4
Chloride.	17	230	76	48	230	120	24	160	72
Sulfate.	0	98	24	17	98	34	5.6	62	30
Bicarbonate.	70	380	260	200	340	290	110	310	260
Dissolved solids (residue at 180°C).	154	848	427	392	848	546	263	618	419
Dissolved solids (sum of constituents).	120	740	383	356	740	496	257	569	378
Hardness.	52	350	240	200	350	270	130	280	240
Noncarbonate hardness.	0	120	26	33	5.0	77	0	90	32
Silica.	.9	25	8.1	4.4	25	10	1.8	13	6.1

1/ Includes analyses from Snake Creek and Davie Road Canals.
2/ Sites 34, 35, and 1.
3/ Sites 4, 5, 7, and 10.

Table 3.—Average, maximum, and minimum concentrations for selected major ions, dissolved solids, and hardness in freshwater reaches--Continued

[Concentrations in milligrams per liter]

Constituent	Middle River4/ 47 samples			Plantation Road5/ 31 samples			North New River6/ 42 samples			South New River7/ 38 samples		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
Calcium.	35	110	77	40	87	67	55	96	77	74	96	87
Magnesium.	1.9	24	6.7	2	7.5	4	7.5	28	15	6	16	11
Sodium.	6.7	94	35	23	83	43	30	84	59	24	71	44
Potassium.	.5	22	2.8	1.3	2.1	5.5	1.3	5.9	2.4	0.9	2.7	1.8
Chloride.	17	130	60	32	100	61	60	170	91	38	100	67
Sulfate.	2.5	61	2.7	12	56	31	0	80	14	0	20	7.6
Bicarbonate.	70	310	230	76	330	200	200	380	300	230	350	300
Dissolved solids (residue at 180°C).	154	581	364	244	517	380	370	607	454	358	514	418
Dissolved solids (sum of constituents).	120	496	326	240	479	330	326	600	411	307	471	378
Hardness.	98	280	220	52	250	180	210	330	260	230	300	260
Noncarbonate hardness.	2	120	34	0	73	23	0	81	17	0	40	13
Silica.												

4/ Sites 37, 36, 11, and 30.
5/ Sites 14, 15, 16, 16E, and 17.
6/ Sites 20, 38, 21, and 22.
7/ Sites 39, 40, 23, and 24.

Table 4.--Average, maximum, and minimum concentrations for selected major ions, dissolved solids, and hardness in freshwater land-use areas[1]/

[Concentrations in milligrams per liter]

Constituent	All sites 272 samples			Conservation area 72 samples			Agricultural 48 samples		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
Calcium.	33	110	79	33	100	80	61	110	85
Magnesium.	1.9	37	9.8	2.3	37	15	2.9	22	11
Sodium.	6.8	170	50	11	150	66	19	110	54
Potassium.	0.5	22	3.3	0.9	6.9	2.9	0.9	22	3.1
Chloride.	17	230	76	17	230	99	30	160	80
Sulfate.	0	98	24	0	98	20	0	55	20
Bicarbonate.	70	380	260	110	380	290	200	340	280
Dissolved solids (residue at 180°C).	154	848	427	294	848	481	329	661	449
Dissolved solids (sum of constituents).	120	740	383	251	740	436	301	600	407
Hardness.	52	350	240	130	350	260	210	310	260
Noncarbonate hardness.	0	120	26	0	92	21	0	63	22
Silica.	0.9	25	8.1	2.4	25	9.9	4.4	16	8

1/ See page 12 for site numbers.

Table 4.--Average, maximum, and minimum concentrations for selected major ions, dissolved solids, and hardness in freshwater land-use areas[1]/--Continued

[Concentrations in milligrams per liter]

Constituent	Urban (82 samples)			Sewage-affected (70 samples)		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Calcium.	35	100	81	40	110	75
Magnesium.	1.9	20	7.7	2	30	6
Sodium.	6.7	110	41	15	170	43
Potassium.	.5	7.4	2.9	1.1	13	4.4
Chloride.	17	160	64	24	130	63
Sulfate.	0	50	22	12	59	31
Bicarbonate.	70	330	250	76	330	220
Dissolved solids (residue at 180°C).	154	610	394	244	581	398
Dissolved solids (sum of constituents).	120	520	352	240	569	350
Hardness.	98	290	240	52	310	210
Noncarbonate hardness.	0	120	28	0	90	32
Silica.	1	11	6.4	3.8	18	8.1

1/ See page 12 for site numbers.

Table 5.--Statistics for selected major ions, dissolved solids and hardness in estuarine sampling sites

[Concentrations in milligrams per liter]

Constituent	Number of samples	Minimum	Maximum	Average	Range
Calcium.	67	60	550	180	490
Magnesium.	67	2.5	1,200	300	1,200
Sodium.	67	20	10,000	2,700	10,000
Potassium.	67	1.4	440	100	440
Chloride.	67	28	18,000	4,800	18,000
Sulfate.	67	1.6	8,700	1,300	8,700
Bicarbonate.	70	150	300	240	150
Dissolved solids (residue at 180°C).	19	281	34,000	4,290	33,700
Dissolved solids (sum of constituents).	67	230	32,500	8,710	32,300
Hardness.	67	160	5,900	1,700	5,700
Noncarbonate hardness.	67	9	5,800	1,500	5,800
Silica.	70	.5	9.9	5.4	9.4

Dissolved Solids

The amount of dissolved material is a commonly determined water-quality parameter and is used to evaluate water-quality conditions and compare waters with one another. Analysis is made by weighing the dry residue after evaporation of the volatile materials at 180°. Dissolved solids can also be calculated by summing the concentrations of the major ions in a sample.

Specific conductance in distilled water is nearly zero. The greater the concentration of ions in the water, the greater its conductance. Thus, specific conductance can be used as an index of water quality and to estimate dissolved solids present.

In the freshwater reaches of Broward County canals, the average concentration of dissolved solids is 427 mg/L, and the range is almost 700 mg/L (table 2). In water from Hillsboro Canal, conservation land-use areas, and agricultural land-use areas, concentrations of dissolved solids and hardness are greater than the overall county average (figs. 6 and 7). This is a result of agricultural runoff and ground-water inflow containing high concentrations of dissolved solids to the Hillsboro Canal and the conservation areas. Average specific conductance in the conservation and agricultural areas were 774 and 715 umhos/cm (micromhos per centimeter at 25°C), respectively; while in the urban and sewage land-use areas, the average value was 627 umhos/cm. Because of the influence of seawater, estuarine sites have very high dissolved-solid concentrations (table 5). Dissolved solids and specific conductance displayed no recognizable pattern of change between 1969 and 1974.

Macronutrients

Carbon, nitrogen, and phosphorus compounds are considered macronutrients because they are major components in cells of all organisms. They are in both reactive inorganic forms and in the organic form, chiefly in plant and animal cells and detritus. These compounds are required for growth, maintenance, reproduction, and regeneration of all organisms.

In Broward County canals, the primary sources of macronutrient compounds are plant detritus, plants, nutrient laden runoff, and in some areas, sewage. Water from the conservation areas characteristically has high concentrations of organic carbon and organic nitrogen, mostly from plant and detrital material (Waller and Earle, 1975). Macronutrients from sewage and runoff cause locally high concentrations in some canals. Examination of the percentage composition of nitrogen and phosphorus species can indicate imbalances in an aquatic system caused by excessive loading of these constituents.

Nutrient concentrations in the Broward County canal system vary greatly (table 6). This variation is due primarily to sewage inputs at some of the sites. The effects of sewage discharge are discussed in detail in the following section.

Carbon

Water samples were collected and analyzed to determine organic and inorganic carbon concentrations in Broward County canals. Organic carbon is contributed to the canals by plant and animal cells and detrital seston. Water, having been in contact with the peat and muck soils in the Everglades, characteristically has high organic carbon concentrations. Inorganic carbon, primarily bicarbonate ions, enters the water mainly by solution of calcite ($CaCO_3$) in the soil and rock.

Inorganic carbon is dominant within the Broward County canal system. It comprises about 70 percent of the total carbon with a slight variation in average concentrations between the primary canals (fig. 8). The Hillsboro and South New River Canals have the greatest average concentrations for inorganic and organic carbon, while the Hollywood-Dania Cutoff Canal (estuarine canal including sites 41 and 24) has the lowest.

Average concentrations of organic and inorganic carbon generally decrease from the conservation area to agricultural areas and decrease further in urban areas (fig. 9). Organic carbon concentrations are slightly greater in sewage-affected urban areas than in other urban areas, probably due to increased plant (phytoplankton) growth. The general decrease from west (conservation areas) to east (urban areas) is the result of decreasing organic soil cover in the eastern parts of Broward County.

Nitrogen

During the investigation, organic nitrogen was the dominant specie of total nitrogen in all Broward County primary canals, except for the Plantation Road Canal (fig. 10 and table 6). Organic nitrogen is primarily protein matter derived from plant detritus, phytoplankton, and other plankters. Excluding Plantation Road Canal analyses, total nitrogen with organic nitrogen correlation coefficient values ranged from 0.82 to 0.96 in the primary canals.

In the Plantation Road Canal, which as previously noted receives large amounts of secondary-treated sewage effluent, the dominant nitrogen specie was ammonium. This highly reactive species of nitrogen is indicative of contaminated water when concentrations exceed 0.50 mg/L (U.S. Environmental Protection Agency, 1977). Ammonium concentrations in Plantation Road Canal had a

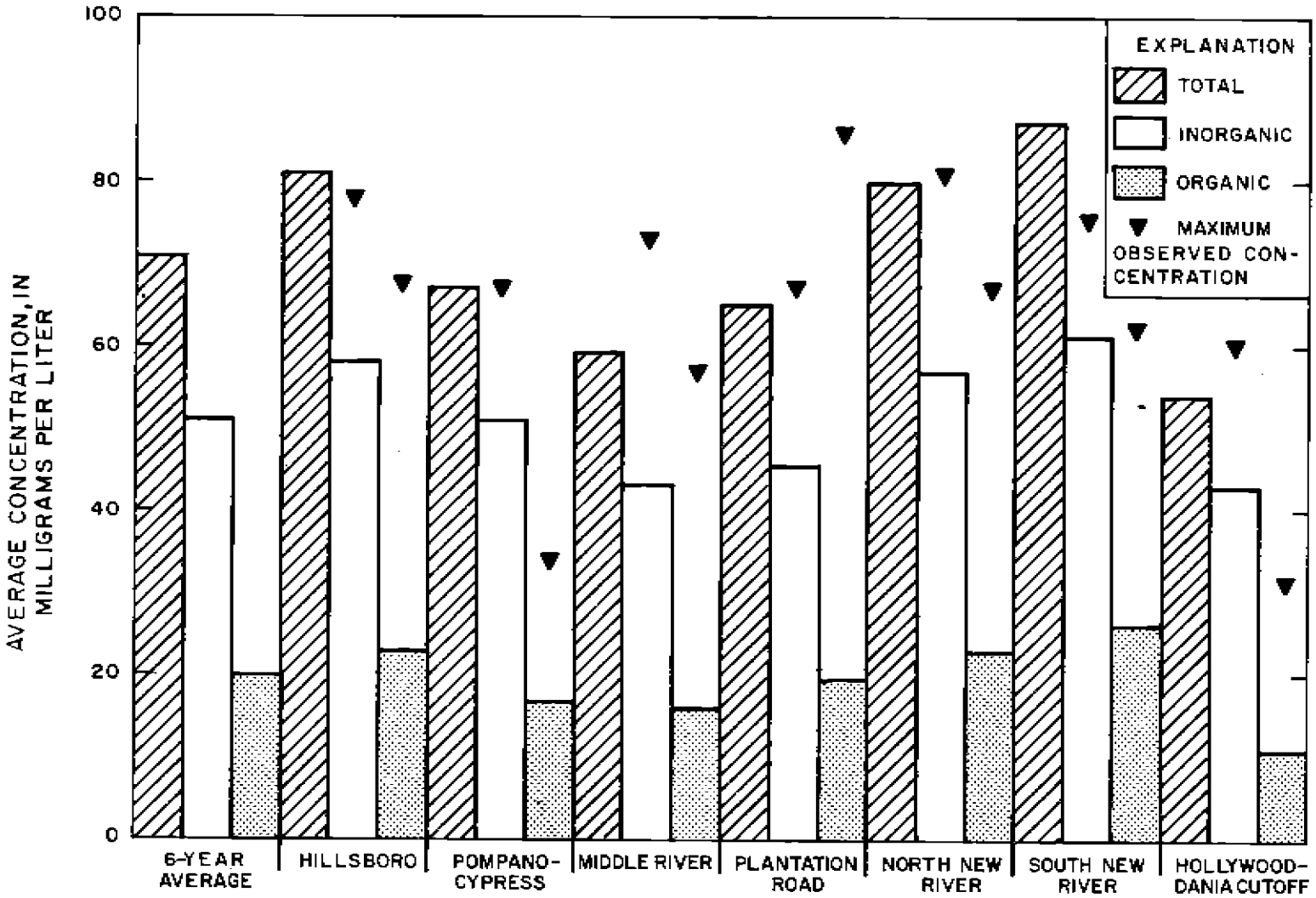

Figure 8.--Average concentration of carbon compounds for each primary canal.

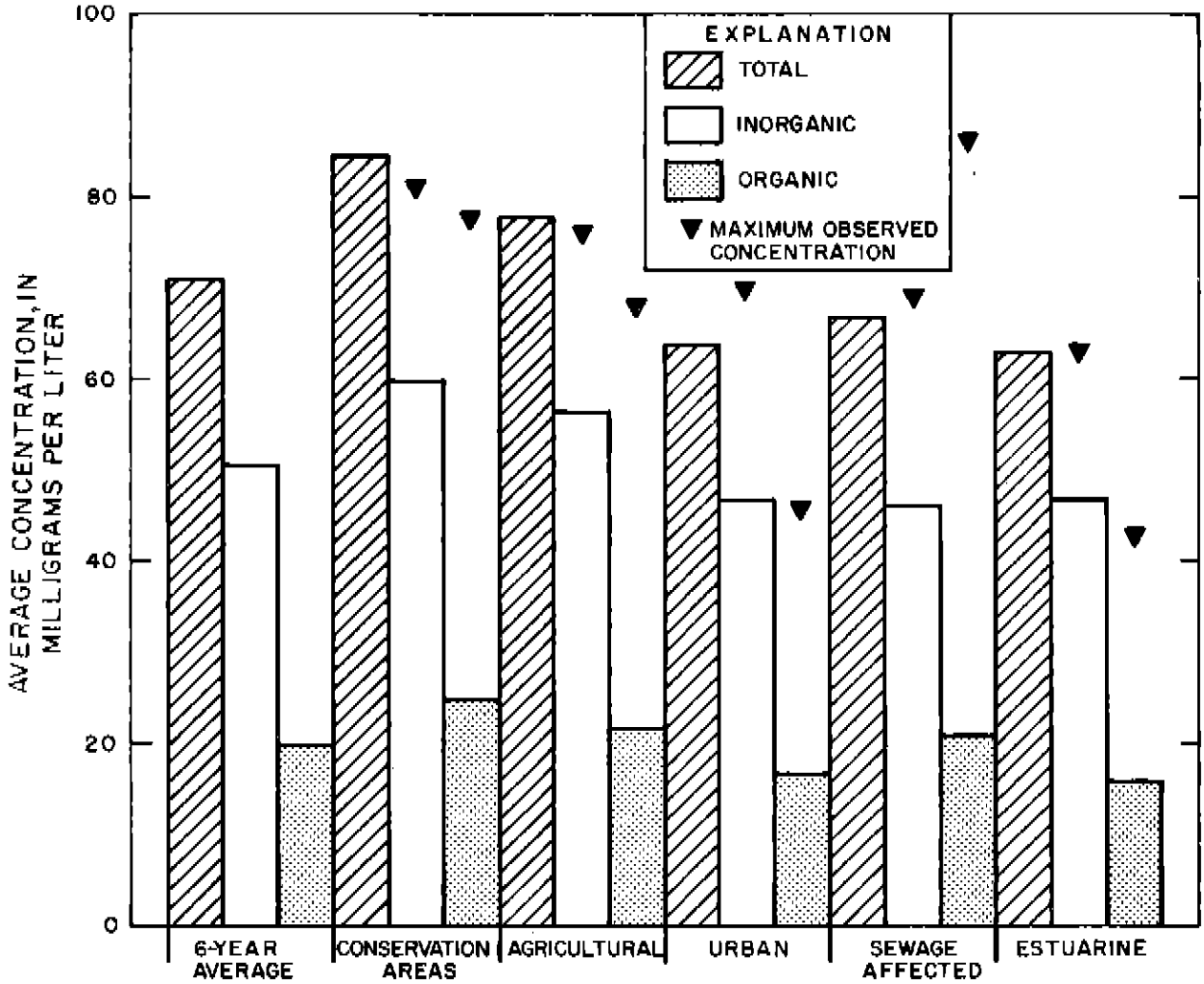

Figure 9.--Average concentration of carbon compounds for each site grouping.

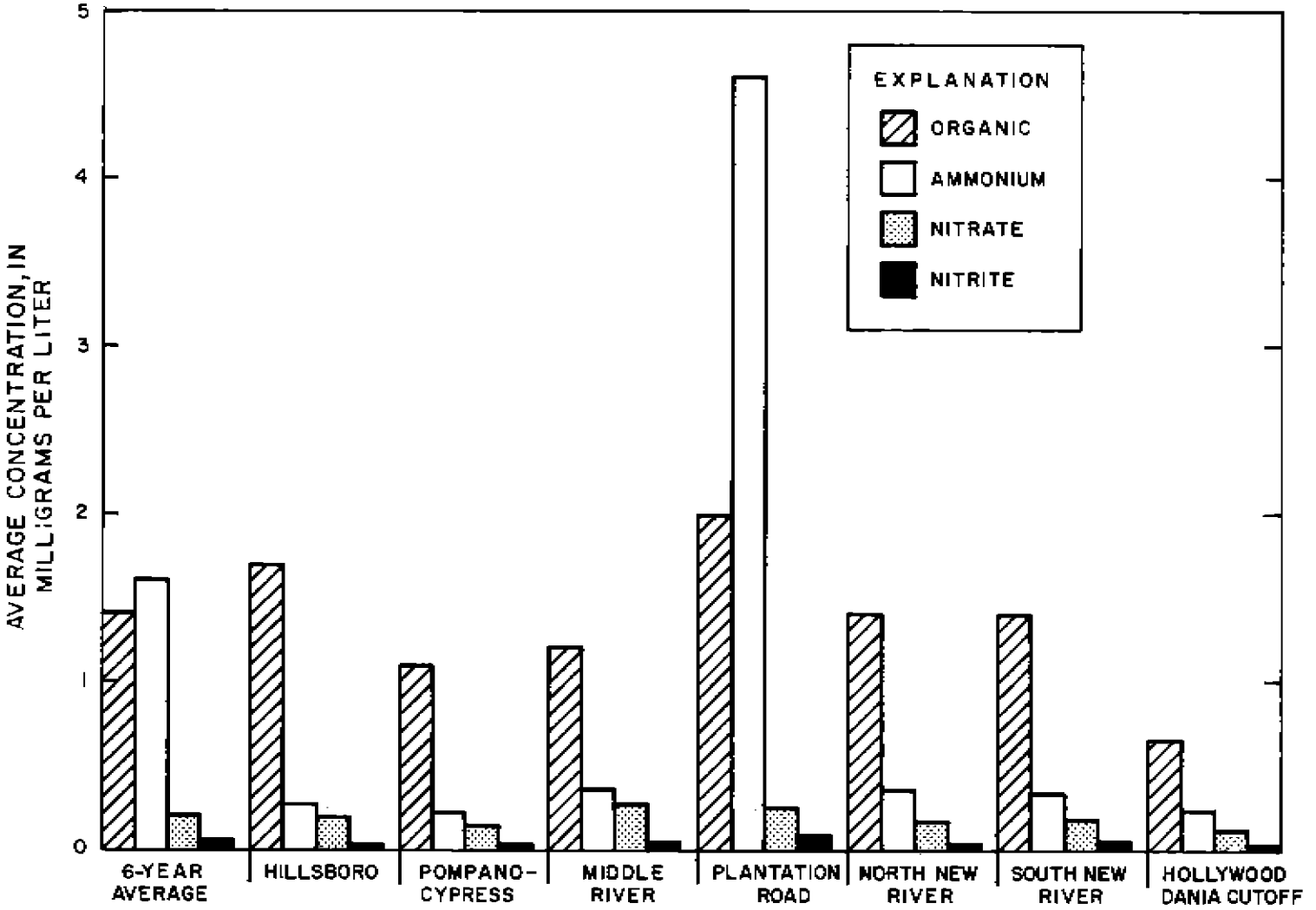

Figure 10.—Average concentration of nitrogen species for each primary canal.

Table 6.—Basic statistics for macronutrient concentrations in surface water for all sites

[Concentrations in milligrams per liter]

Constituent	Number of samples	Average	Standard deviation	Minimum	Maximum	Range
Ammonium (NH_4).	476	1.2	3.2	0.0	30	30
Nitrite (NO_2).	484	.5	.10	.0	1.6	1.6
Nitrate (NO_3).	487	.20	.47	.0	7.9	7.9
Organic nitrogen.	472	1.4	1.6	.0	20	20
Total nitrogen.	470	2.8	4.1	.21	44	43.8
Orthophosphate.	473	.59	1.5	.0	12.1	12.1
Total phosphorus.	484	.63	1.6	.0	12.4	12.4
Organic carbon.	389	20	12.7	2.0	85	83
Inorganic carbon.	389	51	12.8	5.0	80	75
Total carbon.	389	71	19	15	150	135

correlation coefficient with total nitrogen of 0.93 and were sufficiently high to bias the 6-year countywide average ammonia concentration (1.16 mg/L) when included with data from the other primary canals (fig. 10).

The conservation and agricultural areas are similar in average nitrogen specie composition and concentration (fig. 11). The urban areas have slightly lower average concentrations. The sites affected by sewage effluent have greater concentrations of ammonium (3.8 mg/L), nitrate (0.32 mg/L), nitrite (0.09 mg/L), and organic nitrogen (2.2 mg/L) than other site groupings. The estuarine sites show a greater average ammonium concentration than expected, as a result of sewage effluent entering these waterways from the sewage-affected freshwater canals and direct effluent discharge.

Phosphorus

Average concentrations of phosphorus compounds differ in the primary canals. These differences are probably related to land-use patterns with their characteristic runoff; however, the morphometry of the canals and biological reactions in the canals also can affect concentrations. Ground water in Broward County is generally deficient in orthophosphate, and thus, is a minimal source of phosphorus in the canals. The greatest average concentrations of phosphate (fig. 12) are in the Plantation Road Canal (2.5 mg/L) because of sewage discharge; the lowest average values were in the South New River Canal (0.013 mg/L).

Phosphorus concentrations show definite land-use influences when compared by site-grouping categories (fig. 13). As the water flows from conservation areas through agricultural areas to urban areas, phosphorus concentrations generally show an increase similar to that of nitrogen species (fig. 11). The low phosphorus concentrations (0.04 mg/L) in water coming from the conservation areas are caused by assimilation of phosphorus in the large littoral zone of the marshes (Waller and Earle, 1975). Orthophosphate from fertilizers and sewage enter the canals in the agricultural and urban areas. Sewage-affected sites (fig. 2) have the greatest average phosphorus concentrations (2.30 mg/L). The estuarine sites also have high phosphorus concentrations due to discharge from freshwater sewage-affected canals and direct sewage input.

Oxygen-Related Parameters

Many factors--physical, chemical, and biological--affect the oxygen concentration in a body of water. Generally, various combinations of factors control the oxygen level rather than any one factor. The primary oxygen source in the canals is from plants, both submersed and planktonic, which are limited chiefly by light

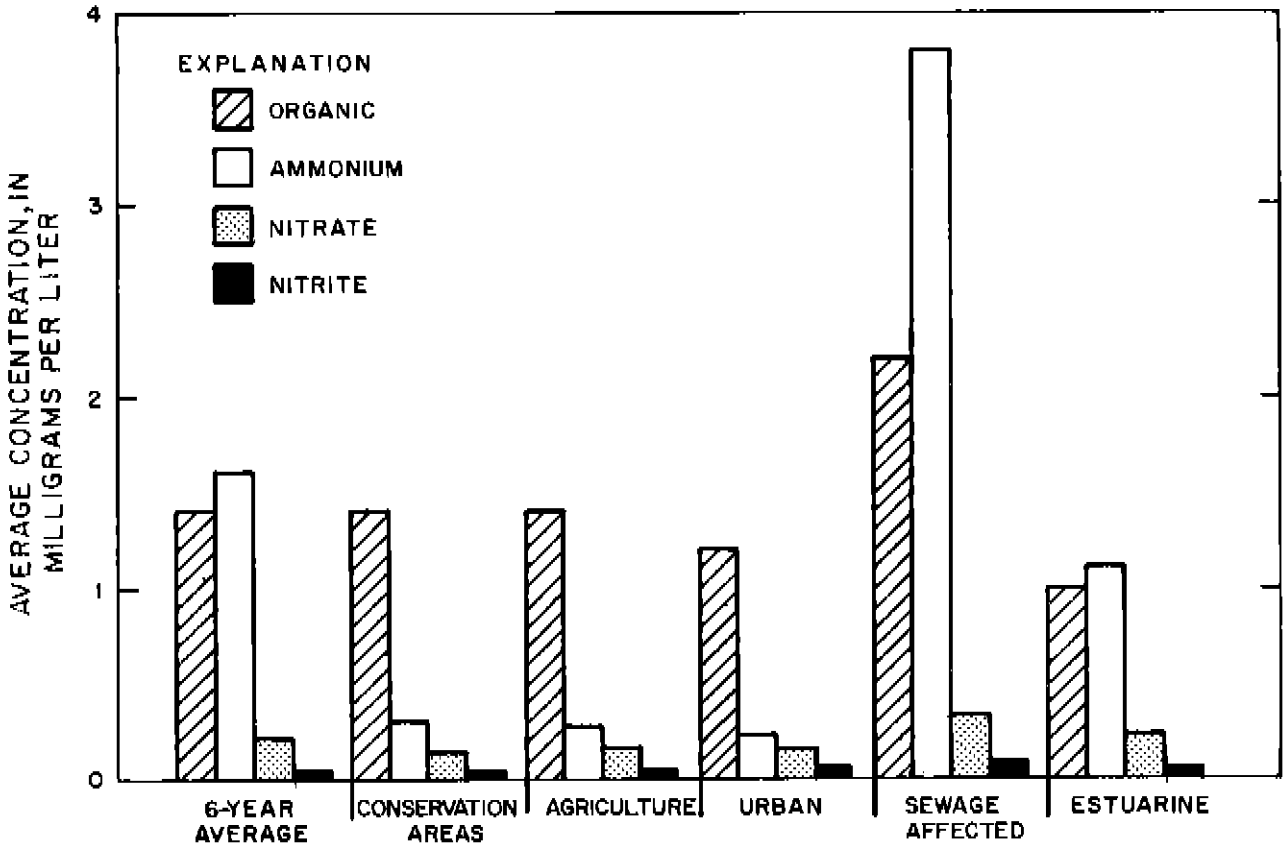

Figure 11.--Average concentration of nitrogen species for each site grouping.

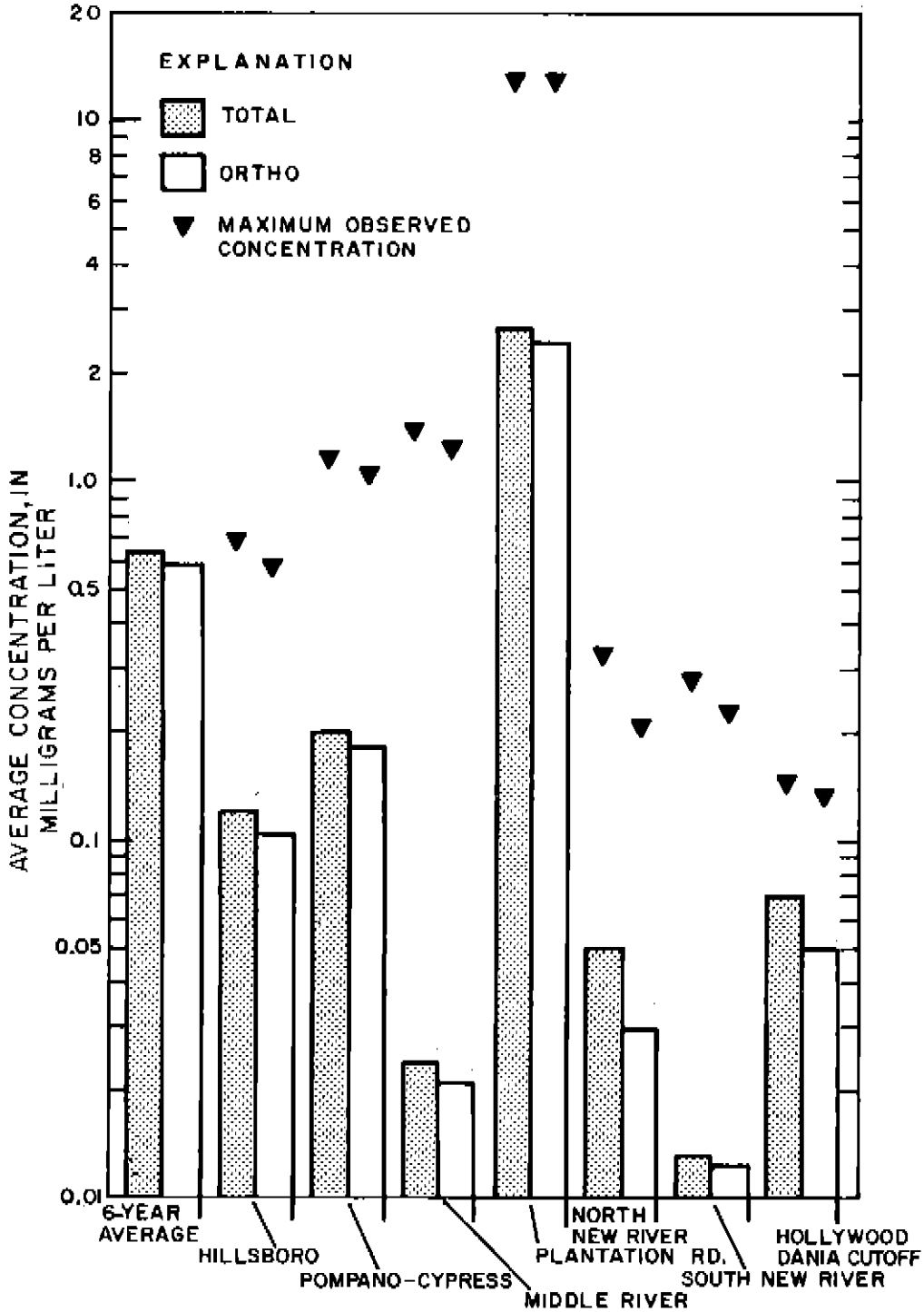

Figure 12.--Average concentration of phosphorus compounds for each primary canal.

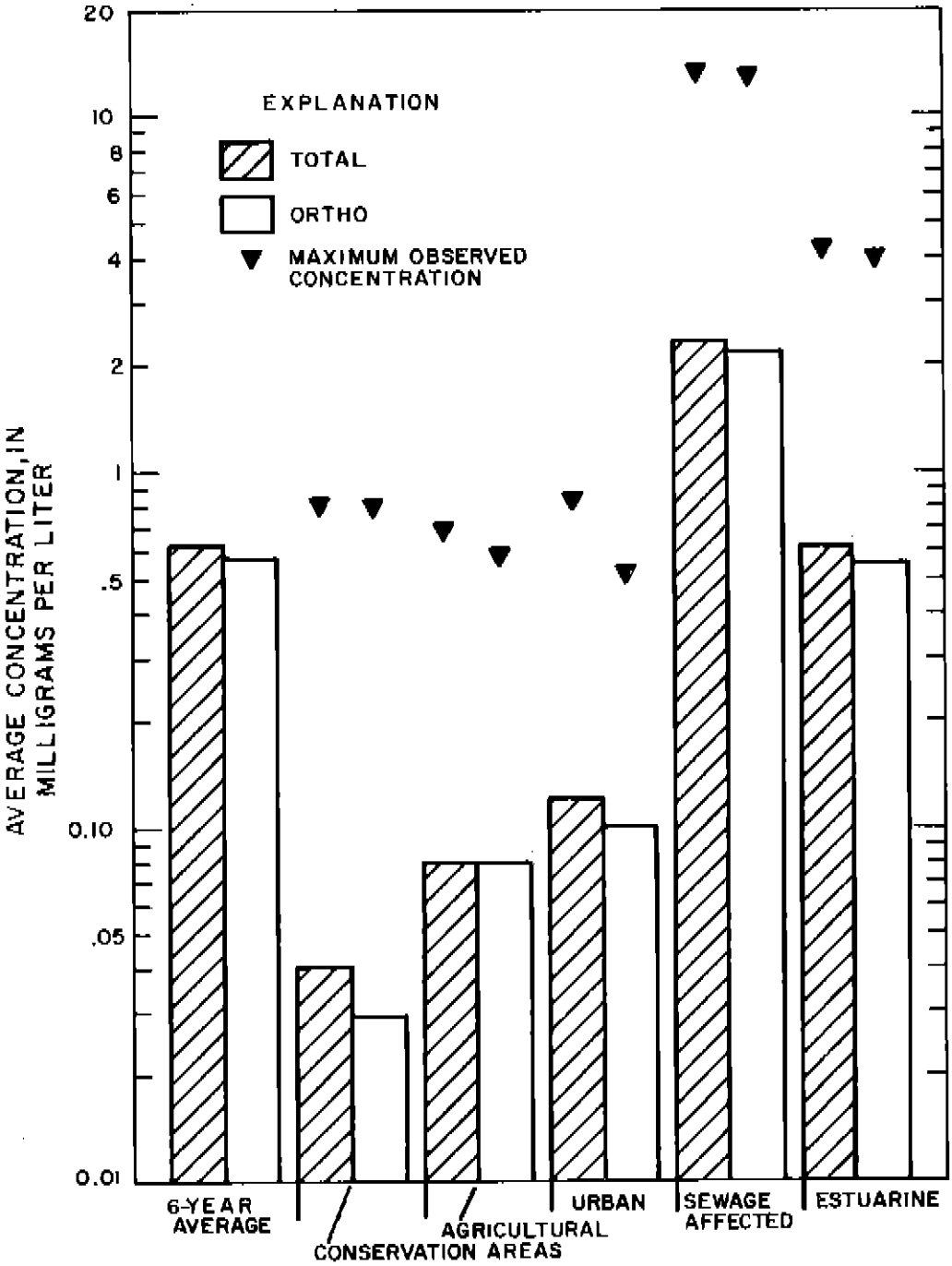

Figure 13.—Average concentration of phosphorus compounds for each site grouping.

penetration. Light penetration is largely controlled by color, turbidity, and floating aquatic plants. Water temperature (which affects oxygen solubility) and flow (which displaces phytoplankton populations and disturbs stable chemical equilibria) also influence oxygen concentrations in the canals.

Turbidity, Color, and Temperature

South Florida waters are typically highly colored because of the lignin, tanins, and humic acids leached from the organic soils. The Broward County canals have an average color between 50 and 60 platinum-cobalt standard (Pt-Co) units with two exceptions (fig. 14). Highly colored water, greater than 80 units, is in the Hillsboro Canal, while the Hollywood-Dania Cutoff Canal has the lowest average color (30 units) due to seawater dilution. The basic statistics for oxygen-related parameters in the Broward County canals are shown in table 7.

Two correlations between color and other variables were observed. In urban areas, color, with a correlation coefficient of 0.93, was directly related to total nitrogen, probably as a result of inflow from the conservation area. The estuarine sites showed an inverse relation between color and specific conductance, as indicated by a correlation coefficient of -0.79, as results of the intrusion of seawater low in color.

Average turbidity levels vary slightly between canals, except in the Plantation Road Canal (fig. 14). The high turbidity levels in this canal are probably caused by sewage effluent which is typically very turbid.

Water temperature varied seasonally with the greatest temperatures recorded in August and September and the lowest in January. During the 6-year study for all canals, temperature ranged from 17.0°C to 34.0°C and averaged 25.6°C.

Dissolved Oxygen

The average dissolved-oxygen (DO) concentration in the Broward County canal system was 4.8 mg/L (table 7), indicating a high level of oxygen in the system during daylight hours. The greater range of DO readings were caused by plankton blooms which occur periodically in some canals. The lower range of DO readings were caused by ground-water inflow and high oxygen demand from sewage effluent.

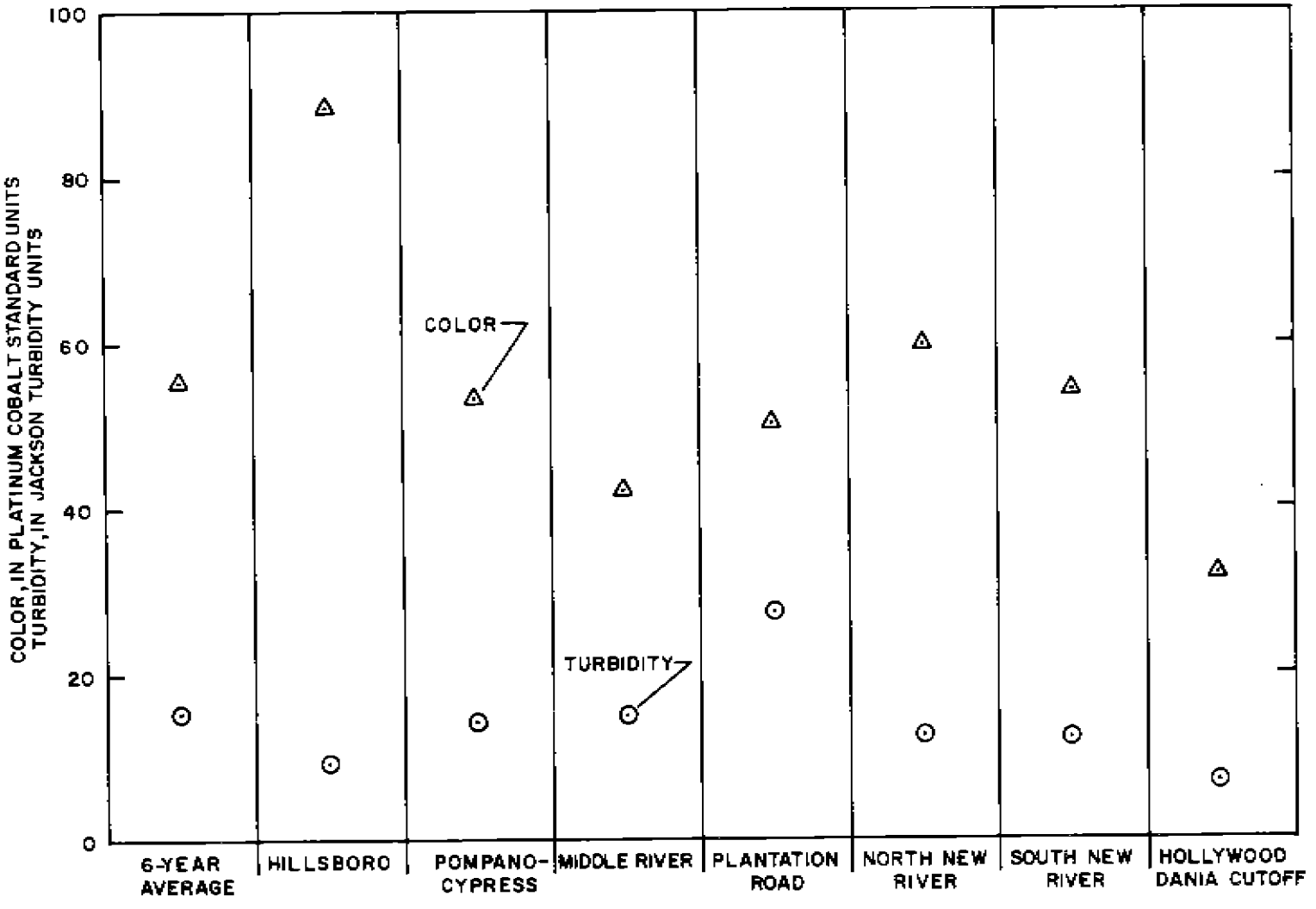

Figure 14.--Average levels of color and turbidity for each primary canal.

Table 7.--Basic statistics of oxygen-related parameter values in surface water for all sites

[Concentrations in milligrams per liter]

Constituent	Number of samples	Average	Standard deviation	Minimum	Maximum	Range
Dissolved oxygen.	387	4.8	3.1	0.10	18	17.9
Biochemical oxygen demand.	434	2.3	1.8	0	9	9
Color (Pt-Co units).	396	55	24	2	160	158
Turbidity (Jackson Turbidity Units).	475	14.7	32	1	600	599
Temperature (°C).	452	25.6	3.2	17	34	17

Concentrations of DO averaged 4.0 mg/L or greater in all but the Hillsboro and Plantation Road Canals (fig. 15 and table 7). The Hillsboro Canal has low DO concentrations because of highly colored water, steep sides (lack of a littoral zone), and ground-water inflow. The Plantation Road Canal DO concentrations are low because of the high average BOD levels (fig. 16), an extensive floating plant community inhibiting light penetration and photosynthesis, and high turbidity.

Average concentrations of DO increase from the conservation area (4.1 mg/L) through the agricultural area (4.9 mg/L) to the urban area (5.9 mg/L) (fig. 16). The average DO concentration in the sewage-affected and estuarine areas was less than the concentration in the remainder of the urban areas. All site groupings had an average DO level greater than 4.0 mg/L for the 6-year period. These average concentrations take into account only DO readings from 1 foot below the surface which were taken during daylight when plant photosynthesis is at a high rate.

Average DO concentrations in the wet and dry season differ. During the wet season, the average DO levels are lower in every canal (fig. 17). The lower values are caused by: (1) Increased flow which displaces phytoplankton and breaks up stratification; (2) ground-water inflow; (3) increased surface runoff that carries oxygen-demanding materials; and (4) greater water temperatures resulting in accelerated oxygen-consuming processes and lower oxygen-carrying capacity.

Biochemical Oxygen Demand

Biochemical oxygen demand is a measure of the amount of oxygen consumed in a given volume of water during a specific time period. In this study, a 5-day BOD (BOD_5) is used to indicate the relative amounts of oxygen-consuming material in a water sample. These oxygen-consuming materials are highly reactive, reduced compounds, bacteria, plankton, and detrital material. Relatively high BOD levels (greater than 3.0 mg/L) indicate oxygen-demanding materials in canals. In the area of investigation, these levels would most likely result from sewage effluent or contaminant laden runoff. Sites that exhibit high BOD may be undergoing deoxygenation, which in turn, leads to noxious odors, lack of diversity in aquatic organisms, and limitation of uses of the water for the community.

Biochemical oxygen demand levels are uniformly low throughout the Broward County canal system, except at sites directly affected by sewage effluent (fig. 16). These data indicate that most canals are not excessively loaded with oxygen-demanding materials, and adequate dissolved oxygen can be maintained. Sewage-affected sites are being so heavily loaded with oxygen-demanding materials that dissolved oxygen may be insufficient for aquatic life. The average BOD exceeds the average DO concentration at the Plantation Road Canal (fig. 15).

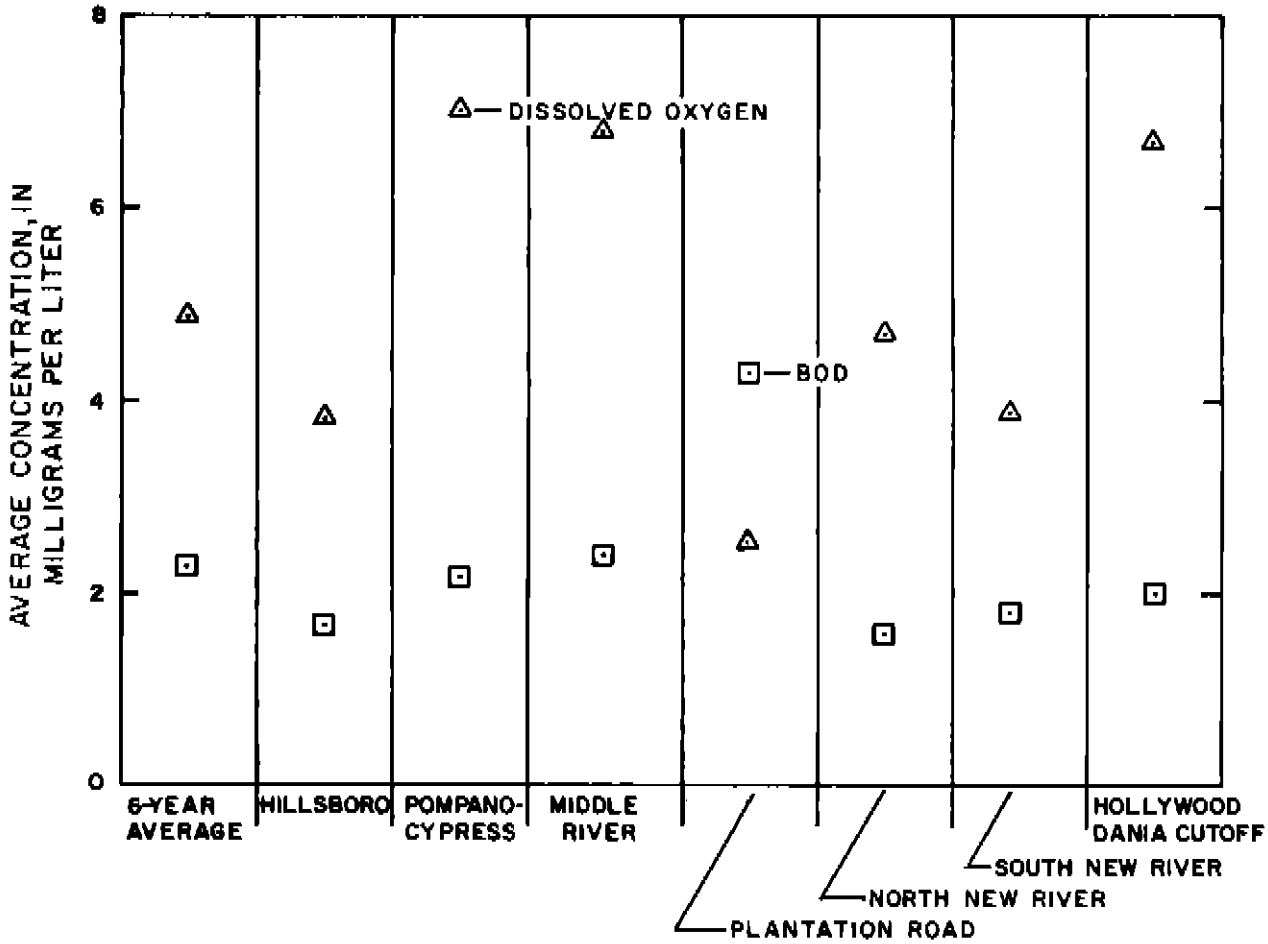

Figure 15.--Average concentration of biochemical oxygen demand and dissolved oxygen for each primary canal.

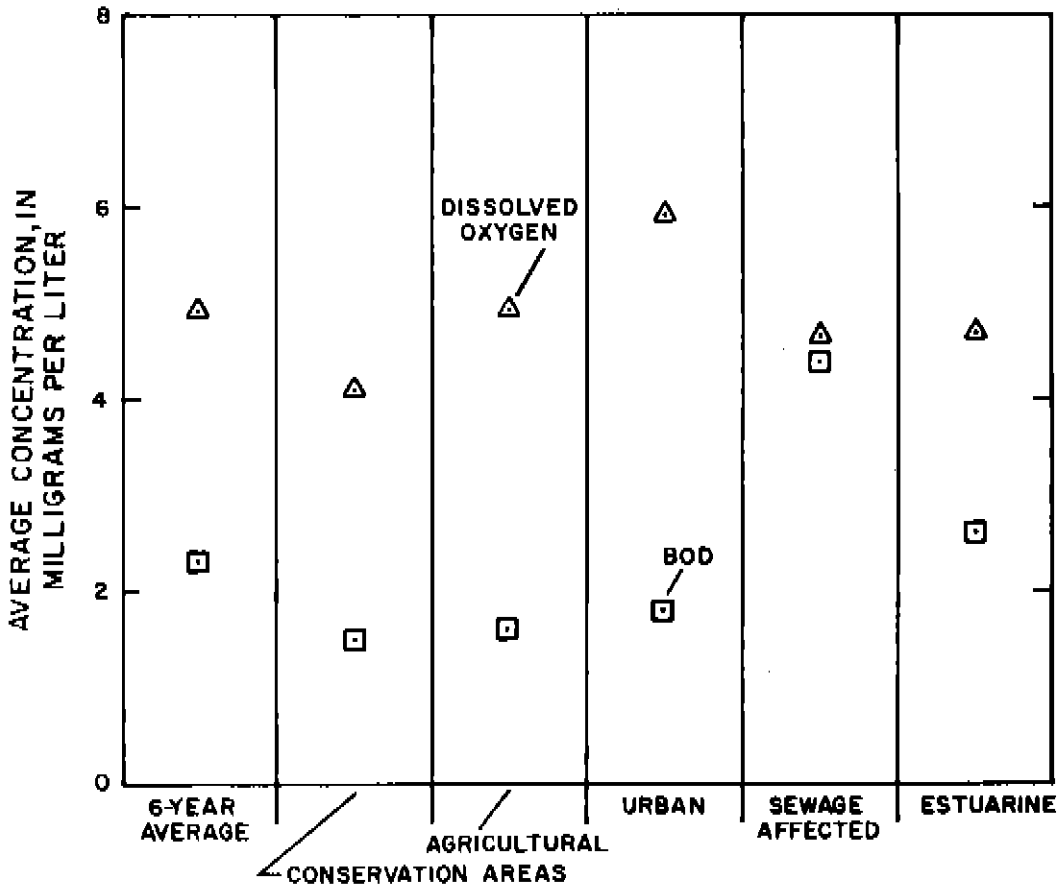

Figure 16.--Average concentration of biochemical oxygen demand and dissolved oxygen for each site grouping.

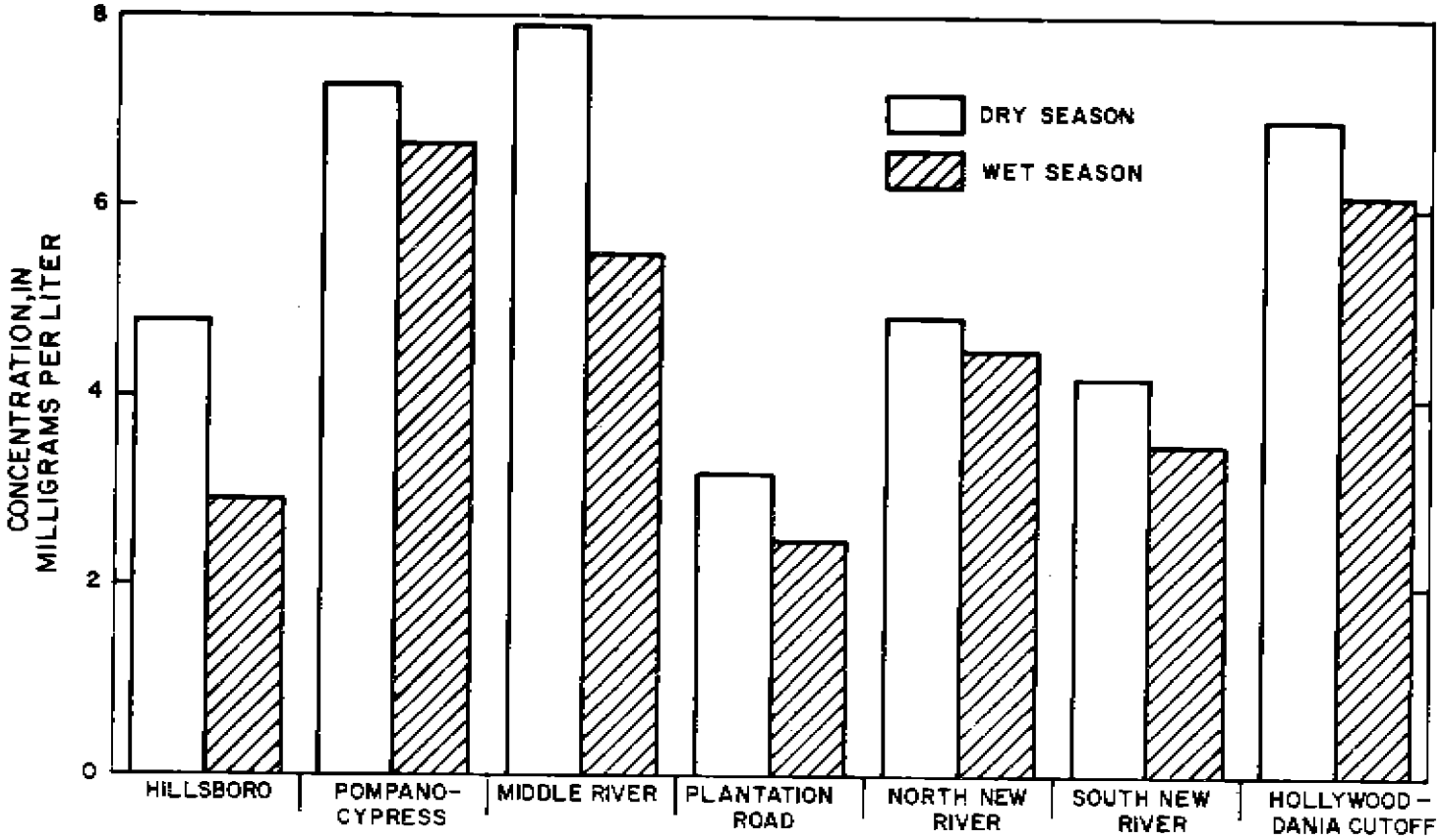

Figure 17.--Seasonal variation in dissolved-oxygen concentration for each primary canal.

Detergents, Oil and Grease

Detergent concentrations in the Broward County canals show little variation between individual canal systems or land-use areas (table 8). However, the areas heavily influenced by sewage effluents and the estuarine areas show a slightly greater average detergent concentration than other areas. Estuarine sites have the greatest average concentrations during the 6-year study.

Oil and grease determinations (table 8) show that average concentrations have little, if any, correlation to either canal or land use. The tendency of these materials to float on the canal surface allows them to migrate throughout the canal system as water levels and flow conditions vary. Consequently, urban areas, normally expected to have the greatest concentrations of oil and grease, may not. Variations in local water conditions at the time of sampling can cause large differences in oil and grease observed at any particular site. Greatest average concentrations were in the agricultural areas, probably due to herbicide application where oil is used as a carrier.

Trace Elements

The trace elements determined occur in many natural compounds, both organic and inorganic. Some are required in small amounts for the metabolic processes of aquatic organisms. Concentrations of these elements are generally low because of physical, chemical, and biological processes. The physiochemical interactions involve solubility, exchange reactions, adsorption-desorption phenomena, and oxidation-reduction equilibria (Rubin, 1974). The nature of the aqueous metal, either organic, inorganic, or complexed, will determine its chemical behavior.

Individual trace-element concentrations were variable at and between sites (Waller and others, 1975). No seasonal or temporal variations could be identified from statistical analyses, probably because of complex reactions involved in controlling the concentrations of these elements in surface water. Most of these elements are held in the biota and bottom sediments of the canals.

The average concentration of trace elements over the last 6 years (tables 9 and 10), however, vary only slightly in most canals, except for the Plantation Road and Hollywood-Dania Canals. These canals exhibit greater average concentrations of most trace elements, because the former is affected by sewage effluent and highway runoff and the latter by sewage effluent, seawater, and boat traffic from the Intracoastal Waterway.

Table 8.--Average concentrations of detergents, and oil and grease by canal and site grouping

[Concentrations in milligrams per liter]

Site grouping	Detergent (methylene blue active substance)	Oil and grease
	Canals	
Hillsboro.	0.05	8.9
Pompano-Cypress.	.05	7.8
Middle River.	.04	15
Plantation Road.	.05	12
North New River.	.08	12
South New River.	.03	29
	Land Use	
Conservation area.	.04	8.6
Agricultural.	.04	25
Urban.	.05	13
Sewage-affected.	.12	10
Estuarine sites.	.24	12
Six-year average:		
All sites.	.10	13
Freshwater sites.	.06	14

Table 9.--Basic statistics for total recoverable trace-element concentrations in surface water for all sites

[Concentrations in micrograms per liter]

Constituent	Number of samples	Average	Standard deviation	Minimum	Maximum and range
Aluminum.	101	127	211	0	1,400
Arsenic.	314	10	13.7	0	200
Boron.	180	494	627	0	3,800
Chromium.	311	1.8	5.3	0	40
Copper.	319	7	9	0	50
Iron.	330	224	683	0	12,000
Lead.	333	8.1	10.6	0	80
Manganese.	335	15	14.9	0	140
Zinc.	333	1/41	931	0	17,000

1/ Value of 17,000 not included in average.

Table 10.—Average concentrations of total recoverable trace elements for each canal

[Concentrations in micrograms per liter]

Canal	Aluminum	Arsenic	Boron	Chromium	Copper	Iron	Lead	Manganese	Zinc
Hillsboro.	91	14	396	1.1	5.4	128	8.3	16	34
Pompano-Cypress.	76	8.7	341	.46	4.9	328	9.0	12	28
Middle River.	95	8.8	401	.75	5.4	150	5.8	9.3	46
Plantation Road.	157	9.7	616	2.7	9.6	232	14.0	9.4	1/49
North New River.	45	14	332	1.8	5.3	217	7.5	16	41
South New River.	71	9.1	257	1.7	5.3	289	8.0	15	36
Hollywood-Dania.	390	6.9	1,370	5.9	27.5	123	7.8	23	45
Six-year average.	127	10	494	1.8	7.0	224	8.1	15	1/41

1/ Value of 17,000 not included in average.

Sites affected directly by sewage effluent and seawater have greater average concentrations of trace elements than other areas (table 11). The estuarine sites are greater in all average trace-element concentrations, except for arsenic and iron, than other site groupings. Sewage-affected sites have relatively high average concentrations of aluminum, boron, chromium, copper, lead, and zinc.

No average concentrations at any site exceeded established criteria (U.S. Environmental Protection Agency, 1977) levels determined toxic to man (table 12). Average iron concentrations for some canals and site groupings exceeded criteria but are not considered toxic, only unesthetic. Throughout the county, iron concentrations are commonly high because of ferriferous lithology.

Pesticides

Pesticides (herbicides and insecticides) are used extensively in the agricultural and urban areas of Broward County. These materials are introduced to the canals in runoff and by direct application. Spraying of insecticides for control of mosquitos and other insects occurs throughout the year, as does application of herbicides for control of both terrestrial and aquatic weeds. The cumulative effects of pesticides in the canals have not been determined, although the deleterious effect of some, such as DDT, are recognized.

Between 1970-74, a total of 5,593 pesticide analyses were made on water samples from the Broward County canals. Pesticides in concentrations greater than 0.009 µg/L (micrograms per liter) were detected in 554 samples (9.9 percent). Table 13 lists the number of samples analyzed for each pesticide, samples in which pesticides were detected, and the maximum, median, and average concentrations for samples where detection occurred. Comparison of the greatest concentrations detected to the average and median values for samples containing pesticide residues, indicates that the high concentrations may reflect pesticide applications near the sampling site immediately prior to sampling. None of the water samples contained pesticide concentrations which exceeded recommended limits for public water supply (U.S. Environmental Protection Agency, 1977).

During the 5 years of sampling, 2,698 analyses were made for pesticides in the canal bottom sediments. Pesticides were detected in 1,028 of the sediment analyses (38 percent). The increased detection rate of pesticides in bottom sediments, compared to surface waters, indicates that pesticides tend to accumulate in bottom sediments, whereas pesticides in surface waters tend to be ephemeral. The maximum, median, and average concentrations for samples with detectable pesticides (table 14) in the bottom sediments are consistently greater than those in the surface water. The cumulative effects of pesticides in the bottom sediments may create long-range alterations in canal environment if bottom dwelling organisms are affected and bioaccumulation occurs because of pesticides entering the aquatic food chain.

Table 11.—Average concentrations of total recoverable trace elements for each site grouping

[Concentrations in micrograms per liter]

Site grouping	Aluminum	Arsenic	Boron	Chromium	Copper	Iron	Lead	Manganese	Zinc
Conservation areas.	87	13	359	1.2	4	237	6.6	14	33
Agricultural.	72	11	317	.68	5.7	190	7.3	16	49
Urban.	96	8.7	331	1.1	4.2	304	8.2	12	32
Sewage affected.	133	11	682	1.9	7.4	172	8.5	14	1/52
Estuarine.	236	8	763	3.7	16	190	9.6	19	41
Six-year average.	127	10	494	1.8	7.1	224	8.1	15	1/41

1/ Value of 17,000 not included in average.

Table 12.—U.S. Environmental Protection Agency (1977) permissible criteria for trace elements in surface water

[Concentrations in micrograms per liter]

Trace Element	Maximum concentration (not to exceed)	Purpose	Objection
Aluminum.	1,500	Fish propagation.	Toxic.
Arsenic.	100	Public supply.	Do.
Boron.	1/1,000	Irrigation.	Plant death.
Chromium.	50	Public supply.	Toxic.
Copper.	1,000	do.	Do.
Iron.	300	do.	Taste, stain and odor.
Lead.	50	do.	Toxic.
Manganese.	50	do.	Taste, stain.
Zinc.	5,000	do.	Taste.

1/ Not to exceed 750 for irrigation of citrus trees.

Table 13.—Statistics of pesticides and polychlorinated biphenyls in surface water

[Concentrations in micrograms per liter]

Common name	Number of samples	Number of detections	Percent of detections	Maximum	Median	Average
		Insecticides				
Aldrin.	317	1	0.3	0.01	0.01	0.01
Chlordane.	168	1	.6	1.0	1.0	1.0
DDD.	317	40	12.6	.06	.01	.01
DDE.	317	16	5.0	.02	.01	.01
DDT.	317	25	7.8	1.0	.01	.02
Dieldrin.	317	77	24.3	.11	.01	.02
Endrin.	317	1	.3	.01	.01	.01
Heptachlor.	317	0	0	—	—	—
Lindane.	317	20	6.3	.09	.01	.02
Toxaphene.	143	0	0	—	—	—
Diazinon.	232	37	15.9	.25	.02	.04
Ethion.	238	4	1.7	.01	.01	.01
Malathion.	240	2	.8	.11	—	.06
Methyl parathion.	239	3	1.3	.02	.01	.01
Methyl trithion.	206	1	.5	T	T	T
Parathion.	236	10	4.2	.22	.01	.08
Trithion.	232	2	.9	T	T	T
		Herbicides				
2,4-D.	317	145	46	18	.05	.18
2,4,5-T.	317	14	4.4	.47	.02	.09
Silvex.	317	145	46	6.0	.03	.12
Polychlorinated biphenyls.	172	10	5.8	1.6	.10	.43

T = <0.01

Table 14.—Statistics of pesticides and polychlorinated biphenyls in bottom sediments

[Concentrations in micrograms per liter]

Common name	Number of samples	Number of detections	Percent of detections	Maximum	Median	Average
		Insecticides				
Aldrin.	243	7	2.8	10	2.7	3.6
Chlordane.	179	119	66	5,000	17	114
DDD.	235	219	93	850	5	154
DDE.	229	213	93	1,400	3.8	31
DDT.	232	133	57	160	2.6	11.7
Dieldrin.	241	171	71	260	.9	6.2
Endrin.	236	2	.9	.9	.9	.9
Heptachlor.	231	0	0	—	—	--
Lindane.	231	0	0	—	—	--
Toxaphene.	44	2	4.5	60	52	52
Diazinon.	46	1	2.1	2.6	2.6	2.6
Ethion.	19	3	15.8	26	7.5	12.6
Malathion.	46	2	4.3	8	5.5	5.5
Methyl parathion.	44	1	2.3	1.8	1.8	1.8
Methyl trithion.	18	0	0	—	—	—
Parathion.	35	1	2.9	1.1	1.1	1.1
Trithion.	17	3	17.6	15	14	12.1
		Herbicides				
2,4-D.	67	6	8.9	2	1.1	1.1
2,4,5-T.	66	0	0	—	—	—
Silvex.	66	17	25.8	32	.9	6.6
Polychlorinated biphenyls.	173	128	74	43,000	1/15	1/81

1/ Value of 43,800 not included in calculation of average.

Herbicides

Weeds and other undesirable plant growths are controlled by herbicides. Silvex, 2,4-D, and 2,4,5-T are the most commonly-used herbicides in the area of investigation. Because these substances are relatively soluble in water, they are rapidly assimilated by living plant organisms. Consequently, concentrations are normally zero or very low in the canal water. Occasionally observed high concentrations are indicative of herbicide applications immediately prior to sampling.

Herbicide concentration data in Broward County for canal waters (Waller and others, 1975) were used to calculate the frequency or percent occurrence of 2,4-D, 2,4,5-T, and silvex in samples collected at 25 sampling sites. This was accomplished by dividing the number of times herbicides were detected at each site by the total number of analyses. Each analysis for a specific herbicide was considered an individual sampling event for this calculation. Site locations and percentage of surface water and bottom sediment samples containing herbicides are shown in figure 18. The greatest frequency of herbicide occurrence tends to be either in the heavily urbanized area or adjacent agricultural zone where herbicides are used extensively.

Herbicide contamination of Broward County canal waters was determined, and a rating system was prepared using a formula with percentage occurrence and numerical rank (table 15). The herbicide contamination rating is calculated as follows: the percentage herbicide occurrence at each of the sampling sites is assigned a numerical rank. This rank is based on increasing percentage occurrence of herbicides at the sites. Averaging the numerical rank designations for all sites on a particular canal produces the herbicide contamination rating for the canal. The rating is relative to other canals in Broward County and applies only to this area.

Plantation Road Canal, previously known to be heavily contaminated by numerous toxic materials (Russo, 1974) with a rating of 15.0 and the Hillsboro Canal with a rating of 17.0, have the greatest incidence of herbicide contamination in the canals surveyed. Rated at 13.0 and 12.5, respectively, the North New River and Pompano-Cypress Canals are succcessively the next most contaminated canals. The Davie Road and Snake Creek Canals have only one sampling site each, and the data are considered insufficient to rate the entire canal.

Land use appears to have some influence on herbicide contamination in both surface water and bottom sediment. The following table lists the percentage of herbicide occurrence in samples from surface water and bottom sediment for each site grouping:

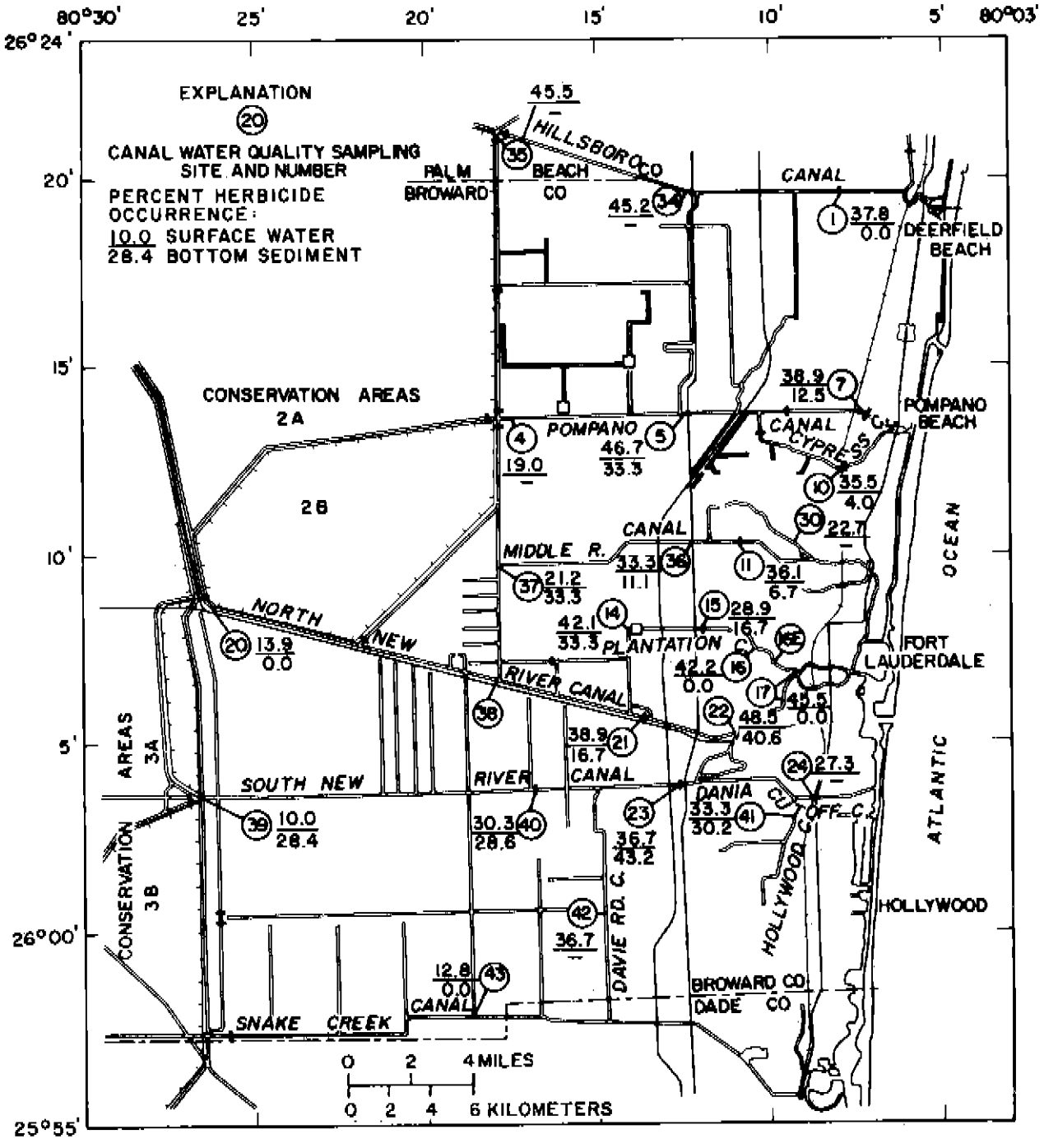

Figure 18.--Percentage of herbicide occurrence in surface water and bottom sediment.

Table 15.--Rating of herbicide contamination in surface water

Canal and site No.	Herbicide percent occurrence	Numerical rank of percent	Herbicide contamination rating[1/]
Hillsboro			
35	45.5	19	
34	45.2	18	17.0
1	37.8	14	
Pompano-Cypress			
4	19.0	4	
5	46.7	20	
7	38.9	15	12.5
10	35.5	11	
Middle River			
37	21.2	5	
36	33.3	10	
11	36.1	12	8.2
30	22.7	6	
North New River			
20	13.9	3	
38	38.9	15	13.0
21	48.5	21	
South New River			
39	10.0	1	
40	30.3	9	
23	36.7	13	8.0
24	27.3	7	
41	33.3	10	
Plantation Road			
14	42.1	16	
15	28.9	8	
16	42.2	17	15.0
17	45.5	19	
Davie Road			
42	36.7	13	13.0
Snake Creek			
43	12.8	2	2.0

1/ Average of numerical rank.

Site grouping	Percent of herbicide occurrence	
	Surface water	Bottom sediment
Conservation areas	20.4	15.4
Agricultural	36.3	19.8
Urban	35.1	12.7
Sewage affected	40.8	22.5
Estuarine	39.4	17.7

The conservation areas show the lowest herbicide contamination in surface water, while the remaining site groupings have approximately the same degree of contamination. The bottom sediments are most contaminated at the sewage-affected sites followed by the estuarine, agricultural, conservation areas, and the urban site groupings.

Bottom sediments collected at the sampling sites and analyzed for herbicides show that contamination exists in up to 44 percent of the bottom sediment samples (fig. 18). The Pompano-Cypress Canal was the most heavily contaminated, based on herbicide contamination ratings (table 16). The South New River Canal, Middle River Canal, and Plantation Road Canal rated successively lower in contamination. Although the Hillsboro Canal has the greatest percentage of herbicide detections in surface water (table 15), it has the lowest in bottom sediment detections. This may be caused by the reactivity of the sediment in the canal, infiltration through the canal bottom, flow displacing the bottom sediment into the tidal areas, or flushing of the herbicides before they come in contact with the bottom material.

Insecticides

Insecticides used extensively in Broward County are primarily chlorinated hydrocarbons and organophosphates. The most commonly detected chlorinated-hydrocarbon insecticides include the DDT family (DDT, DDE, and DDD), dieldrin, endrin, chlordane, and toxaphene; the organophosphates include parathion, malathion, and diazinon. These substances are relatively insoluble in water and are bound to the organic fraction of bottom sediments by ionic attraction, covalent bonding, absorption, and entrapment. Seldom are more than trace concentrations of these insecticides found in the surface waters.

Analytical data for insecticides present in surface water and bottom sediments (Waller and others, 1975) indicate relatively few detections in surface waters (table 13) and a greater incidence in the bottom sediments (table 14); the average and median concentrations of all insecticides detected are low. The greatest recorded values are probably the result of water samples being collected shortly after insecticide application. The percentage of samples which contained insecticides at each sampling site along the canals (fig. 19), indicates that greater amounts of these substances were detected in canals in the heavily urbanized areas than elsewhere.

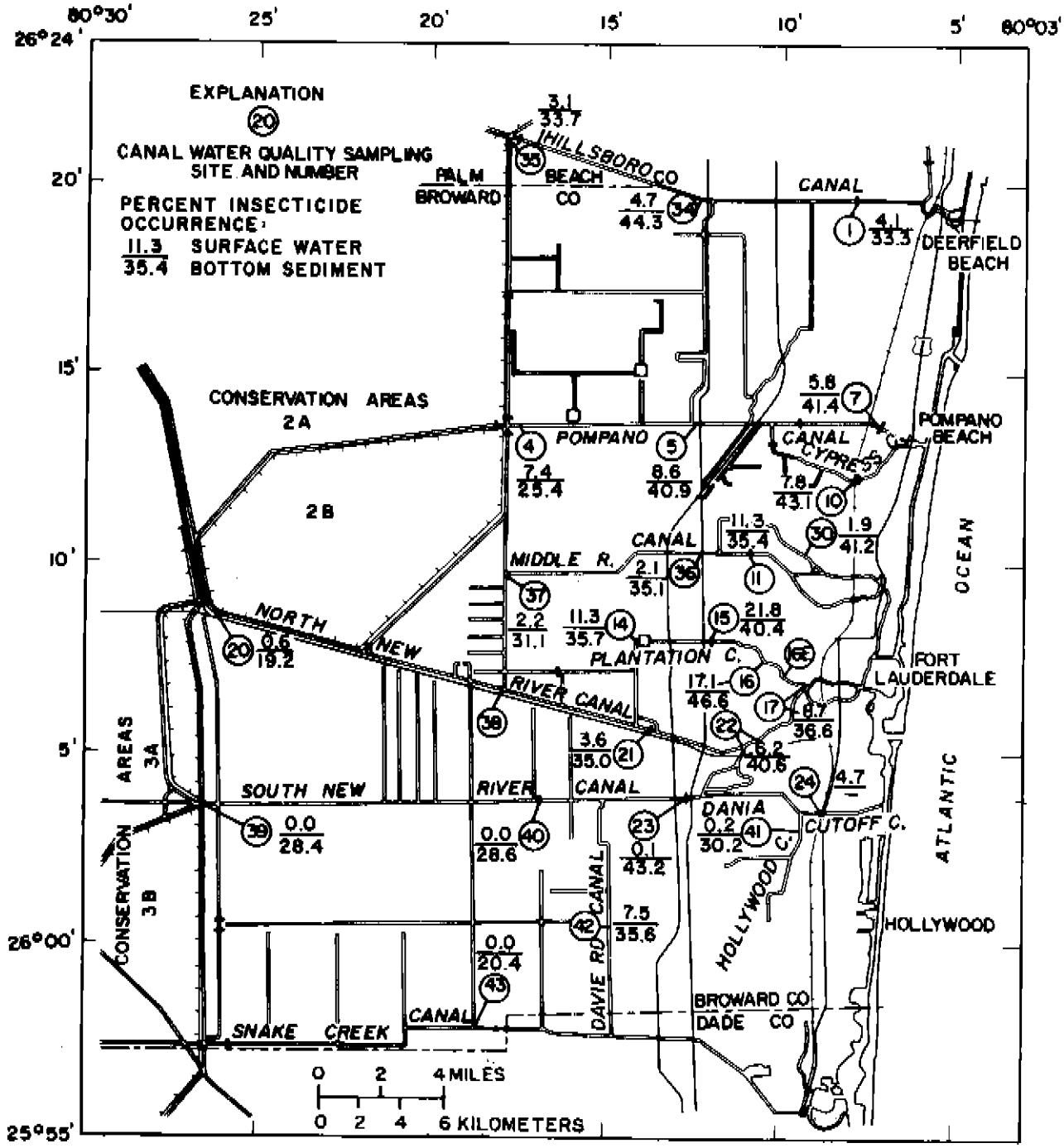

Figure 19.--Percentage of insecticide occurrence in surface water and bottom sediment.

Table 16.--Rating of herbicide contamination in bottom sediments

Canal and site No.	Herbicide percent occurrence	Numerical rank of percent	Herbicide contamination rating[1/]
Hillsboro			
35	--	--	
34	--	--	1.0
1	0	1	
Pompano-Cypress			
4	--	--	
5	33.3	7	
7	12.5	5	4.7
10	4.0	2	
Middle River			
37	33.3	7	
36	11.1	4	
11	6.7	3	3.8
30	0	1	
North New River			
20	0	1	
38	--	--	3.5
21	16.7	6	
South New River			
39	0	1	
40	44.4	8	
23	16.7	6	4.0
41	0	1	
Plantation Road			
14	33.3	7	
15	16.7	6	
16	0	1	3.8
17	0	1	
Davie Road			
42	--	--	--
Snake Creek			
43	0	1	1.0

1/ Average of numerical rank.

An insecticide contamination rating system identical to that used for herbicides was prepared to determine relative contamination (table 17) of the canals. Plantation Road Canal with a rating of 18.5 and Pompano-Cypress Canal with 13.8 had the greatest frequency of insecticide occurrence in surface water. Davie Road Canal with one sampling site was rated at 14.0.

In the Broward County canals, insecticides in bottom sediments were detected more frequently and in greater concentration than in the surface waters (fig. 19). Rating for insecticide contamination (table 18) indicates that sediments in the Plantation Road Canal have the greatest contamination. The next two most contaminated canals are the Pompano-Cypress and Hillsboro Canals. The previously noted chemical reactivity and low solubility of insecticides in water account for their tendency to accumulate in the bottom sediments. The accumulation of insecticides in canal bottom sediments may seriously affect conditions in the canals by bioaccumulation, even though insecticide concentrations and occurrence in the waters remain relatively low. The effects of such accumulation are not well defined, and recommended limits for insecticide concentrations in bottom sediments have not been established.

Land use generally has an effect on insecticide contamination in canal water. However, contamination of the bottom sediments in the canals by insecticides is ubiquitous and does not follow any patterns in terms of land use. The following table lists the percentage of occurrence of insecticides in surface water and bottom sediment for each site grouping.

Site grouping	Percent of insecticide occurrence	
	Surface water	Bottom sediment
Conservation areas	2.3	26.4
Agricultural	2.5	35.6
Urban	3.9	39.5
Sewage affected	12.1	37.6
Estuarine	7.4	37.8

The sewage-affected and estuarine sites show the greatest contamination from insecticides in surface water. The sites near the conservation areas show the least contamination in both surface water and bottom sediment.

Polychlorinated biphenyls (PCB), although not pesticides, are closely related to chlorinated-hydrocarbon pesticides and are thought to react similarly in the environment. They have a wide variety of industrial uses, primarily in plastic products and as a pesticide extender to increase toxicity. There are no established criteria for acceptable levels of PCB in water and bottom sediment, though recent concern has been raised over the increasing number of detections and their ubiquitous nature.

Table 17.—Rating of insecticide contamination in surface water

Canal and site No.	Insecticide percent occurrence	Numerical rank of percent	Insecticide contamination rating[1/]
Hillsboro			
35	3.1	7	
34	4.7	10	8.7
1	4.1	9	
Pompano-Cypress			
4	7.4	13	
5	8.6	16	
7	5.8	11	13.8
10	7.8	15	
Middle River			
37	2.2	6	
36	2.6	7	
11	11.3	18	9.0
30	1.9	5	
North New River			
20	0.6	4	
21	3.6	8	8.0
22	6.2	12	
South New River			
39	0	1	
40	0	1	
23	0.1	2	3.4
24	4.7	10	
41	0.2	3	
Plantation Road			
14	11.3	18	
15	21.8	20	
16	17.1	19	18.5
17	8.7	17	
Davie Road			
42	7.5	14	14.0
Snake Creek			
43	0	1	1.0

1/ Average of numerical rank.

Table 18.--Rating of insecticide contamination in bottom sediments

Canal and site No.	Insecticide percent occurrence	Numerical rank of percent	Insecticide contamination rating[1/]
Hillsboro			
35	33.7	9	
34	44.3	24	13.7
1	33.3	8	
Pompano-Cypress			
4	25.4	3	
5	40.9	19	
7	41.4	20	15.8
10	43.1	21	
Middle River			
37	31.1	7	
36	35.1	12	
11	34.4	13	12.5
30	41.2	18	
North New River			
20	19.2	1	
38	34.5	10	
21	35.0	11	9.8
22	40.6	17	
South New River			
39	28.4	4	
40	28.6	5	
23	43.2	22	9.3
41	30.2	6	
Plantation Road			
14	35.7	14	
15	40.4	16	
16	46.6	25	17.5
17	36.6	15	
Davie Road			
42	35.6	14	14.0
Snake Creek			
43	20.4	2	2.0

1/ Average of numerical rank.

Polychlorinated biphenyls were detected, primarily in the bottom sediment, in every Broward County canal. They are insoluble in water, and thus, rarely detected. During the investigation, only 10 water samples contained PCB, and of these, 5 were detected in North New River Canal and 3 in South New River Canal. Detections of PCB are more numerous in bottom sediments. The percentage detection in bottom material for each canal system is as follows:

Canal system	Percent of detection of PCB in bottom material
Hillsboro	52
Pompano-Cypress	83
Middle River	69
Plantation Road	95
North New River	81
South New River	69
Davie Road	71
Snake Creek	62

Sites at which detection occurred in more than 90 percent of the samples taken were either urban (7, 10, 22, and 23), affected by sewage discharge (11, 14, 16, and 17), or road runoff (20).

Concentrations of PCB in bottom sediment were variable. Most detections (88 percent) were less than 11 µg/kg (micrograms per kilogram), and 98 percent were less than 1,000 µg/kg. Four PCB detections were greater than 1,000 µg/kg. They are Middle River Canal at site 30 (1,500 µg/kg), Plantation Road Canal at site 14 (12,000 µg/kg), and North New River Canal at site 22 (1,100 and 43,800 µg/kg). The high concentration at site 22 was thought to be an anomalous, contaminated sample. Subsequent sampling at site 22 showed that this high concentration (43,800 µg/kg) was an anomaly and not characteristic of this area.

BACTERIOLOGICAL CHARACTERISTICS OF CANAL WATER

Most natural aquatic systems contain bacteria, some of which may be pathogenic. The most common way that pathogenic bacteria may enter the water is through discharge of domestic sewage into the waterway or from feedlot runoff. Certain nonpathogenic bacteria, coliforms, and fecal streptococci are used as indicators of pathogens. The numbers of these bacteria will indicate the degree of the contamination, and their ratios may indicate the source.

The bacterial counts determined are good indicators of the contamination level within the canals. Die-off rates or additional growth within the canal are not taken into consideration. These cell counts are used only as indicators of fecal contamination.

Coliform Bacteria

Coliform bacteria are the most commonly used indicators of domestic sewage and agricultural runoff entering a body of water. The coliform group of bacteria includes Escherichia coli, a variety of intermediary species from warm-blooded animals. Coliform bacteria include a variety of species occurring naturally in soils.

Because of the possibility of pathogens associated with coliforms, criteria have been established by the U.S. Environmental Protection Agency (1977) for permissible coliform levels when water is used for supply purposes or body contact. Total coliform counts should not exceed 20,000 cells/100 mL. When fecal coliforms exceed 200 cells/100 mL, there is greater than 90 percent chance of Salmonella contamination (Sykes and Skinner, 1971).

All but two sites (30 and 41) had at least one sample which exceeded total coliform criteria for geometric mean (table 19). Median cell counts are used as a better indication of the overall contamination in these canals. The median counts at two sites (15 and 16) on the Plantation Road Canal system exceed the U.S. Environmental Protection Agency (1977) criteria for geometric mean. Two other sites (14 and 42) have high median counts (13,000 and 11,000 cells/100 mL, respectively), although not exceeding criteria. These sites are all known to be directly affected by sewage discharge (fig. 5). The remaining sites have relatively low median total coliform levels, though they can fluctuate widely throughout the year.

At seven sites (14, 15, 16, 24, 38, 42, and 43), fecal coliform contamination from livestock, fowl, and human waste exceeded criteria in at least one sample. The median fecal coliform counts do not exceed the criteria for geometric mean. Greatest mean values were in the Plantation Road Canal system, lower reach of the South New River Canal, Hollywood Canal, and Davie Road Canal. The fecal contamination at these sites, except for the South New River Canal, can be traced to sewage effluent entering the canals. The high fecal coliform counts in the South New River Canal are probably from livestock waste and waterfowl excrement.

Fecal Streptococci

To further distinguish between the sources of fecal coliforms, the prevalence of fecal streptococci bacteria is determined. These bacteria are in greater numbers within the intestines of warm-blooded animals than in human intestines. The ratios of FC/FS (fecal coliform to fecal streptococci bacteria) indicate the source of fecal contamination. A ratio greater than 4.0 indicates definite contamination from human sources (Geldreich and Kenner, 1969). A ratio less than 0.7 indicates that the coliform bacteria are derived chiefly from wildlife, livestock, or poultry wastes. Ratios ranging between 0.7 and 4.0 are caused by mixed sources of fecal contamination.

Table 19.—Range and median concentrations of total and fecal coliform and fecal streptococci bacteria for all sites

[Concentrations in colonies per 100 milliliters]

Canal	Site[1]/	Total coliform		Fecal coliform		Fecal streptococci	
		Range	Median	Range	Median	Range	Median
Hillsboro	35	180 - 42,000	1,700	5 - 490	55	69 - 1,500	230
	34	160 - 77,000	3,800	15 - 440	70	94 - 1,700	170
	1	30 - 37,000	3,800	0 - 320	68	0 - 1,000	330
Pompano	4	120 - 51,000	2,500	5 - 360	50	8 - 530	15
	5	150 - 150,000	2,800	15 - 1,900	78	35 - 7,400	76
	7	490 - 40,000	6,600	10 - 900	75	30 - 2,800	98
Cypress	10	10 - 35,000	1,900	0 - 470	22	0 - 1,800	84
Middle River	37	160 - 30,000	2,100	1 - 110	26	0 - 8,500	40
	36	100 - 27,000	1,700	0 - 450	20	8 - 640	40
	11	140 - 40,000	3,700	0 - 160	50	4 - 450	70
Feeder	30	90 - 19,000	1,700	0 - 210	75	24 - 490	46
Plantation Road	14	1,000 - 1,200,000	13,000	0 - 26,000	300	40 - 400	130
	15	45 - 7,100,000	30,000	10 - 20,000	900	29 - 8,400	150
	16	1,700 - 930,000	41,000	40 - 7,300	760	54 - 2,100	600
	16E	3,100 - 170,000	5,600	50 - 720	310	36 - 1,000	300
	17	310 - 28,000	2,300	0 - 450	110	10 - 240	96
North New River	20	120 - 36,000	3,900	0 - 1,100	20	7 - 1,100	160
	38	100 - 70,000	1,900	4 - 4,100	44	0 - 300	42
	21	30 - 24,000	2,400	10 - 1,100	25	4 - 260	42
	22	170 - 26,000	3,200	0 - 1,000	70	4 - 370	130

1/ Site locations shown in figure 2.

Table 19.—Range and median concentrations of total and fecal coliform and fecal streptococci bacteria for all sites--Continued

[Concentrations in colonies per 100 milliliters]

Canal	Site[1]/	Total coliform		Fecal coliform		Fecal streptococci	
		Range	Median	Range	Median	Range	Median
South New River	39	110 - 20,000	1,300	0 - 1,000	36	10 - 3,800	66
	40	1,000 - 42,000	5,600	12 - 1,500	210	52 - 1,700	500
	23	260 - 53,000	4,000	32 - 900	150	0 - 760	160
Hollywood	41	140 - 16,000	2,100	10 - 1,900	160	0 - 1,200	60
Dania Cutoff	24	120 - 2,000,000	1,800	0 - 5,500	60	8 - 150	25
Davie Road	42	400 - 390,000	11,000	0 - 2,700	260	16 - 1,000	100
Snake Creek	43	60 - 22,000	1,300	0 - 2,400	18	0 - 950	30

1/ Site locations shown in figure 2.

There are no established water-quality criteria for fecal streptococci bacterial counts because they are used only as an indicator of the source of the contamination. Within the Broward County canal system, the greatest median fecal streptococci counts (equal to or exceeding 100 cells/100 mL) were along the Hillsboro and Plantation Road Canals, at two sites on the North New River (20 and 22) and South New River Canals (23 and 40), and at the Davie Road Canal (table 19).

The FC/FS ratios calculated for each site (fig. 20) indicate the variance in the sources of contamination and also the predominance of the sources. Sites 14, 15, 16, and 16E along the Plantation Road Canal and downstream estuarine area, two sites along the North New River Canal (38 and 22), the Hollywood Canal (41), and Davie Road Canal (42) are contaminated with human waste. The Hillsboro Canal (sites 35, 34, and 1), Cypress Canal (10), North New River Canal at S-34 (20), South New River Canal (39), and Snake Creek Canal (43) average ratios indicate little or no human fecal contamination. The remaining sites have mixed sources of fecal contamination.

CHANGES IN WATER QUALITY

Since the start of this monitoring program in 1968, numerous changes have occurred within the area of investigation. In recently developed sections of the county, secondary canals have been added, runoff characteristics have changed, and most importantly the quantity and chemical characteristics of sewage effluent have varied. All these factors influenced the water quality in the canals to a degree. Changes that have been made to improve the quality include advanced treatment of sewage and hookups to connect many sewage plants to a more efficient regional wastewater system.

Analysis of changes in the water quality caused by the above mentioned improvements was done by evaluating statistics over 2-year timespans. This method is thought to best determine and document any changes in the canals during the 6-year study.

A slight change was determined by comparing ion concentrations in wet and dry seasons (fig. 21). There was a slight increase in concentration of most ions during the dry season. This increase is due to a greater percentage of ground-water inflow to the canals, more evapotranspiration, and increased discharge from the conservation areas which have characteristically greater levels of dissolved solids.

Estuarine sites showed a seasonal variation in major-ion concentrations (table 20). During the dry season, this increase is attributed primarily to decreased surface-water discharge to the ocean.

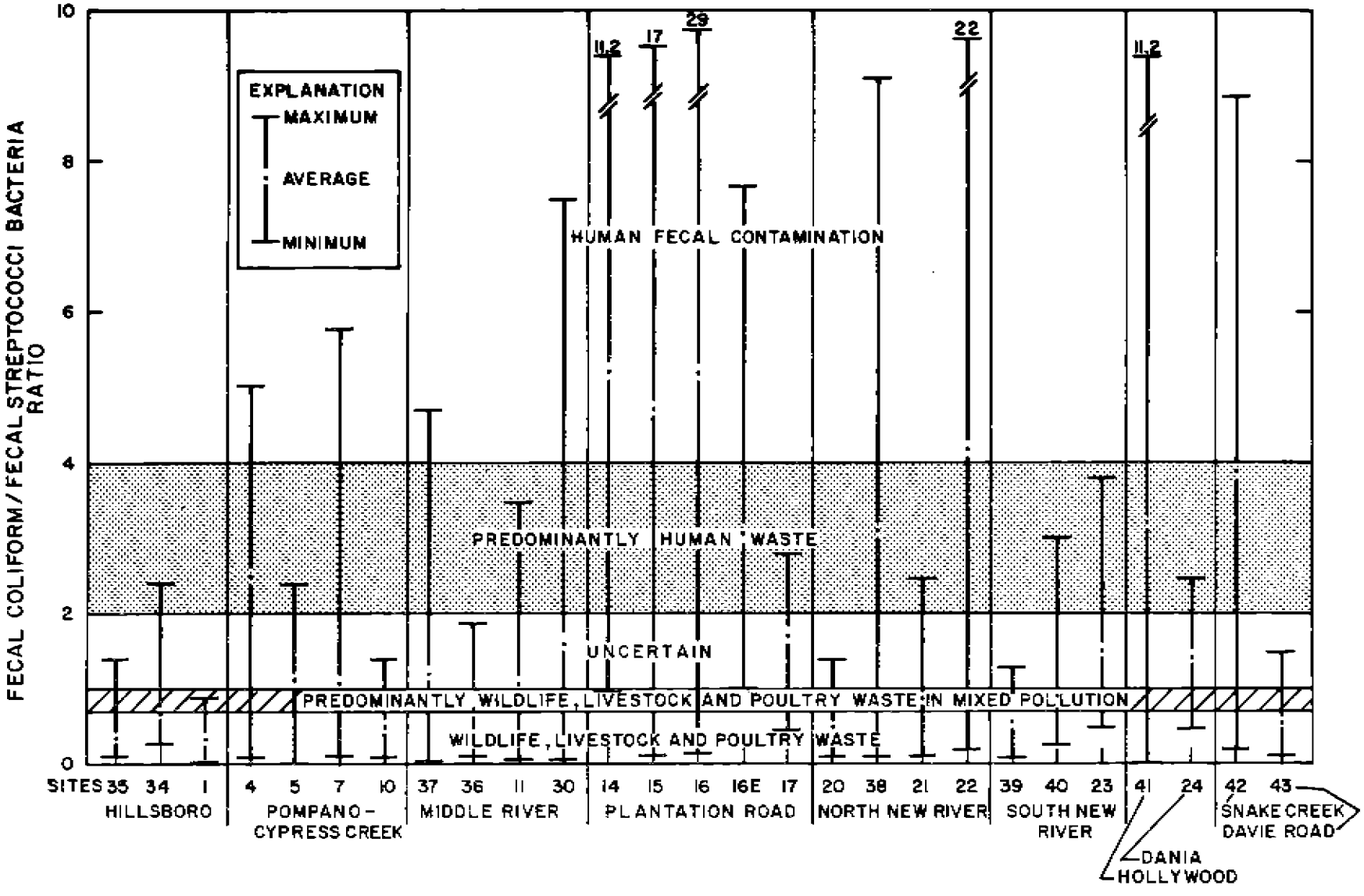

Figure 20.—Range and average ratios of fecal coliform to fecal streptococci bacteria for all sites.

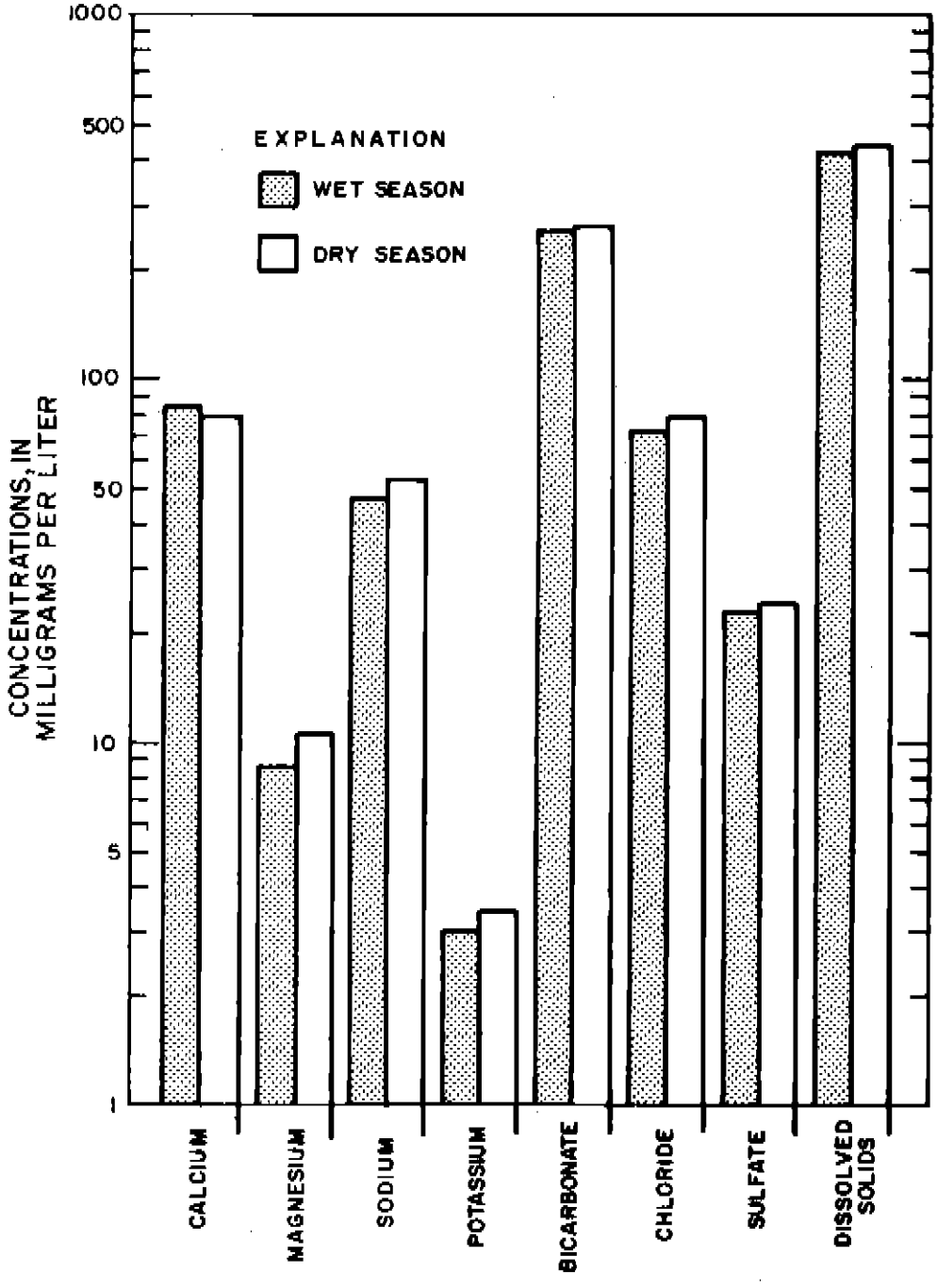

Figure 21.--Seasonal variation in selected major ion and dissolved-solid concentrations.

Table 20.--Seasonal variation in average concentrations of major ions, dissolved solids, and hardness for estuarine sites

[Concentrations in milligrams per liter]

Constituent	Number of samples	Wet season			Number of samples	Dry season		
		Maximum	Minimum	Average		Maximum	Minimum	Average
Calcium.	27	320	60	149	40	550	72	209
Magnesium.	27	900	2.5	185	40	1,200	2.6	382
Sodium.	27	8,200	20	1,720	40	10,000	24	3,360
Potassium.	27	280	1.6	65	40	440	1.4	129
Bicarbonate.	30	280	150	240	41	300	180	234
Chloride.	27	14,000	28	3,060	40	18,000	37	5,950
Sulfate.	27	3,200	2.4	798	40	8,700	1.6	1,650
Dissolved solids (sum of constituents).	27	25,800	230	5,910	40	32,500	290	10,600
Hardnesss.	27	4,500	160	1,110	40	5,900	190	2,100
Noncarbonate hardness.	27	4,300	10	921	40	5,800	9	1,900

Changes in macronutrient concentrations could not be determined between the first two 2-year periods (1969-70 vs. 1971-72). Comparison with the last 2-year grouping shows a definite reduction of nitrogen and phosphorus concentrations (fig. 22). Carbon concentrations did not fluctuate greatly during the 6-year study. The lower average levels of nitrogen and phosphorus are attributed to improvements in the treatment of sewage effluent and the decrease of sewage inflow.

Seasonal changes in macronutrient concentrations are slight, but noticeable for wet and dry seasons (fig. 23). Lower concentrations during the wet season occur because of increased flow, more chance for dilution, less chance of buildup in the canals, increased plant growth, and greater possibility of uptake by increased metabolic activity at greater temperatures.

Concentrations of trace elements, pesticides, oil and grease, and detergents showed no yearly or seasonal variations, although their levels did fluctuate widely (Waller and others, 1975). These compounds, which are toxic to man at given concentrations, are thought to be maintained at stable levels by biological uptake, microbial action, and chemical and physical reactions with the bottom sediment. These compounds are derived chiefly from urban and agricultural practices and are not related directly to season. Wide variations in concentrations occur when point sources of contamination are affecting the water quality in the canals.

Bacterial contamination in the canals is a concern because of the health hazards posed by pathogens that are associated with domestic sewage. Sources of this contamination are indicated by the FC/FS ratio. Since the time when this ratio was first calculated in 1972, there has been a noticeable decrease in the detection of human waste in the canals (Waller and others, 1975). Two noticeable exceptions to this overall decrease are at sites 4 on the Pompano Canal and 38 on the North New River Canal, which have shown an increase in FC/FS ratios, thus indicating human waste contamination.

CONCLUSIONS

Major ion concentrations vary between canals and seasonally, but annual averages generally remained constant between 1969 and 1974. The ionic character of most Broward County canals is mixed with a codominance of calcium bicarbonate and sodium chloride.

The primary sources of macronutrient compounds in Broward County canals are plant detritus, plants, nutrient laden runoff, and sewage effluent. Macronutrient concentrations generally decrease as water flows from the conservation areas to urban areas not affected by sewage. Phosphorus concentrations are an exception to this and increase as the water flows through agricultural and urban areas, probably as a result of fertilizer applications.

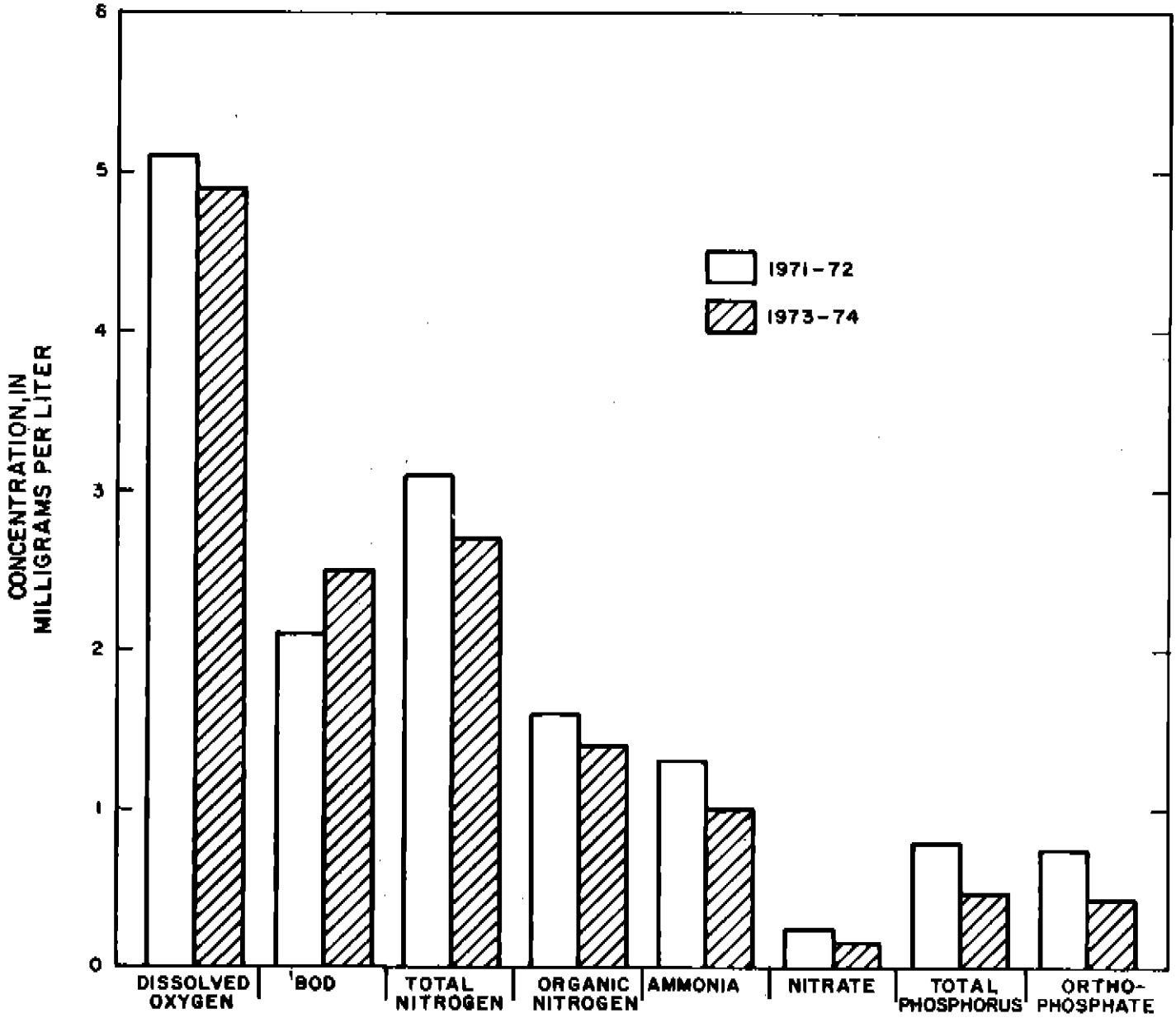

Figure 22.--Variation in concentration of selected constituents over two 2-year periods, 1971-72 and and 1973-74.

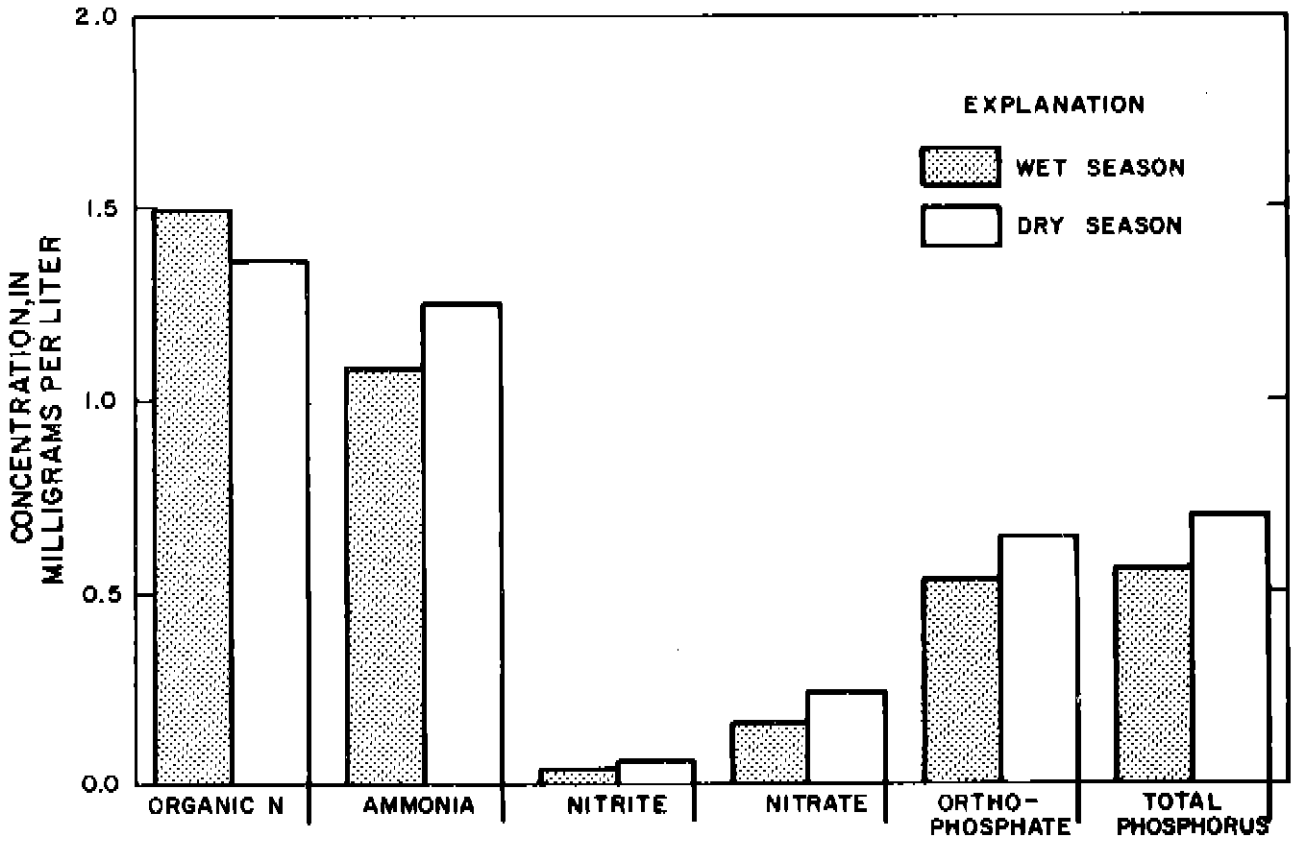

Figure 23.--Seasonal variation in concentration of nitrogen and phosphorus species.

Trace-element concentrations fluctuate widely but do not show any seasonal or temporal variations. Concentrations of these elements are generally low because of physical, chemical, and biological processes which tend to remove them from the water. Sites affected by sewage effluent and seawater have concentrations of trace elements greater than the countywide average.

The conservation areas have the lowest herbicide contamination in surface water, while the remaining site groupings have approximately the same degree of contamination. The bottom sediments are most contaminated at the sewage-affected sites followed by the estuarine, agricultural, conservation area, and urban site groupings. The Hillsboro Canal had the greatest percentage of detections of herbicides in surface water.

Insecticide concentrations and the frequency of detection in surface water and bottom sediments were greatest in the Plantation Road, Pompano-Cypress, and Hillsboro Canals. As a result of chemical reactivity and low solubility, chlorinated-hydrocarbon and organophosphate insecticides were detected more frequently and in greater concentrations in bottom sediments than in surface water.

The primary factor degrading water quality in the Broward County canal system is sewage effluent. In addition to parameters previously discussed, bacterial cell counts indicate that canals affected by sewage are most likely to contain pathogenic bacteria. The Plantation Road Canal generally exceeds total coliform criteria for recreational use. Contaminants associated with sewage effluent have decreased since 1972 probably because of better sewage-treatment facilities and the implementation of canal-flow augmentation procedures.

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