III. Freshwater Canals

A. Introduction

Broward County's current system of drainage consists of approximately two hundred and sixty-six miles of waterways (Broward County Planning Council 1989). The primary drainage system is managed by the South Florida Water Management District (SFWMD) and consists of nine major canals and their corresponding drainage basins (Figure III.1): Hillsboro Canal, C-14 (Cypress Creek) Canal, Pompano Canal, C-13 (Middle River) Canal, C-12 (Plantation) Canal, North New River Canal, C-11 (South New River) Canal, C-9 (Snake Creek) Canal, and the C-10 (Hollywood) Canal. These nine major canals, along with secondary and tertiary canals, eventually drain to the main estuarine areas (i.e., Intracoastal Waterway; see Section IV). The exception is the western segment of the C-11 Canal which is normally backpumped into the Water Conservation Area (WCAs). Overall, the canals are primarily used for flood control, however, secondary uses include drainage of land for development, discharge of excess water to and from the WCAs, prevention of saltwater intrusion, and recharge of wellfields (Cooper and Lane 1987). The result is a highly managed, intricate system of canals and retention ponds with control structures and pumps that maintain the balance between flood prevention and over drainage. The chemical characteristics of canals must be studied in order to understand possible 'downstream effects' on receiving water bodies (i.e., the Everglades and coastal systems).

While the canal system's primary function has been and continues to be conveyance, the waterways are currently considered waters of the state of Florida also known as Class III waters (see Florida Administrative Code [FAC] 62-302; State of Florida 1998). Class III waters are designated as being used for "recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife" (FAC 62-302.400). Despite habitat limitations, aquatic populations exist within the canals but the abundance and diversity of these organisms has rarely been quantified in Broward's urban waterways (but see Florida Game and Freshwater Fish Commission 1985). The canals are used by a relatively large group of recreational fishers. Largemouth bass, *Micropterus salmoides*, is a popular species of choice, as well as the recently introduced peacock bass, *Cichla ocellaris*, which has thrived in Miami-Dade and Broward Counties (http://www.state.fl.us/ gfc/fishing/Fishes). Thus, these waterways are being used in ways that differ from their primary function of drainage but are consistent to some extent with their regulatory classification. Understanding the chemistry of these canals is important in determining the water bodies' potential to support biological populations.

B. Objectives and Scope

Four major objectives constitute the framework for the study and include:

- Determine water quality conditions (long-term and current) at each freshwater canal sampling site;
- Determine compliance patterns with Broward County's Chapter 27 water quality standards (Broward County 2000);

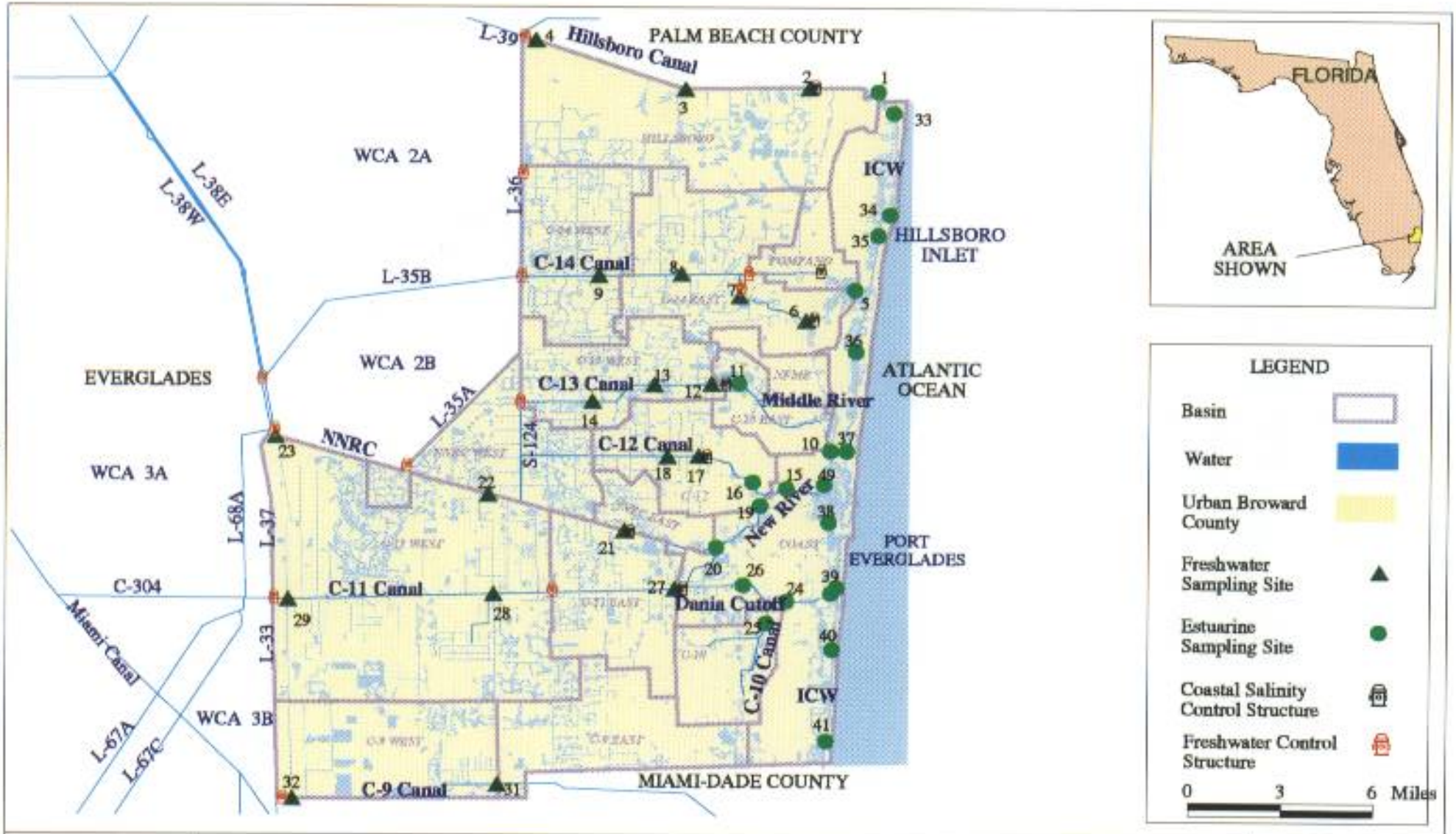


Figure III.1. Urban Broward County Drainage Basins and Major Waterways. Estuarine and freshwater ambient water quality sampling sites are also shown. Coastal salinity structures, as well as water control structures (operated by South Florida Water Management District) on freshwater canals are also displayed.

- Determine similarities and differences existing within each basin or region; and

- Formulate research questions, needs, and direction for better management of the entire Broward freshwater canal system.

At the core of this freshwater canal investigation is a three-part data analysis performed at each sampling site in a particular basin.

- An initial descriptive statistical analysis of all parameters and data collection years for each site;

- Graphical analyses of major parameters (dissolved oxygen, total phosphorus, total nitrogen, and fecal coliform) at each site; and

- Graphical and statistical analyses of major parameters collected during post-wastewater treatment plant discharge years with a focus on seasonal concentrations.

The descriptive analysis provides a historic snapshot of the total sampling effort at each particular site. Graphical analysis was performed to investigate inter- and intra- annual variation. Furthermore, graphical analyses was performed to better understand the influence of wastewater treatment plant (WWTP) discharges to surface waters to both the observed concentrations and water quality standard compliance. Finally, an attempt to discern seasonal differences was performed graphically and statistically for the years 1989 through 1997. This also allowed for better interpretation of overall water quality post-WWTPs, as well as integrating known dry, wet, and average rainfall years similar to modeling efforts of the Water Preserve Areas (WPA) Feasibility Study (http://www.evergladesplan.org /projects/wpa_main.htm). The WPA study is looking at the possibility of storing water in the western portions of developed south Florida for better management of water supply to Everglades Restoration and public water supplies.

C. Freshwater Regions

A majority of the nine drainage basins have freshwater canals that discharge eastward to estuarine sections through coastal salinity control structures depending on water elevations (Figure III.1). Estuaries are semi-enclosed water bodies with a free connection to the sea and a defined freshwater source (Comp and Seaman 1985). Some stretches of a similarly named water body may be considered the headwaters and the tailwaters of a control structure (Table III.1). Perhaps more importantly, certain canals (e.g., Hillsboro) have both freshwater and estuarine segments. The C-10 Canal is actually all within an estuarine system and will be discussed in Section IV. For this section, the freshwater segments are the primary focus with the exception of one C-13 Canal location (Site 11) which is immediately east of the control structure S-36 (Figure III.1).

Table III.1. Description of Headwaters and Tailwaters of Major Coastal Water Control Structures. Major structures are operated by the South Florida Water Management District. Primary information gathered from Cooper and Lane (1987).

MAJOR STRUCTURE	HEADWATERS (ALL FRESHWATER)	BASIN(S) (HEADWATERS)	TAILWATERS	BASIN(S) (TAILWATERS)	ESTUARINE CONNECTION(S)	BASIN(S)
G-56	Hillsboro Canal	Hillsboro	Hillsboro Canal (Estuarine)	Hillsboro; Coastal	Intracoastal Waterway (ICW)	Coastal
G-65	C-14 Canal	C-14 East	Pompano Canal (Freshwater)	Pompano	G-57	N/A
G-57	Pompano Canal	Pompano	Pompano Canal (Estuarine)	Pompano	C-14 Canal (Estuarine) to ICW	Coastal
S-37B	C-14 Canal	C-14 West, C-14 East	C-14 Canal (Cypress Creek; Freshwater)	C-14 East	S-37A	N/A
S-37A	C-14 Canal (Cypress Creek)	C-14 East	C-14 Canal (Estuarine)	C-14 East; Coastal	ICW	Coastal
S-36	C-13 Canal	C-13 West	C-13 Canal (Estuarine)	C-13 East	North and South Forks Middle River; ICW	C-13 East; North Fork Middle River; Coastal
S-33	C-12 Canal	C-12	North Fork New River (Estuarine)	C-12	New River (Main); ICW	Coastal
G-54 (Sewell Lock)	North New River Canal	North New River (East)	North New River Canal (Estuarine)	North New River (East)	South Fork New River; New River (Main); ICW	Coastal

MAJOR STRUCTURE	HEADWATERS (ALL FRESHWATER)	BASIN(S) (HEADWATERS)	TAILWATERS	BASIN(S) (TAILWATERS)	ESTUARINE CONNECTION(S)	BASIN(S)
S-13A	C-11 Canal*	C-11 West	C-11 Canal (Freshwater)	C-11 East	S-13	N/A
S-13	C-11 Canal	C-11 East	Dania Cut-off Canal	Coastal	ICW; South Fork New River **	Coastal
None***	N/A	N/A	N/A	N/A	C-10; Dania Cut-off Canal; ICW	C-10; Coastal
S-29****	C-9 Canal	C-9 East	Dumfoundling Bay (Miami-Dade County)	Coastal	ICW	Coastal

* C-11 Canal is distinctly divided into a western flowing segment and an eastern flowing section.

** The overall influence of the Dania Cut-off Canal on the South Fork of the New River is not known at this time.

*** The C-10 Canal is entirely an estuarine water body with, uniquely, no major headwaters.

**** S-29 is located in Miami-Dade County.

From Table III.1, the freshwater canal regions of the county can be broken down into the following eight major canals from north to south- Hillsboro, C-14, Pompano, C-13, C-12, North New River, C-11, and C-9. A long term data set does not exist for the Pompano Canal, thus, seven freshwater regions will be addressed in this report. The Pompano Canal Basin, located in northeastern Broward, is the smallest in the county with an area of just over seven miles square (mi^2, Cooper and Lane 1987). However, BCDPEP began monitoring the Pompano Canal at Dixie Highway in 1999, in part, to better understand the water quality of discharges to estuarine waters. Future reports will detail water characteristics of this basin.

D. General Hydrological Characteristics

Water management by the SFWMD, Broward County Office of Environmental Services (BCOES) and/or Independent Drainage Districts is often determined by rainfall, water elevations, and/or threat of tropical storms and hurricanes. Thus, flow volume and rate can be quite variable within the same canal system, as well as between adjacent canals. In essence, Broward's waterways represent a large, complex "outdoor plumbing" system designed to provide flood protection and drinking water aquifer recharge and to maintain groundwater elevations. Basin specific hydrological information primarily derived from Cooper and Lane (1987) will be presented with each of the seven canals.

Groundwater can also be an important inflow to the South Florida freshwater canals due primarily to the transmissive nature of the Biscayne Aquifer (Lietz 1999). Groundwater interaction with the canals is highly dependent on rainfall, tidal flow, and consumptive use patterns by the local population. Waterways can either be classified as "gaining" water from groundwater or "losing" it to groundwater (see Lietz 1999, his Figure 6). Thus, the interaction of surface waters and groundwater is an important factor in the operation of water control structures to protect public water supplies and water quality characteristics.

A highly variable average annual rainfall of almost fifty-three inches includes a wet season (June thru October) with average rainfalls of 35 inches and a dry season (November thru May) that experiences average rainfalls of 17.4 inches (McPherson and Halley 1997). These rainfall amounts coupled with a large area of impervious, urban land uses, make Broward's stormwater a major transport mechanism for land-based pollutants. Conveyance through secondary and tertiary canals adds to the complexity of understanding the fate of stormwater pollutants. The data in the current report is ambient water quality monitoring and not direct stormwater observations. Overall, the following results should be viewed as a 'snapshot' of how a water body's chemistry integrates stormwater inflows, groundwater interaction, as well as the biological and physical processes that occur in aquatic systems. However, BCDPEP's sampling strategy has focused on a specific calendar date regardless of previous climatic conditions. Some sampling dates may have had rainfall events within a period which would influence the water quality observations of that day. Due in part to the size of the database, an initial screening for sampling events during or after rainfall was not performed. Potentially, some of the outliers within the data are the result of sampling during or immediately after a storm event.

E. Hillsboro Canal

1. Basin and Canal Structure

Completed in 1914, the Hillsboro Canal drains an area of one hundred and two mi^2 (Cooper and Lane 1987). Forty mi^2 of this relatively large basin are located in northeastern Broward County and the remaining area (sixty-two mi^2) lies within the boundaries of southeastern Palm Beach County. The canal's headwaters are in Palm Beach County where the SFWMD's water control structure S-39 sits at the confluence of the L-39 and L-40 waterways (see Table III.1).

The L-39 is a conveyance canal that divides Water Conservation Areas (WCAs) 1 and 2 (Figure III.2). The L-40 flows along the eastern range of WCA 1 (primarily Arthur R. Marshall Loxahatchee Natural Wildlife Refuge) and the western populated portions of Palm Beach County. Water can also enter the Hillsboro Canal from the south via the L-36 through S-39A (Cooper and Lane 1987).

From the S-39, Hillsboro Canal water normally flows eastward to the SFWMD's water control structure G-56 (Cooper and Lane 1987). Water is discharged at the G-56 to the estuarine portion of the Hillsboro Canal and eventually reaches the Intracoastal Waterway (see Section IV). Major inflows to the Hillsboro Canal are from the Lake Worth Drainage District (Cooper and Lane 1987), in particular the E-1 Canal located at the State Road 7 (US 441) bridge. In addition, BCOES operates a system of secondary and tertiary canals which either withdraw from or discharge into the Hillsboro Canal (BCDNRP 1998).

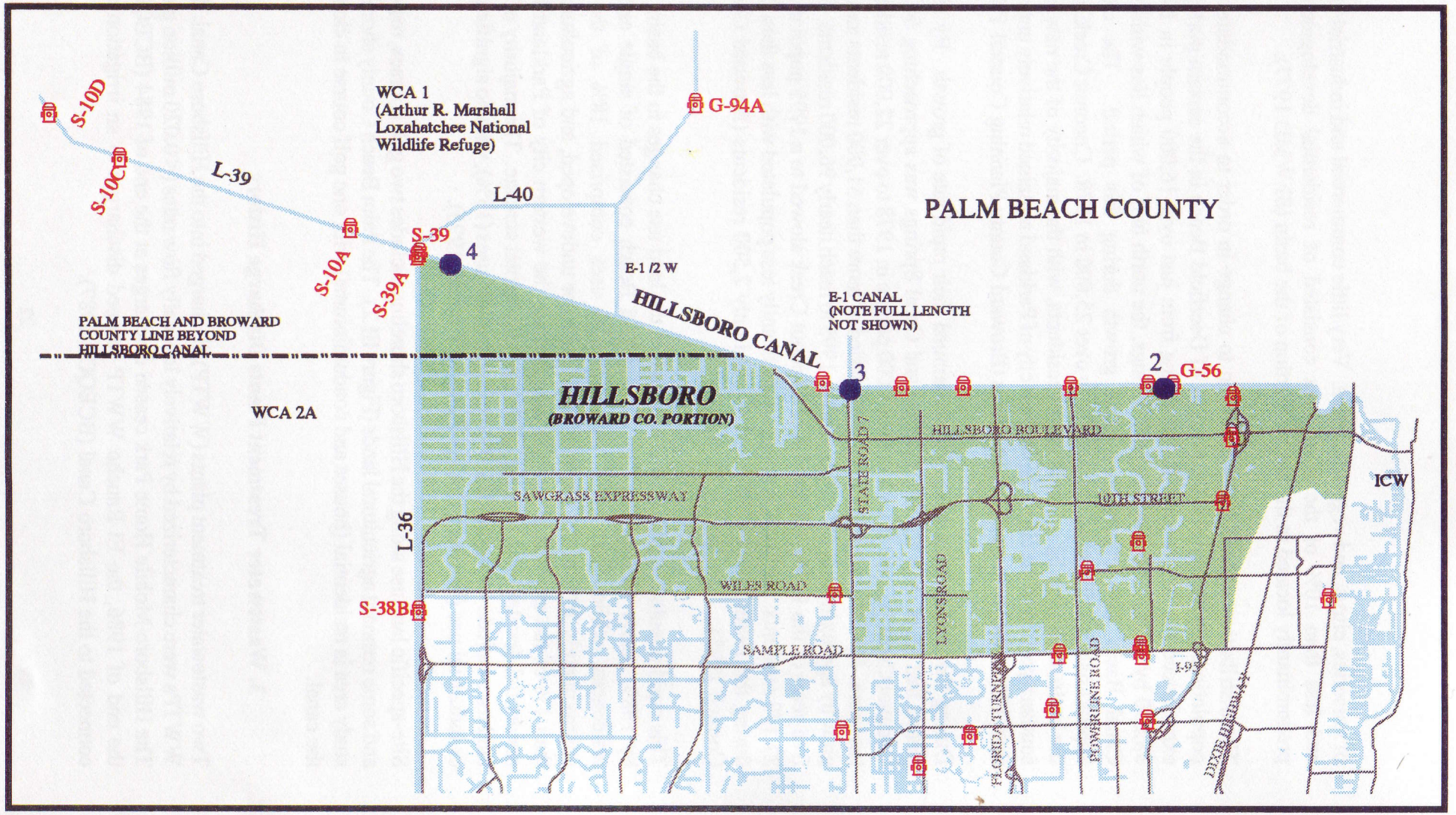
Despite the extensive canal network, drainage continues to be a problem in the southwestern portion of the basin. Because of this, the SFWMD stormwater regulations require retention of all stormwater runoff for 48 hours. Within the Hillsboro Basin's western areas, two independent drainage districts (North Springs Improvement District and Pine Tree Water Control District [WCD]) control water management activities. Broward County OES through its WCDs, including the dependent Cocomar WCD, regulate water flows and elevations in the basin's eastern range (see Section I, Figure I.4).

2. Municipalities and Land Uses

Within Broward County, the Hillsboro Canal Basin includes the cities of Hillsboro Beach, Parkland, Deerfield Beach, the northern half of Coconut Creek and approximately half of Coral Springs (see Section I, Figure I.3). The eastern portion of this basin was one of the earlier areas of the county to be developed. Deerfield Beach, located in the eastern half of the basin was incorporated in the early 1920s, around the same time as Oakland Park and Hollywood. It was not until the post-World War II population boom that the remainder of the cities in the basin were incorporated. Parkland and Coral Springs were incorporated in 1964 and Coconut Creek was incorporated three years later (Broward County Planning Council 1977).

In the mid-1970s, the major land use in the Hillsboro Canal Basin was agriculture which comprised approximately 42% of the basin. Improved pasture in the southwest portion of the basin defined almost

Figure III.2. The Hillsboro Canal Basin and Broward County (BCDPEP) Sampling Site Location Map. The Hillsboro Canal and other major waterbodies with corresponding South Florida Water Management District (SFWMD) water control structures (labeled) are depicted. Note water control structures without labels are secondary structures operated by other entities than the SFWMD. For example, unmarked structures along Hillsboro Canal are primarily operated by the Broward County Office of Environmental Services and are not on the main channel but are along the south bank.



This map is for informational purposes only. For further information, please contact BCDPEP Water Resources Division (954) 519-1270.

half of the agricultural land while the remaining agricultural uses consisted of nurseries, citrus, and vegetable farms. Very little commercial and industrial land use existed and less than 10% of the basin area consisted of residential development, which was predominantly located in the eastern portion of the basin (SFWMD 1977).

The distribution of land use soon began to change in order to accommodate the expanding population. By the late 1970s, the City of Deerfield Beach in the eastern portion of the basin experienced the largest growth, increasing from just over 16,000 people in 1970 to close to 38,000 by 1978. The City of Coral Springs, the north half of which lies within the Hillsboro Canal Basin, also experienced rapid growth during this period. The city grew from approximately 1,500 residents in 1970 to over 25,000 in 1978. Coconut Creek, in the center of the basin, also grew by a few thousand residents, with the majority of the new residents in the southern portion of the city. The western city of Parkland remained relatively unpopulated at less than 500 residents throughout the 1970s (Broward County Planning Council 1987).

During the 1980s, these same cities continued their rapid rate of growth. By 1987, Deerfield Beach had more than 45,000 residents and Coral Springs was approaching 64,000 residents. Coconut Creek jumped from less than 5,000 people in 1978 to over 22,000 residents in less than ten years. By 1995, Deerfield Beach consisted of more than 51,000 residents and Coral Springs grew by approximately 50% from 1987 to 1995 to reach nearly 96,000 residents. During the first five years of the 1990s, the growth of Coconut Creek slowed to a 1995 population of just over 27,149 residents. Parkland remained significantly less populated with less than 2,000 residents during the 1980s, and by 1995 had reached only 2,500 residents (Broward County Planning Council 1995).

This rapid population growth was reflected in the land use changes in the basin. For example, by 1989, nearly 60% of the City of Deerfield Beach consisted of single and multi-family residences, while commercial and industrial uses comprised 18% of the area. Only approximately 10% of the city remained vacant or undeveloped, and agriculture made up less than 1% of the city's land use. In comparison, the western city of Parkland had much less residential development totaling 23% of the city's total acreage. The majority of the remaining land uses include vacant land (60%) and agricultural uses (13%), with no significant commercial or industrial use (Broward County Planning Council 1995).

Site-specific land use along the Hillsboro shoreline includes two golf courses, residential homes, and some remnant agricultural lands (Figure III.2). The Palm Beach County shoreline within the study area is residential (houses and condominiums) with one golf course in close proximity to the canal.

3. Wastewater Treatment Plants Discharge History

Two wastewater treatment plants (WWTP) discharged into the Hillsboro Canal. However, both WWTPs were characterized by relatively low daily flow rates (< 0.020 million gallons per day). The Hillsboro Mobile Home Park ceased discharges at the end of 1984 (BCEQCB 1985). By the end of 1986, the El Rancho WWTP stopped discharges to an irrigation ditch that was connected to the Hillsboro Canal (BCEQCB 1987).

4. Other Influences on Water Quality

a. Soils

The soil types within the Hillsboro Canal Basin are varied (see Section I, Figure I.5). The western edge contains poorly drained, deep muck soils of the Everglades-Loxahatchee Association. The central area of the basin is predominantly poorly drained, sandy soils with underlying limestone. The eastern portion of the basin contains poorly drained, acidic sands, as well as areas of excessively drained sands near the coast. The soils in the eastern portion of the basin are only slightly limiting to construction which contributed to the earlier development of this area. The soils in the western half of the basin are severely limiting to development (Reynolds, Smith and Hills Inc., 1972). In order to prevent flooding of the development in the western portion of the basin, additional drainage or increased land elevation has been necessary.

b. Roadways

Three major north-south oriented roads cross the Hillsboro waterway (State Road 7, Florida Turnpike, and Powerline Road). Thus, stormwater outfalls directly associated with transportation are not as abundant relative to other Broward waterways. However, the Broward County's side of the Hillsboro Basin, is characterized by an abundance of outfalls that drain a variety of land uses (residential, commercial, and transportation). Information on the Palm Beach side was not obtained for this study. However, the E-1 Canal is immediately parallel to State Road 7 and potentially has runoff associated with this major roadway and its connections.

c. Septic Tanks

Most of the eastern half of the Hillsboro Basin is connected to public sewer systems based on a 1993 BCDPEP survey and subsequent Geographical Information System (GIS) Coverage (http://www.broward.org/moi00600.htm). However, Broward's western portion of the basin is characterized by several areas without public sewer service. This includes residential homes around State Road 7 to Lyons Road. The lack of public sewer service area can be used to infer septic tank coverage. Septic tank information for Palm Beach County was not determined for this study.

5. Sampling Locations

All water quality sampling sites are located in freshwater without tidal influence (Figure III.2). Global Position System coordinates and specific site descriptions are given in Appendix 1. Site 2 is located immediately west (~100 feet) of the G-56 and represents the final discharge point into the brackish regions of the canal. Located at the State Road 7 bridge, Site 3 is the central most site. Site 4 is in Palm Beach County at the bridge to Southeast Growers' Association and is immediately east of the S-39 control structure. Site 4 primarily represents water quality discharged to the Hillsboro Canal from the L-39 and L-40. Table III.2 describes the years of collection for each parameter at each site.

Table III.2. Sampling Years for Specific Parameters at the Hillsboro Canal Locations. A sampling year had at least one sample event during that year. Note the biochemical demand was a five-day test from 1973 until 1981 when a seven-day test was implemented until 1993 after which sampling for the parameter ceased at BCDPEP.

Parameter	**Site 2**	**Site 3**	**Site 4**
Temperature	73-97	73-97	73,74, 78-97
pH	73-97	73-97	73,74, 78-97
Specific Conductance	81-97	81-97	81-97
Dissolved Oxygen	73-97	73-97	73,74, 78-97
Biochemical Oxygen Demand	73-93	73-93	73,74, 78-93
Total Organic Carbon	81-97	81-97	81-97
Turbidity	75-97	75-97	78-97
Total Phosphorus	74-97	74-97	78-97
Ammonia-Nitrogen	81-97	81-97	81-97
Nitrite+Nitrate-Nitrogen	81-97	81-97	81-97
Total Kjeldahl Nitrogen	81-97	81-97	81-97
Fecal Coliform	73-97	73-97	73,74, 78-97
Total Coliform	73-97	73-97	73,74, 78-97
Fecal Streptoccocus	76-97	76-97	78-97

6. Results

a. Physical Characteristics

Average water temperatures were relatively similar among all three sites (Table III.3) ranging from 25.1 ± 3.6 degrees Celsius (ºC, Site 2) to 25.4 ± 3.9ºC (Site 4). The overall range was 15.0 to 33.8ºC throughout the canal. The canal's pH levels were also similar between all sites and showed little variability (Table III.3). Means and medians were at or near 7.5 at all three sites. Over twenty-five years, the lowest mean Hillsboro Canal pH value was 6.6 (Site 2 and 4) and the maximum was 8.6 (Site 4).

Specific conductance values generally decreased from west (Site 4) to east (Site 2, Table III.3). For example, Site 4 mean specific conductance was 898 ± 262 Fmhos/cm compared to 766 ± 190 Fmhos/cm and 712 ± 142 Fmhos/cm at Sites 3 and 2, respectively.

Table III.3. Descriptive Statistics for Temperature (Temp; °C= degrees Celsius), pH, and Specific Conductance (Cond; Fmhos = micromhos/centimeter @ 25 °C) in the Hillsboro Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. Number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
2	Temp	°C	362	26.0	25.2	3.5	32.0	15.0	0
3	Temp	°C	157	26.0	25.1	3.6	31.8	16.0	0
4	Temp	°C	107	26.5	25.4	3.9	33.8	15.0	0
2	pH	units	366	7.4	7.5	0.3	8.5	6.6	0
3	pH	units	158	7.4	7.5	0.3	8.4	6.8	0
4	pH	units	108	7.5	7.5	0.3	8.6	6.6	0
2	Cond	Fmhos	284	710	712	142	1360	290	0
3	Cond	Fmhos	67	739	767	190	1260	210	0
4	Cond	Fmhos	67	956	898	262	1460	336	0

b. Total Organic Carbon and Turbidity

All three sites were characterized by total organic carbon (TOC) concentrations above 20.0 mg/l (Table III.4). Site 4 had the highest mean and median TOC content and values decreased as moving east which is downstream based on normal flow patterns (Cooper and Lane 1987). However, Site 2 did have the maximum value (71.8 mg/l) observed in the canal.

Turbidity levels were relatively similar throughout the basin and normally within compliance of the water quality standard of 10.0 nephelometric turbidity units (ntus, Broward County 2000, Table III.4). In fact, mean and median values never exceeded 3.0 ntus at any of the sites. An anomalous maximum value (52 ntus) was observed at Site 2.

Table III.4. Descriptive Statistics for Total Organic Carbon (TOC) Concentrations and Turbidity (Turb) Levels in the Hillsboro Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
2	TOC	mg/l	257	22.80	24.17	6.89	71.80	13.20	0
3	TOC	mg/l	61	25.50	26.53	6.94	43.70	13.10	0
4	TOC	mg/l	61	28.70	29.66	8.68	60.60	7.00	0
2	Turb	ntu	342	1.7	2.4	3.7	52.0	0.6	0
3	Turb	ntu	130	1.7	1.9	0.9	5.8	0.6	0
4	Turb	ntu	91	1.5	1.9	1.0	6.1	0.7	0

c. Dissolved Oxygen and Biochemical Oxygen Demand

Site 2 exhibited the highest mean and median dissolved oxygen values for the entire period (1973-1997, Table III.5). Sites 3 and 4 had relatively similar mean and median dissolved oxygen (DO) concentrations that were typically out of compliance with (i.e., below) the standard (single sample) of 4.0 mg/l. Conversely, mean and median biochemical oxygen demand (BOD) values were at or below 2.5 mg/l at all three sites which is half of the 5.0 mg/l standard (i.e., within compliance; Table III.5).

Table III.5. Descriptive Statistics for Dissolved Oxygen (DO) and Biochemical Oxygen Demand Concentrations (BOD) in the Hillsboro Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculations. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
2	DO	mg/l	363	4.3	4.3	1.9	11.5	0.025	1
3	DO	mg/l	157	2.5	2.8	1.8	8.5	0.025	3
4	DO	mg/l	107	2.5	2.9	2.1	7.4	0.025	2
2	BOD	mg/l	340	2.0	2.5	2.8	46.5	0.2	0
3	BOD	mg/l	130	2.0	2.0	0.7	4.0	0.9	0
4	BOD	mg/l	82	2.3	2.4	0.9	6.0	0.9	0

Yearly averages (Figure III.3) had similar compliance characteristics as means calculated for the whole study period (Table III.5). Mean dissolved oxygen content at Sites 3 and 4 were normally below the single sample dissolved oxygen standard (4.0 mg/l) while Site 2's annual averages were above the standard most of the sampling period. Clear long term trends were not evident but annual variability was occasionally high at all sites.

To better understand compliance patterns within the canal, each DO reading was given a rating based on Broward County's water quality standards. DO concentrations were designated as poor (below the single sample standard; 4.0 mg/l), fair (above the single sample standard but below the daily average standard of 5.0 mg/l), and good (above both standards, Figure III.4). In addition, the changes over time are presented with special reference to the closing of WWTPs within the basin (see Section III.E.3).

Some improvements were observed after WWTP discharges ceased but DO levels still rated poor around 60.0% of the time at Sites 3 and 4 (1987-1997, Figure III.4). In addition, the percentage of good samples at Sites 3 and 4 never exceeded 30.0%. While Site 2 exhibited the canal's highest compliance levels, over one third (38.6%) of DO readings between 1987-1997 rated poor.

Seasonal influences on DO concentrations were investigated by pooling wet (June through October) and dry (November through May) season samples from 1989-1997 (Figure III.5). This era represents

Figure III.3. Annual Mean Dissolved Oxygen (DO) Content Within the Hillsboro Canal Basin from 1973 to 1997. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county environmental regulations, DO levels should be above the Broward County standard (4.0 mg/l) indicated by the dashed line.

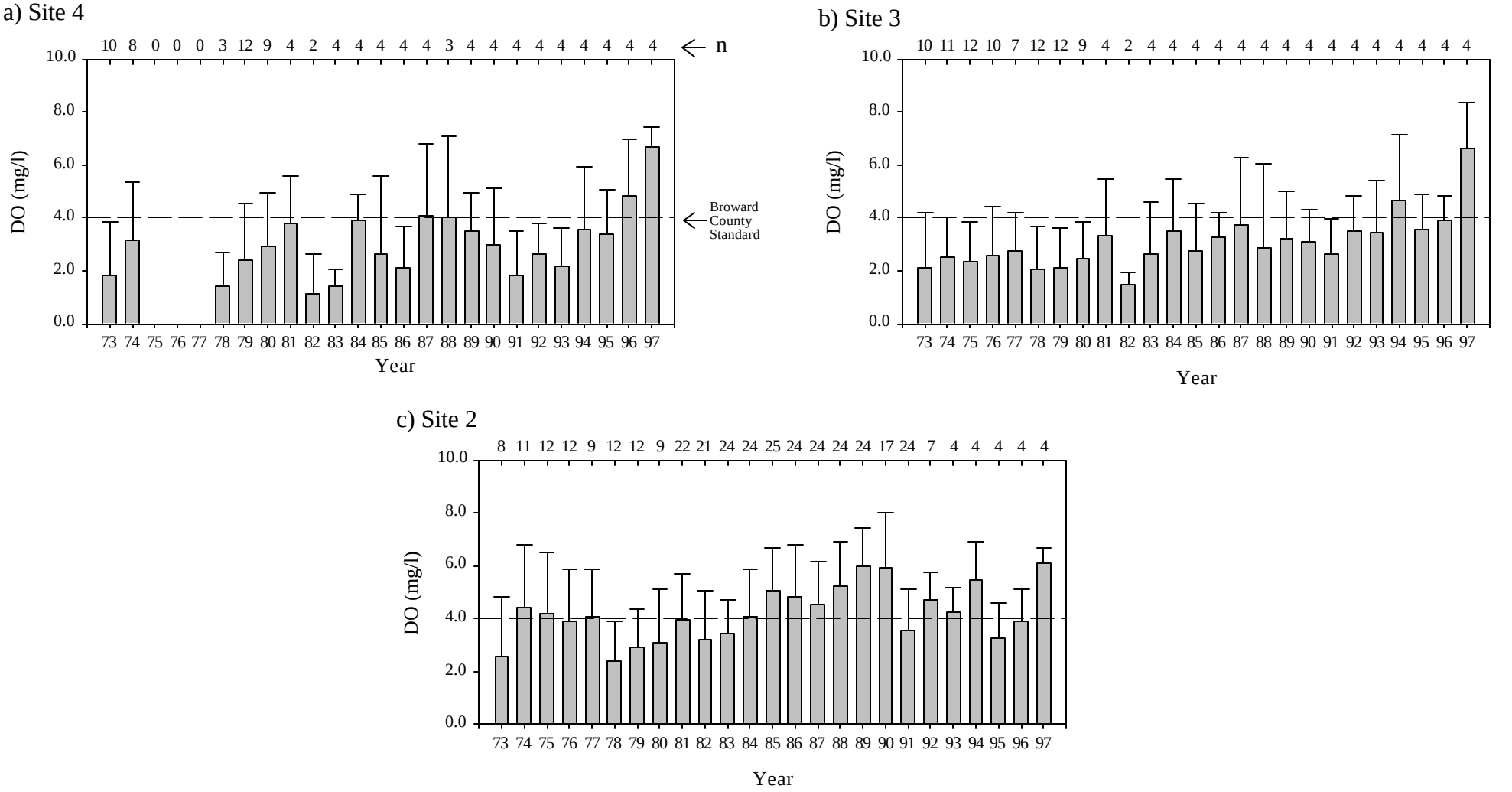


Figure III.4. Dissolved Oxygen (DO) Concentrations Observed in the Hillsboro Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall be below 4.0 mg/l. Thus, all concentrations greater than or equal to 5.0 mg/l are classified as good and DO concentrations between 4.0 to 4.9 mg/l are considered fair. Readings below 4.0 mg/l are defined as poor.

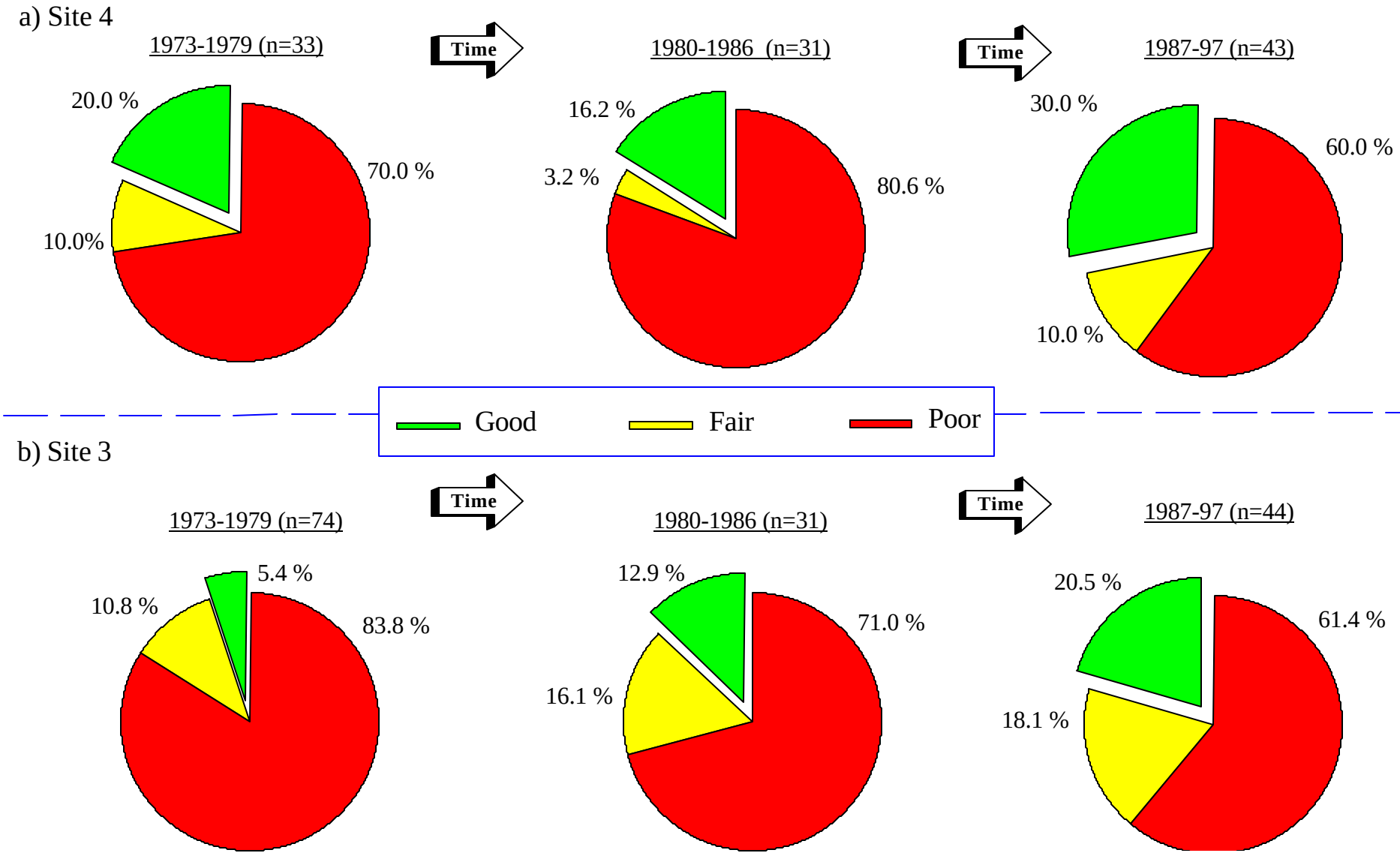


Figure III.4 (Cont.). Dissolved Oxygen (DO) Concentrations Observed in the Hillsboro Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall be below 4.0 mg/l. Thus, all concentrations greater than or equal to 5.0 mg/l are classified as good and DO concentrations between 4.0 to 4.9 mg/l are considered fair. Readings below 4.0 mg/l are defined as poor.

c) Site 2

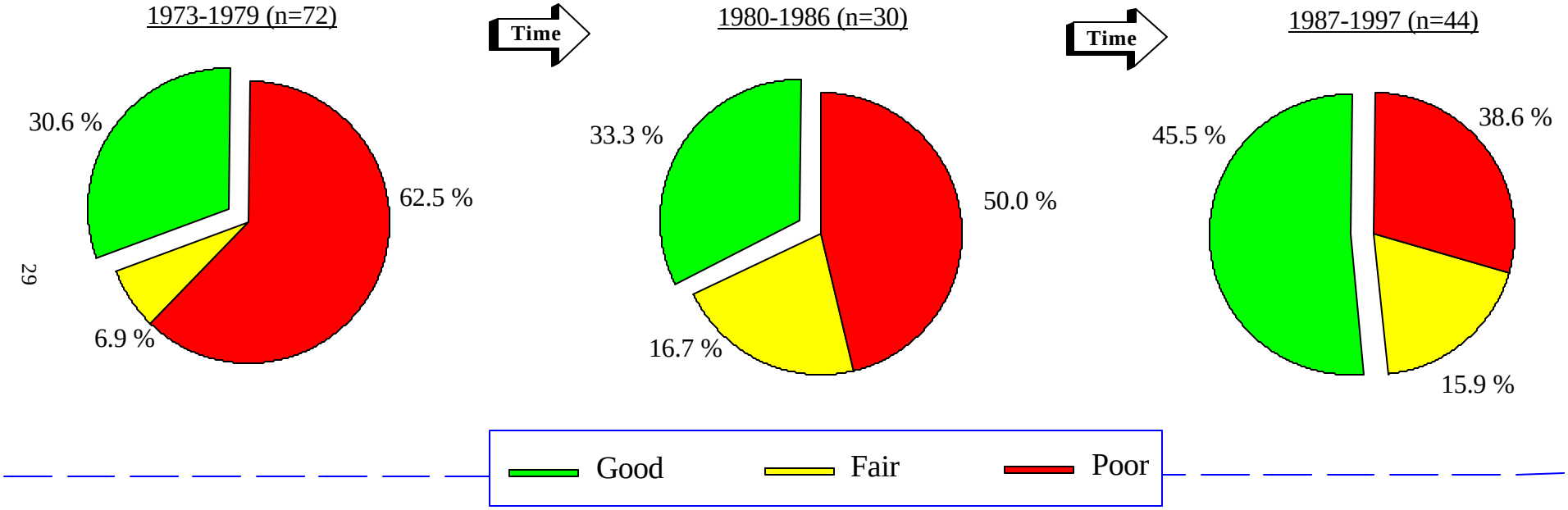
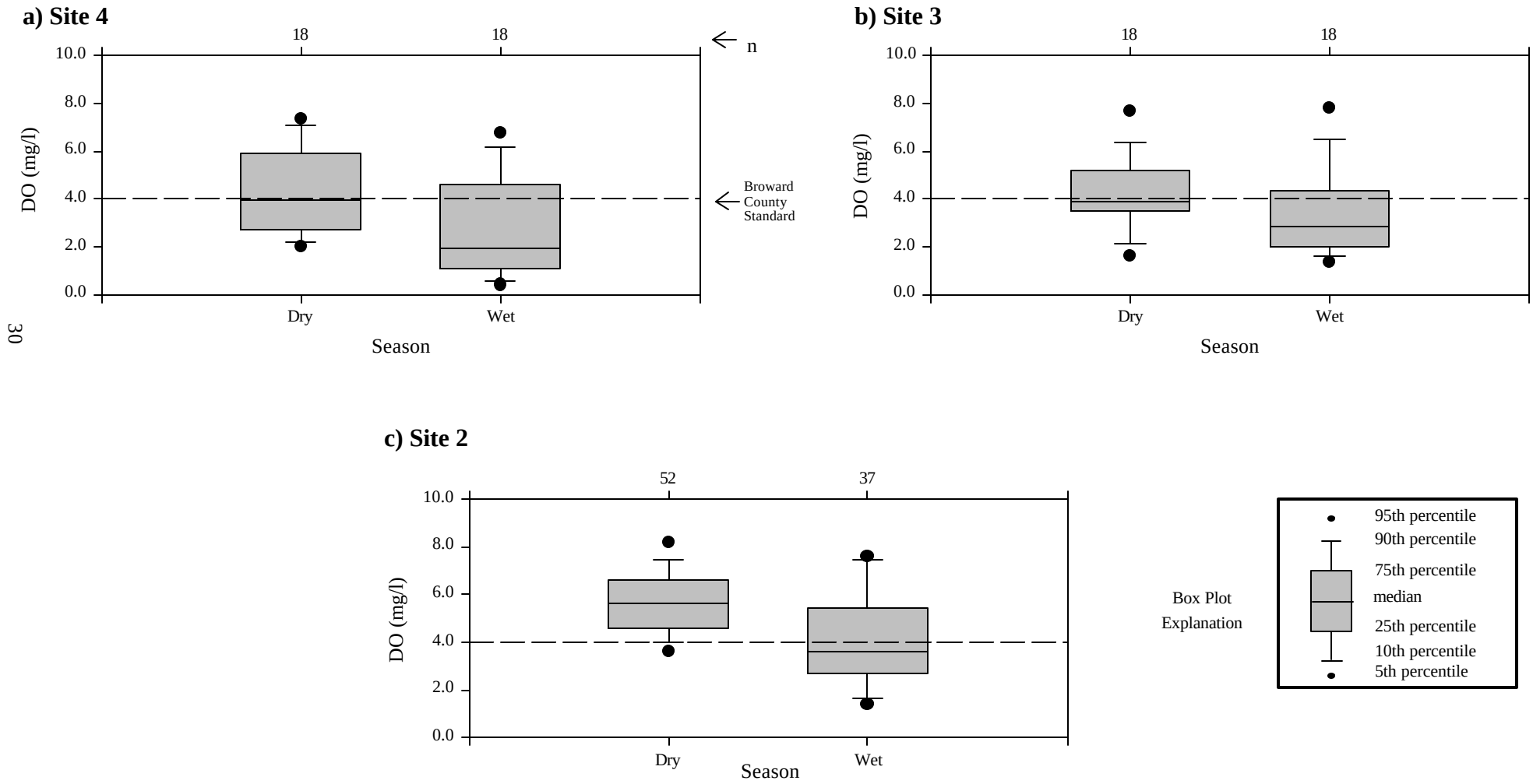


Figure III.5. Hillsboro Canal Basin Dissolved Oxygen (DO) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season means were observed at Sites 2 and 4 ($p < 0.001$ and 0.050, respectively; t-test) but not Site 3.



the period without direct WWTP influence throughout the county. Higher dissolved oxygen values were normally observed during the dry season then during the wet season at all sites (Figure III.5). Statistically significant seasonal differences were observed at Site 2 (t-test, $p < 0.001$) and Site 4 (t-test, $p < 0.05$) but not Site 3. The power of the performed tests at Sites 2, 3, and 4 was 0.995, 0.156, and 0.488, respectively. Thus, power values at Sites 3 and 4 were below the desired power of 0.800 and results should be viewed cautiously.

d. Total Phosphorus

All three sites exhibited twenty-four year (1974-1997) mean total phosphorus (TP) levels above the Broward County freshwater standard of 0.020 mg/l (Table III.6). In particular, mean TP levels at Sites 2 and 3 were almost eight times the standard. Variability around the mean was relatively high at all sites. However, the twenty-four year median TP values were also enhanced at Sites 2 and 3 (0.116 mg/l and 0.092 mg/l, respectively). Notably, relatively few samples within the entire waterway were below the method detection limit.

Table III.6. Descriptive Statistics for Total Phosphorus (TP) Concentrations in the Hillsboro Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculations. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
2	TP	mg/l	343	0.116	0.155	0.204	2.520	0.010	11
3	TP	mg/l	134	0.092	0.155	0.350	3.690	0.010	10
4	TP	mg/l	87	0.041	0.071	0.170	1.580	0.010	14

Enhanced TP levels were observed annually in the central and eastern portions of the basin (Sites 2 and 3) and to a lesser extent at the western Site 4 (Figure III.6). Sites 2 and 3 TP concentrations were characterized by a slight cyclic pattern of three to six years. In addition, extremely high and variable TP values at Sites 2 and 3 occurred before 1984, however, TP content after 1984 still greatly exceeded the freshwater standard (0.020 mg/l). At Site 4, annual mean values before 1989 only exceeded 0.060 mg/l (3 times the standard) once (1981) but from 1989-1997 this occurred five times (Figure III.6).

To further investigate compliance patterns within the canal, all individual samples were rated in terms of Broward County's TP standard (0.020 mg/l). Total phosphorus concentrations were designated poor if they were three times the Broward County freshwater standard (0.060 mg/l). A fair designation was given for values between 0.021 and 0.059 mg/l and a good rating was defined as TP content equal to or less than 0.020 mg/l. In addition, changes over time are presented with special reference to the closing of WWTPs within the basin (see section III.E.3).

For all sampling events, compliance levels with the Broward County freshwater TP standard (0.020 mg/l) were typically low, especially at Sites 2 and 3 (Figure III.7). Interestingly, all sites had the highest

Figure III.6. Annual Mean Total Phosphorus (TP) Levels Within the Hillsboro Canal Basin from 1974 to 1997. Means and standard deviations (error bars) calculated from biweekly, monthly, and/or quarterly samples with the number of samples (n) noted on the upper x-axis. The Broward County single sample standard (0.020 mg/l) is indicated by the dashed line. Numbers in parentheses represent standard deviation outside range of graph. Note difference in y-axis scale compared to TP values in other basins.

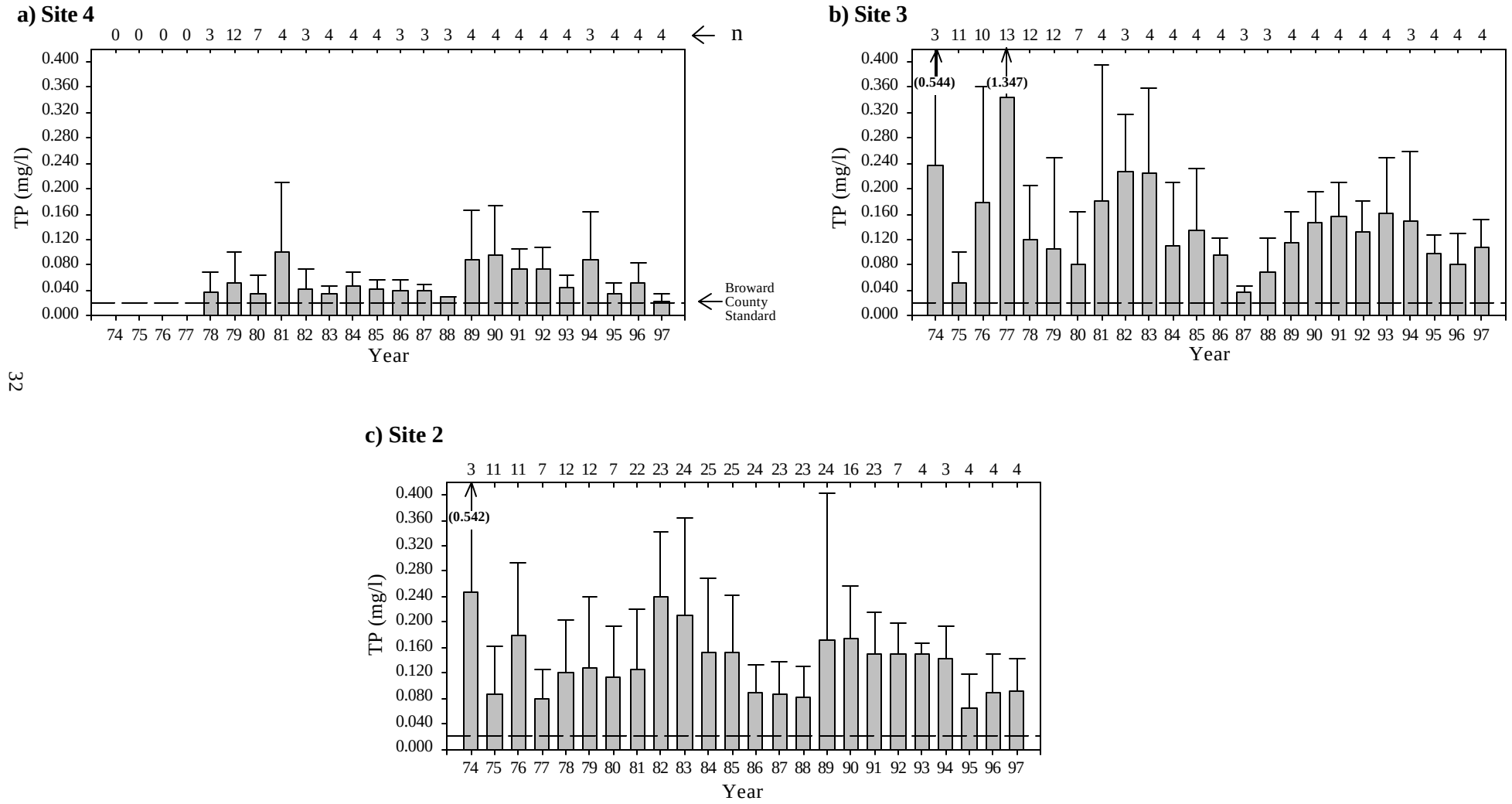


Figure III.7. Total Phosphorus (TP) Concentrations Observed in the Hillsboro Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County freshwater TP standard of 0.020 mg/l. The percentage of samples below 0.020 mg/l are classified as good. A fair rating was given to concentrations between 0.021 mg/l to 0.060 mg/l. Values equal to or greater than three times the standard (i.e., 0.060 mg/l) are classified as poor.

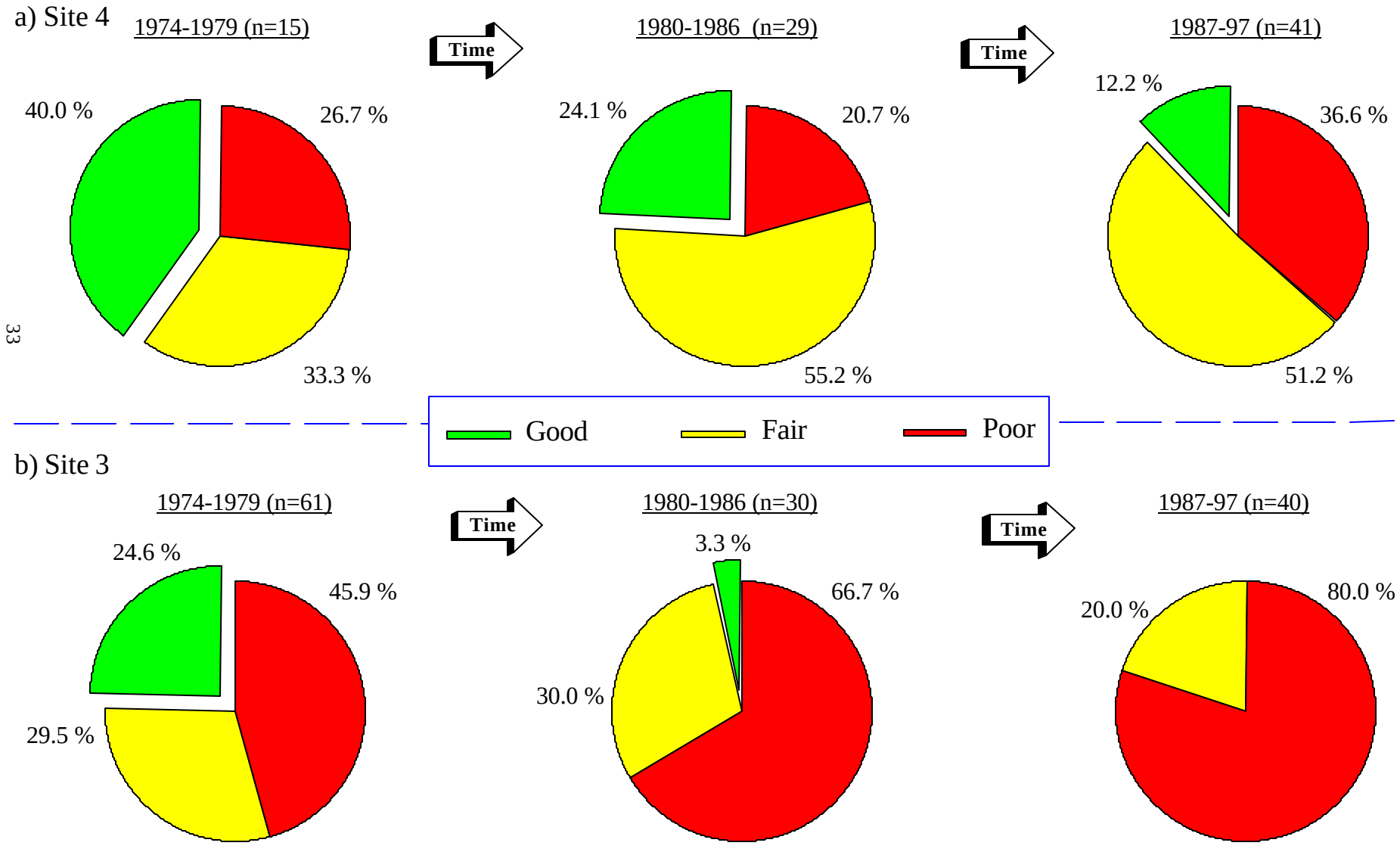
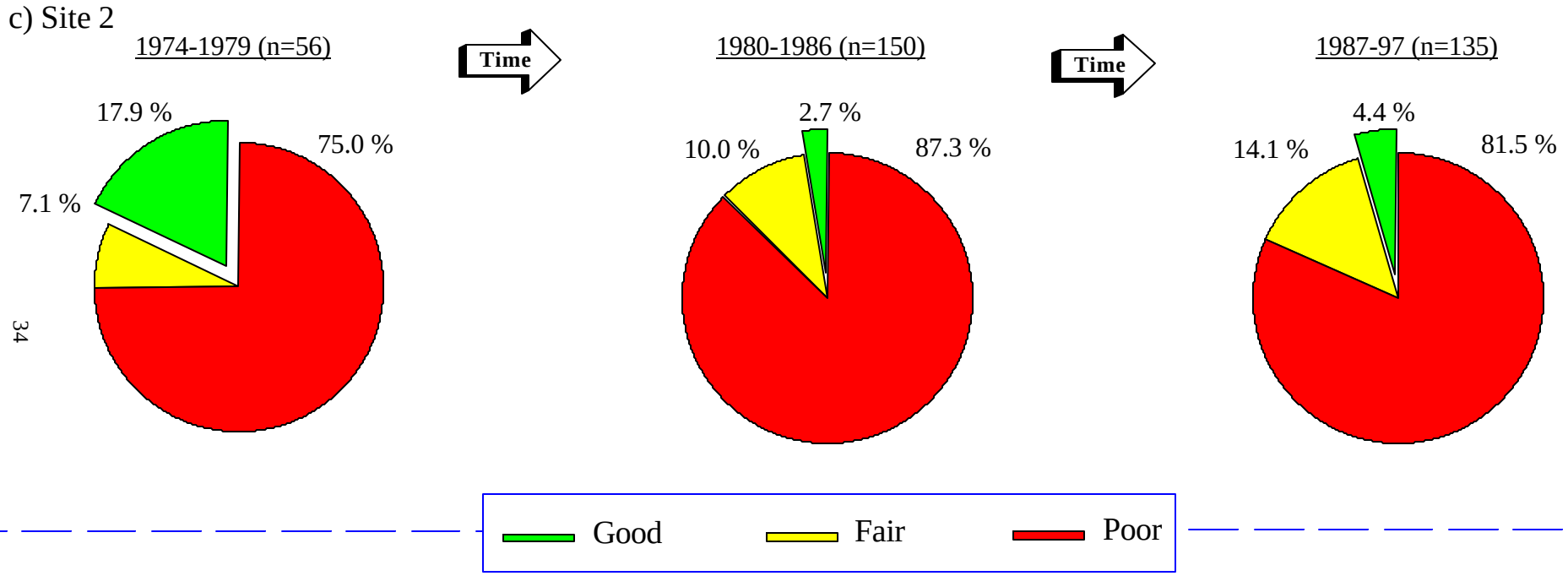


Figure III.7 (Cont.). Total Phosphorus (TP) Concentrations Observed in the Hillsboro Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County freshwater TP standard of 0.020 mg/l. The percentage of samples below 0.020 mg/l are classified as good. A fair rating was given to concentrations between 0.021 mg/l to 0.060 mg/l. Values equal to or greater than three times the standard (i.e., 0.060 mg/l) are classified as poor.



compliance percentages (i.e., good samples) during 1974-1979 and the poorest TP levels were normally seen from 1987-1997. For example, at Sites 2 and 3, a poor rating was observed in 81.5% and 80.0%, respectively between 1987 and 1997. Site 4 had a much lower percentage of poor samples (36.6%) than sites 2 and 3 during 1987 until 1997, but only 12.2 % rated good.

Seasonal analyses were performed for TP concentrations between 1989-1997. Wet season TP concentrations were higher than dry season values at Sites 2 and 3 but not at Site 4 from 1989-97 (Figure III.8). Similarly, statistically significant differences were observed at Site 3 (t-test, $p < 0.05$) and Site 2 (Mann-Whitney Rank Sum Test, $p < 0.01$) but not Site 4. The power of the performed test at Site 3 (0.458) was below the desired power (0.800) and results should be viewed cautiously. At all three sites, the median, 25^{th} and 75^{th} percentile TP values were above the Broward County standard of 0.020 mg/l during both seasons (Figure III.8).

e. Nitrogen

Total nitrogen (TN) levels are calculated as the sum of the total Kjeldahl nitrogen (TKN) and nitrite+nitrate-nitrogen (NO_2+NO_3) concentrations. Mean and median TN values generally decreased from west (Site 4) to east (Site 2). Yet, mean and median TN concentrations were above (i.e., out of compliance) the Broward County freshwater standard (1.500 mg/l) at all Hillsboro Canal sites with the exception of Site 2's median value (1.485 mg/l, Table III.7).

Typically, the majority of the TN (> 85%) was comprised of TKN which measures the total amount of organic nitrogen and ammonia-nitrogen (NH_3, Table III.7). As with TN values, TKN and NH_3 decreased from west to east. Mean NO_2+NO_3 concentrations were relatively similar at all three sites but a slight east to west increase in mean and median content was observed between sites.

Figure III.8. Hillsboro Canal Basin Total Phosphorus (TP) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over nine years is shown on the upper x-axis. Statistically significant differences between wet and dry season means were observed at Sites 2 ($p < 0.01$, Mann-Whitney Rank Sum Test) and 3 ($p < 0.05$, t-test) but not Site 4.

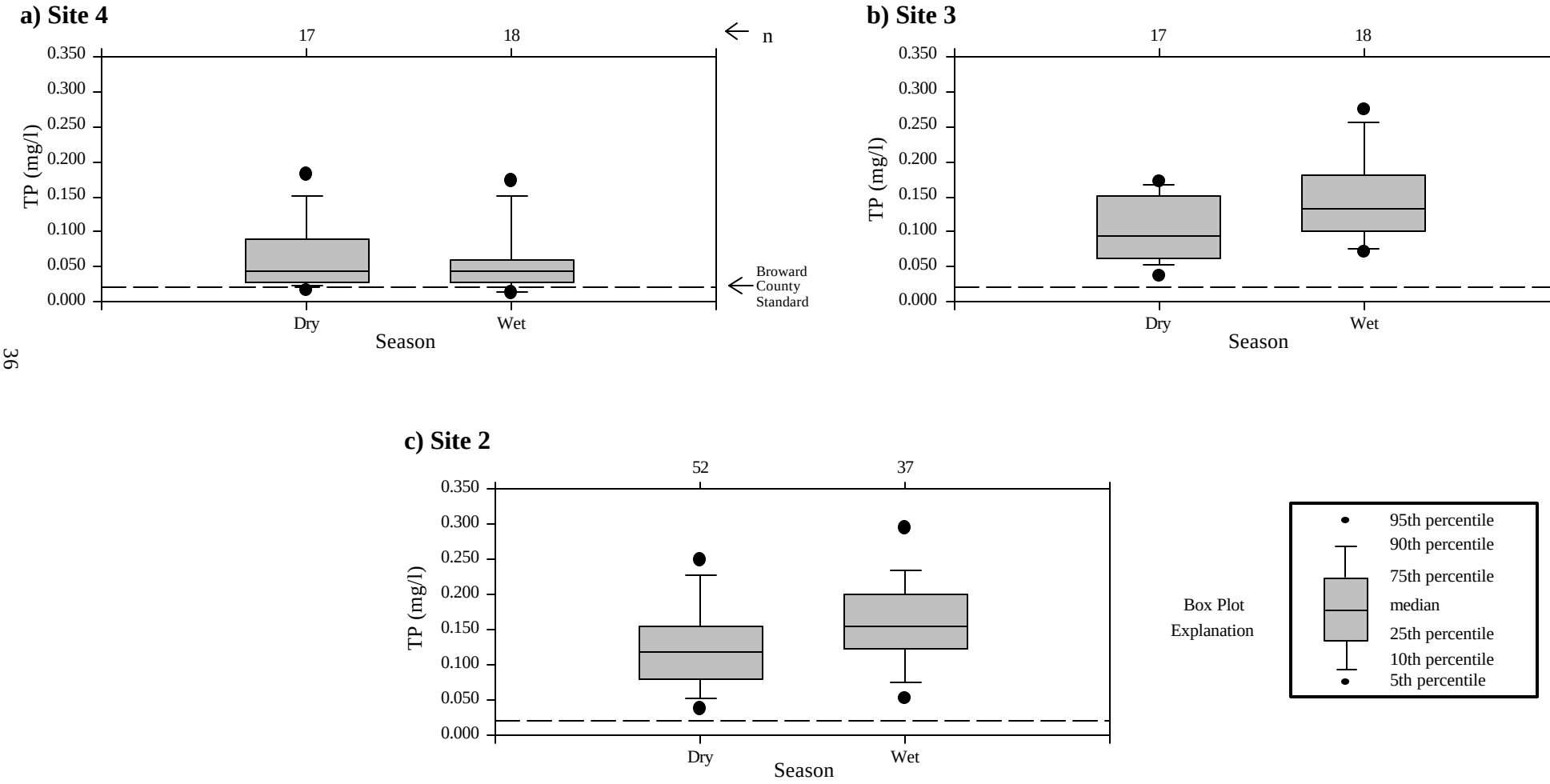


Table III.7. Descriptive Statistics for Nitrite+Nitrate-Nitrogen (NO_2+NO_3), Ammonia-Nitrogen (NH_3), Total Kjeldahl Nitrogen (TKN), and Total Nitrogen (TN) Concentrations in the Hillsboro Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL). TN was calculated as the sum of TKN and NO_2+NO_3.

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
2	NO_2+NO_3	mg/l	283	0.164	0.196	0.190	1.350	0.005	27
3	NO_2+NO_3	mg/l	66	0.120	0.194	0.220	1.080	0.005	2
4	NO_2+NO_3	mg/l	66	0.086	0.169	0.216	0.977	0.005	6
2	NH_3	mg/l	260	0.053	0.091	0.125	1.070	0.005	98
3	NH_3	mg/l	60	0.082	0.127	0.135	0.736	0.005	10
4	NH_3	mg/l	61	0.253	0.276	0.245	1.050	0.005	11
2	TKN	mg/l	278	1.300	1.347	0.540	7.910	0.025	1
3	TKN	mg/l	64	1.500	1.543	0.417	2.870	0.810	0
4	TKN	mg/l	64	1.965	1.960	0.462	3.130	1.060	0
2	TN	mg/l	278	1.485	1.545	0.575	7.920	0.110	N/A
3	TN	mg/l	64	1.620	1.742	0.541	3.590	0.990	N/A
4	TN	mg/l	64	2.165	2.130	0.569	3.690	1.070	N/A

Annual TN averages did not exhibit major trends with time, although the minimum values for all three sites appeared in 1988 (Figure III.9). The maximum values for all three sites bracketed 1988, occurring in 1987, 1989 or 1990. In twelve of the eighteen years, the annual mean exceeded 2.000 mg/l at Site 4 which is 0.500 mg/l above the standard. Conversely, an annual value above 2.000 mg/l was only observed twice at Site 3 and never at Site 2.

To better understand compliance patterns within the canal, each TN sample was given a rating based on Broward County's water quality standards. Total nitrogen concentrations were designated as poor if they were over 2.500 mg/l which is 1.000 mg/l over the Broward County standard of 1.500 mg/l. A fair designation was given for values between 1.501 and 2.500 mg/l. A good designation for TN values was designated as less than or equal to 1.500 mg/l. In addition, changes over time are presented with special reference to the closing of WWTPs within the basin (see section III.E.3).

Site 4 had the highest percentage of poor samples in the canal, especially from 1987 to 1992 (Figure III.10). Furthermore, compliance (i.e., good samples) levels were only at 21.1% from 1993-1997. Site 3 exhibited an improvement in good TN samples through time going from 26.1% (1981-1986) to 52.6% (1993-1997, Figure III.10b). Although Site 2, had a small percentage (< 5%) of poor samples throughout the study, the 1993 to 1997 period realized a decrease of 17% in good samples from the 1989 to 1992 time frame.

Figure III.9. Annual Mean Total Nitrogen (TN) Levels Within the Hillsboro Canal Basin from 1981 to 1997. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. The Broward County standard (1.50 mg/l) is indicated by the dashed line.

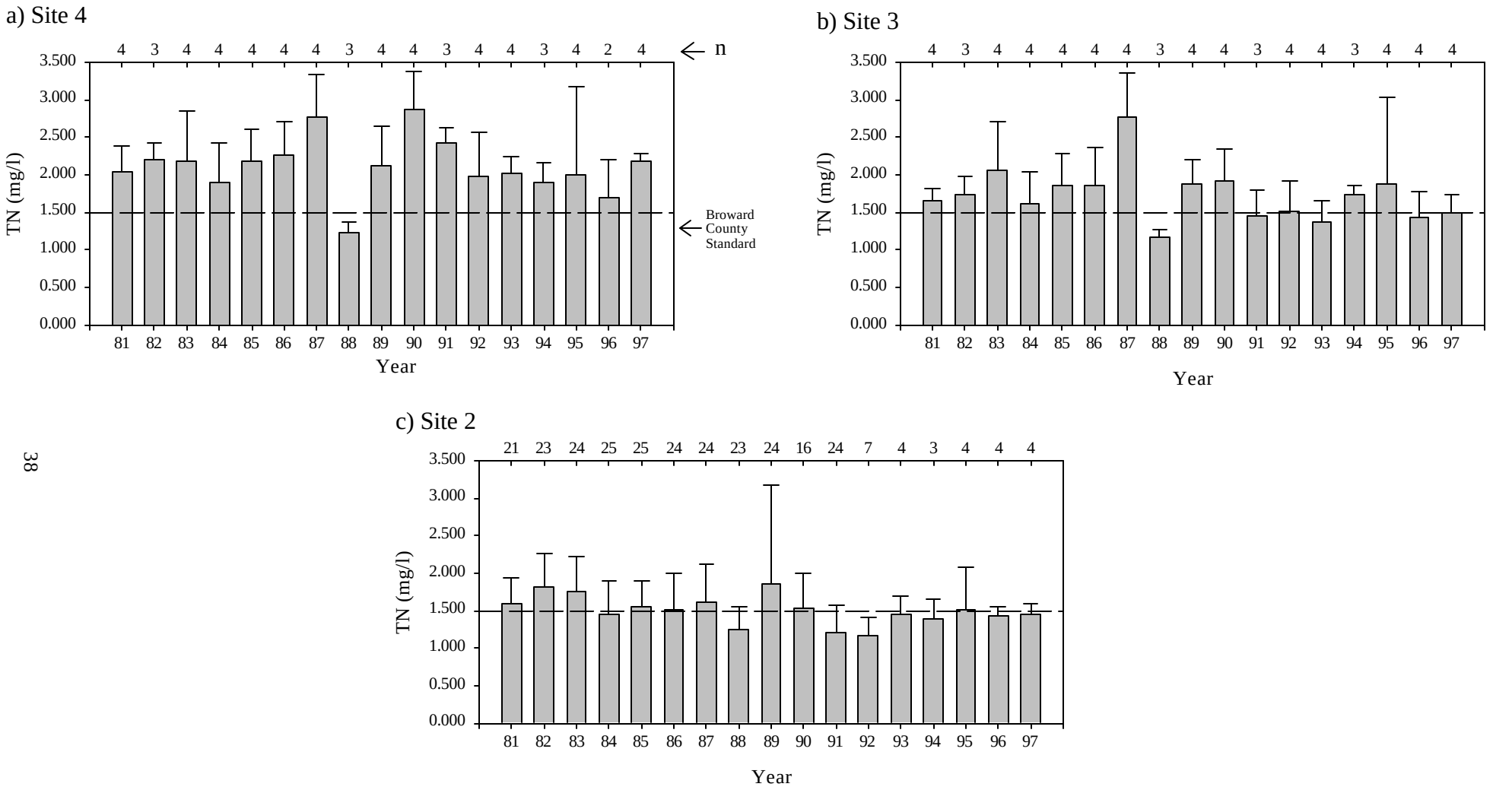


Figure III.10. Total Nitrogen (TN) Concentrations Observed in the Hillsboro Canal Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified as good. A fair rating was given to concentrations between 1.501 mg/l to 2.500 mg/l. Values greater than 2.500 mg/l are classified as poor.

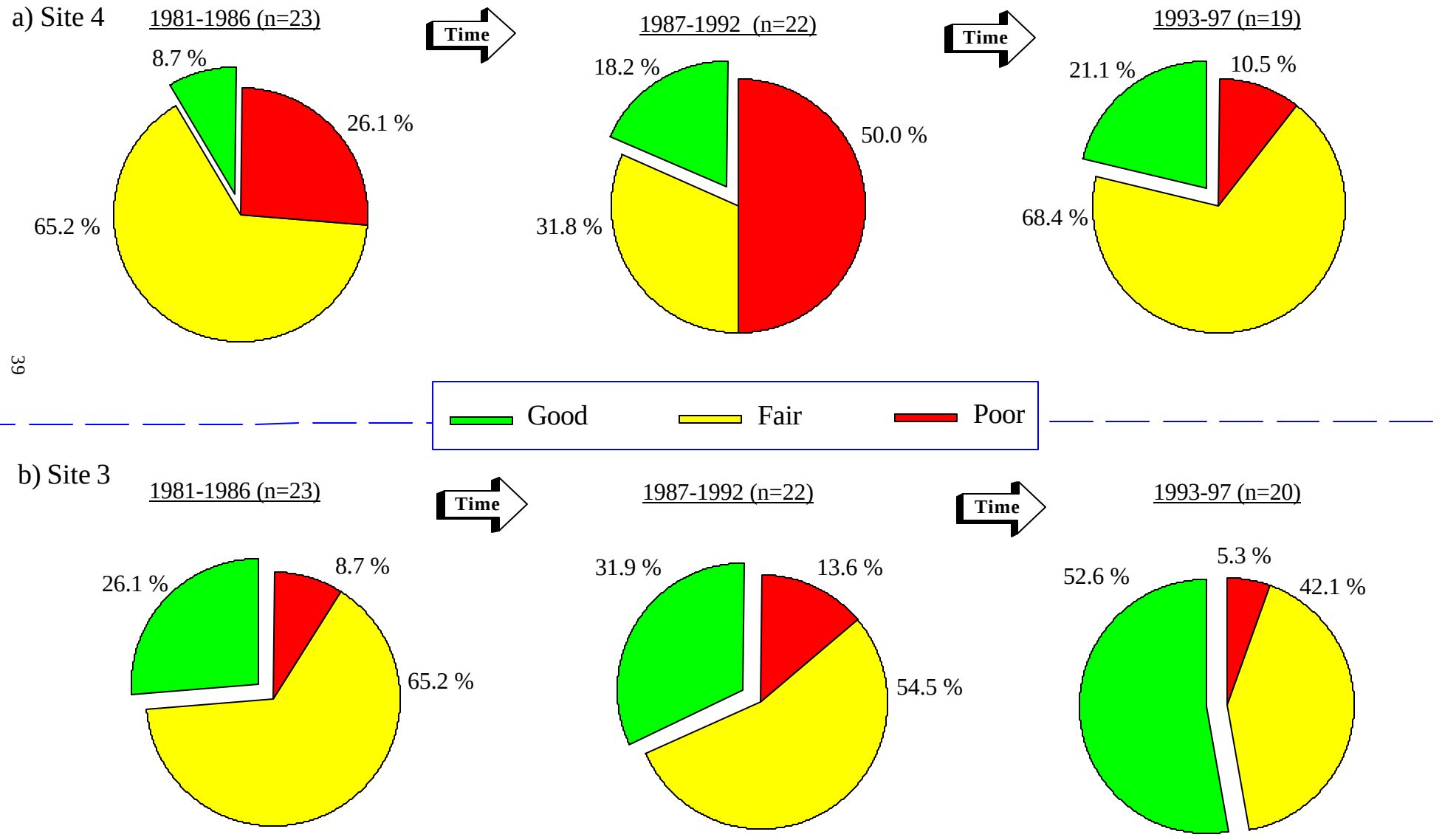
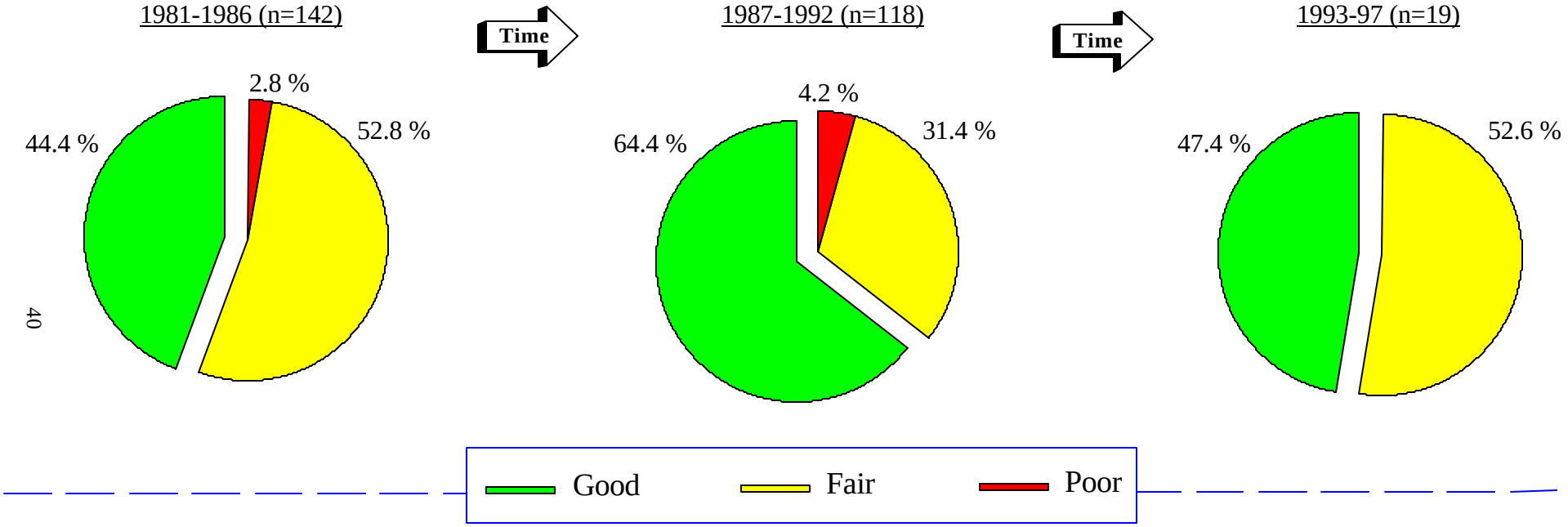


Figure III.10 (Cont.). Total Nitrogen (TN) Concentrations Observed in the Hillsboro Canal Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified as good. A fair rating was given to concentrations between 1.501 mg/l to 2.500 mg/l. Values greater than 2.500 mg/l are classified as poor.

c) Site 2



Between 1989-1997, a statistical difference between wet and dry season TN content was only observed at Site 4 (t-test, $p < 0.05$) although the power of the test (0.457) was below the desired power (0.800) and findings should be viewed cautiously (Figure III.11). Furthermore, Site 4's wet season median value (2.185 mg/l) and 25^{th} to 75^{th} were well above Broward County's compliance standard (i.e., 1.5 mg/l). Farther 'downstream', Site 3's TN values for both seasons were similar to Site 2's with the exception of Site 3's wet season median being greater than 1.500 mg/l.

f. Bacteriological Parameters

Mean fecal coliform (FC), total coliform (TC), and fecal streptococcus (FS) were typically higher than medians (Table III.8), however, bacteriological mean values are often skewed by outstanding high values (BCDNRP 1994). The high standard deviations and large differences between maximum and minimum values attest to the occurrence of this pattern.

Based on the Broward County FC standard of 800 colonies/100 ml and the TC standard of 2,400 colonies/100 ml (both single samples), the Hillsboro Canal was characterized by low median bacteria levels (Table III.8) over the previous twenty-five years. The maximum bacteriological concentrations were high but median values indicate enhanced values were rare.

Table III.8. Descriptive Statistics for Fecal Coliform (FC), Total Coliform (TC), and Fecal Streptococcus (FS) in the Hillsboro Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL) and the unit of measurement is colonies/100 ml (col).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
2	FC	col	359	40	149	610	9200	2	35
3	FC	col	149	62	218	871	9800	5	3
4	FC	col	100	40	275	1507	14800	5	10
2	TC	col	363	340	852	3124	50000	5	7
3	TC	col	157	460	1402	4254	40000	30	0
4	TC	col	108	335	1384	3774	30000	30	0
2	FS	col	335	130	547	2066	27000	10	39
3	FS	col	123	220	968	3138	23000	16.5	1
4	FS	col	91	170	483	959	7300	12	8

Due to the large amount of variability around the mean, yearly box plots were plotted for FC instead of the mean (Figure III.12). For example, three 1995 fecal coliform samples were obtained at Site 2. The results were 30, 50, and 4,200 colonies/100 ml which resulted in a mean of 1,427 ± 2,402 colonies/100 ml but yielded a median of 50 colonies/100 ml.

Figure III.11. Hillsboro Canal Basin Total Nitrogen (TN) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over nine years is shown on the upper x-axis. A statistically significant difference was observed between wet and dry season means ($p < 0.050$, t-test) at Site 4 but not Sites 2 and 3.

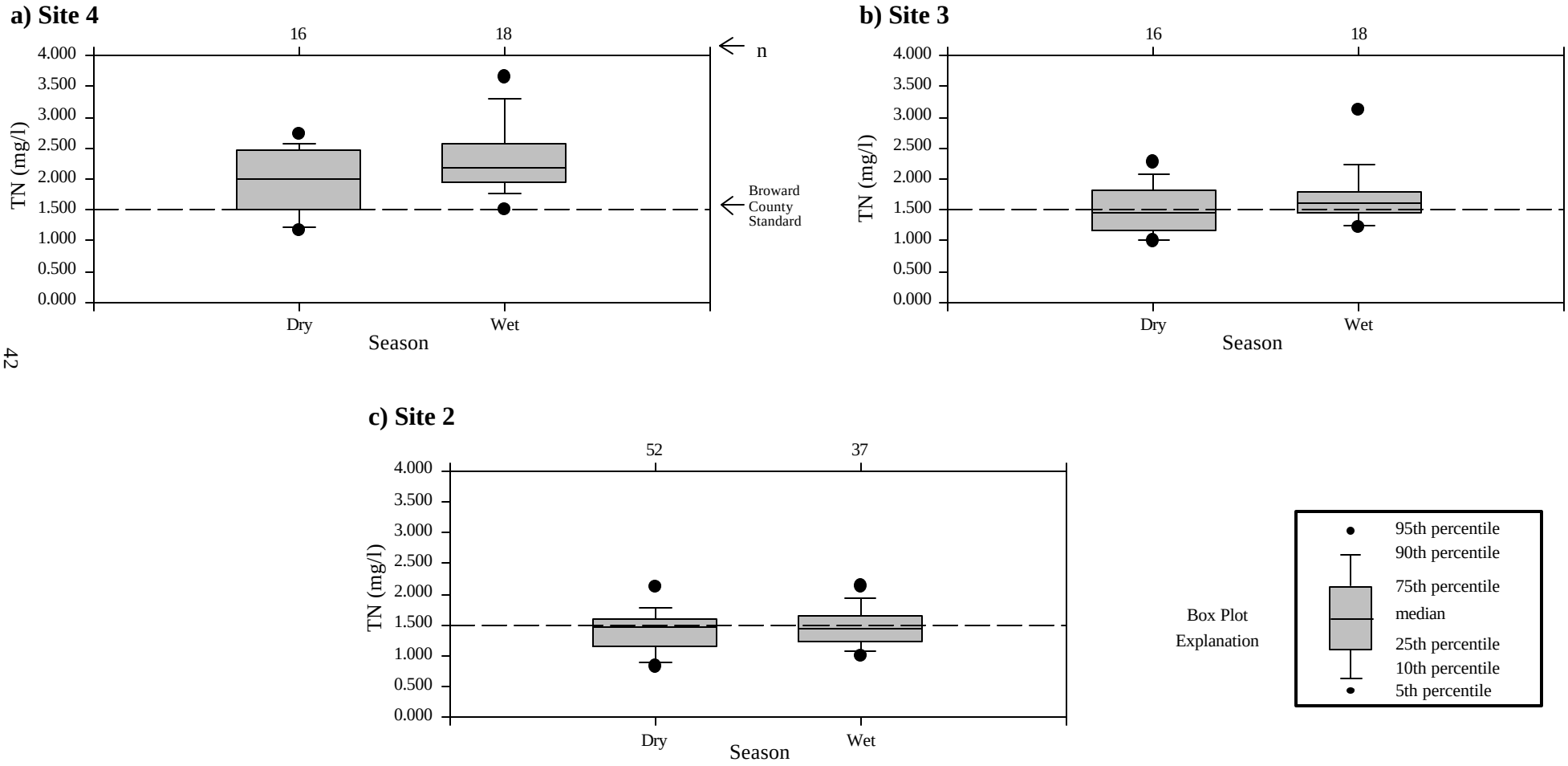
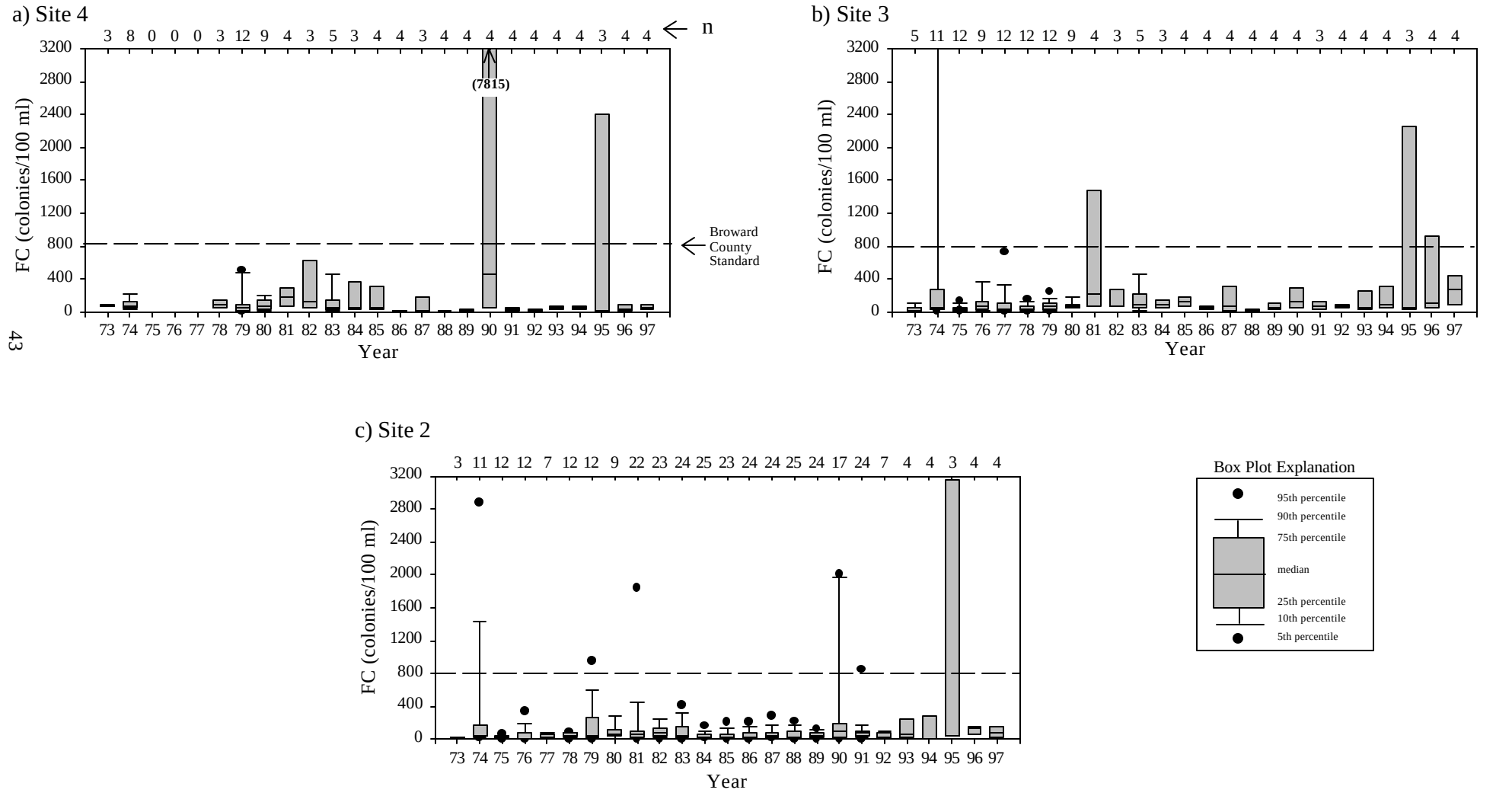


Figure III.12. Annual Box Plots of Fecal Coliform (FC) Levels within the Hillsboro Canal Basin from 1973 to 1997. Medians and percentiles calculated from monthly and quarterly samples with the number of samples (n) noted on the upper axis. The Broward County single sample standard (800 colonies/100 ml) is indicated by the dashed line. Numbers in parentheses represent 75th percentile values that extend beyond the y-axis scale.



Yearly median values were below the single sample standard (800 colonies/100 ml) at all sites during all years (Figure III.12). Occasional high (> 800 colonies/100 ml) fecal coliform concentrations were observed at more than one site in 1974, 1990, and 1995. From 1995-1997, Site 3 exhibited higher annual values than typically seen in the preceding years.

To better investigate compliance patterns within the canal, each specific sample was given a rating based on three different Broward County water quality standards. Monthly FC averages should be equal to or less than 200 colonies/100 ml and ten percent of all samples should be equal to or less than 400 colonies/100 ml. In addition, any single sample should be equal to or below 800 colonies/100 ml.

For this study, a good rating was given to any sample equal to or less than 200 colonies/100 ml. A fair designation was given to fecal coliform values between 201 and 800 colonies/100 ml. Samples that were greater than 800 colonies/100 ml were classified as poor. In addition, the changes over time are presented with special reference to the closing of WWTPs within the basin (see Section III.E.3).

Only Site 3 had an overall decrease through time in good ratings, however, 81.0% of the forty-two samples between 1987 and 1997 still rated good (Figure III.13). Furthermore, all sites were characterized by a poor rating below 10.0%.

Higher FC concentrations from 1989-1997 typically occurred in the wet season than the dry season (Figure III.14). Statistically significant differences were observed at Sites 2, 3, and 4 (Mann-Whitney Rank Sum Test; $p < 0.001$, 0.05, and 0.01, respectively). Notably, only the 90^{th} percentile wet season values were above the Broward County standard (800 colonies/100 ml) at all sites.

7. Basin Summary

Existing within two counties, the Hillsboro Basin has numerous levels of governing entities that influence different hydrological sections of the canal, as well as developmental practices. Furthermore, the water quality monitoring sites within this study cover relatively long distances (> 4.5 miles) and in some cases have unique surrounding land uses. The following will discuss the differences and/or similarities in water quality of this large and complex basin, particularly in terms of the west to east orientation (Site 4 towards Site 2). Additionally, impacts of WWTPs and seasonal effects will be considered. Finally, questions about the canal and basin brought forth by this initial data analysis effort are listed to support future monitoring and resource planning.

a. Influence of WWTP Discharges

Under normal Hillsboro Canal flow conditions of west to east, Site 4 was primarily out of the geographical influence of WWTPs. Thus, Sites 2 and 3 were the main areas expected to have changes in water quality associated with WWTP closures. However, the halting of WWTP discharges on the Hillsboro Canal generally did not influence the water quality observations. Only at Site 2, where the percentage of poor DO samples dropped under fifty percent, were there any indications of water

Figure III.13. Fecal Coliform (FC) Concentrations Observed in the Hillsboro Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100 ml (good rating) and no single reading shall be above 800 colonies/100 ml (poor rating). Values between 201 and 800 colonies/100 ml are defined as fair.

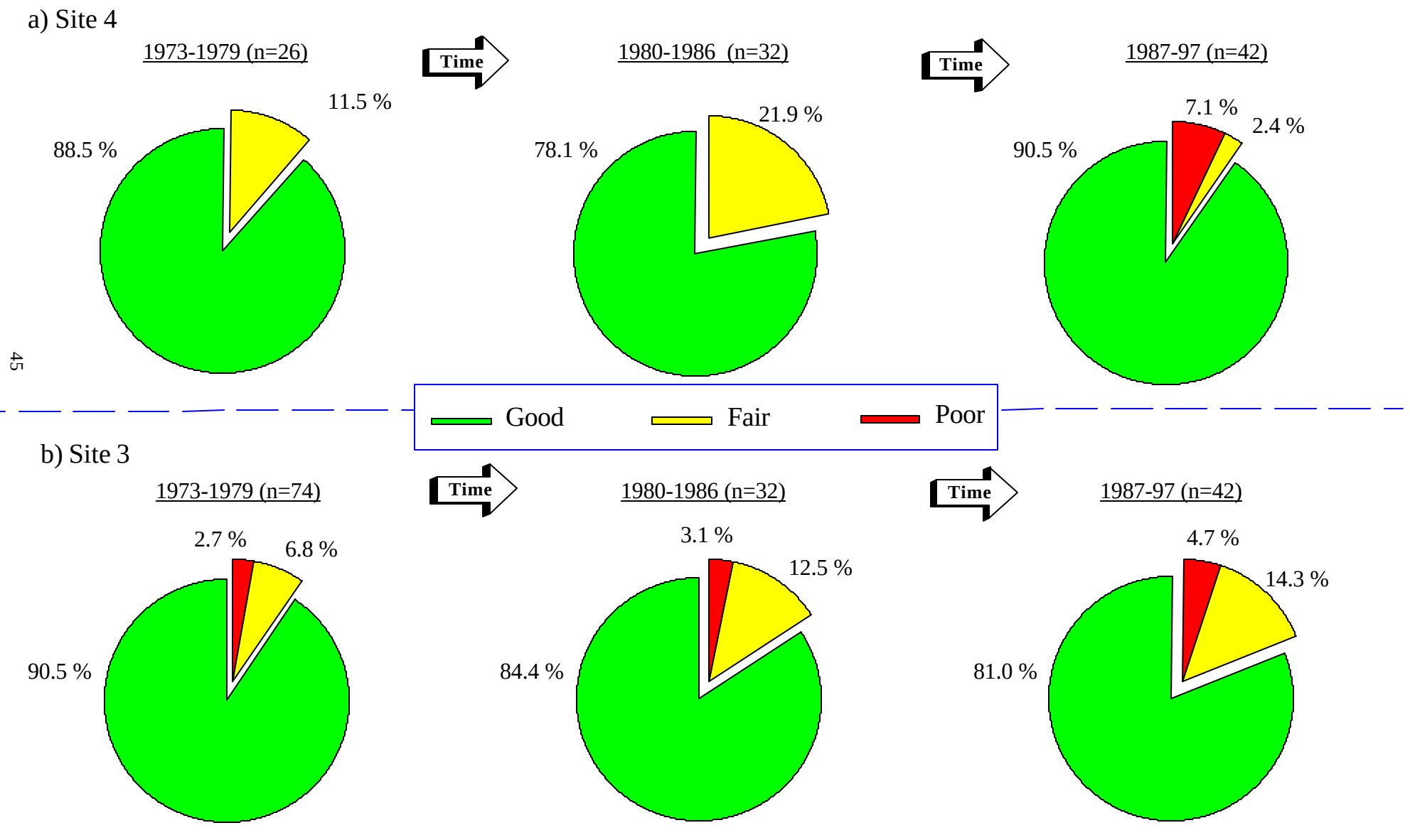


Figure III.13 (Cont.). Fecal Coliform (FC) Concentrations Observed in the Hillsboro Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100 ml (good rating) and no single reading shall be above 800 colonies/100 ml (poor rating). Values between 201 and 800 colonies/100 ml are defined as fair.

c) Site 2

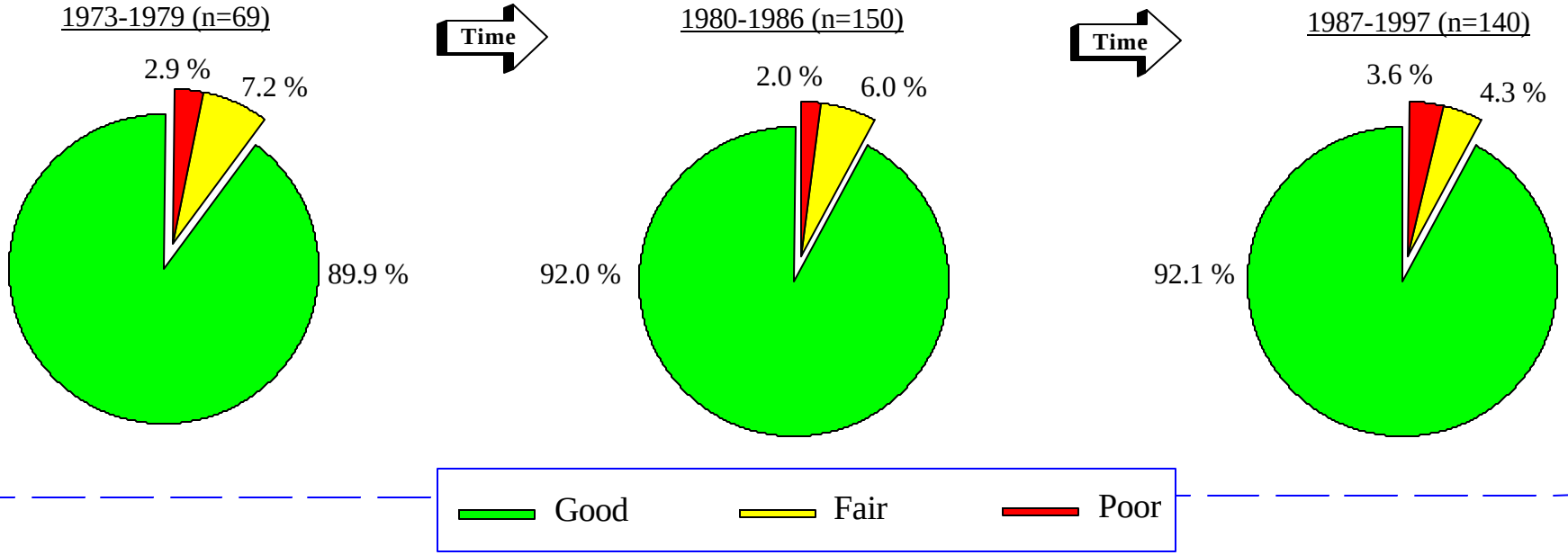
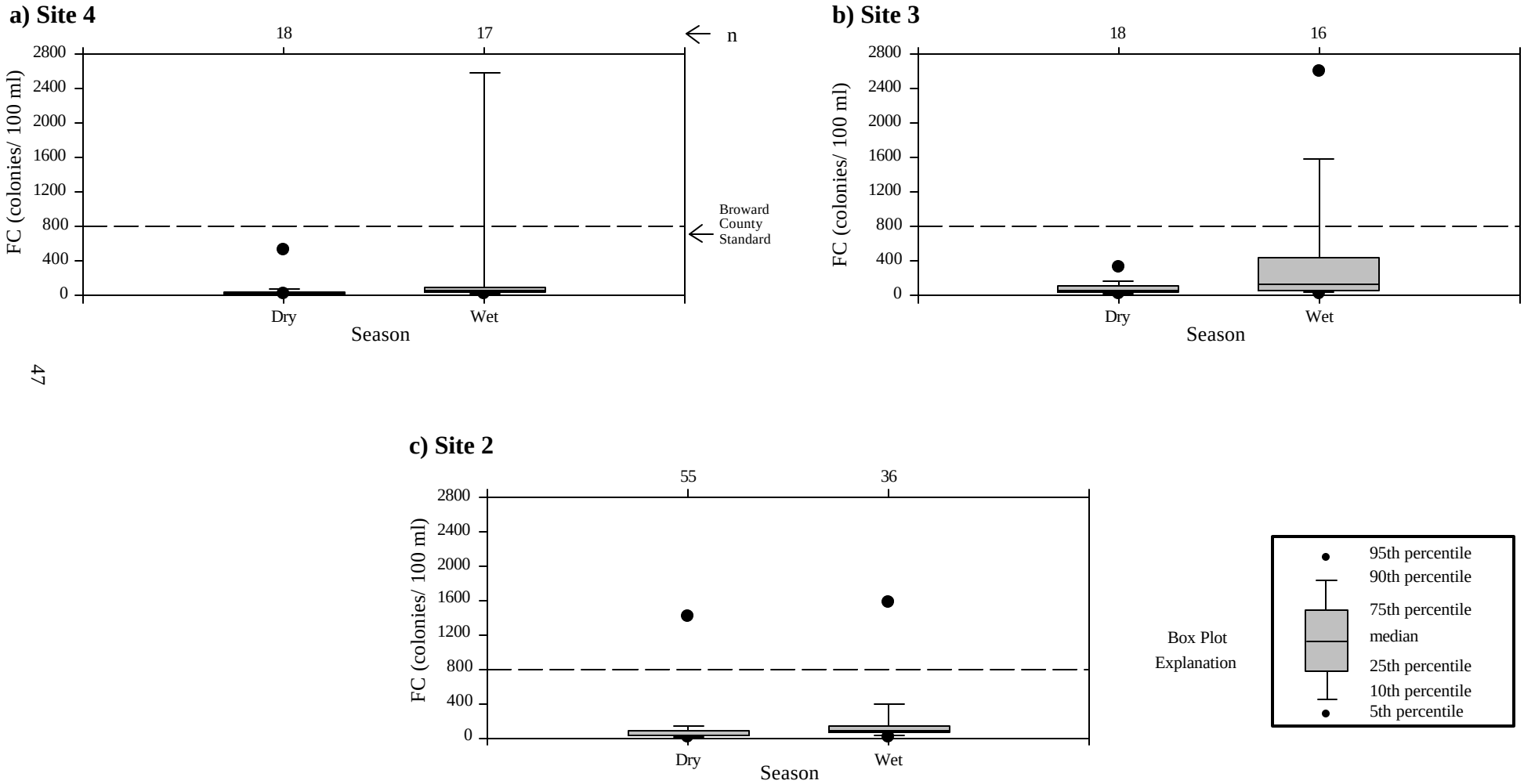


Figure III.14. Hillsboro Canal Basin Fecal Coliform (FC) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over nine years is shown on the upper x-axis. Statistically significant differences between wet and dry season medians were observed at Sites 2, 3, and 4 ($p < 0.001$, 0.05, 0.01, respectively; Mann-Whitney Rank Sum Test).



improvement seen post-WWTPs. Still, poor samples were seen almost forty percent of the time at Site 2.

The relatively low daily flow rates (< 0.020 million gallons per day) for the WWTPs located on the Hillsboro Canal may explain why noticeable changes were not observed post- and pre discharge years. Furthermore, surrounding land uses combined with water management inflows may have masked any relationship before and after the WWTPs closed.

b. Basinwide Water Quality Characteristics (Post-WWTPs)

Overall, the Hillsboro Canal exhibits poor water quality based primarily on nutrient content. Situated approximately 10 miles (6.25 kilometers) from each other, Sites 2 and 4 generally exhibited different water quality characteristics. However, each site also had impaired water quality conditions. The main differences were which nutrient (TP or TN) was enhanced and in overall DO content. As the central location, Site 3's water quality reflected Site 4 for some parameters (e.g., DO) while for others (e.g., TP), the site resembled Site 2.

Levels of TN in the canal were almost always highest at Site 4 where annual means, with one exception, always exceeded the standard of 1.500 mg/l. Ambient TN concentrations suggest levels decrease with movement of water east of the S-39 towards Site 3 and then further east to G-56 (i.e., Site 2). This pattern is seen more prominently in the nineties when WWTP discharges were not occurring in the canal. Water entering the waterway from the WCAs potentially reflects TN export from a natural area (Loxahatchee Natural Preserve). High levels of TOCs also would be reflective of plant decomposition in the WCA such as Loxahatchee preserve. This is consistent with the highest 17-year mean (28.70 mg/l) TOC concentrations in the Hillsboro Canal being observed at Site 4 and then decreasing as moving downstream. Seepage water from the WCA is also typically low in DO values. Low DO levels are consistent throughout the canal, but more readily observed in the western and central areas. Thus, the concentrations of four constituents (TN, TP, TOC, and DO) reflect the major western source of water to the Hillsboro. By the time water reaches State Road 7, basin specific inputs begin to influence the canal's water quality, in particular for TP.

Levels of TP at Site 4 were the lowest in the canal although compliance levels were still low (12.2%) through 1987-1997 (Figure III.7). However, Site 4's poor ranked ($ 0.060) samples (36.6%) were low compared to further east in the canal (Sites 3 and 2) where poor ranked samples were observed 80.0% of the time. The presence of a major secondary canal (Lake Worth District's E-1) at State Road 7 (i.e., Site 3) likely influences TP concentrations. In addition, the combination of three land uses (agriculture, golf courses and highly maintained residential lawns) in the area are likely contributing to TP levels observed at Sites 2 and 3.

c. Seasonal Differences

Temperature may explain the lower DO values observed in the wet versus the dry season at Site 2. However, the extremely low wet season levels at Site 4 highly suggest an influence of seepage water

from the WCAs. The higher wet season TP values at Sites 2 and 3 may suggest more stormwater and/or secondary/tertiary canal inputs. Nonetheless, dry season values were also well above the standard of 0.020 mg/l and suggest a relatively high influx of TP occurs throughout the year.

A TN source appears to exist at Site 4 which appears to have a maximum effect during the wet season. This is likely due to higher volumes of WCA seepage water, particularly from Loxahatchee Preserve being discharged to the Hillsboro Canal. From this initial analysis, in stream TN decreases as moving eastward suggesting the main source exists in the westernmost areas of the basin. Fecal coliform values in the wet season were significantly higher than dry season concentrations at all sites and likely reflects the influence of stormwater. It should be noted FC median values for the 1989-1997 period were well within compliance levels.

d. Future Monitoring Questions

A goal of this report is to develop strategic guidelines for future Broward County water quality monitoring and management. To facilitate this, questions generated by this study's findings are being compiled for each basin. For the Hillsboro Basin, several questions revolve around nutrient concentrations and their potential fate and transport. Furthermore, the hydrology of the northern portion of the basin, in Palm Beach County, needs to be combined with the information from Broward County (see BCDNRP 1998) for a comprehensive picture of the entire basin.

- What is the source of TN to the westernmost Site 4 and why do levels decrease towards the east?

- Why are high (> 0.100 mg/l) TP levels observed more frequently at Sites 3 (central) and 2 (eastern) but not Site 4 (western areas)?

- What is the water quality of the WCAs and Lake Worth Drainage District (Palm Beach County) which eventually drain to the Hillsboro Canal?

- Despite different nutrient distribution (TN versus TP), why were dissolved oxygen patterns different between the western and eastern segments of the waterway?

- Are the excess nutrients in the water column affecting the water column biology (primarily phytoplankton) and/or macrophytes?

F. C-14 Canal

1. Basin and Canal Structure

The C-14 Canal Basin is located in northern Broward County and is one of the larger basins with an area of fifty-nine mi^2 (Cooper and Lane 1987). The basin is divided between a western (twenty-five mi^2) and an eastern (thirty-four mi^2) sub-basin at State Road 7 (Figure III.15). The headwaters to the western sub-basin include the L-35B Canal which can bring excess water from Water Conservation Area (WCA) 2 east through the S-38 (Cooper and Lane 1987). In addition, seepage water from WCA 2 is captured by the L-36 Canal which is oriented in a north-south direction at the western end of the C-14 Basin. Seepage water in the L-36 south of S-38B (border to Hillsboro Canal Basin) enters the C-14 Canal during certain periods of the year via the S-38A. During some hydrological conditions, water from C-14 Basin may be pushed south into the C-13 through the S-38C. Furthermore, water in the L-36 south of S-38C may flow to the C-13 Canal but not the C-14 Canal (Cooper and Lane 1987).

Overall, the freshwater portion of the C-14 Canal is separated into two distinct segments by control structure S-37B. However, the headwaters of S-37B include all of the western sub-basin and portions of the eastern sub-basin. The tailwaters of S-37B are freshwater and include the remnant Cypress Creek channel. The tailwaters of the S-37B are also the headwaters of the S37A and discharge through this structure to the estuarine portions of the C-14 (see Section IV).
The SFWMD controls the major water control structures based on water levels with the WCA 2 and various Broward urban basins. In addition, several independent and dependent drainage districts, as well as municple stormwater entities (e.g., City of Tamarac) exist in the C-14 basin (see Section I, Figure I.4). The western sub-basin has the Coral Springs Improvement District and the Sunshine Drainage District to the north and Broward County's drainage jurisdiction to the south. In the center of the western sub-basin, Broward County has jurisdiction in both the southern and northern areas. However, Turtle Run Community Development District (CDD), Coral Bay CDD and Cypress CDD are located in the northern areas and the North Lauderdale Water Control District also exists in this area.

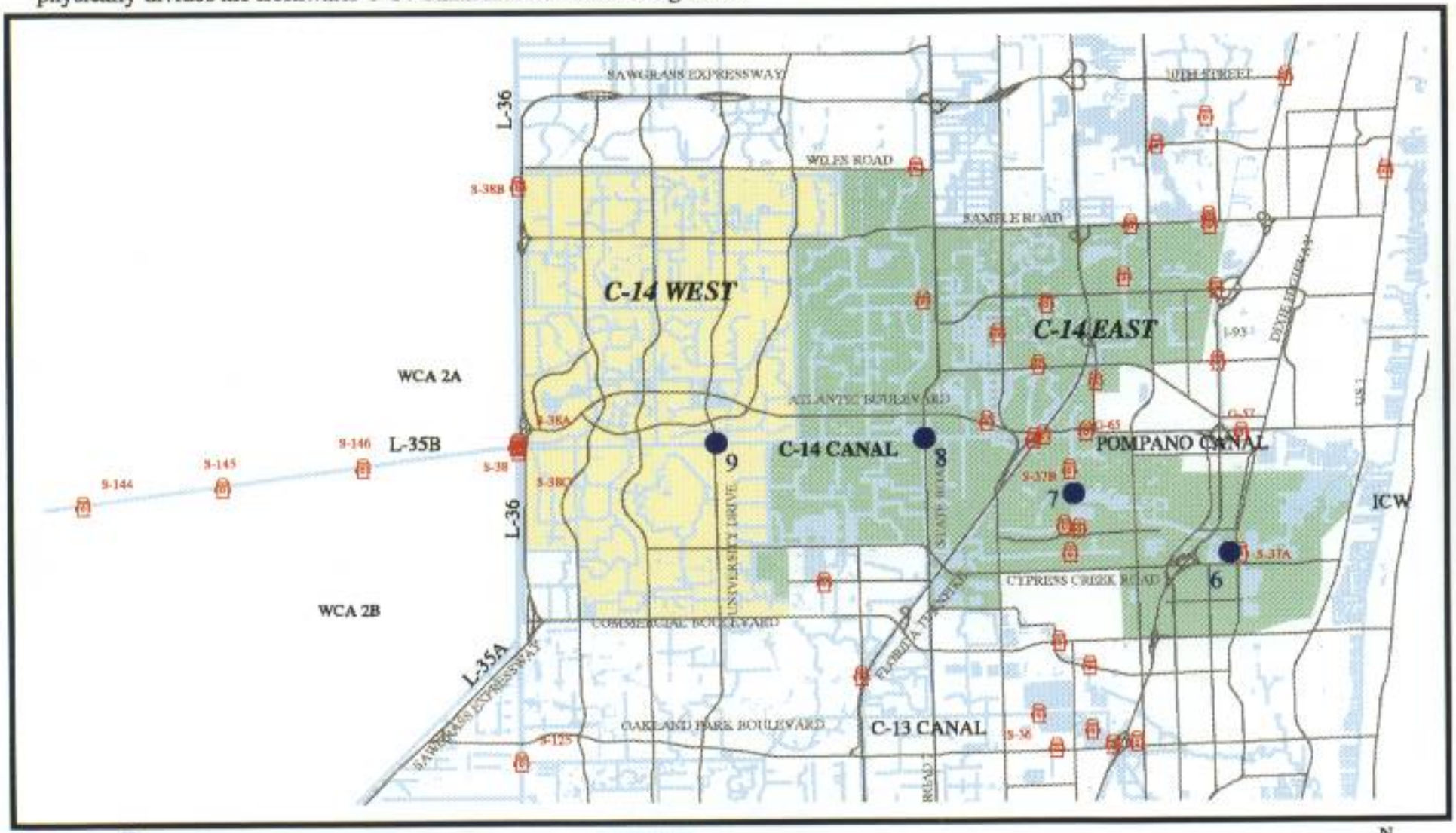
In the eastern extent of the C-14 western sub-basin, the Cocomar WCD and Broward County's WCD 4 are the main drainage districts. Broward County's WCD 4 is the main district within the eastern C-14 sub-basin, however, the southwest portion of WCD 3 also borders the northern corner of the basin.

2. Municipalities and Land Uses

The C-14 western basin includes the southern half of Coral Springs and a large portion of Tamarac (see Section I, Figure I.3). The eastern C-14 basin includes the cities of North Lauderdale, Margate, the western half of Pompano Beach, the southern half of Coconut Creek, and small northwestern sections of Ft. Lauderdale, Oakland Park, as well as unincorporated Broward County.

In 1970, the C-14 Canal Basin was sparsely populated, especially the western portion of the basin.

Figure III.15. The C-14 Canal Basin and Broward County (BCDPEP) Sampling Site Location Map. The C-14 Canal and other major waterbodies with corresponding South Florida Water Management District (SFWMD) water control structures (labeled) are depicted. Note water control structures without labels are secondary structures operated by other entities than the SFWMD. The S-37B (SFWMD) physically divides the freshwater C-14 Canal into two distinct segments.



BROWARD COUNTY

This map is for informational purposes only. For further information, please contact BCDPEP Water Resources Division (954) 519-1270.

By the late 1970s, the population had nearly quadrupled. The city of North Lauderdale grew significantly during this period, increasing from just over 1,000 residents to over 13,000 residents. Coral Springs, which partially lies within the western C-14 Basin, also experienced rapid growth. The entire city's population grew from approximately 1,500 in 1970 to over 26,000 residents by 1978. Margate, in the center of the basin, increased from close to 9,000 residents to over 33,000 residents during the 1970s. Tamarac, in the southwest area of the basin, experienced similar growth to that of Margate, increasing from 5,000 residents to 27,000 residents (Broward County Planning Council 1995). The City of Pompano Beach was relatively well-populated in 1970 in comparison to other cities, with a total of 38,000 residents and grew by almost 50% during the 1970s.

By 1977, the land use in the basin was dominated by open land, which constituted almost two-thirds of the basin. The other significant land use was single family residential (21%). Approximately 8% of the basin was used for agricultural purposes. A significant amount of cultivated crop land and improved pasture area was located north of the C-14 canal, near the Turnpike. Commercial and industrial uses were not prevalent in the basin, comprising less than 3% of the area (Broward County Planning Council 1977).

During the 1980s, the population of the C-14 Canal Basin continued to grow rapidly, with much of the growth occurring in the western areas of the basin. During this decade, the number of residents in North Lauderdale more than doubled, and by 1995, the city's population stood at nearly 30,000. The City of Coral Springs' population nearly tripled during the 1980s, and reached nearly 96,000 residents by 1995. Margate's population had increased to over 42,000 by the end of the 1980s, and by 1995 had increased slightly to just over 44,000 residents. The population of Tamarac continued to follow closely behind Margate, reaching nearly 44,000 residents by 1995. Pompano Beach's growth slowed to 22% during the 1980s the population reached approximately 80,000 residents by 1995 (Broward County Planning Council 1995). Thus, the land use in the C-14 Basin had dramatically changed to predominantly urban uses by 1995, including both residential and commercial uses with very little open area or agricultural land remaining.

3. Wastewater Treatment Plants Discharge History

The Florida Department of Transportation was the first wastewater treatment plant (WWTP) to cease discharges (0.049 million gallons per day; mgd) into the C-14 Canal by October 1979 (BCEQCB 1978, 1979) The City of Coral Springs WWTP stopped sending emergency wastewater overflows to the canal in May of 1981 (BCEQCB 1980, 1981). In 1983, the City of Oakland Park halted an average daily flow of 4.1 mgd to the waterway (BQEQCB 1982, 1983). The City of North Lauderdale used a combination of ponds and the C-14 Canal as discharge points for 3.25 mgd until the end of 1983 (BQEQCB 1982, 1983). In February of 1985, Broward County's District 1B (Palmdale) WWTP stopped pumping to a treatment lake that discharged (0.799 mgd) to the C-14 Canal (BCEQCB 1984, 1985).

4. Other Influences on Water Quality

a. Soils

The western portion of the C-14 Canal Basin contains deep, poorly drained sandy soils as well as some areas of muck soils (see Section I, Figure I.5). These muck soils are severely limiting to construction and development because of the high water table and wetness of the soils. In the eastern areas of the basin, there is a mixture of poorly-drained soil types with a few small areas of well-drained sandy soils. Much of this area is only slightly to moderately limiting to development (Reynolds, Smith and Hills Inc. 1972).

b. Roadways

Numerous major roadways cross the C-14 Canal (see Figure III.15) in both sub-basins. Major north-south oriented roads include University Drive, State Road 7, Rock Island Road, Florida Turnpike, Powerline Road, Andrews Avenue, Interstate 95, and Dixie Highway. In addition, a major east-west connector road, Atlantic Boulevard is parallel to much of the waterway north of S-37B. Thus, transportation associated runoff can be expected through much of the waterway.

c. Septic Tanks

Almost all of the eastern and western C-14 Basin is covered by public sewer service (http://www.broward.org/moi00600.htm). A small area in the Western C-14 Basin exists south of Wiles Road and north of Sample Road between Pine Island Road and University Drive is not covered by sewer service. In the eastern basin, a very small area north of Cypress Creek Road near Powerline Road does not have public sewer service. Perhaps more importantly, all areas along the C-14 Canal are under public sewer service and not septic tanks.

5. Sampling Locations and Period

Four sites cover the western and eastern C-14 basins (Appendix 1). At the Old Dixie Highway Bridge, Site 6 is the easternmost site immediately west of the S-37A structure and represents water quality that is discharged to the brackish regions of the C-14 Canal. Site 7 is located at the South Palm Aire Drive Bridge and is south of control structure S-37B but west of S-37A. Thus, Sites 6 and 7 are in the same segment of the waterway also called the Cypress Creek Canal.

Hydrologically, sites 8 and 9 represent the same section of the western C-14 Canal (i.e., northwest of S-37B) during normal flow condition but are physically in separate drainage areas of the overall C-14 basin. Northwest of S-37B, Site 8 is in the western area of the eastern C-14 sub-basin at State Road 7. Sampling Site 9 is located three miles west of Site 8 at the University Drive bridge but is the only site within the western sub-basin reported in this study (Figure III.15). Table III.9 describes the years of collection for each parameter at each site.

An additional western sub-basin Site 89 exists but due to the relative time differences between it and the other four sites, it was not included in these analyses. It is mentioned here for informational purposes only.

Table III.9. Sampling Years for Specific Parameters at the C-14 Canal Locations. A sampling year had at least one sample event during that year. Note the biochemical oxygen demand was a five-day test from 1973 until 1981 when a seven-day test was implemented until 1993 after which sampling for the parameter ceased at BCDPEP.

Parameter	**Site 6**	**Site 7**	**Site 8**	**Site 9**
Temperature	73-97	81-97	73-97	74-97
pH	73-97	81-97	73-97	73-97
Specific Conductance	81-97	81-97	81-97	81-97
Dissolved Oxygen	73-97	81-97	73-97	73-97
Biological Oxygen Demand	73-93	81-93	73-93	73-93
Total Organic Carbon	81-97	81-97	81-97	81-97
Turbidity	75-97	81-97	75-97	75-97
Total Phosphorus	74-97	81-97	74-97	74-97
Ammonia-Nitrogen	81-97	81-97	81-97	81-97
Nitrite+Nitrate-Nitrogen	81-97	81-97	81-97	81-97
Total Kjeldahl Nitrogen	81-97	81-97	81-97	81-97
Fecal Coliform	73-97	81-97	73-97	73-97
Total Coliform	73-97	81-97	73-97	73-97
Fecal Streptoccocus	76-97	81-97	76-97	76-97

6. Results

a. Physical Characteristics

The C-14 Canal's physical characteristics (water temperature, pH, and specific conductance) were very similar at all sampling locations (Table III.10). Twenty-five year median temperatures ranged from 26.0 to 26.1°C while means ranged from 25.6 to 25.9°C. Mean and median pH values were basically the same at all sites with a value of either 7.7 or 7.8. The westernmost Site (9) had slightly higher specific conductance recordings than Sites 6-8, however, all means and medians were below 700 Fmhos.

Table III.10. Descriptive Statistics for Temperature (Temp; °C= degrees Celsius), pH, and Specific Conductance (Cond; Fmhos =micromhos/centimeter @ 25°C) in the C-14 Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
6	Temp	°C	365	26.0	25.6	3.6	34.0	15.0	0
7	Temp	°C	65	26.0	25.9	3.7	34.0	18.0	0
8	Temp	°C	155	26.1	25.8	3.8	32.6	17.0	0
9	Temp	°C	157	26.0	25.6	3.9	32.3	17.2	0
6	pH	units	372	7.7	7.7	0.3	8.7	6.5	0
7	pH	units	67	7.7	7.7	0.3	8.3	7.0	0
8	pH	units	157	7.8	7.8	0.3	8.4	6.9	0
9	pH	units	159	7.8	7.8	0.3	8.4	6.9	0
6	Cond	Fmhos	288	610	664	157	1210	398	0
7	Cond	Fmhos	66	624	652	154	1050	360	0
8	Cond	Fmhos	67	638	672	190	1170	365	0
9	Cond	Fmhos	67	670	704	198	1170	357	0

b. Total Organic Carbon and Turbidity

All sites were characterized by mean and median total organic carbon (TOC) concentrations around 20.00 mg/l (Table III.11). Maximum values for the entire period ranged from 44.90 mg/l to 63.30 mg/l. Sites 8 and 9 (above S-37B) had nearly identical 18-year mean, standard deviation and median TOC values while Sites 6 and 7 closely reflected each other in TOC content. Currently, TOC is not regulated under local or state water quality standards.

At all sites, turbidity levels were typically low (< 5.0 nephelometric turbidity units, ntus) and normally within compliance of Broward County's standard of 10.0 ntus (Table III.11). Only one maximum value (15.0 ntus, Site 8) was above the standard. Site 8's mean, standard deviation, and median data indicate this was an unusual occurrence.

Table III.11. Descriptive Statistics for Total Organic Carbon Concentrations (TOC) and Turbidity Levels (Turb) in the C-14 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
6	TOC	mg/l	264	18.35	21.08	8.23	63.30	3.90	0
7	TOC	mg/l	61	18.70	21.57	9.74	54.80	9.39	0
8	TOC	mg/l	61	20.20	22.75	10.98	61.10	8.96	0
9	TOC	mg/l	60	20.50	22.79	9.78	44.90	8.16	0
6	Turb	ntu	354	1.5	1.7	1.0	9.6	0.25	1
7	Turb	ntu	67	1.4	1.5	0.7	3.7	0.25	1
8	Turb	ntu	133	2.0	2.4	1.7	15.0	0.25	2
9	Turb	ntu	133	2.0	2.4	1.4	8.2	0.6	0

c. Dissolved Oxygen and Biochemical Oxygen Demand

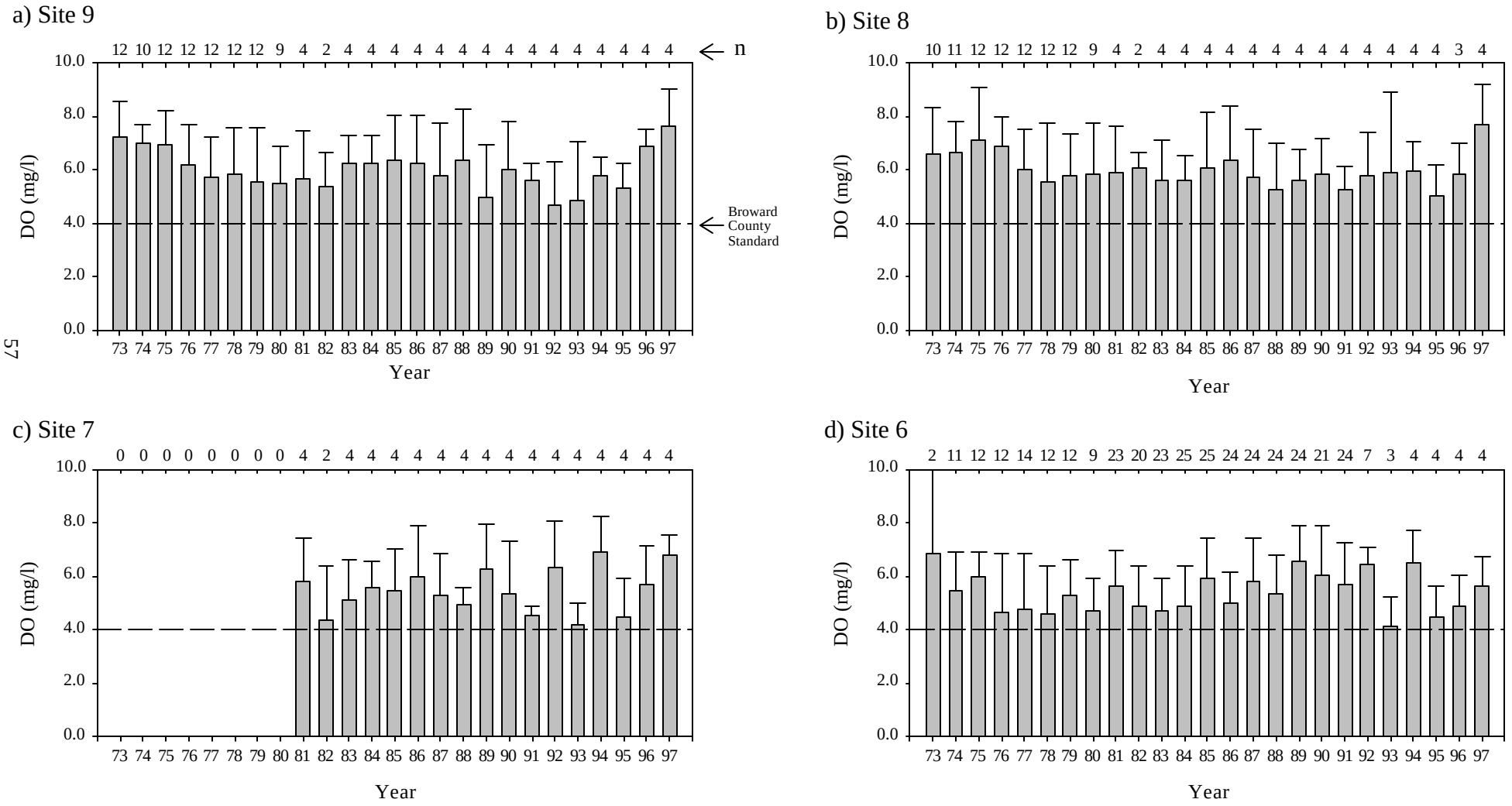
Mean and median dissolved oxygen (DO) concentrations over the full study period were slightly higher in the western sites of the C-14 Canal (Sites 8 and 9) than in the eastern areas (Sites 6 and 7 (Table III.12). However, averages and medians were above (i.e., within compliance) of the Broward County single sample standard of 4.0 mg/l and twenty-four hour average standard of 5.0 mg/l. Biochemical oxygen demand was similar basinwide and normally around 2.0 mg/l.

Table III.12. Descriptive Statistics for Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) Concentrations in the C-14 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculations. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
6	DO	mg/l	367	5.5	5.4	1.6	9.3	0.4	0
7	DO	mg/l	65	5.7	5.5	1.5	8.2	2.90	0
8	DO	mg/l	156	6.1	6.1	1.7	12.7	2.9	0
9	DO	mg/l	158	6.4	6.1	1.6	10.0	0.9	0
6	BOD	mg/l	351	1.5	1.7	0.9	8.4	0.3	0
7	BOD	mg/l	48	1.6	2.0	1.1	5.4	0.8	0
8	BOD	mg/l	131	2.0	2.1	1.0	6.0	0.8	0
9	BOD	mg/l	132	2.0	2.0	0.9	5.0	0.4	0

Basinwide, sites did not exhibit an annual DO average below the Broward County standard of 4.0 mg/l. Sites 8 and 9 exhibited similar annual DO averages (Figure III.16), typically ranging from 5.5 to 6.5 mg/l. Yearly averages at Sites 6 and 7 were similar to the upper ranges of Sites 8 and 9 but were

Figure III.16. Mean Annual Dissolved Oxygen Content Within the C-14 Canal Basin from 1973 to 1997. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance, DO levels should be above the Broward County standard (4.0 mg/l) indicated by the dashed line.



characterized by more values between 4.5 and 5.0 mg/l.

Dissolved oxygen concentrations were designated as poor, fair, and good based on water quality standards (see Section III.E.6.c). In addition, the changes over time are presented with special reference to the closing of WWTPs within the basin (see III.F.3). The overall percentage of DO samples not achieving single sample standard (4.0 mg/l) compliance in the C-14 Canal was typically below 25.0% (Figure III.17). Sites 8 and 9 mirrored each other in their compliance ratings with a decrease in the percentage of good DO samples by the final period (1986-1997), however, the amount of poor DO samples remained relatively low (**#** 11.1%) throughout time. Overall, Sites 6 and 7 (below S-37B) were characterized by slightly more poor samples than Sites 8 and 9 but had similar good ratings.

Seasonal influences on DO concentrations were investigated by grouping wet (June through October) and dry (November through May) season samples from 1989-1997, a period without WWTP influence. Higher dissolved oxygen values were normally observed during the dry season than during the wet season (Figure III.18). All medians were above the Broward County standard but Sites 6 and 7 were characterized by 25^{th} percentile values below 4.0 mg/l. Statistically significant seasonal differences were observed at Sites 6, 7, 8, and 9 (t-test; $p < 0.001$, < 0.05, < 0.001, and < 0.01, respectively). The power of the performed tests at Site 6 (0.598) and Site 9 (0.779) were below the power of 0.800 so findings should be viewed cautiously.

d. Total Phosphorus

Mean and median total phosphorus (TP) levels for the entire sampling period were above the Broward County freshwater standard of 0.020 mg/l standard (Table III.13). Unusually high TP maxima (> 1.5 mg/l) were observed at Sites 7 and 8 that influenced their mean values. TP median values were similar between Sites 6, 7, and 8 ranging from 0.72 to 0.74 mg/l. Site 9 had the lowest median TP within the basin.

Table III.13. Descriptive Statistics for Total Phosphorus (TP) Concentrations in the C-14 Canal Basin. If a sample was below the method detection limit (MDL),half of the MDL value was used in the calculations. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
6	TP	mg/l	358	0.072	0.094	0.077	0.670	0.010	39
7	TP	mg/l	66	0.074	0.122	0.216	1.550	0.010	5
8	TP	mg/l	135	0.074	0.133	0.255	2.550	0.010	17
9	TP	mg/l	135	0.050	0.096	0.124	0.870	0.010	28

Annual TP averages at all sites were normally much lower during 1988 to 1997 than the period from 1974 to 1987 (Figure III.19). Interestingly, extremely high and variable means were observed in 1987 at Sites 7-9. Basinwide differences were not clearly evident and only two sites (Site 6, 1995 and Site

Figure III.17. Dissolved Oxygen (DO) Concentrations Observed in the C-14 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall be below 4.0 mg/l. Thus, all concentrations greater than or equal to 5.0 mg/l are classified as good and DO concentrations between 4.0 to 4.9 mg/l are considered fair. Readings below 4.0 mg/l are defined as poor.

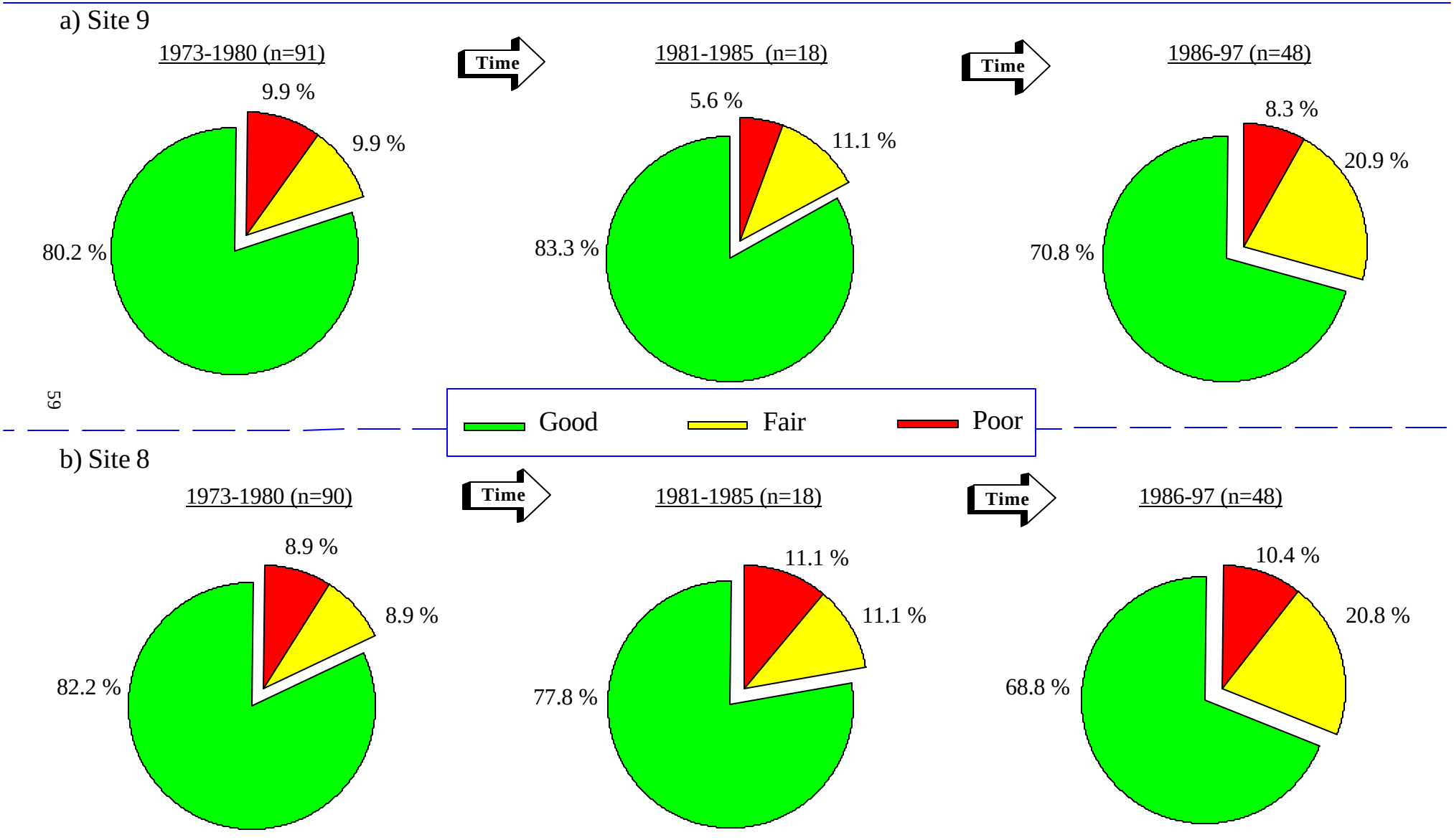
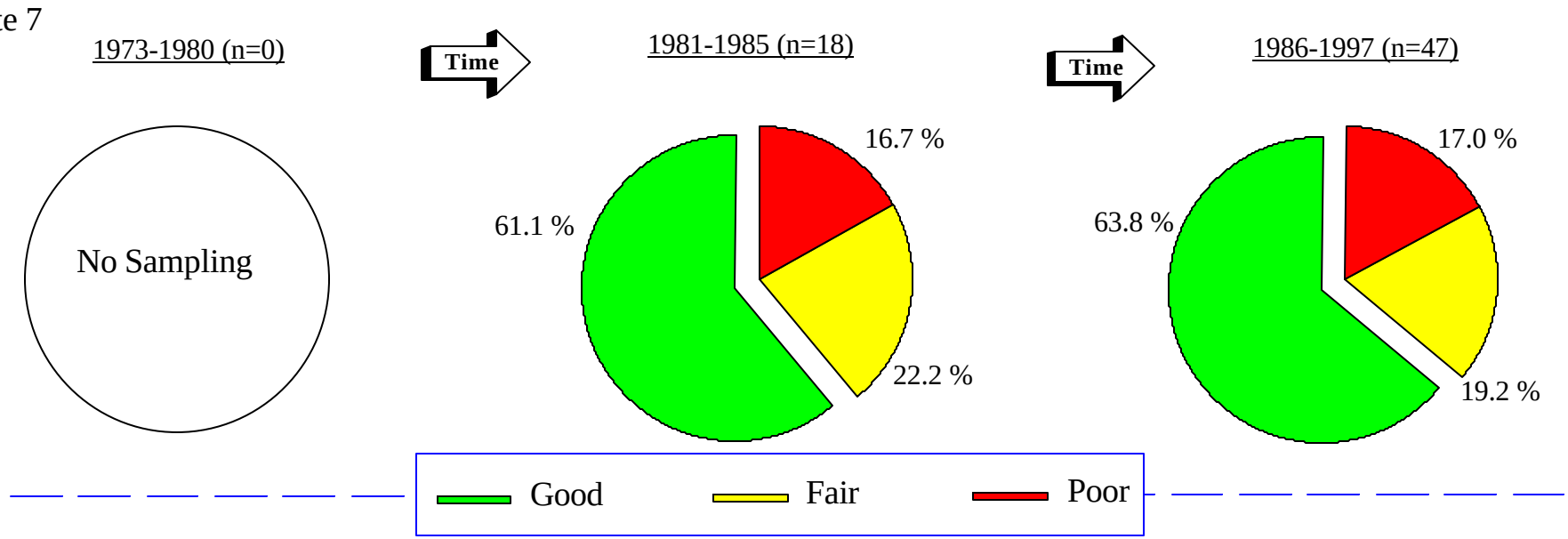


Figure III.17 (Cont.). Dissolved Oxygen (DO) Concentrations Observed in the C-14 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall be below 4.0 mg/l. All concentrations greater than or equal to 5.0 mg/l are classified as good and DO concentrations between 4.0 to 4.9 mg/l are considered fair. Readings below 4.0 mg/l are defined as poor.

c) Site 7



d) Site 6

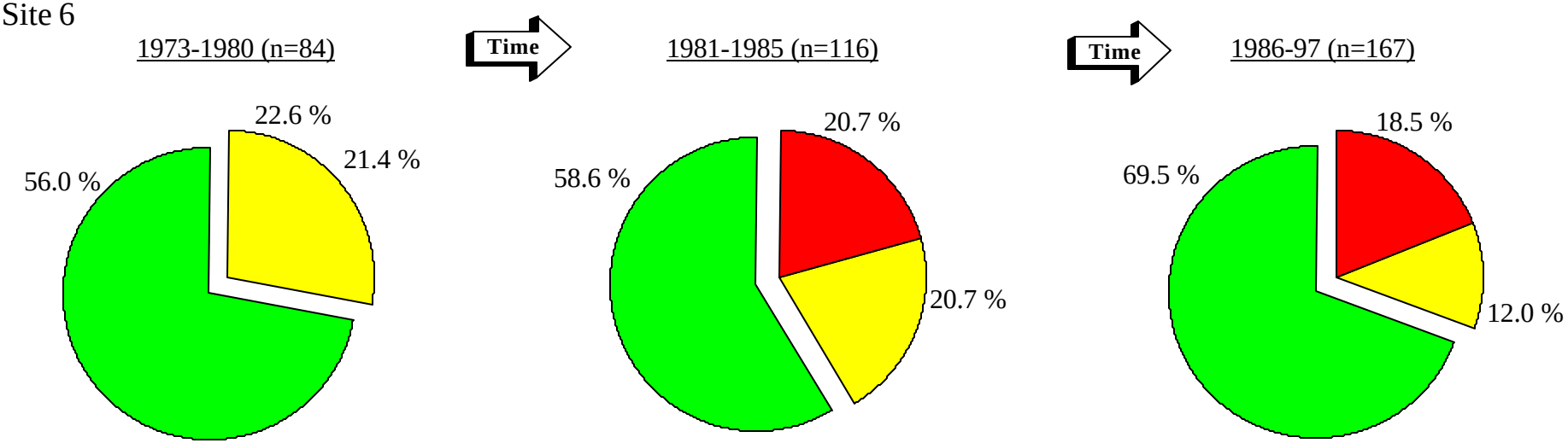


Figure III.18. C-14 Canal Basin Dissolved Oxygen (DO) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season means were observed at Sites 6, 7, 8, and 9 ($p < 0.001$, 0.05, 0.001, and 0.01, respectively; t-test).

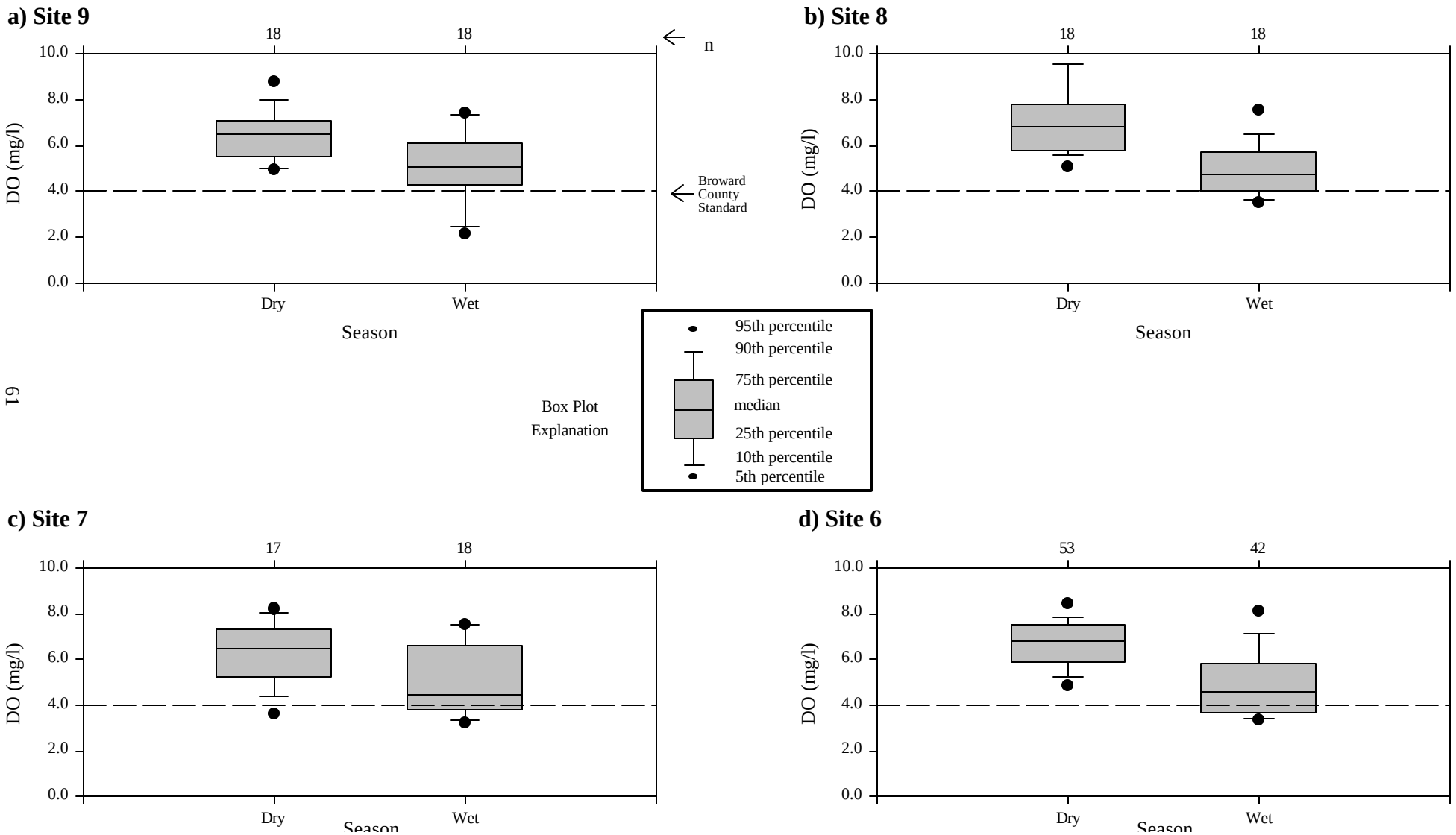
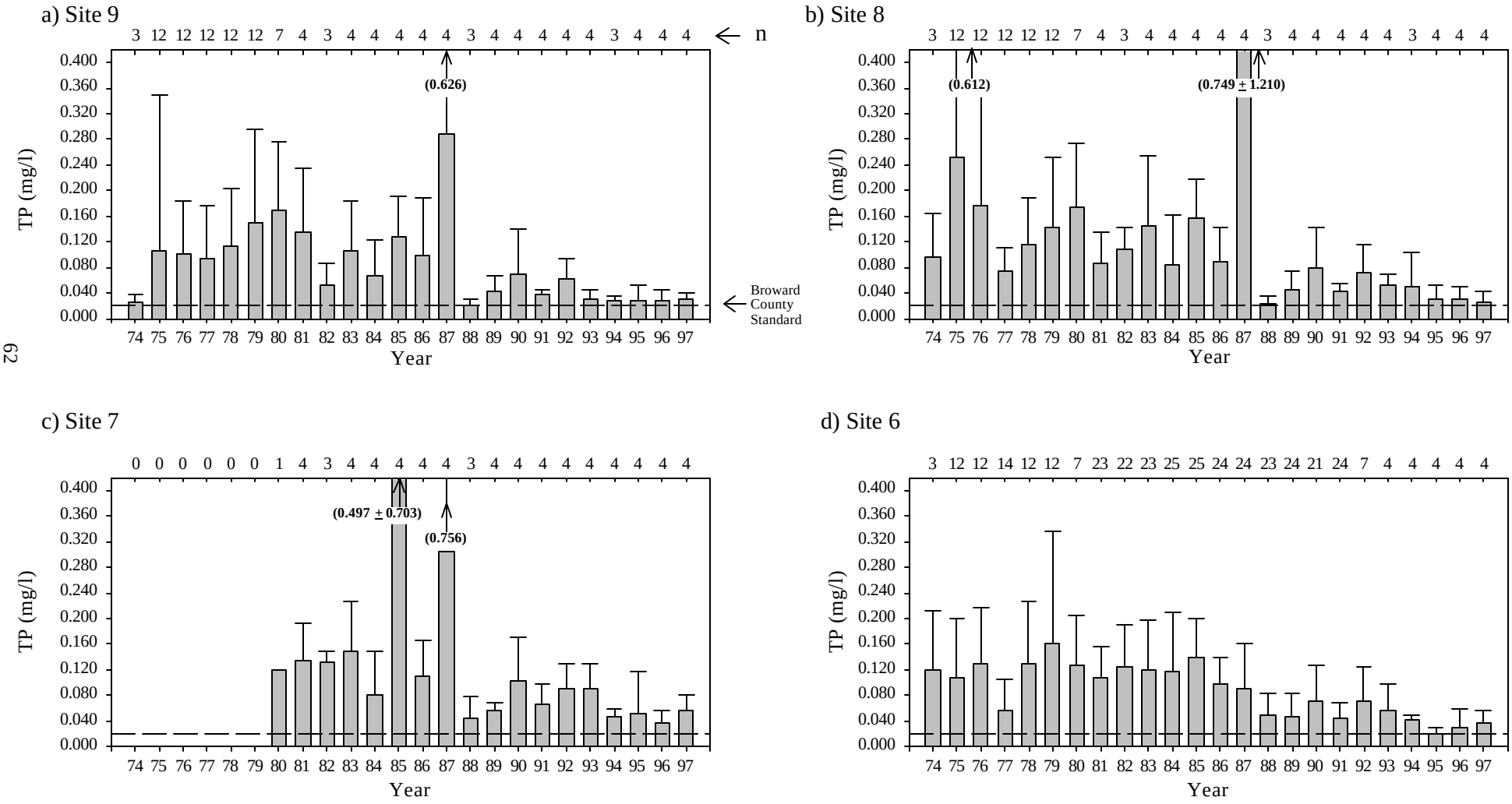


Figure III.19. Annual Mean Total Phosphorus (TP) Levels Within the C-14 Canal Basin from 1974 to 1997. Means and standard deviations (sd; error bars) calculated from biweekly, monthly, and/or quarterly samples with the number of samples (n) per year noted on the upper x-axis. The Broward County single sample standard (0.02 mg/l) is indicated by the dashed line. Numbers in parentheses represent mean plus sd outside range of graph.



9, 1988) had annual means below (i.e., within compliance) of the Broward County standard (0.020 mg/l). However, annual TP means were below 0.030 mg/l over the last three years (1995-1997) at Sites 6 and 8, and over the previous five years at Site 9.

To better examine compliance patterns within the canal, all individual samples were rated in terms of Broward County's TP standard (0.020 mg/l; see Section III.E.6.d) and are presented with special reference to the closing of WWTPs within the basin (see Section III.F.3). At Sites 6, 8, and 9, the amount of poor samples decreased from near or above 70% to less than 38.3% by the final period (1986-1997, Figure III.20). A decrease was also realized at Site 7 but 48.9% of samples still rated poorly between 1986 and 1997. Changes in the C-14 Canal's TP content after 1985 were evident by the large increase in fair rated samples that indicates an improvement in water quality. However, the highest percentage of good samples (i.e., within compliance) was only 29.8% (Site 9) and the lowest percentage was 10.7% (Site 7).

Observations from 1989-97 revealed no statistical differences between wet and dry seasons (Figure III.21) and seasonal values exhibited fairly similar variability. All median values were above the Broward County standard. However, Site 7's 75^{th} percentile TP value was nearly 0.100 mg/l. Wet season 25^{th} percentile TP values were below the standard (i.e., within compliance) at Sites 8 and 9 but above 0.020 mg/l at Sites 6 and 7.

e. Nitrogen

Total nitrogen levels are calculated from the total Kjeldahl nitrogen (TKN) and nitrite+nitrate-nitrogen (NO_2+NO_3) concentrations. Over a 17-year period (1981-1997), all long term mean and median TN values were below the Broward County freshwater standard (1.500 mg/l). The C-14 basins's highest TN content was observed at the westernmost site (Site 9) and the lowest values were observed at the easternmost sampling location (Site 6, Table III.14).

Mean and median TKN content represented over 85.0% of corresponding TN concentrations and followed a similar spatial pattern (Table III.14). Ammonia-nitrogen was below the method detection limit in nearly 45.0% of sampling events in the western region (Sites 8 and 9) compared to 25.8% and 33.4% at Sites 7 and 6, respectively. The highest median and mean (NO_2+NO_3) values were at Site 6 while the lowest were seen at Site 8.

Figure III.20. Total Phosphorus (TP) Concentrations Observed in the C-14 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County freshwater TP standard of 0.020 mg/l. The percentage of samples below 0.020 mg/l are classified as good. A fair rating was given to concentrations between 0.021 mg/l to 0.060 mg/l. Values equal to or greater than three times the standard (i.e., 0.060 mg/l) are classified as poor.

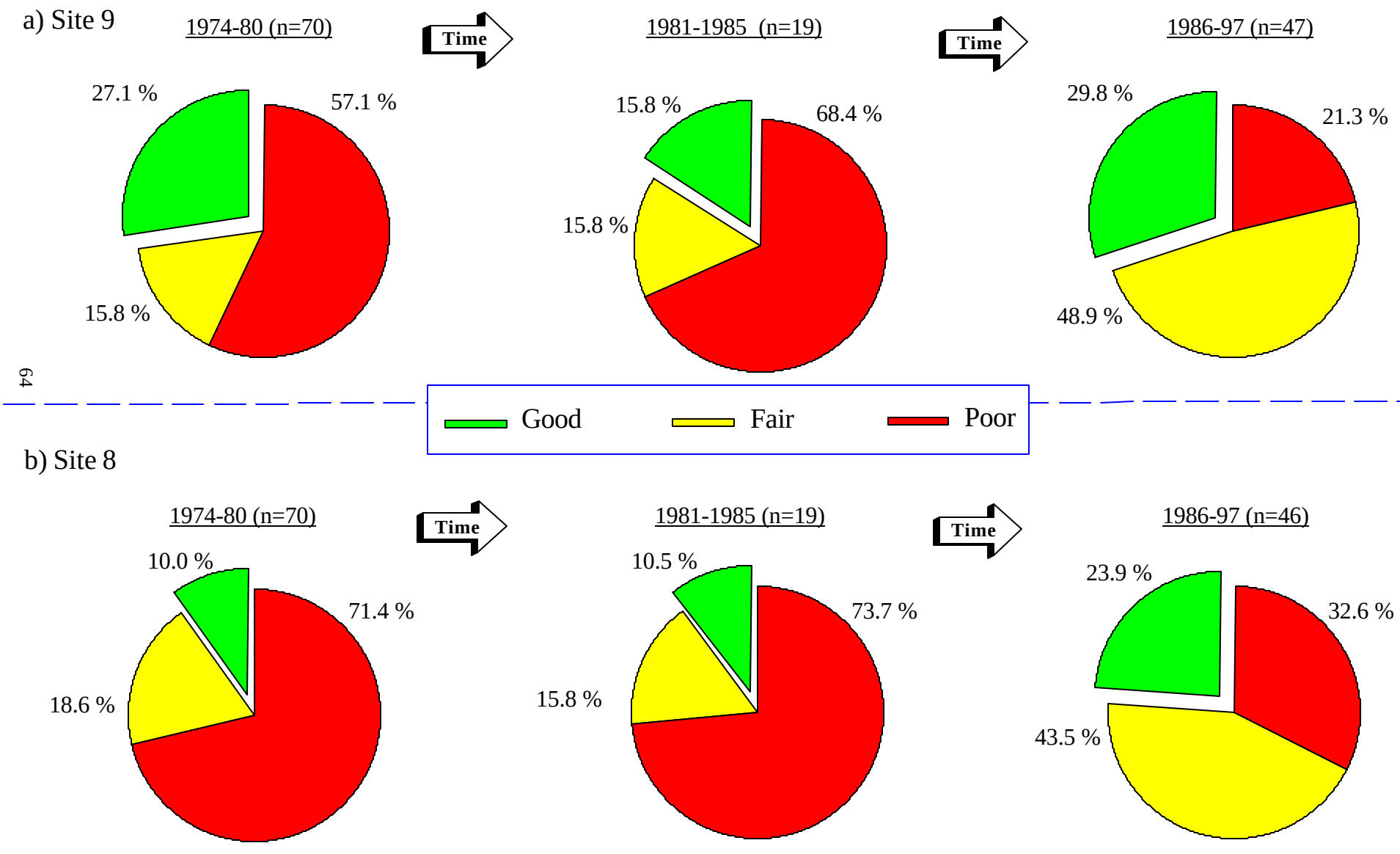


Figure III.20 (cont.). Total Phosphorus (TP) Concentrations Observed in the C-14 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County freshwater TP standard of 0.020 mg/l. The percentage of samples below 0.020 mg/l are classified as good. A fair rating was given to concentrations between 0.021 mg/l to 0.060 mg/l. Values equal to or greater than three times the standard (i.e., 0.060 mg/l) are classified as poor.

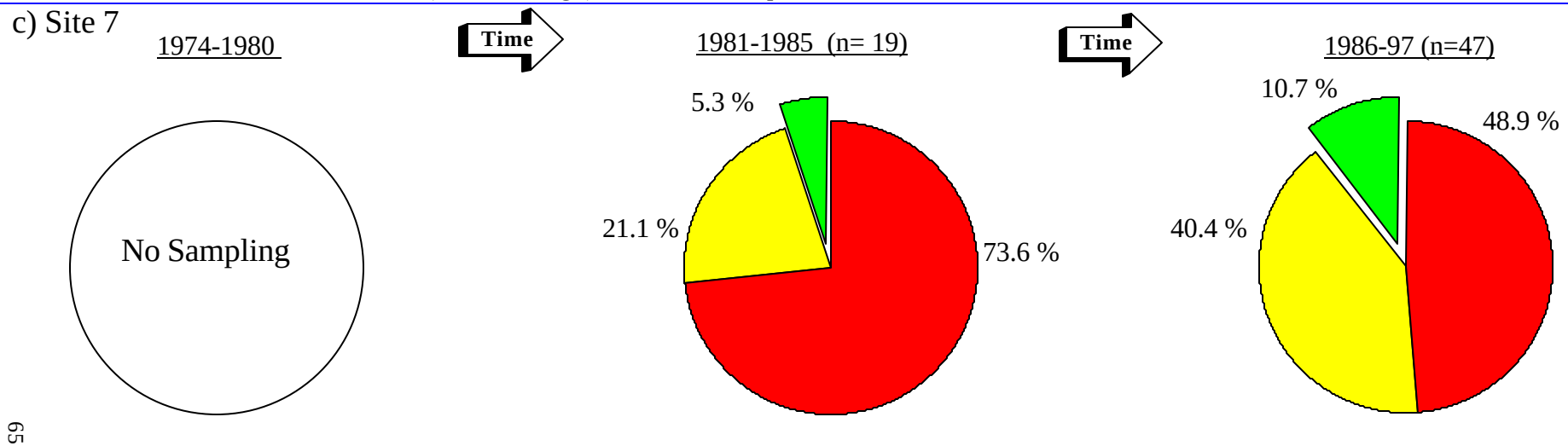


Figure III.21. C-14 Canal Basin Total Phosphorus (TP) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season mean and/or medians were not observed at any site.

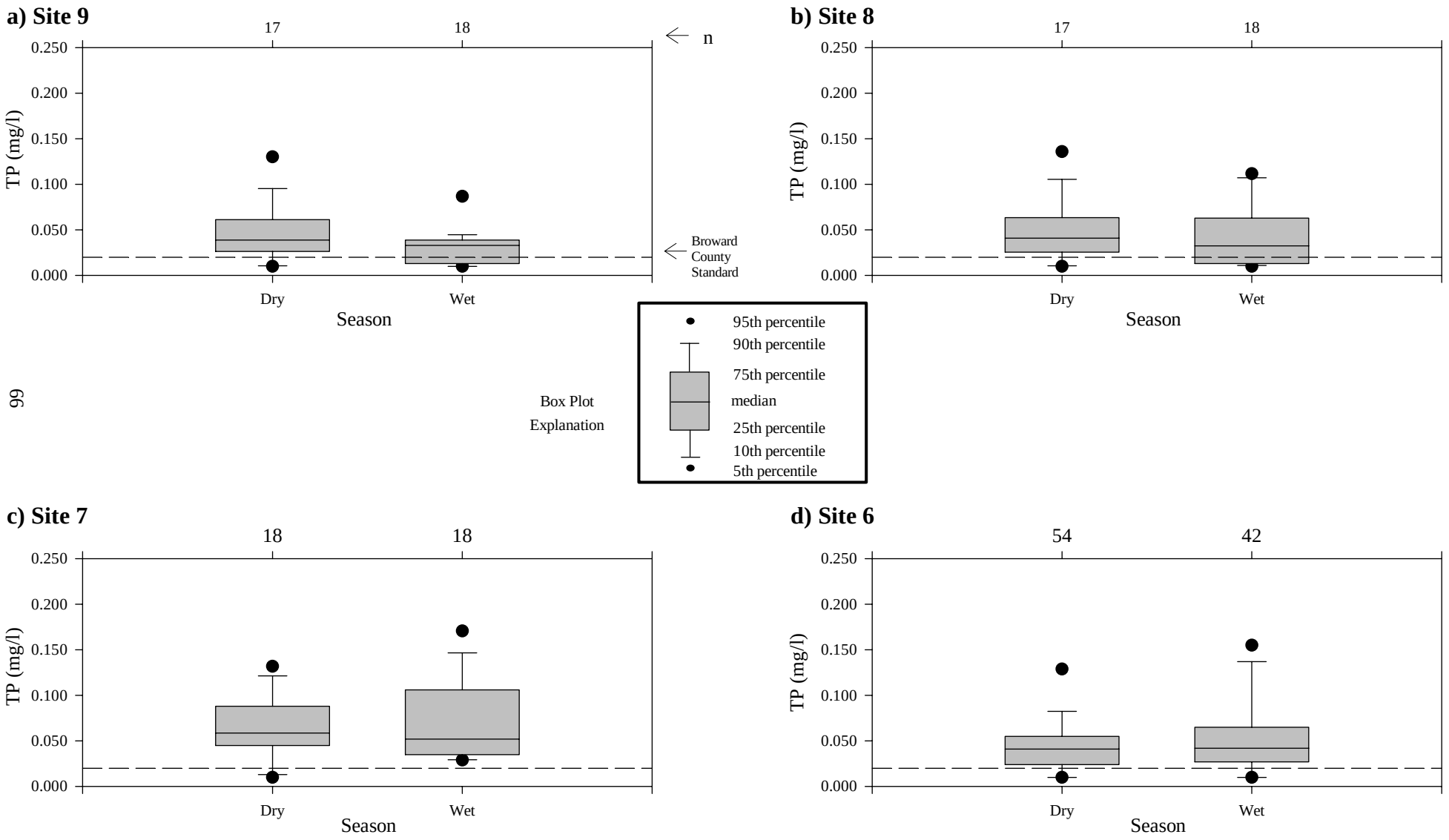


Table III. 14. Descriptive Statistics for Nitrite+Nitrate- Nitrogen (NO_2+NO_3), Ammonia-Nitrogen (NH_3), Total Kjeldahl Nitrogen (TKN) , and Total Nitrogen (TN) Concentrations in the C-14 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL). Total Nitrogen was calculated as the sum of TKN and NO_2+NO_3.

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
6	NO_2+NO_3	mg/l	290	0.114	0.142	0.127	0.819	0.005	24
7	NO_2+NO_3	mg/l	67	0.081	0.111	0.096	0.390	0.005	7
8	NO_2+NO_3	mg/l	66	0.063	0.100	0.119	0.768	0.005	10
9	NO_2+NO_3	mg/l	66	0.064	0.122	0.139	0.757	0.005	7
6	NH_3	mg/l	263	0.056	0.082	0.142	2.050	0.005	88
7	NH_3	mg/l	62	0.051	0.084	0.125	0.887	0.005	16
8	NH_3	mg/l	61	0.026	0.056	0.073	0.328	0.005	28
9	NH_3	mg/l	61	0.029	0.079	0.126	0.803	0.005	27
6	TKN	mg/l	285	1.010	1.125	0.377	2.300	0.359	0
7	TKN	mg/l	65	1.030	1.139	0.408	2.380	0.489	0
8	TKN	mg/l	64	1.150	1.273	0.471	2.500	0.507	0
9	TKN	mg/l	64	1.240	1.268	0.494	2.650	0.199	0
6	TN	mg/l	285	1.194	1.266	0.378	2.444	0.555	N/A
7	TN	mg/l	65	1.218	1.250	0.414	2.411	0.517	N/A
8	TN	mg/l	64	1.220	1.374	0.497	2.738	0.632	N/A
9	TN	mg/l	64	1.408	1.392	0.517	2.900	0.212	N/A

Annual mean total nitrogen (TN) content was generally higher in the 1980's than during the 1990's at all four sites (Figure III.22). Sites 8 and 9 TN levels were very comparable while annual TN content measured at Sites 6 and 7 were more alike. In addition, most exceedances of the Broward County standard (1.500 mg/l) occurred during the 1980's in the canal northwest of S-37B (Sites 8 and 9).

To better understand compliance patterns within the canal, each TN sample was given a rating based on Broward County's water quality standards (see Section III.E.5.e). Additionally, changes over time were investigated based on the closing of WWTPs within the basin (see Section III.F.3). Overall, the majority of TN samples rated good at every site during each period (Figure III.23). The lowest compliance level (65.0%) in the previous five years (1993 to 1997) was at Site 8 while Site 6 had the highest with 90.0%. With 78.9% good rated samples during 1993-1997 compared to 57.7% from 1986-1992, Site 9 exhibited the greatest increase between two periods. Only the locations northwest of S-37B (Sites 8 and 9) exhibited any poor samples but the percentages were always low (< 7.5%) and occurred before 1993.

Dry season TN values were generally higher than wet season values at all sites and all median values were below the 1.500 mg/l level (Figure III.24). However, dry season TN medians were much closer

Figure III.22. Mean Annual Total Nitrogen (TN) Levels Within the C-14 Canal Basin from 1981 to 1997. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. The Broward County standard (1.500 mg/l) is indicated by the dashed line.

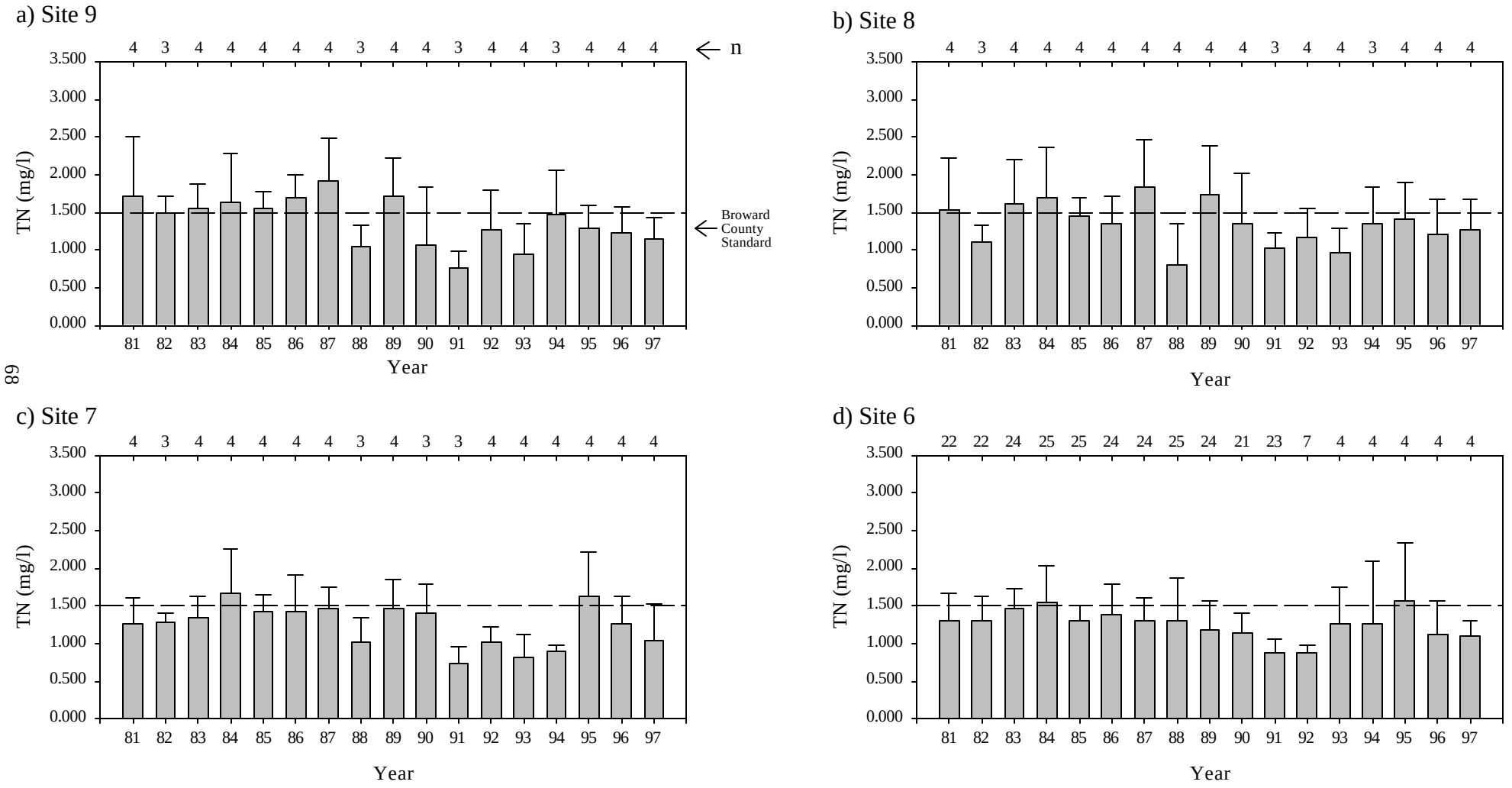


Figure III.23. Total Nitrogen (TN) Concentrations Observed in the C-14 Canal basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified as good. A fair rating was given to concentrations between 1.501 mg/l to 2.500 mg/l. Values greater than 2.500 mg/l are classified as poor.

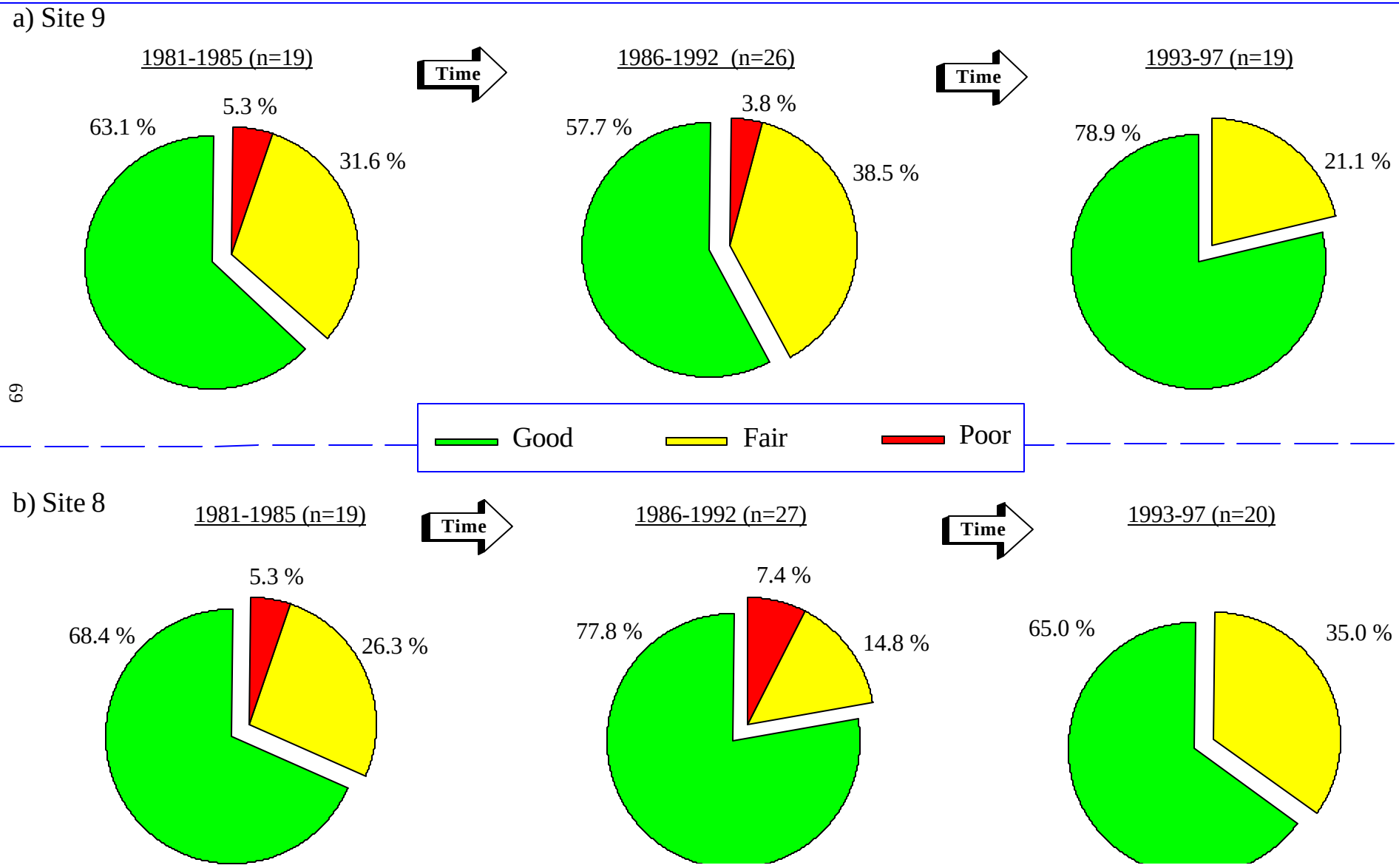


Figure III.23. Total Nitrogen (TN) Concentrations Observed in the C-14 Canal basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified as good. A fair rating was given to concentrations between 1.501 mg/l to 2.500 mg/l. Values greater than 2.500 mg/l are classified as poor.

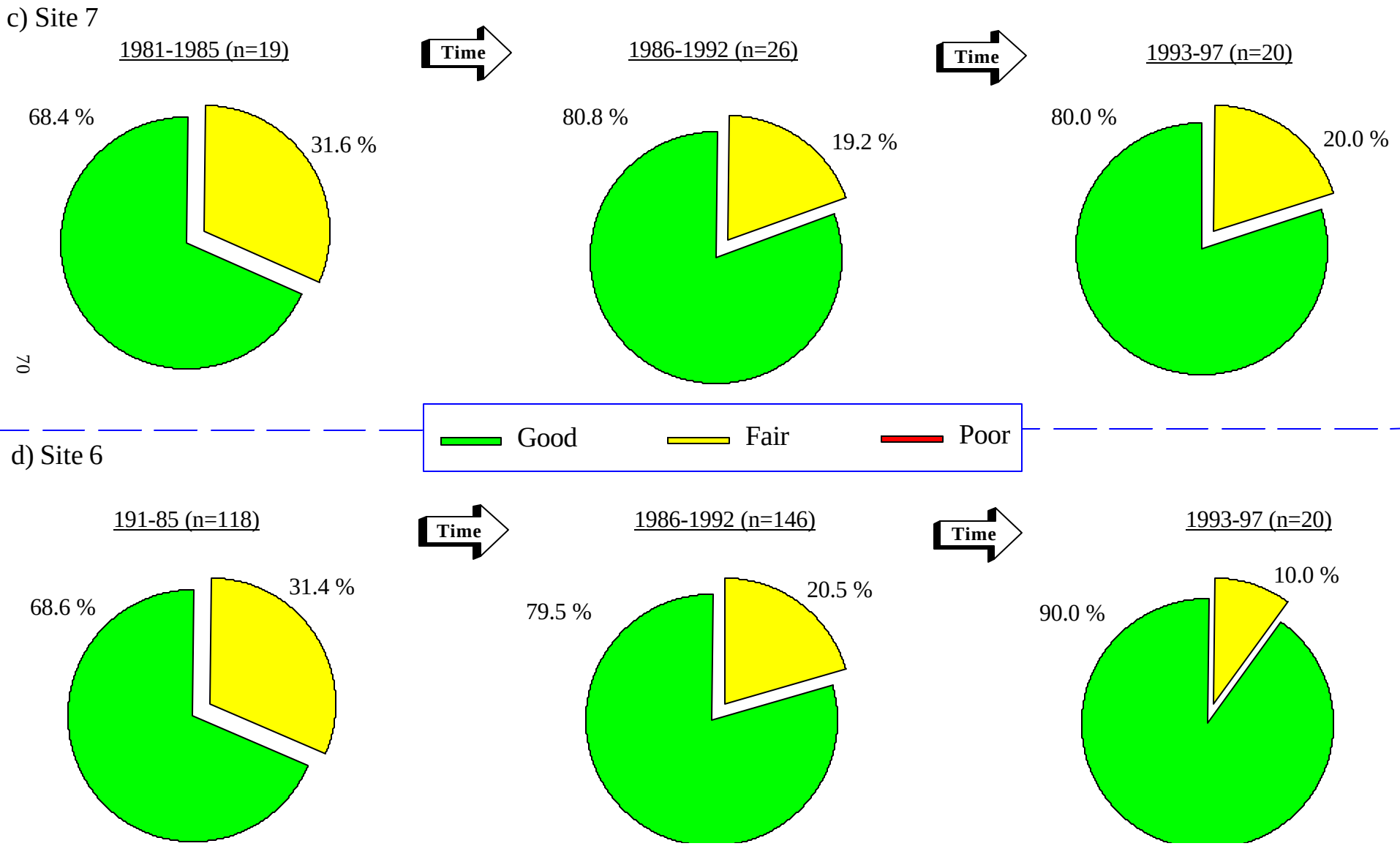
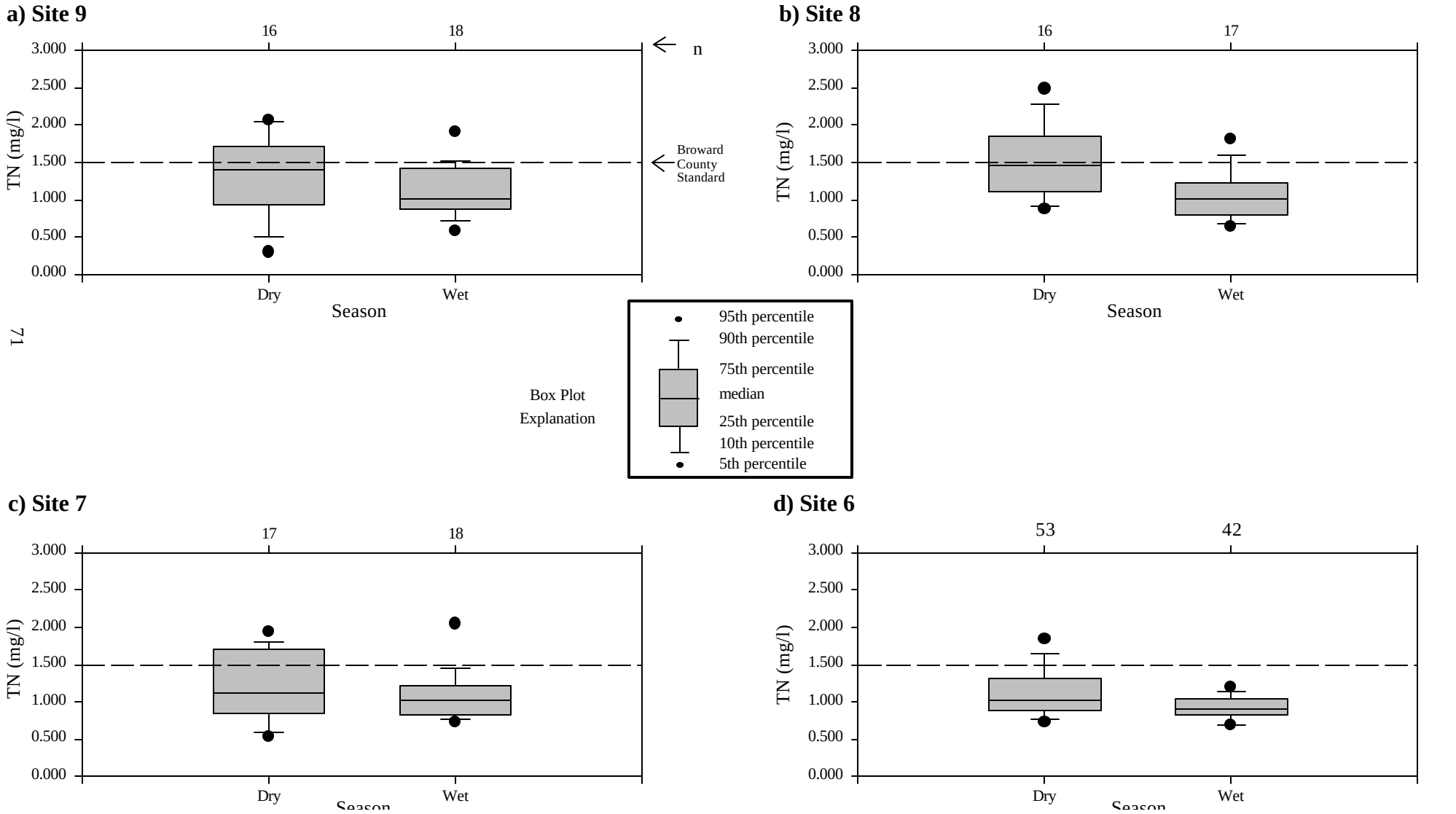


Figure III.24. C-14 Canal Basin Total Nitrogen (TN) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. A statistically significant difference between wet and dry season medians was observed at Site 6 ($p < 0.005$; Mann-Whitney Rank Sum Test) and between mean values at Site 8 ($p < 0.01$, t-test) but not at Sites 7 and 9.



to the standard at Sites 8 and 9 than at Sites 6 and 7. A statistical seasonal difference in median TN content was observed at Site 6 (Mann-Whitney Rank Sum Test, $p < 0.005$) and in mean TN concentrations at Site 8 (t-test, $p < 0.01$).

f. Bacteriological Parameters

Bacteriological parameters included fecal coliform (FC), total coliform (TC), and fecal streptococcus (FS). Mean values were higher than medians (Table III.15). However, bacteriological mean values are often skewed by outstanding high values (BCDNRP 1994). The high standard deviations and large differences between maximum and minimum values attest to the occurrence of this pattern throughout the C-14 Canal.

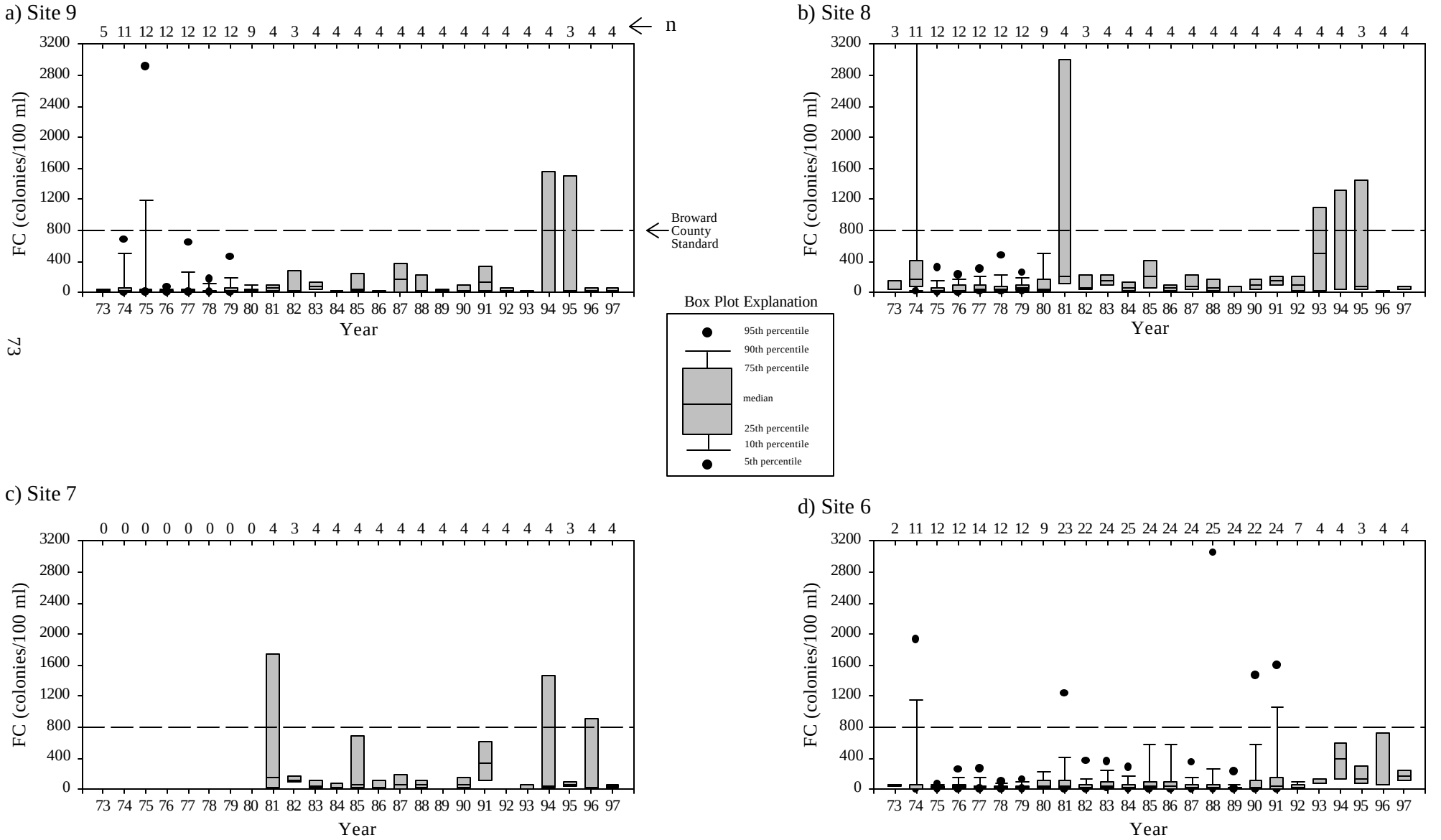
Based on the Broward County FC standard of 800 colonies/100 ml and the TC standard 2,400 colonies/100 ml (both single samples), the C-14 Canal was characterized by low bacteria levels (Table III.15) over the previous twenty-five years. The maximum bacteriological concentrations were high but all FC and FS median values were less than 100 colonies/100 ml and TC median values were under 500 colonies/100 ml. Thus, enhanced ambient bacteriological values were an anomalous occurrence.

Table III.15. Descriptive Statistics for Fecal Coliform (FC), Total Coliform (TC), and Fecal Streptococcus (FS) in the C-14 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL) and the unit of measurement is colonies/100 ml (col).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
6	FC	col	371	30	190.0	928	12000	5	66
7	FC	col	66	32	210	581	3200	5	14
8	FC	col	149	57	265	1117	12000	5	7
9	FC	col	151	20	116	405	3200	5	31
6	TC	col	370	250	1033	4953	80000	12	9
7	TC	col	66	150	567	1707	13000	16.5	2
8	TC	col	156	440	1714	6642	80000	15	2
9	TC	col	159	250	709	1614	14000	16.5	7
6	FS	col	346	98	684	5547	100000	5	73
7	FS	col	67	49	351	781	5000	12	20
8	FS	col	123	98	456	977	6700	5	22
9	FS	col	123	49	277	724	6700	5	32

Due to the large amount of variability around the mean, yearly box plots were plotted for FC median instead of the mean (Figure III.25). For all sites, the annual median FC value never exceeded the Broward County single sample standard of (800 colonies/100 ml). However, the 75th percentile FC

Figure III.25. Yearly Box Plots of Fecal Coliform (FC) Levels within the C-14 Canal Basin from 1973 to 1997. Medians and percentiles calculated from monthly and quarterly samples with the number of samples (n) noted on the upper axis. The Broward County single sample standard (800 colonies/100 ml) is indicated by the dashed line.



values were greater than the standard in 1981, 1993-1995 at Site 8, as well as in 1994 and 1995 at Site 9. Southeast of S-37B, at Site 7, the years of 1981, 1994, and 1996 also had 75th percentile readings above 800 colonies/100 ml. Site 6 was only characterized by an occasional 90th or 95th percentile values out of compliance with the FC standard.

To better understand compliance patterns within the canal, each specific sample was given a rating based on three different Broward County water quality standards (see Section III.E.6.f). and the closing of WWTPs within the basin was addressed (see Section III.F.3). The overall percentage of poor samples was low (<10.0%) throughout all periods at each sampling site (Figure IV 26). Except for Site 7, the highest amount of poor samples was during 1986-1997. However, the percentage of good samples throughout the waterway during the same period was between 85.1% and 88.3%.

From 1989 to 1997, a significant statistical difference between wet and dry season FC values was only observed at Site 6 (Mann-Whitney Rank Sum Test, $p < 0.001$, Figure III.27). More importantly, all wet and dry season median values were well below 800 colonies/100 ml and lower than the monthly FC value of 200 colonies/100 ml. Furthermore, Site 8's wet season was the only 75th percentile value above 400 colonies/100 ml but still below the single sample standard.

7. Basin Summary

Although general C-14 Canal water flow is to the eastern estuarine waters from the WCA 2, the S-37B can act as a divide depending on specific hydrological conditions. In this study, two C-14 Canal sampling locations (Sites 8 and 9) were located west of the S-37B (i.e., upstream) but are actually within different sub-basins (west and east). The other two canal sampling sites (6 and 7) are below the S-37B within the same eastern sub-basin and the remnant Cypress Creek channel. The following will discuss the water quality characteristics of these two different segments. In addition, the influence of WWTP discharges and seasonal effects will also be discussed. Finally, questions about the canal and basin brought forth by this initial data analysis effort are listed to support future monitoring and resource planning.

a. Influence of WWTP Discharges

Generally, the end of WWTP discharges signaled the beginning of improved water quality throughout the C-14 Canal. The most marked change was in TP values with poor levels typically being replaced by fair designations. In addition, annual TP means typically decreased from values over 0.100 mg/l to concentrations less than 0.060 mg/l. Total nitrogen concentration also decreased, although not to the extent of TP. The improvement in TN values was best expressed at the Sites 6 and 7 located southeast of S-37B. However, all sites typically had lower annual averages in the 1990's as compared to the 1980's when WWTPs were operating. Interestingly, DO values were relatively similar between the WWTP era and the period afterward.

Figure III.26. Fecal Coliform (FC) Concentrations Observed in the C-14 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100ml (good rating) and no single reading shall be above 800 colonies/100 ml (poor rating). Values between 201 and 800 colonies per 100 ml are defined as fair.

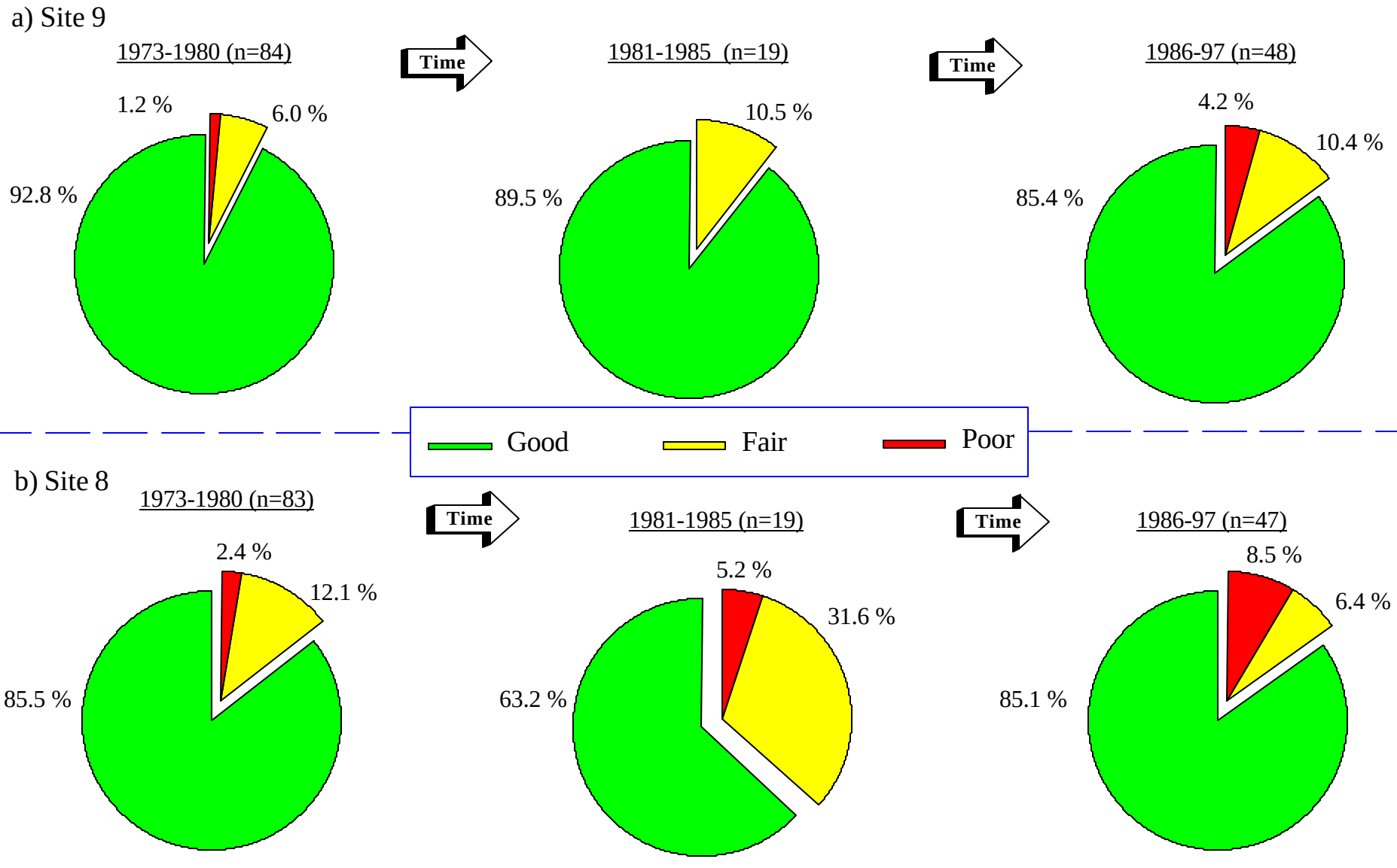
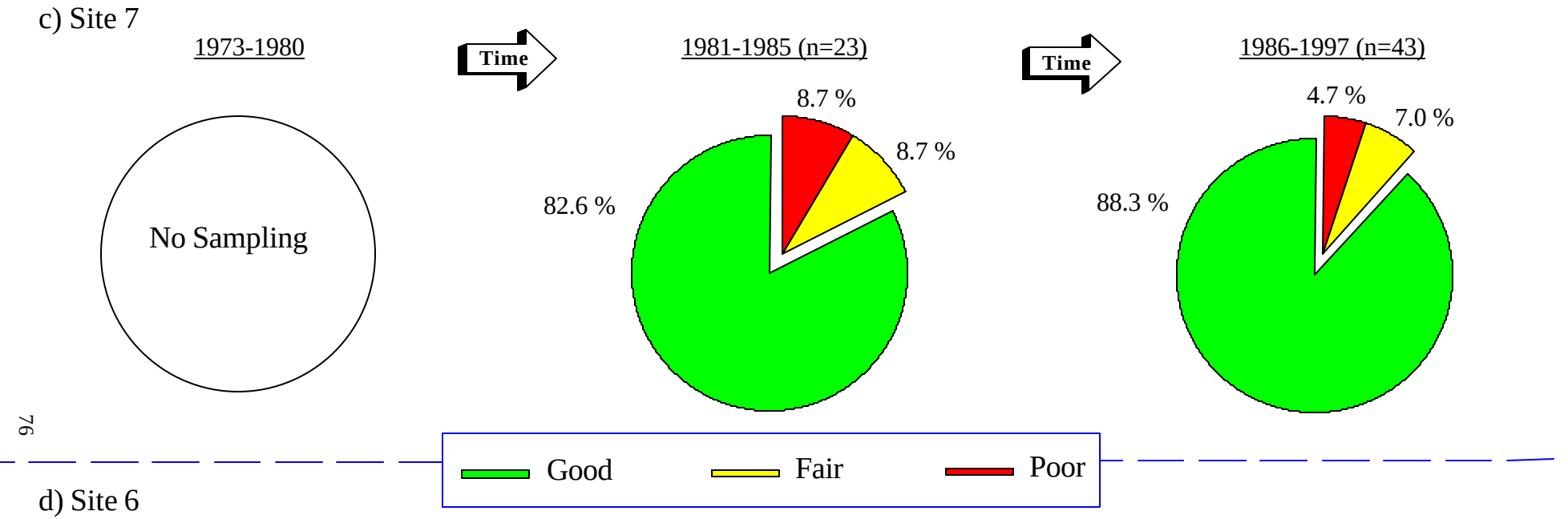


Figure III.26 (Cont.). Fecal Coliform (FC) Concentrations Observed in the C-14 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100ml (good rating) and no single reading shall be above 800 colonies/100 ml (poor rating). Values between 201 and 800 colonies per 100 ml are defined as fair.



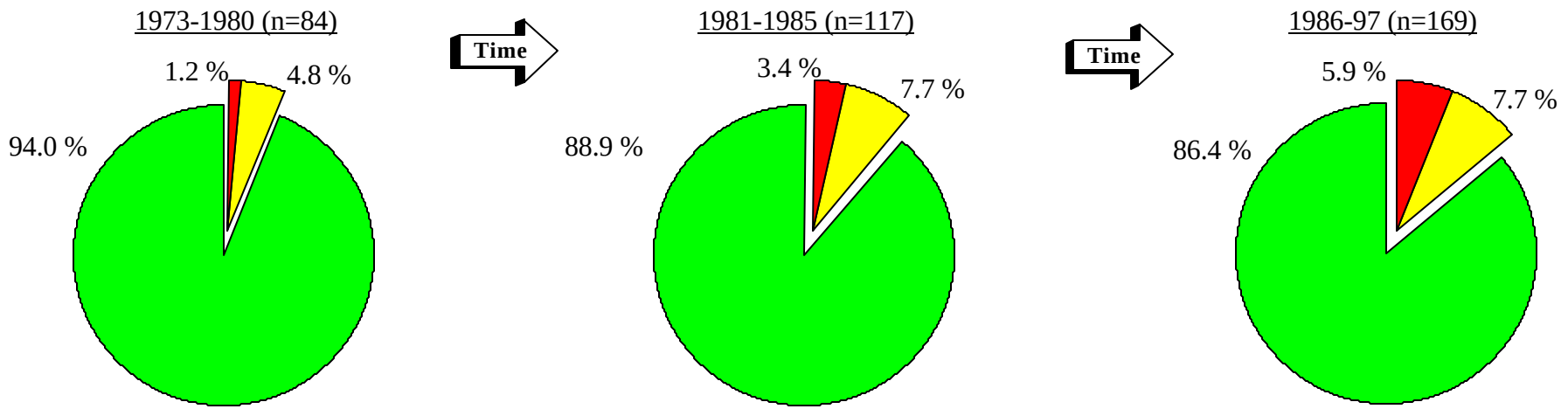
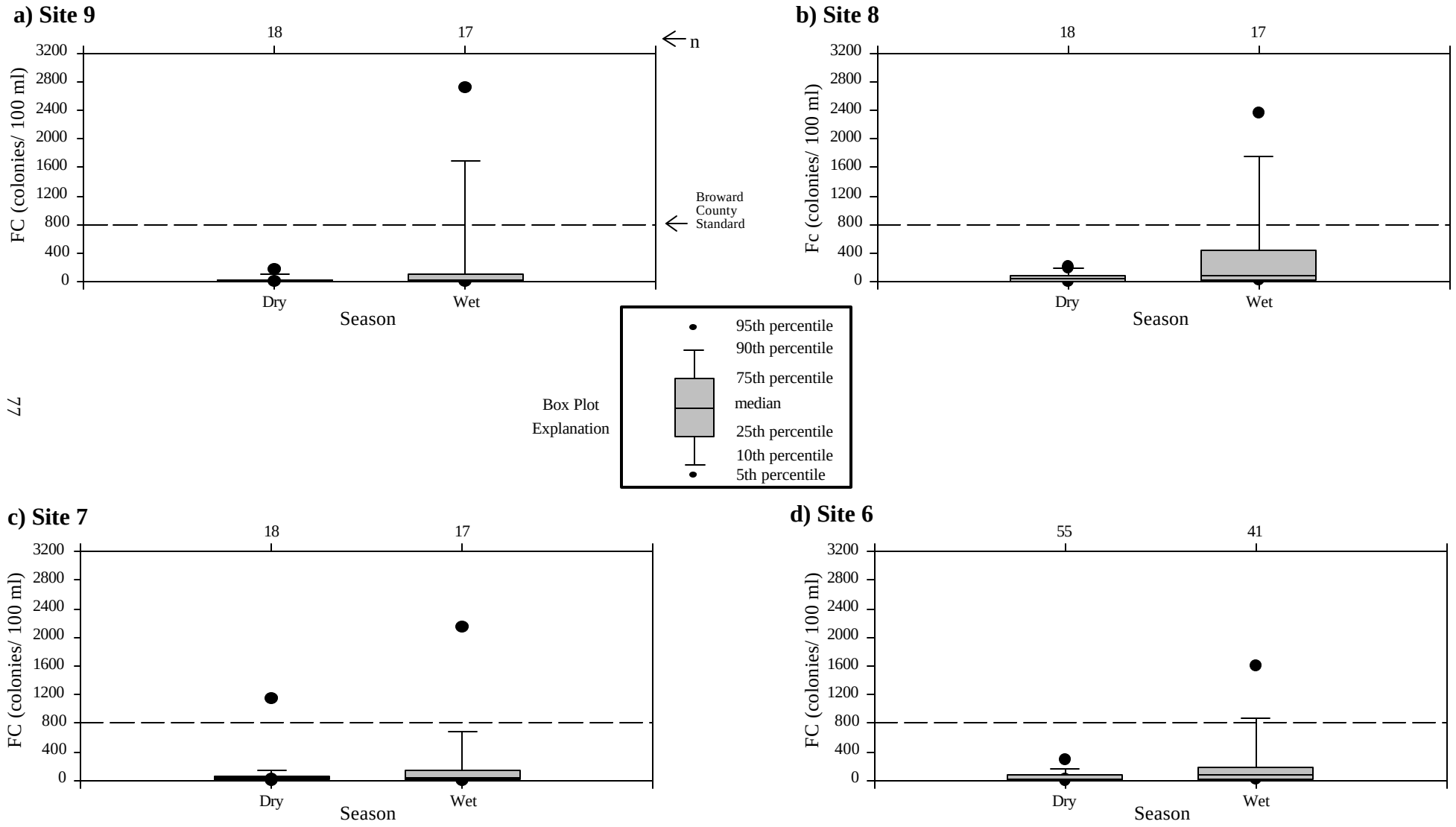


Figure III.27. C-14 Canal Basin Fecal Coliform (FC) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. A statistically significant difference between wet and dry season medians was observed at Site 6 ($p < 0.001$; Mann-Whitney Rank Sum Test) but not at Sites 7 thru 9.



b. Basinwide Water Quality Characteristics (Post-WWTPs)

Overall, water quality was fairly good throughout the C-14 Canal since 1989. In particular, DO concentrations were normally above 5.0 mg/l and rarely below the 4.0 mg/l single sample standard. With the exception of 1995, TN values were normally within compliance (i.e., below) of the 1.500 mg/l standard. Annual FC medians were generally low but a few exceedances of the 800 colonies/100 ml standard were seen, especially in the 1990's.

Total phosphorus levels were the exception to overall good water quality with each site exhibiting less than 30.0% good rated samples (i.e., within standard compliance) even after WWTP discharges ceased. In particular, Site 7 had only 10.7% good samples and 48.9% poor rated samples. Furthermore, wet season values were often near 0.100 mg/l at Site 7. A likely contribution of TP comes from the surrounding land use which is golf courses and plush residential lawns. At the other sites, the large of amount of residential lawns along and/or adjacent to the canal may provide a source of TP through excess fertilizer.

Slight water quality differences were observed between the two sites (8 and 9) upstream of S-37B and the two downstream sites (6 and 7). Upstream sites had slightly higher TOC values over time. In addition, dissolved oxygen concentrations at Sites 8 and 9 were consistently above 5.0 mg/l while Site 6 and 7 exhibited occasional values below 5.0 mg/l. Sites 8 and 9 had higher TN values during the 1980's than Sites 6 and 7 but this was likely due to WWTP discharges. However, dry season median TN content from 1989 thru 1997 (post-WWTP) were more elevated at Sites 8 and 9 than below the S-37B (Sites 6 and 7). Potentially, seasonal flow patterns of the S-37B contribute to the dry season TN observations.

c. Seasonal Patterns

Statistically higher DO means were observed in the dry season than the wet season at all sites and is likely due to temperature differences. Some of the relatively rare low (less than 3.0 mg/l) DO readings at Site 9 may be indicative of seepage water from WCA 2A. Nonetheless, both seasons were characterized by DO values that were normally above the single sample standard of 4.0 mg/l.

Total phosphorus wet and dry season concentrations were very similar with no statistical differences observed. Site 7 had high (> 0.100 mg/l) 75^{th}-95^{th} percentile values and based on its surrounding land use of golf courses is probably affected by runoff from these facilities. Interestingly, median dry season TN concentrations were always higher than wet season values and were statistically significant at Sites 6 and 8. Furthermore, the two highest dry season medians in the basin, 1.464 mg/l and 1.395 mg/l, were observed at Sites 9 and 8, as compared to 1.124 and 1.025 at Sites 7 and 6, respectively. The reasons for this are unclear at this time but may be related to operations of the numerous control structures and surrounding groundwater elevations along the L-36 Canal which borders the western edge of the basin.

d. Future Monitoring Questions

A major goal of this report is to develop strategic guidelines for future Broward County water quality monitoring and management. To facilitate this, questions generated by this study's findings are being compiled for each drainage basin. For the C-14 Basin and Canal, the main questions revolve around TP levels being above the 0.020 mg/l standard throughout the basin, albeit not at the levels seen in the Hillsboro Basin.

- What is the main source of TP for the C-14 basin and in particular what is the influence of the golf courses near Site 7?

- Are nutrient concentrations at Sites 6, 8 and 9 from 1993-1997 or from 1989-1992 more reflective of ambient TP levels in the canal?

- Are the differences in TP content between 1993-1997 versus 1989-1992 due to weather, land-use, water management, or a combination? And if so can those conditions be repeated?

- Why were dry season TN higher than wet season values, particularly northwest of the S37-B?

- Throughout the canal (but particularly at Site 7) are nutrient concentrations creating a problem in water column biology (e.g., chlorophyll a) and/or macrophytes?

- What is stormwater quality like directly entering the canal and its secondary and tertiary tributaries?

G. C-13 Canal

1. Basin and Canal Structure

The C-13 Canal Basin is a medium-sized basin with an area of thirty-nine mi^2 (Cooper and Lane 1987). The basin is located in north-central Broward County and is divided into an eastern (nine mi^2, Figure III.28) and a western basin (thirty mi^2). Western inputs of water occur from the L-36 south of the S-38C via the C-42. Both the L-36 and C-42 are oriented in a north-south direction. The C-42 has an open connection to the east-west oriented C-13 Canal. The S-125 effectively divides the C-13 and North New River Canal (NNRC) Basins south of the confluence of the C-42 and the C-13 Canal.

In addition, portions of the western NNRC Basin may drain seepage and runoff water into the C-13 Canal via the L-35A except during times of flooding (Cooper and Lane 1987). The S-124 determines if water from the L-35A goes to the C-13 or the North New River Canal. The western C-13 Basin includes the entire freshwater section of the C-13 Canal which represents the headwaters of the S-36.

East of the S-36 (i.e., the tailwaters), the eastern C-13 Basin drains entirely into an estuarine section of the C-13 Canal and the remnant Middle River channel. In addition, the North Fork of the Middle River Basin drains five mi^2 (Cooper and Lane 1987) directly to this section of the Broward estuary.

The SFWMD controls the water management of the primary canals and structures within the basin. Independent or dependent drainage districts do not exist in the C-13 Basin (see Section I, Figure I.4), thus Broward County has permit jurisdiction of the basin's drainage into the primary C-13 Canal and maintains the basin along with local municipalities such as Sunrise.

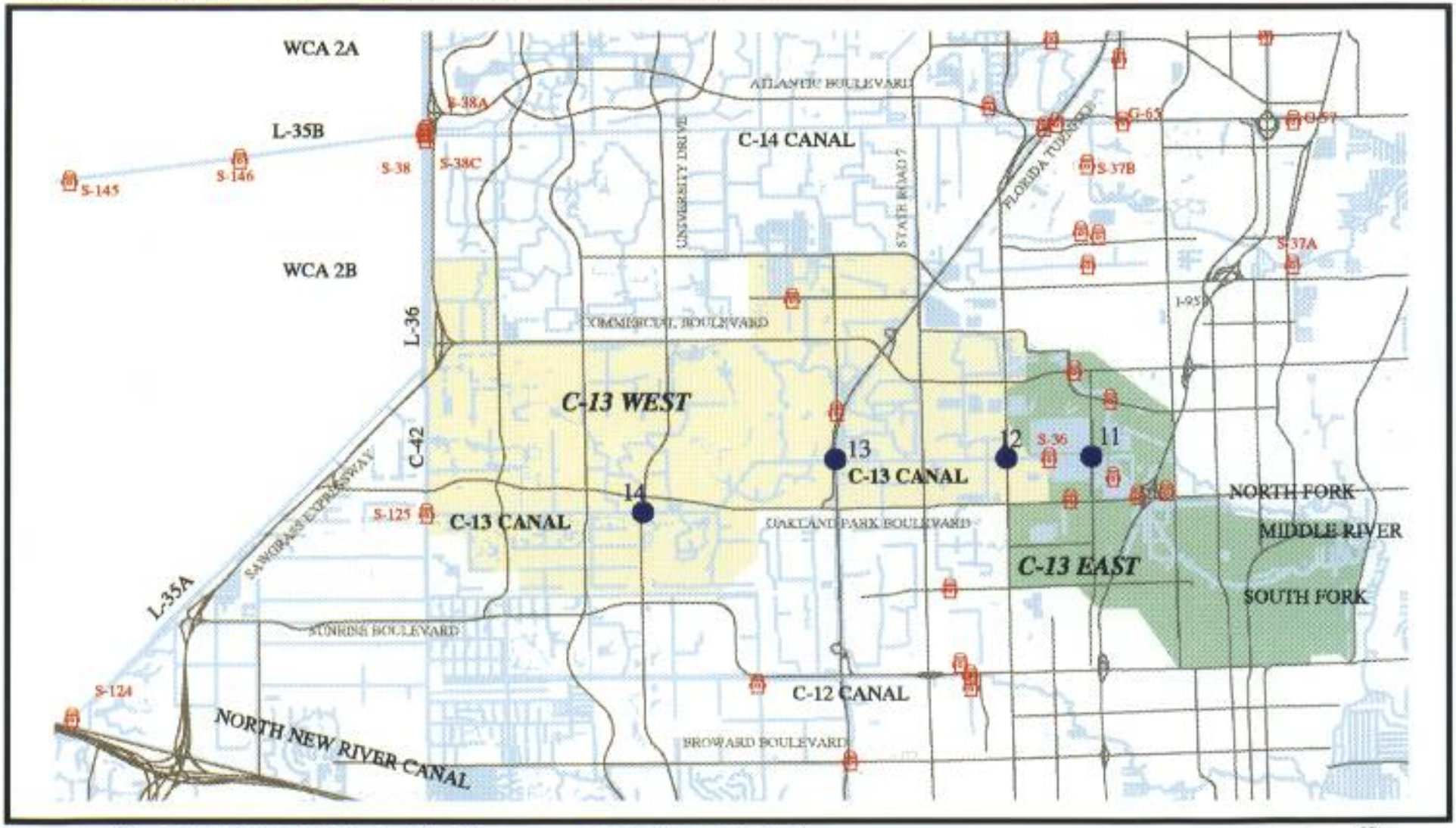
2. Municipalities and Land Uses

The western portion of the C-13 Canal Basin includes the cities of Lauderhill (49,632 residents, Broward County Planning Council 1995), Lauderdale Lakes (29,691 residents), and approximately half of Sunrise (74,084 residents, see Section I, Figure I.3). The eastern portion includes Wilton Manors (13,191 residents, Broward County Planning Council 1995), approximately half of Oakland Park (28,311 residents) and a relatively small portion of Ft. Lauderdale (156,121 residents).

The eastern portion of the C-13 Canal Basin, consisting of Oakland Park, Ft. Lauderdale, and Wilton Manors was developed earlier than many other areas of the county. In 1970, Oakland Park's population consisted of approximately 16,000 residents and the entire city of Ft. Lauderdale had over 139,000 residents, with only a portion of the city lying within the C-13 Basin. Lauderdale Lakes lies in the central portion of the basin, and in 1970, its population was approximately 10,500 residents. Oakland Park increased to nearly 24,000 residents, Lauderdale Lakes doubled in size to approximately 25,000 residents.

By the late 1970s, residential development in the C-13 Basin comprised approximately one-third of the Basin's land area, while commercial and industrial uses comprised 7% of the basin. A large portion

Figure III.28. The C-13 Canal Basin and Broward County (BCDPEP) Sampling Site Location Map. The C-13 Canal and other major waterbodies with corresponding South Florida Water Management District (SFWMD) water control structures (labeled) are depicted. Note water control structures without labels are secondary structures operated by other entities than the SFWMD. The S-125 (SFWMD) is south of the point where the C-42 Canal turns east and becomes the C-13 Canal.



This map is for informational purposes only. For further information, please contact BCDPEP Water Resources Division (954) 519-1270.

of the basin remained vacant, or undeveloped, and a small amount of agricultural land remained in the western areas (Broward County Planning Council 1977).

The current land uses of the C-13 Basin are dominated by commercial and medium- to high- density residential (Broward County Planning Council 1995). Small areas of wetlands and upland forest are located in the northwestern portion of the basin, near Water Conservation Area 2B.

3. Wastewater Treatment Plants Discharge History

In 1975, the Broward County Utilities Numbers $5A_1$ and $5A_2$ were the first wastewater treatment plants (WWTP) to cease discharges into the C-13 Canal. After 1984, the City of Ft. Lauderdale's "E" WWTP (0.500 million gallons per day; mgd) and the City of Tamarac's "East" (0.165 mgd) WWTP stopped releasing into the waterway (BCEQCB 1983, 1984). The City of Sunrise's 1A and 1B plant halted discharging a combined average of 7.8 mgd by 1986 to a holding pond that overflowed during emergencies to the C-13 Canal (BCEQCB 1985, 1986).

4. Other Influences on Water Quality

a. Soils

The soils of the C-13 Basin include poorly drained, deep sandy soils (see Section I, Figure I.5). The eastern portion of the basin contains these sandy soils with an overlying organic layer (Reynolds, Smith and Hills Inc., 1972). In the early 1970s, the majority of the soils in the western portion of the basin were moderately to severely limiting to building and transportation construction (Reynolds, Smith and Hills Inc., 1972) until additional drainage and build up of elevation made the land more suitable for urban uses.

b. Roadways

Similar to the C-14 Canal Basin, several major roadways cross the C-13 Canal (see Figure III.15). However, the estuarine section of the C-13 and the Middle River extends farther west than the C-14 Canal and includes Interstate 95. The major north-south oriented roads include University Drive, State Road 7, Rock Island Road, Florida Turnpike, and NW 31st Avenue. Thus, transportation associated runoff can be expected through some portions of the waterway.

c. Septic Tanks

With the exception of an extremely small strip of land near Bailey Road and State Road 7, the Western C-13 Basin has sewer service (http://www.broward.org/moi00600.htm). The eastern C-13 Canal Basin and North Fork Middle River have some areas without sewer service but the areas are at least a half a mile from the waterway. Thus, the potential septic tank areas are in the estuarine section of the basin and are not covered in this section even by the downstream site at S-36 (BCDPEP Site 11).

5. Sampling Locations and Period

Four sites (BCDPEP Sites 11-14) are located in the C-13 Canal (Figure III.30, also Appendix 1). Three are west of the S-36 structure and are without tidal influence. These include the easternmost freshwater Site 12 that is immediately west of the S-36 at the 31st Avenue (Lyons Road) bridge. Site 13 is approximately two miles west of Site 12 at the Rock Island Road bridge. Site 14 is the westernmost sampling locale at the University Drive bridge and is approximately two and one half miles east of the confluence of the C-13 and C-42 Canals. Table III.16 describes the years of collection for each parameter at each site.

Site 11 is immediately downstream (east) of the S-36 water control structure in the Middle River at the NW 21st Avenue bridge. Site 11 was included with the freshwater canal sections because it is the only tidally influenced monitoring site in close proximity to the tailwaters of a major water control structure. Thus, it was concluded a comparative analysis between upstream (Site 12) and downstream (Site 11) sites was best suited in the same section.

Table III.16. Sampling Years for Specific Parameters at the C-13 Canal Locations. A sampling year had at least one sample event during that year. Note the biochemical oxygen demand was a five-day test from 1973 until 1981 when a seven-day test was implemented until 1993 after which sampling for the parameter was discontinued at BCDPEP.

Parameter	Site 11	Site 12	Site 13	Site 14
Temperature	81-97	73-97	73-97	73-97
pH	81-97	73-97	73-97	73-97
Specific Conductance	81-97	81-97	81-97	81-97
Salinity	87-97	N/A	N/A	N/A
Dissolved Oxygen	81-97	73-97	73-97	73-97
Biological Oxygen Demand	81-93	73-93	73-93	73-93
Total Organic Carbon	81-97	81-97	81-97	81-97
Turbidity	81-97	81-97	81-97	81-97
Total Phosphorus	81-97	74-97	74-97	74-97
Ammonia-Nitrogen	81-97	81-97	81-97	81-97
Nitrite+Nitrate-Nitrogen	81-97	81-97	81-97	81-97
Total Kjeldahl Nitrogen	81-97	81-97	81-97	81-97
Fecal Coliform	81-97	73-97	73-97	73-97
Total Coliform	81-97	73-97	73-97	73-97
Fecal Streptoccocus	81-97	76-97	76-97	76-97

6. Results

a. Physical Characteristics

Measurements of the C-13 Canal's water temperature and pH were very similar at all sampling locations (Table III.17). Mean and median water temperatures were normally between 25.5 and 26.0ºC, respectively. Mean and median pH values were either 7.6 or 7.7 for all sites.

As expected, the tidally influenced Site 11 had the highest mean and maximum specific conductance recordings (Table III.17). However, Site 11's long term median specific conductance value (739 Fmhos/cm) was relatively equal to the freshwater sites (12-14) located on the west side of the SFWMD structure S-36. Furthermore, salinity observations were below the method detection limit (0.5 parts per thousand) 65.9% of the time. Thus, Site 11 is characterized by freshwater with occasional pulses of brackish water likely during low rainfall periods and/or high lunar tidal activity.

Table III.17. Descriptive Statistics for Temperature (Temp;ºC = degrees Celsius), pH, Specific Conductance (Cond; Fmhos =micromhos/centimeter @ 25ºC), and Salinity (Sal; ppt= parts per thousand) in the C-13 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL). Salinity observations were only made at the tidally influenced site (11).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
11	Temp	ºC	65	26.1	25.6	3.4	32.0	17.8	0
12	Temp	ºC	364	26.1	25.6	3.5	32.0	17.2	0
13	Temp	ºC	150	26.0	25.6	3.6	33.0	15.0	0
14	Temp	ºC	156	26.0	25.9	3.4	33.0	19.0	0
11	pH	units	67	7.6	7.6	0.4	8.4	6.5	0
12	pH	units	371	7.7	7.7	0.3	8.7	6.4	0
13	pH	units	150	7.7	7.7	0.4	8.7	6.2	0
14	pH	units	157	7.6	7.6	0.3	8.4	6.5	0
11	Cond	Fmhos	58	739	1692	2533	10900	470	0
12	Cond	Fmhos	288	710	709	114	1360	330	0
13	Cond	Fmhos	66	702	100	118	962	470	0
14	Cond	Fmhos	67	730	717	116	985	470	0
11	sal	ppt	41	0.5	1.7	2.5	11	0.25	27

b. Total Organic Carbon and Turbidity

The C-13 Basin's freshwater sites (12-14) were characterized by slightly higher mean and median total organic carbon (TOC) than the tidal site (number 11; Table III.18). A similar pattern was observed for the maximum and minimum TOC concentrations. Interestingly, TOC concentration initially appears to decrease as moving downstream from Site 14 to 13 but then increases at Site 12. The location of a WWTP and/or the large samples size at Site 12 may have contributed to this observation.

At all sites, mean and median turbidity levels were typically low (< 6.0 nephelometric turbidity units; ntus) and within compliance of Broward County's standard of 10 ntus (Table III.18). Notably, maximum values were well above (> 100 ntus) the standard at Sites 12-14. Potentially, construction and/or dewatering activities may have caused these unusual values.

Table III.18. Descriptive Statistics for Total Organic Carbon (TOC) Concentrations and Turbidity (Turb) Levels in the C-13 Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
11	TOC	mg/l	67	18.50	18.56	5.62	33.90	3.86	0
12	TOC	mg/l	260	23.80	24.23	5.73	45.00	10.40	0
13	TOC	mg/l	61	21.50	22.90	6.09	42.10	12.20	0
14	TOC	mg/l	60	23.00	24.43	6.17	43.40	14.10	0
11	Turb	ntu	67	1.9	3.4	4.9	33.0	0.8	0
12	Turb	ntu	353	2.0	4.3	9.9	100.0	0.5	0
13	Turb	ntu	133	2.6	5.1	14.2	140.0	0.9	0
14	Turb	ntu	132	2.7	5.9	17.4	160.0	1.2	0

c. Dissolved Oxygen and Biochemical Oxygen Demand

Mean and median dissolved oxygen (DO) concentrations for the entire study were very comparable between the eastern freshwater sites (numbers 12 and 13) and the tidal site (number 11; Table III.19). With mean and median values below the 4.0 mg/l standard, the basin's westernmost site (14) had relatively lower DO content than all other sampling points. Biochemical oxygen demand (BOD) concentrations were essentially the same at Sites 11 and 12 while Sites 13 and 14 reflected each other. All C-13 Canal mean and median BOD values were below the standard (within compliance) of 5.0 mg/l.

Table III.19. Descriptive Statistics for Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) Concentrations in the C-13 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculations. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
11	DO	mg/l	65	4.9	4.8	1.7	8.7	1.4	0
12	DO	mg/l	367	4.9	5.0	2.0	11.2	0.90	0
13	DO	mg/l	147	4.7	4.8	2.3	13.6	0.025	2
14	DO	mg/l	156	3.4	3.6	2.0	8.5	0.025	2
11	BOD	mg/l	48	1.7	2.1	1.4	8.8	0.3	0
12	BOD	mg/l	349	1.7	2.0	1.3	8.0	0.2	0
13	BOD	mg/l	131	2.1	2.5	1.4	11.0	0.4	0
14	BOD	mg/l	131	2.0	2.1	1.1	6.0	0.5	0

Site 14 generally had the lowest annual means within the basin, including twelve yearly means below 4.0 mg/l (Figure III.29). However, most of this occurred during a period of WWTP discharges (i.e., before 1987). After 1986, annual DO content was normally above 4.0 mg/l throughout the waterway. Still, Site 14 exhibited the lowest annual averages in the freshwater segment of the canal. Located immediately upstream and downstream of S-36, Sites 12 and 11 showed very similar yearly mean and standard deviations.

To better understand compliance patterns within the canal, each DO reading was given a rating based on Broward County's water quality standards (see Section III.E.6.c). In addition, the changes over time due to the closing of WWTPs within the basin were investigated (see Section III.G.3). Site 12 realized the most improvements in DO content after 1986 with only 17.2% poor rated samples (Figure III.30). Site 14 also showed steady improvement over time but yielded a 34.7% poor rating from 1987 to 1997. While Site 13 had its worst DO ratings from 1982 to 1986, the periods before and after were very similar having 40.7% and 34.1% poorly ranked samples, respectively. Site 11 showed increases in both good and poor ratings from 1987 to 1997.

Seasonal influences on DO concentrations were investigated by pooling wet (June through October) and dry (November through May) season samples from 1989-1997. This was a period without WWTP influence throughout the county. At all sites, differences between dry season and wet season DO content were highly significant (t-test; $p < 0.001$, Figure III.31). In fact, the 5^{th} percentile dry season values typically corresponded to the wet season's median number. Furthermore, almost all dry season DO data in Figure III.32 is above (i.e., within compliance) the Broward County standard line of 4.0 mg/l while the majority of wet season concentrations are below it.

Figure III.29. Annual Mean Dissolved Oxygen Content Within the C-13 Canal Basin from 1973 to 1997. Means and standard deviations (sd; error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. The Broward County standard (4.0 mg/l) is indicated by the dashed line. Numbers in parentheses represent mean plus sd outside range of graph.

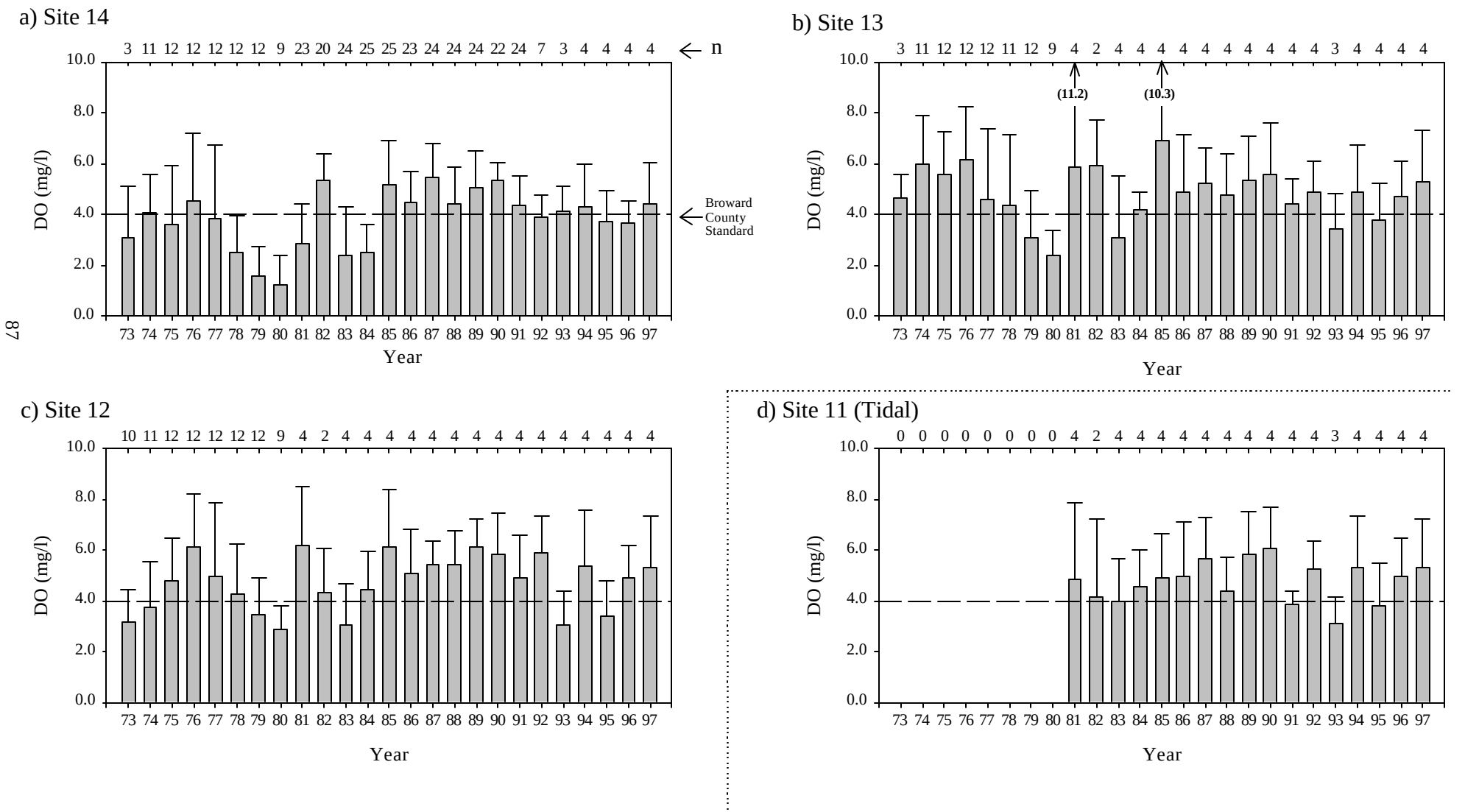


Figure III.30. Dissolved Oxygen (DO) Concentrations Observed in the C-13 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall be below 4.0 mg/l. Thus, all concentrations greater than or equal to 5.0 mg/l are classified as good and DO concentrations between 4.0 to 4.9 mg/l are considered fair. Readings below 4.0 mg/l are defined as poor.

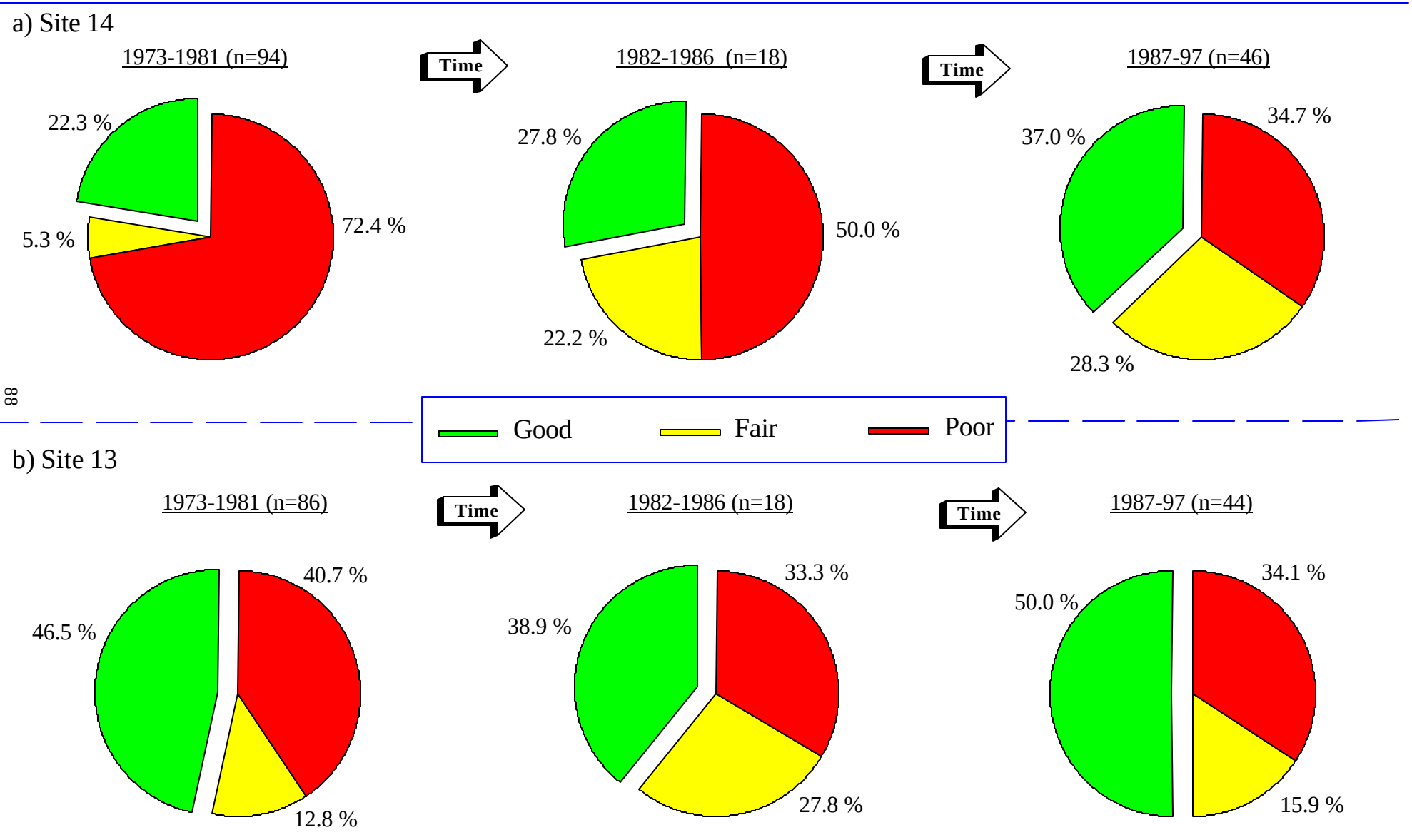
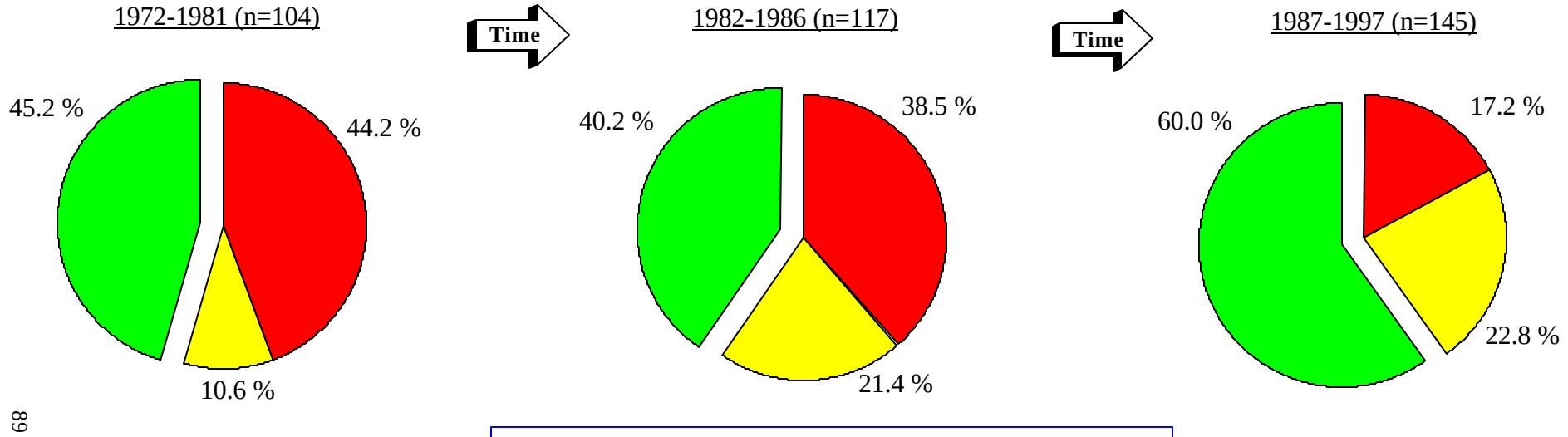


Figure III.30 (Cont.). Dissolved Oxygen (DO) Concentrations Observed in the C-13 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall be below 4.0 mg/l. Thus, all concentrations greater than or equal to 5.0 mg/l are classified as good and DO concentrations between 4.0 to 4.9 mg/l are considered fair. Readings below 4.0 mg/l are defined as poor.

c) Site 12



d) Site 11 (Tidal)

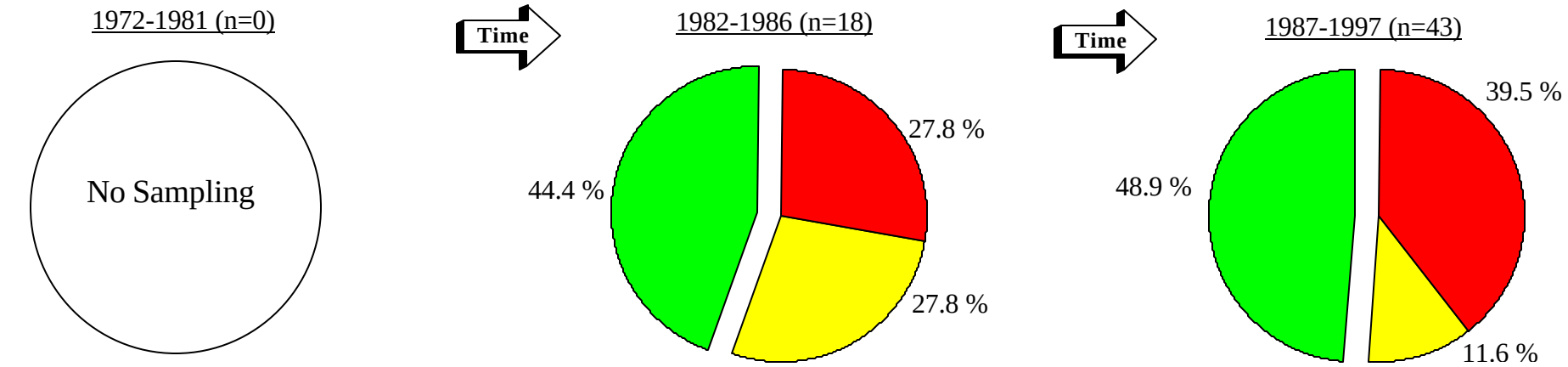
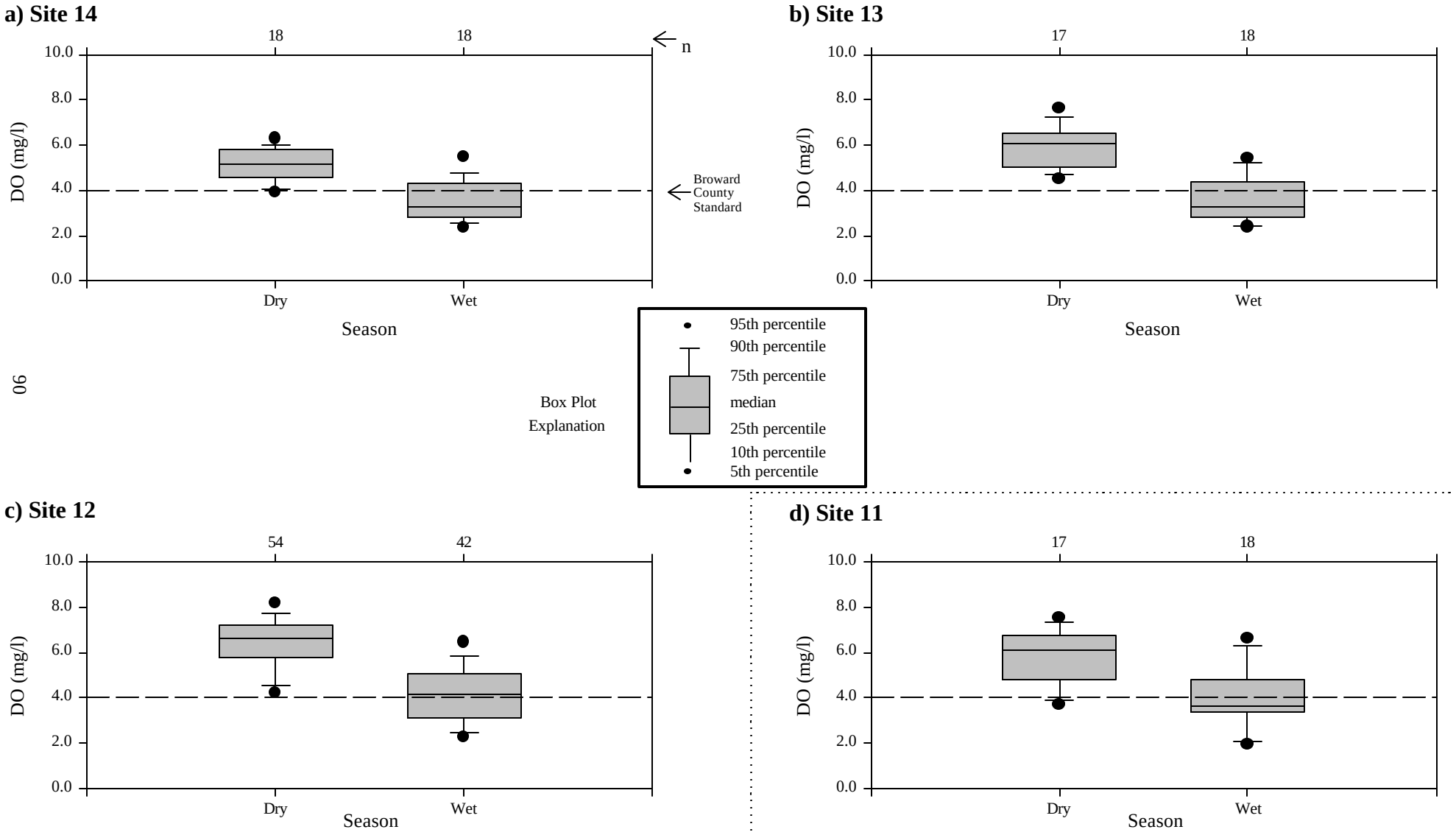


Figure III.31. C-13 Canal Basin Dissolved Oxygen (DO) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season means were observed at all sites ($p < 0.001$, t-test). Site 11 is downstream (i.e., tidal) of a water control structure (S-36).



d. Total Phosphorus

Twenty-four year mean total phosphorus (TP) concentrations were much higher than the respective medians at each site (Table III.20). However, variability around the mean was high due, in part, to large maximum values. Thus, medians were much closer to the freshwater TP standard (0.020 mg/l) for Sites 12-14 and the marine standard (0.050) mg/l for Site 11 than mean values. Additionally, nearly 30.0% of TP measurements at Sites 12 and 14 were below the method detection limit. The marine TP standard was used for Site 11 because, technically, it is a tidal water body and under Broward County's Chapter 27 subject to that standard (See Article V in Broward County 2000).

Table III.20. Descriptive Statistics for Total Phosphorus (TP) Concentrations in the C-13 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculations. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
11	TP	mg/l	66	0.053	0.129	0.253	1.560	0.010	17
12	TP	mg/l	355	0.043	0.071	0.102	1.090	0.010	103
13	TP	mg/l	138	0.060	0.087	0.120	1.100	0.010	29
14	TP	mg/l	137	0.030	0.080	0.206	2.080	0.005	44

Generally, annual TP averages were much lower in the 1990's than the previous decades (Figure III.32). In particular, mean TP levels from 1993 to 1997 were normally within compliance (i.e., below) of the Broward County freshwater standard of 0.020 mg/l at Sites 12 thru 14. In addition, the standard deviations during that period were relatively low at the freshwater sites. However, the drought years, 1989 through 1992, were characterized by relatively elevated levels after the cessation of WWTP discharges (1986). During the 1990's, Site 11 exhibited higher values than Sites 12-14 but was typically compliant with the Broward County marine standard of 0.050 mg/l.

An analysis of total samples within compliance of the Broward County freshwater standard (0.020 mg/l; see III.E.5.d) was performed for Sites 12-14. The marine TP standard was used for Site 11. For marine (i.e., estuarine) water, total phosphorus concentrations were designated as poor if they were twice the Broward County marine standard of 0.050 mg/l. A fair designation was given for values between 0.051 and 0.099 mg/l and concentrations greater than 0.100 mg/l were defined as poor. In addition, changes over time are presented with special reference to the closing of WWTPs within the basin for all four sites (see Section III.G.3).

All sites showed large (> 25.0%) improvements in TP compliance percentages after 1986 (i.e., post-WWTPs, Figure III.33). Site 12 realized a 47.3% increase in good rated samples from the period 1982-1986 to 1987-1997. Perhaps more importantly, the overall percentage of poor samples also dramatically decreased in the freshwater sites (12-14) during the same period. For example, 73.7% of Site 13's TP samples between 1982-1986 were designated poor while only 14.0% had the same classification from 1987-1997. Although a different rating system (marine) was used, Site 11 had the highest good and poor ranked samples from 1987-1997.

Figure III.32. Annual Mean Total Phosphorus (TP) Levels Within the C-13 Canal Basin from 1974 to 1997. Means and standard deviations (sd; error bars) calculated from biweekly, monthly, and/or quarterly samples with the number of samples (n) per year noted on the upper x-axis. The Broward County single sample standard (0.020 mg/l) is indicated by the dashed line. For the tidal Site 11 (d), the marine TP standard (0.050 mg/l) is shown (dotted line). Numbers in parentheses represent mean and/or sd outside y-axis range.

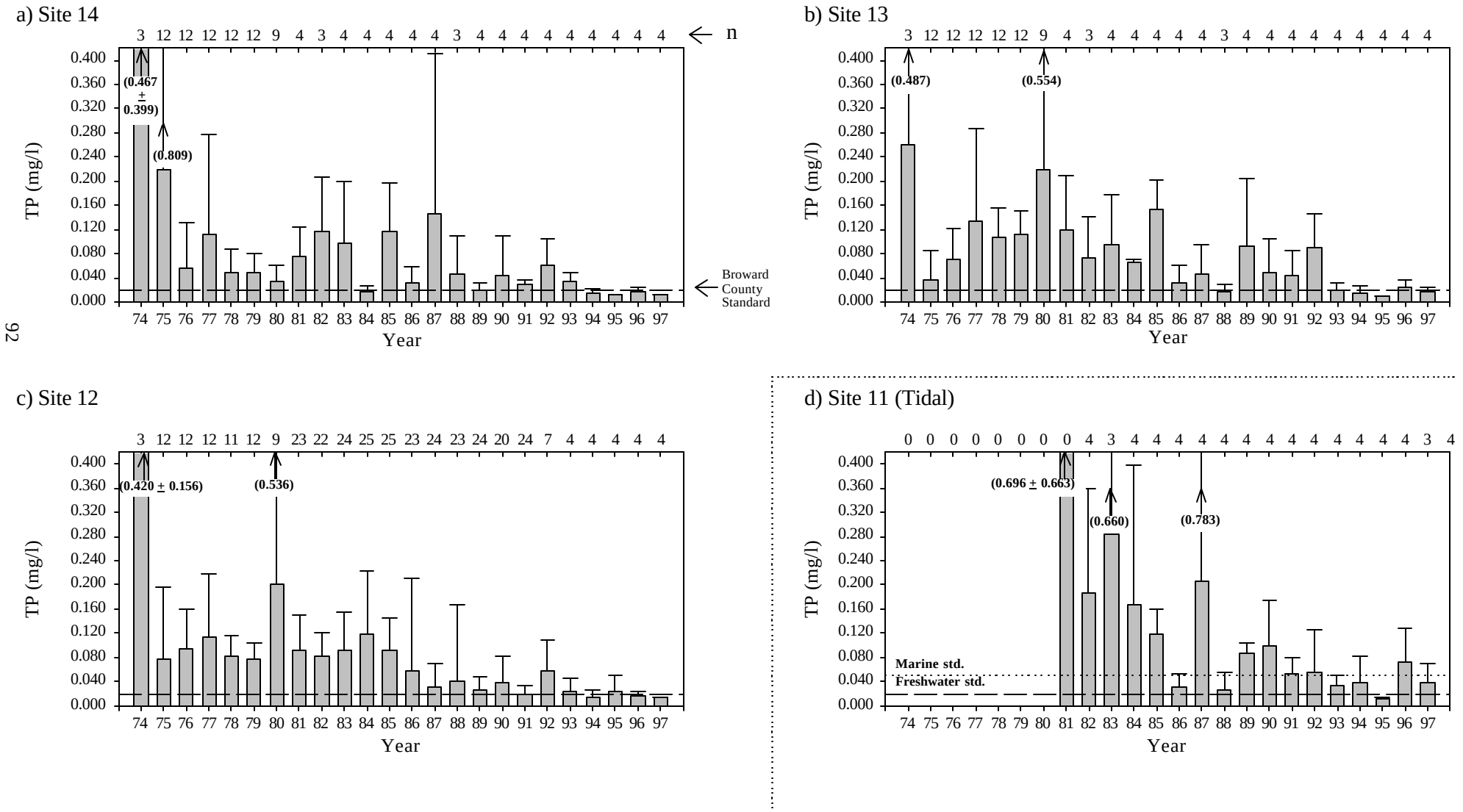


Figure III.33. Total Phosphorus (TP) Concentrations Observed in the C-13 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County freshwater TP standard of 0.020 mg/l. The percentage of samples below 0.020 mg/l are classified as good. A fair rating was given to concentrations between 0.021 mg/l to 0.060 mg/l. Values greater than three times the standard (i.e., 0.060 mg/l) are classified as poor.

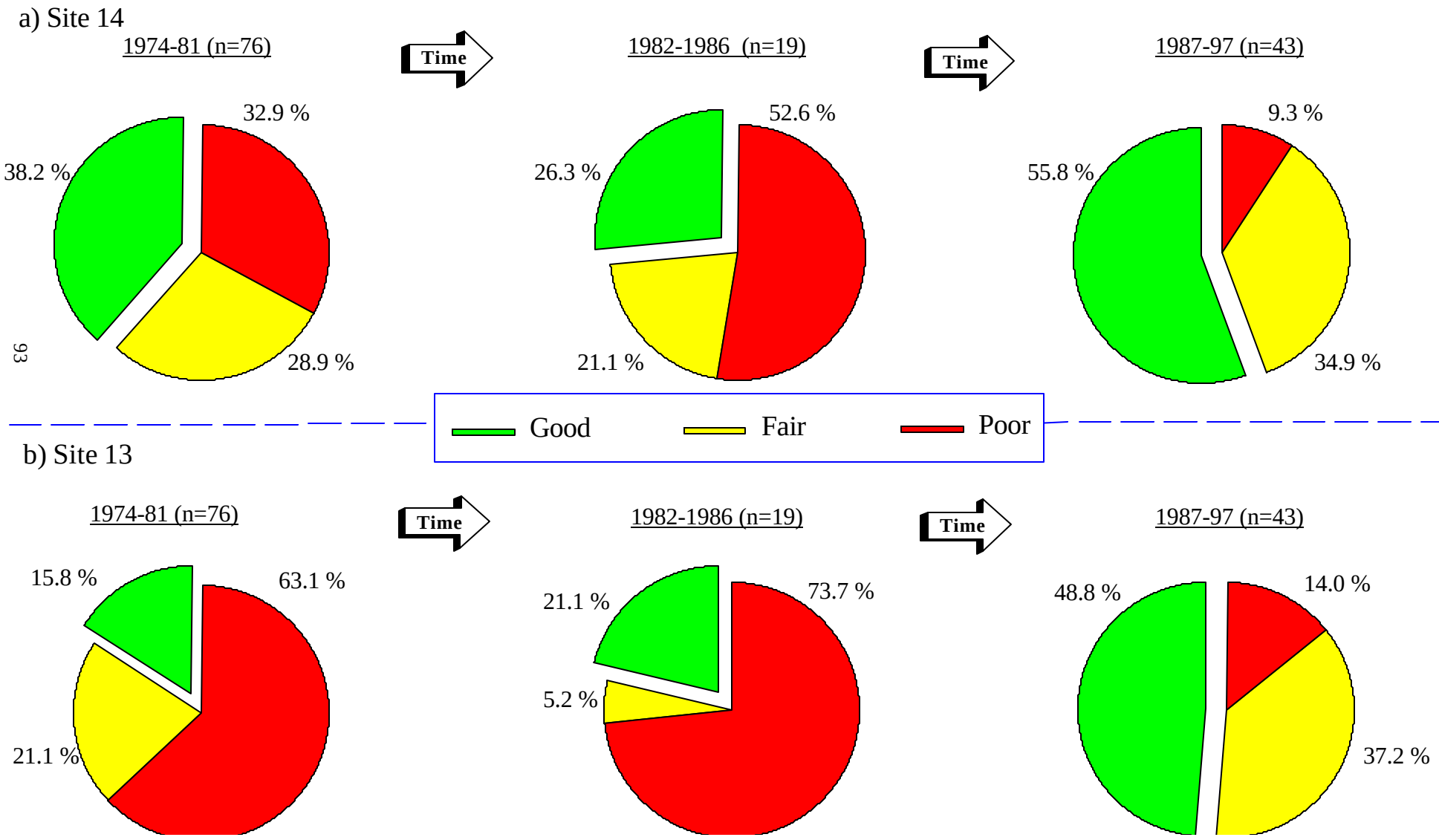
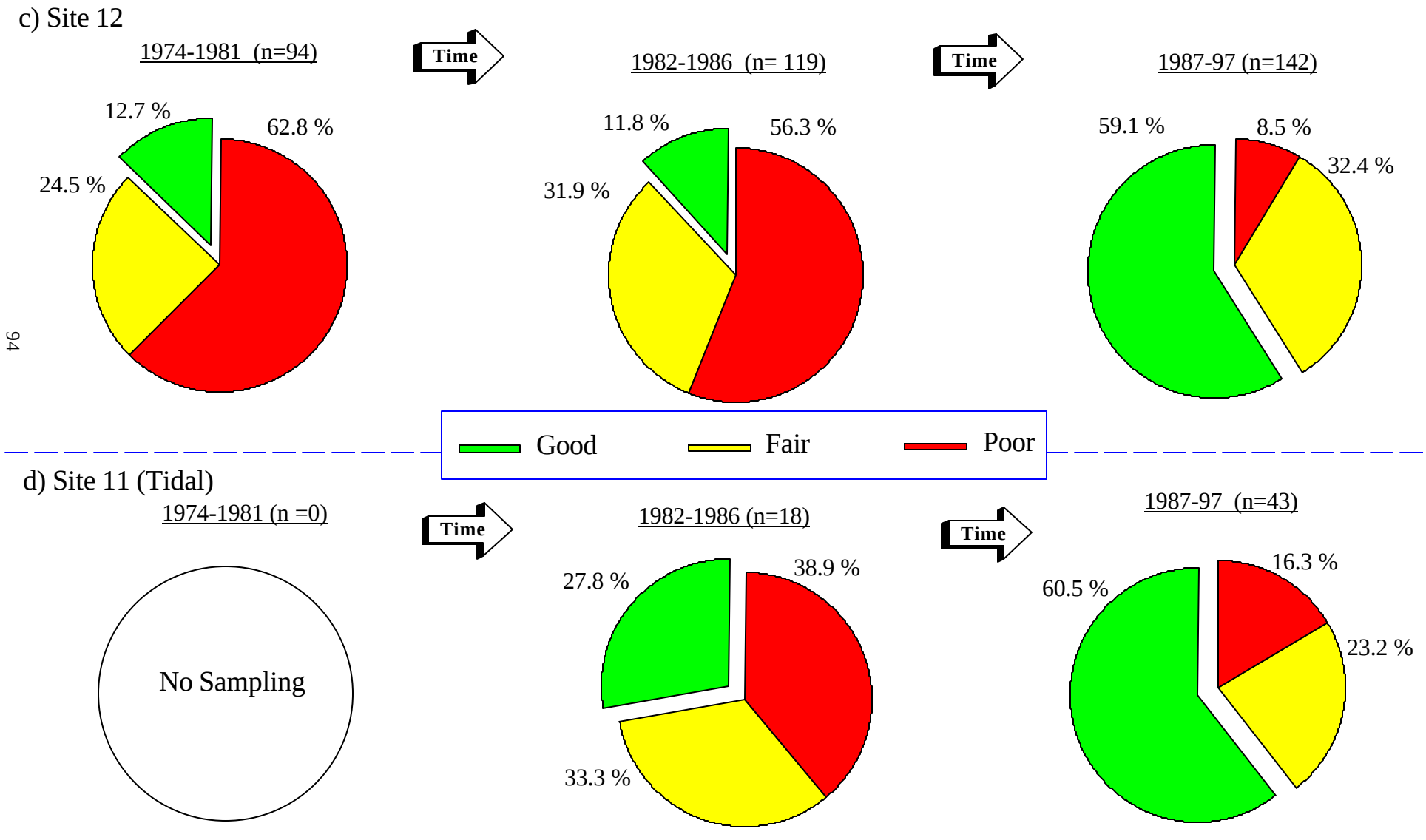


Figure III.33 (Cont.). Total Phosphorus (TP) Concentrations Observed in the C-13 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County freshwater TP standard of 0.020 mg/l. The percentage of samples below 0.020 mg/l are classified as good. A fair rating was given to concentrations between 0.021 mg/l to 0.060 mg/l. Values greater than three times the standard (i.e., 0.060 mg/l) are classified as poor.



Statistical differences were not observed between wet and dry season TP concentrations in the C-13 Canal (Figure III.34). At the freshwater sampling points (Sites 12 thru 14), dry season TP values were characterized by larger variability and the highest overall 95th percentile values. At Site 11 (tidal), the dry season median was above the marine standard of 0.050 mg/l while the wet season was within compliance.

e. Total Nitrogen

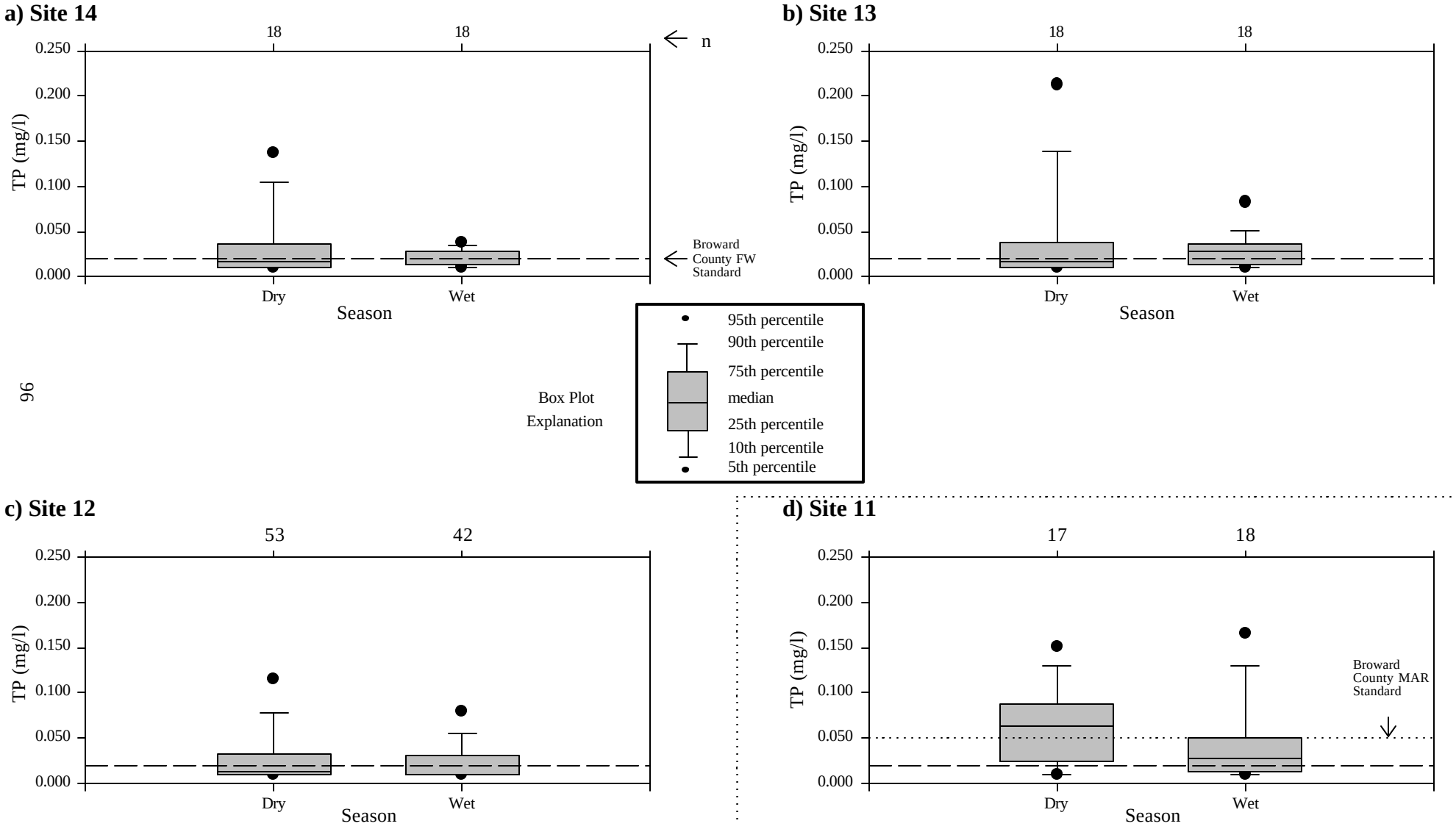
Total nitrogen levels are calculated from the total Kjeldahl nitrogen (TKN) and nitrite+nitrate -nitrogen (NO_2+NO_3) concentrations. Within the freshwater section of the C-13 Canal, 17-year mean and median TN values were above the Broward County's standard (1.5 mg/l, Table III.21) which is the same for both freshwater and marine. Site 11's median value was below (i.e., within compliance) of the standard and the mean (1.523 mg/l) barely exceeded it.

Over 80% of median TN levels at Sites 11 and 12 was comprised of TKN while 90% was observed at Sites 13 and 14. Within the freshwater reach, Site 12 had the highest nitrate-nitrite levels but the lowest ammonia-nitrogen concentrations (means and medians).

Table III.21. Descriptive Statistics for Nitrite+Nitrate-Nitrogen (NO_2+NO_3), Ammonia-Nitrogen (NH_3), Total Kjeldahl Nitrogen (TKN) , and Total Nitrogen (TN) Concentrations in the C-13 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL). Total Nitrogen was calculated as the sum of TKN and NO_2+NO_3.

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
11	NO_2+NO_3	mg/l	67	0.182	0.215	0.186	1.130	0.005	3
12	NO_2+NO_3	mg/l	288	0.236	0.275	0.181	0.936	0.005	3
13	NO_2+NO_3	mg/l	67	0.167	0.202	0.139	0.837	0.005	1
14	NO_2+NO_3	mg/l	66	0.122	0.149	0.112	0.540	0.005	1
11	NH_3	mg/l	62	0.089	0.325	0.869	5.670	0.005	14
12	NH_3	mg/l	265	0.115	0.158	0.144	0.551	0.005	55
13	NH_3	mg/l	62	0.178	0.204	0.182	0.686	0.005	10
14	NH_3	mg/l	61	0.222	0.270	0.203	0.734	0.005	7
11	TKN	mg/l	66	1.125	1.307	0.956	6.640	0.364	0
12	TKN	mg/l	283	1.380	1.393	0.316	3.340	0.135	0
13	TKN	mg/l	65	1.430	1.427	0.376	2.290	0.573	0
14	TKN	mg/l	64	1.545	1.503	0.380	2.260	0.509	0
11	TN	mg/l	66	1.315	1.523	1.088	7.366	0.520	N/A
12	TN	mg/l	283	1.690	1.668	0.369	3.661	0.512	N/A
13	TN	mg/l	65	1.583	1.630	0.417	2.366	0.665	N/A
14	TN	mg/l	64	1.711	1.654	0.417	2.544	0.628	N/A

Figure III.34. C-13 Canal Basin Total Phosphorus (TP) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season means and medians were not observed at any station. Site 11 is downstream (i.e., tidal) of a water control structure (S-36) and the marine (MAR) TP standard is shown.



Annual mean total nitrogen (TN) values showed higher values in the 1980's than during the 1990's at all four sites (Figure III.35). In particular, means from 1995-1997 were under 1.500 mg/l at all sampling sites. Within the freshwater section (Sites 12-14), annual TN values were relatively similar between sites with a few exceptions (e.g., Site 12, 1988). Site 11 experienced the most dramatic decline in annual mean TN content after 1988.

To better understand compliance patterns within the canal, each TN sample was given a rating based on Broward County's water quality standards (see Section III.E.5.e). Additionally, changes over time were investigated with special reference to the closing of WWTPs within the basin (see Section III.G.3). In the C-13's freshwater segment, TN compliance percentages dramatically increased through time beginning with the closure of WWTP discharges after 1986 (Figure III.36). For example, Site 13 had zero samples rated good between 1981-1986 but realized 45.5% good (i.e., within compliance) samples from 1987-1992. By the period of 1993-1997, 80.0% of TN samples ranked good at Site 13. Sites 12 and 14 were similar in the magnitude and time period of improvement. Interestingly, large-scale changes at Site 11 came earlier (1987-1992) than the freshwater sections (1993-1997).

Between 1989-1997, dry season median TN values were higher than wet season medians but statistically significant differences were only observed at Site 12 (t-test, $p < 0.001$, Figure III.37). Median values were near or at 1.500 mg/l during dry season measurements while below that standard value in the wet season. Furthermore, dry season 75th percentile values were always above 1.500 mg/l at the freshwater locations (12-14) but during the wet season monitoring.

f. Bacteriological Parameters

Long term median fecal coliform FC values were relatively similar at Sites 12-14 (freshwater) and well below the 200 colonies/100 ml which is the Broward County monthly average standard (Table III.22). Site 11 had a higher median than sites west of the S-36 structure but this was also below the monthly standard. Even mean values that are normally skewed by high maximum values were below the Broward County single sample standard of 800 colonies/100 ml.

Median total coliform values were not quite as uniform as FC content but were still well below the standard of 2,400 colonies/100 ml (Table III.22). Fecal streptococcus median concentrations were very similar between all four sites ranging from 98 to 125 colonies/100 ml.

Figure III.35. Mean Annual Total Nitrogen (TN) Levels Within the C-13 Canal Basin from 1981 to 1997. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. The Broward County standard (1.50 mg/l) is indicated by the dashed line. Numbers in parentheses represent mean and/or sd outside of range of graph.

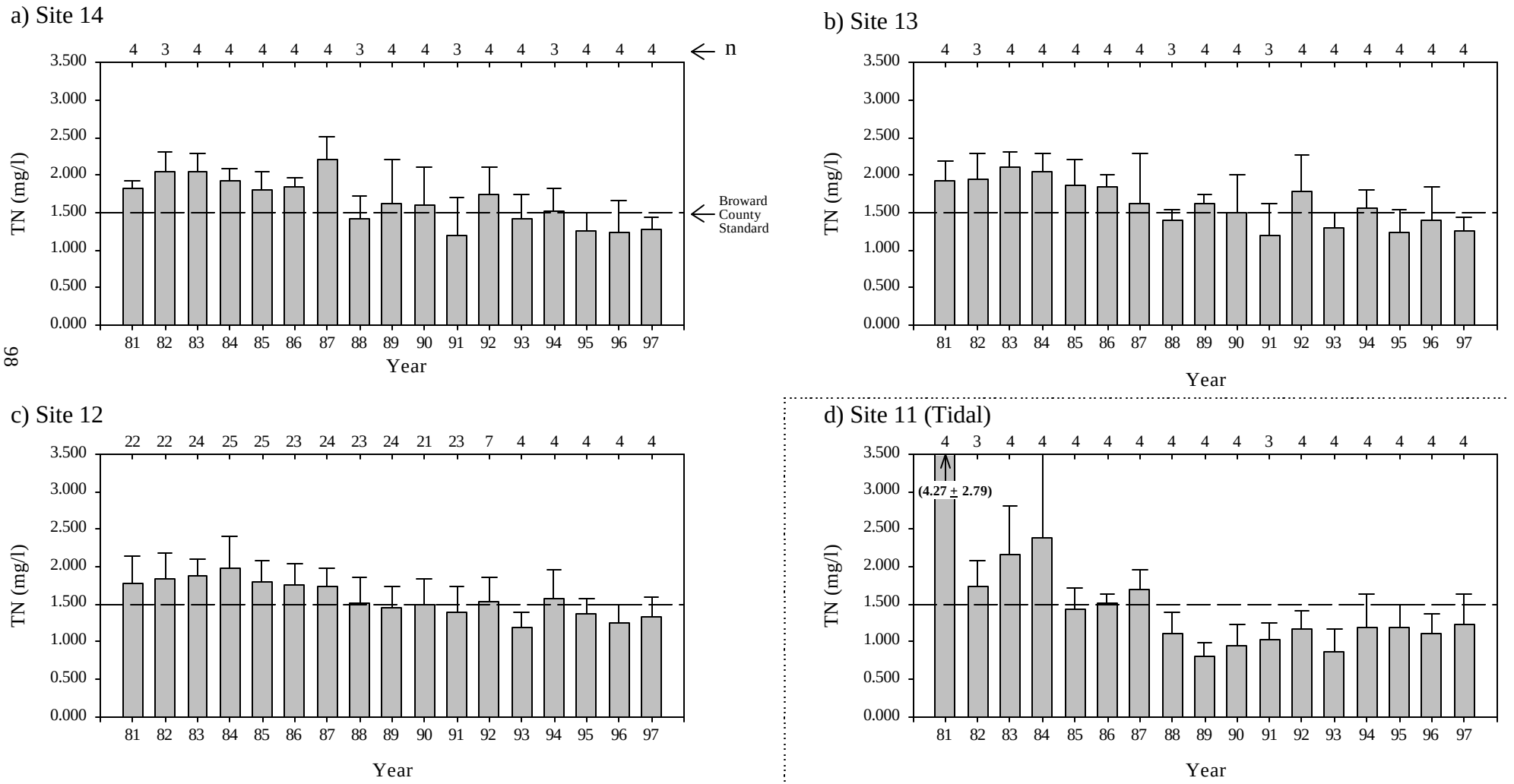


Figure III.36. Total Nitrogen (TN) Concentrations Observed in the C-13 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified as good. A fair rating was given to concentrations between 1.501 mg/l to 2.500 mg/l. Values greater than 2.500 mg/l are classified as poor.

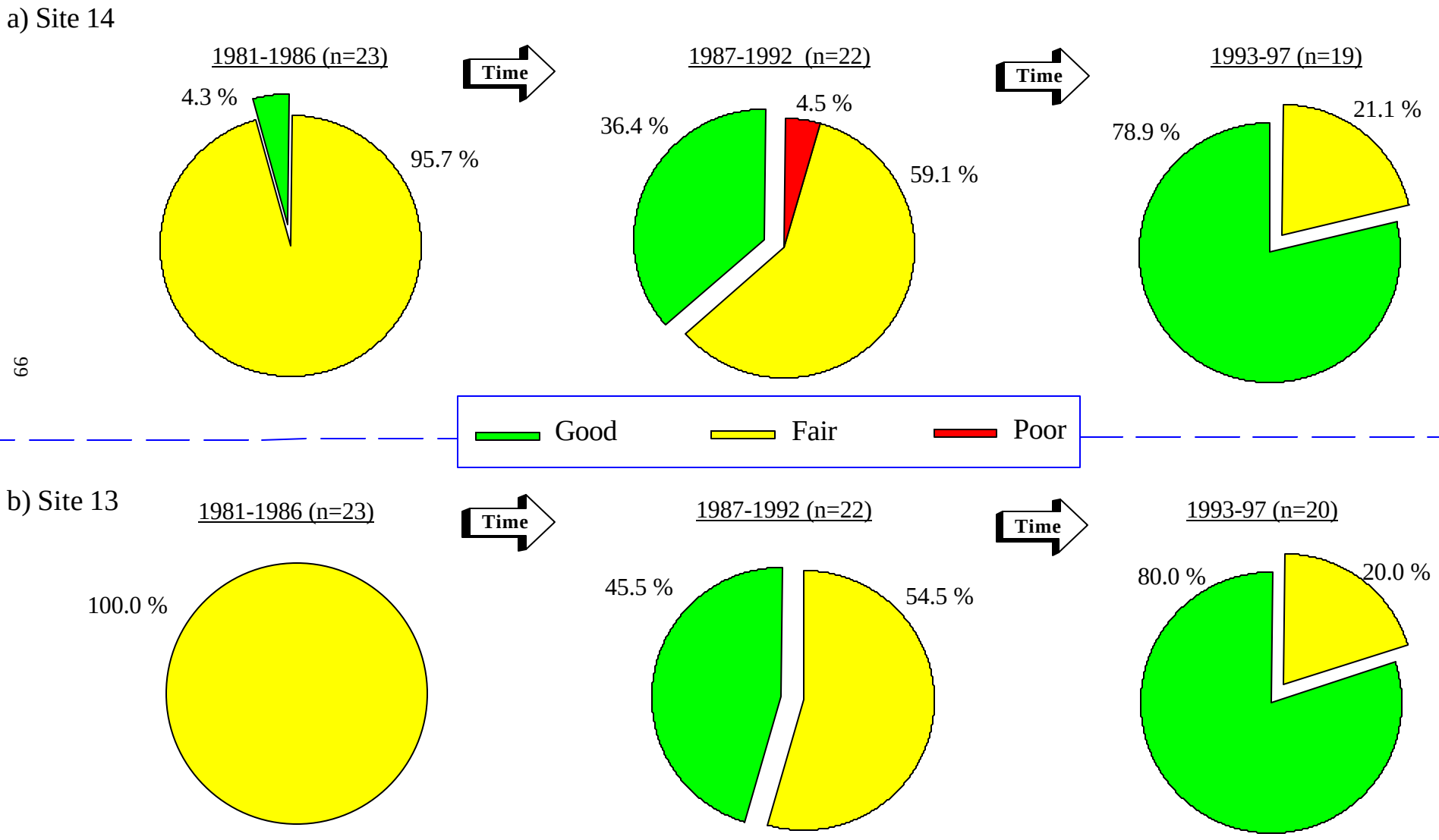


Figure III.36 (Cont). Total Nitrogen (TN) Concentrations Observed in the C-13 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified as good. A fair rating was given to concentrations between 1.501 mg/l to 2.500 mg/l. Values greater than 2.500 mg/l are classified as poor. Note Site 11 is a tidal waterbody.

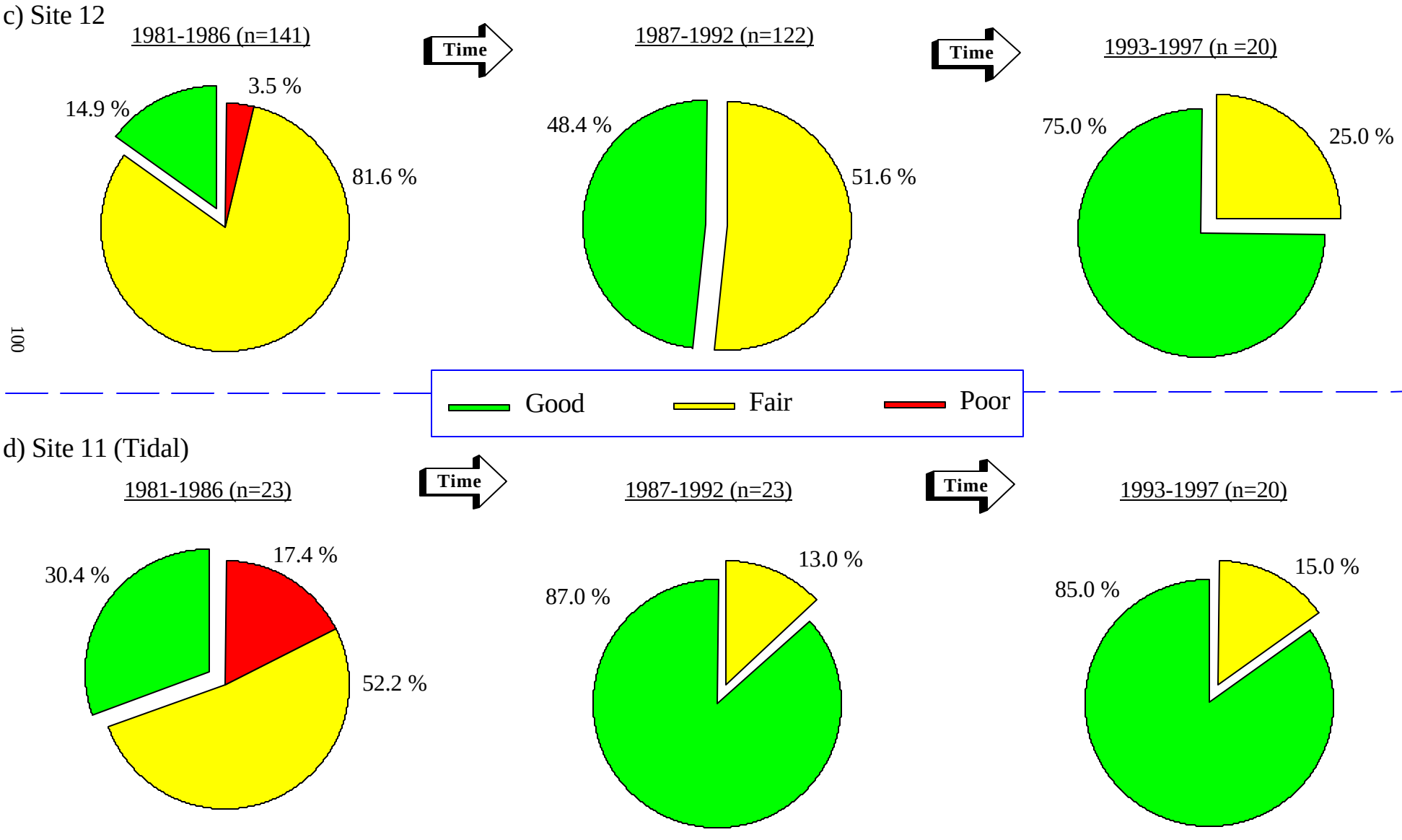


Figure III.37. C-13 Canal Basin Total Nitrogen (TN) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. A statistically significant difference between wet and dry season means was observed at Site 12 ($p < 0.001$, t-test) but not at Sites 11, 13, and 14. Site 11 is downstream (i.e., tidal) of a water control structure (S-36).

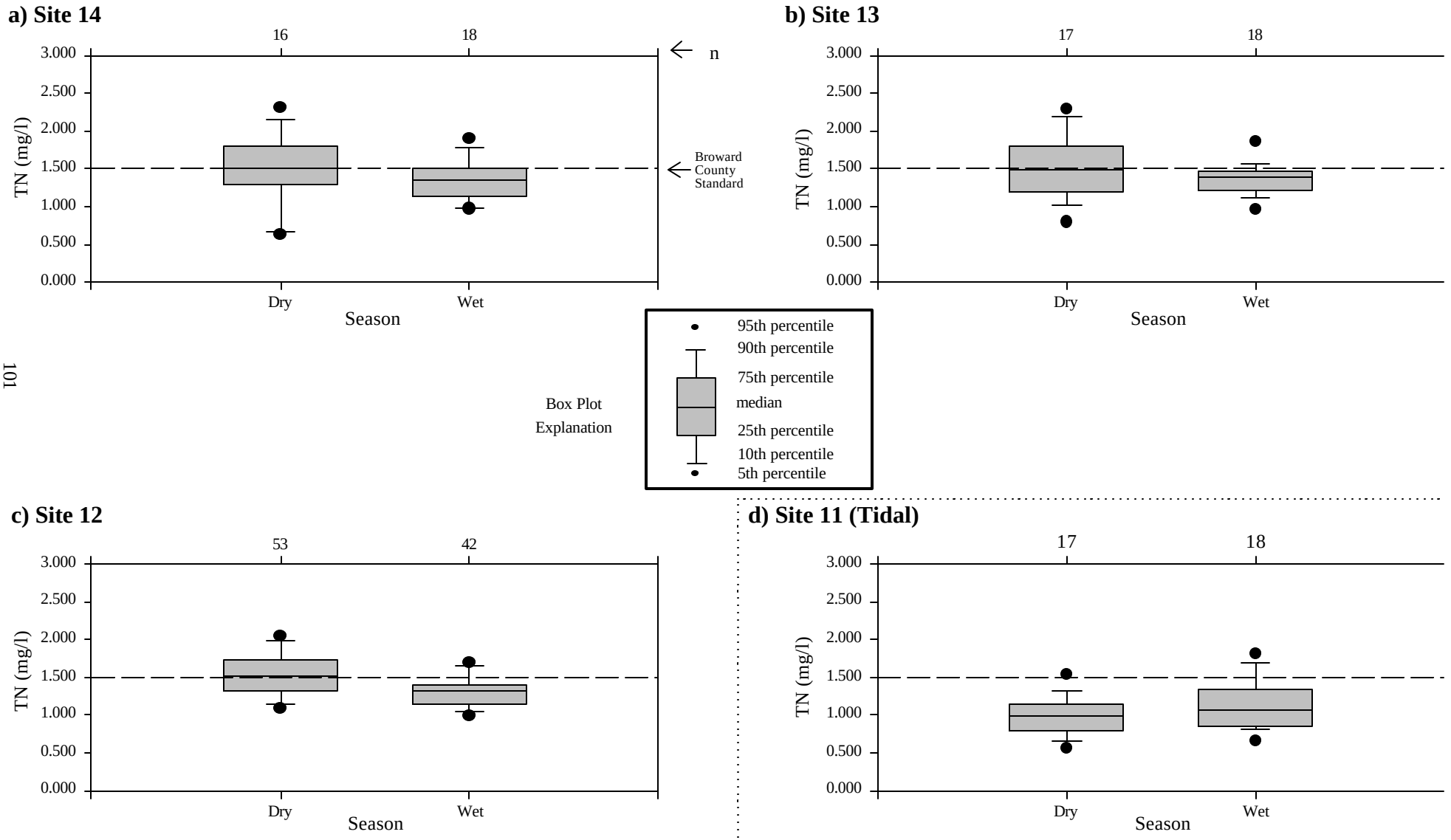


Table III.22. Descriptive Statistics for Fecal Coliform (FC), Total Coliform (TC), and Fecal Streptococcus (FS) in the C-13 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL) and the unit of measurement is colonies/100 ml (col).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
11	FC	col	66	115	256	474	2600	5	3
12	FC	col	369	37	193	820	12000	5	43
13	FC	col	149	46	266	1062	12000	5	10
14	FC	col	149	52	144	340	3400	5	12
11	TC	col	66	310	1959	9829	80000	5	2
12	TC	col	368	270	1289	5926	80000	12	8
13	TC	col	149	460	1120	2583	28000	16.5	1
14	TC	col	156	500	2056	7239	73000	33	0
11	FS	col	67	100	413	1447	11000	12	9
12	FS	col	344	98	357	1096	14000	3	74
13	FS	col	124	115	508	1444	12000	10	9
14	FS	col	124	125	1390	9148	100000	5	16

Due to the large amount of variability around the mean (Table III.22), yearly box plots were plotted for fecal coliform instead of the mean (Figure III.38). Beyond one year (1981) at Site 11, annual medians were never above the 800 colonies/100 ml standard at any site. In fact, yearly medians did not exceed 300 colonies/100 ml in the freshwater segment (Sites 12-14). Only occasional 75th percentile values exceeded the single sample standard (800 colonies/100 ml). Site 12,with substantially more sampling events from 1981-1991, had some 90th percentile and higher values greater than the standard.

To better understand conformity of water quality standards within the canal, each specific sample was given a rating based on three different Broward County standards (see Section III.E.5.e). In addition, all FC concentrations were pooled into specific eras based on the closing of WWTPs within the basin (see Section III.G.3). The closing of WWTPs did not have any apparent effect on FC levels, as the percentage of good ranked samples remained fairly similar after 1986 (Figure III.39). Interestingly, Site 13 did realize a slight decrease in the amount of good samples by the final period but only 4.7% of all samples were rated poor. Over all periods, FC concentrations were never out of compliance (i.e., poor samples) greater than 11% of the time.

Only Site 12 had a statistical difference between wet and dry season FC concentrations from 1989 thru 1997 (Mann-Whitney Rank Sum Test, $p < 0.05$, Figure III.40). Site 11 had the only 90th percentile value (dry season) above the 800 colonies/100 ml standard. However, the majority of samples at all sites were below the monthly average standard value of 200 colonies/100 ml.

Figure III.38. Yearly Box Plots of Fecal Coliform (FC) Levels within the C-13 Canal Basin from 1973 to 1997. Medians and percentiles calculated from biweekly, monthly, and quarterly samples with the number of samples (n) per year noted on the upper axis. The Broward County single sample standard (800 colonies/100 ml) is indicated by the dashed line.

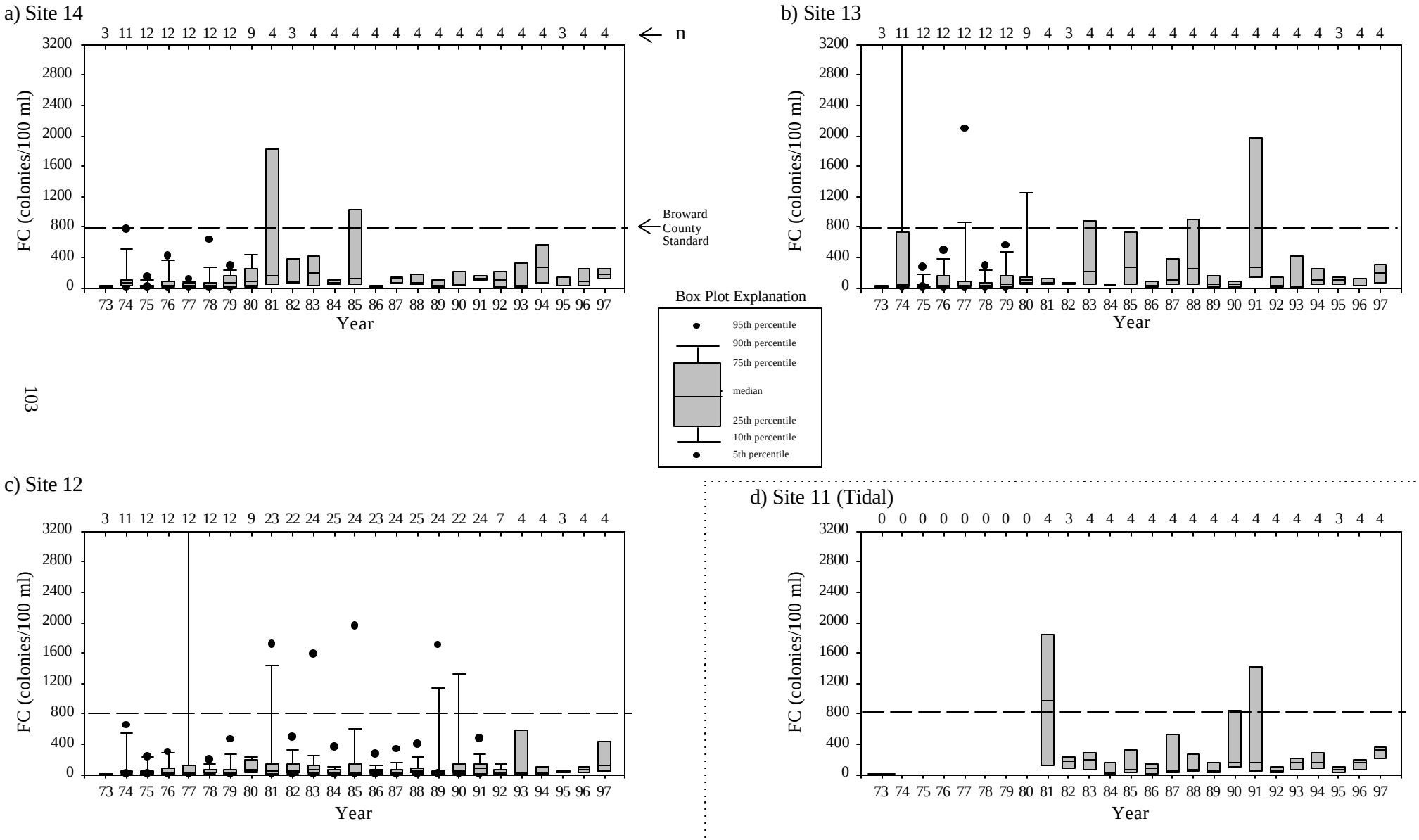


Figure III.39. Fecal Coliform (FC) Concentrations Observed in the C-13 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100 ml (good rating) and no single reading shall be above 800 colonies/100 ml (poor rating). Values between 201 and 800 colonies/100 ml are defined as fair.

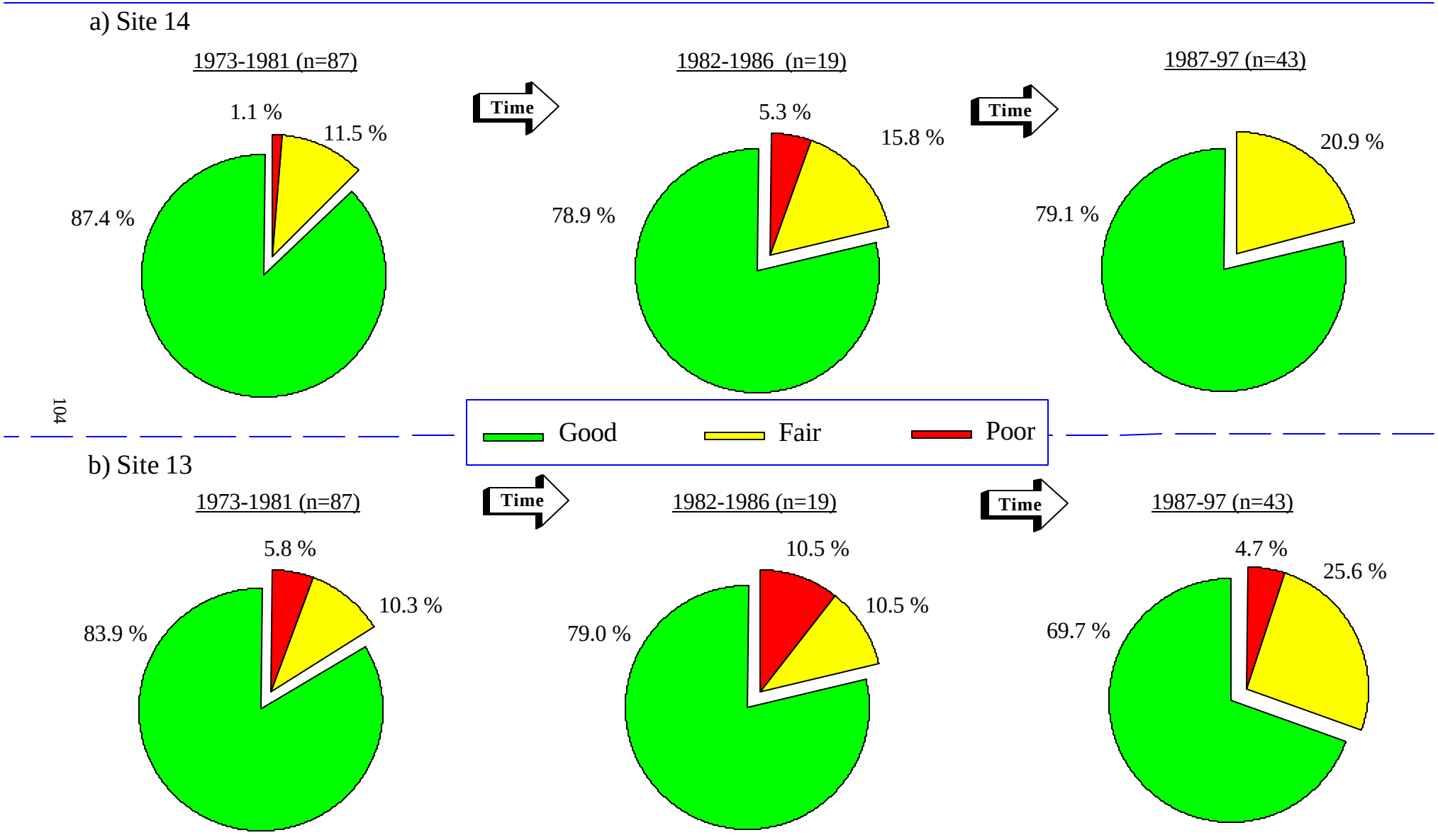
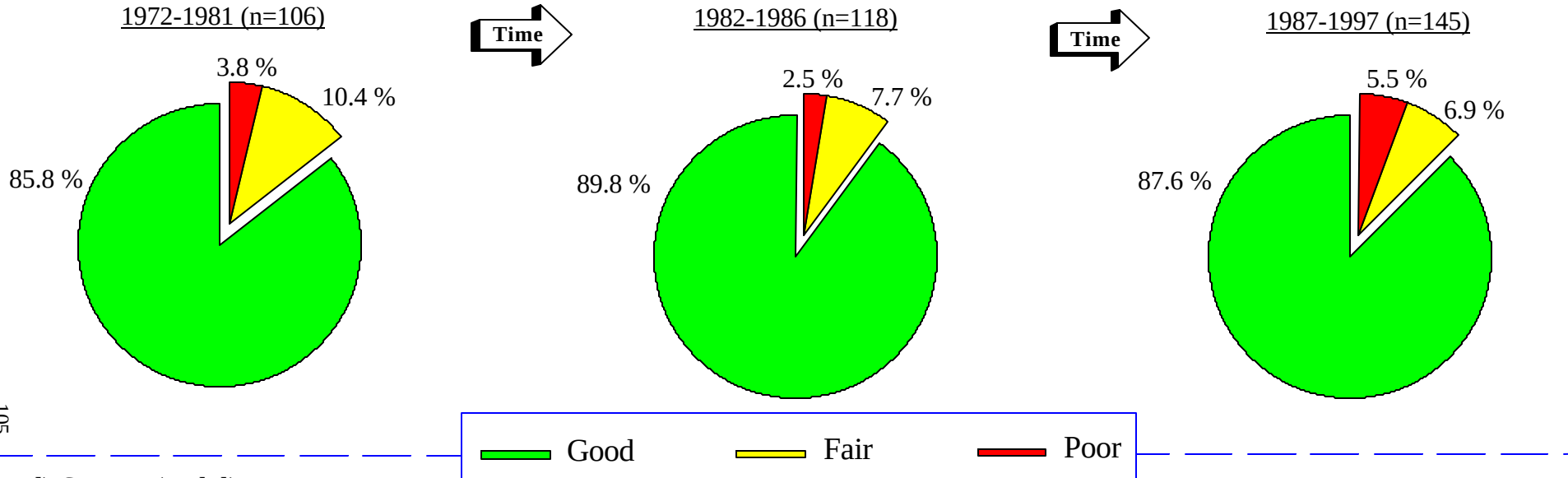


Figure III.39 (Cont.). Fecal Coliform (FC) Concentrations Observed in the C-13 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100 ml (good rating) and no single reading shall be above 800 colonies/100 ml (poor rating). Values between 201 and 800 colonies per 100 ml are defined as fair. Note Site 11 is in a tidal waterbody.

c) Site 12



d) Site 11 (Tidal)

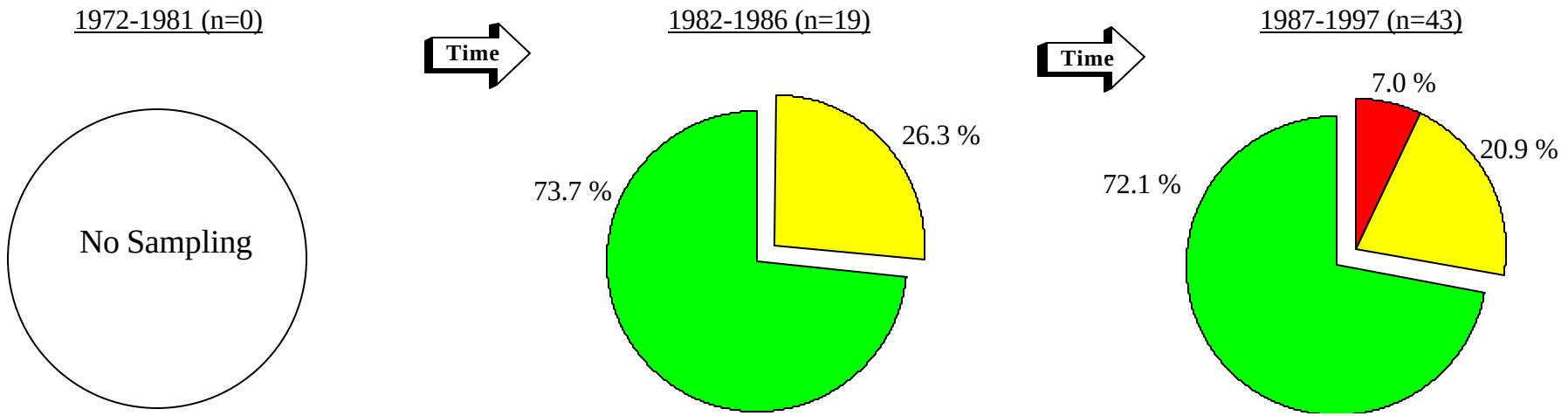
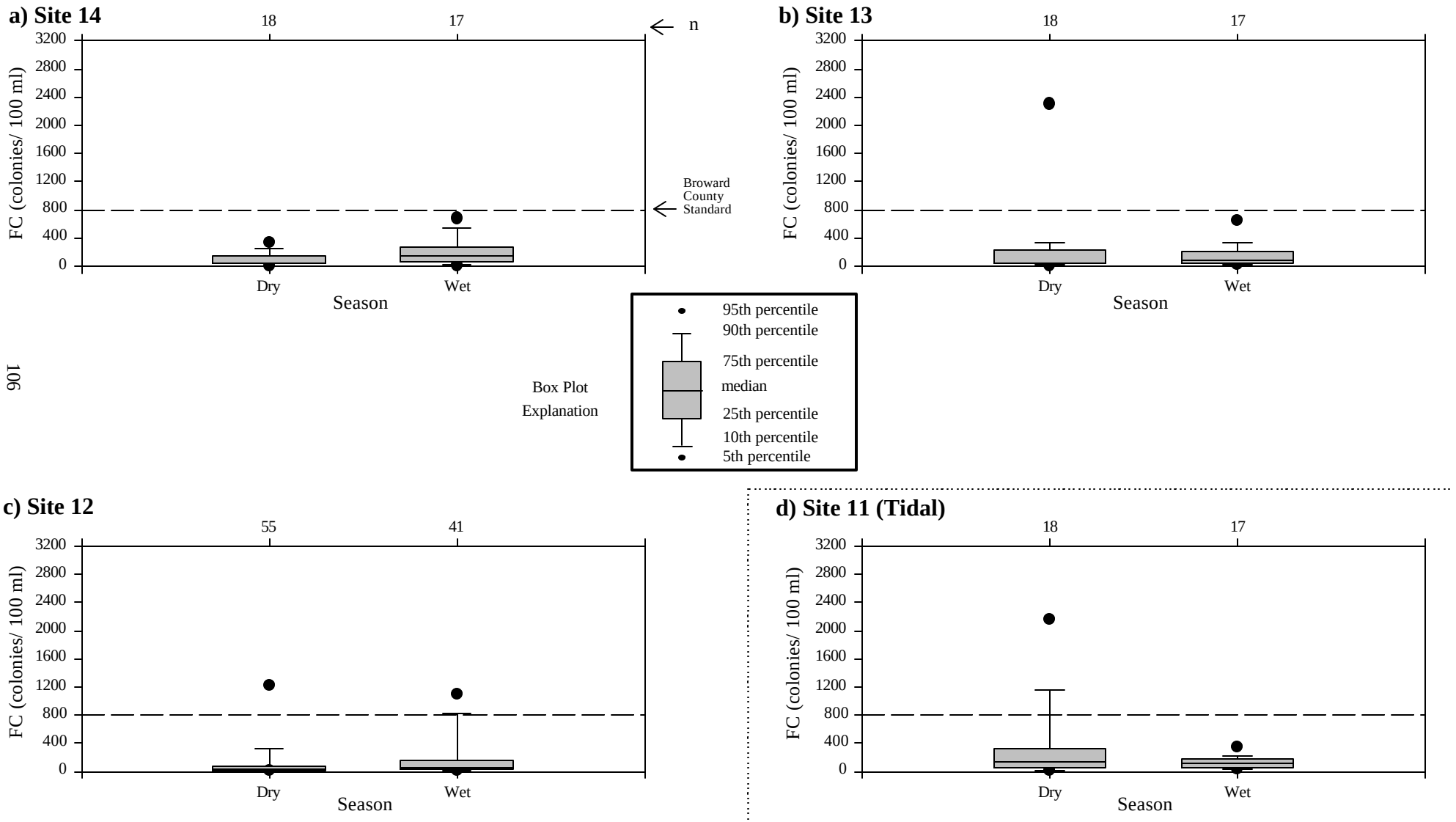


Figure III.40. C-13 Canal Basin Fecal Coliform (FC) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. A statistically significant difference between wet and dry season medians was observed at Site 12 ($p < 0.05$, Mann-Whitney Rank Sum test) but not at Sites 11, 13, and 14. Site 11 is downstream (i.e., tidal) of a water control structure (S-36).



7. Basin Summary

Generally, C-13 Canal water flow is from the confluence of the C-42 to the eastern estuarine waters via S-36. Sites 14 through 12 represent west to east sampling sites of a contiguous waterway within the same drainage basin. Site 11 represents the water quality immediately downstream of the S-36 and, though characterized by freshwater, is a tidal water body. The following will discuss the water quality characteristics observed basinwide at these sampling locales. In addition, the influence of WWTP discharges and seasonal effects will also be discussed. Finally, questions about the canal and basin brought forth by this initial data analysis effort are listed to support future monitoring and resource planning.

a. Influence of WWTP Discharges

The C-13 Canal showed substantial decreases in nutrient content at all four sites after WWTPs halted discharges. Nutrient compliance percentages typically increased by nearly 30% at all locations and in some cases (e.g., Site 12 TP levels) an improvement of nearly 50% was realized. Dissolved oxygen levels generally improved but not to the extent as nutrient concentrations.

b. Basinwide Water Quality Characteristics

In general, ambient water quality ranges from fair to good within the C-13 Basin. Furthermore, the years of 1993 through 1997 were characterized by good water quality based on nutrient standards (TP and TN). Interestingly, this period also had a few observations of DO averages below (i.e, out of compliance) the standard of 4.0 mg/l. Potentially, the low nutrient and low DO water reflects the increased discharges of seepage water from the WCAs to the estuarine waters from 1993 to 1997. In particular, if high seepage rates were exhibited by WCA 2B into the L-35A, this water would have been sent to the C-13 Canal unless flooding was occurring (see Section III.G.1). An analysis of hydrological flows would assist in determining the actual influence of both water management practices, as well as groundwater inflow on C-13's water quality.

Thus, initial observations suggest long term weather patterns and subsequent water management practices may mask any short term stormwater impacts on ambient water quality in the freshwater segment of the C-13 Canal. This includes periods of low rainfall. In general, the years from 1989 to 1992 had higher nutrient concentrations at all sites than 1993 to 1997. Thus, a lesser volume of low nutrient WCA water may have been entering the C-13 Canal during this period and the primary surface water inputs may have been short stormwater events. However, groundwater elevations and subsequent interaction with canal water will also need to be examined to further understand the relatively elevated nutrients during 1989-1992.

Within the C-13 Canal, between site differences after 1988 were subtle to non-existent. Site 14 had slightly lower annual DO averages and the lowest compliance percentages yet Site 12 had the two lowest annual averages of the nineties. Sites 13 and 14 had wet and dry season medians from 1989-1997 more similar to each other than Site 12. Concentrations of TP were very similar among the

freshwater sites (12-14) after post- WWTPs. However, Site 11 did exhibit higher TP values than the upstream Site 12, especially from 1993 to 1997. Conversely, Site 11 had lower TN values throughout the sampling period (post-WWTP) and was the only site with a higher wet season median than corresponding dry season (1989-1997). The influence of eastern tidal water and/or the discharge pattern of the S-36 may be possible explanations for slightly different nutrient observations at Site 11. Basinwide, ambient FC values were low (< 200 colonies/100 ml) (freshwater and tidal) and only rare exceedances of the single samples standard (800 colonies/100 ml) were seen.

c. Seasonal Patterns

A distinct seasonal pattern was observed for DO concentrations at all sites. Beyond the influence of temperature, wet season DO levels of 3.0 mg/l may be indicative of WCA water and/or local groundwater. Although dry season TN values were typically higher than the wet season observations, only one statistical difference was seen (Site 12). Thus, an important aspect of TN concentrations may be their slightly enhanced values (i.e., near or above 1.500 mg/l). Specifically, TN values were over the 1.500 mg/l standard at least 20% of the time at the freshwater sites from 1993 to 1997. Furthermore, the period from 1987 to 1992 was characterized by samples below 1.500 mg/l less than 50% of the time even though WWTP discharges had ceased.

d. Future Monitoring Questions

A major goal of this report is to develop strategic guidelines for future Broward County water quality monitoring and management. To facilitate this, questions generated by this study's findings are being compiled for each drainage basin. For the C-13 Basin and Canal, the main questions revolve around two different periods after WWTPs halted discharges..

- Are nutrient concentrations at Sites 12, 13, and 14 from 1993-1997 or from 1989-1992 more reflective of ambient levels in the canal?

- Are the differences in nutrient content between 1993-1997 versus 1989-1992 due to weather, land-use, water management, or a combination? And if so can those conditions be repeated?

- What is water column biology (e.g., chlorophyll a) and/or macrophytes response to the apparent different eras of nutrient concentrations?

- How much of an effect does the eastern tidal waters have on Site 11 and why were different nutrient patterns observed between Sites 11 (downstream) and 12 (upstream)?

H. C-12 Canal

1. Basin and Canal Structure

The C-12 Basin has a relatively small drainage area of nineteen mi^2 and is located in east-central Broward County (Cooper and Lane 1987, Figure III.41). The C-12 Canal forms the headwaters of the S-33 control structure. Within the C-12 Basin, the tailwaters of the S-33 exist in the North Fork of the New River, an estuarine water body (See Section IV.I). The C-12 Basin is unique among the major basins because no temporary or permanent flow originates from WCA seepage and water supply to the basin is limited to rainfall (Cooper and Lane 1987). The Old Plantation Water Control District (see Section I, Figure I.4) has a pump site at the western end of the canal that is inactive. Thus, overall flow in the canal is basically limited to major storm events. For example, a recent BCDPEP (1999) study compiled the SFWMD flow estimations for fourteen months and showed that zero flow occurred 85% of the time at the S-33.

2. Municipalities and Land Uses

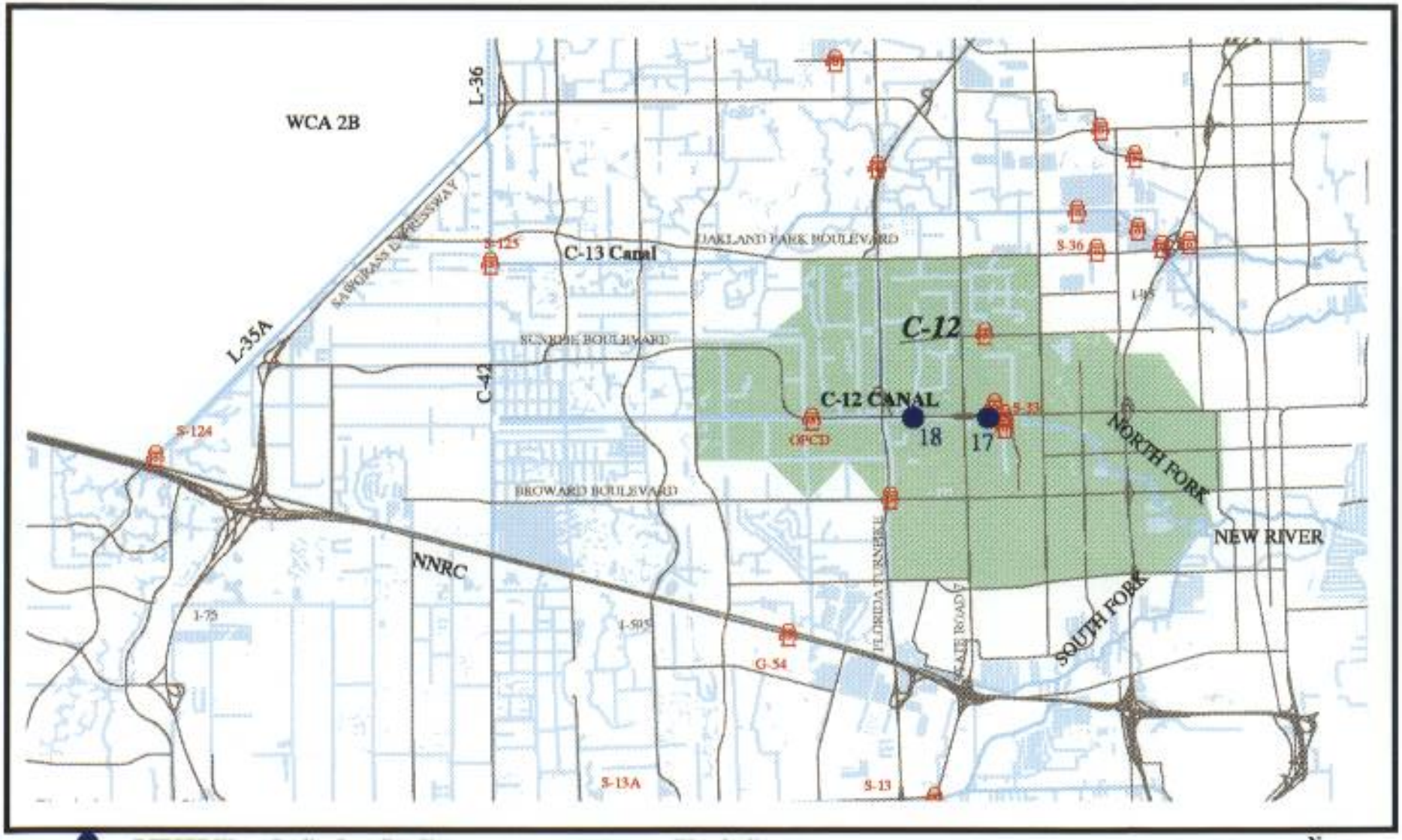
The C-12 Basin includes much of western Ft. Lauderdale, Lauderdale Lakes, southern Lauderhill, and eastern Plantation while much of the central basin is unincorporated Broward County (see Section I, Figure I.3). This basin was one of the earlier basins to be developed as seen by the populations of its municipalities in the early 1970s as compared to other areas of the county. In 1970, Ft. Lauderdale was heavily populated with nearly 140,000 residents. Lauderdale Lakes, which almost entirely lies within the basin, had a population of over 10,000 residents. Lauderhill contained approximately 9,000 residents (U.S. Bureau of Census 1970). The remainder of the population in the C-12 Basin resided in the unincorporated areas.

The population of the cities in the C-12 Basin grew significantly during the 1970s and early 1980's. By 1987, the population of Ft. Lauderdale had grown to over 150,000 residents and in 1995 was 156,121 (Broward County Planning Council 1995). During the same period, Lauderdale Lakes more than doubled in population while Lauderhill expanded by more than four times its population in 1970. By 1995, Lauderdale Lakes had a population of 29,691 and Lauderhill consisted of 49,000 residents (Broward County Planning Council 1995). Plantation's population in 1995 numbered 78,318.

3. Wastewater Treatment Plants Discharge History

Direct wastewater discharges were abundant to the C-12 Canal. Before the implementation of regulatory changes prohibiting such discharges in the mid- to late-80s, five sewage treatment plants released effluent into the canal. The first plant closed in 1975 when the Broward County Utilities Plant # 7 stopped discharging 1.377 million gallons per day (mgd) into the C-12 Canal. The last of these plants (Plantation North 3.3 mgd) was taken out of service in 1987 (BCEQCB, 1988).

Figure III.41. The C-12 Canal Basin and Broward County (BCDPEP) Sampling Site Location Map. The C-12 Canal and other major waterbodies with corresponding South Florida Water Management District (SFWMD) water control structures (labeled) are depicted. Note water control structures without labels are secondary structures operated by other entities than the SFWMD. For example, the Old Plantation Water Control District (OPCD) operates a pump station on the western boundary of the C-12 Canal.



BCDPEP Water Quality Sampling Site

Water Control Structures (primarily SFWMD)

Waterbodies

Major Roadways

0 1 2 3 Miles

N W E S

This map is for informational purposes only. For further information, please contact BCDPEP Water Resources Division (954) 519-1270.

4. Other Influences on Water Quality

a. Soils

The soils in the C-12 Basin (see Section I, Figure I.5) are primarily deep sandy soils with a poorly drained thick organic surface layer (Reynolds, Smith and Hills Inc. 1972). These soils are only moderately limiting to construction and therefore did not require extensive additional drainage to accommodate the development of the past thirty years.

b. Roadways

A major east-west connector, Sunrise Boulevard, runs parallel for the entire length of the C-12 Canal and drains at several points directly to the waterway. In addition, State Road 7 and the Turnpike are the major north-south roadways which cross the canal.

c. Septic Tanks

A large majority of the C-12 Canal Basin that drains to the freshwater segment is serviced by sewer. In addition, all land adjacent to the waterway is serviced by sewer. Conversely, the portion of the basin that drains to the estuarine reach (i.e., North Fork of the New River) has large areas with no sewer service (See Section IV.H).

5. Sampling Locations

Site 18 is located at the Northwest 9th Drive bridge (Figure III.40). Site 17 is situated immediately west of the S-33 control structure. The closest bridge to the S-33 is located to the east at 34th Avenue. Table III.23 describes the years of collection for each parameter at each site. Appendix 1 details the geographic location of the sites.

Table III.23. Sampling Years for Specific Parameters at the C-12 Canal Locations. A sampling year had at least one sample event during that year. Note the biochemical oxygen demand was a five-day test from 1973 until 1981 when a seven-day test was implemented until 1993 after which sampling for the parameter ceased at BCDPEP.

Parameter	Site 17	Site 18
Temperature	73-97	80-97
pH	73-97	80-97
Specific Conductance	80-97	80-97
Dissolved Oxygen	73-97	80-97
Biological Oxygen Demand	73-93	80-93
Total Organic Carbon	80-97	80-97
Turbidity	75-97	80-97
Total Phosphorus	74-97	80-97
Ammonia-Nitrogen	80-97	80-97
Nitrite+Nitrate-Nitrogen	80-97	80-97
Total Kjeldahl Nitrogen	80-97	80-97
Fecal Coliform	73-97	80-97
Total Coliform	73-97	80-97
Fecal Streptoccocus	76-97	80-97

6. Results

a. Physical Characteristics

Median and mean water temperatures were relatively similar at both sites with Site 18 having slightly higher values (Table III.24). Likewise, the C-12's pH levels were nearly identical at both sampling sites. Specific conductance values were particularly low as compared to other basins within close geographical proximity (see C-13 Canal, Table III.17 and North New River Canal, Table III.31).

Table III.24 Descriptive Statistics for Temperature (Temp; °C= degrees Celsius), pH, and Specific Conductance (Cond; Fmhos = micromhos/centimeter @ 25ºC) in the C-12 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. Number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
17	Temp	°C	377	26.0	25.4	3.7	32.4	14.0	0
18	Temp	°C	68	26.6	25.8	3.9	33.0	17.0	0
17	pH	units	384	7.6	7.7	0.6	10.1	6.7	0
18	pH	units	68	7.7	7.8	0.5	9.6	6.7	0
17	Cond	Fmhos	291	470	473	130	1120	150	0
18	Cond	Fmhos	68	510	532	140	930	306	0

b. Total Organic Carbon and Turbidity

Nearly identical TOC values (16.5 and 16.9 mg/l) were observed at Sites 17 and 18, respectively (Table III.25). An extremely high maximum (87.3 mg/l) at Site 18 caused a slightly higher TOC average then calculated for Site 17. As with TOC, turbidity levels were relatively similar at both sites and mean and median values were around 25% or less of the county standard of 10 ntus (Table III.25). Only the maximum turbidity concentrations were above the standard (i.e., out of compliance) and these values appeared to be rare based on the mean and standard deviations calculated for each site.

Table III.25. Descriptive Statistics for Total Organic Carbon (TOC) Concentrations and Turbidity (Turb) Levels in the C-12 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
17	TOC	mg/l	262	16.50	17.17	5.00	35.50	7.30	0
18	TOC	mg/l	62	16.90	19.65	12.27	87.30	7.10	0
17	Turb	ntu	356	1.9	2.5	2.3	34.0	0.3	3
18	Turb	ntu	68	1.7	2.6	5.4	45.0	0.3	1

c. Dissolved Oxygen and Biochemical Oxygen Demand

Long term dissolved oxygen levels differed slightly between Site 17 and 18 (Table III.26). Site 17 was characterized by long term DO averages and medians below 5.0 mg/l but above the single sample standard of 4.0 mg/l (i.e., within compliance). Conversely, Site 18 had means and medians above the 5.0 mg/l threshold. Beyond sample size, both sites exhibited large variability around the means (see standard deviations, Table III.26).

Mean and median biochemical oxygen demand values were near or above 3.0 mg/l at both sites which is below the standard of 5.0 mg/l. However, maximum values and standard deviations suggest BOD content did exceed the standard on occasion.

Table III.26. Descriptive Statistics for Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) Concentrations in the C-12 Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculations. The number of samples below the method detection limit is shown in the last column (# MDL).

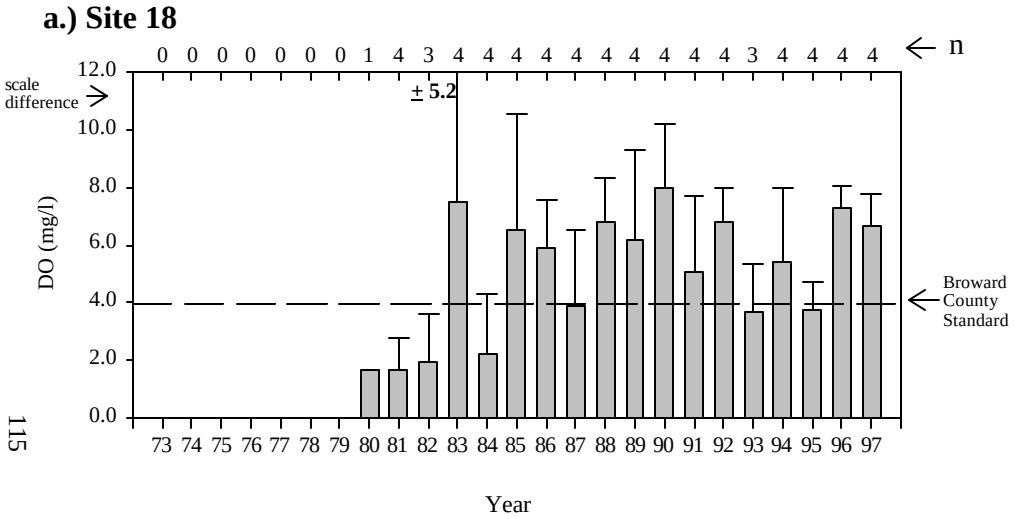
Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
17	DO	mg/l	380	4.3	4.8	3.2	14.7	0.025	6
18	DO	mg/l	67	5.1	5.3	2.9	12.1	0.025	3
17	BOD	mg/l	349	3.0	3.8	2.7	20.1	0.6	0
18	BOD	mg/l	48	2.8	3.1	2.0	10.5	0.8	0

Annual DO averages at both sites showed substantial increases after 1984 with almost all years having values greater than 4.0 mg/l (Figure III. 42). In the 1990s, Site 17's yearly means occasionally differed from Site 18's annual values by over 2.0 mg/l (e.g., 1995).

Dissolved oxygen concentrations were designated as poor, fair, and good based on water quality standards (see Section III.E.5.c). In addition, the changes over time are presented with reference to the closing of WWTPs (see Section III.H.3). The stoppage of WWTPs clearly allowed an increase in DO levels with the amount of good samples increasing by nearly 25% at both sites (Figure III.43). Furthermore, Site 17 also showed incremental improvements after 1980 when poor rated samples decreased by approximately 45%. Despite the improvements, poor rated samples were still observed over 20% of the time from 1989-1997.

From 1989 to 1997, higher dissolved oxygen values were normally observed during the dry season than during the wet season (Figure III.44). Statistically significant seasonal differences were observed between wet and dry seasons means at both sites (t-test, $p < 0.001$). All seasonal medians were above 4.0 mg/l but 25th percentile DO concentrations were below the single sample standard.

Figure III.42. Yearly Mean Dissolved Oxygen (DO) Levels within the C-12 Canal Basin from 1973 to 1997. Yearly means and standard deviations (error bars) calculated from monthly and quarterly samples with the number of samples (n) listed on the upper x-axis. DO levels should be above the Broward County standard (4.0 mg/l) indicated by the dashed line. Note scale difference on y-axis as compared to other basin DO figures. Number in parentheses represents standard deviation beyond scale.



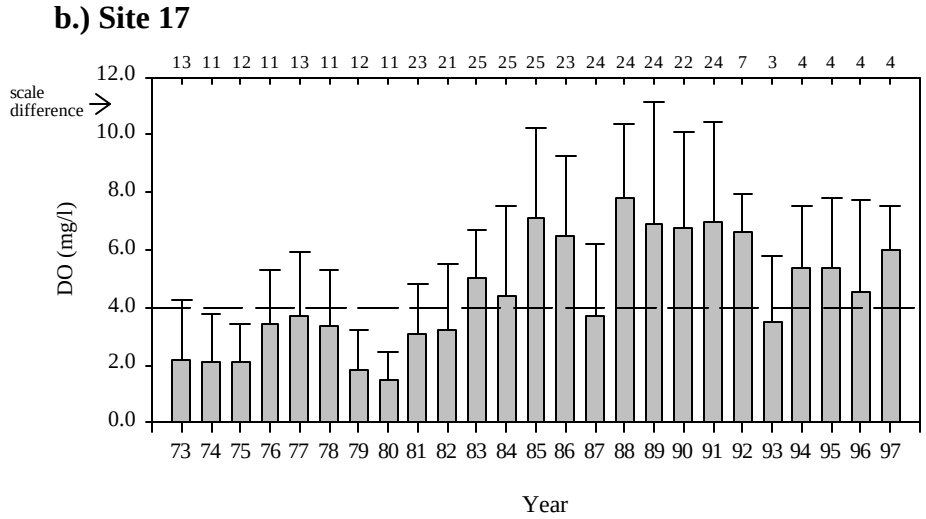


Figure III.43. Dissolved Oxygen (DO) Concentrations Observed in the C-12 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall be below 4.0 mg/l. Thus, all concentrations greater than or equal to 5.0 mg/l are classified as good and DO concentrations between 4.0 to 4.9 mg/l are considered fair. Readings below 4.0 mg/l are defined as poor.

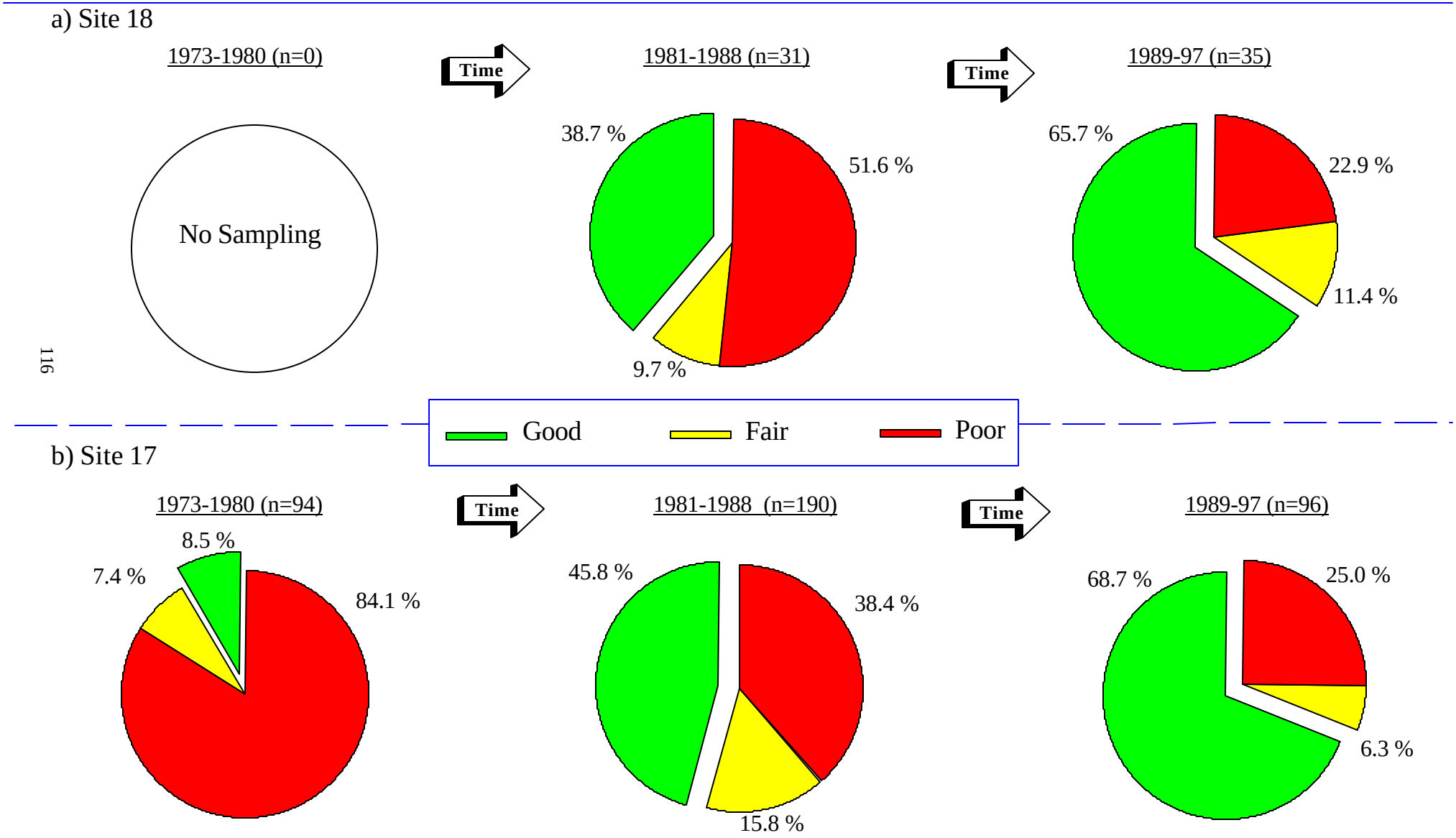
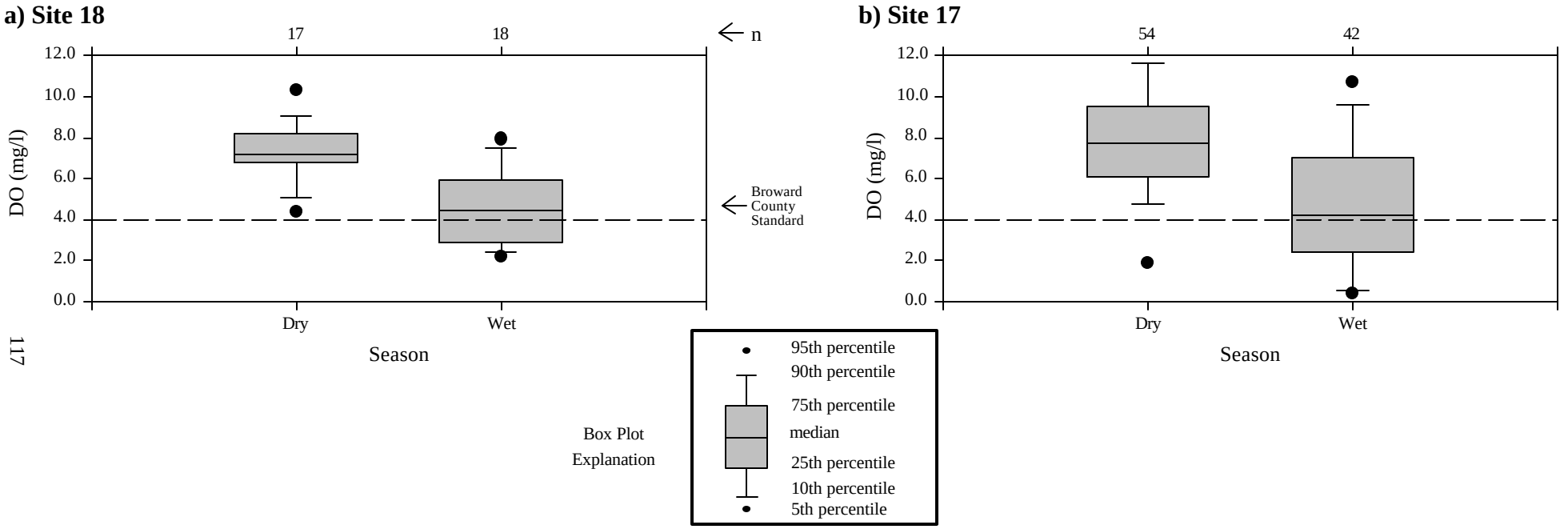


Figure III.44. C-12 Canal Basin Dissolved Oxygen (DO) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season means was observed at both sites ($p < 0.001$, t-test).



d. Total Phosphorus

Total phosphorus mean and median concentrations were elevated at both Sites 17 and 18 (Table III.27) with means being exceptionally high. In particular, Site 17's long term values were above 0.300 mg/l. The occurrence of extremely high maximum values (> 3.0 mg/l) undoubtedly skewed both the means and medians in this particular analysis.

Table III.27. Descriptive Statistics for Total Phosphorus (TP) Concentrations in the C-12 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculations. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
17	TP	mg/l	360	0.318	0.499	0.697	6.000	0.010	16
18	TP	mg/l	67	0.118	0.315	0.496	3.570	0.010	7

The annual averages (Figure III.45) illustrate how TP concentrations changed dramatically over time and how the long term descriptive statistics (see Table III.27) were largely influenced by data collected before 1988. Yearly mean TP between 1974 and 1980 were substantially high (> 1.0 mg/l). Values between 1981 and 1987 decreased by half but generally were around 0.500 mg/l. With the closing of the final WTTP, TP values were typically between 0.050 and 0.080 mg/l at both Sites 17 and 18 (Figure III.45).

To better examine compliance patterns within the canal, all individual samples were rated in terms of Broward County's TP standard (0.020 mg/l; see Section III.E.6.d) and are presented with special reference to the closing of WWTPs within the basin (see Section III.H.3). With at least 88.4% poor rated samples, the C-12 Canal clearly had significant TP inputs from WWTP during 1974 through 1987 (Figure III.46). Despite substantial improvements observed after WWTPs ceased, poor rated samples were still observed over 40% of the time between 1989-1997.

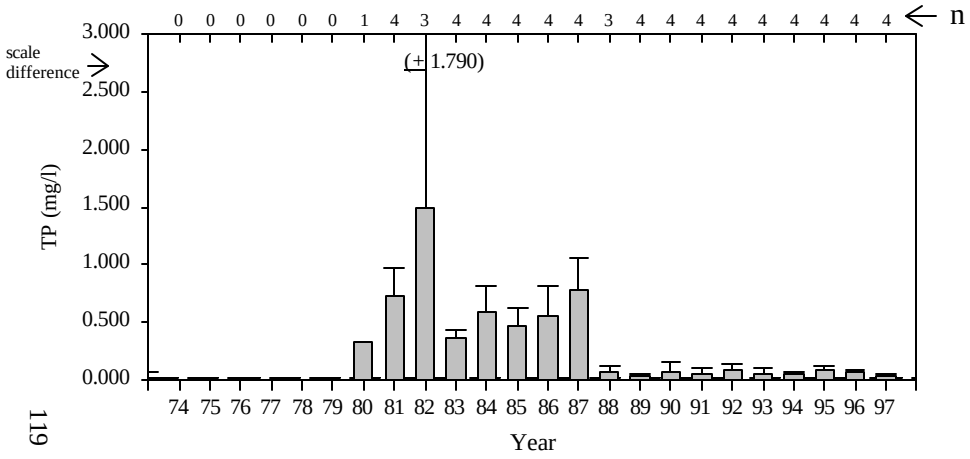
Statistically significant values were not observed between wet and dry season mean or median values (Figure III.47). However 25th percentile and higher concentrations were above the 0.020 mg/l standard at both sites. Site 17 showed nearly uniform concentrations based on the median and spread of percentiles.

e. Total Nitrogen

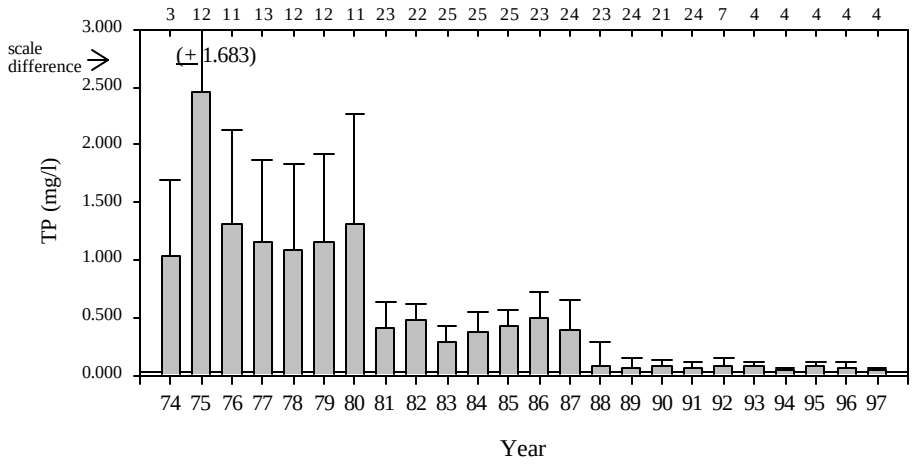
Total nitrogen (TN) levels are calculated from the total Kjeldahl nitrogen (TKN) and nitrite+nitrate-nitrogen (NO_2+NO_3) concentrations. The mean TN content at Site 18 (1.634 mg/l) was above the 1.500 mg/l standard level (i.e., out of compliance) but was due to an extremely anomalous observation 17.098 mg/l (Table III.28). Thus, median TN values probably reflected the concentrations more satisfactorily and both C-12 sites were near 1.200 mg/l.

Figure III.45. Annual Mean Total Phosphorus (TP) Levels within the C-12 Canal Basin from 1974 to1997. Yearly means calculated from quarterly and monthly sampling with the number of events (n) per year noted on upper x-axis. Error bars represent the standard deviation (sd). TP levels should be below the Broward County freshwater standard (0.020 mg/l) indicated by the dashed line. Numbers in parentheses represent sd values greater than the y-axis scale. The years 1988-1997 (figures c+d) are also shown on additional graphs due to the large difference in scale (y-axis) before and after 1988.

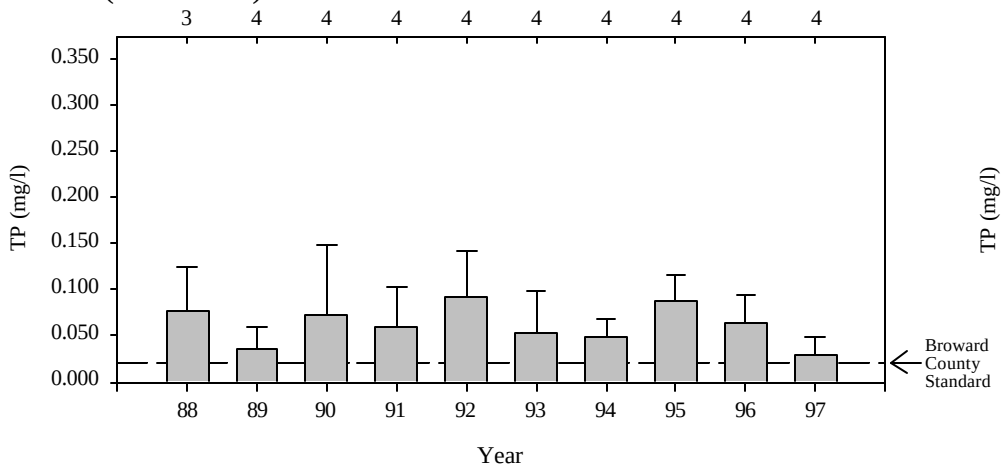
a) Site 18



b) Site 17



c) Site 18 (1988-1997)



d) Site 17 (1988-1997)

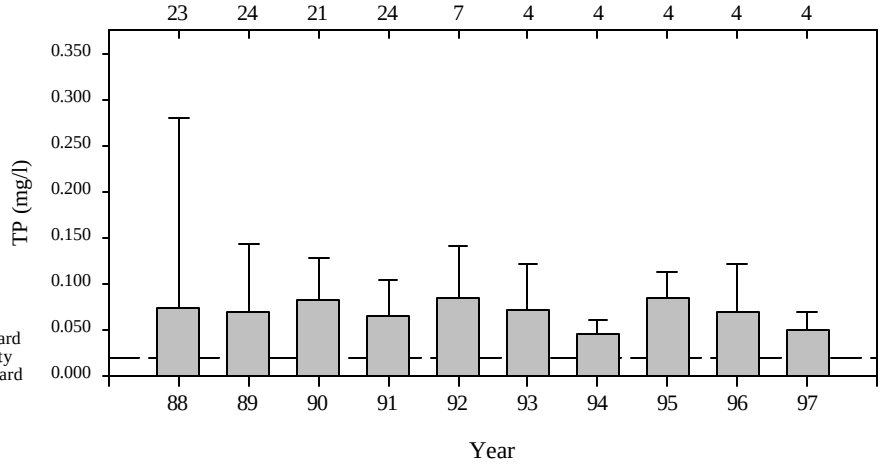


Figure III.46. Total Phosphorus (TP) Concentrations Observed in the C-12 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County freshwater TP standard of 0.020 mg/l. The percentage of samples below 0.020 mg/l are classified as good. A fair rating was given to concentrations between 0.021 mg/l to 0.060 mg/l. Values equal to or greater than three times the standard (i.e., 0.060 mg/l) are classified as poor.

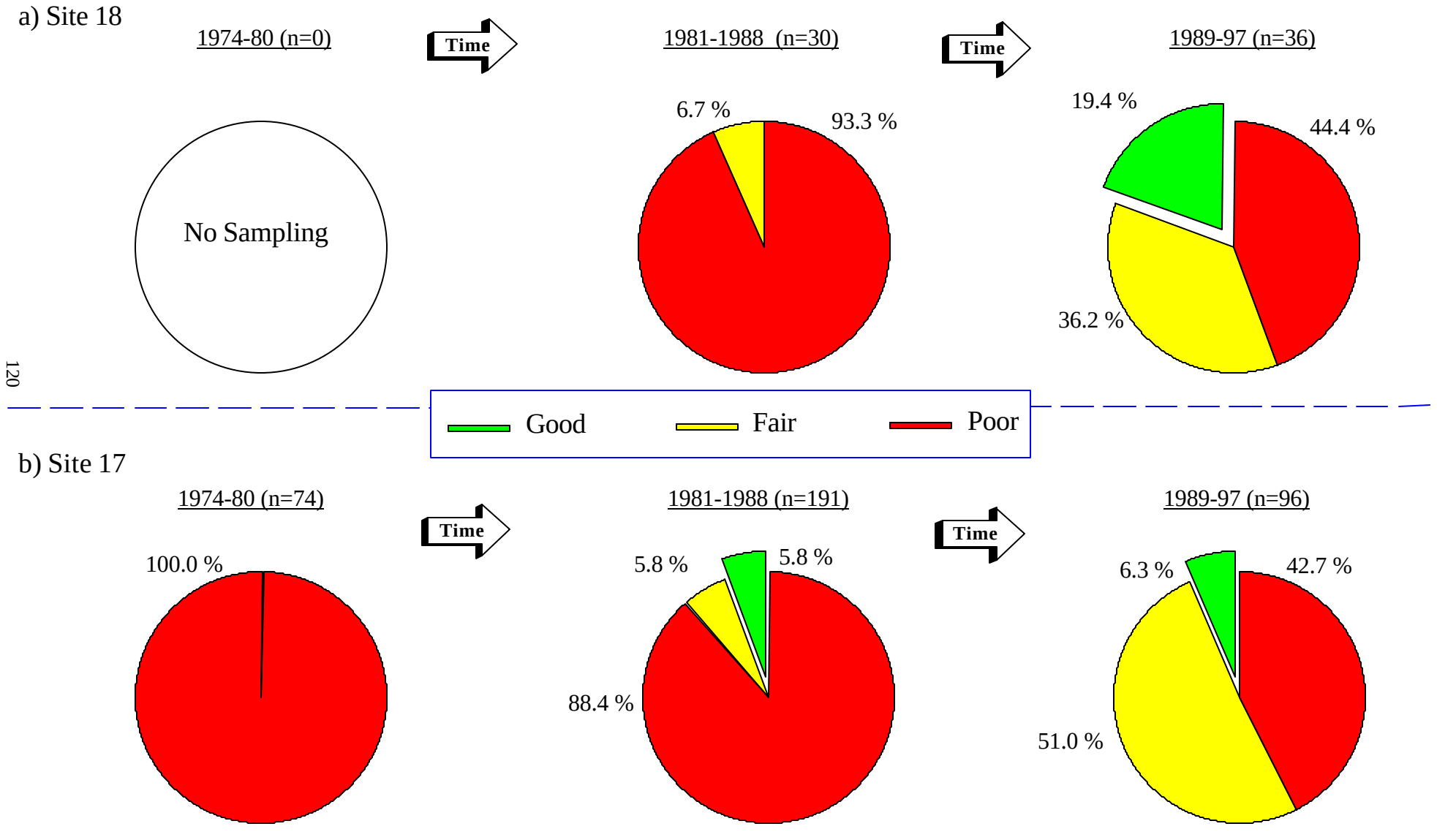
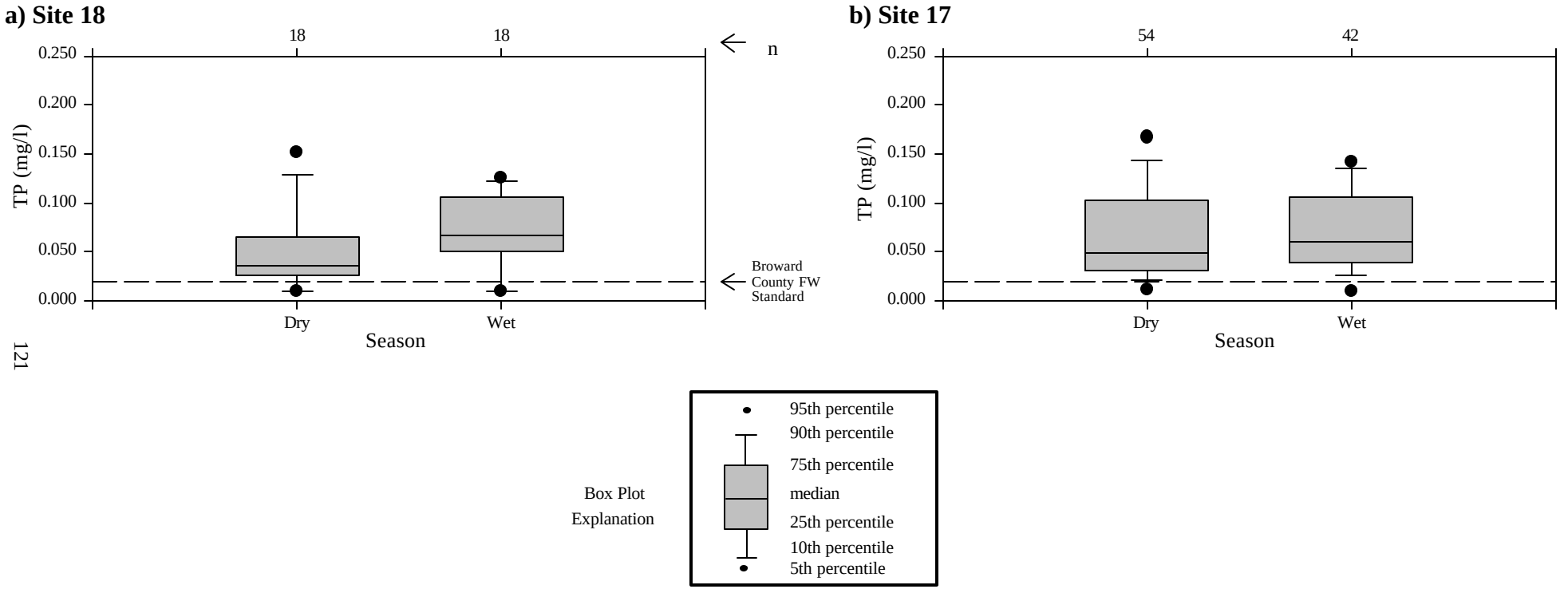


Figure III.47. C-12 Canal Basin Total Phosphorus (TP) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season means and/or medians were not observed at either station.



Over 90% of TN was contributed by TKN at both locations (Table III.28). In addition, each site had very different median and mean (long term) NO_2+NO_3 and ammonia-nitrogen concentrations. This was due, in part, to extremely high maximum values and is also demonstrated by the large standard deviations. Ammonia-nitrogen was also characterized by observations below the method detection limit around 50% of the time at both sites.

Table III.28. Descriptive Statistics for Nitrite+Nitrate-Nitrogen (NO_2+NO_3), Ammonia-Nitrogen (NH_3), Total Kjeldahl Nitrogen (TKN), and Total Nitrogen (TN) in the C-12 Canal Basin. All calculations represent seventeen years of sampling, however, the number of samples (n) varies between sites. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL). Total nitrogen was calculated as the sum of TKN and NO_2+NO_3.

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
17	NO_2+NO_3	mg/l	291	0.040	0.154	0.256	1.660	0.005	89
18	NO_2+NO_3	mg/l	68	0.067	0.189	0.301	1.380	0.005	13
17	NH_3	mg/l	267	0.025	0.144	0.341	2.950	0.005	144
18	NH_3	mg/l	64	0.025	0.189	0.327	1.485	0.005	29
17	TKN	mg/l	286	1.100	1.196	0.511	3.384	0.179	0
18	TKN	mg/l	66	1.105	1.440	1.969	16.700	0.245	0
17	TN	mg/l	286	1.211	1.352	0.646	4.920	0.195	N/A
18	TN	mg/l	66	1.190	1.634	2.045	17.098	0.250	N/A

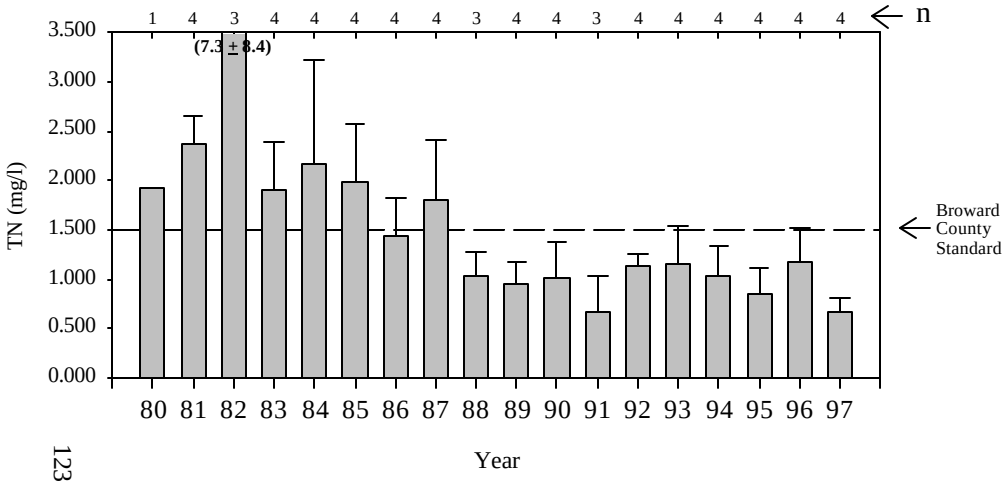
Annual TN content exhibited a similar pattern as TP levels in the eras before and after WWTP discharges. Yearly means dropped by nearly 1.0 mg/l at Site 18 and around 0.075 mg/l at Site 17 after 1987 (Figure III.48). In fact, annual averages at both sites were normally below the 1.500 mg/l standard subsequent to the halting of WWTP discharge practices.

The similarity in C-12 sampling site concentrations was further borne out by the percentage of good rated samples between 1989 through 1997 being high (at least 90%, Figure III.49). Each TN sample was given a rating based on Broward County's water quality standards (see Section III.E.5.e). Additionally, changes over time were investigated with special reference to the closing of WWTPs within the basin (see Section III.H.3).

Between 1989-1997, seasonal median TN values were very similar between sites and statistical differences were not observed for the mean or median seasonal TN content (Figure III.50). Only the 95th percentile TN values were above Broward County's compliance standard.

Figure III.48. Annual Mean Total Nitrogen (TN) Levels within the C-12 Basin from 1981 to 1997. Yearly means calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis and error bars represent the standard deviation (sd). TN levels should be below the Broward County standard (1.500 mg/l) indicated by the dashed line. Numbers in parentheses represent mean and sd values greater than the y-scale (note differnent scale than other basins).

a) Site 18



b) Site 17

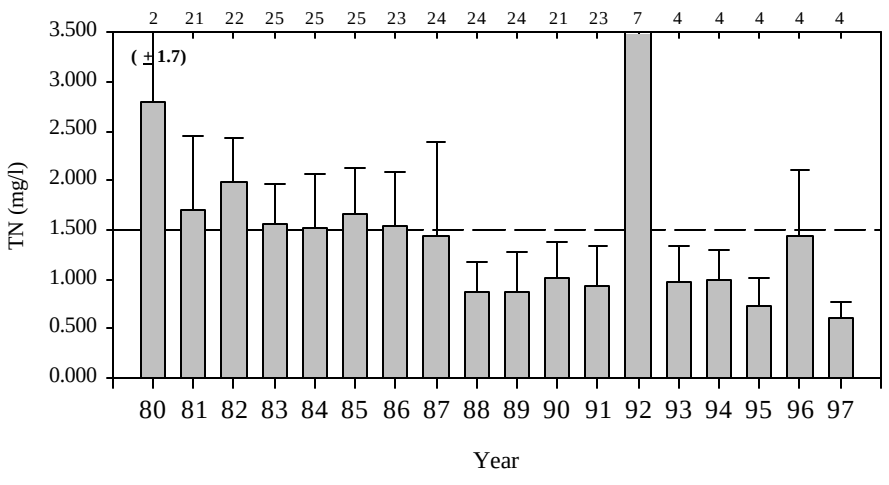


Figure III.49. Total Nitrogen (TN) Concentrations Observed in the C-12 Canal Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified as good. A fair rating was given to concentrations between 1.501 mg/l to 2.500 mg/l. Values greater than 2.500 mg/l are classified as poor.

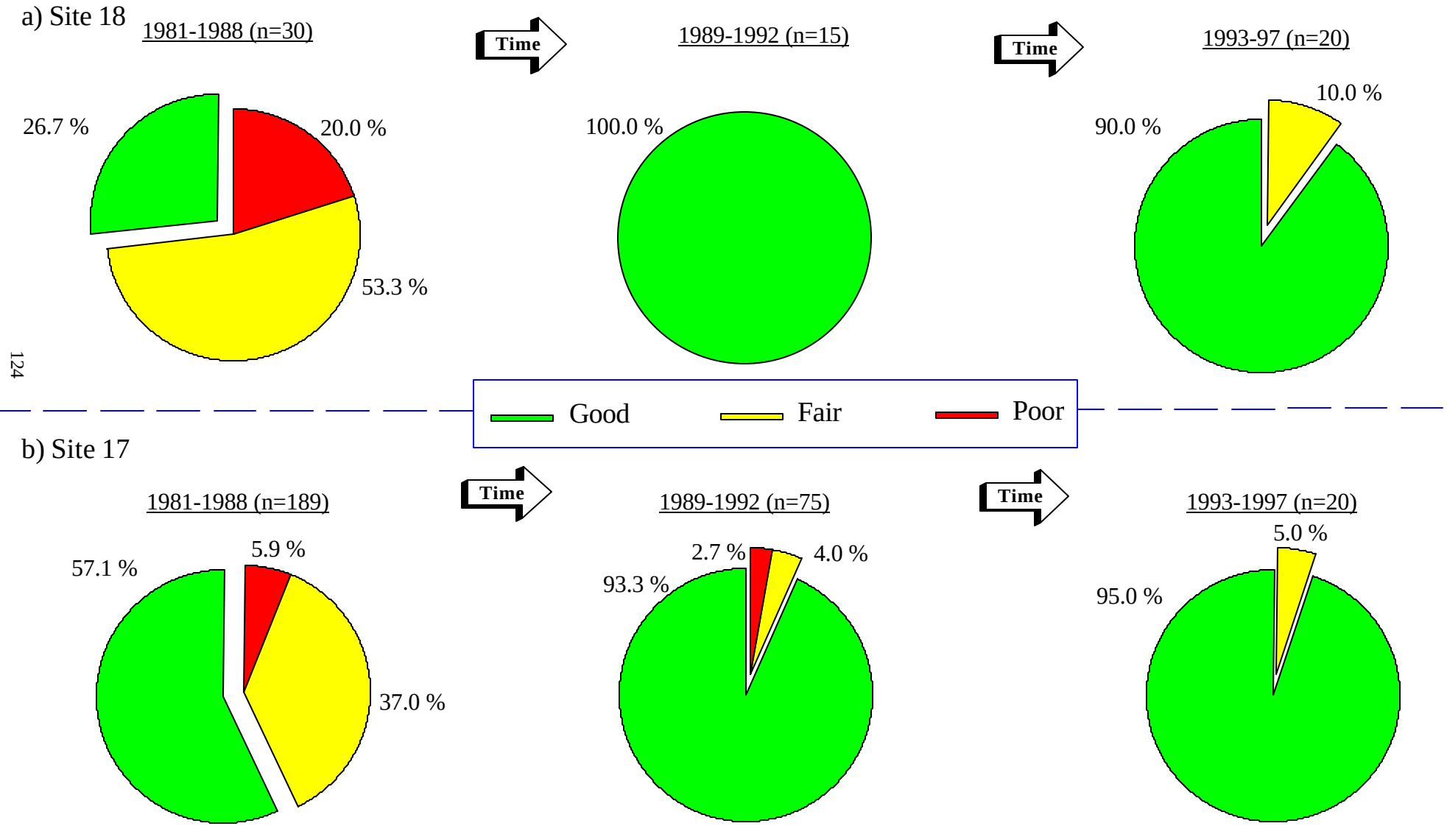
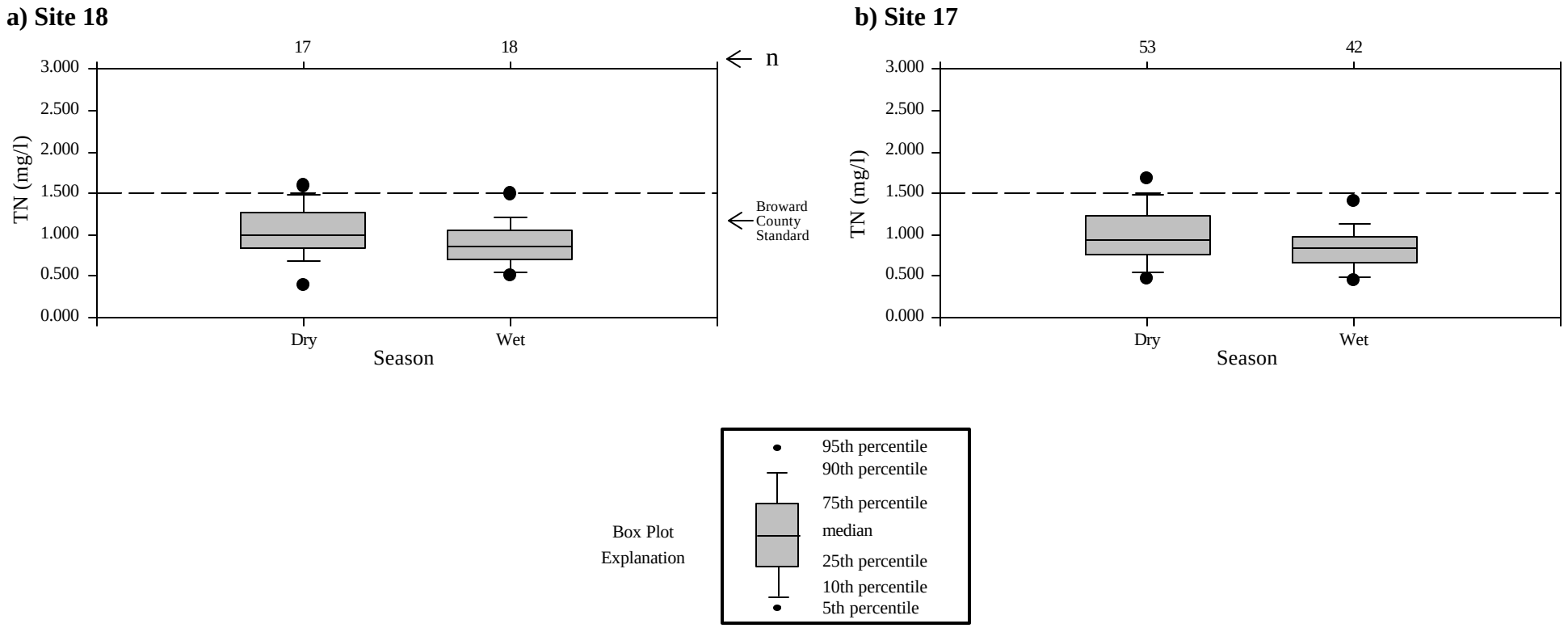


Figure III.50. C-12 Canal Basin Total Nitrogen (TN) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season means and/or medians were not observed at either station.



f. Bacteriological Parameters

Bacteriological parameters measured from 1981-1997 included fecal coliform (FC), total coliform (TC), and fecal streptococcus (FS). Mean values were higher than medians (Table III.29), however, bacteriological mean values are often skewed by outstanding high values (BCDNRP 1994). The high standard deviations (Table III.29) and large differences between maximum and minimum values attest to the occurrence of this pattern. Median values were typically low and below (i.e., within compliance) water quality standards.

Table III.29. Descriptive Statistics for Fecal Coliform (FC), Total Coliform (TC), and Fecal Streptococcus (FS) in the C-12 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL) and the unit of measurement is colonies/100 ml (col).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
17	FC	col	375	70	438	1272	12000	3.5	60
18	FC	col	146	96	597	1838	12000	5	7
17	TC	col	379	660	5753	16997	80000	5	11
18	TC	col	70	295	1204	3468	26000	12	3
17	FS	col	347	120	1251	6922	100000	5	88
18	FS	col	68	99	526	1115	6900	12	14

Yearly median values were normally below the single sample standard (800 colonies/100 ml) at both sites (Figure III.51). However, occasional high fecal coliform concentrations were observed, particularly during 1994 which exhibited the highest annual medians and 75th percentile values during the 1990's. Exceedances before 1989 are likely due to insufficient WWTP chlorination.

To better understand compliance patterns within the canal, each specific sample was given a rating based on three different Broward County water quality standards (see III.E.5.f) and the closing of WWTPs within the basin was addressed (see section III.H.3). Poor rated FC concentrations were only occasionally observed (< 15.0%) after 1980 (Figure III.52) and good rated samples (< 200 colonies/100 ml) were the typical (> 64.0%) observations in the 1980's and 1990's.

Wet season FC values tended to be higher than dry season concentrations at both sites (Figure III.53). Statistically significant differences from 1989-1997 were observed at both monitoring locations (Mann-Whitney Rank Sum Test, $p < 0.05$). However, exceedances of the 800 colonies/100 ml standard were rare.

Figure III.51. Yearly Box Plots of Fecal Coliform (FC) Levels within the C-12 Canal Basin from 1973 to 1997. Medians and percentiles calculated from monthly and quarterly samples with the number of samples (n) noted on the upper axis. The Broward County single sample standard (800 colonies/100 mL) is indicated by the dashed line. Numbers in parentheses represent 75th percentile values that extend beyond the y-axis scale. Note difference in y-scale axis compared to other basins.

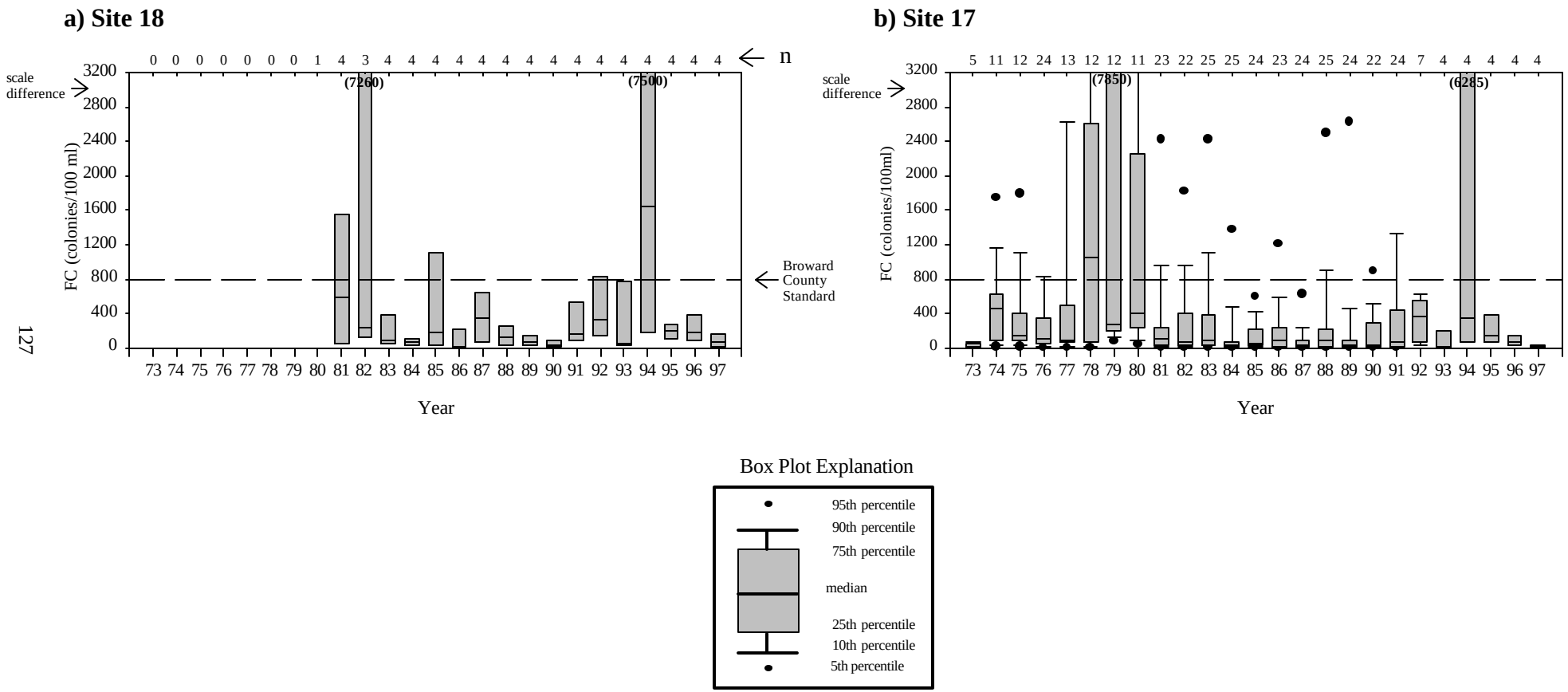


Figure III.52. Fecal Coliform (FC) Concentrations Observed in the C-12 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100 ml (good rating) and no single reading shall be above 800 colonies/100 ml (poor rating). Values between 201 and 800 colonies/100 ml are defined as fair.

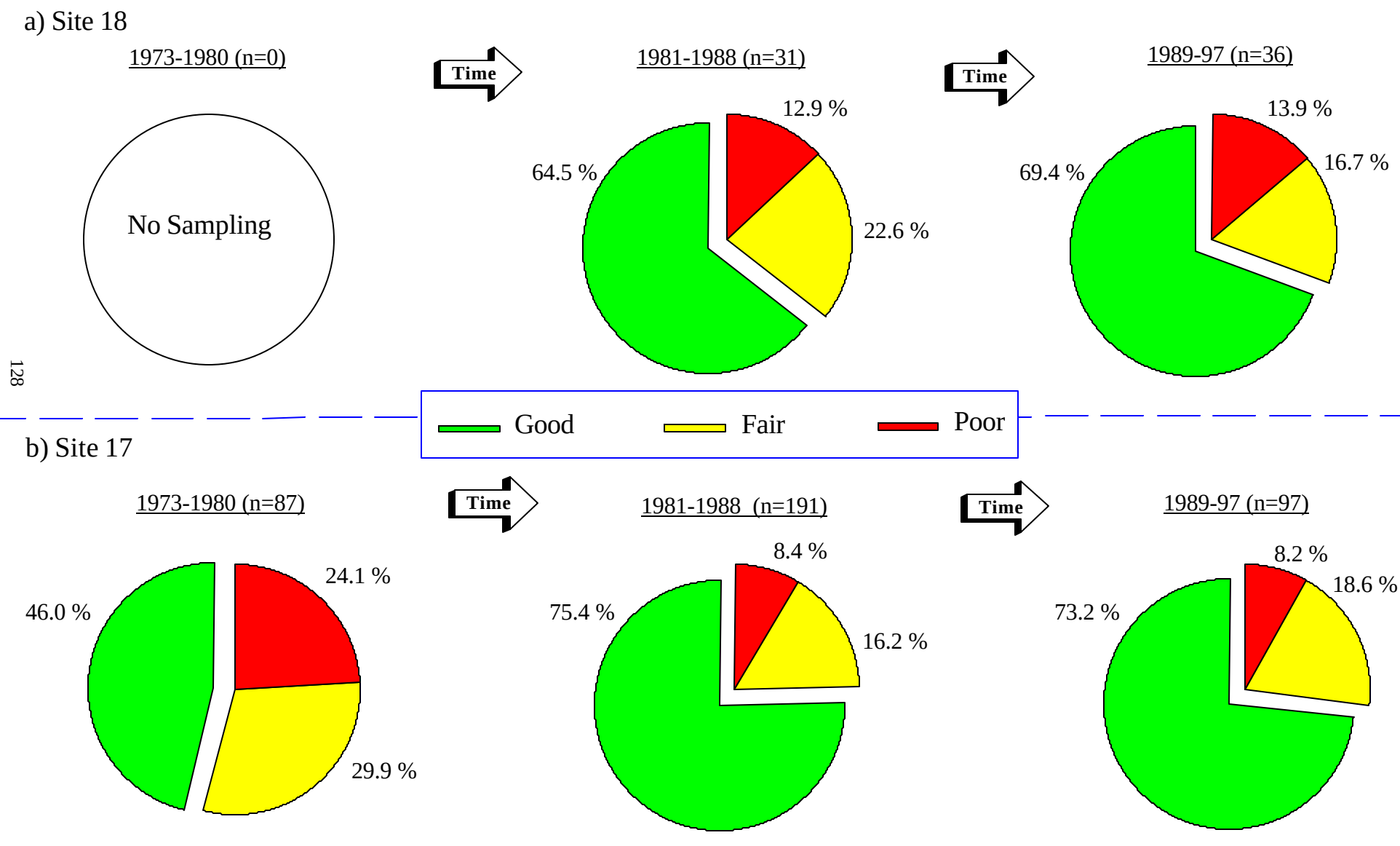
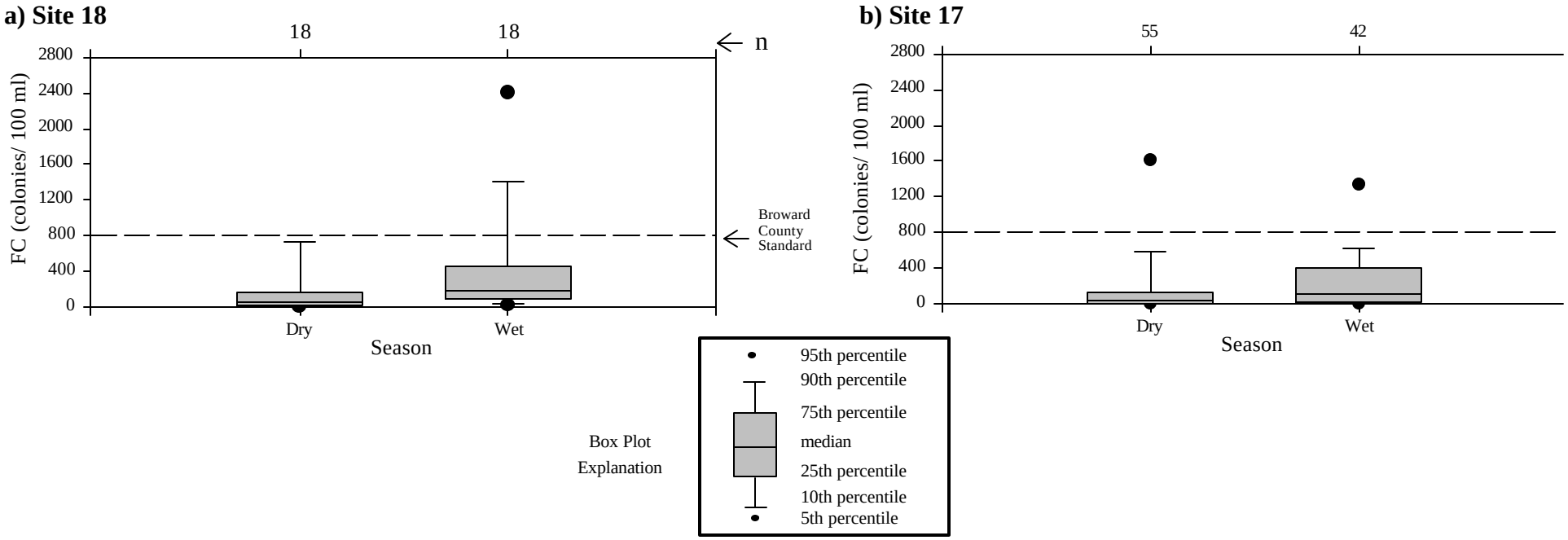


Figure III.53. C-12 Canal Basin Fecal Coliform (FC) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season means was observed at both sites ($p < 0.05$, Mann-Whitney Rank Sum test).



7. Basin Summary

The C-12 Canal is hydrologically unique in Broward County because it has no direct or indirect link to seepage water from the WCAs. Due to its importance as the headwaters of the North Fork of the New River (see Section IV), the canal has been studied more extensively by BCDPEP in the last ten years than other freshwater canals. Specifically, a recent investigation (BCDPEP 1999) compiled SFWMD flow rate data through the S-33 and showed the structure was closed 85 percent of the time. Thus, the C-12 Canal typically is a "closed" water body which receives inputs primarily from groundwater and stormwater depending on rainfall patterns.

The following will discuss how the canal has, at least, historically improved due primarily to the closing of WWTP. For a finer time and space scale sampling study (deployed Hydrolab® and bi-weekly sampling) please see BCDPEP (1999). Questions about the canal and basin brought forth by this historical data analysis effort are listed to support future monitoring and resource planning.

a. Influence of WWTP Discharges

The major observation through this historical analysis was the dramatic improvement in water quality after 1988. In particular, TP concentrations decreased by two orders of magnitude from the 1970's to the 1990's. Although TN was only monitored since 1981, it also decreased by a relatively large amount (typically > 0.75 mg/l). The large change is most likely due to a relatively small surface area in the canal being influenced by a large volume of wastewater. Furthermore, the lack of any consistent flow from the western areas of the county contributed to stagnation in the canal.

b. Basinwide Water Quality Characteristics (Post-WWTPs)

Generally, Sites 17 and 18 water quality characteristics were very similar which is also likely due to the overall low volume of flow in the canal. In addition, observations of the historical C-12 data set from 1989 to 1997 are very consistent with values measured bi-weekly for one year (BCDPEP 1999). The major parameter of concern in the canal is TP. Potentially, sediments within some reaches of the canal may still have high TP levels because of the settlement of particulates from the WWTP discharges. Thus, C-12 sediments may also be a source of TP to the water column may partly explain why TP levels were still slightly elevated from 1989-1997.

A recent study found median chlorophyll a (chl a) value of less than 10 mg/m^3 and 95^{th} percentile values just over 20 mg/m^3 over a period of one year in the C-12 Canal (n=25; BCDPEP 1999). This suggests that nutrient levels do not normally lead to excessive blooms (> 60 mg/m^3) in the waterway. However, other factors may be limiting (e.g., light) phytoplankton populations and/or the nutrient content though above standards was not conducive to bloom conditions. The continuing chl a measurements by BCDPEP's quarterly monitoring program which began in 1995 should assist in determining long term trends.

The downstream receiving water body (North Fork of New River) has TP levels which are nearly twice the C-12 Canal levels (see Section IV.H.5.d) and statistically significant differences have been demonstrated between the two water bodies (see BCDEP 1999). Thus, the ongoing effort to bring

more C-12 water to the North Fork of the New River would, theoretically, improve ambient downstream conditions. Additionally, a more consistent physical process of flow would potentially improve TP levels in both water bodies.

Having two sites, approximately 1.5 miles apart, with similar water quality also suggests site specific drainage and land use are similar. With potential hydrological changes likely occurring in the next five to ten years either due to local efforts (see BCDPEP 1999) or the Everglades Restoration (http://www.evergladesplan.org), continued sampling of both sites should be considered to monitor changes in water quality.

c. Seasonal Patterns

Seasonal observations were primarily seen for DO content and as discussed before temperature can influence DO readings. However, the extremely low DO concentrations (< 2.0 mg/l) suggest some localized ground water seepage occurs. The very low (500 Fmhos/cm) specific conductance values observed in this study and further confirmed in 1997-1998 (BCDPEP 1999) suggest groundwater inputs are important to the canal. Statistically significant differences in seasonal FC content are likely due to stormwater runoff into a relatively stagnant water body. Nonetheless, non-compliance with the single sample standard was relatively rare in both this and other studies (BCDPEP 1999).

d. Future Monitoring Questions

One goal of this report is to develop strategic guidelines for future Broward County water quality monitoring and management. To facilitate this, questions generated by this study's findings are being compiled for each drainage basin. For the C-12 Basin and Canal, some questions have at least been partially resolved with more intensive sampling efforts (BCDPEP 1999). Some still exist though based on this historical analysis.

- Are the excessive water column nutrients observed up until 1986, bound or available in the sediments?
- What is stormwater quality like entering the C-12 Canal?
- Will canal infrastructure changes improve the levels of TP in the C-12 and downstream in the North Fork?
- What are long term chl a levels in the waterway and will they reflect recent studies (BCDPEP 1999)?

I. North New River Canal

1. Basin and Canal Structure

The North New River Canal (NNRC) Basin is a medium-sized drainage area of approximately thirty mi^2. The NNRC is divided into a western (twenty-three mi^2) and an eastern (seven mi^2) sub-basin with the approximate dividing boundary at University Drive (SR 817, Cooper and Lane 1987, Figure III.54). Construction of the NNRC began in 1906 and was completed in 1912. The waterway was the first in Broward County to connect to Lake Okeechobee through a series of levees and water control structures. The portion within populated Broward County starts at the US-27 and I-75 highway interchange. Due, in part, to the convergence of three WCAs, the South Florida Water Management District (SFWMD) has a complex set of water control structures including, S-141, S-142, S-34, and G-123, northwest near the US-27 and I-75 interchange.

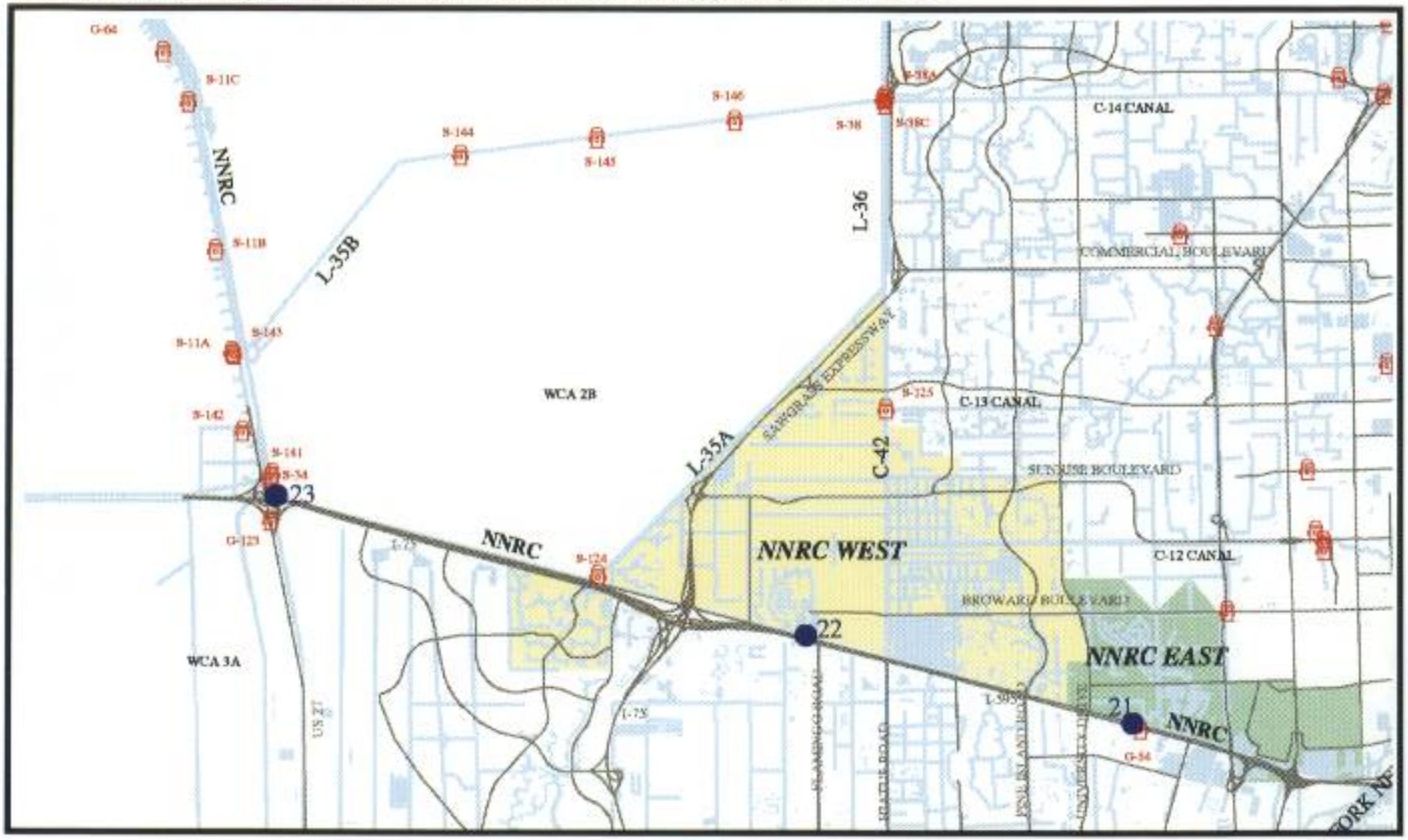
The main western inflow of water is from the WCA 2 via the S-143 and S-34 (Cooper and Lane 1987). Additional water from WCA 2B and/or WCA 3A may be discharged to the NNRC by S-141 and S-142, respectively through the S-34 depending on specific water elevations (Cooper and Lane 1987). In certain hydrological conditions (see Cooper and Lane 1987), NNRC water may be discharged through G-123 and S-142 into WCA 3A.

East of S-34, the NNRC becomes the headwaters of the Sewell Lock (G-54) which separates the fresh and estuarine sections of the waterway. The tidal NNRC meets the South Fork of the New River approximately four miles east of the Sewell Lock (see Section IV.H). The freshwater NNRC is a contiguous waterway through the western NNRC Basin. However, important hydrological connections occur in this segment. In the western NNRC Basin, the S-124 normally allows water in the L-35A to be discharged to the C-13 Basin (see Section III.G). However, during periods of flooding, the S-124 allows water to flow southwest into the NNRC. In addition, the C-42 generally flows south of S-125 (see C-13 Basin, Section III.G.1) and has a direct open connection to the NNRC at Hiatus Road.

The smaller, eastern NNRC Basin overlaps the freshwater and estuarine sections of the NNRC. However, all drainage, via pumps or gravity, discharges into the NNRC segment east of the Sewell Lock (i.e., estuarine). This particular stretch of the NNRC is estuarine and will be further discussed as part of the New River Basin in Section IV.H. Most of the land area to the south of the NNRC drains to the C-11 Canal Basin (see III.J.1). However, Bonaventure is within the NNRC Basin and the Shendandoah development drains north to the NNRC during storm events (Cooper and Lane 1987).

The major drainage districts existing to the north of the canal include the Old Plantation Water Control District and the Plantation Acres Improvement District (see Section I, Figure I.4). In particular, these districts have a series of secondary and tertiary canals that either withdraw from or discharge to NNRC depending on local water elevations. The West Lauderdale Control District (see Figure I.4) is located in the northeast corner of the City of Weston and manages the Bonaventure and Shenandoah areas (Cooper and Lane 1987).

Figure III.54. The North New River Canal (NNRC) Basin and Broward County (BCDPEP) Sampling Site Location Map. The NNRC and other major waterbodies with corresponding South Florida Water Management District (SFWMD) water control structures (labeled) are depicted. Note water control structures without labels are secondary structures operated by other entities than the SFWMD. The S-124 (SFWMD) is at the southwest point of the L-35A and is not physically on the NNRC.



This map is for informational purposes only. For further information, please contact BCDPEP Water Resources Division (954) 519-1270.

2. Municipalities and Land Use

The NNRC Basin consists of Plantation and the western portion of Sunrise, as well as a small portion of unincorporated Broward County (see Section I, Figure I.3). During the 1970s, the City of Plantation grew from just over 23,000 residents to almost 50,000 residents. By the late 1980s, the city had over 60,000 residents. From 1990 to 1995 the population grew by approximately 23%, reaching over 78,000 residents by 1995. The population growth of Sunrise during the past 25 years has been very similar to Plantation's growth. By the end of the 1980s, the population of Sunrise had reached over 64,000, and by 1995, 74,000 people resided in the city (Broward County Planning Council 1995).

In 1977, approximately one-third of the NNRC Basin consisted of agricultural land use, half of which was improved pasture. An additional 41% was comprised of open, or undeveloped land. The residential acreage (predominantly low density) of the NNRC Basin was approximately 22% of the land use, and commercial land use comprised less than 2% of the basin (Broward County 1978).

Currently, the NNRC Basin's land use is predominantly residential and commercial, especially in the eastern areas of the basin. A significant amount of open area and some agricultural land remains in the westernmost portions of the basin, including a regional Broward County park (Markham Park). Furthermore, the residential land use in the western areas is mostly low density, single family housing.

3. Wastewater Treatment Plants Discharge History

In 1975, West Broward Utilities stopped discharging 0.350 million gallons per day (mg/d) into the North New River Canal. The City of Plantation West Plant Number 1 and Bonaventure Utilities ceased by 1978. Gulfstream Utilities phased out WWTP discharges by 1980. Two small facilities (0.010 mg/d), Pediatric Care Center and Anne Storck Center were phased out by 1982 and 1984, respectively. The final WWTPs to stop discharging into the North New River Canal by 1988 were the City of Plantation's North, Central, and South WWTPs (7.02 mgd) via the Holloway Canal that also could release to the northern C-12 Canal depending on operating conditions (Broward County Environmental Quality Control Board 1988, 1989).

4. Other Influences on Water Quality

a. Soils

The western NNRC Basin is predominantly made up of poorly drained, deep sandy soils with some areas of limestone outcrop (see Section I, Figure I.5). The eastern basin consists of poorly drained, deep sandy soils with a thick organic surface layer in some areas. These soils of the basin are moderately to severely limiting to building construction and development primarily due to the wetness of the soil and high water table which creates flooding hazards (Reynolds, Smith and Hills Inc. 1972).

b. Roadways

Two major east-west roadways, Interstate 595/75 and State Road 84 run contiguous with the NNRC. In addition, the headwaters (north of S-34) of the urban NNRC are paralleled by US 27. Numerous north south connectors also cross the NNRC, including University Drive, Pine Island Road, Hiatus Road, Flamingo Road, among others.

c. Septic Tanks

The area of the Western NNRC Basin managed by Plantation Acres Improvement District is not serviced by a sewer system and has approximately a mile long stretch along the NNRC (see http://www.broward.org/moi00600.htm). The eastern NNRC also has areas not serviced by sewers but all waters drain to the estuarine portion of the NNRC which will be discussed in Section IV.

5. Sampling Locations and Period

All sampling site location information (e.g., coordinates) is shown in Appendix 1. Briefly, Site 23 is located at the US 27 and Interstate 75 interchange and primarily represents water quality from the L-38 Canal system to the north. Site 22 is at the southwest 125th Avenue bridge approximately eight miles east of Site 23. Site 21 is immediately west of the Sewell Lock, five miles east of Site 22. Table III.30 describes the years of collection for each parameter at each site.

Table III.30. Sampling Years for Specific Parameters at the North New River Canal Locations. A sampling year had at least one sample event during that year. Note the biochemical oxygen demand was a five-day test from 1973 until 1981 when a seven-day test was implemented until 1993 after which sampling for the parameter ceased at BCDPEP.

Parameter	Site 21	Site 22	Site 23
Temperature	72,73,75-97	73-97	73-97
pH	72,73,75-97	73-97	73-97
Specific Conductance	81-97	81-97	81-97
Dissolved Oxygen	72,73,75-97	73-97	73-97
Biological Oxygen Demand	73,75-93	73-93	73-93
Total Organic Carbon	81-97	81-97	81-97
Turbidity	75-97	75-97	75-97
Total Phosphorus	75-97	74-97	74-97
Ammonia-Nitrogen	81-97	81-97	81-97
Nitrite+Nitrate-Nitrogen	81-97	81-97	81-97
Total Kjeldahl Nitrogen	81-97	81-97	81-97
Fecal Coliform	72,75-97	73-97	73-97
Total Coliform	72,73,75-97	73-97	73-97
Fecal Streptoccocus	76-97	76-97	76-97

6. Results

a. Physical Characteristics

Water temperatures were essentially the same at all sites with means and medians at or near 26.0 ^{o}C (Table III.31). With the largest sample size, Site 21 also exhibited the greatest range of data. Mean and median pH values were also very similar ranging from 7.5 to 7.7 at all three sites.

The westernmost Site 23 had mean and median specific conductance values over 850 Fmhos/cm. Sites 21 and 22 were more similar with 750 Fmhos/cm most typically recorded (Table III.31). Although only a small relative difference in specific conductance, the values do represent 18 years of observations and the results, especially medians, suggest Site 23's water had slightly different specific conductance.

Table III.31. Descriptive Statistics for Temperature (Temp;°C = degrees Celsius), pH, and Specific Conductance (Cond; Fmhos = micromhos/centimeter @ 25°C) in the North New River Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
21	Temp	°C	345	26.0	26.0	3.6	34.3	15.0	0
22	Temp	°C	156	26.1	25.6	3.3	32.2	17.2	0
23	Temp	°C	156	26.1	25.6	3.3	32.7	17.8	0
21	pH	units	350	7.7	7.7	0.3	8.5	6.6	0
22	pH	units	157	7.5	7.5	0.3	8.3	6.8	0
23	pH	units	156	7.6	7.6	0.3	8.3	6.3	0
21	Cond	Fmhos	288	750	756	106	1280	471	0
22	Cond	Fmhos	67	750	753	87	1030	560	0
23	Cond	Fmhos	68	891	867	143	1220	549	0

b. Total Organic Carbon and Turbidity

The basin's westernmost site (23) exhibited the highest mean, median, and maximum total organic carbon (TOC) values (Table III.32). Site 23's median value (29.30 mg/l) was nearly 4.00 mg/l higher than TOC content at Sites 22 and 21. At all sites, turbidity levels were typically low and normally within compliance of Broward County's standard of 10 nephelometric turbidity units (ntus, Table III.32). Only Site 21's maximum value was above the standard but this was a rare occurrence based on the median, as well as standard deviation values.

Table III.32. Descriptive Statistics for Total Organic Carbon (TOC) Concentrations and Turbidity (Turb) Levels in the North New River Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
21	TOC	mg/l	259	25.60	25.97	4.95	54.90	3.30	0
22	TOC	mg/l	60	24.75	25.34	6.12	62.20	15.80	0
23	TOC	mg/l	61	29.30	29.28	7.47	69.40	17.30	0
21	Turb	ntu	340	1.5	2.1	1.8	22.0	0.6	0
22	Turb	ntu	134	1.8	2.0	0.8	5.0	0.7	0
23	Turb	ntu	135	1.2	1.5	1.1	8.7	0.3	1

c. Dissolved Oxygen and Biochemical Oxygen Demand

Long term mean and median dissolved oxygen concentrations were below the standard of 4.0 mg/l at Sites 23 and 22 (Table III.33). In fact, Site 22's median dissolved oxygen concentration was below 2.0 mg/l. Interestingly, the westernmost site (23) had long term average and median values more comparable to the easternmost site (21) than Site 22. Biological oxygen demand was essentially the same at all three sites and below (i.e., within compliance) the 5.0 mg/l standard (Table III.33).

Table III.33. Descriptive Statistics for Dissolved Oxygen (DO) and Biochemical Oxygen Demand Concentrations in the North New River Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculations. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
21	DO	mg/l	347	4.5	4.5	2.5	11.7	0.1	1
22	DO	mg/l	163	1.9	2.5	1.9	9.2	0.05	2
23	DO	mg/l	155	3.8	3.9	1.9	8.9	0.4	0
21	BOD	mg/l	320	1.9	2.0	1.0	8.9	0.3	0
22	BOD	mg/l	132	1.8	1.8	0.8	4.8	0.5	0
23	BOD	mg/l	131	2.0	2.0	0.8	6.0	0.8	0

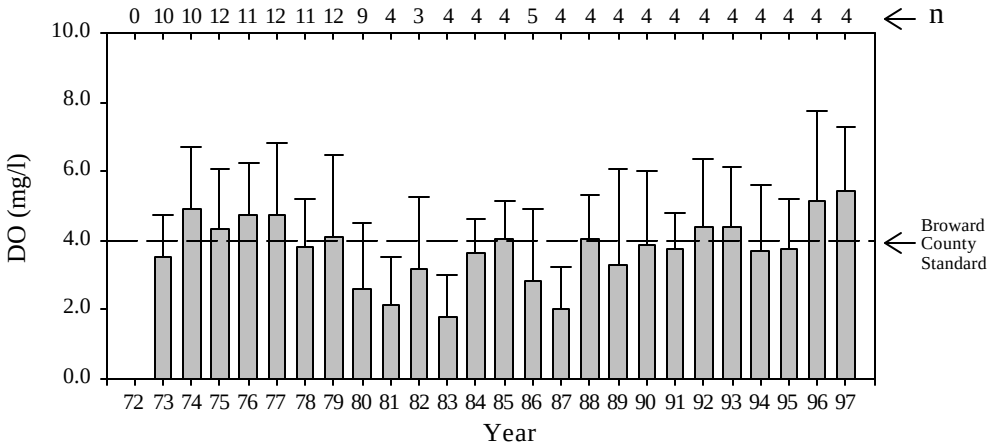
Yearly averages revealed a period from 1978 to 1988 of particularly low dissolved oxygen levels at Site 22 (Figure III.55). The City of Plantation's WWTPs stopped discharging to the NNRC after 1988. Although values have increased since 1988, annual DO averages still remained below 4.0 mg/l at Site 22 through much of the nineties. Site 23 also had several years with DO values below 4.0 mg/l during the post-WWTP era. With some exceptions, Site 21 had the highest annual DO concentrations, as well as being the most standard compliant location.

To better understand compliance patterns within the canal, each DO reading was given a rating based on Broward County's water quality standards (see III.E.5.c). In addition, the changes over time are presented with special reference to the closing of WWTPs within the basin (see Section III.I.3). Site 21 exhibited the greatest improvement with a 36.7% increase in the number of good samples after 1988 (i.e.,post-WWTPs, Figure III.56). Sites 22 and 23 had poor rated samples decrease by 32.5% and 27.8%, respectively. Nonetheless, poor rated samples were still observed in over half of the combined seventy-two DO readings.

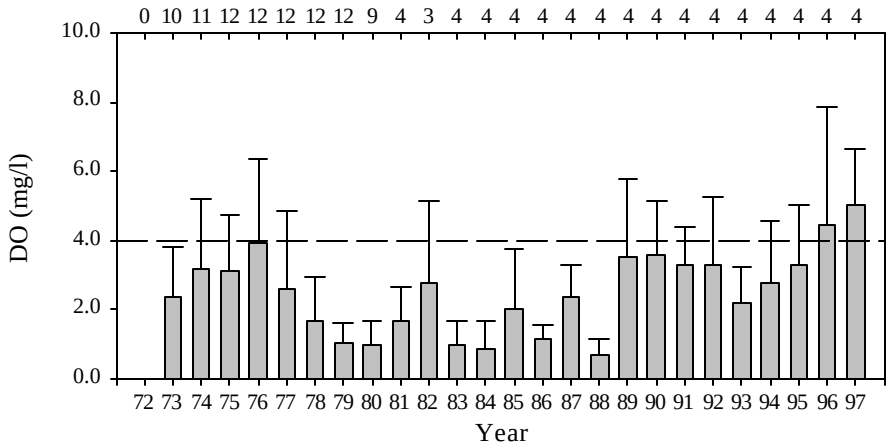
From 1989 to 1997, higher dissolved oxygen values were typically observed during the dry (November through May, Figure III.57) than the wet season. Statistically significant differences were observed at Sites 21(Mann-Whitney Rank Sum Test, $p < 0.001$) and 22 (t-test, $p < 0.05$) but not Site 23. The power of the performed test at Site 22 (0.586) was below the desired power of 0.800 and the statistical analysis should be viewed cautiously for that site.

Figure III.55. Mean Annual Dissolved Oxygen (DO) Content Within the North New River Canal Basin from 1972 to 1997. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance, DO levels should be above the Broward County standard (4.0 mg/l) indicated by the dashed line.

a) Site 23



b) Site 22



c) Site 21

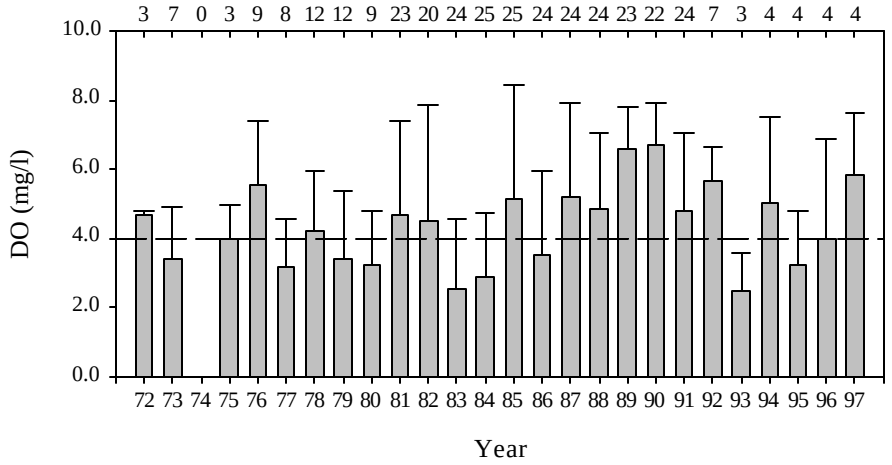


Figure III.56. Dissolved Oxygen (DO) Concentrations Observed in the North New River Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall be below 4.0 mg/l. All concentrations greater than or equal to 5.0 mg/l are classified as good and DO concentrations between 4.0 to 4.9 mg/l are considered fair. Readings below 4.0 mg/l are defined as poor.

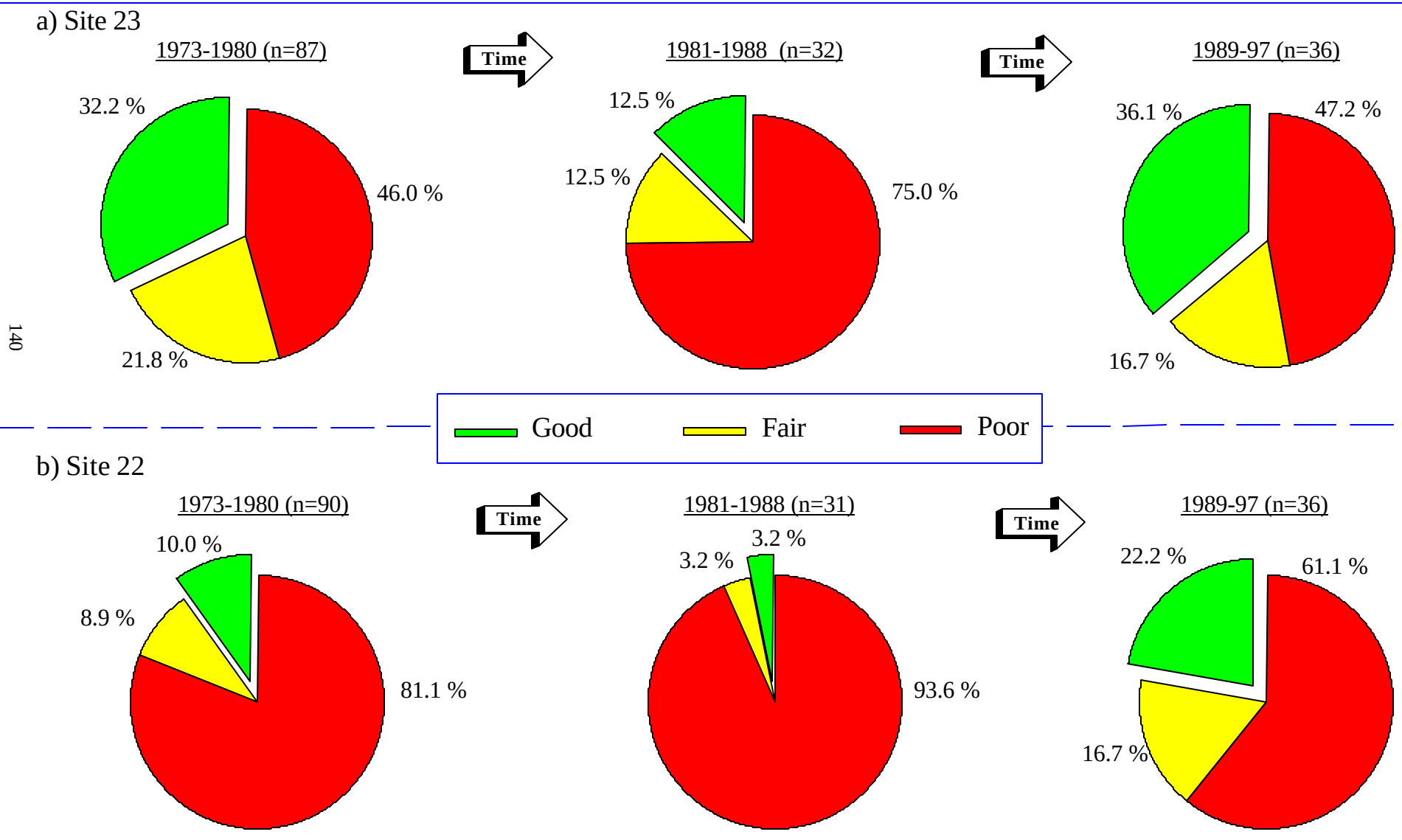


Figure III.56 (Cont.). Dissolved Oxygen (DO) Concentrations Observed in the North New River Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall be below 4.0 mg/l. Concentrations greater than or equal to 5.0 mg/l are classified as good and DO concentrations between 4.0 to 4.9 mg/l are considered fair. Readings below 4.0 mg/l are defined as poor.

c) Site 21

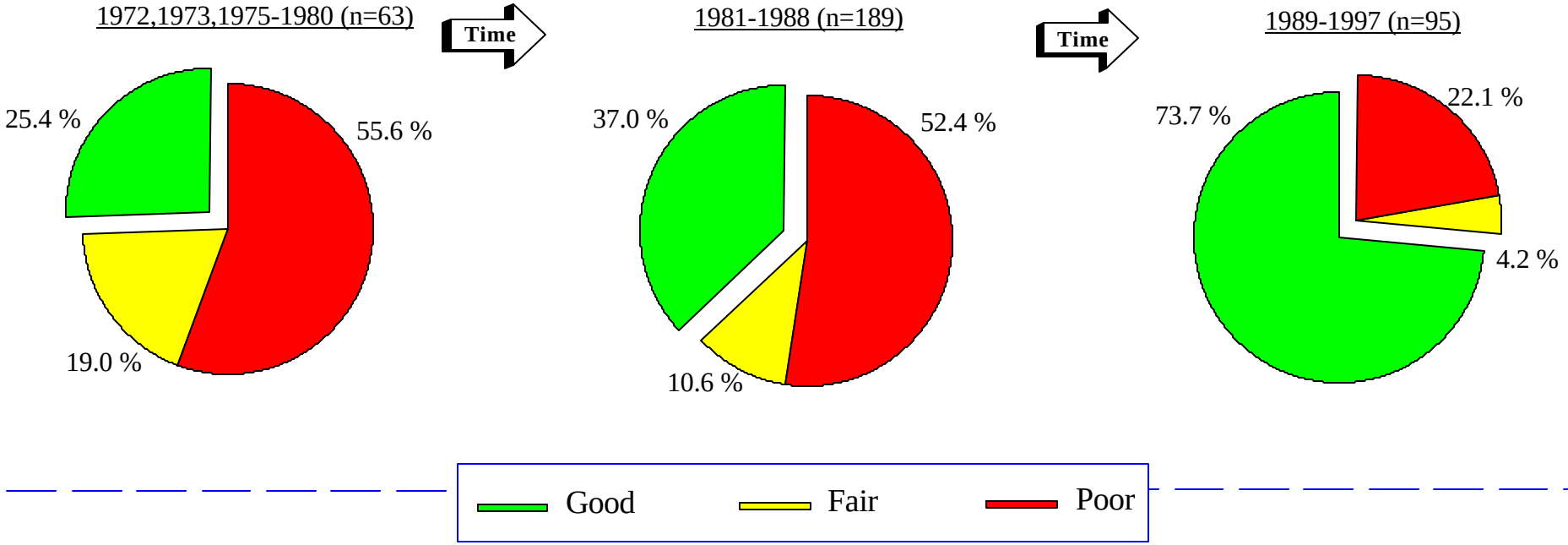
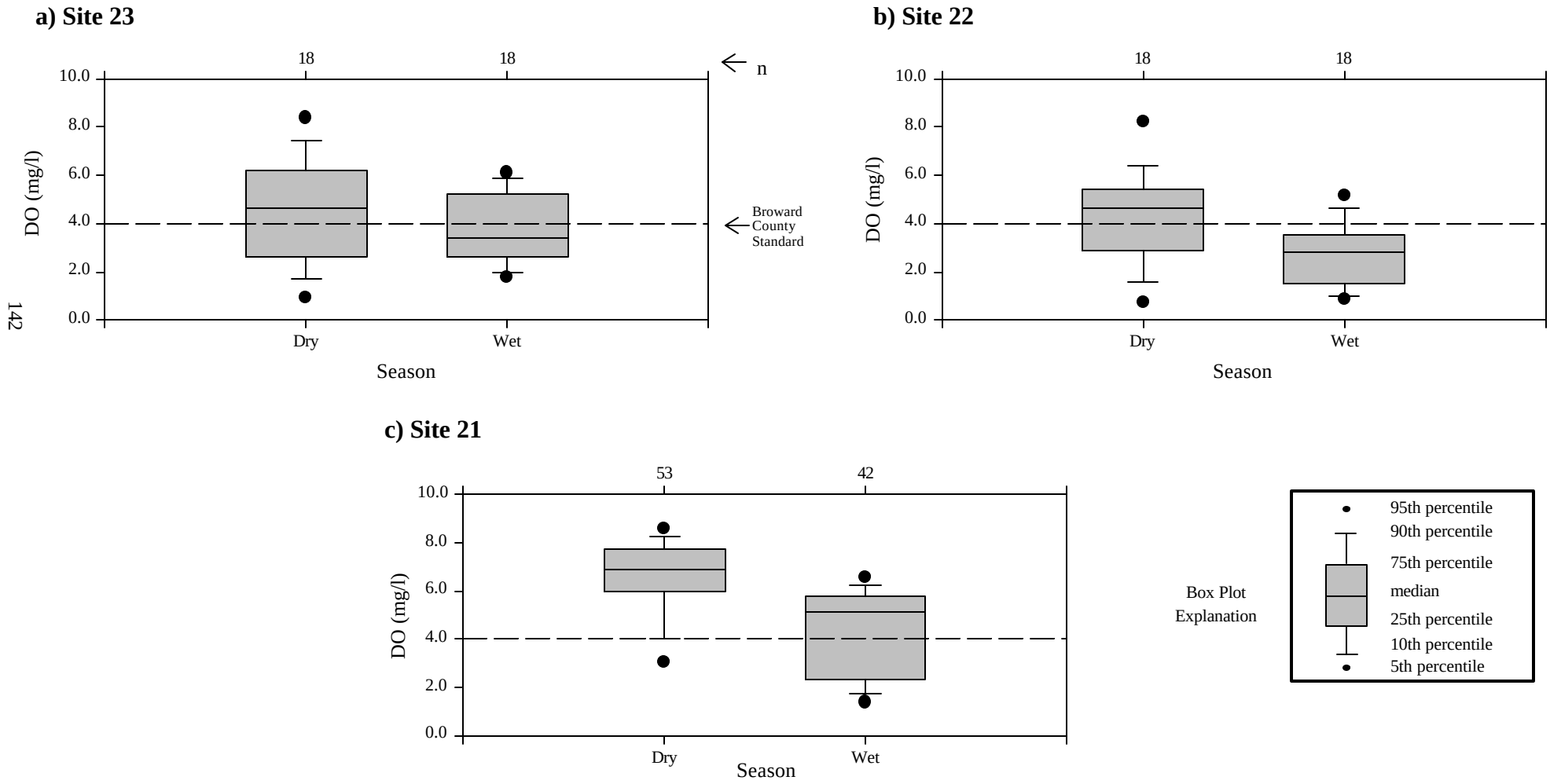


Figure III.57. North New River Canal Basin Dissolved Oxygen (DO) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season medians were observed at Site 21 ($p < 0.001$, Mann-Whitney Rank Sum test), as well as mean values at Site 22 ($p < 0.05$, t-test). Significant differences were not observed at Site 23.



d. Total Phosphorus

Long term median total phosphorus (TP) content (0.036 mg/l) was highest at Site 21 and exceeded the Broward County freshwater standard of 0.020 mg/l (Table III.34). Conversely, Sites 22 and 23 had median values equal to half the TP method detection limit (MDL) used to approximate TP content when observations were below MDLs (i.e., < 0.020 mg/l). Mean values were higher than corresponding medians due, in part, to relatively enhanced maximum TP concentrations at all three sites, especially Site 21 (4.020 mg/l).

Table III.34. Descriptive Statistics for Total Phosphorus (TP) Concentrations the North New River Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculations. The number of samples below the method detection limit is shown in the last column (# MDL).

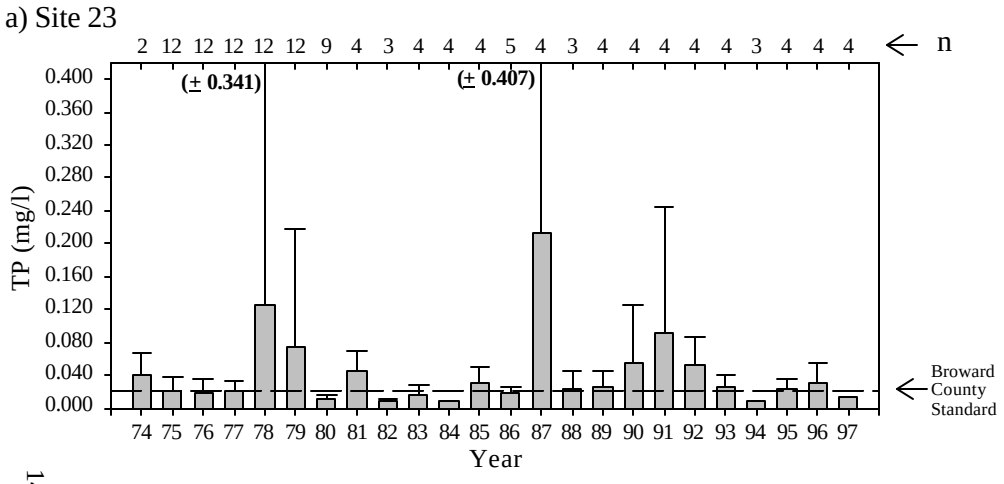
Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
21	TP	mg/l	338	0.036	0.071	0.236	4.020	0.005	101
22	TP	mg/l	137	0.010	0.035	0.101	0.962	0.010	77
23	TP	mg/l	137	0.010	0.045	0.132	1.200	0.005	77

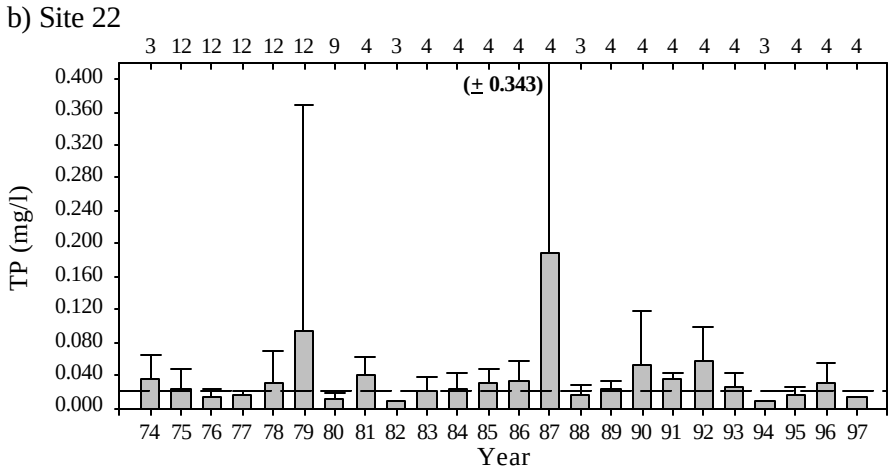
Annual mean TP concentrations revealed much higher TP values before 1989 than afterwards at Site 21 (Figure III.58) While extreme values were more prevalent before 1989 at Sites 22 and 23, most values before and after WWTP discharges were relatively similar at these sites. During the 1990s, the period of 1990 to 1992 showed relatively elevated concentrations as compared to 1993 through 1997, especially at Site 23.

To better understand compliance patterns within the canal, each TP reading was given a rating based on Broward County's water quality standards (see Section III.E.5.d). In addition, the changes over time due to the closing of WWTPs within the basin were investigated (see Section III.I.4). For Sites 22 and 23, the amount of good TP samples decreased through time by at least thirty percent (Figure III.59). The main increase through time at Sites 22 and 23 was in the amount of fair samples, as poor rated samples remained relatively consistent. Conversely, Site 21 exhibited a 65.4% decrease in poor rated samples and a 45.3% increase in good samples by the final period. Despite the disparity in temporal patterns, overall compliance with the TP standard (i.e., good samples) was relatively the same at three sites from 1989-1997.

Observations from 1989-1997 revealed statistical differences between wet and dry seasons at Sites 22 and 23 ($p < 0.01$ and 0.05, Mann-Whitney Rank Sum Test, respectively) but not Site 21 (Figure III.60). Dry season medians were at or above the Broward County standard (i.e., out of compliance) while wet season values were not at all sites. However, most TP observations in the basin were less than 0.050 mg/l.

Figure III.58. Annual Mean Total Phosphorus (TP) Levels Within the North New River Canal Basin from 1974 to 1997. Means and standard deviations calculated from biweekly, monthly, and/or quarterly samples with the number of samples (n) noted on the upper x-axis. The Broward County single sample standard (0.020 mg/l) is indicated by the dashed line. Numbers in parentheses represent standard deviation outside range of graph.





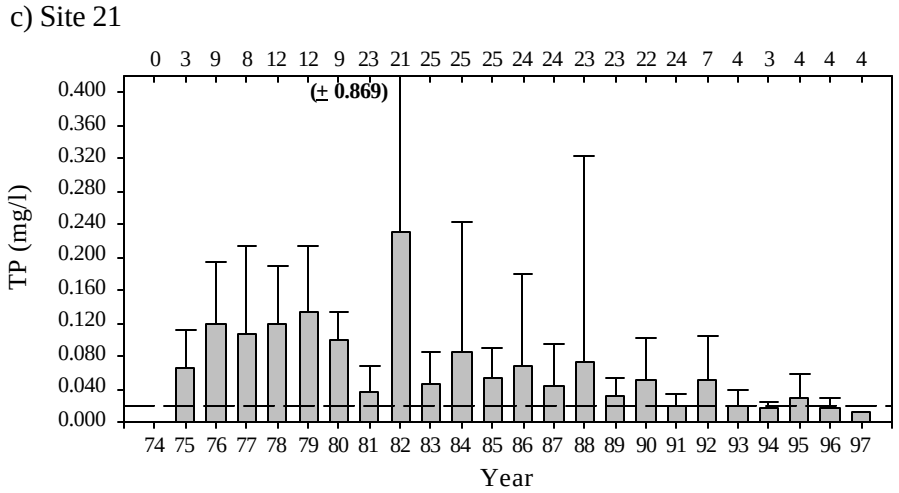


Figure III.59. Total Phosphorus (TP) Concentrations Observed in the North New River Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County freshwater TP standard of 0.020 mg/l. The percentage of samples below 0.020 mg/l are classified as good. A fair rating was given to concentrations between 0.021 mg/l to 0.060 mg/l. Values greater than three times the standard (i.e., 0.060 mg/l) are classified as poor.

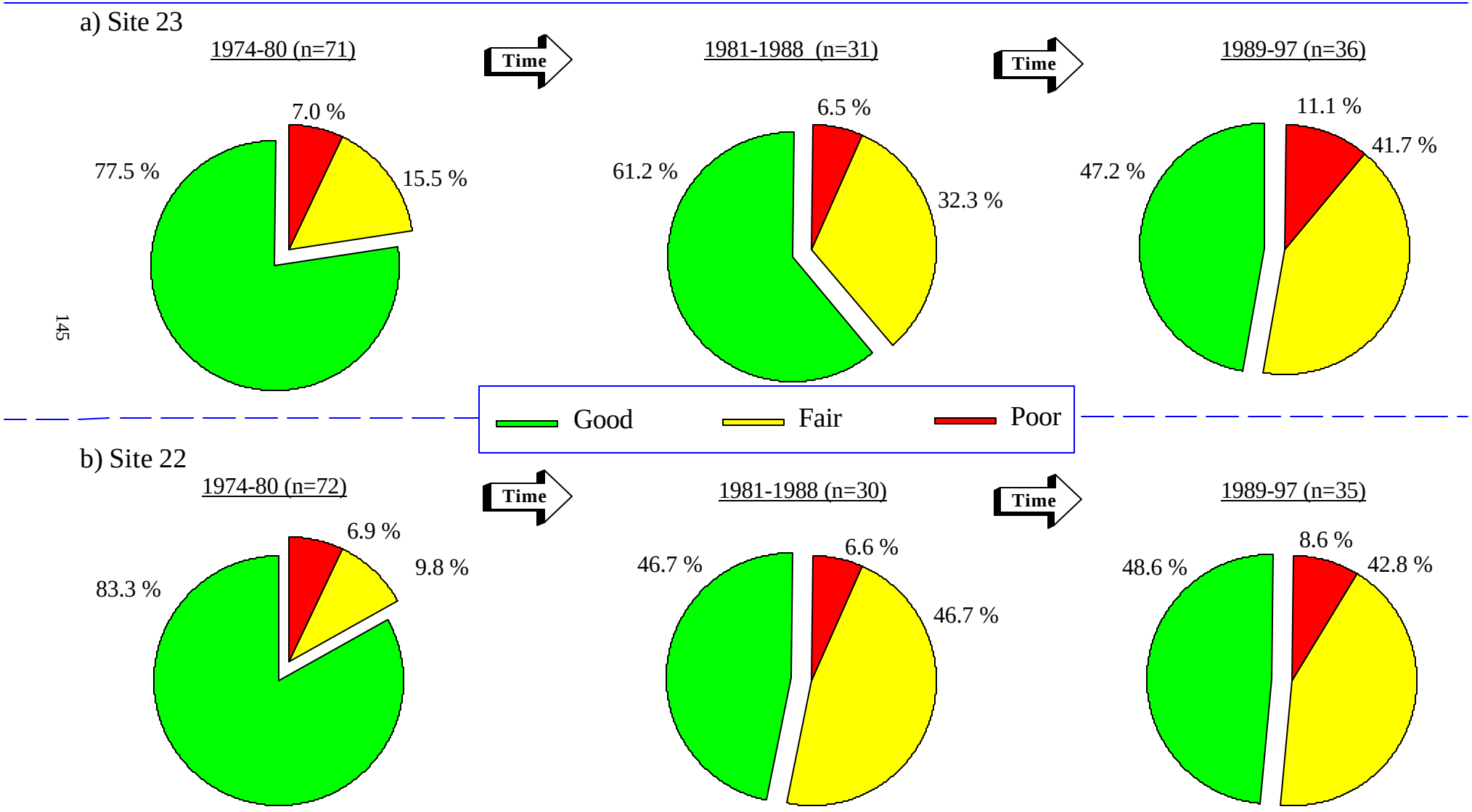


Figure III.59 (Cont.). Total Phosphorus (TP) Concentrations Observed in the North New River Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County freshwater TP standard of 0.020 mg/l. The percentage of samples below 0.020 mg/l are classified as good. A fair rating was given to concentrations between 0.021 mg/l to 0.060 mg/l. Values greater than three times the standard (i.e., 0.060 mg/l) are classified as poor.

c) Site 21

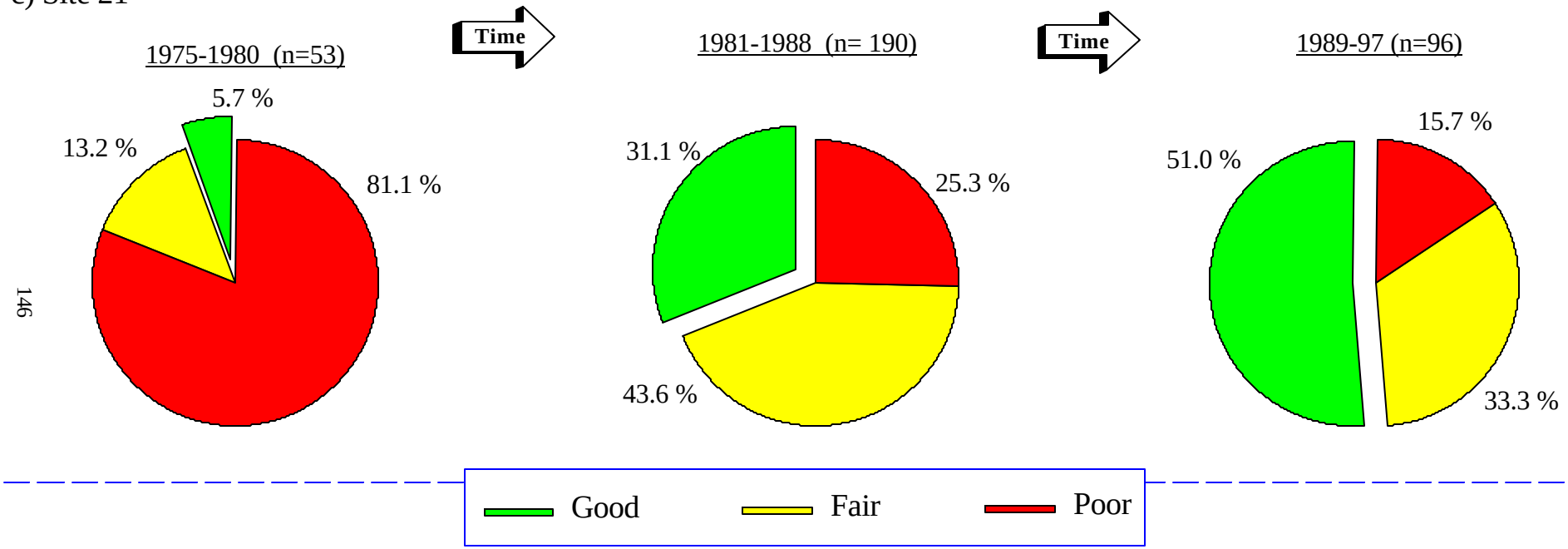
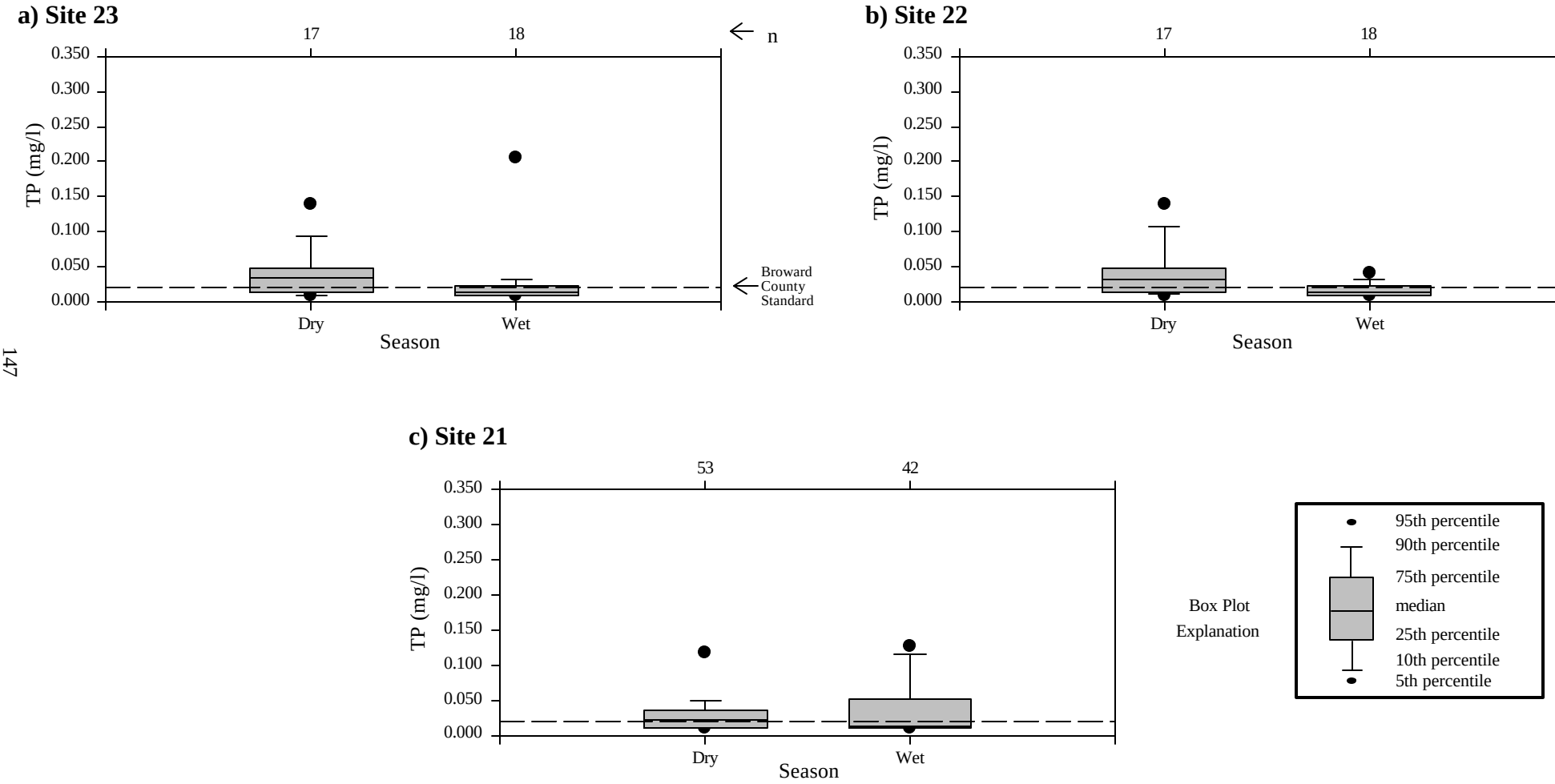


Figure III.60. North New River Canal Basin Total Phosphorus (TP) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season medians were observed at Sites 22 and 23 ($p < 0.01$ and 0.05, respectively; Mann-Whitney Rank Sum test) but not at Site 21.



e. Total Nitrogen

Total nitrogen levels are calculated from the total Kjeldahl nitrogen (TKN) and nitrite+nitrate-nitrogen (NO_2+NO_3) concentrations. All three NNRC sites exhibited long term mean and median TN values above the Broward County standard (1.500 mg/l, Table III.35). Interestingly, long term mean TN concentrations were less than median values all three sites.

The TKN concentrations represented 84% of median TN levels at Site 23 but comprised over 95% of TN at Sites 22 and 23. Thus, NO_2+NO_3-nitrogen levels reflected the same spatial pattern with the highest values being observed at Site 21 and relatively low concentrations (particularly medians) seen at Sites 22 and 23. Median ammonia-nitrogen levels were enhanced (0.418 mg/l) at Site 22, which is consistent with the low DO levels recorded there over the same period (see Section III.I.5.c.).

Table III.35. Descriptive Statistics for Nitrite-Nitrate Nitrogen (NO_2+NO_3), Ammonia-Nitrogen (NH_3), Total Kjeldahl Nitrogen (TKN), and Total Nitrogen (TN) Concentrations in the North New River Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL). Total nitrogen was calculated as the sum of TKN and NO_2+NO_3.

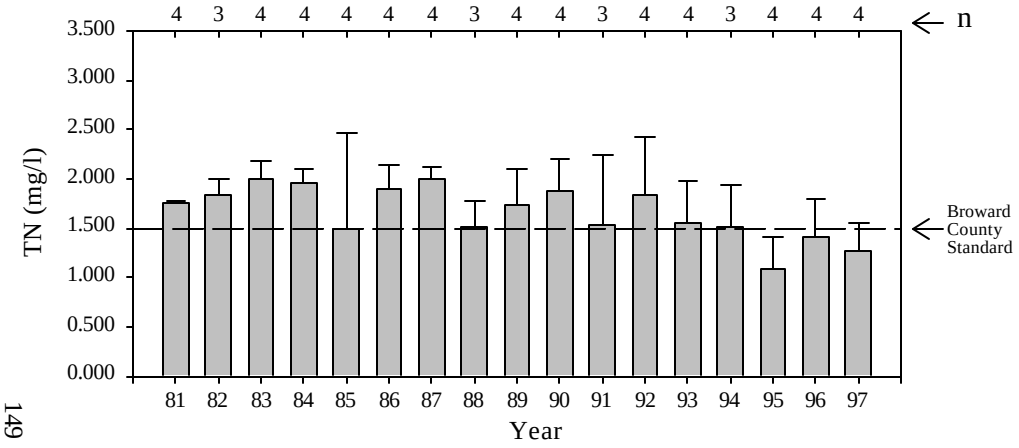
Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
21	NO_2+NO_3	mg/l	288	0.161	0.210	0.186	1.120	0.005	28
22	NO_2+NO_3	mg/l	67	0.050	0.071	0.060	0.346	0.005	5
23	NO_2+NO_3	mg/l	70	0.047	0.074	0.092	0.470	0.005	12
21	NH_3	mg/l	263	0.099	0.200	0.223	1.440	0.005	78
22	NH_3	mg/l	61	0.418	0.402	0.245	0.823	0.005	3
23	NH_3	mg/l	61	0.177	0.243	0.199	0.880	0.005	7
21	TKN	mg/l	283	1.490	1.511	0.346	2.610	0.020	1
22	TKN	mg/l	64	1.705	1.601	0.374	2.140	0.604	0
23	TKN	mg/l	65	1.740	1.598	0.428	2.300	0.421	0
21	TN	mg/l	283	1.774	1.720	0.379	2.819	0.181	N/A
22	TN	mg/l	64	1.768	1.672	0.377	2.238	0.699	N/A
23	TN	mg/l	65	1.810	1.672	0.445	2.630	0.486	N/A

Basinwide, yearly TN means were generally higher in the 1980's then the 1990's and all sites normally had similar temporal patterns (Figure III.61). However, the early 1990's did have values comparable to WWTP discharge years (i.e., before 1989). The final three years of measurements showed a marked decrease at all sites with annual averages being below the 1.500 mg/l standard.

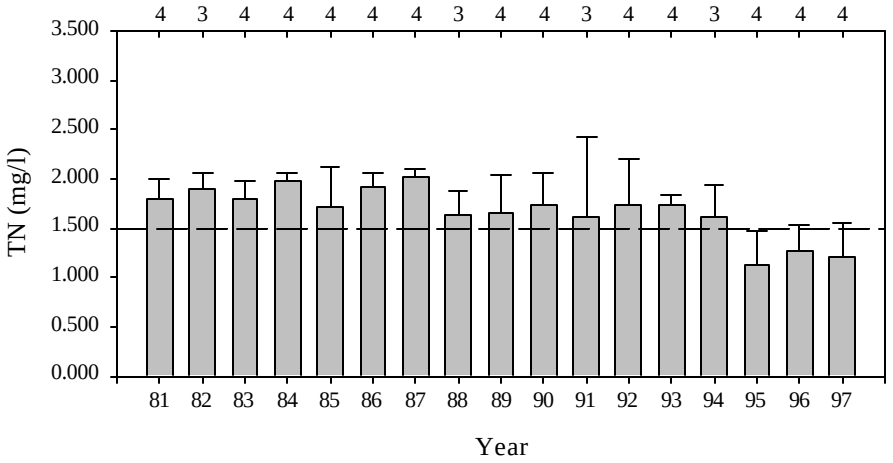
To further understand compliance patterns within the canal, each TN sample was given a rating based on Broward County's water quality standards (see Section III.E.5.e). Additionally, changes over time

Figure III.61. Annual Mean Total Nitrogen (TN) Levels Within the North New River Canal Basin from 1981 to 1997. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. The Broward County standard (1.500 mg/l) is indicated by the dashed line.

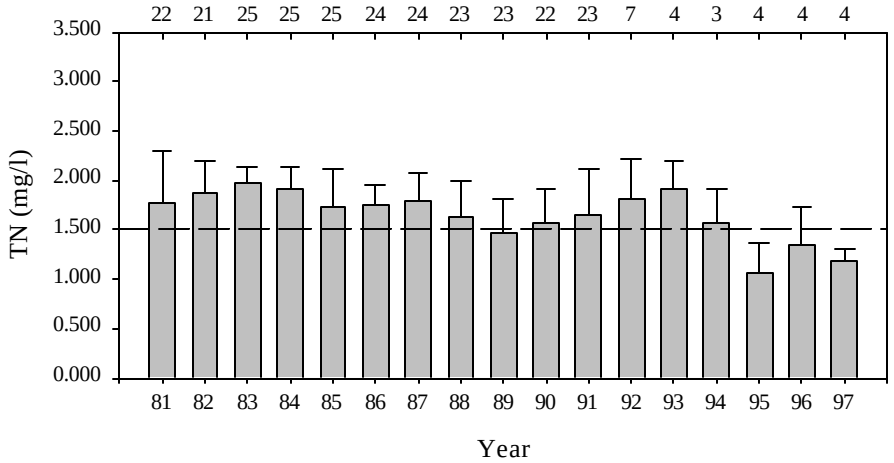
a) Site 23



b) Site 22



c) Site 21



were investigated based on the closing of WWTPs within the basin (see Section III.B.3). All three NNRC sites realized nearly a 50.0% increase in good samples by the final period of 1993 to 1997. However, an interesting pattern was seen immediately after WWTPs ceased discharging (1989-1992) when either little (Site 23) or lower levels (Site 22 and 21) of change were observed than seen for 1993 through 1997.

Statistical seasonal differences in TN content were not observed at any site (Figure III.63). Both seasonal medians for Sites 22 and 23 were above (i.e., out of compliance) the Broward standard while only Site 21's dry season, median TN exceeded 1.500 mg/l. Based on both the annual averages (Figure III.61) and the pie chart analysis (Figure III.62), the relatively high TN values (median, 75th percentile, etc.) seen on the box plots primarily represent the period of 1989 through 1992.

f. Bacteriological Parameters

Fecal coliform (FC), total coliform (TC), and fecal streptococcus (FS) levels were the bacteriological parameters measured in the NNRC. Median FC values were relatively similar throughout the study area and almost an order of magnitude below (i.e., within compliance) the single sample standard of 200 colonies/100 ml (Table III.36). Median TC and FS values were also relatively low, although Sites 22 and 23 had relatively higher median FS values than Site 21. Currently, a standard does not exist for FS.

Table III.36. Descriptive Statistics for Fecal Coliform (FC), Total Coliform (TC), and Fecal Streptococcus (FS) in the North New River Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL) and the unit of measurement is colonies/100 ml (col).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
21	FC	col	340	30	93	284	4000	3.5	65
22	FC	col	149	37	348	3028	37000	3.5	16
23	FC	col	149	22	182	1031	12000	3.5	31
21	TC	col	346	170	979	5263	80000	5	24
22	TC	col	158	370	1344	6770	80000	12	6
23	TC	col	158	300	933	2511	25000	15	3
21	FS	col	330	73	385	1542	21000	5	71
22	FS	col	124	165	397	678	5500	5	9
23	FS	col	125	200	1326	9034	100000	5	6

Figure III.62. Total Nitrogen (TN) Concentrations Observed in the North New River Canal Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified as good. A fair rating was given to concentrations between 1.501 mg/l to 2.500 mg/l. Values greater than 2.500 mg/l are classified as poor.

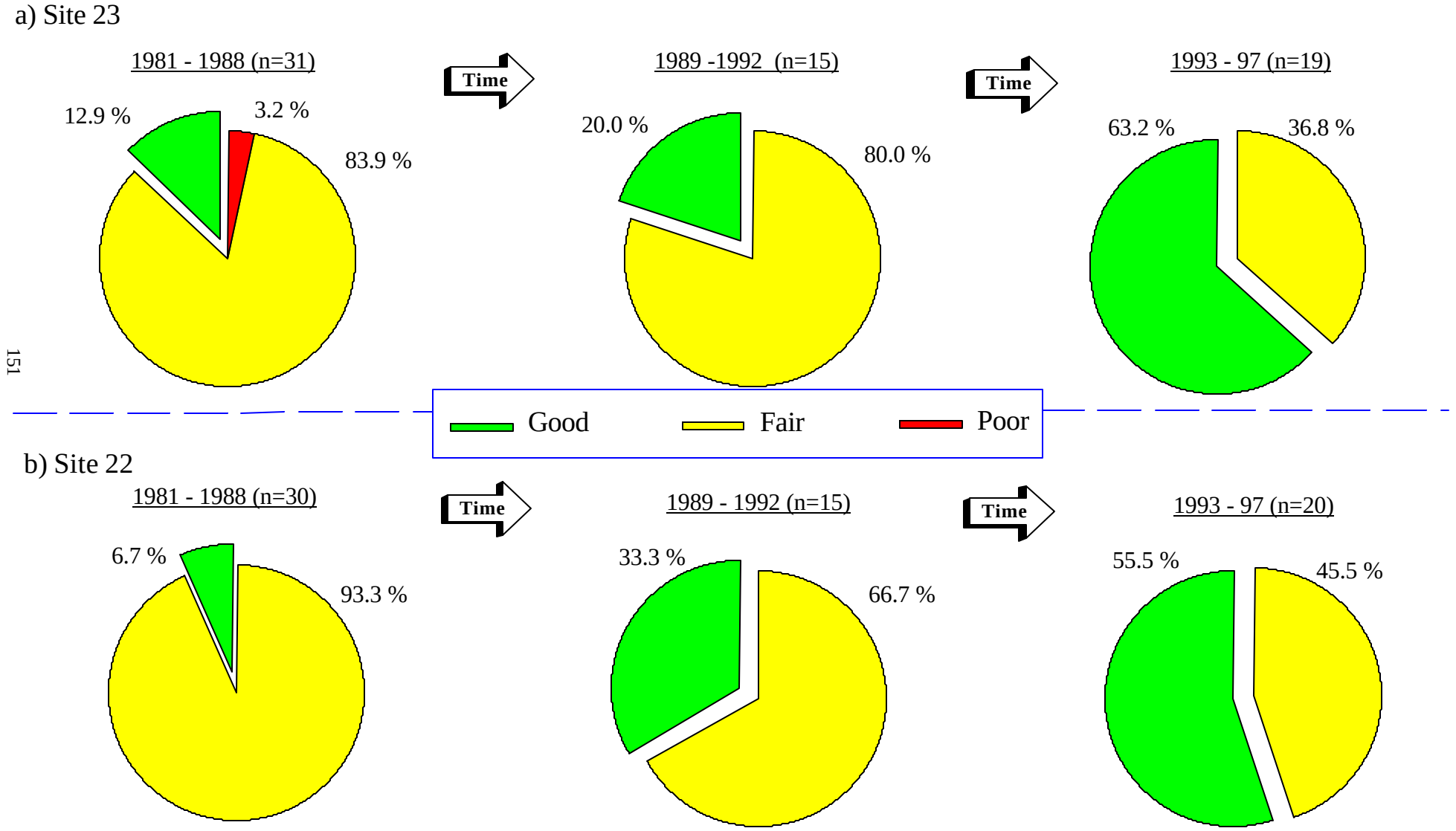


Figure III.62 (Cont.). Total Nitrogen (TN) Concentrations Observed in the North New River Canal Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified as good. A fair rating was given to concentrations between 1.501 mg/l to 2.500 mg/l. Values greater than 2.500 mg/l are classified as poor.

c) Site 21

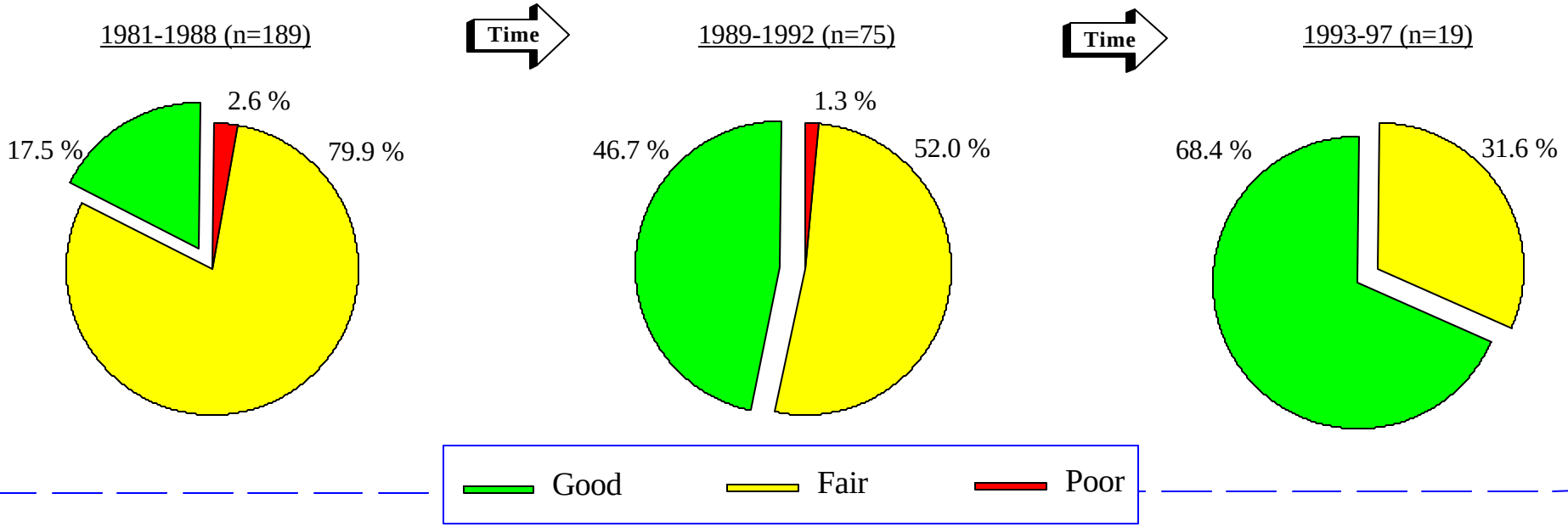
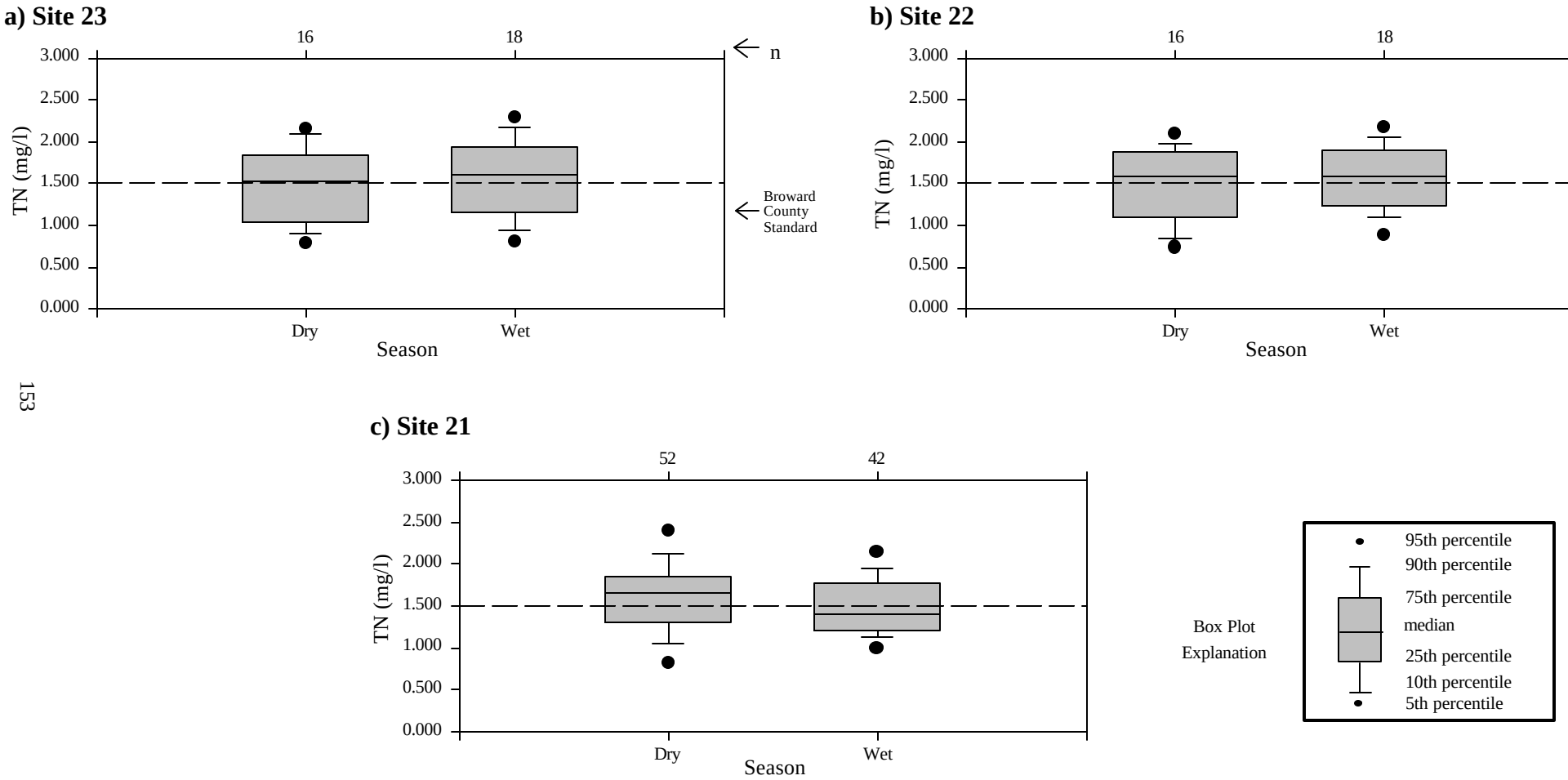


Figure III.63. North New River Canal Basin Total Nitrogen (TN) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season means and/or medians were not observed at any site.



Due to the large amount of variability around the mean, yearly box plots were plotted for fecal coliform (FC) instead of the mean (Figure III.64). All annual medians were below 800 colonies/100 ml and values above 200 colonies/100 ml were rare. A few 75th percentile data, particularly at Site 22, were above the monthly FC sample standard (200 colonies/100 ml).

To improve the knowledge of compliance patterns within the NNRC, each specific sample was given a rating based on three different Broward County water quality standards (see Section III.E.5.f). and the closing of WWTPs within the basin was addressed (see Section III.I.3). Each site had at least 75% good rated samples during all periods and the occurrence of poor rated samples (> 800 colonies/100 ml) was rare (Figure III.65). Only Site 22 showed a negative temporal pattern with the amount of fair samples increasing from 4.9% in the first period (1973-1980) to 21.6% by 1989 through 1997.

Statistical differences were observed for 1989-1997 seasonal median FC values at Sites 21, 22, and 23 (Mann-Whitney Rank Sum Test, $p < 0.001$, < 0.005, and 0.05, respectively; Figure III.66). However, no medians were above 200 colonies/100 ml and only Site 22's 95th percentile value was above the single sample standard of 800 colonies/100 ml.

7. Basin Summary

The freshwater NNRC is a contiguous waterway from the WCA tailwaters to an estuarine discharge point. In this study, Site 23 represents the initial water quality from upstream of the S-34 and Site 21 defines water leaving the freshwater NNRC via the G-54 to the estuarine reaches of the waterway. Site 22 describes the parameters approximately half way between Sites 21 and 23. The following will describe differences and similarities between these NNRC segments, as well as discuss WWTP and seasonal influences. Finally, questions for future monitoring and management are posed.

a. Influence of WWTP Discharges

The end of WWTPs was most readily seen at Site 21 which showed dramatic improvements in TP and DO levels as compared to local standards. In addition, TN levels immediately improved after WWTP discharges stopped as compared to the western sites (22 and 23) which demonstrated an apparent lag effect likely due to other independent influences (e.g., rainfall levels). The geographical proximity of WWTPs to Site 21 also explains why the site exhibited the most substantial changes.

b. Basinwide Water Quality Characteristics (Post-WWTPs)

Based on DO and TN values, Site 21 generally had the best water quality within the NNRC after WWTPs halted discharges. The continued low DO values at the western sites (22 and 23) are likely due to the seepage waters from the WCAs. Additionally, the slightly higher TN values may also be indicative of the western water sources. However, an increase in DO levels observed at these sites during the entire 1990's suggests some hydrological changes may have occurred either due to rainfall and/or management practices.

Figure III.64. Yearly Box Plots of Fecal Coliform (FC) Levels within the North New River Canal Canal Basin from 1972 to 1997. Medians and percentiles calculated from bi-weekly, monthly, and/or quarterly samples with the number of samples (n) per year noted on the upper axis. The Broward County single sample standard (800 colonies/100 ml) is indicated by the dashed line. Numbers in parentheses represent 75th percentile values that extend beyond the y-axis scale.

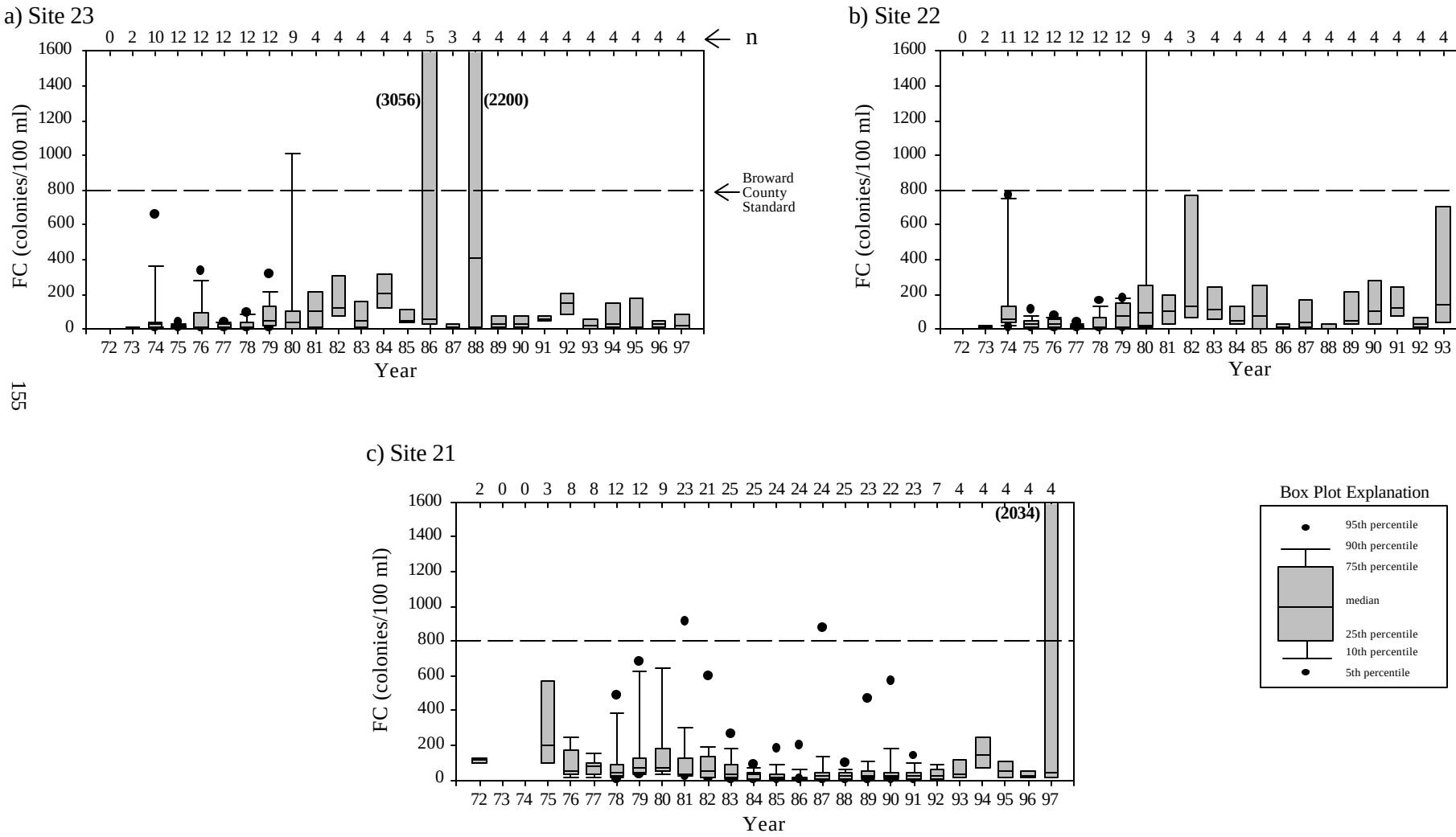


Figure III.65. Fecal Coliform (FC) Concentrations Observed in the North New River Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100 ml (good rating) and no single reading shall be above 800 colonies/100 ml (poor rating). Values between 201 and 800 colonies/100 ml are defined as fair.

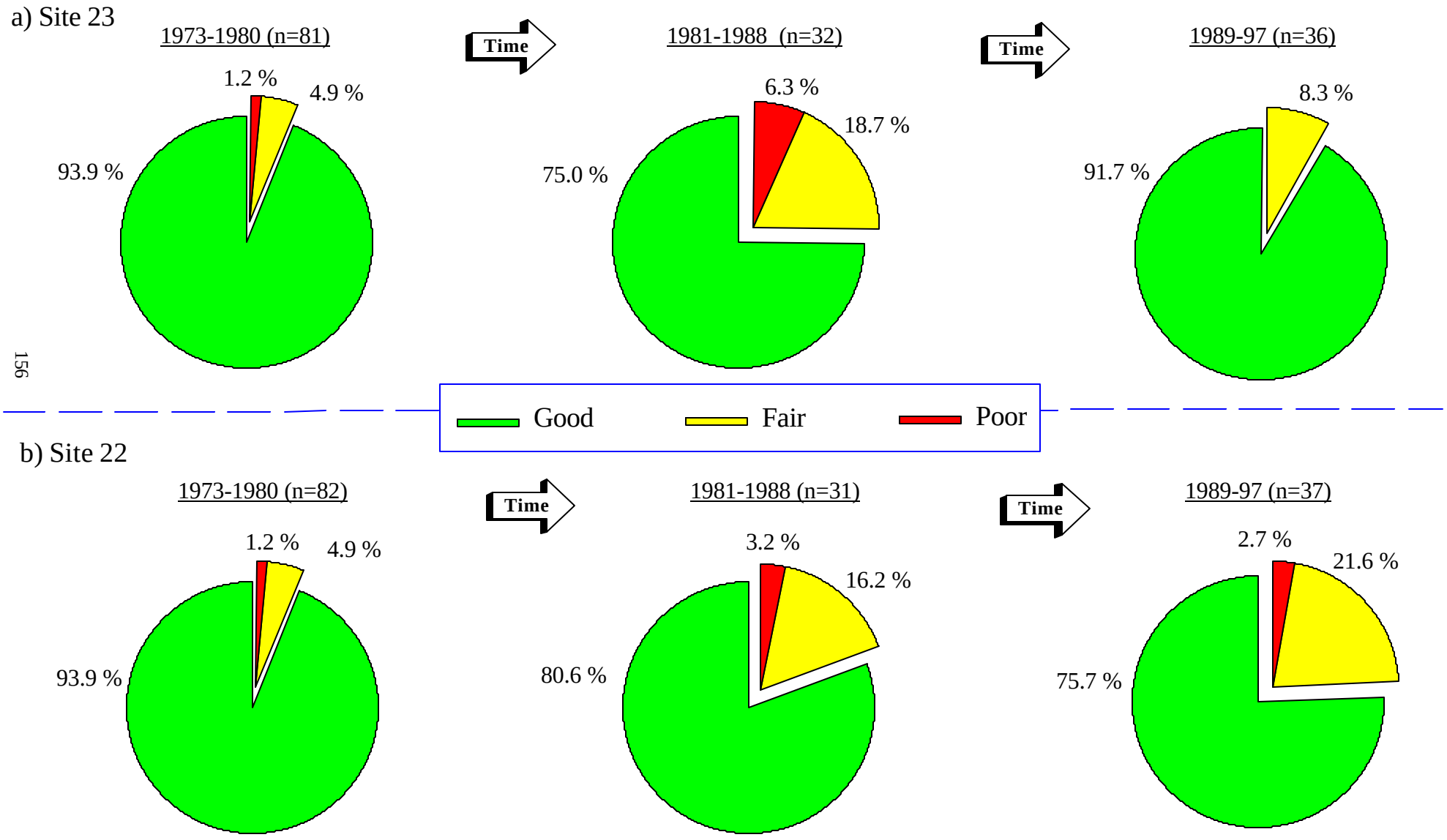


Figure III.65 (Cont.). Fecal Coliform (FC) Concentrations Observed in the North New River Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100 ml (good rating) and no single reading shall be above 800 colonies/100 ml (poor rating). Values between 201 and 800 colonies/100 ml are defined as fair.

c) Site 21

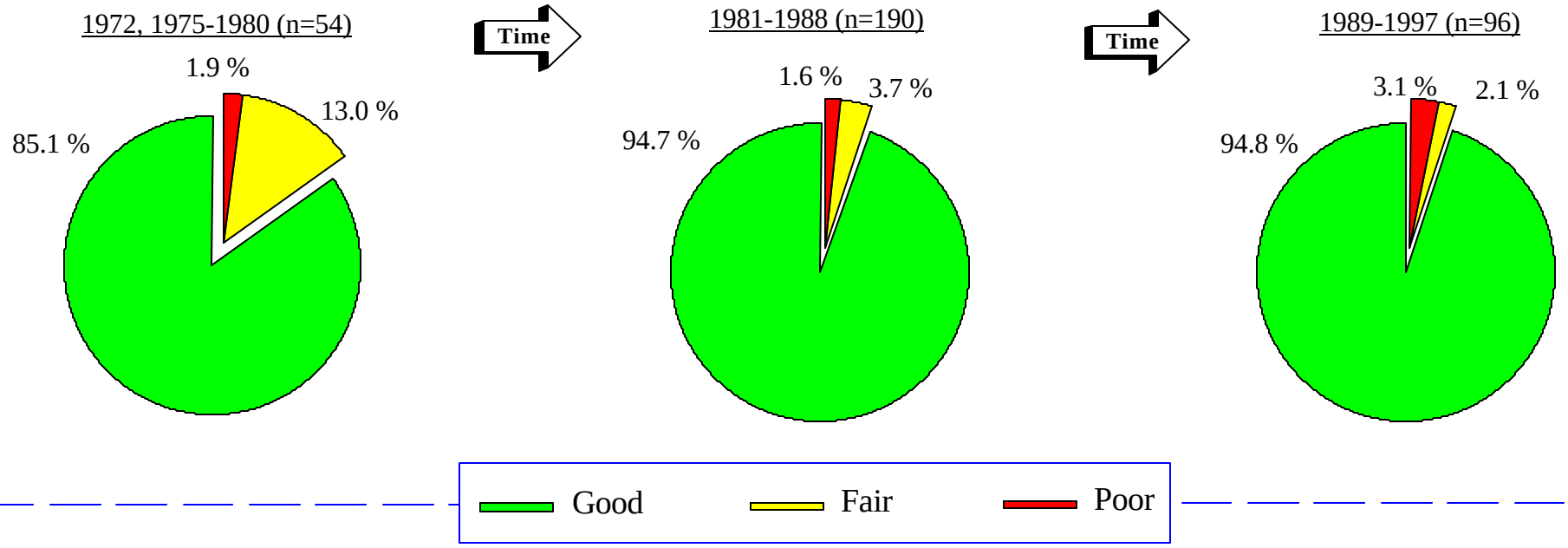
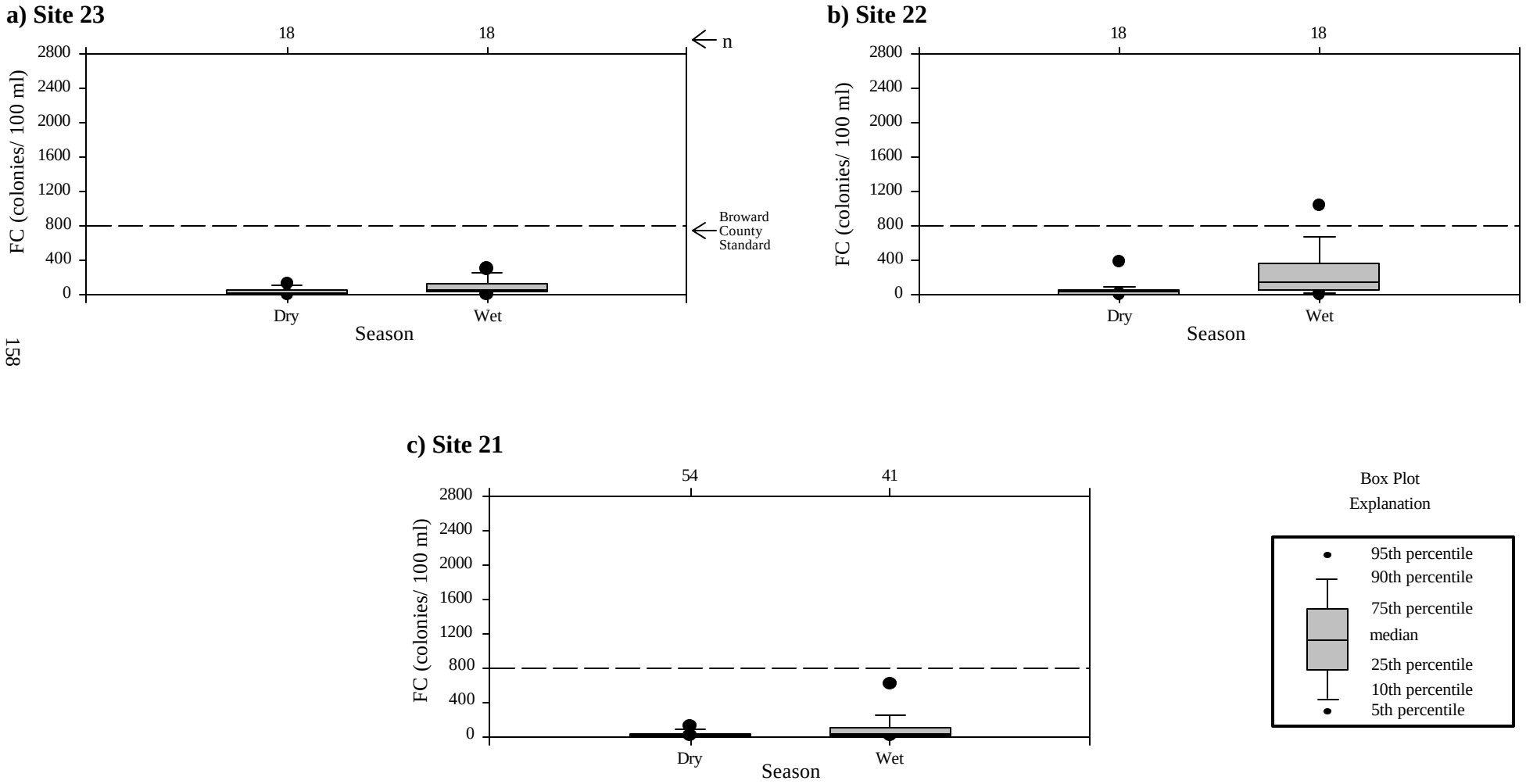


Figure III.66. North New River Canal Basin Fecal Coliform (FC) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season medians were observed at Sites 21, 22, and 23 ($p < 0.001$, $p < 0.005$, and $p < 0.05$, respectively; Mann-Whitney Rank Sum test).



All sites displayed relatively low (< 0.020 mg/l) TP levels during 1993 to 1997 which was near or at standard compliance levels. However, the period immediately after WWTPs (1989-1992) was characterized by levels as high or higher than some WWTP discharge years, especially at Sites 22 and 23. Similarly, some of the highest post-WWTP TN concentrations were seen during the same time period at Sites 23 and 21 and to a lesser extent at Site 22. Potentially, this pattern may relate to the low rainfall period of 1988 through 1990. Although, it would appear a lag effect occurred if this explanation is valid because of the relatively high TP content observed in 1991 and 1992.

Overall, FC values were typically low and well within standard compliance. However, Site 22 did exhibit some annual 75th percentile values that were relatively elevated above 200 colonies/ 100 ml but below the 800 colonies/ 100 ml standard.

c. Seasonal Differences

As observed throughout most of the sites in the county, dry season DO values were higher than wet season due, in part, to temperature. The extremely low (< 2.0 mg/l) values, especially in the wet season also suggest seepage water is entering the canal and affecting DO readings. The lack of statistical difference at Site 23 may be reflective of a more consistent water input source (e.g., WCA groundwater seepage) year round.

Interestingly, statistical differences in TP were observed with dry season values being higher than wet season at Sites 22 and 23 while no seasonal pattern was observed for total nitrogen. Potentially, the dry season allows for more stagnation and evaporation which concentrates the TP in the canals. In addition, lower volumes of WCA seepage water with relatively low TP concentrations enter the NNRC during dry periods than wet. Conversely, FC values were statistically higher during the wet season which is likely due to stormwater runoff.

d. Future Monitoring Questions

A major goal of this report is to develop strategic guidelines for future Broward County water quality monitoring and management. To facilitate this, questions generated by this study's findings are being compiled for each drainage basin. For the North New River Canal and Basin, the main questions revolve around TP levels around an apparent change in the post-WWTP canal between 1989-1992 and 1993-1997.

- Are nutrient concentrations from 1993-1997 or from 1989-1992 more reflective of ambient TP levels in the canal?

- Are the differences in TP content between 1993-1997 versus 1989-1992 due to weather, land-use, water management, or a combination?

- Throughout the canal are nutrient concentrations creating a problem in water column biology (e.g., chlorophyll a) and/or macrophytes?

- What is stormwater quality like entering the canal and its tributaries?

J. C-11 Canal

1. Basin and Canal Structure

With an area of 104 mi^2, the C-11 Canal Basin is the largest basin located entirely within the county. The basin is in southwest Broward County and is divided into western (81 mi^2) and eastern (23 m^2) basins (Cooper and Lane 1987; Figure III.67). The S-13A effectively divides the C-11 Canal into typically western and eastern flowing segments that correspond to the respective western and eastern basins. Elevation and subsequently the amount of flow westward is controlled by the S-9 pump structure while the eastern waterway's elevation and flow is controlled by the S-13 which has both pump and gravity flow capacity. During certain hydrological conditions the S-13A may be opened to allow western C-11 Basin water to flow to the east, in order to maintain barriers to salt water intrusion or for flood protection (Cooper and Lane 1987).

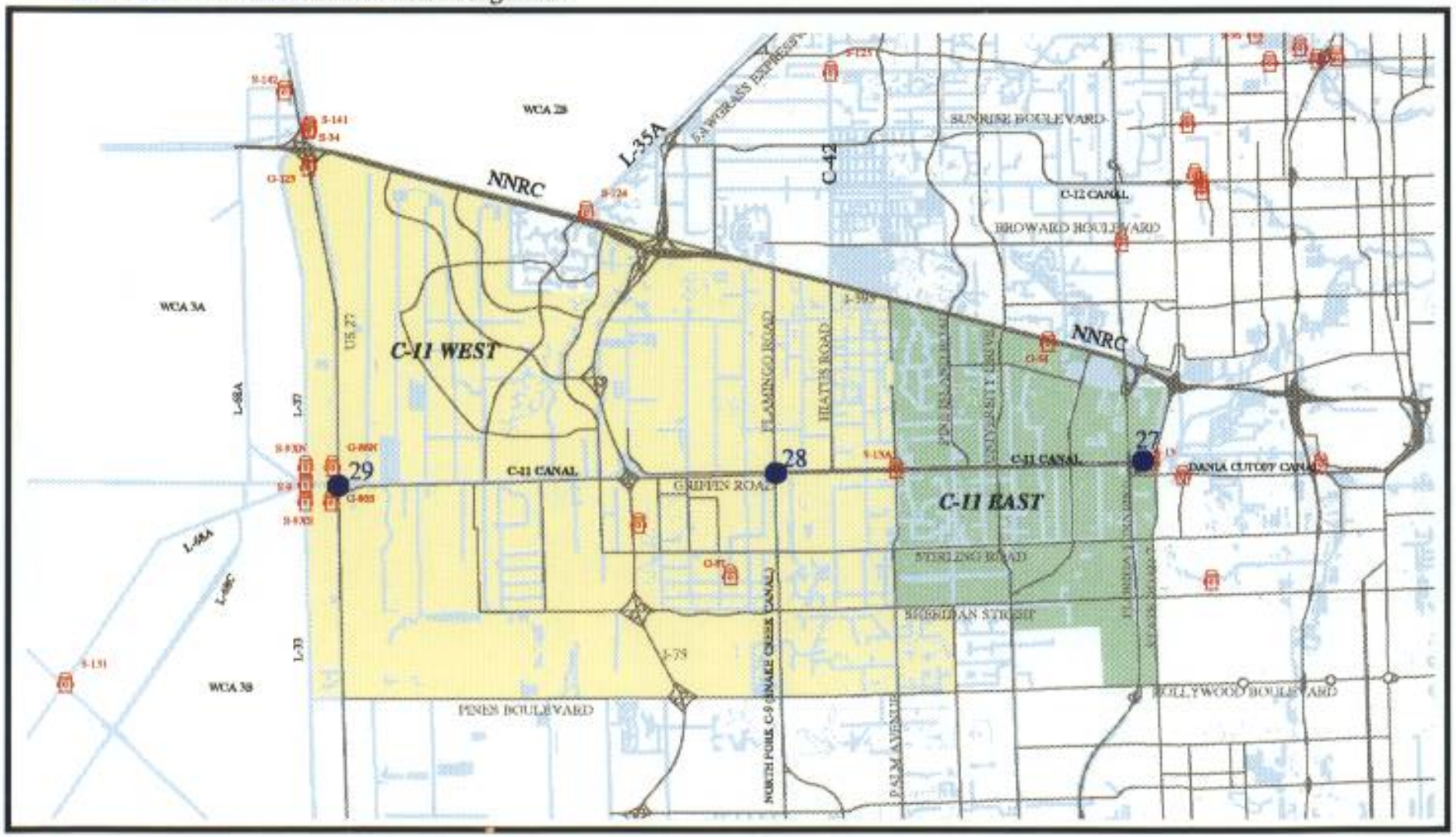
The S-9 is a three unit pump system (960 cubic feet per second capacity) that back pumps C-11 Canal water to the WCA 3A (Cooper and Lane 1987). Water may also arrive from the northern L-37 Canal via S-9XN which primarily collects seepage from WCA 3A. The L-37 Canal does not make a northern connection to the North New River Canal. The L-33 is south of S-9 and connects to the C-9 Canal (see Section III.K). Flow direction (north or south) in the L-33 is dependent on the S-9XS, S-30, and S-32. However, normal operations have the WCA 3A's seepage water in the L-33 flowing south to the C-9 Canal (Cooper and Lane 1987). Two gates also exist along the US 27 drainage ditch that is oriented in a north-south direction east of the S-9. The G-86N and the G-86S are gated culverts that control the water elevation in the north and south drainage ditches, respectively. Within the southeast section of the Western C-11 Basin, the C-11S normally flows north along Flamingo Road into the main C-11 Canal. The G-87 is the drainage divide between the C-11 and C-9 Basins.

Four independent drainage districts (see Section I, Figure I.4) oversee the basin's secondary and tertiary canals that eventually release to the South Florida Water Management District's (SFWMD) C-11 Canal. The Central Broward Drainage District manages the vast majority of the eastern sub-basin and also exists in the large portions of the western sub-basin. The Tindell Hammock Drainage District is in the northeast corner of the eastern C-11 sub-Basin. The South Broward and the Indian Trace Drainage Districts are on the south and north sides, respectively, of the western sub-basin.

2. Municipalities and Land Use

The C-11 Canal Basin is partially encompassed by the Town of Davie, Cooper City, the northern half of City of Pembroke Pines, a western section of the City of Hollywood, and unincorporated Broward County (see Section I, Figure I.3). In recent years, the City of Pembroke Pines had some the fastest growth in the county going from 53,706 residents in 1987 to 101,307 by 1995 (Broward County Planning Council 1995). Hollywood remained the second largest city in Broward, going from over 124,000 to 138,000 residents over the same period. The Town of Davie had 51,230 residents and Cooper City had 23,146 people in 1995. In addition, the Weston became an official city in 1996 towards the end of the current study era (1997).

Figure III.67. The C-11 Canal Basin and Broward County (BCDPEP) Sampling Site Location Map. The C-11 Canal and other major waterbodies with corresponding South Florida Water Management District (SFWMD) water control structures (labeled) are depicted. Note water control structures without labels are secondary structures operated by other entities than the SFWMD. The S-13A (SFWMD) divides the C-11 Canal into two distinct segments.



BCDPEP Water Quality Sampling Site

Water Control Structures (primarily SFWMD)

Waterbodies

Major Roadways

0 1 2 3 Miles

N W E S

This map is for informational purposes only. For further information, please contact BCDPEP Water Resources Division (954) 519-1270.

By the end of the 1970's, the land in the C-11 Canal Basin was predominantly open (42%) or in agricultural use (38%). The remainder of the land use was comprised of low density residential (18%), and less than 2% of the basin was used for commercial or industrial uses (Broward County Planning Council 1977). During the 1980s and early 1990s, the westward expansion of the population resulted in the urban development of many areas of the C-11 Basin. For example, from 1989 to 1995 the Town of Davie experienced a 32% decline in vacant land. Residential land use increased from 27% to approximately 38%, with the majority of the acreage consisting of estate or single family homes. Other land uses such as commercial, industrial, and agriculture remained fairly constant. The amount of vacant or undeveloped land declined by approximately 50%, while residential land use increased from 47% to 55% of the total land area. Commercial and industrial land use also increased from 7% in 1989 to 12% in 1995 (Broward County Planning Council 1995). Although there is not a large amount of crop cultivation in Broward County, southwest Broward, has seen a significant trend in the development of plant nurseries (South Florida Regional Planning Council 1990).

3. Wastewater Treatment Plants Discharge History

In June of 1983, the Modern Mobile Home was the first WWTP to cease discharging into the C-11 Canal. The Cooper City East Plant (after 1988, the Hollywood Lakes Country Club (0.05 mgd) stopped discharging into the C-11 Canal via the North Fork of the C-9 Canal. The Town of Davie's Plant I (0.96 mgd) also halted WWTP dumping practices in 1988 via the N-5 Canal in the eastern sub-basin.

4. Other Influences on Water Quality

a. Soils

The western portion of the C-11 Basin consists of poorly drained peats and muck soils, as well as poorly drained deep sandy soils (see Section I, Figure I.5). The eastern area of the basin predominantly has poorly drained deep sandy soils with thick black surface layers (Reynolds, Smith and Hills Inc. 1972).

b. Roadways

Two major roads (Griffin Road and Orange Drive) run parallel along a majority of the canal's shoreline. In addition, several north/south oriented roads (e.g., Florida Turnpike and University Drive) cross the canal. Currently, seventy-six stormwater outfalls (BCDPEP Geographical Information System database, unpublished), primarily associated with these roadways, discharge directly into the C-11 canal. Almost half (thirty-six) are at least 15 inches in diameter. The surrounding C-11 Basin (east and west) has an additional one hundred and seventy-four outfalls that discharge into secondary and/or tertiary canals before eventual discharge into the C-11 Canal.

c. Septic Tanks

Both C-11 sub-basins are characterized by large areas of no sewer service based on a 1993 survey

(http://www.broward.org/moi00600.htm). However, these basins, in particular the western C-11 Basin, have experienced the most rapid growth over last five years which has led to new sewer infrastructure. At the time of this writing, an updated analysis of septic tank coverage county-wide had not been performed. Several areas (e.g., Southwest Ranches), are still characterized by septic tanks as a mechanism for wastewater disposal. However, the basinwide influence of septic tanks will be difficult to determine until an update is performed.

5. Sampling Locations and Period

Three C-11 sampling sites (27-29) are monitored by the BCDPEP and all sites are located west of the S-13 water control structure (Figure III.72). Global Position System coordinates and specific site descriptions are given in Appendix 1.

Site 27 exists in the eastern sub-basin immediately west of the S-13 structure (Figure III.67). Located at the Flamingo Road bridge, Site 28 is west of S-13A and is the central most site along the canal. Site 28 also represents water quality in the eastern extent of the western C-11 sub-basin. Site 29 is located at the western end of the canal and is immediately east of the S-9 structure at the US 27 highway bridge.

Table III.37. Sampling Years for Specific Parameters at the C-11 Canal Locations. A sampling year had at least one sample event during that year. Note the biochemical oxygen demand was a five-day test from 1973 until 1981 when a seven-day test was implemented until 1993 after which sampling for the parameter ceased at BCDPEP.

Parameter	Site 27	Site 28	Site 39
Temperature	73-97	72-97	73-97
pH	73-97	72-97	73-97
Specific Conductance	81-97	81-97	81-97
Dissolved Oxygen	73-97	72-97	73-97
Biological Oxygen Demand	73-93	73-93	73-93
Total Organic Carbon	81-97	81-97	81-97
Turbidity	75-97	75-97	75-97
Total Phosphorus	75-97	74-97	74-97
Ammonia-Nitrogen	81-97	81-97	81-97
Nitrite+Nitrate-Nitrogen	81-97	81-97	81-97
Total Kjeldahl Nitrogen	81-97	81-97	81-97
Fecal Coliform	73-97	72-97	73-97
Total Coliform	73-97	72-97	73-97
Fecal Streptoccocus	76-97	76-97	76-97

6. Results

a. Physical Characteristics

Mean and median water temperatures were essentially the same at all three C-11 Canal sites (Table III.38). Site 27 had a wider range of temperature than Sites 28 and 29 but had over twice as many observations. Long term average and median pH readings were also similar at all sites, ranging from 7.3 to 7.5.

Small differences in specific conductance values were observed between the eastern (Site 27) and the western sub-basins (Sites 28 and 29, Table III.38). From 1981 until 1997, Site 27 exhibited mean and median specific conductance values below 700 Fmhos/centimeter (Fmhos/cm). During the same period, Sites 28 and 29 were characterized by means of 764 and 818 Fmhos/cm, as well as medians of 758 and 820 Fmhos/cm, respectively.

Table III.38. Descriptive Statistics for Temperature (Temp; C=Celsius), pH, Specific Conductance (Cond; Fmhos = micromhos/centimeter @ 25ºC) in the C-11 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
27	Temp	^{o}C	370	26.0	25.7	3.5	33.0	14.0	0
28	Temp	^{o}C	162	26.0	25.5	3.1	31.5	17.0	0
29	Temp	^{o}C	149	26.0	25.2	2.4	30.5	20.0	0
27	pH	units	377	7.5	7.5	0.3	8.4	6.4	0
28	pH	units	161	7.5	7.5	0.3	8.1	6.3	0
29	pH	units	148	7.4	7.3	0.2	7.9	6.6	0
27	Cond	Fmhos	284	680	685	100	1330	336	0
28	Cond	Fmhos	68	758	764	91	950	510	0
29	Cond	Fmhos	65	820	818	70	970	600	0

b. Total Organic Carbon and Turbidity

Total organic carbon (TOC) mean and median concentrations were fairly similar between all three sites ranging from 23.72 mg/l (Site 28) to 26.66 mg/l (Site 27; Table III.39). Site 27 exhibited the widest range due to an elevated maximum concentration (82.60 mg/l).

At all sites, turbidity levels were typically low and normally within compliance of Broward County's standard of 10 nephelometric turbidity units (ntus, Table III.39). Maximum values were equal to or above the standard at each site but these were rare observations based on the median, as well as standard deviation values.

Table III.39. Descriptive Statistics for Total Organic Carbon (TOC) Concentrations and Turbidity (Turb) Levels in the C-11 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
27	TOC	mg/l	262	26.20	26.66	5.96	82.60	7.40	0
28	TOC	mg/l	62	24.65	23.72	4.57	32.70	12.90	0
29	TOC	mg/l	59	25.80	24.93	4.51	35.50	14.60	0
27	Turb	ntu	356	2.5	2.9	1.5	12.0	0.8	0
28	Turb	ntu	135	2.3	3.1	3.4	28.0	0.8	0
29	Turb	ntu	125	2.8	3.3	1.7	10.0	0.8	0

c. Dissolved Oxygen and Biochemcial Oxygen Demand

Long term mean and median dissolved oxygen (DO) concentrations were all below the Broward County single sample standard of 4.0 mg/l (i.e., out of compliance; Table III.40). In particular, the western sub-basin sites (28 and 29) exhibited DO values below 3.0 mg/l with Site 29 having ten samples below the method detection limit. Biochemical oxygen demand median and mean concentrations were fairly similar at all sites and were below (i.e., within compliance) of the county's standard of 5.0 mg/l (Table III.40).

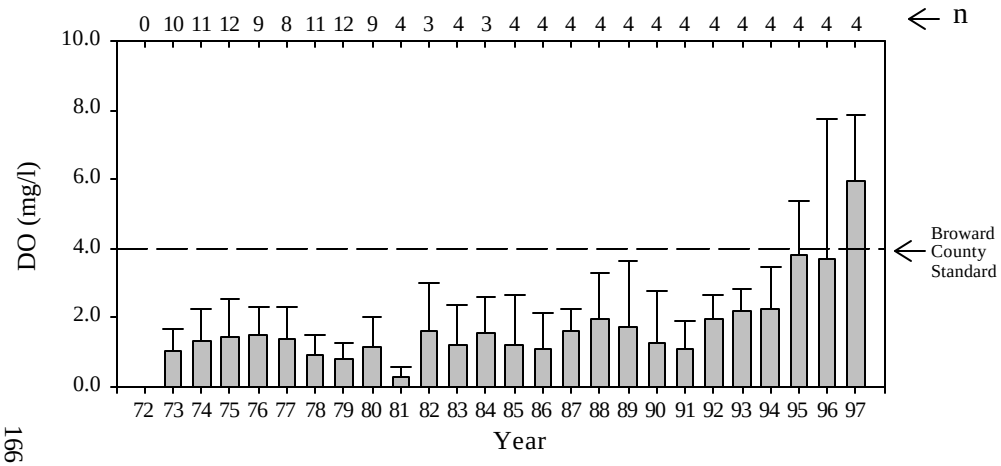
Table III.40. Descriptive Statistics for Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) Concentrations in the C-11 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculations. The number of samples below the method detection limit is shown in the last column # MDL).

Site	**Parameter**	**unit**	**n**	**Median**	**Mean**	**SD**	**Max**	**Min**	**# MDL**
27	DO	mg/l	372	3.4	3.7	2.0	11.1	0.3	0
28	DO	mg/l	163	2.0	2.4	1.7	7.5	0.20	0
29	DO	mg/l	148	1.2	1.6	1.5	9.4	0.025	10
27	BOD	mg/l	348	2.0	2.4	1.3	11.9	0.8	0
28	BOD	mg/l	133	1.4	1.7	1.6	18.0	0.4	0
29	BOD	mg/l	123	2.0	2.0	0.9	5.0	0.7	0

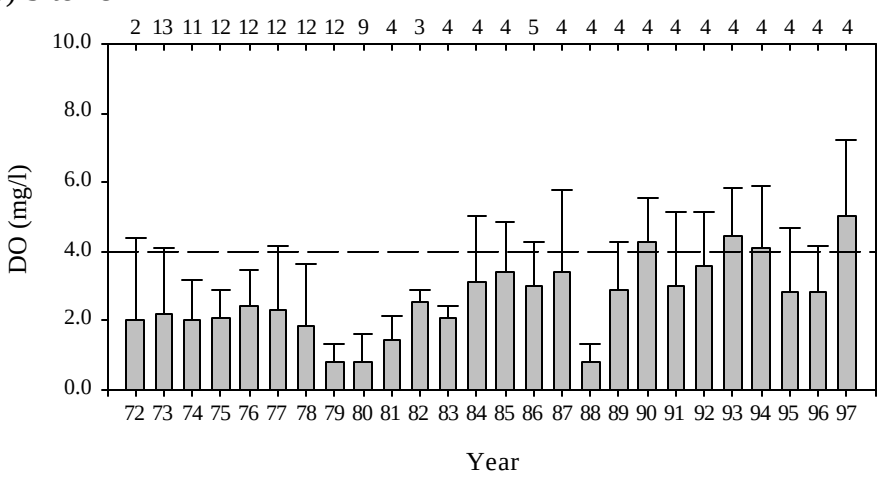
The western C-11 sub-basin (Sites 28 and 29) exhibited generally higher yearly DO averages in the 1990's compared to the previous decades (Figure III.68). In particular, Site 28's annual averages were within compliance with the standard of 4.0 mg/l four times in the 1990's but never in the 1970's or 1980's. From 1995 to 1997, Site 29 showed exceptional increases in DO content although 1996 was characterized by high variability around the mean (3.7 ± 4.0 mg/l). While Site 27 generally had the highest annual DO content in the C-11 Canal, most years were either below or around the 4.0 mg/l level.

Figure III.68. Annual Mean Dissolved Oxygen Content Within the C-11 Canal Basin from 1972 to 1997. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. The Broward County standard (4.0 mg/l) is indicated by the dashed line.

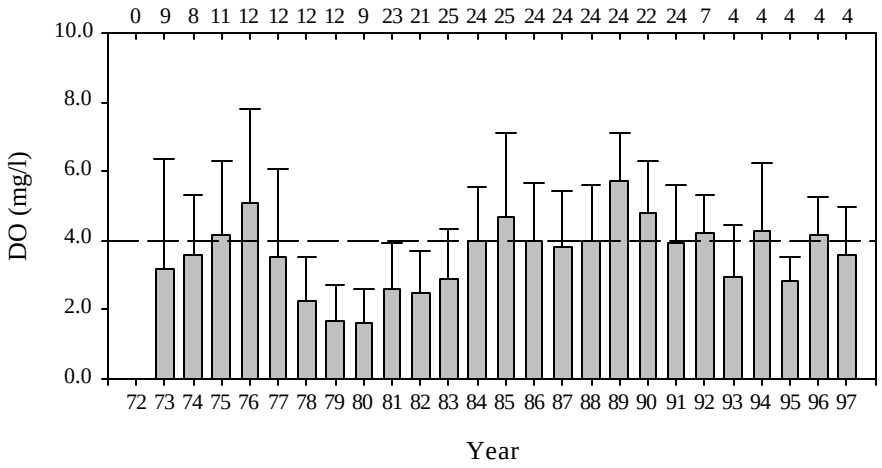
a) Site 29



b) Site 28



c) Site 27



To further understand compliance patterns within the canal, individual DO observations were rated in relation to Broward County's water quality standards (see Section III.E.5.c). In addition, the influence of WWTP discharges was looked into by separating data into different periods (see Section III.J.3). Within the C-11 Canal, the eastern sub-basin (Site 27) exhibited the highest percentage of good samples (> 5.0 mg/l) through each period (Figure III.69). However, 39.2% of poor rated samples still existed during the period after WWTP discharges (1989-1997). The percentage of dissolved oxygen samples achieving standard compliance was low in the western sub-basin, especially at Site 29, however, some improvements were observed over the last eight years.

From 1989 to 1997, DO readings above (within compliance) the 4.0 mg/l standard were not readily observed at Site 28 and to an even lesser extent at Site 29 (Figure III.70). Site 27's dry season DO content was conversely very compliant with the standard but the wet season observations were not. Site 27 had the only statistical significant difference between seasons (t-test, $p < 0.001$).

d. Total Phosphorus

For the entire study period, Site 27 was characterized by exceptionally higher total phosphorus (TP) concentrations than the western sub-basin (Sites 28 and 29; Table III.41). Both long term median and mean TP concentrations were above 0.100 mg/l at Site 27 but never reached over 0.050 mg/l at Sites 28 and 29. The amount of samples below the method detection limit (MDL) was 55.4% and 46.0% for Sites 29 and 28, respectively. Only 8.1% of Site 27's three hundred fifty-seven samples were below the MDL.

Table III.41. Descriptive Statistics for Total Phosphorus (TP) Concentrations in the C-11 Canal Basin. TP calculations represent twenty-four years of sampling at Sites 28 and 29, while Site 27 has been sampled for twenty-three years. However, the number of samples (n) varies between sites. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculations. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
27	TP	mg/l	357	0.123	0.129	0.096	0.992	0.010	29
28	TP	mg/l	139	0.020	0.045	0.098	0.900	0.010	64
29	TP	mg/l	128	0.013	0.027	0.033	0.239	0.010	71

Annual TP averages were typically much higher at Site 27 than observed for Sites 28 and 29 (Figure III.71). Site 27 yearly mean TP values were normally above 0.120 mg/l from 1975 to 1987 but never exceeded 0.090 mg/l after 1987. Site 29 exhibited the lowest TP concentrations in the basin, particularly from 1993 to 1997 when yearly averages were near or below (i.e., within compliance) the county standard of 0.020 mg/l. The lowest TP levels at Site 28 were also from 1993 to 1997. Interestingly, relatively elevated TP concentrations were observed at Sites 28 and 29 even though WWTP discharges had ceased.

Figure III.69. Dissolved Oxygen (DO) Concentrations Observed in the C-11 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall be below 4.0 mg/l. All concentrations greater than or equal to 5.0 mg/l are classified as good and DO concentrations between 4.0 to 4.9 mg/l are considered fair. Readings below 4.0 mg/l are defined as poor.

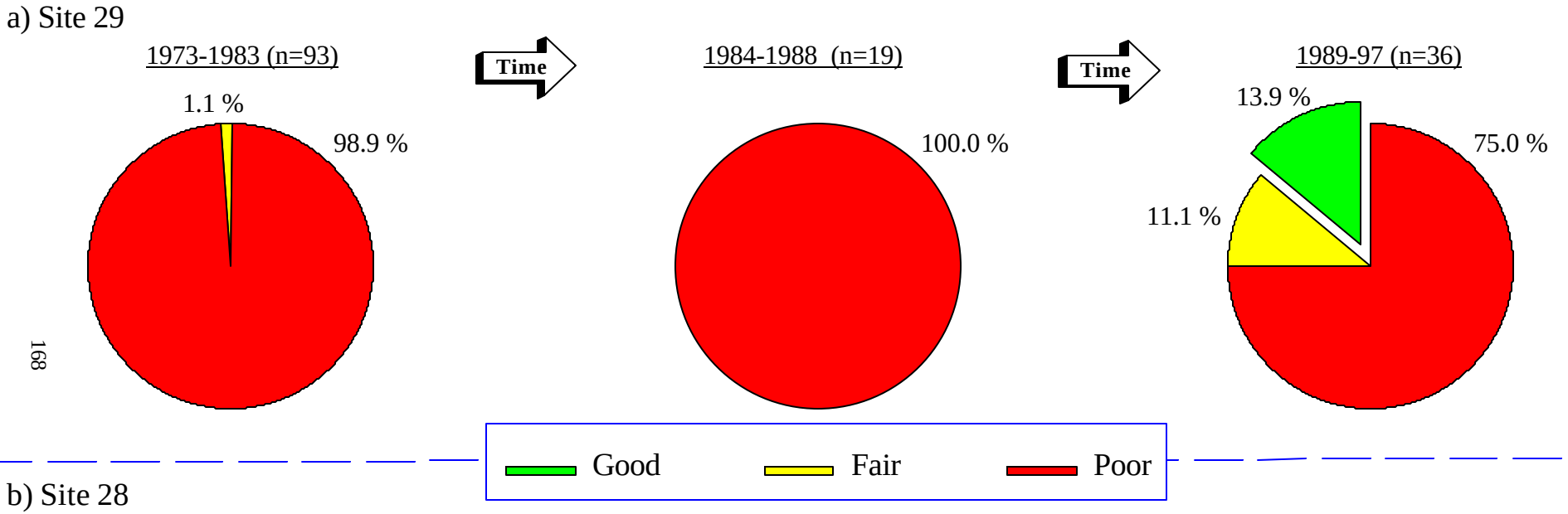


Figure III.69 (Cont.). Dissolved Oxygen (DO) Concentrations Observed in the C-11 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall be below 4.0 mg/l. All concentrations greater than or equal to 5.0 mg/l are classified as good and DO concentrations between 4.0 to 4.9 mg/l are considered fair. Readings below 4.0 mg/l are defined as poor.

c) Site 27

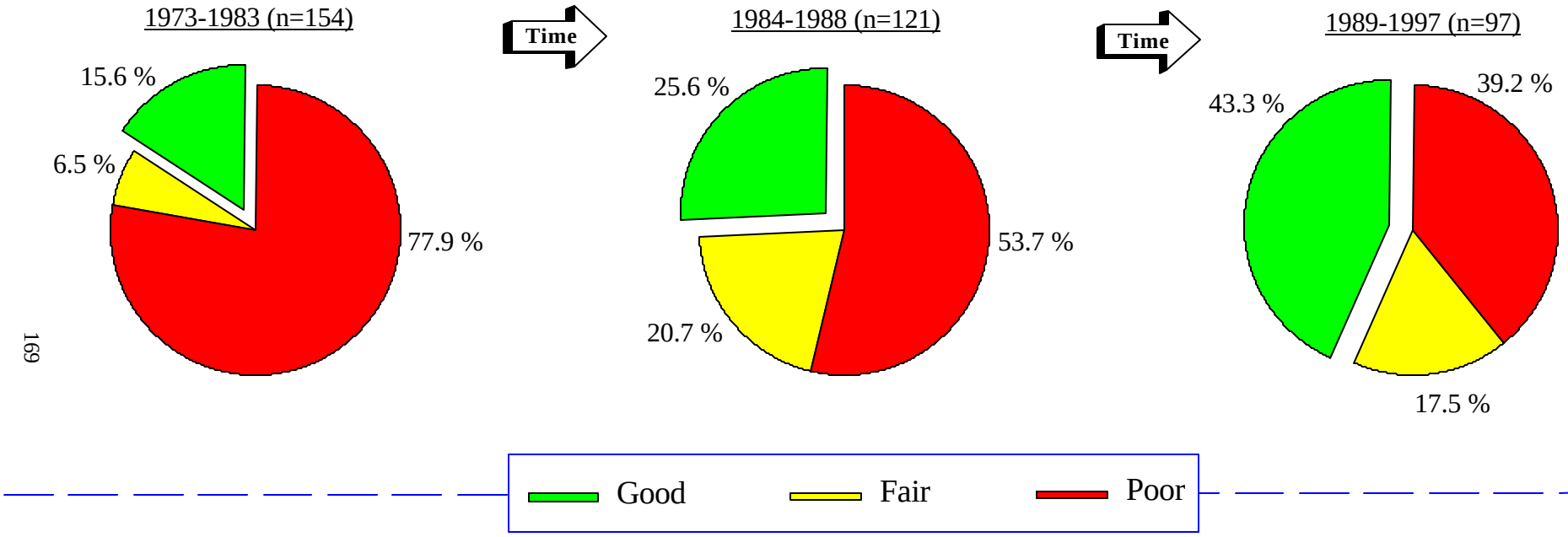


Figure III.70. C-11 Canal Basin Dissolved Oxygen (DO) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season means was observed at Site 27 ($p < 0.001$, t- test) but not at Sites 28 and 29. Site 27 (Eastern C-11 Basin) is distinctly separated from Sites 28 and 29 (Western C-11 Basin).

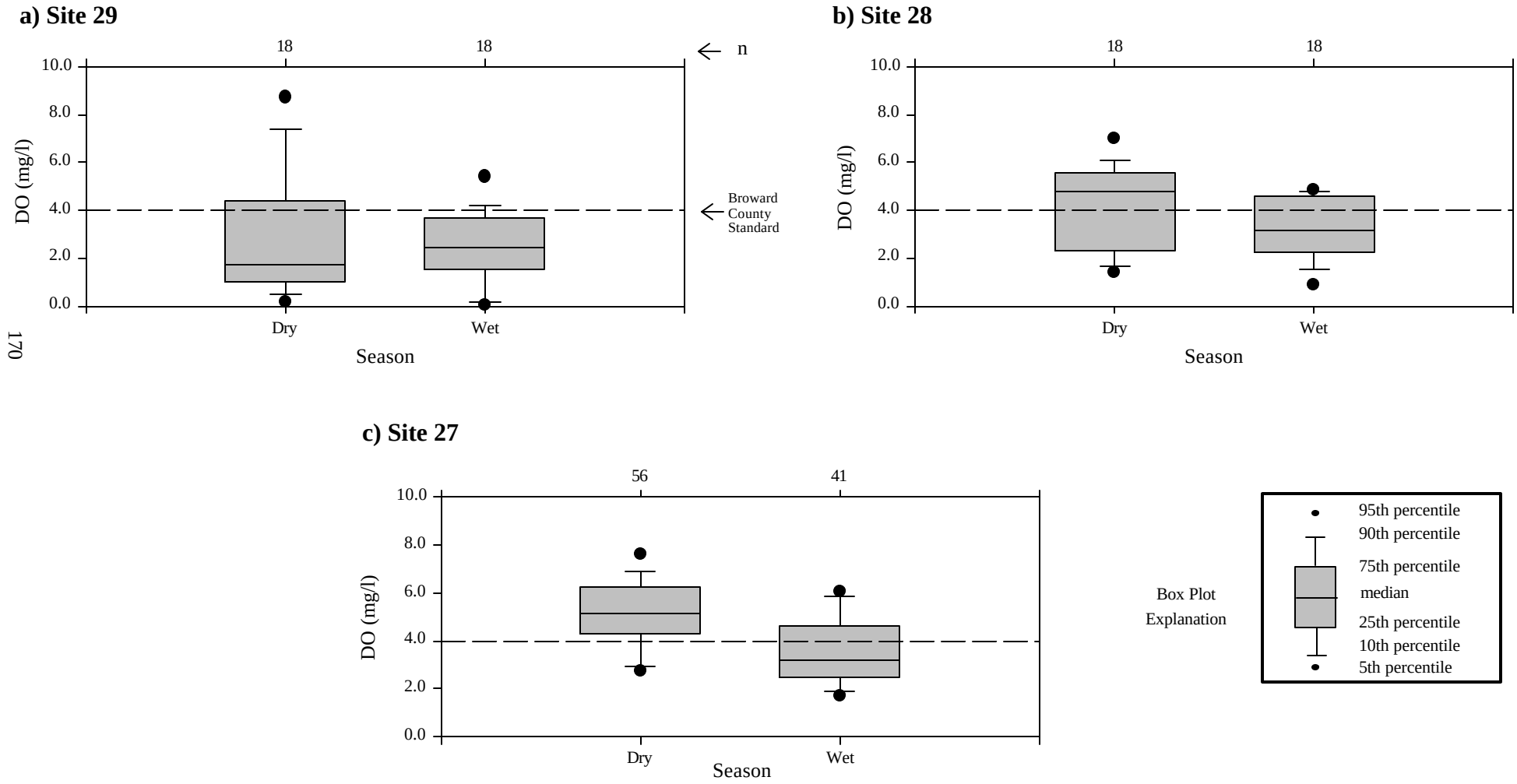
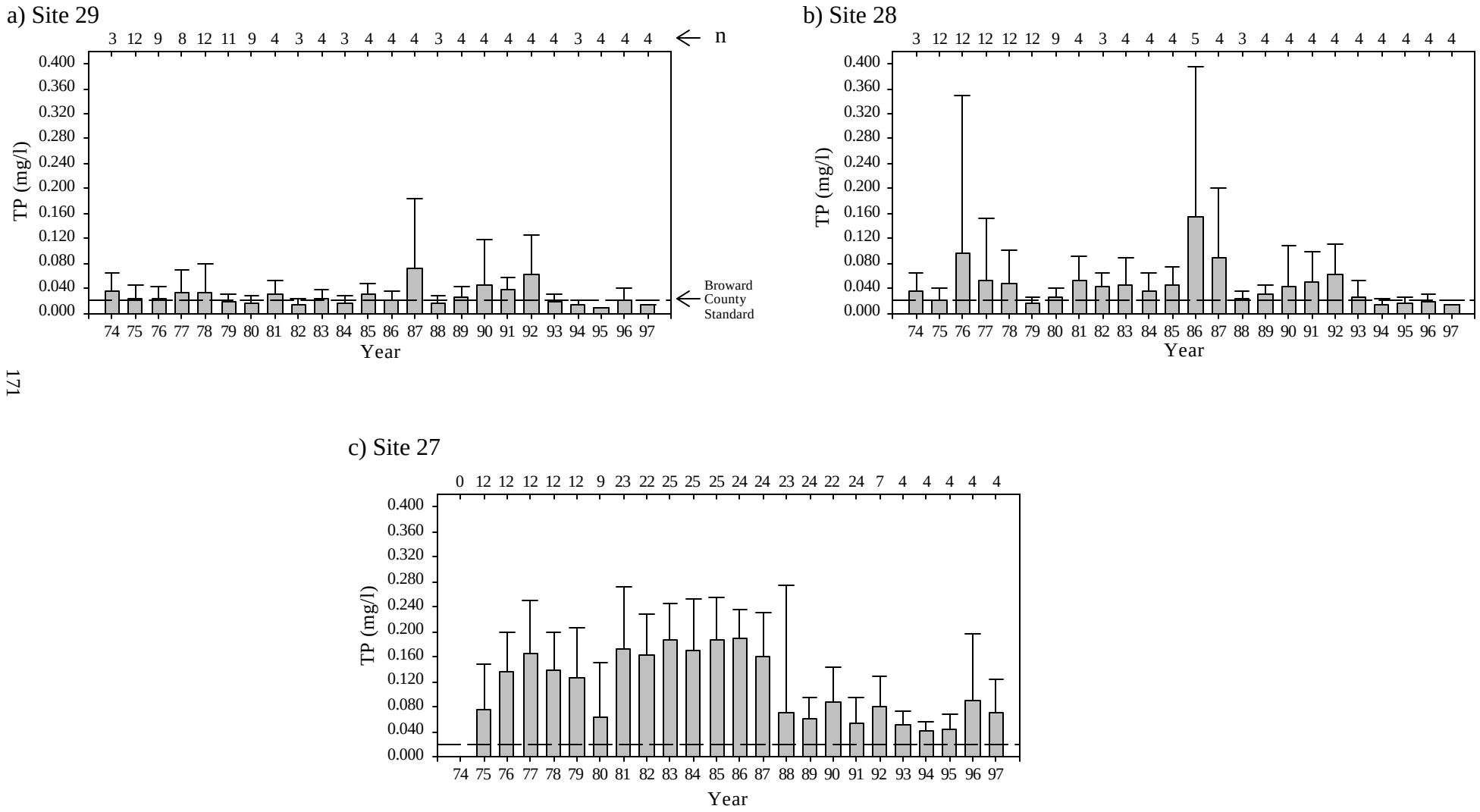


Figure III.71. Annual Mean Total Phosphorus (TP) Levels Within the C-11 Canal Basin from 1974 to 1997. Means and standard deviations (sd; error bars) calculated from biweekly, monthly, and/or quarterly samples with the number of samples (n) per year noted on the upper x-axis. The Broward County freshwater standard (0.020 mg/l) is indicated by the dashed line.



To further investigate compliance patterns within the canal, all individual samples were rated in terms of Broward County's TP standard (0.020 mg/l, see Section III.E.5.d). In addition, changes over time were investigated with special reference to the closing of WWTPs within the basin (see Section III.J.3). Both Sites 28 and 29 exhibited an initial decrease in water quality through time (1984 thru 1988) followed by an improvement after 1988 (last year of WWTP discharge, Figure III.72). This pattern was most distinct at Site 28. Site 27 had the C-11's highest percentage of poor ratings during each period but realized a 43.5% decrease in poor samples by the final time frame (1989-1997). Yet, only 9.3% of Site 27's TP samples were within compliance of the 0.020 mg/l standard between 1989 and 1997 despite the stoppage of WWTP discharges into the canal.

Between 1989 and 1997, a significant difference was observed between Site 27's dry and wet season median TP concentrations (Mann-Whitney Rank Sum Test, $p < 0.001$) but not at Sites 28 and 29 (Figure III.73). Site 27's dry season TP concentrations also displayed a wider range of values than observed for the wet season. Furthermore, almost all wet and dry season values were above the 0.020 mg/l standard at Site 27. Conversely, Site 28 and 29 median observations were below (i.e., within compliance) the standard.

e. Nitrogen

Total nitrogen (TN) levels are calculated from the total Kjeldahl nitrogen (TKN) and nitrite+nitrate-nitrogen (NO_2+NO_3) concentrations. Sites 28 and 29 (western sub-basin) were characterized by very similar TN content (approximately 1.600 mg/l) while the canal's highest mean and median TN values were observed at Site 27 (eastern sub-basin; Table III.42). Furthermore, all C-11 Canal long term mean and median TN values were above the Broward County standard (1.500 mg/l).

Total Kjeldahl nitrogen represented just over 80.0% of mean TN levels at the eastern most Site (27) and increased to over 90% at the canal's western extent (Site 29; Table III.42). Conversely, NO_2+NO_3 content decreased moving westward from Site 27 which had elevated levels (> 0.400 mg/l). Ammonia-nitrogen concentrations were typically higher at the C-11 canal's eastern and western boundaries (Sites 27 and 29, respectively) and lowest in the center (Site 28).

Figure III.72. Total Phosphorus (TP) Concentrations Observed in the C-11 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County freshwater TP standard of 0.020 mg/l. The percentage of samples below 0.020 mg/l are classified as good. A fair rating was given to concentrations between 0.021 mg/l to 0.060 mg/l. Values equal to or greater than three times the standard (i.e., 0.060 mg/l) are classified as poor.

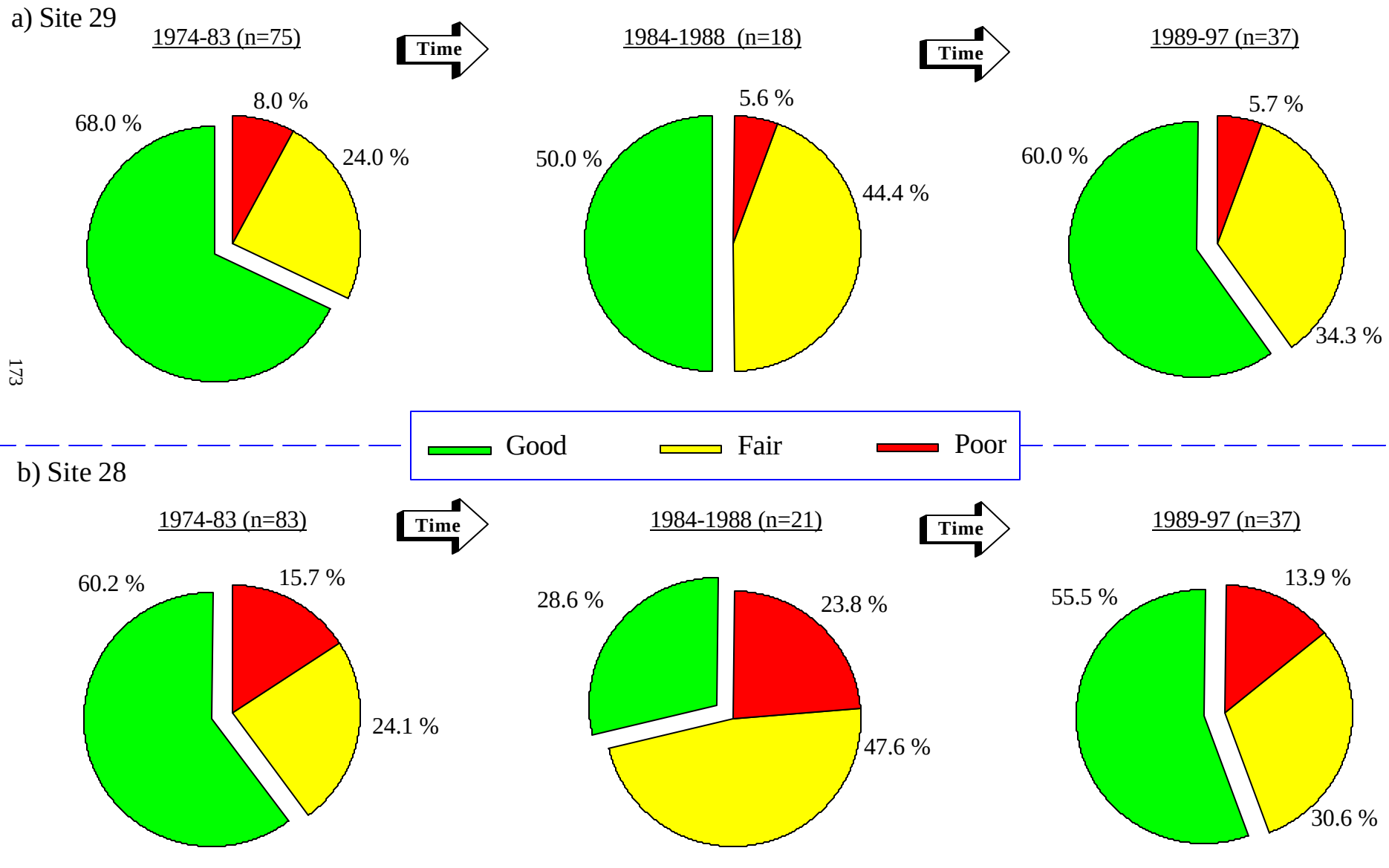


Figure III.72 (Cont.). Total Phosphorus (TP) Concentrations Observed in the C-11 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County freshwater TP standard of 0.020 mg/l. The percentage of samples below 0.020 mg/l are classified as good. A fair rating was given to concentrations between 0.021 mg/l to 0.060 mg/l. Values equal to or greater than three times the standard (i.e., 0.060 mg/l) are classified as poor.

c) Site 27

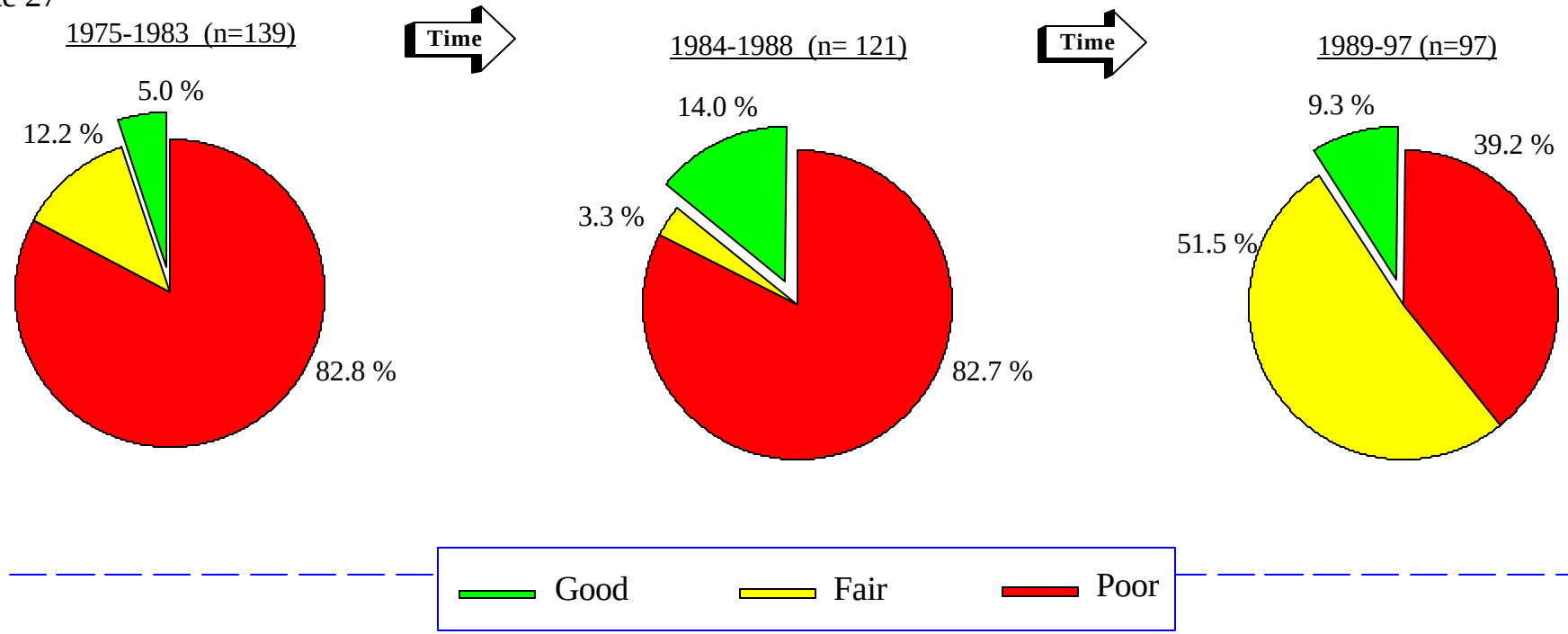


Figure III.73. C-11 Canal Basin Total Phosphorus (TP) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. A statistically significant difference between wet and dry season means was observed at Site 27 ($p < 0.001$, Mann-Whitney Rank Sum test) but not at sites 28 and 29. Site 27 (Eastern C-11 Basin) is hydrologically distinct from Sites 28 and 29 (Western C-11 Basin).

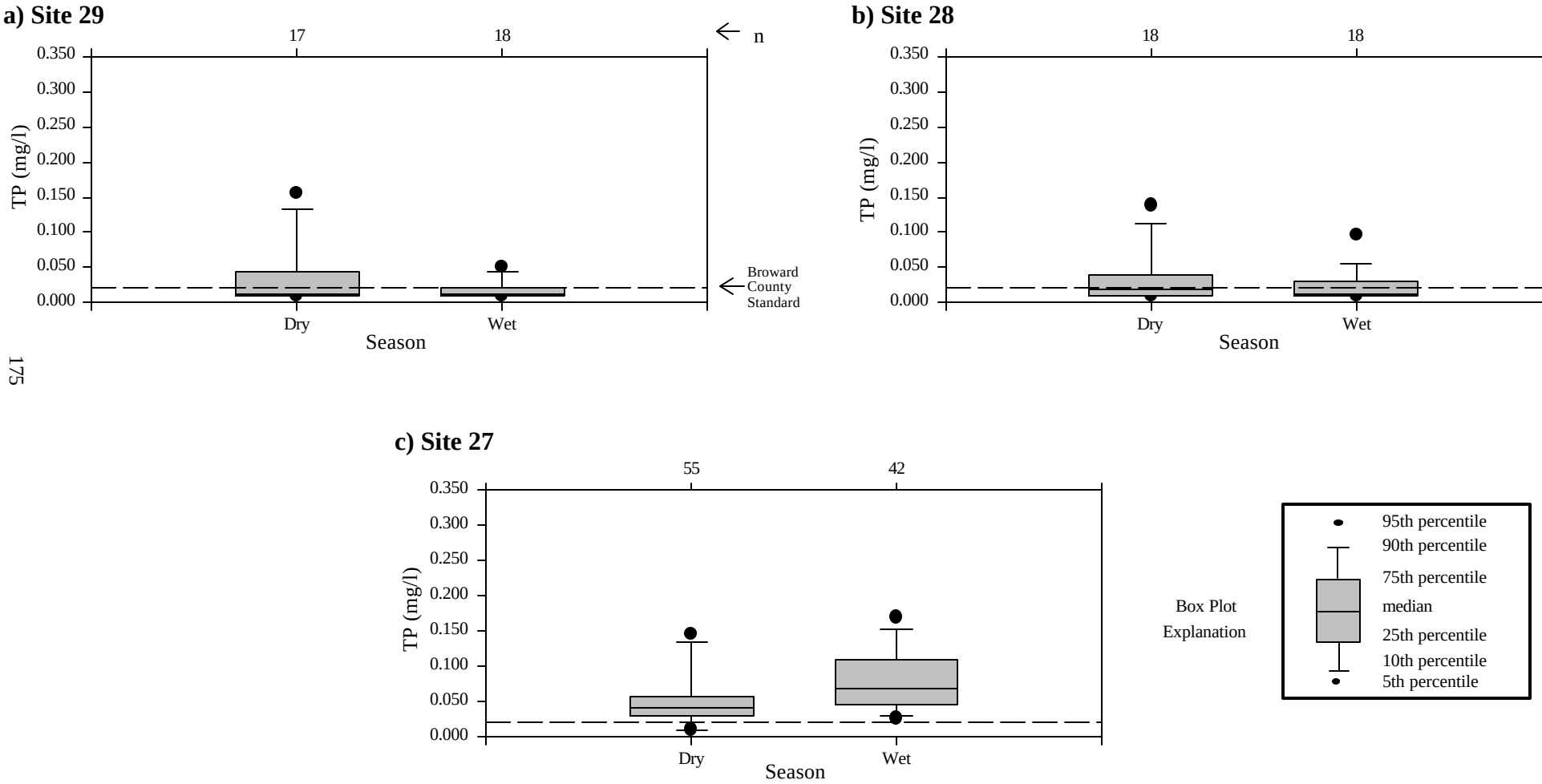


Table III.42. Descriptive Statistics for Nitrite+Nitrate-Nitrogen (NO_2+NO_3), Ammonia-Nitrogen (NH_3), Total Kjeldahl Nitrogen (TKN), and Total Nitrogen (TN) Concentrations in the C-11 Canal Basin. Overall, the number of samples (n) varies between sites. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL). TN was calculated as the sum of TKN and NO_2+NO_3.

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
27	NO_2+NO_3	mg/l	290	0.420	0.425	0.176	0.976	0.005	1
28	NO_2+NO_3	mg/l	68	0.220	0.249	0.161	0.990	0.010	1
29	NO_2+NO_3	mg/l	65	0.095	0.095	0.010	0.388	0.005	14
27	NH_3	mg/l	266	0.304	0.316	0.282	2.440	0.005	45
28	NH_3	mg/l	63	0.163	0.205	0.200	1.040	0.005	4
29	NH_3	mg/l	60	0.312	0.343	0.175	0.990	0.005	2
27	TKN	mg/l	286	1.770	1.769	0.393	3.100	0.310	0
28	TKN	mg/l	66	1.350	1.359	0.293	2.330	0.684	0
29	TKN	mg/l	63	1.540	1.520	0.264	2.180	0.902	0
27	TN	mg/l	286	2.173	2.190	0.445	3.689	0.527	N/A
28	TN	mg/l	66	1.598	1.611	0.323	2.804	0.807	N/A
29	TN	mg/l	63	1.618	1.617	0.255	2.185	0.911	N/A

For each site, annual mean total nitrogen (TN) content was generally higher before 1988 (i.e., WWTP discharge stoppage) then afterwards (Figure III.74). Site 27 exhibited the highest mean TN content each year throughout the canal and barely achieved compliance with the county standard in only one year (1996, 1.496 ± 0.215 mg/l). Within, the western sub-basin, Site 29 had slightly higher TN annual averages than Site 28 during the 1990's. However, both Sites 28 and 29 were typically at or near compliance throughout the last ten years (1988-1997).

Each TN sample was given a rating based on Broward County's water quality standards (see III.E.5.e). Patterns through time were investigated with the closing of WWTPs within the basin (see Section III.J.3). Both western sub-basin sites (28 and 29) displayed improvements with time (Figure III.75). In particular, Sites 28 and 29 had 65.0% or higher good rated samples during the final period (1993-1997) compared to only 10.3% or lower during the first period (1981-1988). While poor samples did not exist after 1988, the percentage of good samples at Site 27 during 1993-1997 was only 15.0%.

Statistical differences were not observed between median or mean wet and dry TN season concentrations between 1989 and 1997 (Figure III.76). The western sub-basin Sites 28 and 29 had median values below the county standard while a majority of TN concentrations in the eastern sub-basin (Site 27) were above 1.500 mg/l (Figure III.76).

Figure III.74. Annual Mean Total Nitrogen (TN) Levels Within the C-11 Canal Basin from 1981 to 1997. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. The Broward County standard (1.500 mg/l) is indicated by the dashed line. Note different y-axis scale for Site 27 (c).

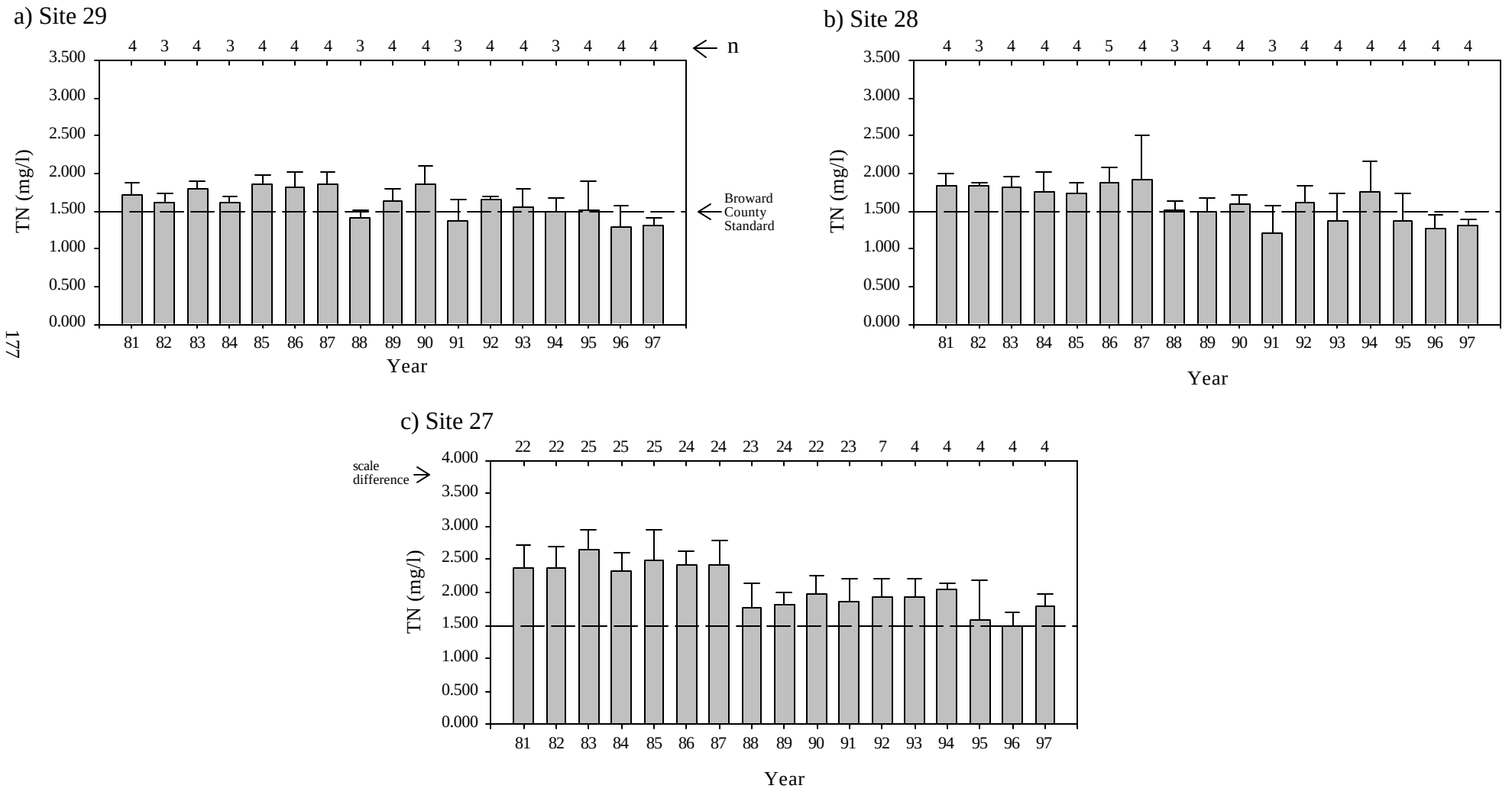


Figure III.75. Total Nitrogen (TN) Concentrations Observed in the C-11 Canal Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified as good. A fair rating was given to concentrations between 1.501 mg/l to 2.500 mg/l. Values greater than 2.500 mg/l are classified as poor.

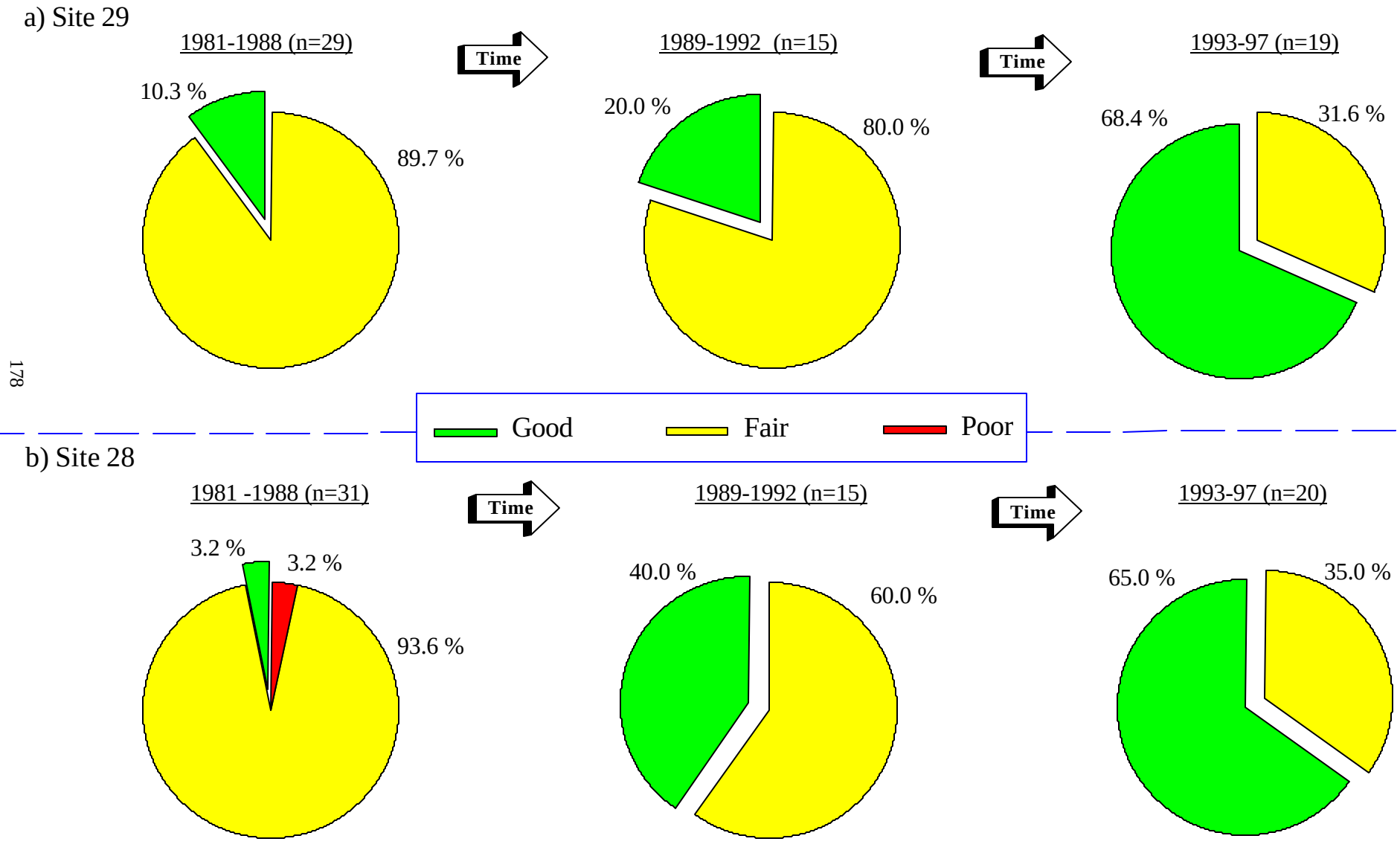


Figure III.75 (Cont.). Total Nitrogen (TN) Concentrations Observed in the C-11 Canal Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified as good. A fair rating was given to concentrations between 1.501 mg/l to 2.500 mg/l. Values greater than 2.500 mg/l are classified as poor.

c) Site 27

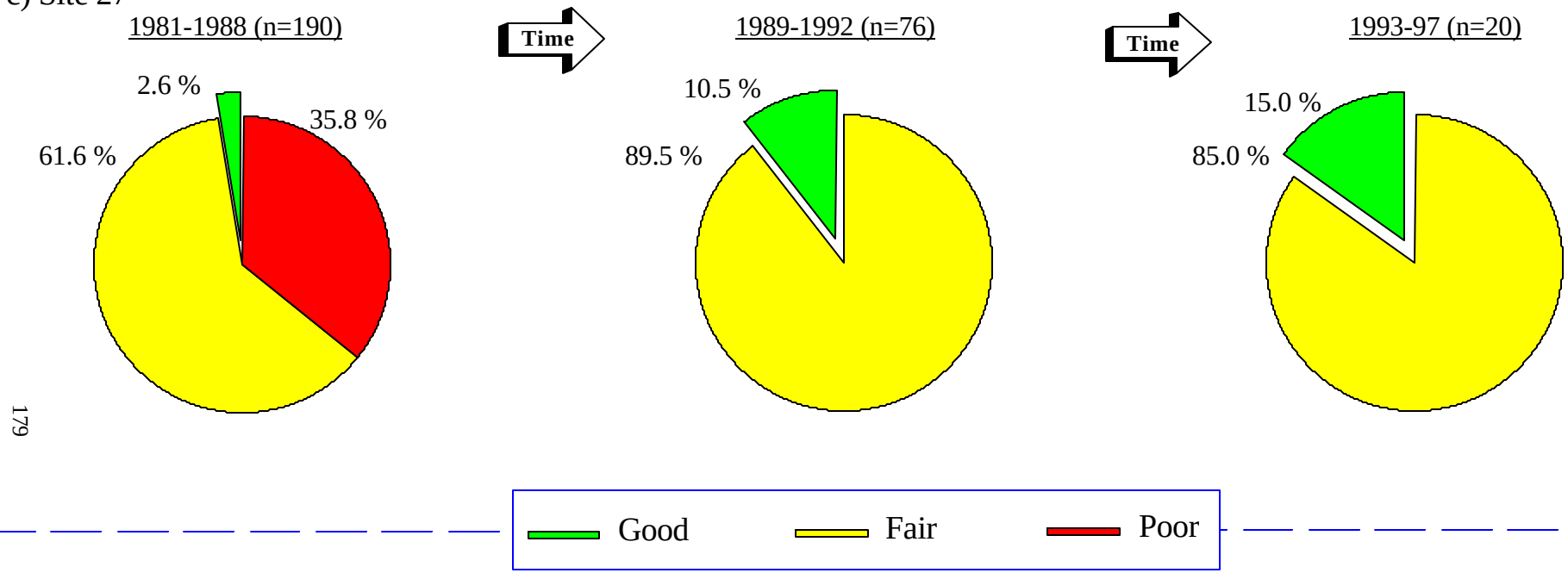
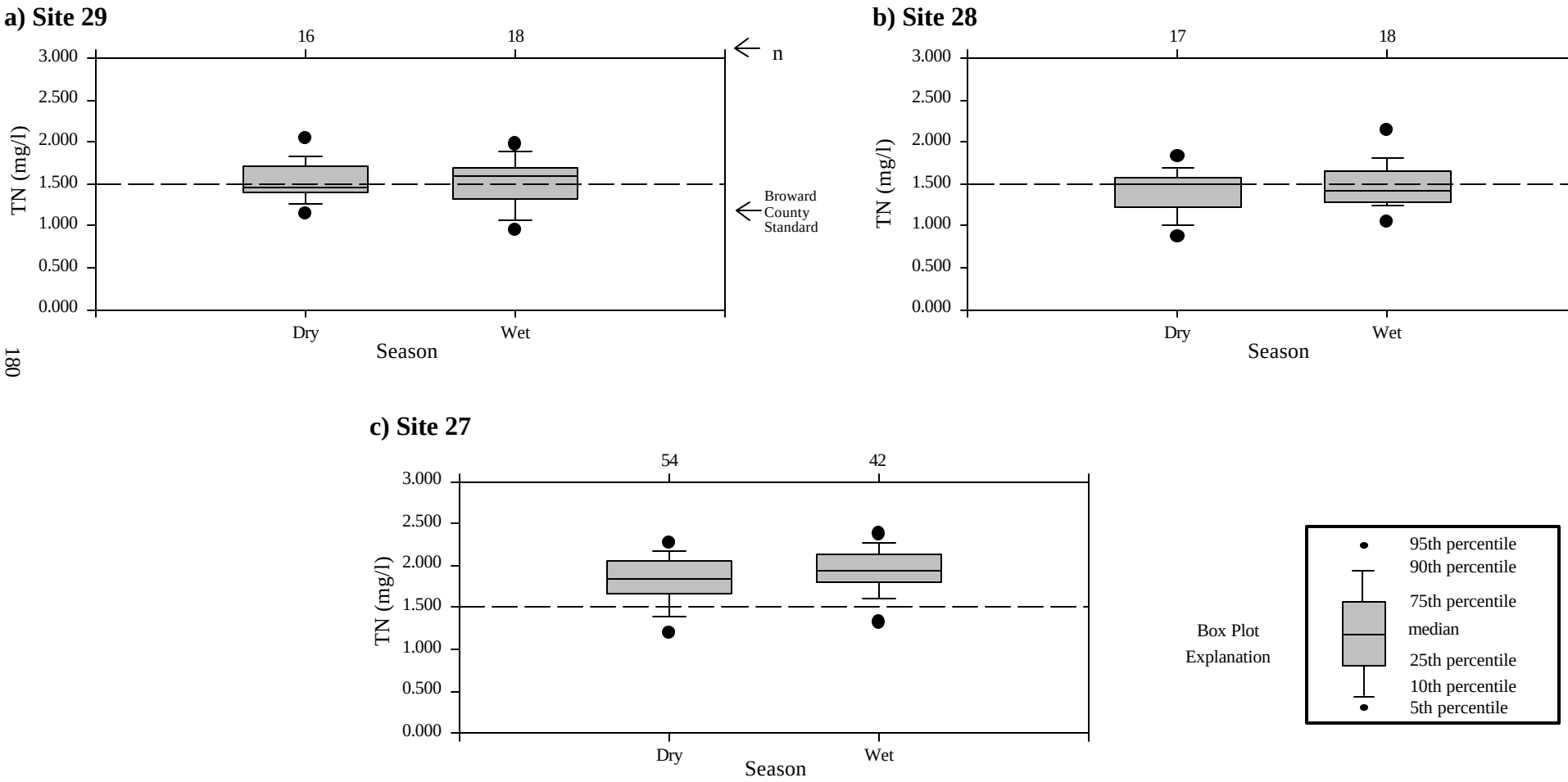


Figure III.76. C-11 Canal Basin Total Nitrogen (TN) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season means and/or medians were not observed at any site. Site 27 (Eastern C-11 Basin) is hydrologically distinct from Sites 28 and 29 (Western C-11 Basin).



f. Bacteriological Parameters

Overall, bacteriological concentrations increased as moving eastward in the C-11 Canal and Site 27 had the highest median FC, TC, and FS values. Mean fecal coliform (FC), total coliform (TC), and fecal streptococcus (FS) were typically higher than medians (Table III.43), however, bacteriological mean values are often skewed by outstanding high values (BCDNRP 1994). High standard deviations and the wide range between maximum and minimum values further illustrate the variability of bacteriological sampling.

Table III.43. Descriptive Statistics for Fecal Coliform (FC), Total Coliform (TC), and Fecal Streptococcus (FS) in C-11 Canal Basin. The number of samples (n) varies between sites. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL) and the unit of measurement is colonies/100 ml (col).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
27	FC	col	368	205	529	1185	12000	5	8
28	FC	col	155	150	334	810	7600	5	3
29	FC	col	141	48	125	209	1300	3	17
27	TC	col	373	830	2753	6928	80000	33	0
28	TC	col	161	630	1319	2406	22000	16.5	4
29	TC	col	147	470	714	904	6000	12	2
27	FS	col	346	300	1323	6129	100000	12	19
28	FS	col	125	270	2214	12075	100000	16.5	6
29	FS	col	116	200	520	989	7600	10	12

Due to the large amount of variability around the mean (Table III.43), yearly box plots were plotted for fecal coliform instead of the mean and standard deviations (Figure III.77). At all sites in the C-11 Canal, the years with the highest fecal coliform content were from 1980 to 1986. In the last ten years (1988-1997) median values were normally below 200 colonies/100 ml at Sites 28 and 29 and below 400 colonies/100 ml at Site 27. Only one annual (1972) median value (Site 28; 1,198 colonies/100 ml) was over the single sample standard of 800 colonies/100 ml.

Compliance patterns within the canal were investigated by comparing all FC values to water quality standards (see Section III.E.5.f). The effect of WWTP closures was looked into by pooling different years of data for the analysis (see Section III.J.3). From 1989-1997, the westernmost Site 29 had very high (94.4%) good ratings while the central (Site 28) and the eastern (Site 27) sites each had around 63.0% samples designated as good (Figure III.78). Site 27 had the most occurrences of poor samples, however, those observations were not typical in the C-11 Canal for any period.

Figure III.77. Yearly Box Plots of Fecal Coliform (FC) Levels within the C-11 Canal Basin from 1972 to 1997. Medians and percentiles calculated from monthly and quarterly samples with the number of samples (n) per year noted on the upper axis. The Broward County single sample standard (800 colonies/100 ml) is indicated by the dashed line. Numbers in parentheses represent 75th percentile values that extend beyond the y-axis scale.

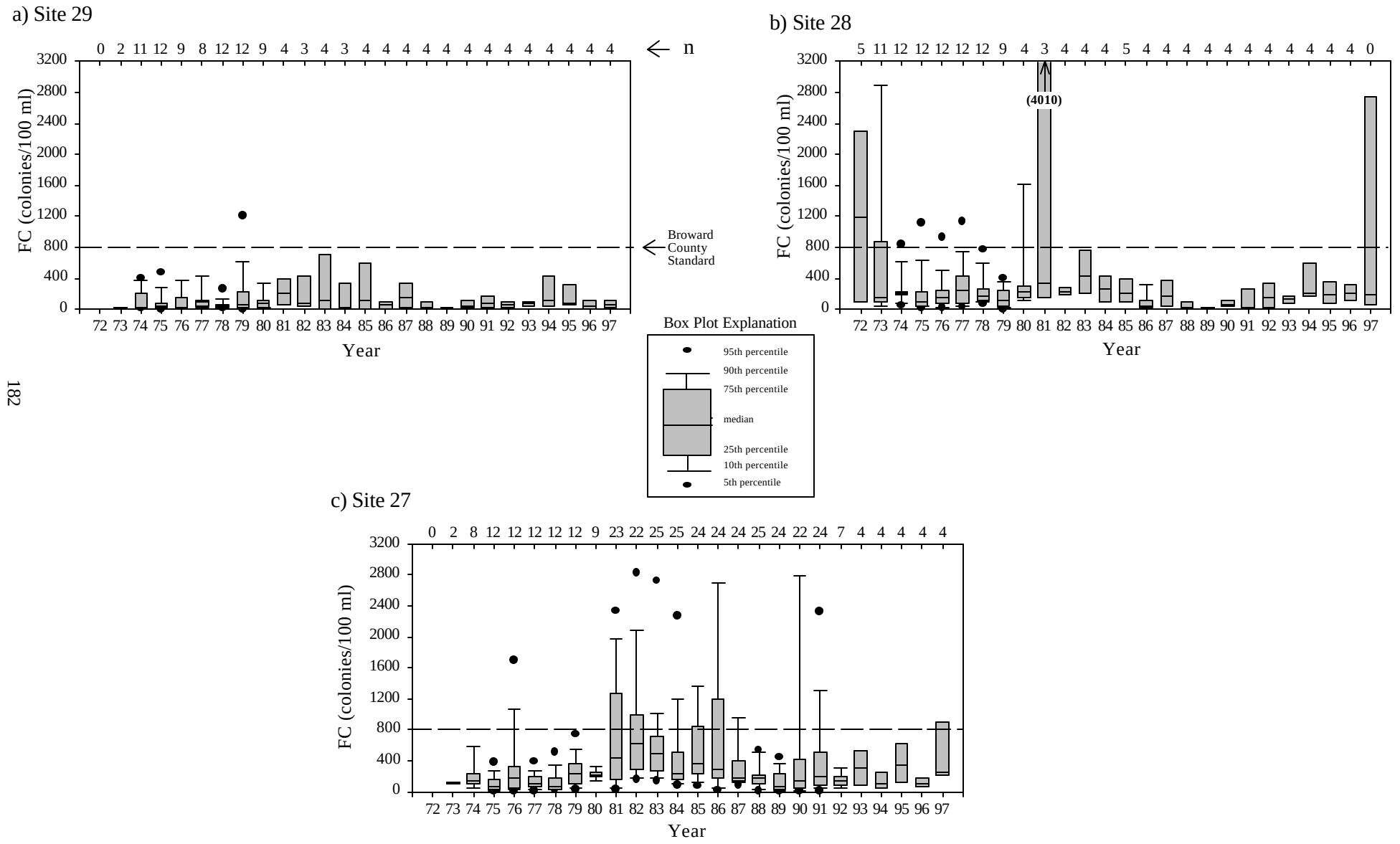


Figure III.78. Fecal Coliform (FC) Concentrations Observed in the C-11 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100 ml (good rating) and no single reading shall be above 800 colonies/100 ml (poor rating). Values between 201 and 800 colonies/100 ml are defined as fair.

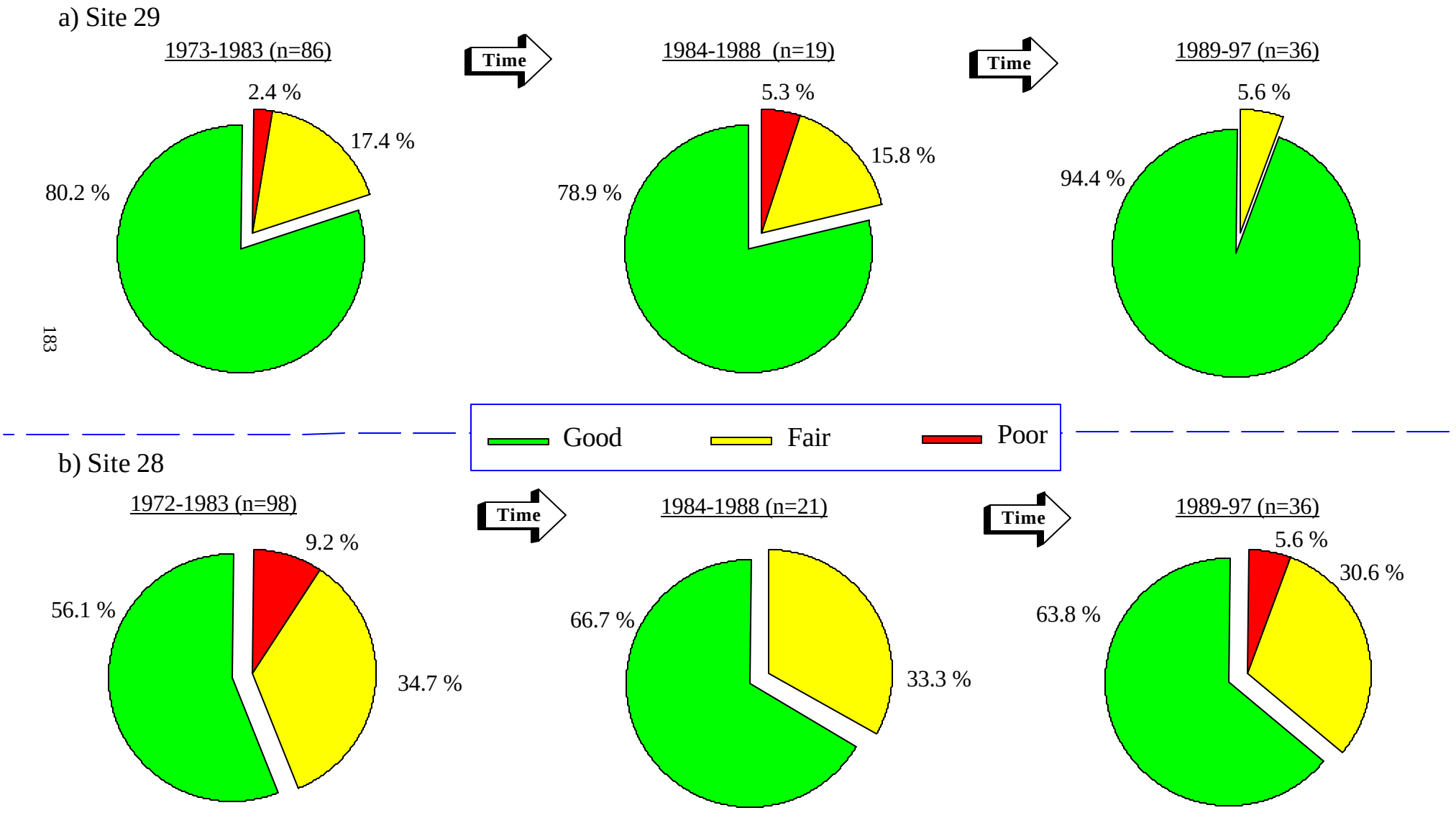
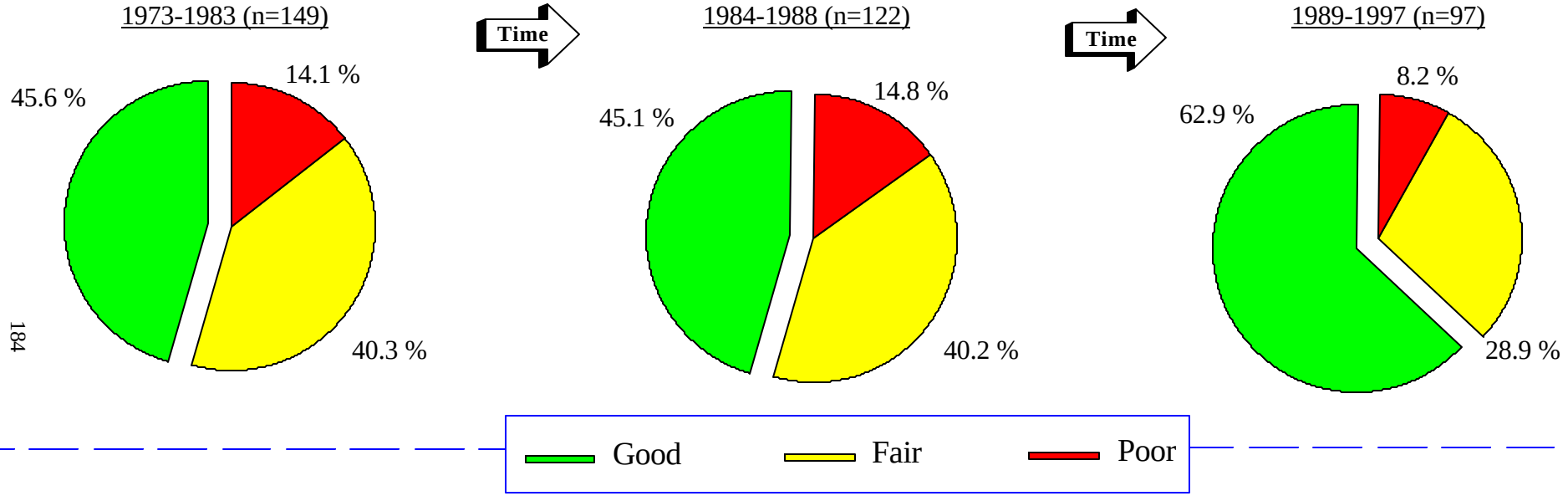


Figure III.78 (Cont.). Fecal Coliform (FC) Concentrations Observed in the C-11 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100 ml (good rating) and no single reading shall be above 800 colonies/100 ml (poor rating). Values between 201 and 800 colonies/100 ml are defined as fair.

c) Site 27



From 1989 thru 1997, wet season median values were higher than dry season values at all sites (Figure III.79). Statistical differences were observed at Site 27 (Mann-Whitney Rank Sum Test; $p < 0.001$) and at Site 29 (Mann-Whitney Rank Sum Test; $p < 0.05$) but not at Site 28. All median values at all sites were at or below 250 colonies/100 ml. Values greater than the single samples standard (800 colonies/100 ml) were rare (95^{th} percentile or higher).

7. Basin Summary

The C-11 Canal is separated into two different water bodies by the S-13A structure. Furthermore, the C-11 Basin is unique, in that, the canal does not typically flow the same direction. The portion of the canal in the western sub-basin normally flows west to the WCA 3 through S-9 and the eastern segment flows east to the Broward estuary via S-13. In this study, two water quality sampling locations (Sites 28 and 29) represent the western sub-basin while one represents the eastern sub-basin (Site 27). The following will discuss the water quality characteristics of the canal's two distinct sections. In addition, the influence of WWTP discharges and seasonal effects will also be discussed. Finally, questions about the canal and basin brought forth by this initial data analysis effort are listed to support future monitoring and resource planning.

a. Influence of WWTP Discharges

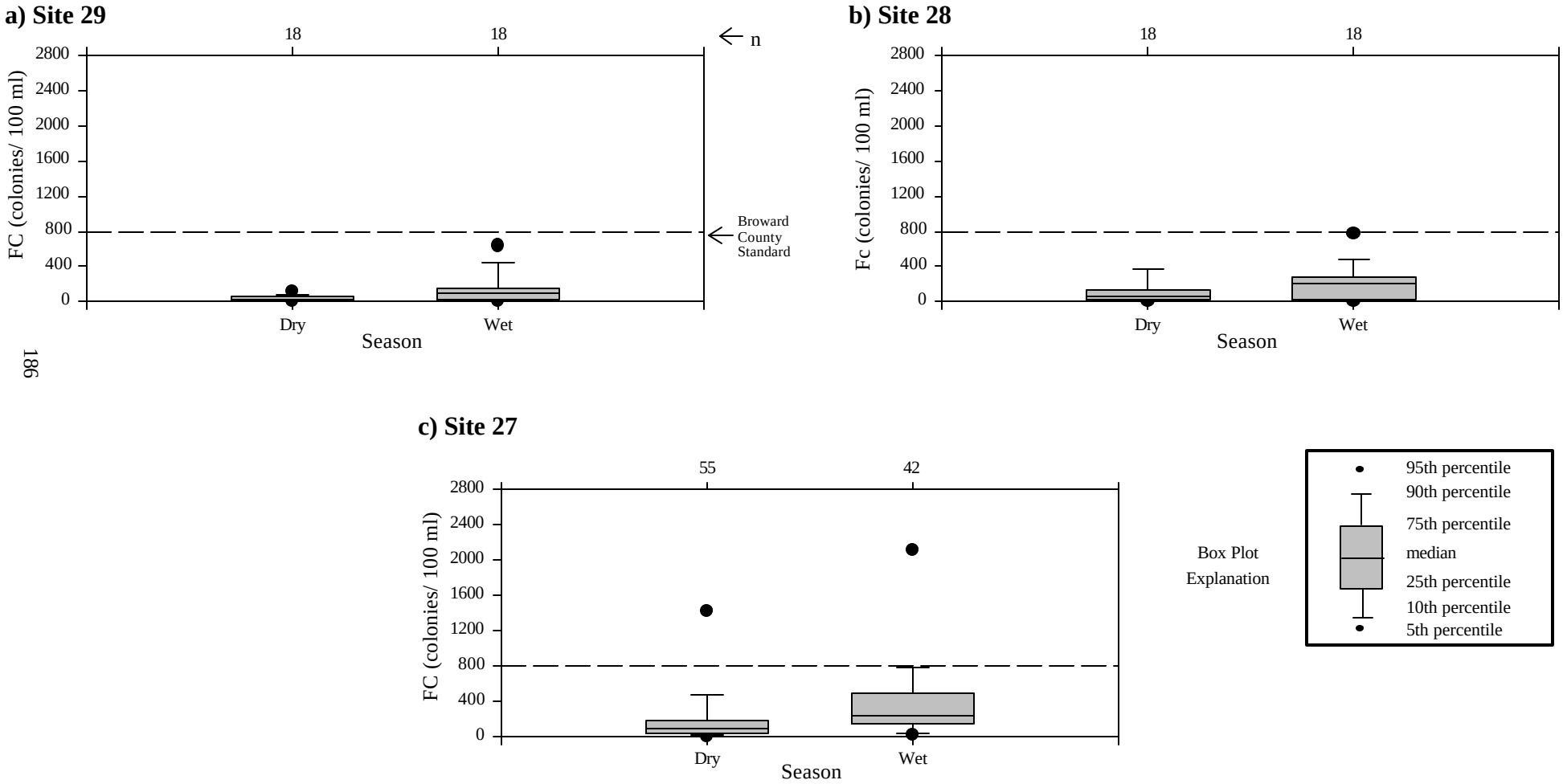
Generally, the end of WWTP discharges signaled the beginning of improved water quality in the eastern sub-basin of C-11 Canal (Site 27). Although Site 27 still has the worst water quality in the canal, TP concentrations have substantially decreased and improvements in TN content were observed after 1988. Furthermore, fecal coliform content also subsided after a few years (1981-1987) of enhanced concentrations during WWTP discharges.

Overall, nutrient levels at Sites 28 and 29 exhibited slight but less notable improvements after WWTP closure than Site 27. Sites 28 and 29 TP levels showed a decrease in compliance achievement from 1984 to 1988. Afterwards (1989-1997), TP compliance increased to levels observed from 1974 to 1983, especially at Site 28. This may reflect a change in WWTP flow rates into the C-11 Canal during 1984 to 1988 due, in part, to population increase. TN values were only monitored since 1981, but both Sites 28 and 29 have generally had lower TN values since 1988.

b. Basinwide Water Quality Characteristics (Post-WWTPs)

In general, Site 27's (eastern sub-basin) water quality has historically been and continues to be much poorer than either Sites 28 and 29 (western sub-basin). Total phosphorus, TN, and bacteriological parameters values were normally higher throughout the entire study period at Site 27 than the western sampling sites. Some parameters, particularly Site 27's TP levels, were considerably different than the western sub-basin's values and compliance levels with water quality standards were lowest at Site 27.

Figure III.79. C-11 Canal Basin Fecal Coliform (FC) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season medians were observed at Site 27 and 29 ($p < 0.001$ and 0.05, respectively; Mann-Whitney Rank Sum test) but not at Site 28. Site 27 (Eastern C-11 Basin) is distinctly separated from Sites 28 and 29 (Western C-11 Basin).



Low (i.e., < 4.0 mg/l) DO content existed throughout the waterway. Although, Site 27's DO concentrations were typically the highest in the C-11 Canal (indicating better water quality), only 43.3% of DO samples were above the compliance level (4.0 mg/l) from 1989-1997. Potentially, Site 27's low DO concentrations are caused by enhanced nutrient loading. Conversely, low DO content in the western sub-basin (Sites 28 and 29) is most likely due to WCA seepage and/or local groundwater influx. DO levels in southwestern Broward County canals (SFWMD 1976, BCDNRP 1996) have been linked with groundwater due to the area's low elevation and seepage characteristics.

While improvements were realized over time, Site 27's nutrient (TN and TP) concentrations are the parameters of most concern. Less than 20% of the time TN and TP values were within standard compliance over the last five years at Site 27. Conversely, TP and TN compliance was, at the minimum, greater than 55% for Sites 28 and 29.

The effect of nutrient levels observed within the C-11 Canal is not well known at this time. Excessive nutrient concentrations can cause ecological imbalances, especially in water column, where phytoplankton (microscopic algae) exist. Phytoplankton populations often form harmful blooms under certain condition, including excessive nutrient. BCDPEP recently (1995) began monitoring chlorophyll a concentrations which is an indicator of phytoplankton biomass. Bloom conditions (> 40 milligrams per meter cubed) have not been observed in the C-11 Canal between 1995 through 1997. Potentially light limitation or grazing pressures by zooplankton exist in the canal but more periodic sampling is needed to better understand nutrient and phytoplankton dynamics.

Beyond intra-canal consequences, the export of nutrients to downstream water bodies occurs when water is pumped beyond the western (S-9) and eastern (S-13) water control structures. The western C-11 Canal water is pumped to Water Conservation Area 3 (Everglades region) while the eastern C-11 water eventually is directed to the Dania Cut-off Canal. In general, the Water Conservation Areas and Everglades (freshwater systems) are less tolerant of nutrient loading than the eastern brackish regions, especially in terms of phosphorus. Thus, water at Site 29, with a relatively small increase in TP content (e.g., 1990-1992), could impact downstream entities relatively more than Site 27's TP concentrations would impact its receiving waters. Due, in part, to the sensitivity of the S-9's tailwaters, the SFWMD (Morban, unpublished data) is currently collecting samples on much higher time and space scales than BCDPEP's ambient network and their results should assist greatly an understanding of the C-11 western sub-basin's nutrient dynamics.

Export of TN may be more important in the eastern sub-basin because that portion of the C-11 discharges into a marine system which are, generally, more nitrogen limited. However, brackish waterways (estuaries) such as the Dania Cut-off Canal are often hard to generalize because of extreme salinity fluctuations. It should be noted that Site 27 had very high NO_2+NO_3-N and NH_3-N (dissolved inorganic nitrogen, DIN) concentrations even after WWTP halted discharges. Phytoplankton typically more readily use DIN than other forms of nitrogen (see Appendix 2). Section IV of this document more fully investigates the water quality in Dania Cut-off Canal and possible impacts from upstream waters.

Overall, differences between the eastern and western sub-basins' hydrology and/or water management practices likely explain contrasts in the C-11's water quality. Due to the relatively long length of the C-11 Canal, localized rainfall levels could also influence sub-basin differences. At the very least, weather patterns undoubtedly account for some of the interannual water quality variability observed over time.

An important sampling design consideration surrounds the location of Site 27 at the eastern border of the eastern basin. This is approximately 4.5 miles east of the S-13A structure, and represents the water quality of C-11 canal water being discharged to the Dania Cut-off Canal. As the canal's endpoint, the site may reflect the integration of all water being drained from the eastern-sub-basin. Alternatively, Site 27's water quality may reflect localized land uses that are atypical of the eastern sub-basin. A closer examination the eastern sub-basin's land use characteristics and water flow dynamics would help determine if Site 27 reflects the entire eastern sub-basin. In addition, this would better determine if water quality differences observed in this study between sub-basins exists throughout the entire C-11 Canal.

c. Seasonal Differences

Wet and dry season differences were mainly observed in DO and FC content. FC levels were statistically higher at Sites 27 and 29 during the wet season. Only Site 27 had statistically significant less DO content during the wet season than the dry. Summertime temperatures influence DO readings, as well as potential runoff of oxygen demanding substances.

Site 27 exhibited the only seasonal difference observed for nutrient levels with higher wet season TP levels than dry season. This likely occurred because of stormwater runoff, including the possibility of groundwater. Much of the eastern sub-basin is on septic tanks and, potentially wet season groundwater elevations would be more conducive to nutrient loading of surface waters. It would appear the western sub-basin nutrient content may be more influenced by longer time scales of rainfall patterns based on the 1990-1992 TP observations as compared to 1993 through 1997. Short term rainfall events also likely occur throughout both basins depending on the amount of rainfall and the amount of time between rainfall events. The current SFWMD (Morban, unpublished) study includes stormwater event sampling.

d. Future Monitoring Questions

One goal of this report is to develop strategic guidelines for future Broward County water quality monitoring and management. To facilitate this, questions generated by this study's findings are being compiled for each drainage basin. For the C-11 Basin and Canal, several questions revolve around nutrient concentrations. First, in the eastern sub-basin (Site 27), consistently high nutrient levels are still being observed even after closure of WWTPs. Secondly, the western sub-basin's downstream destination is the WCAs which are not tolerant of enhanced nutrient loading and thus, C-11 Canal concentrations are critical in understanding localized ecological imbalances.

- Why does Site 27 have elevated nutrient levels and is it reflective of the whole eastern sub-basin ?

- Throughout the canal (but particularly at Site 27) are nutrient concentrations creating a problem in water column biology (e.g., chlorophyll a) and/or macrophytes?

- Are nutrient concentrations from 1993-1997 or from 1990-1992 more reflective of TP levels at Sites 28 and 29?

- At Sites 28 and 29, are the differences in TP content between 1993-1997 versus 1990-1992 due to weather, land-use, water management, or a combination? And if so can those conditions be repeated?

- Are recent increases in DO levels (1995-97) in the western areas (especially Site 29) the result of nutrient inputs not detected by quarterly monitoring (e.g., stormwater inputs) or due to other factors (e.g., water management practices)?

- What is the stormwater quality directly entering the canal and its secondary and tertiary tributaries (note this is currently being addressed by SFWMD in western C-11 Basin)?

- What would be the impacts of reduced seepage water from the WCAs to the C-11 Basin?

K. C-9 Canal

1. Basin and Canal Structure

The C-9 Canal drains a relatively large basin with an area of approximately 98 mi^2 (Figure III.80). The majority of this basin lies within southern Broward County (59 mi^2) and the remainder lies in northern Miami-Dade County (39 mi^2, Cooper and Lane 1987). In addition, the C-9 Basin is split into a western sub-basin (53 mi^2) and an eastern (45 mi^2) sub-basin which overlap the two counties. The total length of the C-9 Canal (approximately 20 miles) is almost evenly divided between the two counties.

The flow in the C-9 Canal is normally to the east with a final discharge into the estuarine Dumfoundling Bay via SFWMD control structure S-29 (Miami-Dade County). Several seepage control canals and structures determine the volume and rate of flow in the waterway. The L-33 Canal is oriented in a north-south direction and makes a connection at the westernmost end of the C-9 Canal (west of US 27). The S-30 is immediately to the east of the confluence of the L-33 and C-9 canals and either allows water to move east or stores it west of the structure. The S-32 is located below the Broward County line and along with S-30 and S-9XS (see C-11 Basin, Section III.J.1) determine the L-33 Canal's stage which, in turn, controls the rate of seepage from WCA 3B (Cooper and Lane 1987).

A small north-south oriented canal, the North Fork of the C-9 Canal (also Flamingo Canal), exists on the west side of Flamingo Road and runs parallel along the roadway until making an open connection to the C-9 Canal (Cooper and Lane 1987). Flow is normally to the south and water originates in portions of the C-11 Basin in Pembroke Pines. Some water may be diverted to the C-8 Canal (Miami-Dade County) by way of a secondary canal along NW 67th Avenue. Beyond the Flamingo Canal, six north-south oriented secondary canals also exist in the western sub-basin.

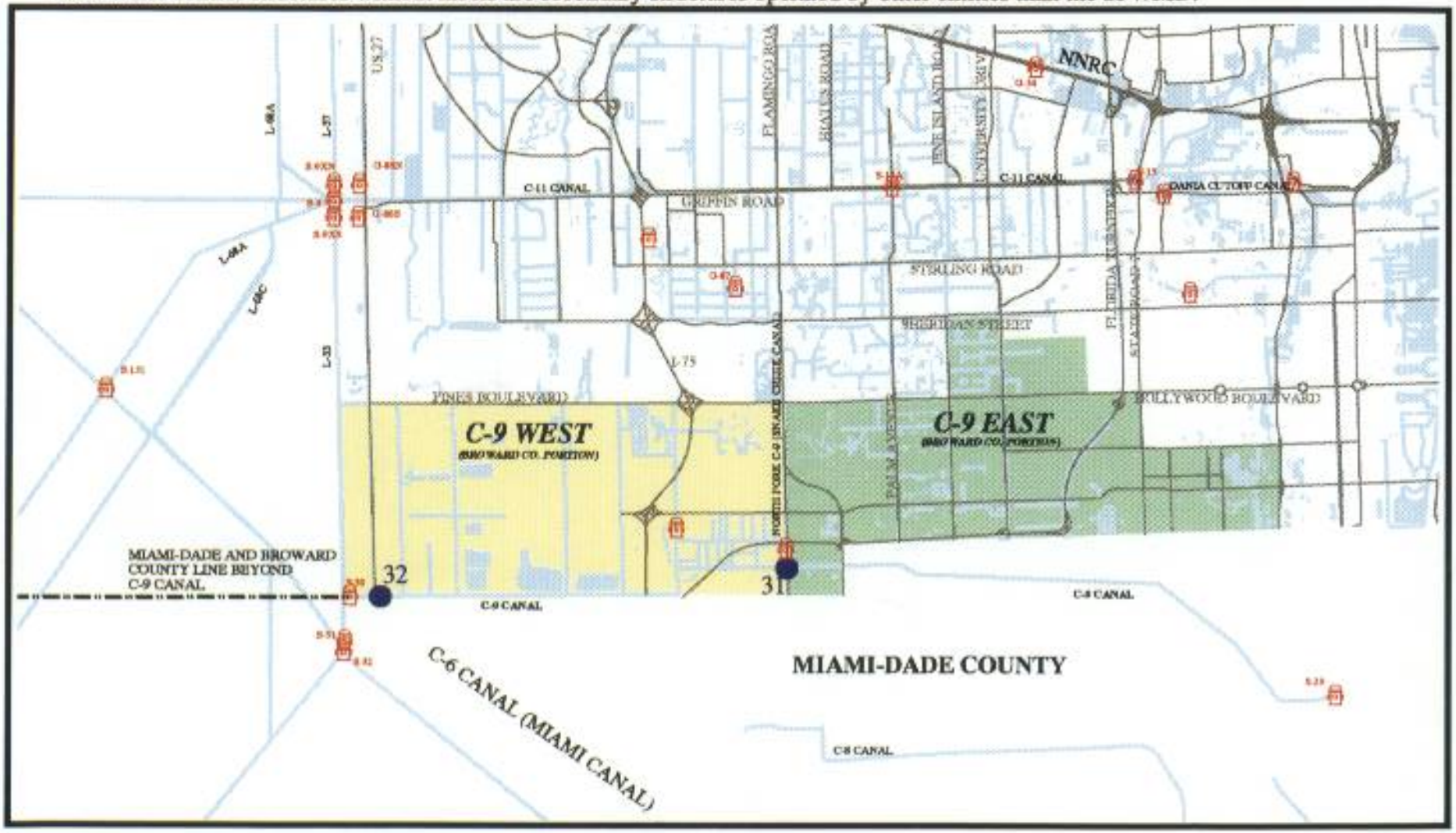
The SFWMD controls the operations of the main canal and structures. Within Broward County, the South Broward Drainage District is the main local management body (see Section I, Figure I.4). Miami-Dade County does not have a system of dependent and independent districts.

2. Municipalities and Land Uses

The western area of the C-9 Basin includes the southwestern edge of the City of Pembroke Pines and the western half of Miramar (see Section I, Figure I.3). The eastern area of the basin includes the remaining half of Miramar and the entire city of Pembroke Park. During the 1970s, the C-9 Basin was much less populated than other areas of the county. The population of Pembroke Park increased from approximately 3,000 residents in 1970 to just over 5,000 residents in the late 1970s. During the same period, Miramar's population also increased from 24,000 residents to over 30,000 residents.

During this time, the land was dominated by open land (58%). Another large portion of the land was designated for agricultural uses (21%), which include improved pasture and plant nurseries in addition to cultivated crops. Approximately 15% of the basin was low density residential, and less than 5% of

Figure III.80. The C-9 Canal Basin and Broward County (BCDPEP) Sampling Site Location Map. The C-9 Canal and other major waterbodies with corresponding South Florida Water Management District (SFWMD) water control structures (labeled) are depicted. Note water control structures without labels are secondary structures operated by other entities than the SFWMD.



BCDPEP Water Quality Sampling Site

Water Control Structures (primarily SFWMD)

Waterbodies

Major Roadways

0 1 2 3 Miles

N W E S

This map is for informational purposes only. For further information, please contact BCDPEP Water Resources Division (954) 519-1270.

the land was used for commercial or industrial purposes (Broward County Planning Council 1977). The lack of urban and residential development is likely due to the flooding hazard in the area caused by low elevation and poor soil drainage.

Rapid growth in this basin did not occur until the late 1980s and early 1990s. The City of Pembroke Pines had some of the fastest growth in the county going from 53,706 residents in 1987 to 101,307 by 1995 (Broward County Planning Council 1995). Growth in Miramar also continued during this time as well. By 1987, the city's population had increased to over 37,000 people, and by 1995, the population had reached 45,000 residents (Broward County Planning Council 1995). By the late 1980s, the population of Pembroke Park had increased to just over 6,000 residents and by 1995, the population decreased slightly to approximately 5,600 residents.
The predominant land use along the C-9 canal has remained undeveloped rangeland. While the land use has not changed much since 1982 in the Miami-Dade County portion of the C-9 Canal Basin (FDER; cited in South Regional Planning Council 1990), a rapid expansion of residential and commercial development into southwestern Broward has occurred. Agricultural and undeveloped land remained the primary land use in the basin in 1988 (BCDNRP 1996). However, from 1989 to 1995, the City of Miramar experienced a significant decline in undeveloped land acreage. In 1989, undeveloped land comprised approximately 70% of the 19,600 total city acres and had decreased to 60% of the city's acreage by 1995. Residential land use increased by approximately 12%, while commercial and industrial land use remained at 3%. Furthermore, rock pit acreage in Miramar has almost doubled from 680 acres in 1989 to 1,221 acres in 1995 (Broward County Planning Council 1995).

Pembroke Park residential land use comprised less than half of the city in the late 1980s and did not increase from 1989 to 1995. During this period, there was some fluctuation in commercial, industrial and undeveloped land uses. By 1989, commercial and industrial land uses comprised approximately 48% of the city's land area, while by 1995 it had decreased to 25% of the area. However, undeveloped land in 1989 comprised only 3% and increased to 24% of the city's land area by 1995 (Broward County Planning Council 1995).

3. Wastewater Treatment Plants Discharge History

The City of Miramar operated the main wastewater treatment plant (WWTP) discharging into the C-9 Canal. The city halted an average daily flow of 2.53 million gallons per day (mgd) by 1978. The Hollywood Country Club WWTP (< 0.02 mgd) discharged to North Fork of the C-9 canal (also known as the Flamingo Canal) and then to the C-11 Canal (BCEQCB 1982) until 1988 (BCEQCB 1988). As this waterway can also discharge into the primary C-9 Canal (Cooper and Lane 1987), the Hollywood Country Club WWTP potentially influenced both C-9 and C-11 canals. However, the volume of wastewater (< 0.02 mgd) was low compared to most WWTPs that operated at that time throughout the county.

4. Other Influences on Water Quality

a. Soils

In the western portion of the C-9 Basin, primarily west of Flamingo Road, the soil association consists entirely of poorly drained, moderately deep peats and mucks (see Section I, Figure I.5) overlying marl and sand (Reynolds, Smith and Hills Inc. 1972). The drainage of this area is poor due both to the soil type and because the Biscayne Aquifer is close to the surface in this region (South Florida Regional Planning Council 1990). The east C-9 Basin consists of poorly drained deep sandy soils and excessively-drained sandy soils near the urbanized areas of the coast (Reynolds, Smith and Hills Inc. 1972).

b. Roadways

The western extent (approximately 5 miles) of the C-9 Canal only has one major roadway (US Highway 27) that crosses the waterway. Conversely the central portion of the western C-9 Basin has two major highway (Interstate 75 and Florida Turnpike) bridges, as well as Flamingo and Red Road bridges. However, in the Broward County section, major east-west roads do not run immediately adjacent to the canal. Once the canal enters Miami-Dade County, the typical array of South Florida urban roadways exists.

c. Septic Tanks

Both C-9 sub-basins are characterized by large areas of no sewer service based on a 1993 survey (see http://www.broward.org/moi00600.htm). However, these basins, similar to the Western C-11 Basin have experienced the most rapid development over the last five years and new sewer infrastructure exists. At the time of this writing, an updated analysis of septic tank coverage county-wide had not been performed. Most of the Broward portion of the shoreline is either characterized by rangeland and/or low residential development, thus the number of septic tanks along the waterway is likely low. The Dade County sewer coverage was not determined for this study.

d. Miami-Dade County Landfill

An additional potential pollution source for the C-9 Canal is the North Miami Dade County municipal landfill located at the Broward and Miami-Dade County border (BCDNRP 1996). The Metropolitan Miami Dade County Department of Solid Waste Management and Department of Environmental Resources Management currently monitor any potential impacts to groundwater and surface water in this region.

5. Sampling Locations and Period

Two sampling locations exist for the C-9 Canal - Sites 31 and 32. Site 31 is at the Flamingo Road Bridge west of the Dade County border. Site 32 is located at the US Highway 27 bridge, immediately

east of the S-30. Sampling years for each specific parameter are shown in Table III.44. Appendix 1 details the geographical information for each site.

Table III.44. Sampling Years for Specific Parameters at the C-9 Canal Locations. A sampling year had at least one sample event during that year. Note the biochemical oxygen demand was a five-day test from 1973 until 1981 when a seven-day test was implemented until 1993 after which sampling for the parameter ceased at BCDPEP.

Parameter	Site 31	Site 32
Temperature	73-97	73-97
pH	73-97	73-97
Specific Conductance	81-97	81-97
Dissolved Oxygen	73-97	73-97
Biological Oxygen Demand	73-93	74-93
Total Organic Carbon	81-97	81-97
Turbidity	75-97	75-97
Total Phosphorus	74-97	74-97
Ammonia-Nitrogen	81-97	81-97
Nitrite+Nitrate-Nitrogen	81-97	81-97
Total Kjeldahl Nitrogen	81-97	81-97
Fecal Coliform	73-97	73-97
Total Coliform	73-97	73-97
Fecal Streptoccocus	76-97	76-97

6. Results

a. Physical Characteristics

At or near 25.0EC, median and mean water temperatures were almost identical for both C-9 monitoring locations sites (Table III.45). Mean and median pH recordings were nearly the same being around 7.3 to 7.4. Specific conductance readings at Sites 31 and 32 also reflected similar water masses.

Table III.45. Descriptive Statistics for Temperature (Temp;ºC= degrees Celsius), pH, Specific Conductance (Cond; Fmhos = micromhos/centimeter @ 25ºC), and Salinity (Sal; ppt= parts per thousand) in the C-9 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. Number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
31	Temp	ºC	148	25.0	25.1	2.6	30.0	18.0	0
32	Temp	ºC	152	25.0	25.2	2.5	30.0	17.2	0
31	pH	units	153	7.4	7.4	0.3	8.2	6.2	0
32	pH	units	152	7.4	7.3	0.3	8.2	6.0	0
31	Cond	Fmhos	66	699	693	75	900	480	0
32	Cond	Fmhos	66	724	719	64	862	500	0

b. Total Organic Carbon and Turbidity

Site 32 was characterized by mean and median total organic carbon values of 23.4 ± 5.6 mg/l and 24.0 mg/l, respectively (Table III.46). Observations at Site 31 were slightly lower with a mean of 21.5 ± 3.70 mg/l and median equal to 22.25 mg/l. Both median and mean turbidity levels were similar at both sites and well within compliance of water quality standards.

Table III.46. Descriptive Statistics for Total Organic Carbon (TOC) Concentrations and Turbidity (Turb) Levels in the C-9 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
31	TOC	mg/l	60	22.25	21.52	3.70	32.20	14.00	0
32	TOC	mg/l	59	23.90	23.40	5.56	49.60	13.60	0
31	Turb	ntu	126	2.2	2.5	1.8	17.0	0.6	0
32	Turb	ntu	126	1.0	1.2	1.2	13.0	0.25	8

c. Dissolved Oxygen and Biochemical Oxygen Demand

The C-9 Canal dissolved oxygen (DO) concentrations were low (< 3.0 mg/l) but especially so at Site 32 where values were below 2.0 mg/l (Table III.47). Despite the low DO observations, biochemical oxygen demand levels were also low (1.0 mg/l) and well within compliance of the 5.0 mg/l standard.

Table III.47. Descriptive Statistics for Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) Concentrations in the C-9 Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculations. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
31	DO	mg/l	153	2.5	2.8	1.7	7.1	0.2	0
32	DO	mg/l	153	1.0	1.5	1.3	7.1	0.05	4
31	BOD	mg/l	125	1.0	1.3	0.6	3.4	0.4	0
32	BOD	mg/l	120	1.3	1.5	1.0	7.0	0.2	0

With the exception of the early 1970's, yearly DO averages were always below 4.0 mg/l at Sites 31 and 32 (Figure III.81). Site 32 was characterized by extremely low (< 1.0 mg/l) values during most of the study period, including post-WWTPs. Annual averages were closer to 3.0 mg/l at Site 31.

To better understand compliance patterns within the canal, individual DO observations were rated in relation to Broward County's water quality standards (see Section III.E.6.c). In addition, the influence of WWTP discharges were investigated by separating data into different periods (see Section III.K.3). The compliance levels were extremely low throughout the basin with poor rated samples typically over 85% at Site 31 and over 90% at Site 32 (Figure III.82). Site 31 did have an early period (1973-1978) with only 57.6% poor rated samples and 22.7% of observations ranked good.

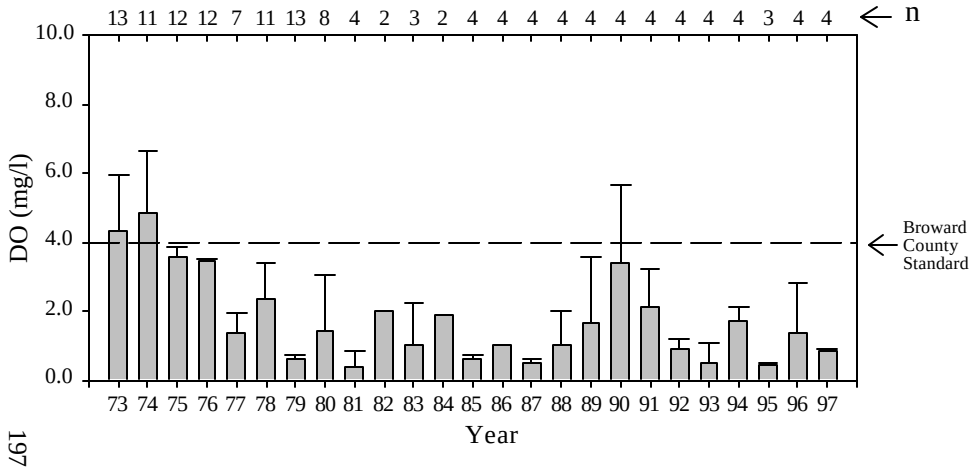
From 1989 to 1997, almost all dissolved oxygen readings were below the 4.0 mg/l single sample standard and no statistically significant seasonal differences were observed between wet and dry season data (Figure III.83). Median values at Site 32 were particularly low (less than or equal to 1.0 mg/l) in both seasons.

d. Total Phosphorus

Total phosphorus was typically not detected in the C-9 Canal Basin with method detection limits ranging from 0.020 to 0.026 mg/l (Table III.48). In fact, 61.8% and 70.5% of all observations were below detection limits at Site 31 and 32, respectively. Mean values were similar and above the MDL but were most likely caused by the unusual high maximum values at both Site 31 and 32.

Figure III.81. Annual Mean Dissolved Oxygen Content Within the C-9 Canal Basin from 1973 to 1997. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. DO concentrations should be above the Broward County standard (4.0 mg/l) indicated by the dashed line.

a) Site 32



b) Site 31

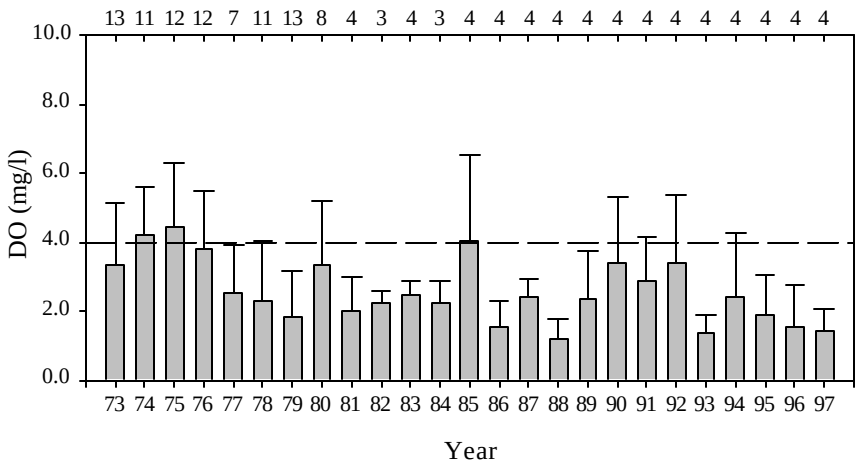


Figure III.82 . Dissolved Oxygen (DO) Concentrations Observed in the C-9 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall be below 4.0 mg/l. All concentrations greater than or equal to 5.0 mg/l are classified as good and DO concentrations between 4.0 to 4.9 mg/l are considered fair. Readings below 4.0 mg/l are defined as poor.

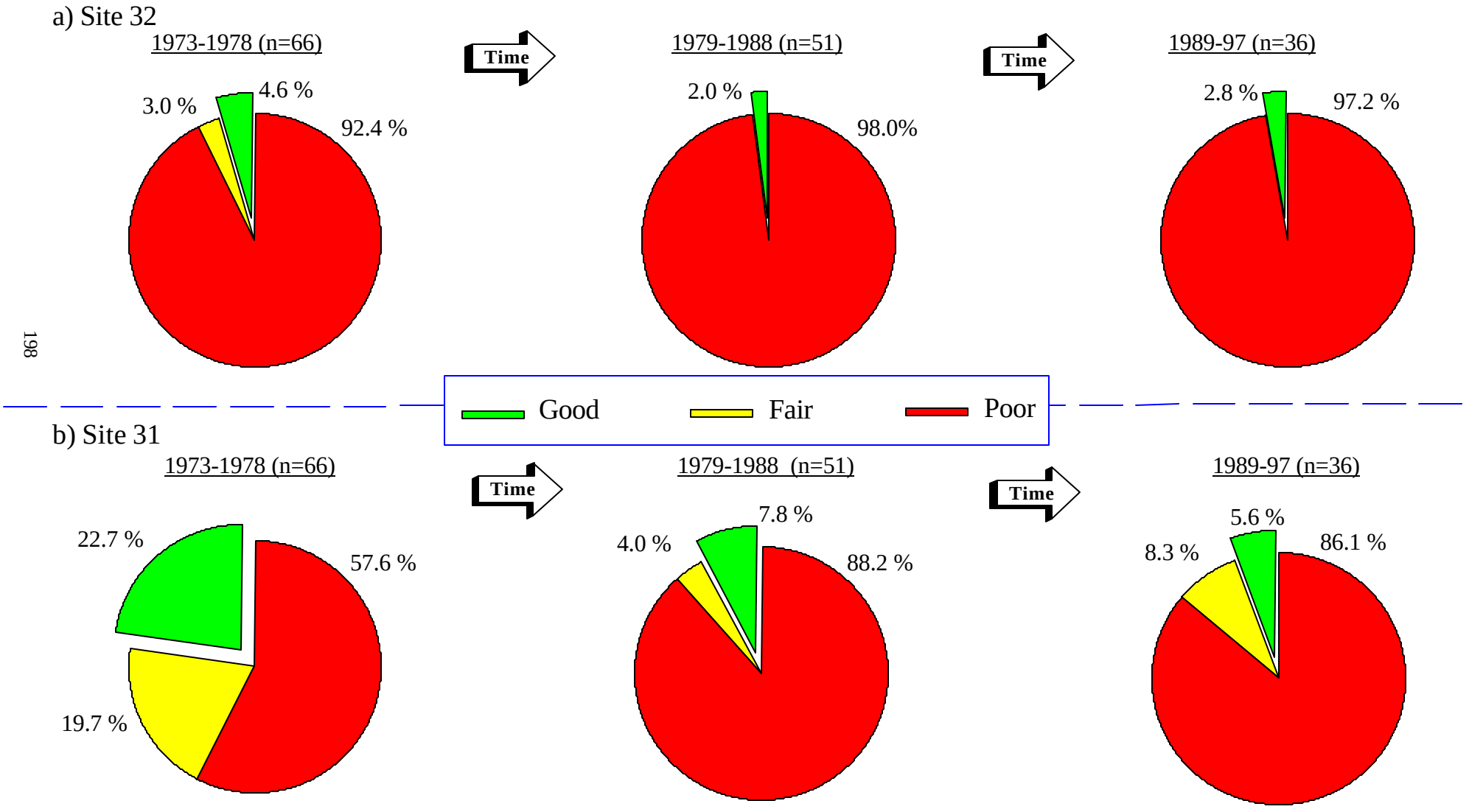


Figure III.83. C-9 Canal Basin Dissolved Oxygen (DO) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season means and/or medians were not observed at either site.

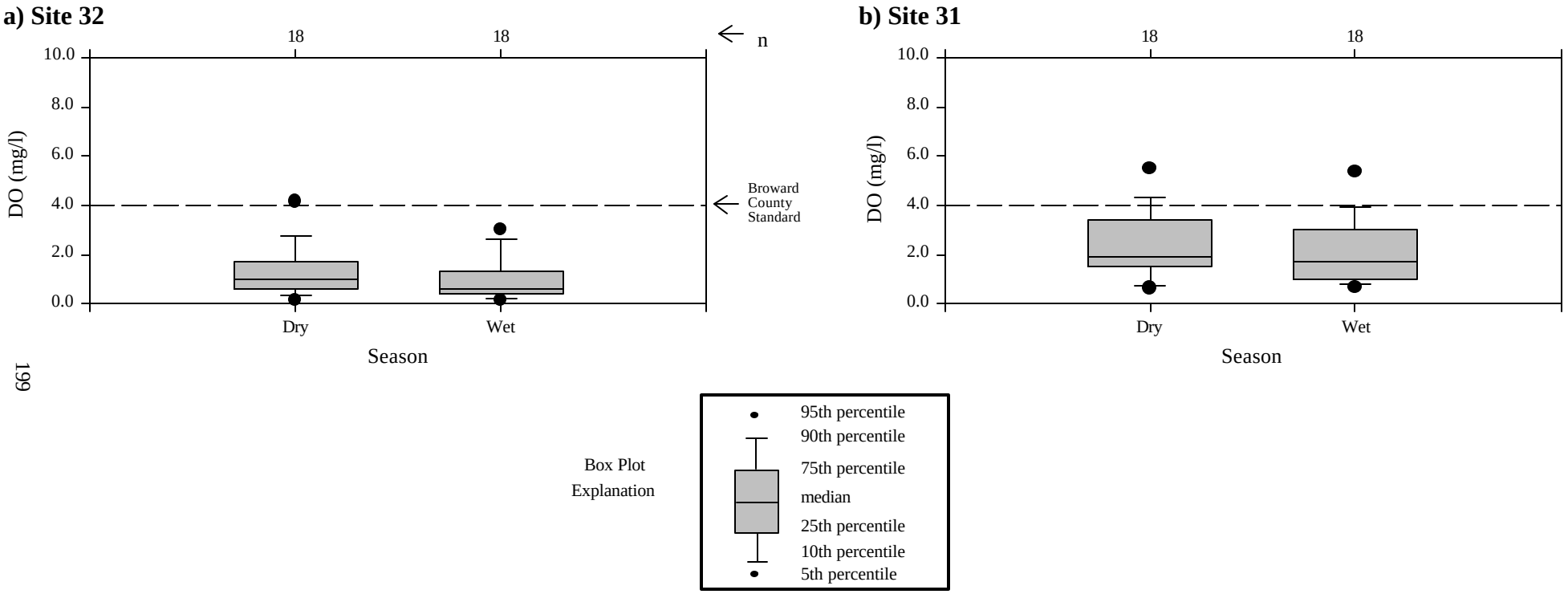


Table III.48. Descriptive Statistics for Total Phosphorus (TP) Concentrations in the C-9 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculations. The number of samples below the method detection limit is shown in the last column (# MDL).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
31	TP	mg/l	131	0.010	0.036	0.145	1.630	0.010	81
32	TP	mg/l	129	0.010	0.032	0.121	1.310	0.010	91

Annual TP concentrations were normally below the 0.020 mg/l with occasional exceptions (Figure III.84). An interesting period of high (relative to the basin) TP values were observed from 1989-1993 at both sites though more readily at Site 32. However, most years with values greater than 0.020 mg/l were characterized by large standard deviations typically caused by one enhanced TP sample (data not shown).

To better observe compliance patterns within the canal, all individual samples were rated in terms of Broward County's TP standard (0.020 mg/l; see Section III.E.5.d). In addition, changes over time were presented with special reference to the closing of WWTPs within the basin (see Section III.K.3). At least two thirds of all samples were within compliance of the 0.020 mg/l standard (i.e., good samples) at both sites (Figure III.85). However, a slight decrease (approximately 15.0%) was seen in the good designated samples over time. Nonetheless, poor rated samples were relatively rare (< 10.0%).

From 1989-97, statistical differences were not observed between wet and dry season mean or median TP values (Figure III.86). At Sites 31 and 32, median values for both seasons were below the 0.020 mg/l standard and 75th percentiles were typically around 0.040 mg/l.

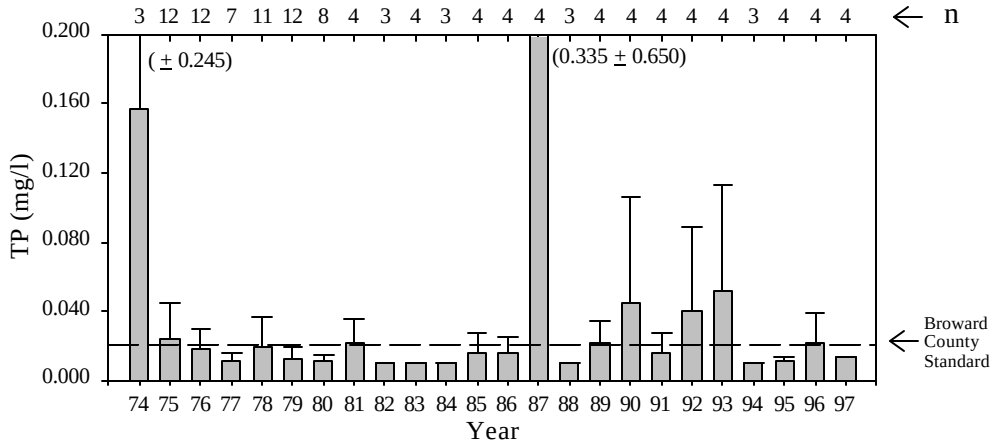
e. Total Nitrogen

Total nitrogen (TN) levels were calculated from the total Kjeldahl nitrogen (TKN) and nitrite+nitrate-nitrogen (NO_2+NO_3) concentrations. Ranging from 1.300 to 1.350 mg/l, mean and median TN values over the seventeen-year period were very similar at Sites 31 and 32 and were within compliance of the 1.500 mg/l standard (Table III.49).

Typically, the vast majority of the TN (> 97%) was comprised of TKN which measures the total amount of organic nitrogen and ammonia-nitrogen (NH_3; Table III.49). Ammonia-nitrogen levels at both locales were relatively enhanced (> 0.200 mg/l, Table III.49). Conversely, median and mean NO_2+NO_3 values were highest at Site 31 while approximately 50.0% of observations were below the MDL at Site 32.

Figure III.84. Annual Mean Total Phosphorus (TP) Levels Within the C-9 Canal Basin from 1974 to 1997. Means and standard deviations (sd; error bars) calculated from monthly and/or quarterly samples with the number of samples (n) noted on the upper x-axis. The Broward County freshwater standard (0.020 mg/l) is indicated by the dashed line. Values in parentheses indicate means and standard deviations above the y-axis.

a) Site 32



b) Site 31

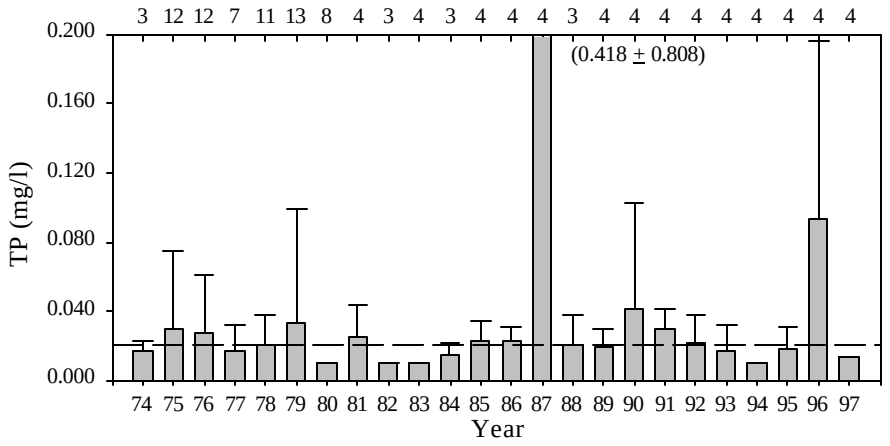


Figure III.85. Total Phosphorus (TP) Concentrations Observed in the C-9 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County freshwater TP standard of 0.020 mg/l. The percentage of samples below 0.020 mg/l are classified as good. A fair rating was given to concentrations between 0.021 mg/l to 0.060 mg/l. Values greater than three times the standard (i.e., 0.060 mg/l) are classified as poor.

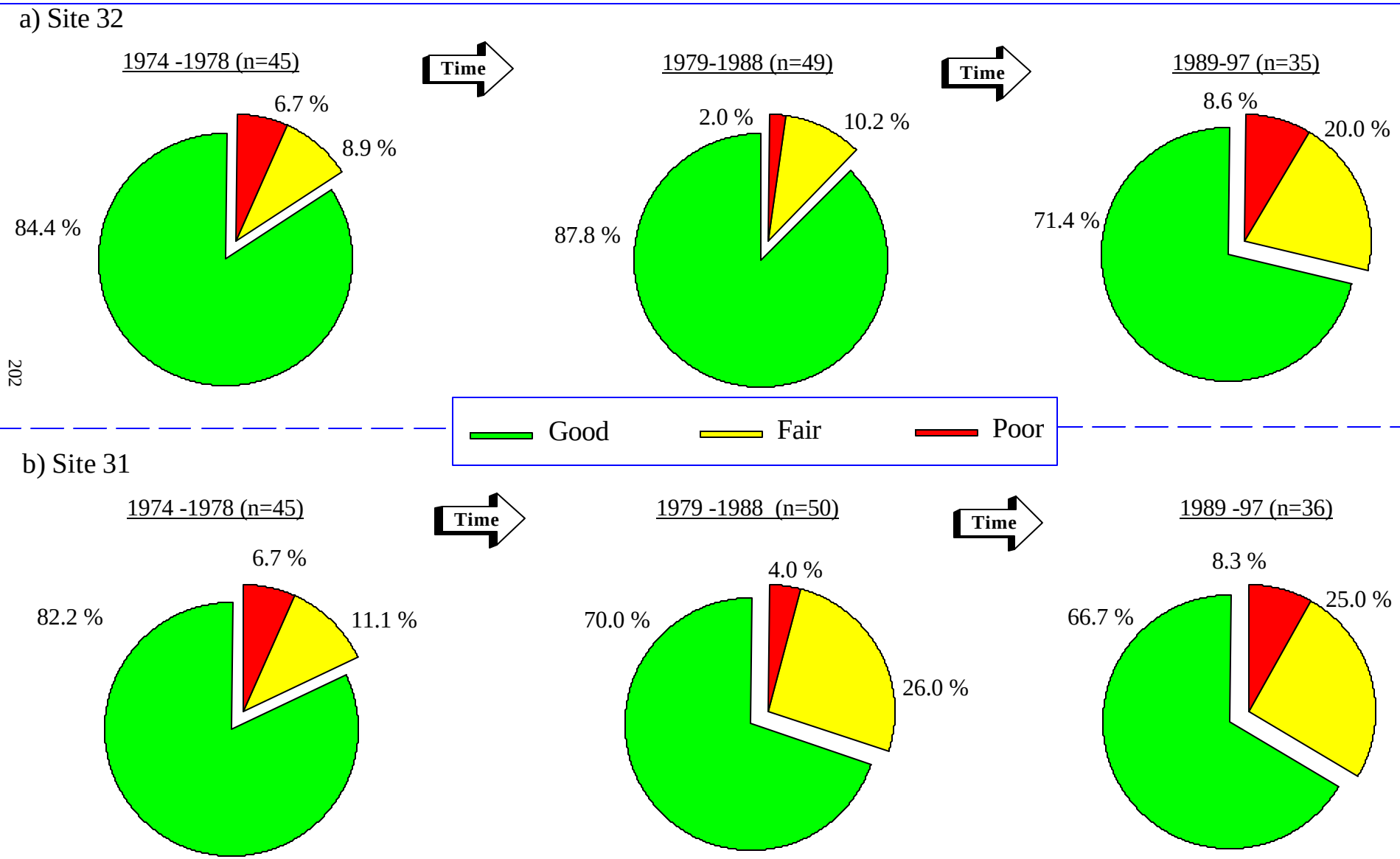


Figure III.86. C-9 Canal Basin Total Phosphorus (TP) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season means and/or medians were not observed at either site.

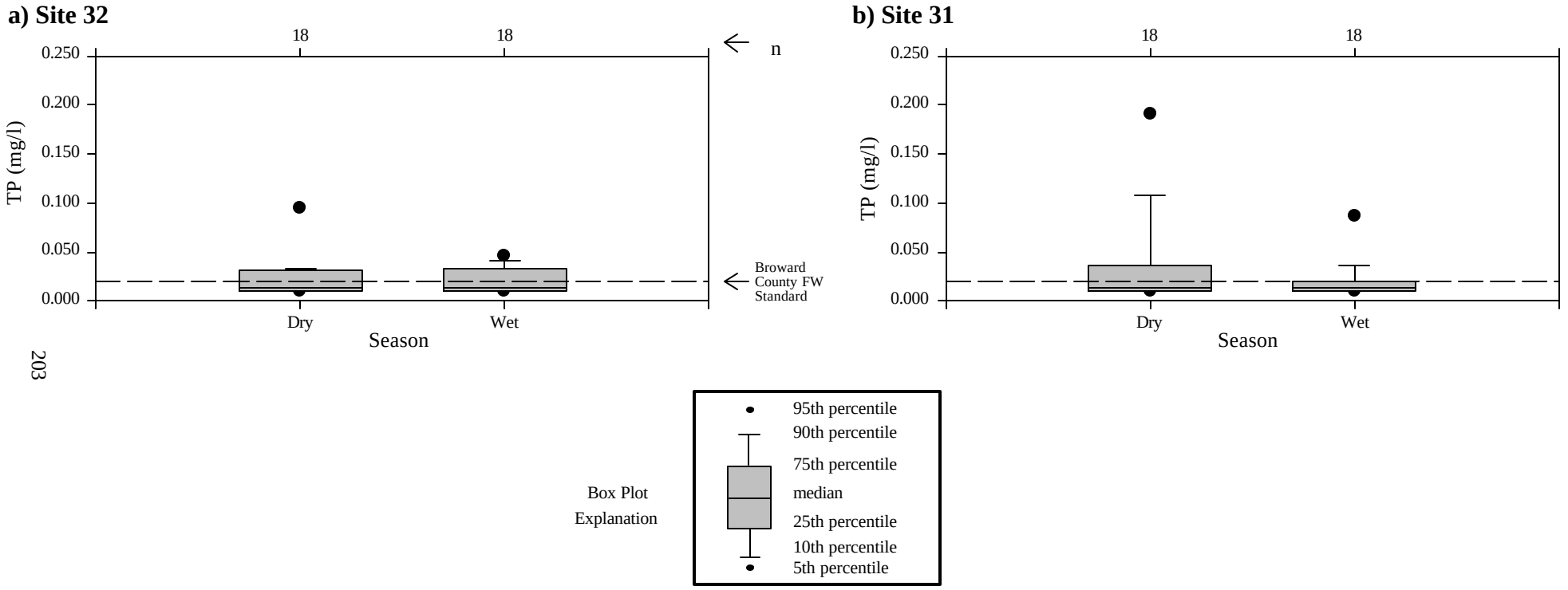


Table III.49. Descriptive Statistics for Nitrite+Nitrate-Nitrogen (NO_2+NO_3), Ammonia-Nitrogen (NH_3), Total Kjeldahl Nitrogen (TKN) , and Total Nitrogen (TN) Concentrations in the C-9 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the MDL is shown in the last column (# MDL). Total nitrogen was calculated as the sum of TKN and NO_2+NO_3.

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
31	NO_2+NO_3	mg/l	66	0.054	0.071	0.065	0.372	0.005	4
32	NO_2+NO_3	mg/l	65	0.009	0.023	0.042	0.244	0.005	39
31	NH_3	mg/l	61	0.228	0.229	0.109	0.566	0.018	1
32	NH_3	mg/l	60	0.219	0.216	0.097	0.573	0.005	3
31	TKN	mg/l	64	1.305	1.286	0.262	1.940	0.649	0
32	TKN	mg/l	63	1.290	1.300	0.259	1.950	0.676	0
31	TN	mg/l	64	1.340	1.354	0.281	2.160	0.690	N/A
32	TN	mg/l	63	1.300	1.325	0.265	1.970	0.700	N/A

Annual TN values generally decreased below (i.e., within compliance) the 1.500 mg/l standard after 1987 at Site 31 and remained fairly similar through the late 1980s and 1990s (Figure III.87). This pattern occurred to a lesser extent at Site 32, primarily because of two slightly elevated annual means in 1992 and 1993.

Each TN sample was given a rating based on Broward County's water quality standards (see Section III.E.5.e). Patterns through time were investigated with the closing of WWTPs within the basin (see Section III.K.3). Basinwide, TN compliance was very good, particularly after 1988 (Figure III.88). This pattern was most evident at Site 31. Fair rated samples decreased to at least 15.0% by 1993 through 1997.

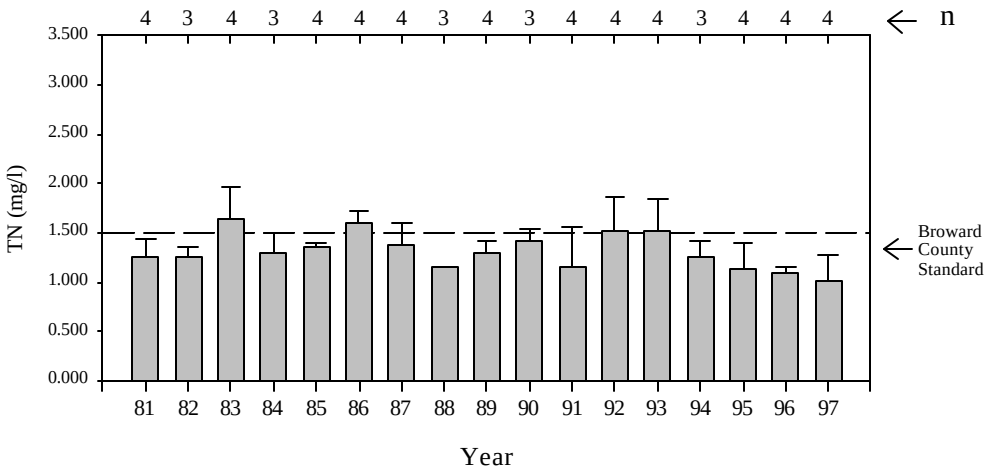
Between 1989-1997, statistical differences were not observed between mean and/or median wet and dry season total nitrogen content at any site (Figure III.89). More importantly, nearly all values were within Broward County's compliance standard (i.e., 1.500 mg/l).

f. Bacteriological Parameters

Bacteriological parameters measured from 1981-1997 included fecal coliform (FC), total coliform (TC), and fecal streptococcus (FS; Table III.50). Mean values were higher than medians, however, bacteriological mean values are often skewed by outstanding high values (BCDNRP 1994). Interestingly, even mean bacteriological values were relatively low to other basins in the county and within county single sample standards. Median values further showed the low ambient bacteria content in the waterway.

Figure III.87. Annual Mean Total Nitrogen (TN) Levels Within the C-9 Canal Basin from 1981 to 1997. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. The Broward County standard (1.500 mg/l) is indicated by the dashed line.

a) Site 32



b) Site 31

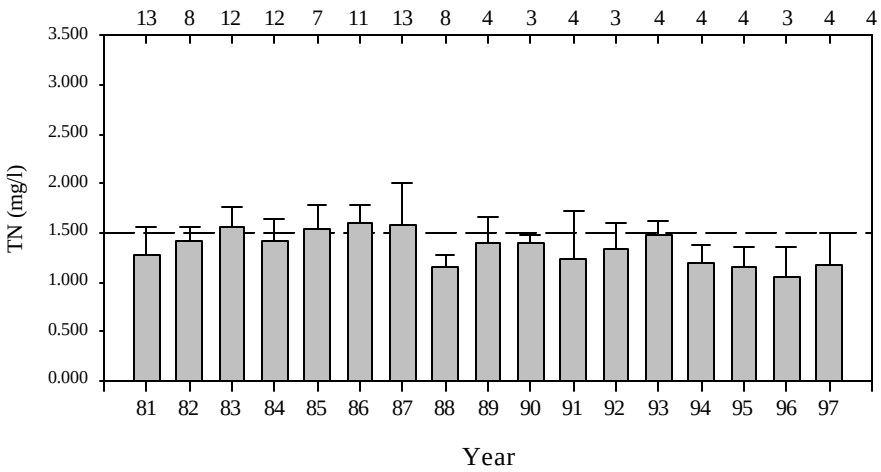


Figure III.88. Total Nitrogen (TN) Concentrations Observed in the C-9 Canal Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified as good. A fair rating was given to concentrations between 1.501 mg/l to 2.500 mg/l. Values greater than 2.500 mg/l are classified as poor.

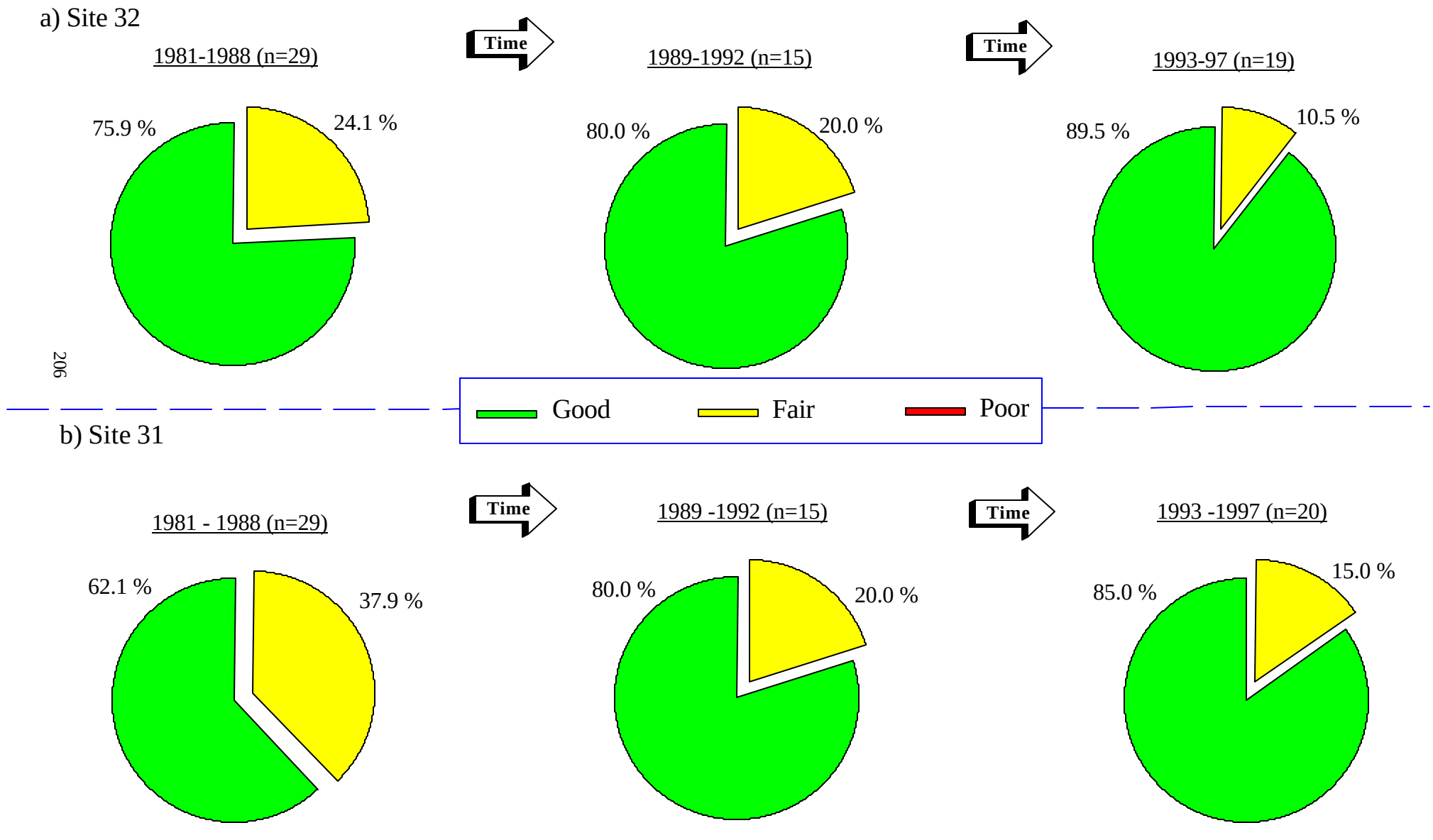


Figure III.89. C-9 Canal Basin Total Nitrogen (TN) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season means and/or medians were not observed at either site.

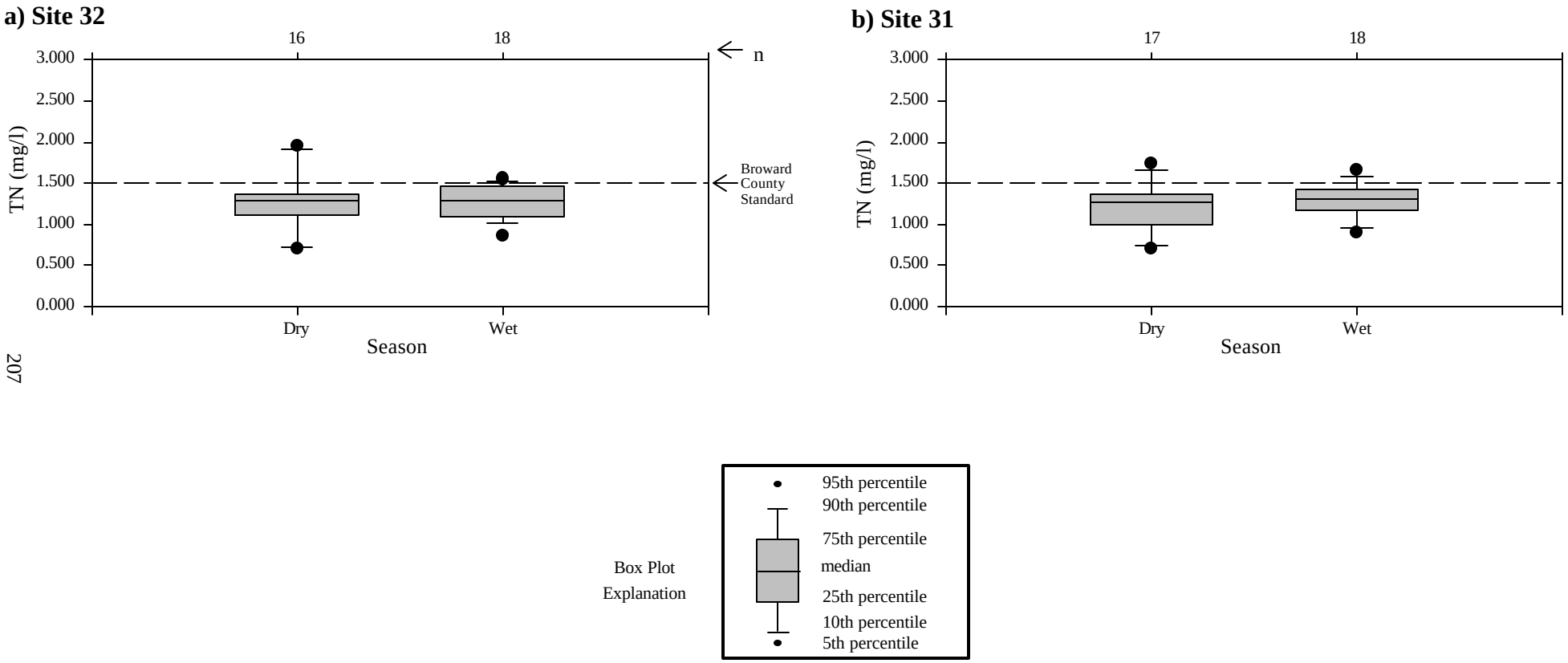


Table III.50. Descriptive Statistics for Fecal Coliform (FC), Total Coliform (TC), and Fecal Streptococcus (FS) in the C-9 Canal Basin. If a sample was below the method detection limit (MDL), half of the MDL value was used in the calculation. The number of samples below the MDL is shown in the last column (# MDL) and the unit of measurement is colonies/100 ml (col).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
31	FC	col	146	31	79	127	810	3.5	19
32	FC	col	146	8	31	94	980	3.5	71
31	TC	col	152	225	632	1640	14000	12	4
32	TC	col	152	100	391	784	6000	5	25
31	FS	col	117	80	339	1003	9000	5	19
32	FS	col	116	33	287	1106	10000	5	34

Yearly box plots were plotted for fecal coliform instead of the mean due to the relative variability (Figure III.90). Site 32 only had one annual median FC value above 50 colonies/100 ml. Although Site 31 normally had higher FC content than Site 32, yearly medians never exceeded 200 colonies/100 ml.

Compliance patterns within the canal were investigated by comparing all FC values to water quality standards (see Section III.E.5.f). The effect of WWTP closures was investigated by pooling different years of data for the analysis (see Section III.K.3). Site 32 had nearly 100% good rated samples during the whole study (1973 through 1997) with only two samples out of 146 observations being over 200 colonies/100 ml. Site 31 had fewer good rated samples than Site 32 but values were still normally less than 200 colonies/100 ml.

Seasonal differences from 1989-1997 were observed at Site 31 (Mann-Whitney Rank Sum Test, $p < 0.05$) but not at Site 32 (Figure III.92). However, concentrations of FC were typically low (< 100 colonies/100 ml) throughout the waterway with medians and percentiles all below the single sample standard of 800 colonies/100 ml.

7. Basin Summary

The C-9 Canal traverses two counties (Broward and Miami-Dade) before normally discharging to the Miami-Dade estuarine region. The westernmost sub-basin has relatively lower residential land use as compared to the eastern portion in urban Miami-Dade. Site 32 represents the relatively uninhabited area that is heavily influenced by the adjacent WCA 3B giving it groundwater seepage characteristics. Site 31 represents an area which is likely influenced hydrologically by WCA 3B seepage water but this sampling locale is also in an area of transition from rangeland and/or low intensity agricultural to urban residential. The following will discuss the water quality characteristics of the canal, including the influence of WWTP discharges and seasonal effects. Finally, questions about the canal and basin brought forth by this initial data analysis effort are listed to support future monitoring and resource planning.

Figure III.90. Yearly Box Plots of Fecal Coliform (FC) Levels within the C-9 Canal Basin from 1973 to 1997. Medians and percentiles (25th and 75th) calculated from quarterly samples (i.e., n = 4) unless noted on upper axis. The Broward County single sample standard (800 colonies/100 ml) is indicated by the dashed line.

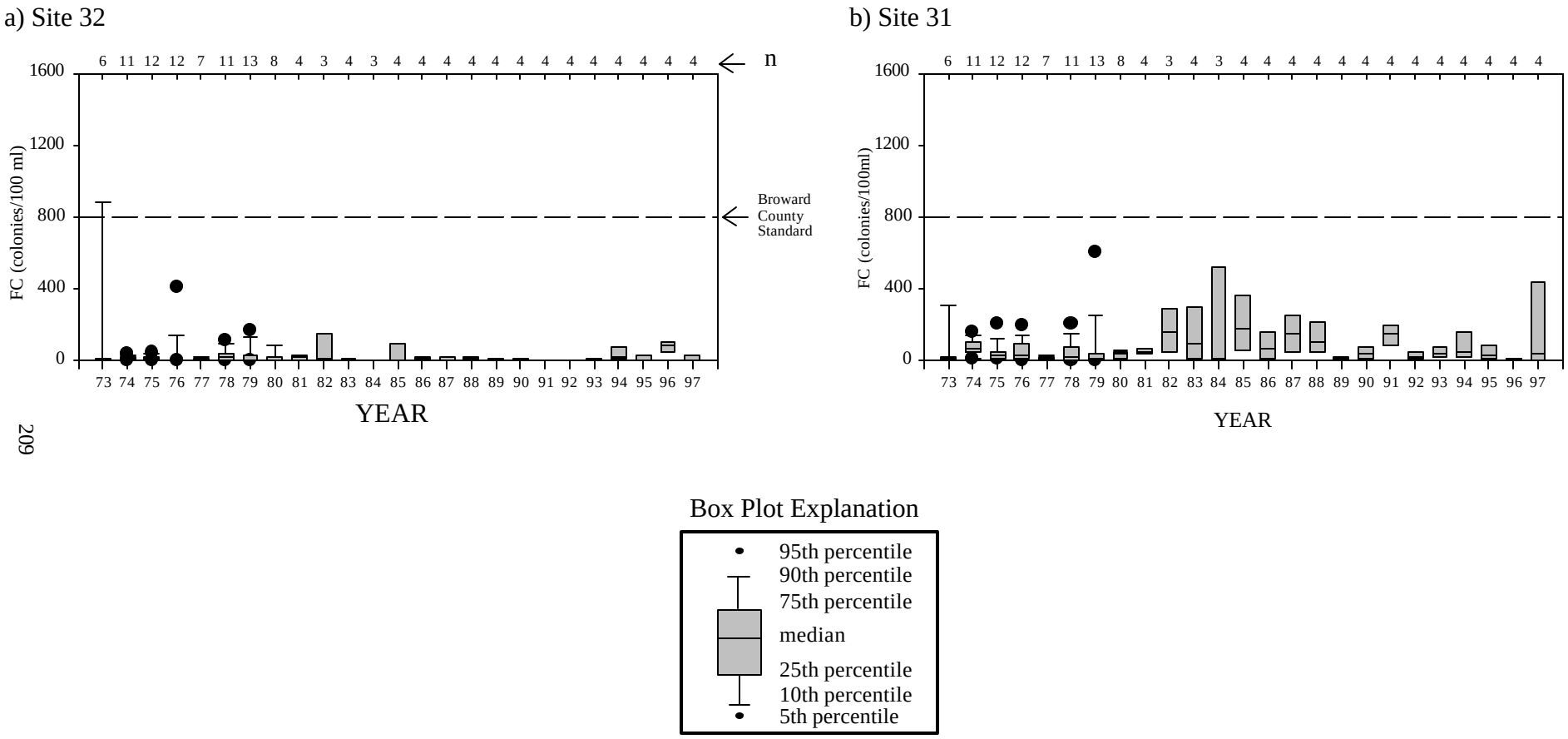
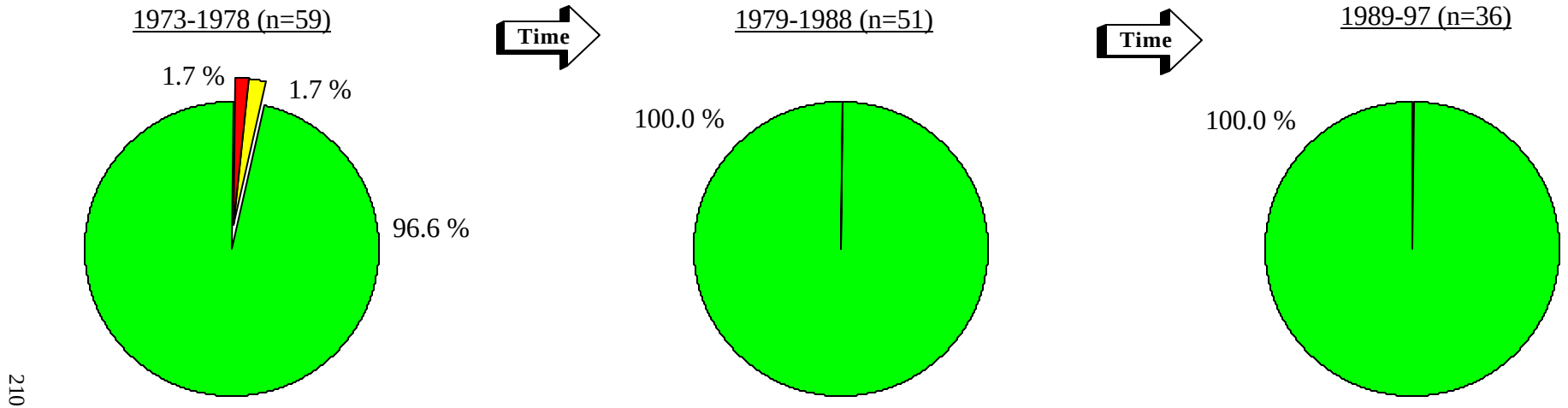
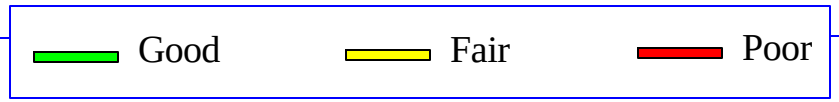


Figure III.91. Fecal Coliform (FC) Observed in the C-9 Canal Basin over Three Time Periods for Sites 32 (a) and 31 (b). Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100 ml (Good) and no single reading shall be above 800 colonies/100 ml (Poor rating). Values between 201 and 800 colonies per 100 ml have been defined as Fair.

a) Site 32





b) Site 31

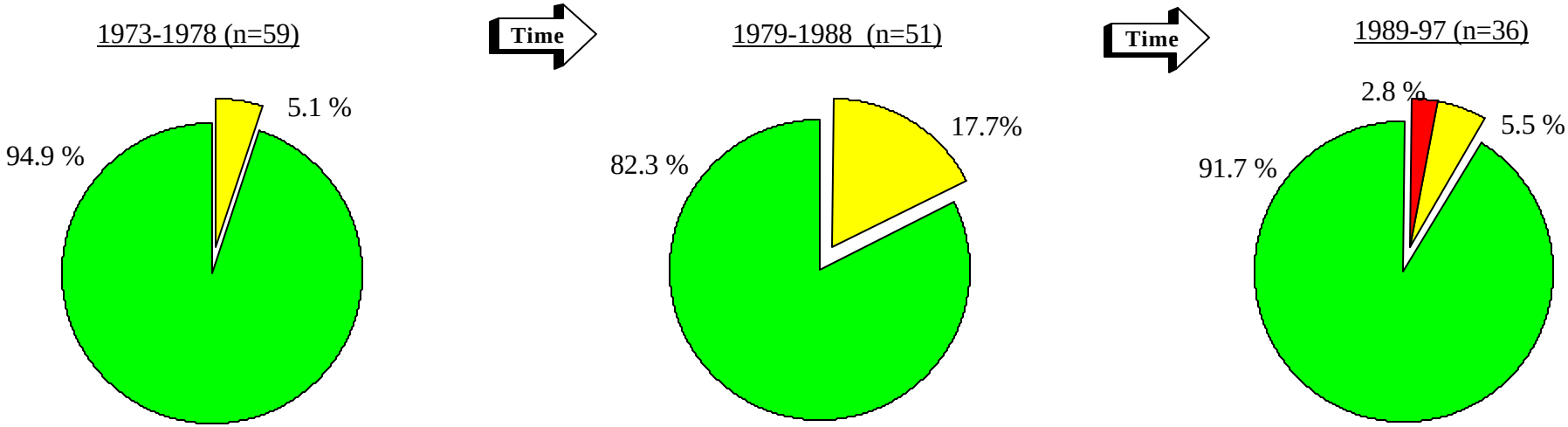
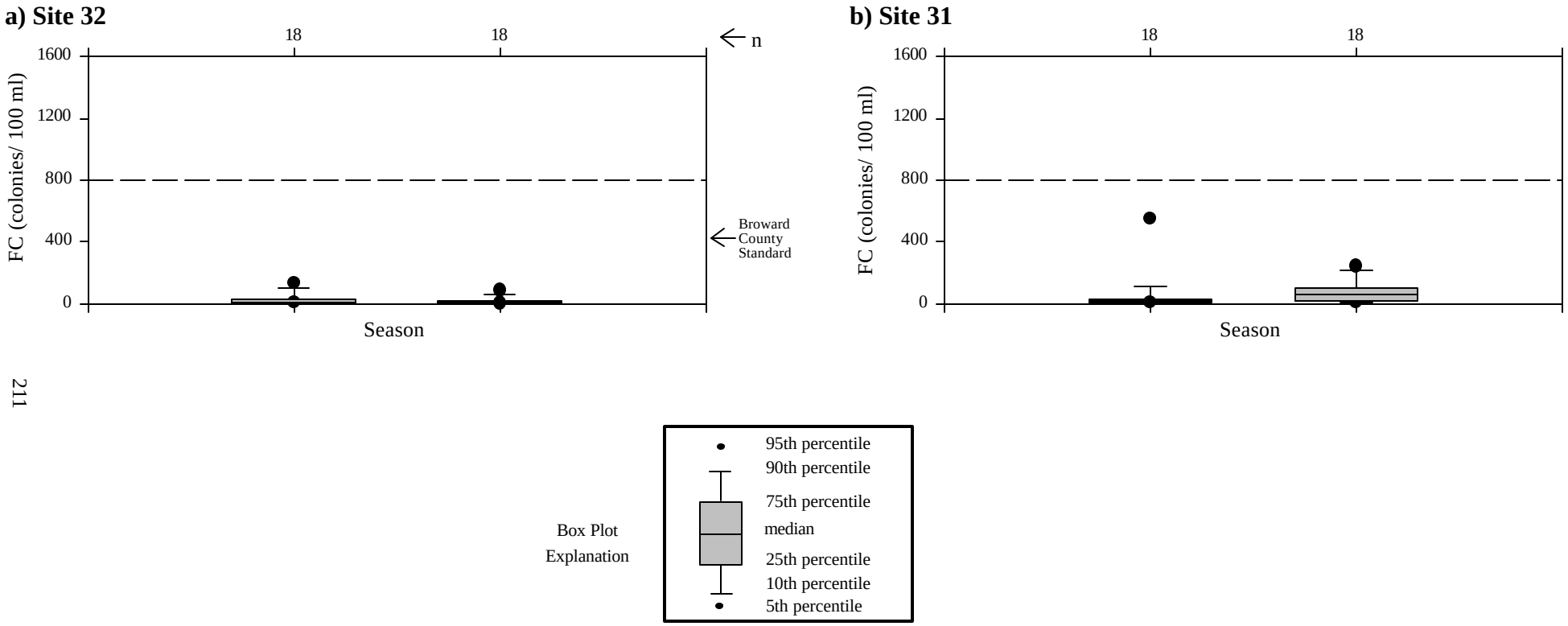


Figure III.92. C-9 Canal Basin Fecal Coliform (FC) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. A statistically significant difference between wet and dry medians was observed at Site 31 ($p < 0.05$; Mann-Whitney Rank Sum test) but not at Site 32.



a. Influence of WWTP Discharges

The C-9 exhibited a slight response to the closure of the Hollywood Country Club WWTP with TN values showing some improvement, particularly at Site 31. With flow in the C-9 Canal typically to the east (Cooper and Lane 1987), Site 31 would have been the primary location to show any effect of WWTP discharges to the canal. Site 32 was primarily removed from the area of WWTP influence.

An important factor in determining the influence of WWTPs in this basin was the major WWTP (City of Miramar) closed in 1978. Thus, no TN values as reported in this study were obtained during this period. Nitrogen was monitored by Broward County Environmental Quality Control Board during the 1970's but not with similar methods as adopted in 1981 (i.e., TKN, NH_3, and NO_2+NO_3) and thus was not reported here. With an apparent improvement in TN after Hollywood Country Club ceased discharges, it is possible the more historical nitrogen analyses also demonstrated improvements. Future studies may consider analyzing these historical nitrogen observations by BCEQCB from the early seventies to validate this.

Some of the highest annual TP concentrations at Site 31 were from 1975 through 1978 but these mean values were also characterized by large variability. Furthermore, the percentage of good samples in the TP pie chart analysis (Figure III.85) actually decreased after the City of Miramar closed its WWTP. Thus, TP values did not readily show changes after WWTP operations ceased discharges as seen in other basins.

Interestingly, dissolved oxygen concentrations were actually higher during the period of Miramar's WWTP operation at Site 31 (see Figure III.82). This apparent pattern may seem contradictory to 'typical' response of WWTP plants to surface waters which includes increased biochemical oxygen demand and a decrease in DO levels. However, the DO dynamics of the C-9 Canal are relatively unique as discussed below.

b. Basinwide Water Quality Characteristics (Post-WWTPs)

A major observation is the extremely low DO values in the C-9 Canal, in particular at Site 32 and to a some extent at Site 31. This is very consistent with some of the earliest investigations of the canal (SFWMD 1976) which attributed the low DO values to groundwater input. Relatively recent work also observed extremely low DO content was uniform in the water column (BCDNRP 1996).

Another pattern of interest with DO (see 1990, Figure III.81) content was that the highest annual levels generally occurred during corresponding times of relatively high TP. While this is a qualitative observation and was not always apparent, it suggests relatively high inputs of TP may promote biological production (i.e., phytoplankton) which to some extent may enhance DO levels. While this mechanism can also lead to eutrophication in some water bodies, the uniqueness of the C-9's hydrology may allow for a different response in the water column. Another factor for both DO and TP may also

be the meteorological condition of the late 1980's and 1990 had dryer conditions than normal which likely reduced groundwater seepage.

Another parameter of interest in the C-9 canal was ammonia-nitrogen levels. With concentrations normally above 0.200 mg/l even after 1989, the canal has some of the highest NH_3 in the county. The low DO levels and subsequent denitrification likely influence the ambient NH_3 levels. Potentially, the rangeland surrounding this area which has some cattle may contribute to the ammonia-nitrogen concentrations in the canal. The main response may be more important downstream where the C-9 Canal empties to the estuaries. However, it may be likely other urban influences occur during transport of C-9 water. A comparison of databases with Miami-Dade County would assist in understanding the overall influence of nitrogen loading in the eastern C-9 and coastal basins.

c. Seasonal Differences

The only statistical seasonal difference was observed for FC concentrations at Site 31. However, both wet and dry season values were relatively low, particularly when compared to other sites countywide. Perhaps, the most important seasonal observation was the lack of a statistical difference in DO content. Potentially the groundwater interaction and low elevation of the basin override seasonal differences.

d. Future Monitoring Questions

One goal of this report is to develop strategic guidelines for future Broward County water quality monitoring and management. To facilitate this, questions generated by this study's findings are being compiled for each drainage basin. For the C-9 Basin and Canal, the importance of cooperation between the two counties that it traverses (Miami-Dade and Broward) and the SFWMD will be important to future management issues such as WPAs.

- Are moderately enhanced ammonia-nitrogen levels influencing nitrogen loading in Miami Dade's estuarine waters (e.g., Biscayne Bay)?

- Are nutrient concentrations from 1994-1997 or from 1990-1993 more reflective of TP levels?

- What is stormwater quality like directly entering the canal and its secondary and tertiary tributaries, particularly the seven north-south oriented canals in the western basin?

- What would be the impacts of reduced seepage water from the WCAs to the C-9 Canal Basin?

L. Freshwater Discussion

Four major objectives constituted the framework for the study and include:

- Determine water quality conditions (long-term and current) at each freshwater canal sampling site;
- Determine compliance patterns with Broward County's Chapter 27 water quality standards (Broward County 2000);
- Determine similarities and differences existing within each basin or region; and
- Formulate research questions, needs, and direction for better management of the entire Broward freshwater canal system.

The preceding sections on each basin addressed each objective, especially the first two. The following text will primarily discuss objectives three and four by comparing and contrasting all freshwater basins.

1. Pre- and Post-Wastewater Treatment Plants Discharge Eras

Overall, wastewater treatment plant (WWTP) discharges negatively impacted the water quality at most freshwater canal sites. Although some exceptions existed (e.g., TP levels in the Hillsboro Canal), nutrient content was typically the best indicator of improvements. The C-12 Basin, in particular, realized a twofold order of magnitude improvement in TP levels. Other basins such as the C-13 and C-14 also exhibited substantial improvements in TP levels. Some geographically distinct improvements within a specific basin were also observed and likely due to the proximity of a monitoring site to WWTP discharges (e.g., North New River Canal's (NNRC) Site 21 vs. Site 23). We conclude that the prohibition of WWTP discharges into surface water bodies was a sound regulatory decision resulting in improved water quality of Broward's inland, freshwater canals.

The analysis on the entire data set (pre- and post-WWTP years) was the initial 'data mining' and should be viewed as a historic view of the total sampling effort at each particular site. While annual averages, pie charts, and seasonal box plots were developed for the four major parameters to differentiate the pre- and post-WWTP eras, future ambient sampling reports may consider reporting values for all water quality constituents starting in 1989 (i.e., post-WWTP). Similarly, any analysis of Broward's waters for determining statewide impaired water bodies (http://www.dep.state.fl.us/water/division/tmdl/default.htm) and/or regional planning efforts (e.g., Water Preserve Feasibility Study Analysis (http://www. evergladesplan.org/projects/wpa_main.htm) should consider the years of data collection from 1989 to the present.

Thus, the remaining discussion on freshwater canal characteristics, will focus on the years 1989-1997 to avoid any direct influence of WWTP discharges. Potentially, indirect influences of WWTP disposal

may have or still exist in freshwater sediments. In particular, sediment and water column nutrient interaction can occur in shallow waters such as most of Broward's freshwater canals which are typically less than 10 feet (3 meters) in depth. Another advantage of focusing on the sampling years 1989-1997 is an integration of variable rainfall over time. For example, the SFWMD in its Water Preserve Feasibility Study Analysis are using dry years (1989-1990), average years (1992 and 1993) and wet years (1994 and 1995) for modeling purposes. Thus, the 1989-1997 time frame contains all three scenarios. A detailed breakout of the different conditions (dry, wet, and average) was not performed in this report, however, some meteorological and hydrological data will be discussed.

2. Ambient Nutrient Concentrations

a. Total Phosphorus

Overall, the Hillsboro Canal had the highest TP in the county (Figure III.93). In fact, the 25th percentile values for Sites 2 and 3 were above the countywide 75th percentile TP concentration (0.073 mg/l) even after the WWTP era. In addition, median TP values at Sites 2 and 3 were statistically different from every other site in the county with the exception of Site 7 (Table III.51, Kruskal-Wallis One Way Analysis of Variance on Ranks/ Dunn's Method ($p < 0.05$). The Hillsboro Canal receives water from a major Palm Beach County secondary canal where an increase in overall canal TP occurs (see Site 4 vs. Site 3). Additionally, the waterway has several land uses (residential, agriculture, and golf course), as well as septic tanks in both counties (Broward and Palm Beach) that could contribute to elevated TP concentrations. Currently, the SFWMD is investigating the entire basin as part of the Water Preserve Area Feasibility Study (S. Kone, personal communication) and their results should assist in understanding potential TP sources, fate, and transport mechanisms.

Beyond the Hillsboro Canal, median TP concentrations in the C-14 (Sites 6 through 9), C-12 (Sites 17 and 18), and eastern C-11 (Site 27) were greater than the county wide median of 0.036 mg/l and exhibited the second highest number of statistical differences with other sites (Table III.51). In particular, Site 7 had the highest median TP in the C-14 Basin likely due, in part, to surrounding golf courses and well maintained yards. Overall, the C-14's TP levels and other constituents are also likely influenced by the adjacent, major water control structure (S-37B). Site 27's TP levels (eastern C-11 Canal) were higher than Sites 28 and 29 values and illustrates the differences between the western and eastern C-11 Canal sections, separated hydrologically by the S-13A (see Figure III.67). The C-12 Canal's median TP was surrounded by a large area of variability and may be due to variable freshwater inputs to the system. The C-12 and the eastern C-11 are not directly connected to a western seepage canal such as the L-35A. Thus, stormwater and localized groundwater are main freshwater inputs to both the C-12 and the eastern C-11 Canal and Water Conservation Areas (WCAs) water does not normally reach these systems in a similar manner as the NNRC, western C-11, C-9 Canals. Thus, hydrological separation and distance from WCAs likely increases the influence of the surrounding urban land use on in stream TP levels in the eastern C-11 and the C-12 Canal.

The lowest levels of TP were observed in the western C-13, NNRC, western C-11, and C-9 Canals. All of these areas are influenced by WCA seepage water. These sites likely lowered the overall county

Figure III.93. Total Phosphorus Values at each Freshwater Water Quality Site from 1989-1997. Box plots describe data for each individual site from the Hillsboro (HILL), C-14, C-13, C-12, North New River (NNR), C-11, and C-9 Canal Basins. In addition, Site 11 is shown which exists at downstream of the S-36, immediately east of the western C-13 basin. Individual sites are also compared to the median, 25th, and 75th percentile values for all freshwater sites through the time period (n=1065).

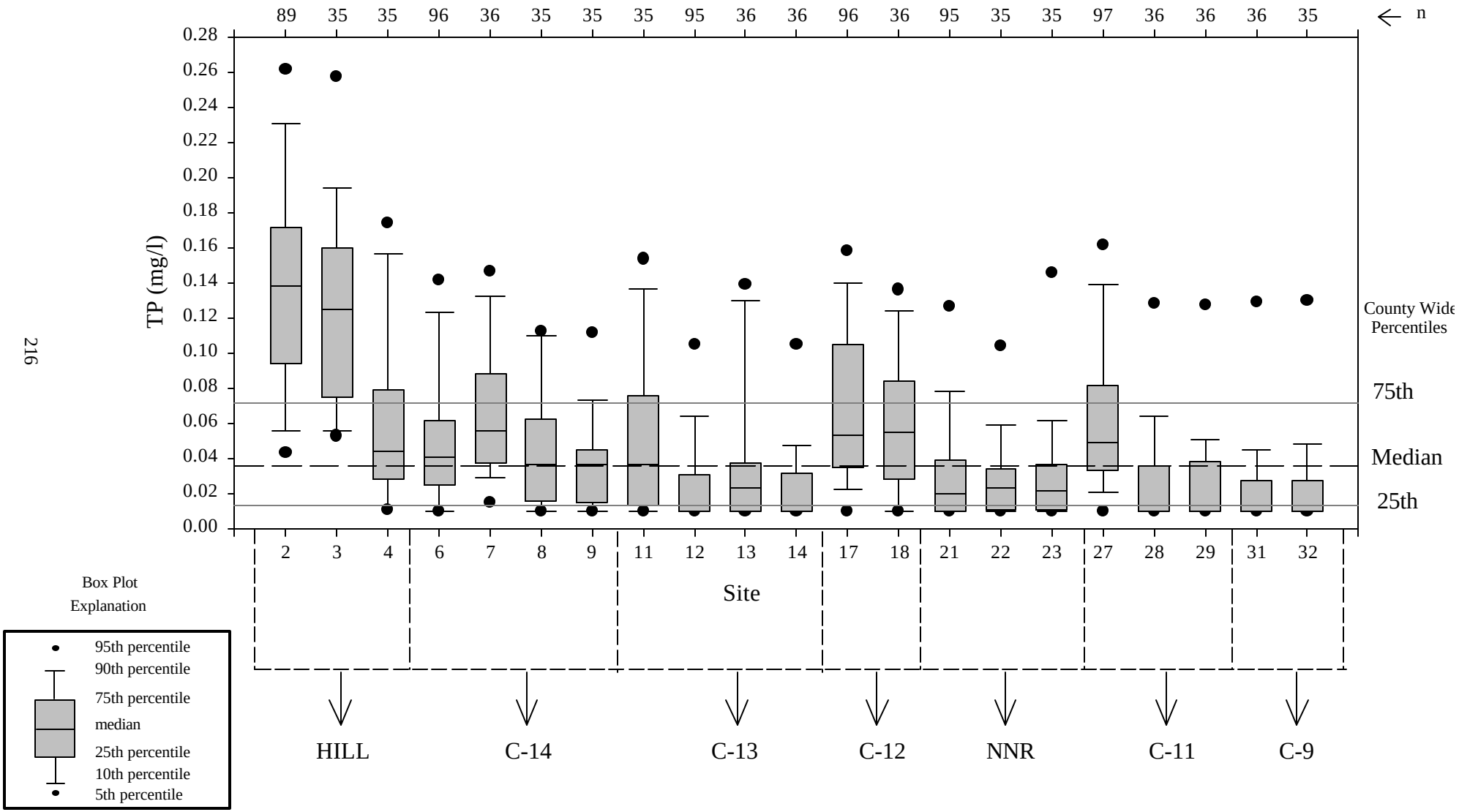
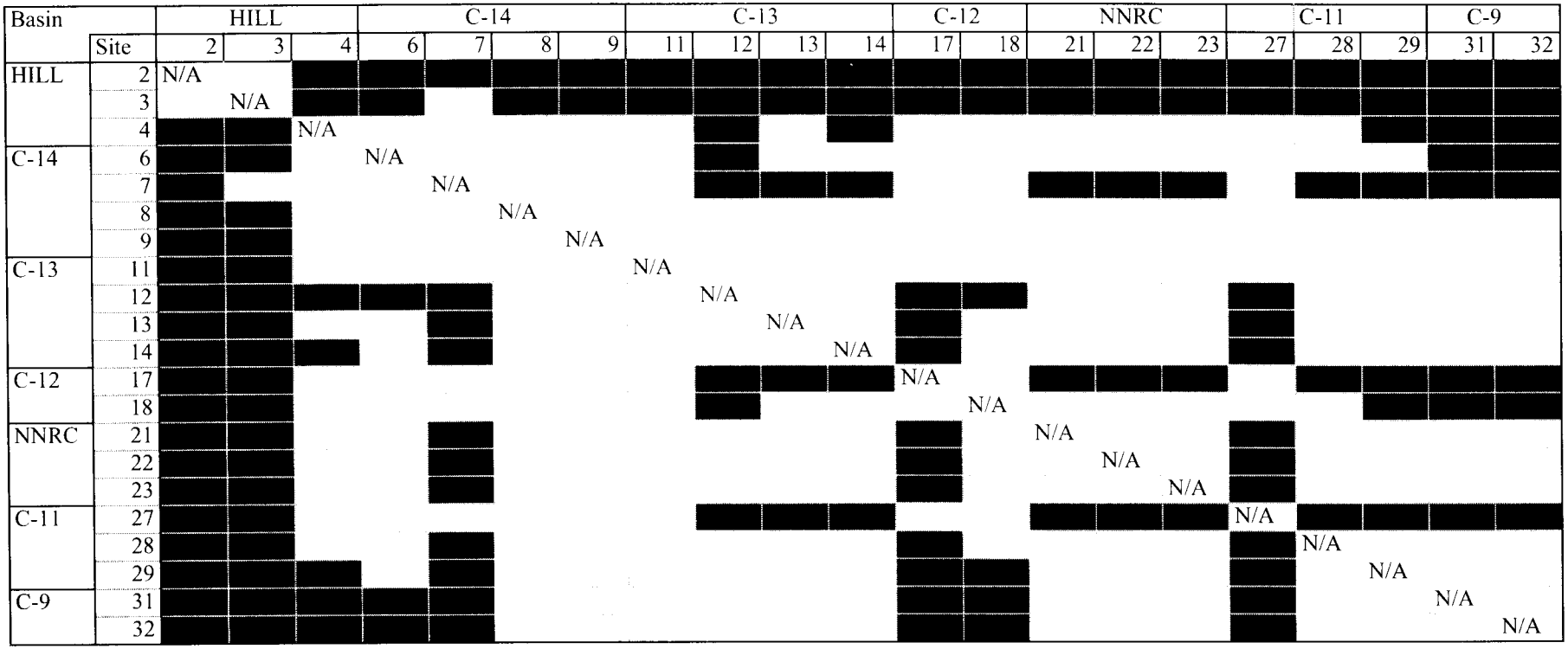


Table III.51. Statistical Differences Observed Between Freshwater Sampling Site Median TP Values (1989-1997). A black box indicates the medians between the two sites were statistically significant based on a Kruskal-Wallis One Way Analysis of Variance on Ranks and an isolated analysis with Dunn's Method ($p < 0.05$). Median and percentile values shown in Figure III.93.



median (0.037 mg/l) closer to the Broward County standard of 0.020 mg/l. Interestingly, 334 of the 1099 (30.4%) TP samples at all Broward County freshwater sites taken between 1989 and 1997 were below the MDL (0.020 or 0.026 mg/l). A large abundance of these "nondetects" were seen at the western C-13, NNR, western C-11, and C-9 Canals sampling sites (see Tables III.27, III.34, III.41, and III.48).

b. Total Nitrogen

The Hillsboro Canal had the highest TN content in the county due primarily to Site 4 (Figure III.94). Site 4's median TN had the most statistically significant differences between all other freshwater sites (Table III.52, Kruskal-Wallis One Way Analysis of Variance on Ranks/ Dunn's Method; $p < 0.05$). The proximity to the WCA 1 (Arthur R. Marshall Loxahatchee National Wildlife Refuge) may allow for transport of relatively high TN originating from organic detritus. The relatively high levels of TKN at Site 4 (see Table III.7) suggests this transport occurs although agricultural land use and secondary canal input may also influence TN values. Data from the SFWMD's current Hillsboro Basin investigation should assist in determining the nitrogen dynamics of the area and the influence of the WCA seepage and direct flow.

Site 27 in the eastern C-11 Basin was the only site beyond Site 4 with median TN greater than the countywide 75th percentile of 1.698 mg/l and also exhibited a number of statistical differences when compared to other sites (Table III.52, Kruskal-Wallis One Way Analysis of Variance on Ranks/ Dunn's Method; $p < 0.05$). Furthermore, the relatively narrow width between the 25th and 75th percentiles suggest relatively static nitrogen levels as compared to other basins (e.g., NNRC). As with TP, Site 27's TN values further show the differences between the eastern and western C-11 Basins and also illustrates the need for a land use/ water quality investigation in the area. Moderate levels of TN were seen in the C-13, North New River, western C-11, and C-9 Canals while the lowest TN concentrations were seen in the C-14 and C-12 Canals.

The speciation or type of nitrogen is important to the overall TN content. For, example, the amount of inorganic nitrogen is essential to water column biology, especially estuarine phytoplankton population dynamics. Site 27 of the eastern C-11 had the highest nitrite+nitrate-nitrogen (NO_2+NO_3; a portion of inorganic nitrogen) concentrations at the coastal water control structures where freshwater discharges to Broward's estuarine waters through the S-13 (Figure III.95). Although, a Broward County water quality standard does not exist, Site 27's NO_2+NO_3 concentrations substantially exceeded the state of Florida's Water Quality Index (WQI) level for poor water quality. The WQI is used to compare relatively similar water bodies around the state and is used in the state of Florida's 305B report to the United State Environmental Protection Agency (Paulic, M. et al. 1996 or http://199.73.196.31/water/division/monitoring/pdf/main305b.pdf. Thus, some of the highest freshwater NO_2+NO_3 concentrations in the state exist at Site 27. The current BCDPEP chlorophyll a monitoring should detail the potential phytoplankton response to enhanced NO_2+NO_3 in the eastern C-11 Canal (headwaters) and the estuarine water body (tailwaters) Dania Cut-off Canal.

Figure 94. Total Nitrogen Values at each Freshwater Water Quality Site from 1989-1997. Box plots describe data for each individual site from the Hillsboro (HILL), C-14, C-13, C-12, North New River (NNR), C-11, and C-9 Canal Basins. In addition, Site 11 is shown which exists downstream of the S-36, immediately east of the C-13 basin. Individual sites are also compared to the median, 25th, and 75th percentile values for all freshwater sites through the time period (n=1042).

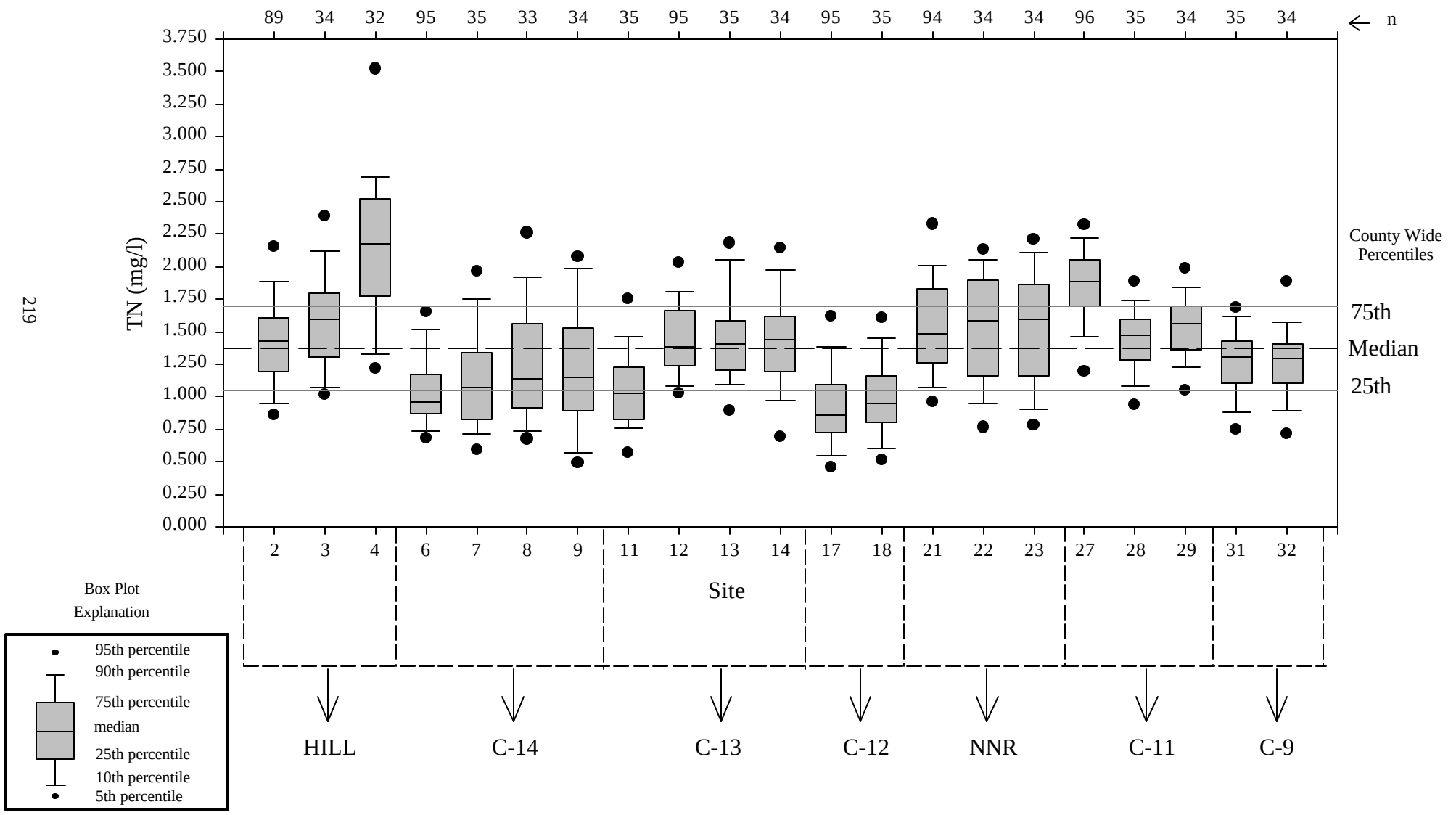


Table III.52. Statistical Differences Observed Between Freshwater Sampling Site Median TN Values (1989-1997). A black box indicates the medians between the two sites were statistically significant based on a Kruskal-Wallis One Way Analysis of Variance on Ranks and an isolated analysis with Dunn's Method ($p < 0.05$). Median and percentile values shown in Figure III.94.

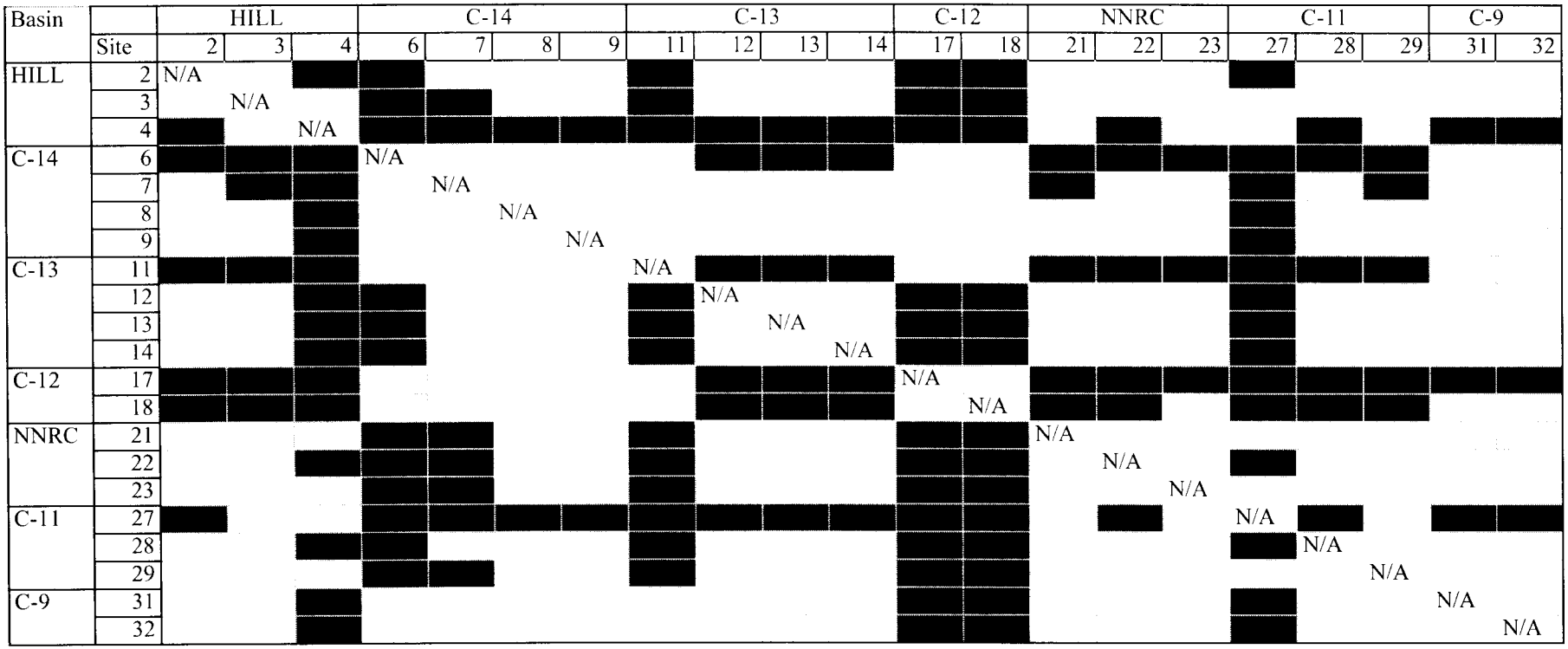
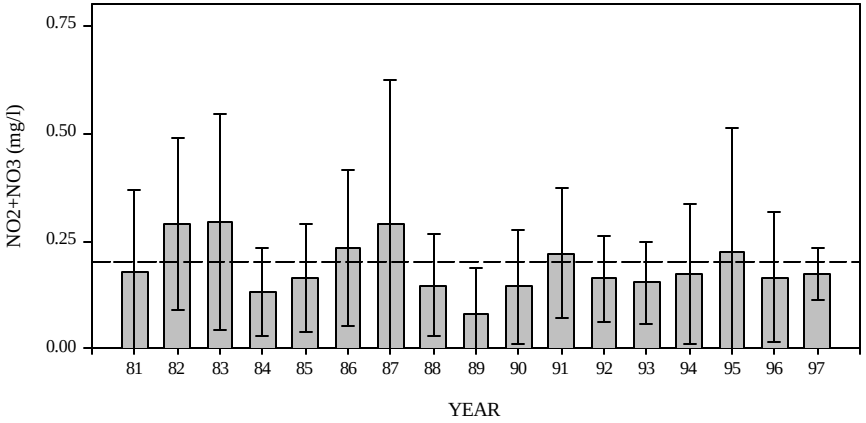
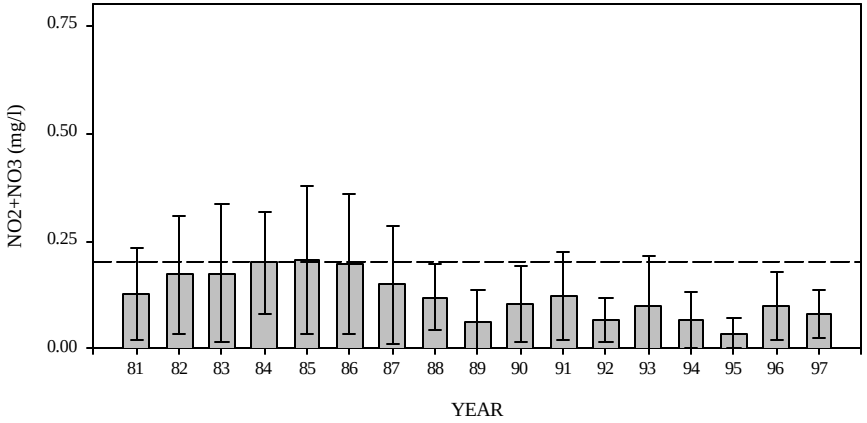


Figure III.95. Annual Mean Nitrite+Nitrate-Nitrogen (NO2+NO3) Concentrations Observed At Headwaters of Major Salinity Control Structures in Broward County. Means and standard deviations calculated from bi-weekly monitoring before 1992. In 1992, six to seven samples were obtained while quarterly observations were made afterwards. The major canals and associated control structures are also listed. The Florida Department of Environmental Protection's (1998) Water Quality Index poor level is also shown.

a) SITE 2 (Hillsboro Canal; G-56)



b) SITE 6 (C-14 Canal; S-37A)



c) SITE 21 (North New River Canal; G-54)

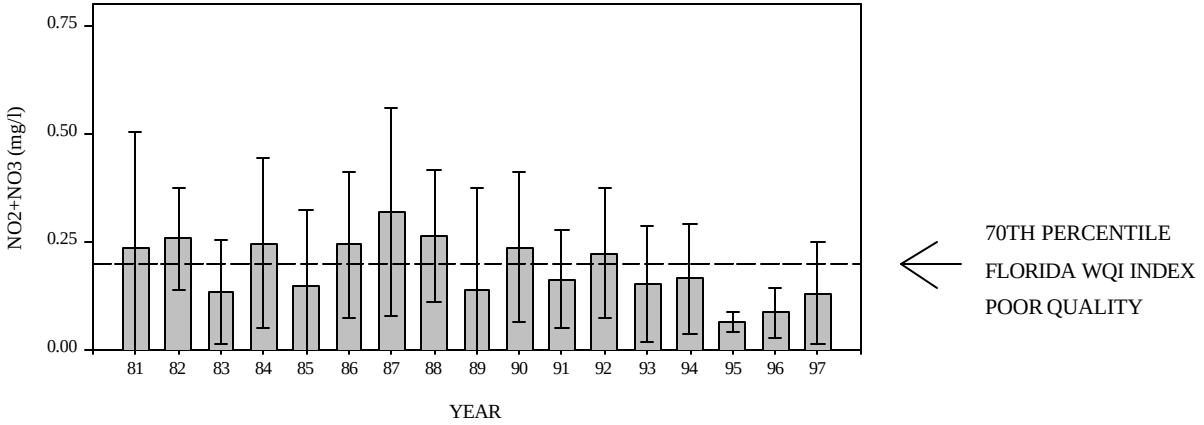
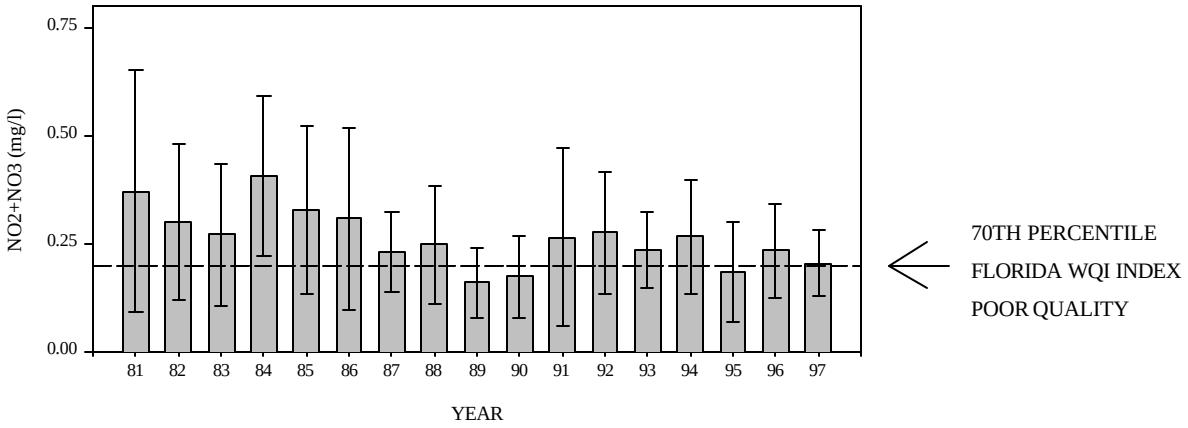
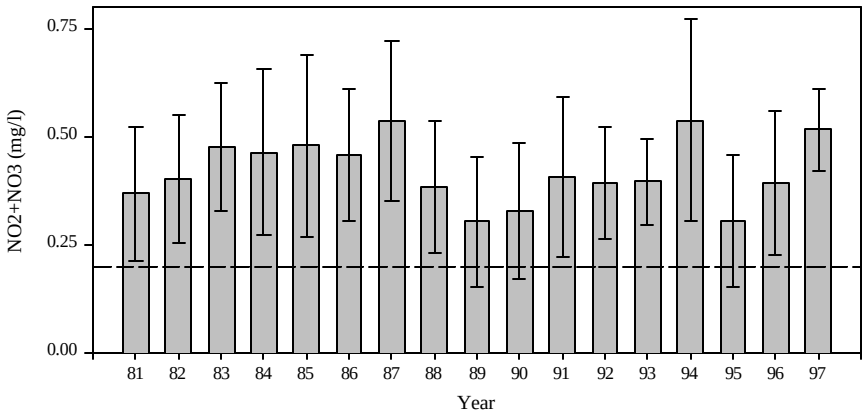


Figure III.95 (Cont.). Annual Mean Nitrite+Nitrate-Nitrogen (NO2+NO3) Concentrations Observed At Headwaters of Major Salinity Control Structures in Broward County. Means and standard deviations calculated from bi-weekly monitoring before 1992. In 1992, six to seven samples were obtained while quarterly observations were made afterwards. The major canals and associated control structures are also listed. The Florida Department of Environmental Protection's (1998) Water Quality Index poor level is also shown.

d) SITE 12 (C-13 Canal; S-36)



e) SITE 27 (C-11 Canal; S-13)



c. Broward County Nutrient Groups

To further investigate spatial nutrient patterns, median TN was plotted against median TP concentrations (Figure III.96). Initially, three data clusters appeared together and were characterized by different basins. The first two groupings were either associated with highly elevated (> 0.100 mg/l) TP concentrations with moderately high TN (near 1.5 mg/l) or consisted of the highest TN (near 2.0 mg/l) concentrations in the county with moderately high TP (0.04 to 0.06 mg/l). These four sites were in the Hillsboro Canal (Sites 2-4) and the eastern C-11 Canal (Site 27).

The third cluster contained the remaining basins of the county. By not including the Hillsboro Canal and eastern C-11 Canal in a second plot (Figure III.96) an apparent pattern emerged with some sites characterized by low TP and relatively moderate TN values while other sites had relatively low TN content but moderate TP values. This also was basin specific, with the C-14 and C-12 Canals typified by moderate TP values and relatively low TN concentrations. The C-13, NNRC, Western C-11, and C-9 Canal Basins were all within the moderate TN and low TP group.

Thus, a preliminary Broward County freshwater canal nutrient group designation was derived to begin a framework for understanding loading and assimilation dynamics. The C-12 and C-14 Canals are placed in BC Nutrient Group I (Moderate TP:Low TN) while the C-13, NNRC, Western C-11, and the C-9 Canal fall into BC Nutrient Group II (Low TP:Moderate TN). BC Nutrient Group III consists of water bodies with highly elevated TP and/or TN (i.e., Hillsboro Canal and the Eastern C-11. From a water quality management perspective, BC Nutrient Group III rates the highest priority for future basin investigations.

To more clearly understand why this pattern was seen over nine years of sampling, TN and TP were also plotted in Figure III.97 against a physical parameter- specific conductance. The relatively moderate TN (BC Nutrient Group II) areas were clustered more tightly than the moderate TP sites (BC Nutrient Group I) and were characterized by specific conductance values primarily above 750 Fmhos, although a few exceptions did exist. The moderate TP sites had specific conductance values which were below 700. Though the differences in specific conductance are not large, the inclusion of nine years of sampling suggests some degree of distinctness in the water masses of the different canals.

Furthermore, correlation analyses revealed a strong relationship between median nutrient values and specific conductance. Specifically, TN had a positive correlation r = 0.91; Figure III.97a) while TP values were inversely correlated with median specific conductance values r = 0.82; Figure III.97b). These correlations suggest water bodies with specific conductance values more typical of seepage water, in particular from the WCAs, will likely have lower ambient TP and moderate TN concentrations. Areas with more prominent localized TP sources (e.g., Site 7) will tend to have moderate levels, potentially from surrounding land use and/or water management activity. In essence, specific conductance may be seen as a tracer of water, particularly of WCA water entering the western low-lying canals. The use of specific conductance as a tracer in South Florida has been done previously for the WCAs (USGS 1987).

Figure III.96. Median Total Phosphorus (TP) Concentrations Versus Median Total Nitrogen (TN) Concentrations at each Freshwater Water Quality Site from 1989-1997. The two circled areas indicate Nutrient Group III (i.e., Hillsboro, and Eastern C-11 Basins). The square encompasses the remaining basins in the county (C-14, C-13, C-12, North New River Canal, C-11, and C-9 Canal Basins). Site 11 was excluded from this analysis because of tidal influences.

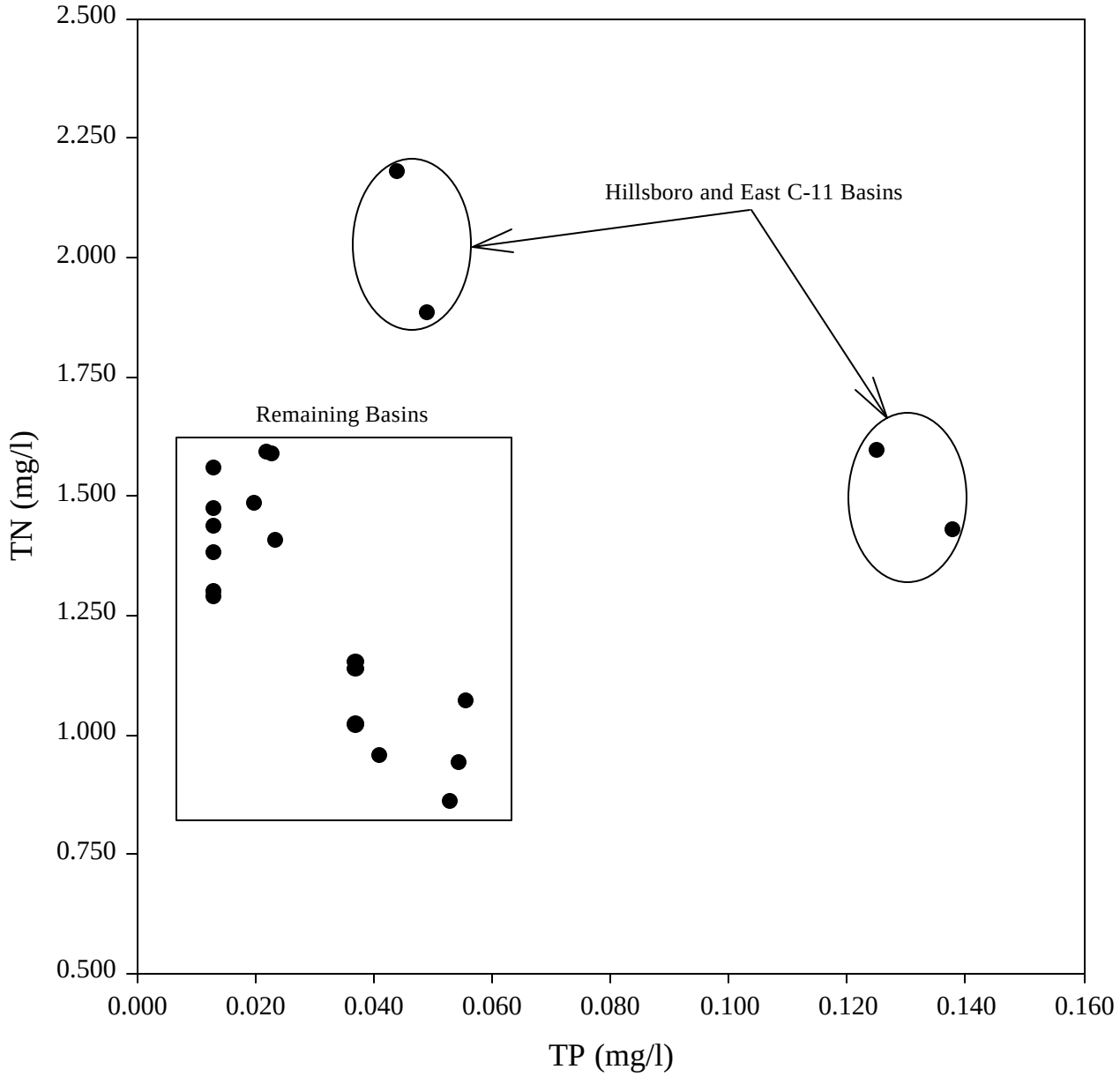


Figure III.97. Median Total Phosphorus (TP) Versus Total Nitrogen (TN) Versus Specific Conductance (Cond) for BC Nutrient Groups I and II. Medians calculated from 1989-1997 observations.

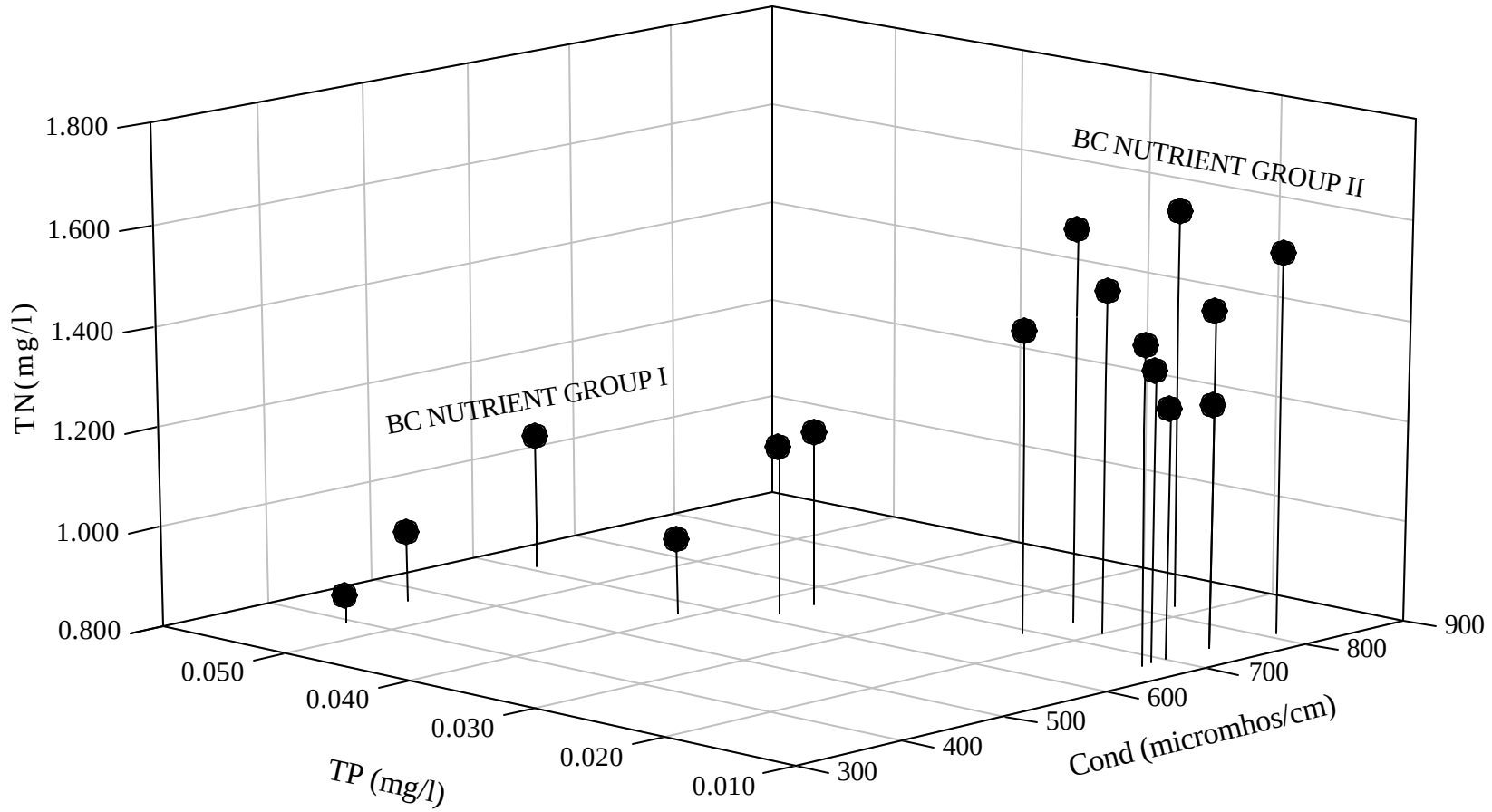


Figure III.98. Median Total Phosphorus (TP) Concentrations Versus Median Specific Conductance (COND), as well as Median Total Nitrogen (TN) versus COND for BC Nutrient Groups I and II. Medians calculated from 1989-1997 observations.

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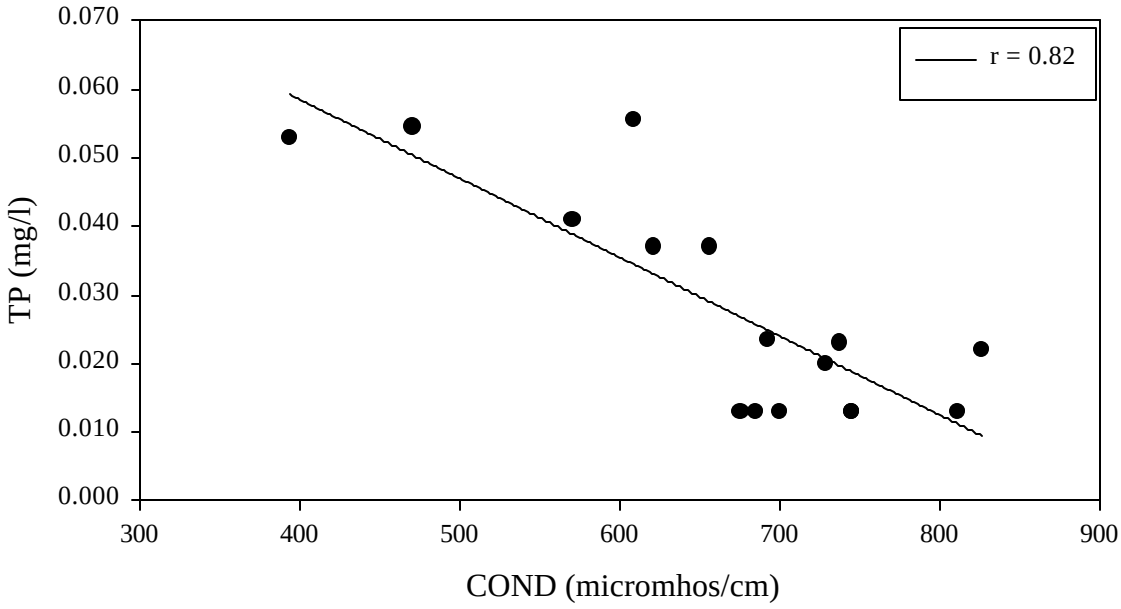
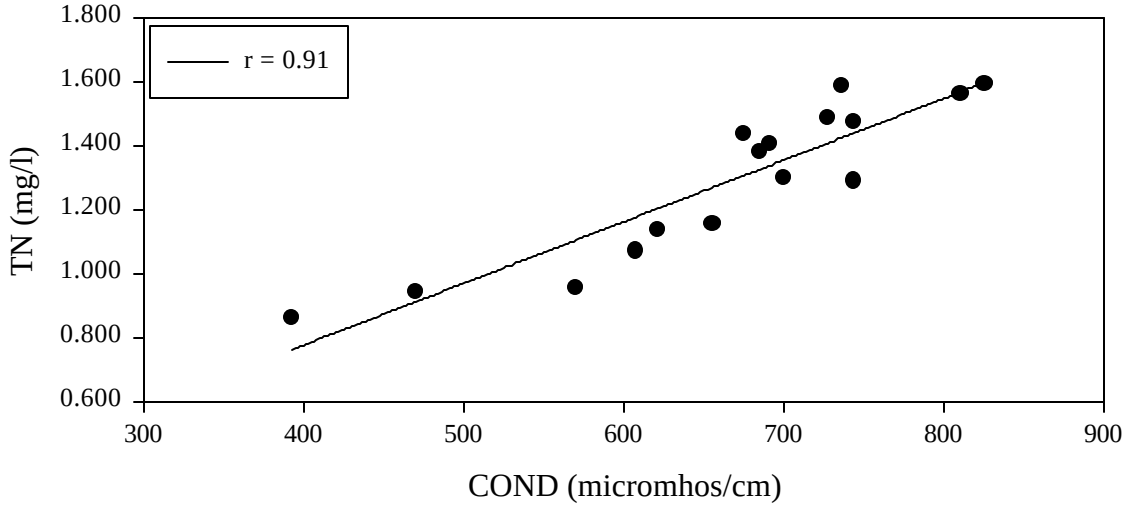
a) TP vs COND



b) TN vs COND



Despite potential drawbacks (e.g., direct influence of stormwater), a countywide, ambient nutrient description provides an initial framework for future investigations. Coupled with BCDPEP's monitoring of a chlorophyll a database which began in 1995, the potential exists to develop canal specific trophic state indices to better understand the importance of the observed nutrient concentrations. By having canal-specific information that incorporates not only nutrient content as well as surrogates of nutrient water column response (i.e., chlorophyll a), water quality management should work in better concert with the future water quantity management.

3. Influence of Climate

The period of 1988 to 1990 is typically recognized as a drought period in South Florida. While a comprehensive rainfall and hydrological (including structure elevation and flow regime) was not performed for this study, Figure III.99 illustrates the difference over the 1989-1997 period in water elevations (SFWMD public information data) at the North New River Canal. The weekly rolling average exhibits some variability but a generalized pattern of low to high canal elevations can be observed with a distinct increase at the beginning of the 1992 wet season.

Throughout almost every basin, TP values were relatively enhanced during the period of 1990-1992 with some sites also displaying high values in 1989. In particular, the BC Nutrient group II (Low TP: Moderate TN) illustrated this general pattern based on a rolling quarterly average analysis (Figure III.100). For examples, Figure III.98 shows the rolling TP average from 1989 through 1997 in the NNRC. For sites 22 and 23 a more definitive decreasing trend is observed due, in part, to a differing number of samples collected at Site 21. When compared to Figure III.99, a slight inverse pattern is seen between water elevation and TP levels.

Thus, qualitatively, a potential scenario may be theorized where groundwater levels existed that promoted either surface water exfiltrations and/or stagnation. Low rainfall and groundwater levels would reduce overall flow through the canals allowing stagnation and TP to become more concentrated in the water column. The less dynamic canals would allow a more abundant phytoplankton community which could contribute to more eutrophic environment. Chlorophyll a was not collected by BCDPEP during this period. However, the influence of stagnation of the many Broward County secondary and tertiary canals is often readily seen by eutrophic responses in the water column (personal observation) and is considered one of the largest problems in the North Fork of the New River, a relatively stagnant waterway (BCDNRP 1993, BCDPEP 1999).

The reason for an apparent lag response in TP content from 1989-1992 to drought conditions observed primarily from 1988 to 1990 is not clear at this time. However, the importance of understanding the period of relatively high TP values is two-fold. First, it needs to be ascertained whether conditions could occur again for high TP values and if so could those conditions be managed. Secondly, future Everglades Restoration and Water Preserve Area construction will likely reduce seepage and flow rates within the primary freshwater canals. While, the water quality of primary conveyance canals may not be as high of priority as Everglades Restoration and public water supplies, a future scenario similar to 1990-1992 may be more explainable if a range of expected ambient water quality values can be matched to certain hydrological patterns and water management practices.

Figure III.99. Moving Weekly Average Elevation of North New River Canal (NNRC) at Sewell Lock (G-54). Daily elevations (NGVD) were obtained from the South Florida Water Management District and transformed to a seven-day moving average. The Sewell Lock controls elevations within the NNRC (Cooper and Lane 1987).

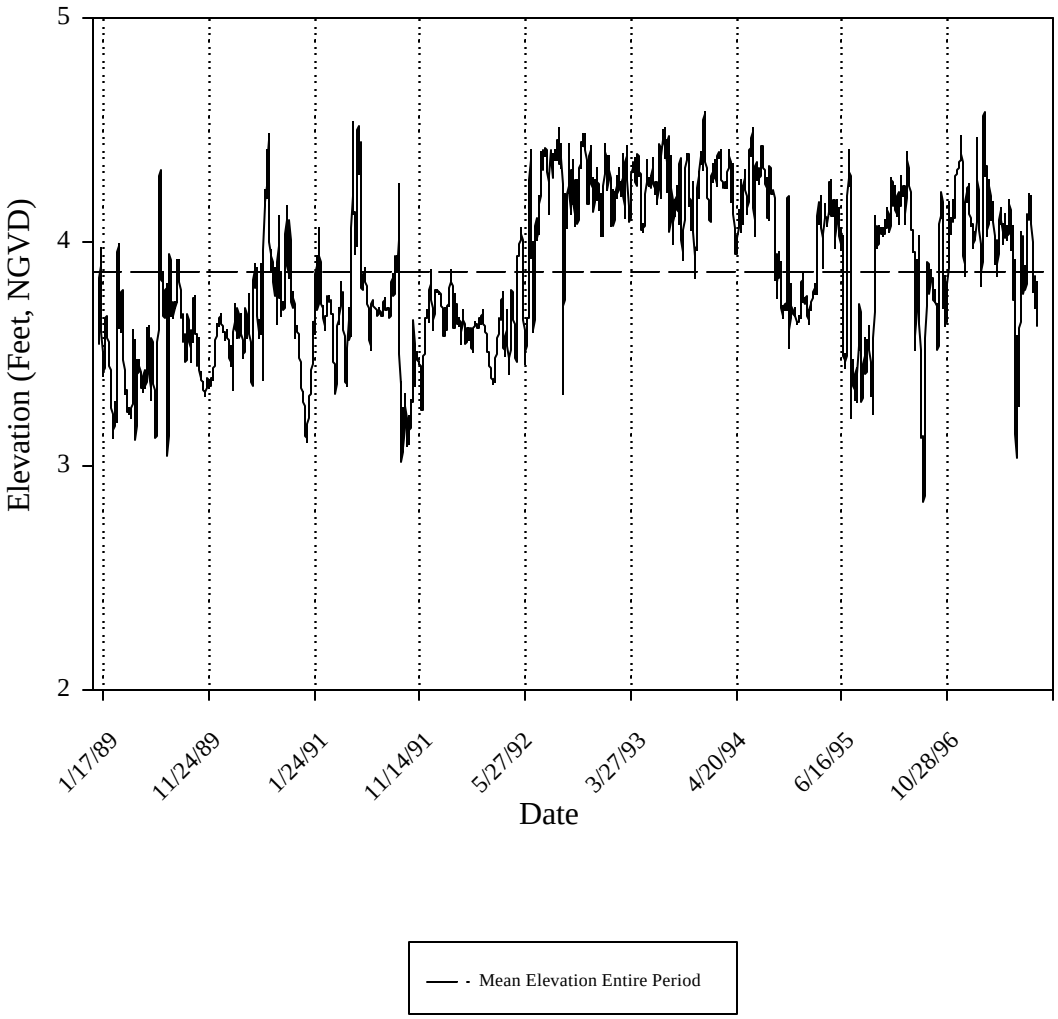
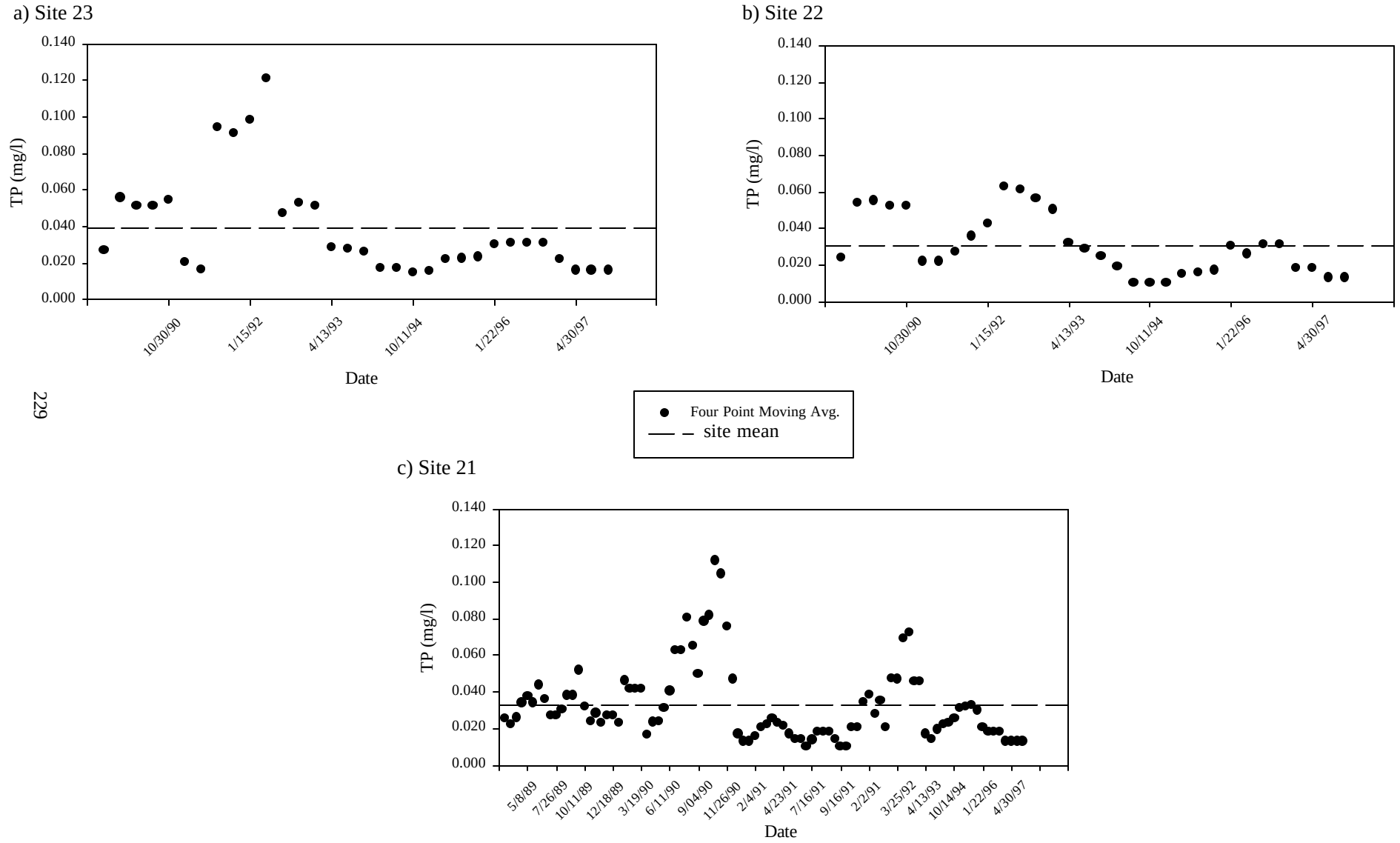


Figure III.98. Moving Four-Point Average of Total Phosphorus Levels in the North New River Canal from 1989-1997. Note the x-axis scale is different for Site 21 (c) because of biweekly measurements made from 1989-1997. Quarterly measurements were taken through the whole period at Sites 22 and 23.



M. Conclusions and Recommendations

- The implementation of the USEPA policy to stop WWTP discharges into surface water bodies improved the water quality of Broward's inland, freshwater canals.

- Two geographical areas of concern post-WWTPs are the Hillsboro Canal and the eastern C-11 Canal due to ambient nutrient (TN and/or TP) concentrations.

- Beyond the Hillsboro Canal and the eastern C-11 Canal, two initial nutrient groupings appear to occur throughout the remaining parts of the county:

    1. Nutrient Group I (Low TN, moderate TP): C-14 and C-12 Canals

    2. Nutrient Group II (Low TP, moderate TN): C-13, North New River, western C-11, and C-9 Canals

- Combined, Nutrient Groups I and II had median TP concentrations inversely correlated with median specific conductance values while median TN content was positively correlated with specific conductance.

- The correlations suggest that specific conductance may be a good tracer of distinct water masses and nutrient concentrations may reflect the geographical proximity to the Water Conservation Areas. However, basin specific elevation, soil type, and land uses must also be considered in future analyses.

- The early 1990's were typified by relatively high TP values at nearly every sampling site suggesting a countywide pattern such as rainfall amounts and/or groundwater elevations influence water quality observations.

- Although, in stream water quality constituents are important, the fate of the 'downstream' water bodies is of particular importance for the Everglades and the estuarine waters. Furthermore, the tolerance of the different 'receiving water bodies' may be quite different based on the ecotype (e.g., low TP Everglades vs. inorganic nitrogen to estuaries).

Specific research questions were developed for each basin. While each basin may have had unique questions (e.g., total phosphorus sources in Hillsboro Canal), the following recommendations were typically found in all basins. A prioritization of these recommendations should be performed as part of a Broward surface water management plan. For now, the following major recommendations include:

- As conveyance systems, a coupling of water quality conditions with water management activities (e.g., flow rates) and meterological conditions should be performed and compared to ambient water quality.

- The influence of land use and public infrastructure (e.g., sewer systems) needs to be better understood. A coupling of ambient water quality with upcoming NPDES stormwater and land use analyses should be performed.

- In-stream water quality investigations during and immediately after storm events would allow a more comprehensive understanding of these systems than currently exists.

- A better understanding is also needed on other parameters (e.g., potential toxics) in the urban canals, particularly after rain events.

- In Broward County, the biological response to nutrients needs to be better quantified, including continued chlorophyll a measurements.

- Biological characterization (phytoplankton, zooplankton, fish, and macroinvertebrates) should be performed to understand what types of organisms are living in these Class III waters of the state to determine if ecological imbalances have been and/or are occurring because of water quality conditions.

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