IV. Estuarine Waters

A. Introduction

Estuaries are semi-enclosed water bodies with a free connection to the sea and a defined freshwater source (Comp and Seaman, Jr. 1985). In addition, estuarine waters normally have a definitive salinity gradient. The importance of Florida estuaries as a nursery ground for numerous fish and invertebrate species has been well documented (Comp and Seaman Jr. 1985). In particular, mangrove (Lewis et al. 1985) and salt marsh habitats (Durako et al. 1985) occur around the state. Due largely to their biological significance, estuarine water quality has been and continues to be an important area of assessment in the state of Florida (Lietz 1999, Paulic et. al. 1996 or http://199.73.196.31/water/division/monitoring/pdf/ main305b.pdf, Hayward and Chamberlain 1996, Hillsborough County 1995, Graves and Strom 1992). These dynamic water bodies are typically dominated by a bay (e.g., Tampa Bay; http://www.tbep.org/) or a lagoon such as the Indian River Lagoon (http://www. evergladesplan.org/ projects/irl_main.htm) in central and northeast Florida. In the South Florida watershed, Biscayne Bay (http://www.evergladesplan.org/proj/feas_study/biscayne/index.htm, South Florida Water Management District 1989) lies to the south of Broward County in Miami-Dade County, while Lake Worth Lagoon (Palm Beach County Environmental Resource Management 1992) exists in Palm Beach County.

Broward County's estuarine waters are unique within the state of Florida because of the absence of a major bay or lagoon. In addition, habitats such as salt marshes and mangroves are relatively small compared to the linear miles of bulkheaded seawalls. Nonetheless, two contiguous Outstanding Florida Water bodies (John U. Lloyd State Park and West Lake Park, primarily mangrove forests; (see Florida Administrative Code [FAC] 62-302.700, State of Florida 1998) do exist in the southeast portion of the county (Figure IV.I). Furthermore, coral and artificial reef systems, as well as dynamic coastal fisheries exist offshore and include numerous species with estuarine dependent life stages. A large human population including commercial and recreational boaters and fishers also utilize the estuary. Finally, local citizen groups, such as the Broward Urban River Trails (Florida Greenways Program - 1000 Friends of Florida and the Conservation Fund 1995), have recently formed to raise awareness and enjoyment of these inland waterways. All of these components necessitate a water quality assessment of Broward's unique estuarine waters. An initial analysis will lead to a better understanding of historic and current conditions, as well as assist in the development of a surface water management plan similar to other estuaries around the state (e.g., Biscayne Bay Surface Water Implementation Plan, SFWMD 1989).

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 estuarine sampling site;
- Determine compliance patterns with Broward County's Chapter 27 water quality standards (Broward County 2000);

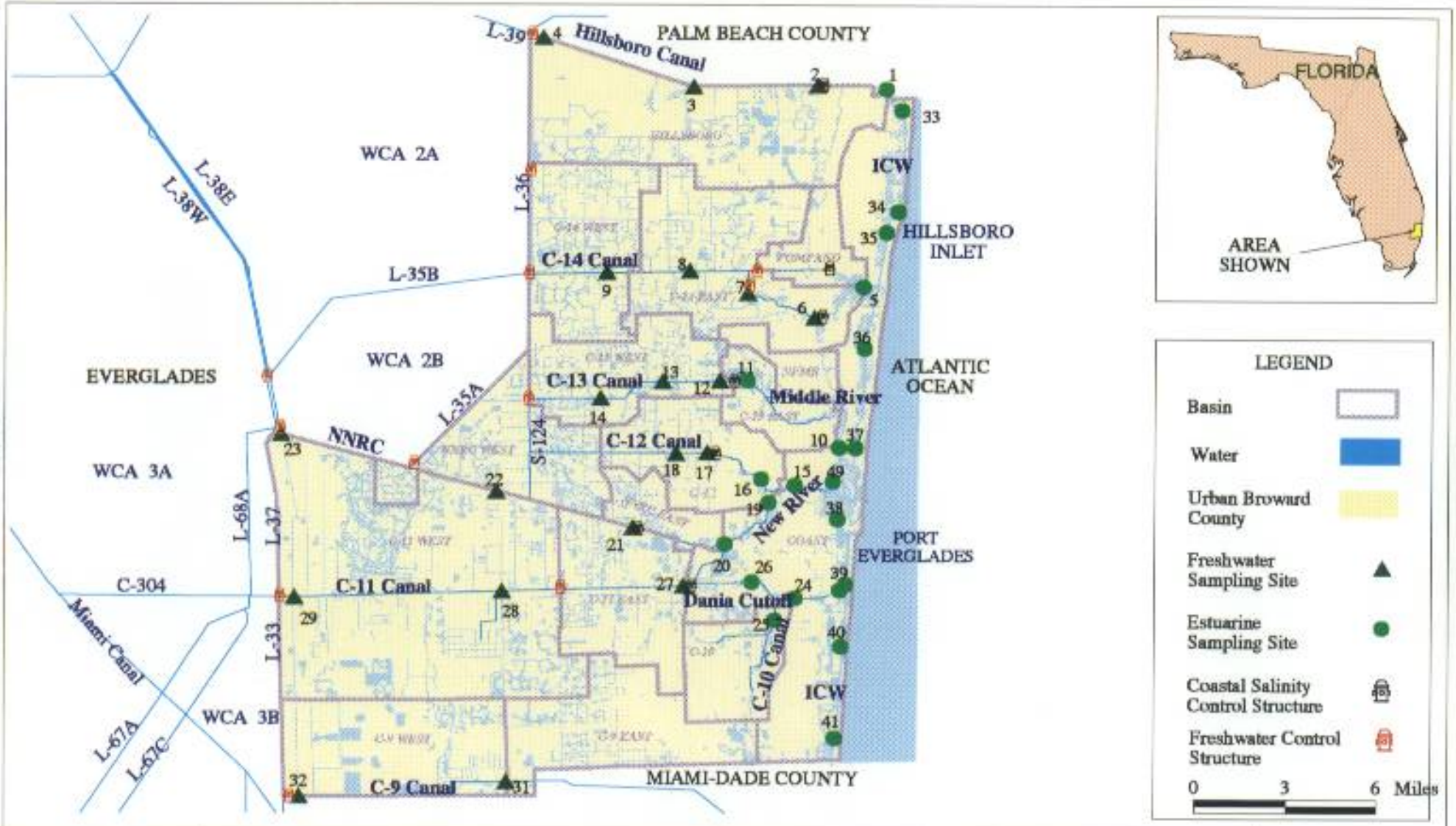

Figure IV.1. Urban Broward County Drainage Basins and Major Waterways. Estuarine and freshwater ambient water quality sampling sites are also shown. Coastal salinity structures, as well as water control structures (operated by South Florida Water Management District) on freshwater canals are also displayed.

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

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

At the core of this estuarine water quality investigation is a three-part process to be 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 is a historic snapshot of the total sampling effort at each particular site. The graphical analysis was performed to investigate inter-and intra- annual variation. Furthermore, graphical analyses were 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 Feasibility Study (http://www.evergladesplan.org/projects/wpa_main.htm).

C. Estuarine Regions

The estuarine regions in Broward County include the eastern, tidal components of the Hillsboro, C-14, C-13, and North New River Canals (Figure IV.1). The Dania Cut-off Canal is the eastern tailwaters of the S-13 control structure whose headwaters are the freshwater C-11 Canal system. The C-10 Canal is directly connected to the Dania Cut-off Canal and no structure exists between the two water bodies. In addition, remnant tidal rivers such as the New River and Middle River exist in central part of the county. Overall, the ICW and the New River system (including brackish North New River Canal, North and South Forks, main New River, and Tarpon River) are the two largest estuarine reaches. However, the two water bodies differ in their general flow characteristics and geographical orientation (Figure IV.1). In fact, the New River is a major tributary to the ICW's central region.

Currently, the ICW is the only waterway with a direct connection to the Atlantic Ocean. Two tidal inlets allow the main saltwater inflow. Port Everglades is the southern oceanic inlet located in the central region of the county and the Hillsboro Inlet exists at the northern end (Figure IV.1). Different flow regimes characterize the two inlets due, primarily, to their different shapes and water depth. The considerably deeper and wider inlet is Port Everglades which is a major commercial seaport with a

depth between 45 to 48 feet (approximately 15.0 meters, http://www.saj.usace.army.mil/conops/navigation/surveys/hydro.htm) and a channel width of approximately 0.5 miles (0.8 kilometers). Thus, a larger volume of water exchange occurs at Port Everglades than the Hillsboro Inlet which is more typical of the ICW morphology.

Originally constructed between 1893-1896, the ICW was further dredged to its current condition in 1965 (Crawford 1998). The ICW's average depth at low tide water is approximately 10 feet (3.0 meters) and average channel width is 125 feet (38.1 meters, Crawford 1998) with the exception being Port Everglades. Overall, the ICW extends approximately 24.5 linear miles (15.2 kilometers) in a north-south direction through eastern Broward County (Fig IV.1).

Six primary South Florida Water Management District (SFWMD) freshwater canals (see Section III.C) feed into five brackish tributary systems (Hillsboro Canal, C-14 Canal, Middle River, New River, and the Dania Cut-off/ C-10 Canals) to the west of the ICW (Figure IV.1). Overall, freshwater flows from the western areas of the county are intermittent because of the water control structures on each of the canals which artificially separate the freshwater basins from the eastern, brackish waters (see Cooper and Lane 1987).

For this report, the Broward estuary has been divided into five main areas including the division of the ICW into three geographical basins- north (NICW), central (CICW), and south (SICW), as well as the New River and Dania Cut-off/C-10 Canals systems (Figure IV.1). The ICW divisions were based on the proximity of the specific oceanic inlets and the western canals. Some hydrological overlaps likely exist between the three areas and adjacent counties, particularly between the northern and central basins. For example, the NICW basin is likely influenced by Palm Beach County and the Boca Raton Inlet.

The tributaries of the Hillsboro and C-14 canals were included in the NICW because of the close proximity of their monitoring sites to the ICW and they represent a single site for each canal (Figure IV.1). The CICW basin includes inflows from the C-13/Middle River system and the largest tributary system in the county, the New River, which receives freshwater primarily from the North New River Canal, C-12 Canal, and a large cooling discharge lake used by a Florida Power and Light electrical plant. The Middle River was not separated into a distinct region because no long term sampling sites exist within the main reaches of the river. Instead, sampling locations exist at the tailwaters of the S-36 in the tidal C-13 Canal (see BCDPEP Site 11, Section III.G) and near the confluence with the central region of the ICW which is included in the CICW.

The southern ICW basin is spatially distinct from the northern two areas due primarily to Port Everglades (Figure IV.1). Additionally, the southern end of the ICW is likely influenced by land use, water management practices, and discharges from Miami-Dade County, as well as tidal influences from Haulover Inlet. The C-11 (South New River Canal)/C-10/Dania Cut-off Canal system is the primary western source of water to the southern ICW Basin. However, this tributary probably only influences the northern extent of the SICW.

D. General Hydrological Characteristics

Within each freshwater basin that discharges to the upper estuarine regions, water control structure management by the SFWMD, Broward County Office of Environmental Services and/or Independent Drainage Districts is often determined by rainfall, water elevations, and/or threat of tropical storms and hurricanes. Flow volumes and rates 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. This results in the downstream estuarine waters being characterized by highly manipulated hydrological patterns (e.g., salinity regime), as well as modified channels and extensive seawall-lined shorelines. Most water input from the eastern areas is due to urban drainage while heavily modified flows occur because of the coastal control structures. Similar hydrologic conditions occur throughout the South Florida watershed and have been the focus of intensive studies and management plans in Biscayne Bay (Lietz 1999, SFWMD 1989) and the St. Lucie Estuary (Graves and Strom 1992; Chamberlain and Hayward 1996). However, the substantial loss of 'natural' habitat is primarily found in Broward, Miami-Dade, and Palm Beach counties.

Groundwater can also be an important inflow to the South Florida estuarine waters due primarily to the transmissive nature of the Biscayne Aquifer (Lietz 1999). Groundwater interaction with the estuarine waters 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, their figure 6). Thus, the interaction of estuarine waters and groundwater is an important factor in the operation of water control structures to protect public water supplies. Broward County is currently developing saltwater intrusion mapping to better understand these processes within the current study area (BCDPEP, in preparation).

With an average of fifty three inches of rain a year (see http://www.sfwmd.gov) and a large area of impervious, urban land uses, Broward's stormwater is considered a major transport mechanism for land based pollutants. Thus, stormwater infrastructure is often antiquated with little or no treatment of 'first flush' pollutants. For example, a recent study of the North Fork of the New River (BCDPEP 1999a) found very enhanced levels of pollutants in both the stormwater (e.g., total phosphorus) and riverine sediments adjacent to stormwater discharge outfalls (e.g., polycyclic aromatic hydrocarbons).

The data in the current report are from an ambient water quality monitoring program and not stormwater observations. Thus, the following results should be viewed as a 'snaphot' of how a waterbody's chemistry integrates stormwater inflows, groundwater interaction, salinity structure inflows, coastal water inflows, as well as the biological and physical processes that occur in aquatic systems.

E. ICW - Northern Basin

1. Geographic Locale

The Northern ICW basin (NICW) is located in the northeast corner of Broward County (Figure IV.2). The primary municipalities in this area are Deerfield Beach, Hillsboro Beach, Lighthouse Point, and Pompano Beach. Freshwater originates primarily from the Hillsboro and C-14 (Cypress Creek/Pompano) Canal systems while oceanic water enters the basin tidally from the Hillsboro Inlet.

2. Land Use and Activities Impacting Water Quality

A majority of the shoreline is densely populated with residential (houses and condominiums) and commercial properties (hotels, restaurants, and marinas). Very few areas along the ICW are without some type of buildings or structure and either a lawn and/or parking lot. Furthermore, bulkheaded seawalls dominate the main channel and numerous finger canal shorelines. One exception is the confluence of the Hillsboro Canal and the ICW where Deerfield Park Island (primarily mangrove and upland forest dominated communities) exists. The waterway is used primarily by a large volume of boat (recreational and commercial) traffic less than 100 feet in length. However, some large recreational and commercial boats (between 100-200 feet) also utilize the channel.

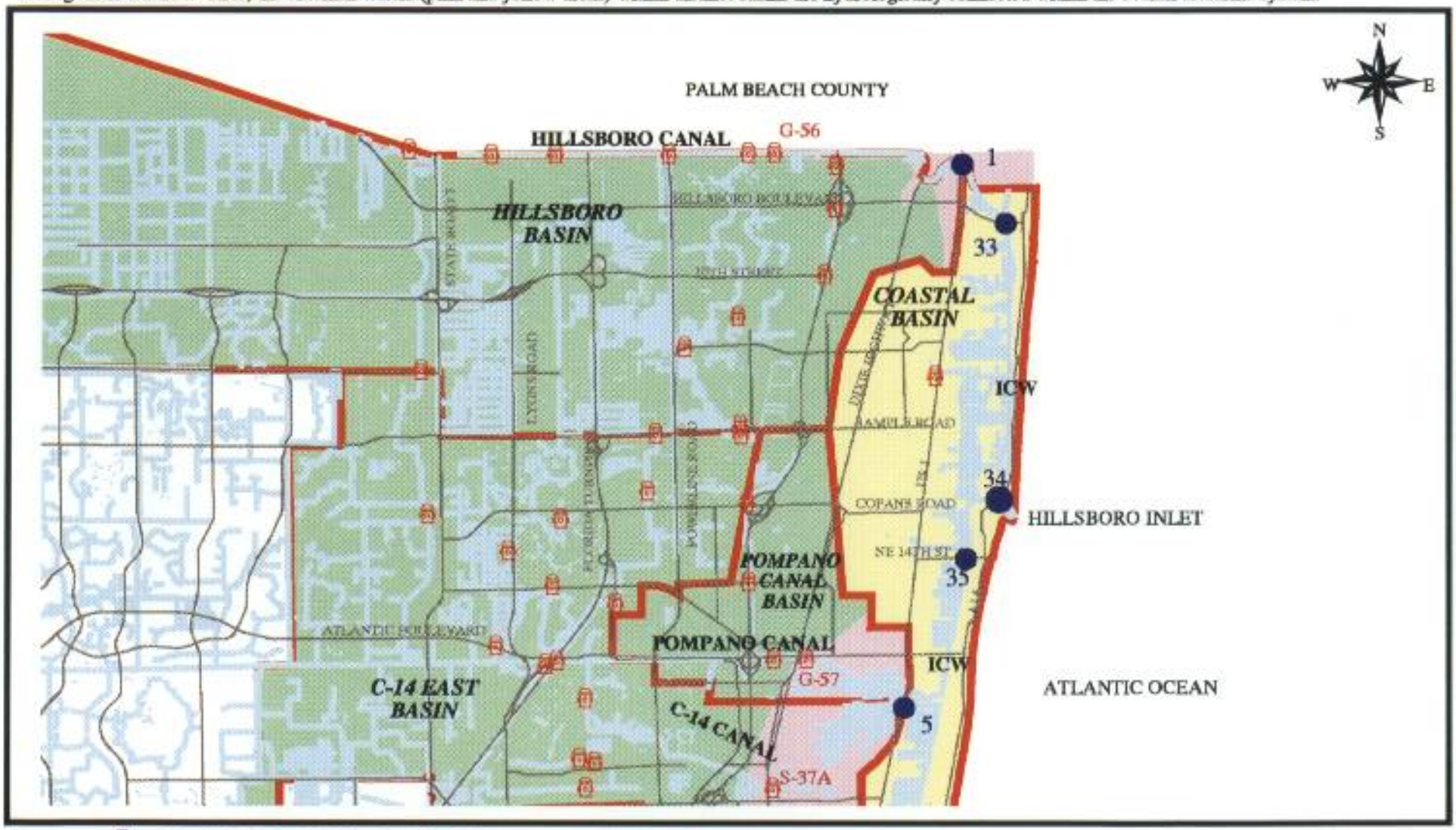
In some places, runoff occurs from the major roadways that run parallel to the ICW including Federal Highway and AIA. In addition, five major bridges are present in this study area. However, the majority of stormwater outfalls are at the dead end of finger canals that are prominent throughout the area. Two initial investigations have been performed by BCDPEP to understand the impacts of these outfalls to the surrounding waters (BCDNRP 1998, BCDPEP unpublished data). However the cumulative effect (acute and/or chronic) on the ICW is not known at this time.

The southeast corner of the basin is served by septic systems. This area is in unincorporated Broward County southeast of Lake Santa Barbara and west of State Road A1A (see Figure IV.2). The Sea Ranch Lakes community lies to the south and Pompano Beach is to the north. To date, a study on the potential influence of these septic systems has not been performed.

3. Wastewater Treatment Plants Discharge History

A majority of the wastewater treatment plants (WWTPs) stopped discharging into the NICW before 1980. The elimination of WWTP discharges into the C-14 Canal occurred after 1980 with the City of Oakland Park WWTP (4.10 million gallons per day capacity, mgd) closing in 1983. The Hillsboro Canal received at least some WWTP discharges until 1986, however, the highest volume of wastewater (3.57 million gallons per day capacity, City of Deerfield Beach) was phased out after 1981.

Figure IV.2. The Northern Intracoastal Waterway Basin and Broward County (BCDPEP) Sampling Sites Location Map. The brackish sections of the Hillsboro, Pompano, and C-14 Canals are shown in pink. These areas were delineated by the United States Army Corps of Engineers as separate basins from the Coastal basin. However, the respective receiving waterbodies are tidally connected and are downstream of the coastal water control structures (G-56, G-57, and S-37) operated by South Florida Water Management District. Thus, the brackish waters (pink and yellow areas) within distinct basins are hydrologically connected within the overall estuarine system.



BROWARD COUNTY

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4. Sampling Locations and Period

All monitoring sites are located in tidally influenced waters in the northeast corner of Broward County (Figure IV.2). Latitude and longitude measurements were determined by Global Position System and specific site descriptions are given in Appendix 1. Site 1 is in the eastern, tidal range of the Hillsboro Canal and is sampled from a bridge (US 1). Site 33 represents the northern-most ICW site and the area most influenced by the Hillsboro Canal. This site is sampled from a boat south of the Hillsboro Boulevard Bridge. Site 5 is in the eastern, tidal range of the C-14 Canal and is sampled from the US 1 bridge. Site 35 is located in the basin's southern ICW region at the 14th Street Causeway. Site 34 is located at the confluence of the ICW and the Hillsboro Inlet that leads to the Atlantic Ocean. Both Sites 34 and 35 are sampled by boat.

Sites 33 thru 35 have been sampled by BCDPEP since 1980, while Sites 1 and 5 have been monitored since 1973. As a major objective was to investigate each basin's differences and similarities, the data analysis in this section is restricted to the previous 18 years (i.e., 1980 thru 1997). Only temperature, dissolved oxygen, salinity, pH, and turbidity were measured during 1980. A majority of the remaining parameters (total Kjeldahl nitrogen, nitrite+nitrate-nitrogen, ammonia-nitrogen, total nitrogen [calculated], fecal coliform, total coliform, fecal streptococcus, total phosphorus, total organic carbon) were monitored beginning in 1981. Biochemical oxygen demand (7-day test) monitoring occurred from 1981 thru 1993 and specific conductance was recorded from 1990 thru 1997. Data methodology and manipulation for this section was performed as detailed in the methodology section (Section II).

5. Results

a. Physical Characteristics

Water temperatures throughout the basin were relatively similar and ranged between 18.0 degrees Celsius (^{o}C) and 32.2 ^{o}C (Table IV.1). Mean water temperatures from 1980-1997 ranged from 25.6 ± (standard deviation) 3.8^{o}C at Site 1 to 26.0 ± 3.3^{o}C for Site 35. The NICW Basin pH levels were also relatively similar between sites and showed little variability. The highest mean pH level was 7.9 ± 0.2 at Site 34 (Table IV.1). The two lowest averages were at the inland sites (1 and 5) where mean pH levels of 7.6 ± 0.2 (Sites 1 and 5) were recorded.

Large salinity ranges were observed throughout the basin between 1980 and 1997 (Table IV.1). Salinities at the two main channel ICW sites (33 and 35) were typically in the lower twenties but ranged from 1.4 to 34.5 parts per thousand (ppt, Site 33) and 3.6 to 36.5 ppt (Site 35). Site 34, adjacent to an oceanic inlet, exhibited the highest mean salinity in the basin (28.6 ± 7.7 ppt; Table IV.1) while the lowest mean salinity levels were observed at the inland Sites 1 (8.7 ± 7.4 ppt) and 5 (14.9 ± 10.2 ppt). Specific conductance was measured over a shorter time period than salinity but was also characterized by a wide range of values.

Table IV.1. Descriptive Statistics for Temperature (Temp;°C= Degrees Celsius), pH, Specific Conductance (Cond; Fmhos = micromhos), and Salinity (Sal; ppt= parts per thousand) in the NICW Basin. Calculations represent eighteen years of sampling (except Cond sampled 1980, 89, 90-97). However, the number of samples per year occasionally varied at each site. 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
1	Temp	°C	75	26.0	25.6	3.8	32.2	18	0
5	Temp	°C	65	26.5	26.0	3.5	32.0	18	0
33	Temp	°C	70	25.9	25.8	3.2	32.0	18	0
34	Temp	°C	69	25.7	25.7	3.2	31.5	18	0
35	Temp	°C	69	26.0	26.0	3.3	32.0	18	0
1	pH	units	75	7.6	7.6	0.2	8.3	6.9	0.0
5	pH	units	67	7.6	7.6	0.2	7.9	6.8	0.0
33	pH	units	73	7.8	7.7	0.3	8.2	7.0	0.0
34	pH	units	72	7.9	7.9	0.2	8.4	7.2	0.0
35	pH	units	72	7.9	7.8	0.3	8.4	6.8	0.0
1	Cond	Fmhos	32	12200	14599	12473	36100	688	0
5	Cond	Fmhos	32	23750	23373	15062	45800	1000	0
33	Cond	Fmhos	36	41750	33271	17508	51600	2800	0
34	Cond	Fmhos	36	49050	45919	9555	54800	15700	0
35	Cond	Fmhos	36	46050	40311	12739	55000	3200	0
1	Sal	ppt	72	7.4	8.7	7.4	24.9	0.25	10
5	Sal	ppt	64	18.0	14.9	10.2	29.8	0.25	4
33	Sal	ppt	69	23.9	21.0	10.2	34.5	1.40	0
34	Sal	ppt	70	32.0	28.6	7.7	36.2	6.80	0
35	Sal	ppt	69	27.2	24.9	8.3	36.5	3.60	0

b. Turbidity and Total Organic Carbon

With a mean of 16.53 ± 6.47 mg/l (n=60), Site 1 had the highest total organic carbon (TOC) concentrations during the 17 years of observations (Table IV.2). The two lowest TOC averages, 7.27 ± 5.83 mg/l (Site 34) and 7.97 ± 4.35 mg/l (Site 35) were observed closest to the Hillsboro Inlet. The basin's maximum total organic carbon concentration was 57.90 mg/l at Site 5.

Mean and median turbidity levels within the NICW were typically low and always within compliance of the Broward County water quality standard of 10 nephelometric turbidity units (ntus, Table IV.2). The basin's maximum turbidity value was 9.5 ntus at Site 1. However, all values were below (i.e., within compliance) of the standard of 10 ntus. From 1981 thru 1997, Site 1 also exhibited the highest mean of 2.4 ± 1.2 ntus (n=75), however, the remaining sites showed relatively similar values.

Table IV.2. Descriptive Statistics for Total Organic Carbon (TOC) and Turbidity (Turb) Concentrations in the NICW Basin. TOC (mg/l = milligrams per liter) and turbidity (ntu = nephelometric turbidity units) calculations represent seventeen and eighteen years, respectively, of sampling events. However, the number of samples per year occasionally varied at each site. 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
1	TOC	mg/l	60	15.85	16.53	6.47	33.80	4.16	0
5	TOC	mg/l	62	11.05	12.87	8.12	57.90	5.09	0
33	TOC	mg/l	60	9.65	11.13	6.54	37.90	0.32	0
34	TOC	mg/l	59	5.60	7.27	5.83	39.80	0.61	0
35	TOC	mg/l	60	7.00	7.97	4.35	25.10	1.66	0
1	Turb	ntu	75	2.2	2.4	1.2	9.5	0.8	0
5	Turb	ntu	67	1.4	1.4	0.6	3.4	0.3	1
33	Turb	ntu	73	1.8	2.3	1.6	8.3	0.5	2
34	Turb	ntu	72	1.3	1.6	1.4	8.1	0.3	4
35	Turb	ntu	72	1.4	1.5	1.0	8.0	0.3	1

c. Dissolved Oxygen and Biochemical Oxygen Demand

Over the eighteen-year period, dissolved oxygen concentrations were normally lower at the tributary sites (1 and 5, Table IV.3) than the ICW locations. Site 34 exhibited the highest average dissolved oxygen levels (6.1 ± 0.9 mg/l) while intermediate means values were observed at Sites 33 and 35. Yet, all eighteen-year averages and medians were above (i.e., within compliance) the Broward County dissolved oxygen standard (single sample) of 4.0 mg/l.

Long term biochemical oxygen demand (BOD) values were slightly higher at the tributary Sites 1 and 5 than at ICW Sites 33 thru 35 (Table IV.3) but values were normally less than 2.0 mg/l throughout the basin. Furthermore, the current marine BOD standard (7.0 mg/l) was never exceeded by maximum values at each site meaning all samples were within compliance.

Table IV.3. Descriptive Statistics for Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) Concentrations in the NICW Basin. All DO (mg/l = milligrams per liter) calculations represent eighteen years of sampling, however, the number of samples per year occasionally varied at each site. BOD samples from 1981 to 1993 were analyzed. 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
1	DO	mg/l	74	5.3	5.1	1.1	7.5	2.1	0
5	DO	mg/l	65	5.0	5.2	1.1	7.6	3.0	0
33	DO	mg/l	72	5.6	5.5	1.1	8.1	2.4	0
34	DO	mg/l	71	6.2	6.1	0.9	8.9	3.9	0
35	DO	mg/l	71	5.9	5.8	1.2	9.4	2.3	0
1	BOD	mg/l	47	2.0	2.1	0.9	5.8	0.5	0
5	BOD	mg/l	48	1.4	1.6	0.8	4.2	0.5	0
33	BOD	mg/l	48	1.2	1.3	0.7	3.4	0.1	0
34	BOD	mg/l	47	1.0	1.2	0.7	3.3	0.2	0
35	BOD	mg/l	47	1.2	1.3	0.7	3.2	0.2	0

Yearly averages also revealed similar compliance with water quality standards as long term descriptive statistics (Figure IV.3). In addition, dissolved oxygen levels were relatively consistent through time with the exception of Site 5 in 1981, when a yearly mean of 3.8 ± 0.5 mg/l was observed. Site 1 exhibited slightly depressed values in 1983 (4.3 ± 1.1 mg/l) and 1995 (4.4 ± 1.0 mg/l).

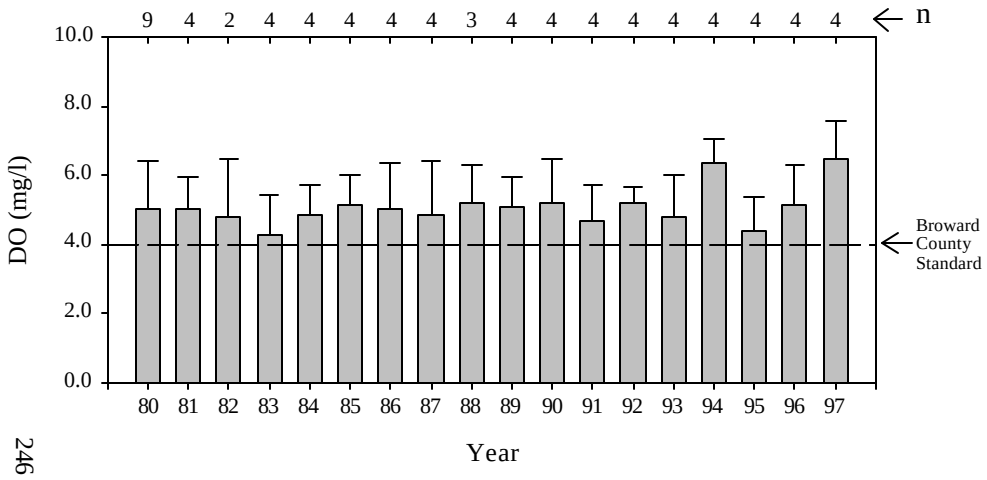
To understand compliance patterns within the basin, each individual DO observation was given a rating based on Broward County's water quality standards. DO concentrations were designated as poor (below the single sample standard; 4.0 mg/l), fair (above the single sample standard but below the daily average standard of 5.0 mg/l), and good (above both standards). In addition, the changes over time are presented with special reference to the closing of WWTPs within in the C-14 and Hillsboro Canals (see Section IV.E.3). The periods shown are 1980-86, 1987-1991, and 1992-1997.

Samples rating poor were normally below twenty percent during the whole study period (Figure IV.4). One exception was at Site 1 during 1987 through 1991, when 26.3% of the samples were below 4.0 mg/l. Furthermore, the northern area of the basin (i.e., Sites 1 and 33) had the highest percentages of poor dissolved oxygen from 1992-1997. However, the combined good and fair percentages were over 85% for all sites during the most recent period. Sites 5 and 35 exhibited general improvements through time, while Sites 33 and 34 were relatively similar in their distribution between good, fair, and poor. Site 34 had the highest percentage of 'good' dissolved oxygen levels in all three time periods.

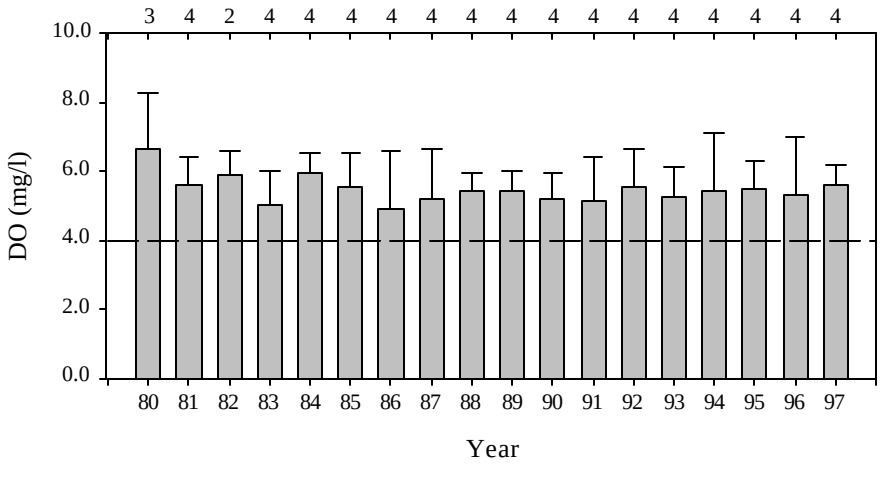
Seasonal influences on DO concentrations were investigated by pooling wet (June through October) and dry (November through May) season samples from 1989-1997, a period without WWTP influence (Figure IV.5). From 1989 to 1997, higher dissolved oxygen values were normally observed during the dry season (November through May) then during the wet season. Statistically significant

Figure IV.3. Annual Mean Dissolved Oxygen (DO) Content Within the Northern Intracoastal Waterway (NICW) Basin from 1980 to 1997. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless 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 1



b) Site 33



c) Site 34

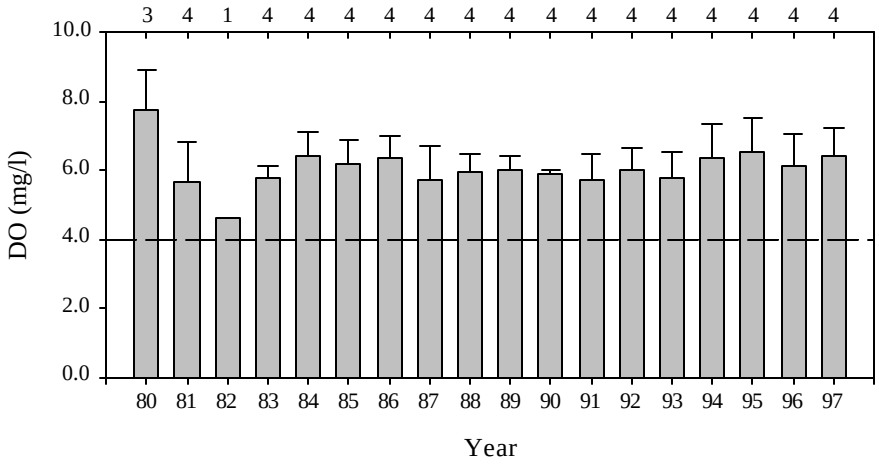
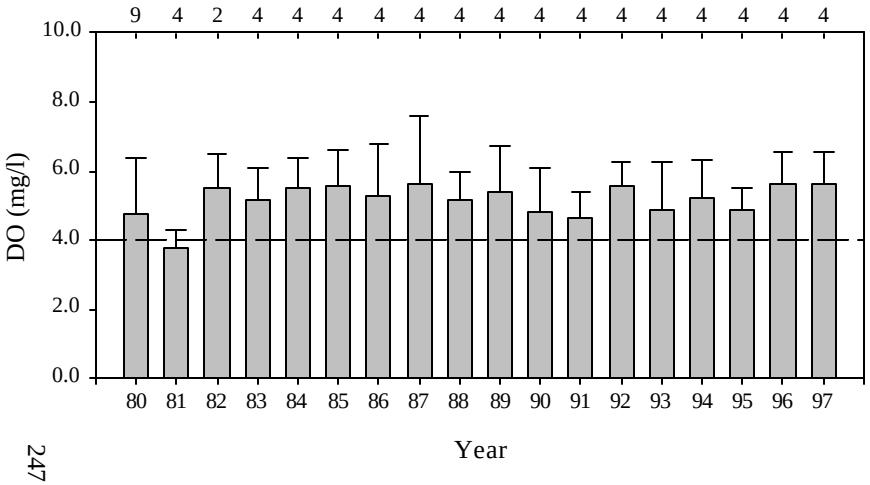


Figure IV.3 (cont.). Annual Mean Dissolved Oxygen (DO) Content Within the Northern Intracoastal Waterway (NICW) Basin from 1980 to 1997. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. DO levels should be above the Broward County standard (4.0 mg/l) indicated by the dashed line.

d) Site 5



e) Site 35

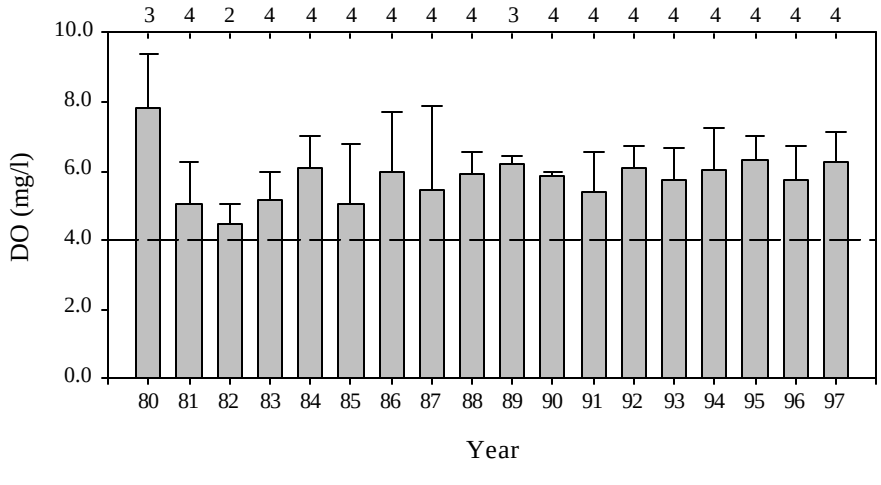


Figure IV.4. Dissolved Oxygen (DO) Concentrations Observed in the Northern Intracoastal Waterway Basin over Three Time Periods. DO samples are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall be below 4.0 mg/l. Thus, all concentrations greater than or equal to 5.0 mg/l are classified as good and DO levels between 4.0 to 4.9 mg/l are labeled fair. The direct influence of wastewater treatment plant discharges ended after 1986.

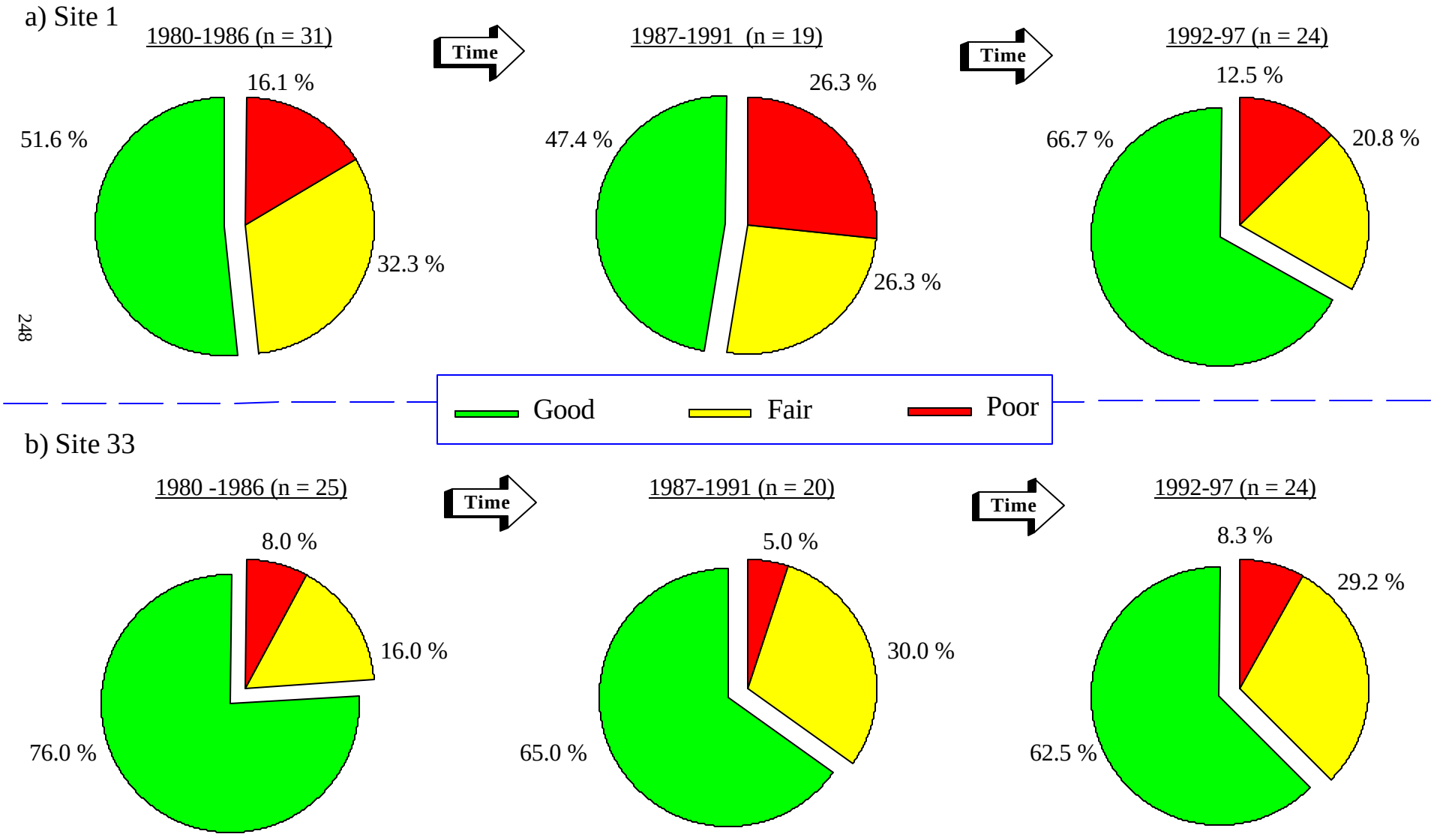
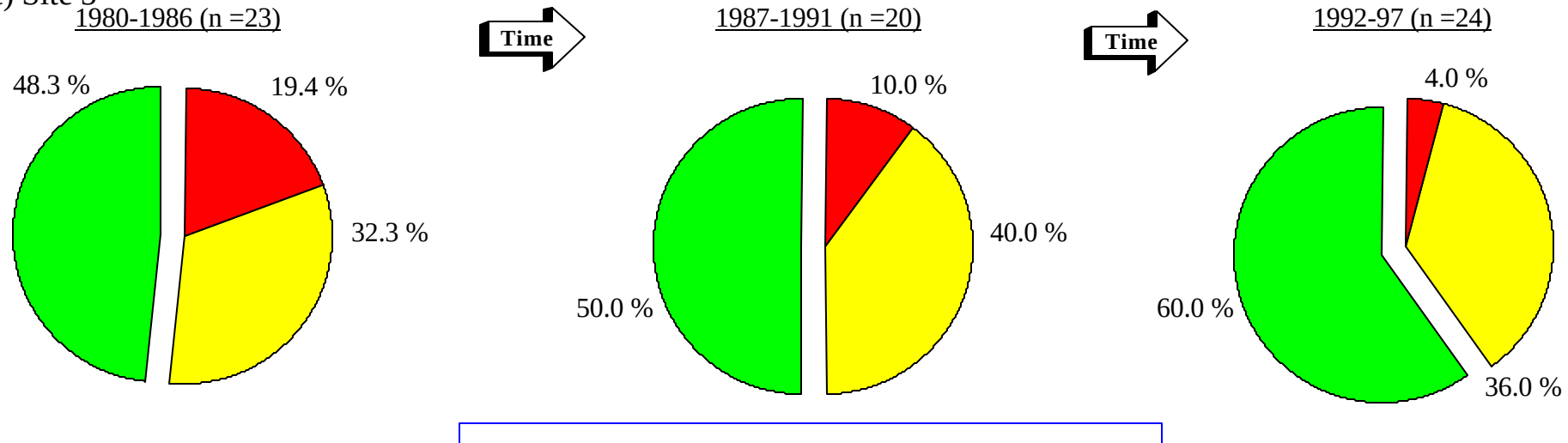
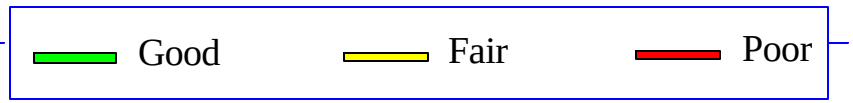


Figure IV.4 (cont.). Dissolved Oxygen (DO) Concentrations Observed in the Northern Intracoastal Waterway Basin over Three Time Periods. DO samples are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading 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 levels between 4.0 to 4.9 mg/l are labeled fair. Readings below 4.0 mg/l are defined as poor.

c) Site 5





d) Site 35

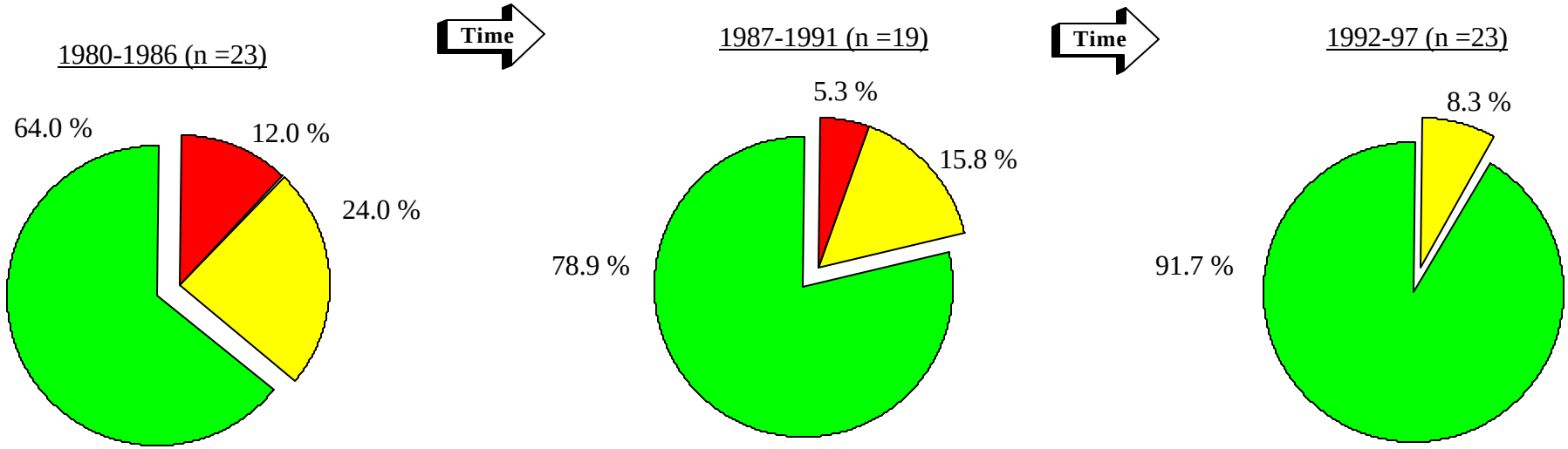


Figure IV.4 (cont.). Dissolved Oxygen (DO) Concentrations Observed in the Northern Intracoastal Waterway Basin over Three Time Periods. DO samples are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading 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 levels between 4.0 to 4.9 mg/l are labeled fair. Readings below 4.0 mg/l are defined as poor.

e) Site 34

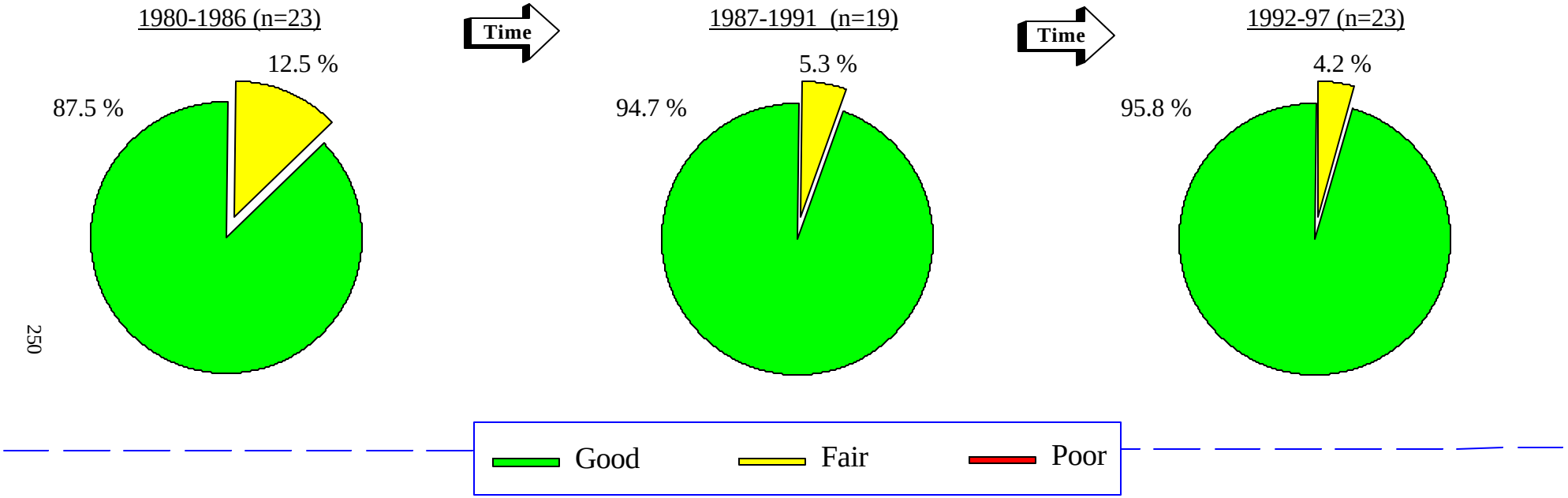


Figure IV.5. Northern Intracoastal Waterway Basin Dissolved Oxygen (DO) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples 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 33, 34, 35, and 5 ($p < 0.001$, t-test), as well as Site 1 ($p < 0.05$, t-test).

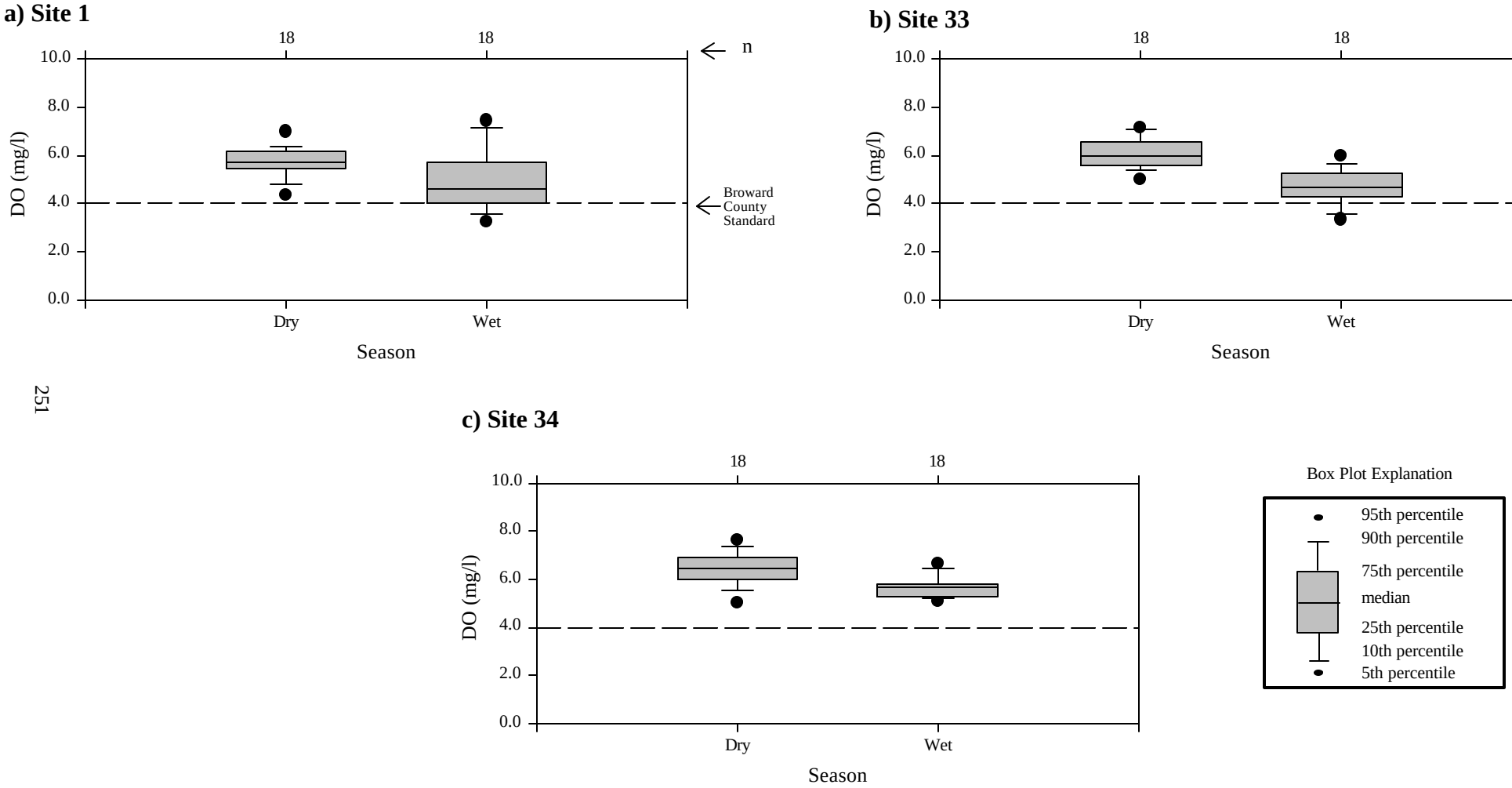
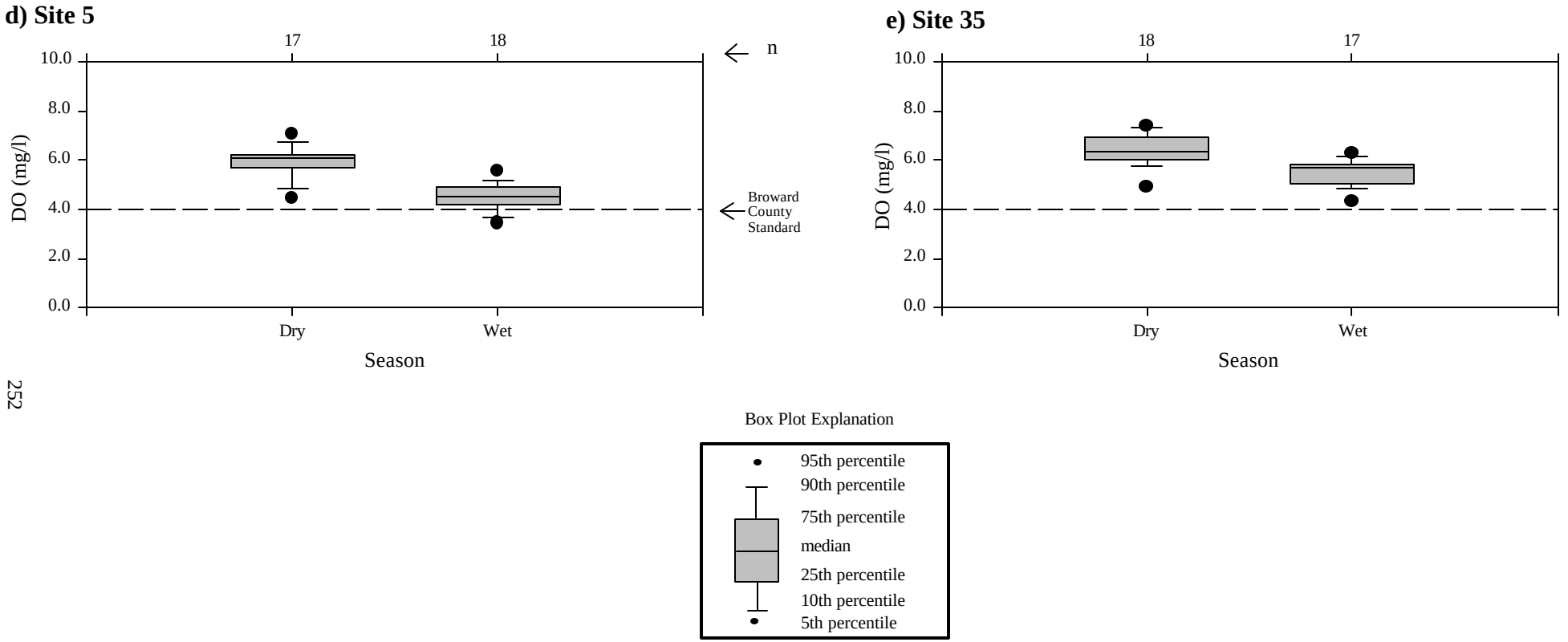


Figure IV.5 (Cont.). Northern Intracoastal Waterway Basin Dissolved Oxygen (DO) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. Statistically significant differences between wet and dry season means were observed at Sites 33, 34, 35, and 5 ($p < 0.001$, t-test), as well as Site 1 ($p < 0.05$, t-test).



differences were observed between seasons at Sites 5, and 33-35 (t-test, $p < 0.001$), as well as Site 1 (t-test, $p < 0.05$). All median values (wet and dry season) were greater than the 4.0 mg/l single sample standard. Site 1 had the most observations below the standard while Sites 34 and 35 had the most above 4.0 mg/l.

d. Total Phosphorus

At all five sites, the seventeen-year mean total phosphorus (TP) levels were elevated above the Broward County marine standard of 0.050 mg/l standard (Table IV.4). Overall, the inland sites exhibited the highest values (0.159 ± 0.115 mg/l; Site 1; 0.126 ± 0.253 mg/l; Site 5). Variability around the mean was relatively high and median values were lower than the means at all sites.

Table IV.4. Descriptive Statistics for Total Phosphorus (TP) Concentrations in the NICW Basin. All calculations represent seventeen years of sampling. However, the number of samples per year occasionally varied at each site. 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
1	TP	mg/l	72	0.145	0.159	0.115	0.898	0.010	3
5	TP	mg/l	67	0.066	0.126	0.254	2.050	0.010	6
33	TP	mg/l	67	0.098	0.101	0.066	0.375	0.010	3
34	TP	mg/l	66	0.043	0.061	0.057	0.279	0.010	18
35	TP	mg/l	66	0.057	0.080	0.090	0.626	0.010	12

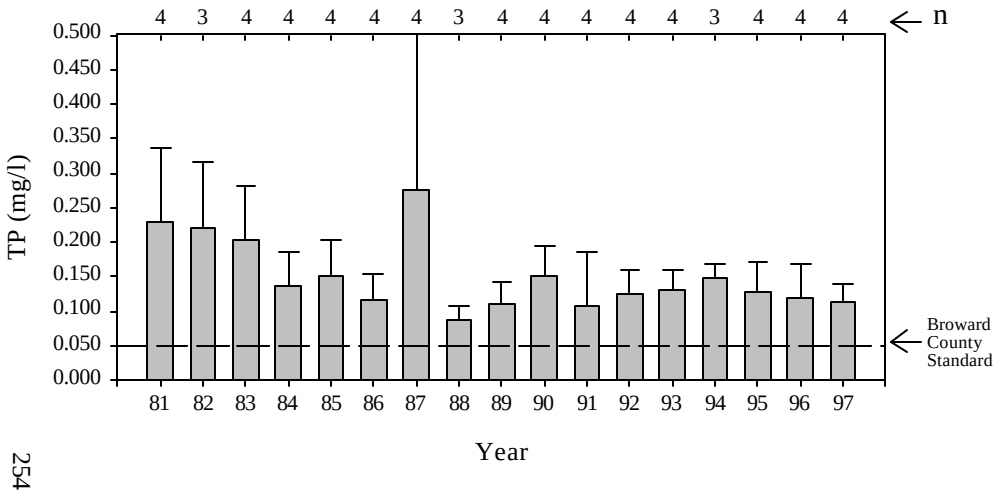
Annual averages explain much of the variability associated with the long term means. For example, Site 5's yearly TP averages were greater than or equal to 0.100 mg/l five times from 1981 to 1987 (Figure IV.6). However, from 1993 to 1997, mean TP concentrations were near or below 0.050 mg/l. With few exceptions, Sites 35 and 34 also show lower TP concentrations during the 1993 thru 1997 period then during the previous years of sampling. However, the northern part of the basin (Sites 1 and 33) displayed elevated yearly TP averages throughout the study period. In particular, the yearly mean for Site 1 was only below 0.100 mg/l once during the seventeen-year span (1988 mean = 0.087 ± 0.022 mg/l).

To further investigate TP values over time, all individual samples were rated in terms of Broward County's marine TP standard (0.050 mg/l). TP concentrations were designated as poor if they are 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. A poor designation was given to values greater than 0.100 mg/l. In addition, changes over time were investigated with special reference to the closing of WWTPs within the basin (see Section IV.E.3). The periods compared were 1981-1986, 1987-1991, and 1992-1997.

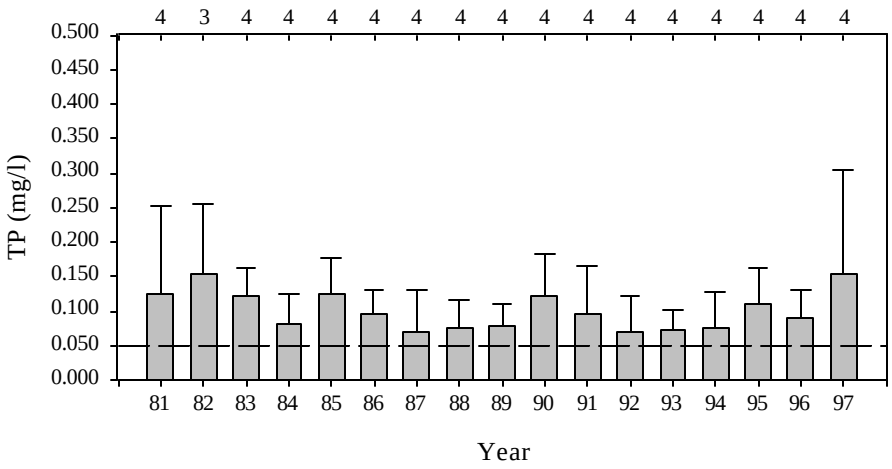
Overall, the northern area of the basin had a majority of TP samples within the poor or fair rating (Figure IV.7). Except for a small percentage of samples (15.8%) during the 1987-1991 period, Site

Figure IV.6. Annual Mean Total Phosphorus (TP) Content Within the Northern Intracoastal Waterway (NICW) Basin from 1981 to 1997. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. TP levels should be below the Broward County marine standard (0.050 mg/l) indicated by the dashed line.

a) Site 1



b) Site 33



c) Site 34

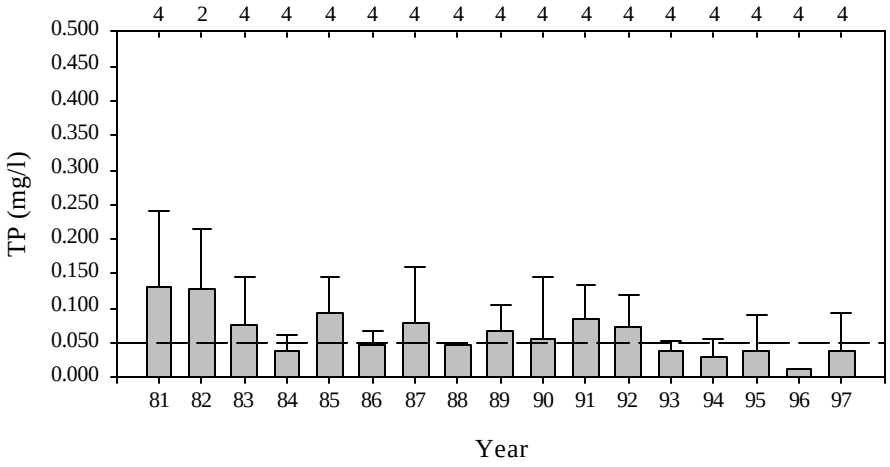
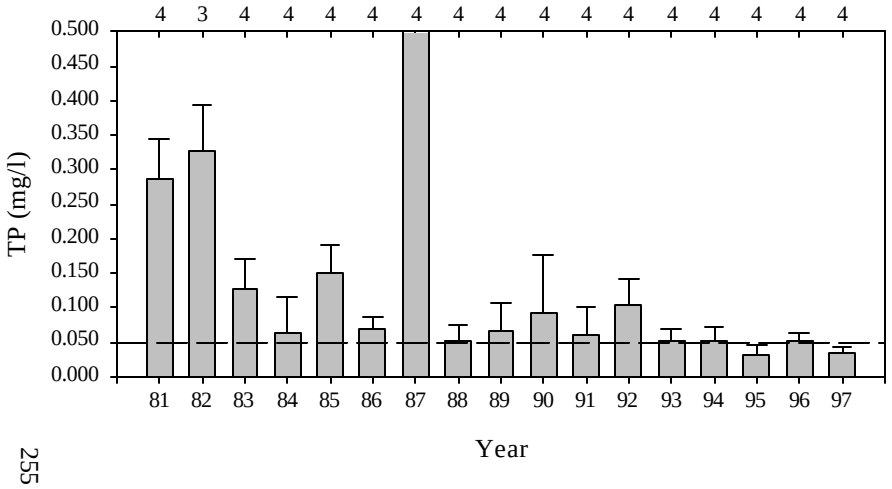


Figure IV.6 (cont.). Annual Mean Total Phosphorus (TP) Content Within the Northern Intracoastal Waterway (NICW) Basin from 1981 to 1997. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. TP levels should be below the Broward County marine standard (0.050 mg/l) indicated by the dashed line.

d) Site 5



e) Site 35

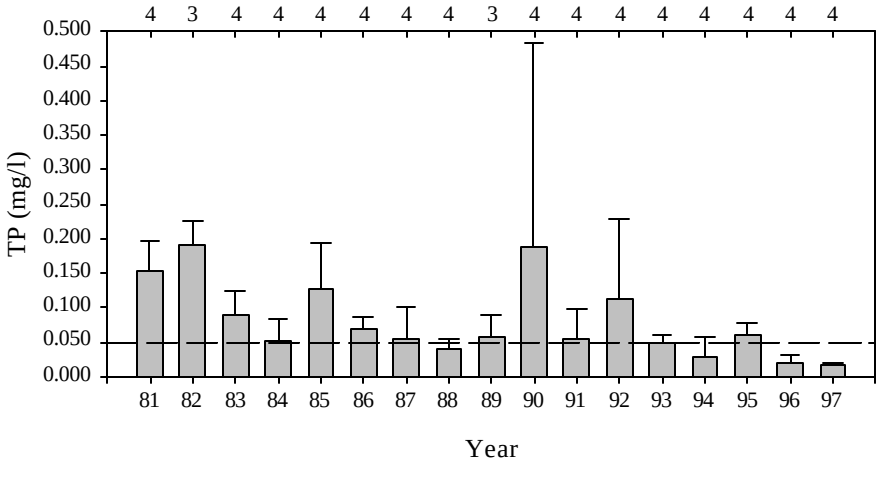


Figure IV.7. Total Phosphorus (TP) Concentrations Observed in the Northern Intracoastal Waterway Basin over Three Time Periods. TP levels are categorized in terms of compliance with the Broward County marine standard of 0.050 mg/l. The percentage below 0.050 mg/l are classified as good. A fair rating was given to values between 0.051 mg/l to 0.099 mg/l. Values equal to or greater than twice the standard (i.e., 0.100 mg/l) are classified as poor.

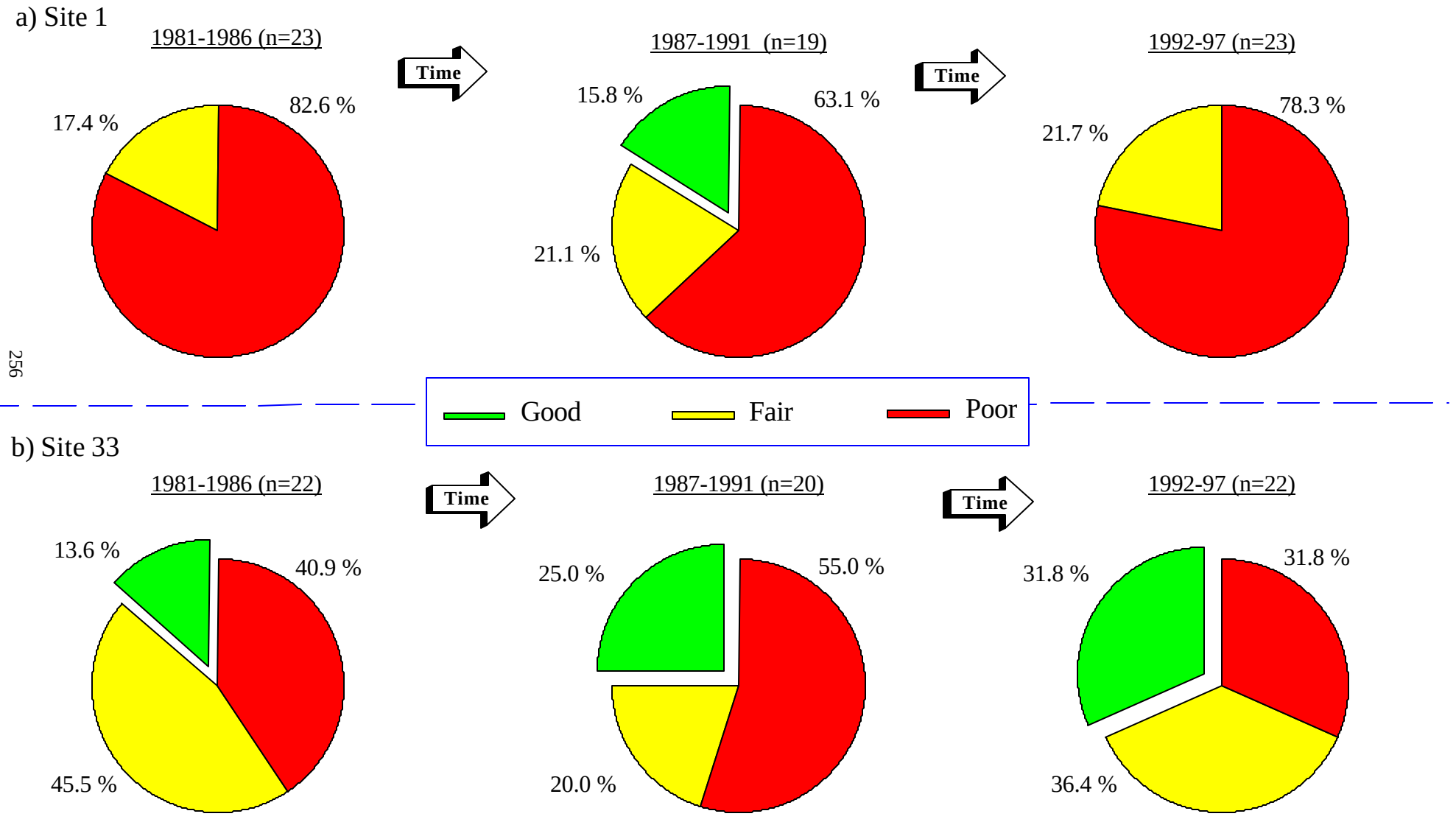
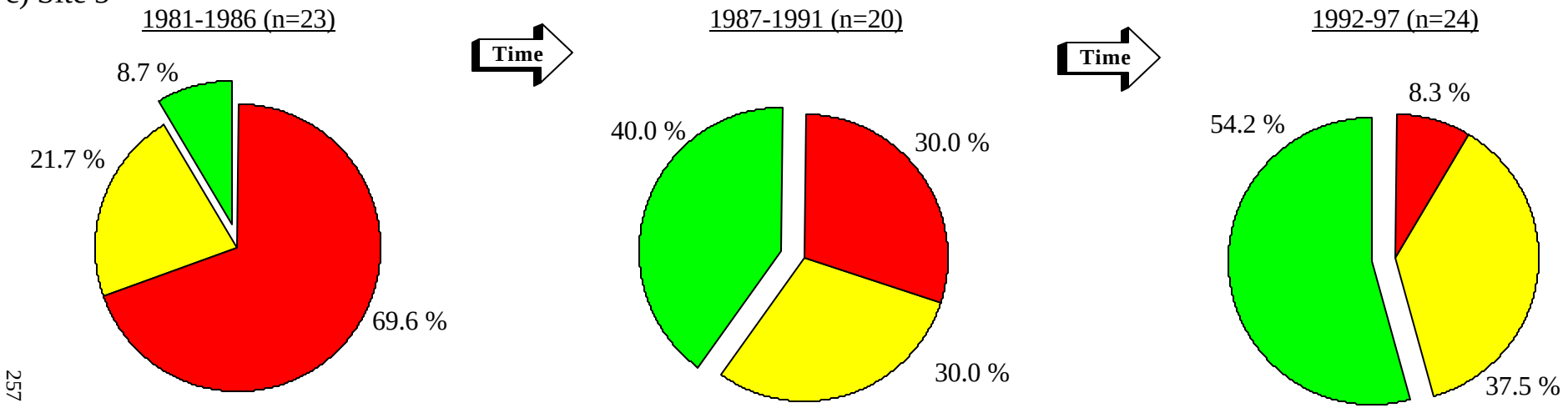
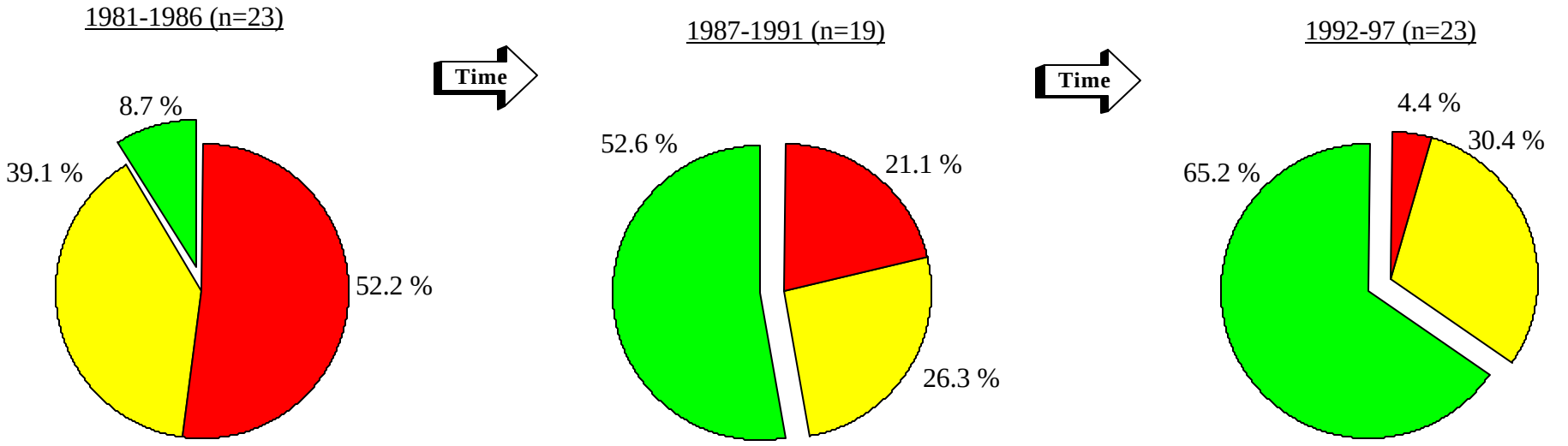


Figure IV.7 (cont.). Total Phosphorus (TP) Concentrations Observed in the Northern Intracoastal Waterway (ICW) Basin over Three Time Periods. TP levels are categorized in terms of compliance with the Broward County marine standard of 0.050 mg/l. The percentage below 0.050 mg/l are classified as good. A fair rating was given to values between 0.051 mg/l to 0.099 mg/l. Values equal to or greater than twice the standard (i.e., 0.100 mg/l) are classified as poor.

c) Site 5



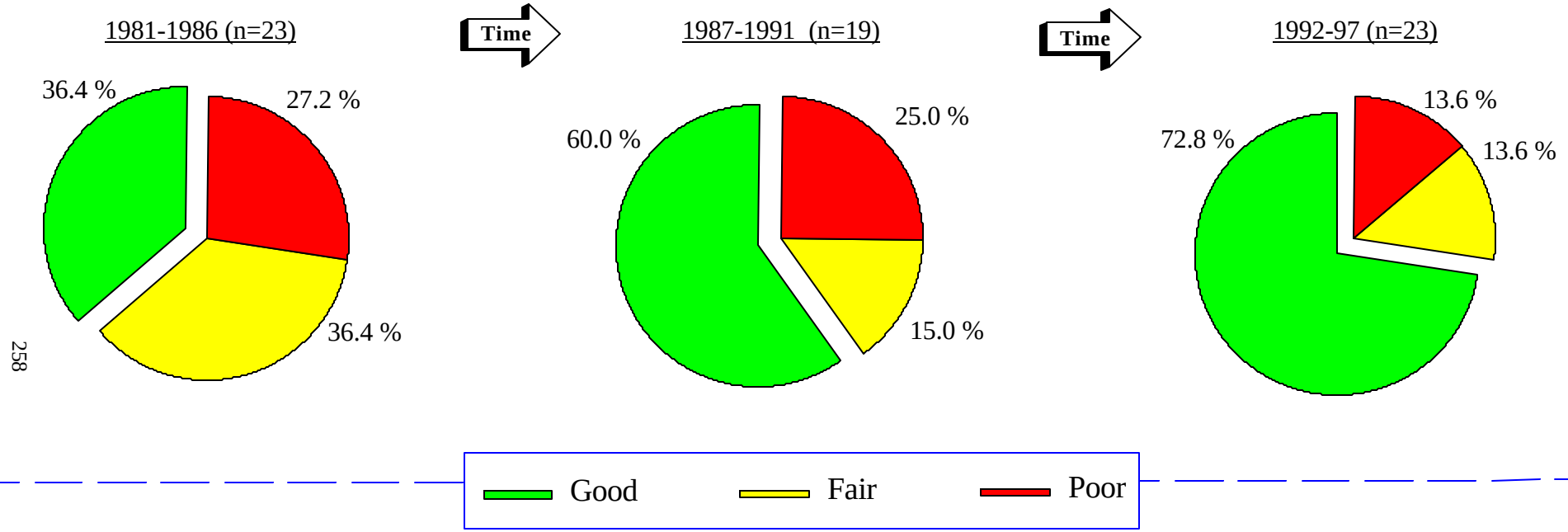
d) Site 35



Good Fair Poor

Figure IV.7 (cont.). Total Phosphorus (TP) Concentrations Observed in the Northern Intracoastal Waterway Basin over Three Time Periods. TP levels are categorized in terms of compliance with the Broward County marine standard of 0.050 mg/l. The percentage below 0.050 mg/l are classified as good. A fair rating was given to values between 0.051 mg/l to 0.099 mg/l. Values equal to or greater than twice the standard (i.e., 0.100 mg/l) are classified as poor.

e) Site 34



1 did not have any TP concentrations classified as good. Site 33 had a higher percentage of good ratings than Site 1, but still contained a large majority of samples above the Broward County standard (i.e., fair and poor combined).

As seen in dissolved oxygen concentrations, the southern portion of the basin showed improvement over time (Figure IV.7). From 1981-1986, only 8.7% of the samples were designated as having good quality at Sites 5 and 35. By the 1992-97 period, the percentage of good samples was 54.2% and 65.2% for Sites 5 and 35, respectively. Site 34 similarly demonstrated improved TP levels over seventeen years and displayed the highest amount of good samples (72.8%, n=23) over the previous six years. However, the percentage of poor samples was slightly higher at Site 34 than either Site 5 or 35 from 1992 to 1997.

Seasonal (wet and dry) observations from 1989-97 revealed relatively no differences between seasons at four of five sites (Figure IV.8). Only at Site 1 was mean wet season total phosphorus content significantly greater than the dry season (t-test, $p < 0.001$). However, the mean dry season total phosphorus content from 1989-1997 was still over twice the Broward County marine standard (0.050 mg/l) and higher than all other NICW sites (wet or dry season medians; Figure IV.8). Site 33 also was characterized by enhanced TP levels and showed the greatest range in values in the basin. Finally, all sites had 75^{th} percentile values above 0.050 mg/l and 90^{th} percentile TP concentrations near or above 0.100 mg/l.

e. Total Nitrogen

Total Nitrogen levels are calculated from the total Kjeldahl nitrogen (TKN) and nitrate+nitrate-nitrogen (NO_2+NO_3) concentrations. Mean TN values over the seventeen-year period were below 1.000 mg/l at four of the five sites and all sites were well within compliance of the Broward County marine standard (1.500 mg/l, Table IV.5). A large majority of the nitrogen was comprised of TKN which measures the total amount of organic nitrogen and ammonia-nitrogen (Table IV.5.). Ammonia-nitrogen levels were typically low and in many cases below the method detection limit. Thus, organic nitrogen was the major form of the total nitrogen values observed during this study. However, long term median NO_2+NO_3 concentrations were relatively higher at the inland sites (1 and 5) compared to other NICW locations and Site 33's median was slightly elevated (> 0.075 mg/l).

Figure IV.8. Northern Intracoastal Waterway 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. A statistically significant difference between wet and dry season means was only observed at Site 1 ($p < 0.001$, t-test).

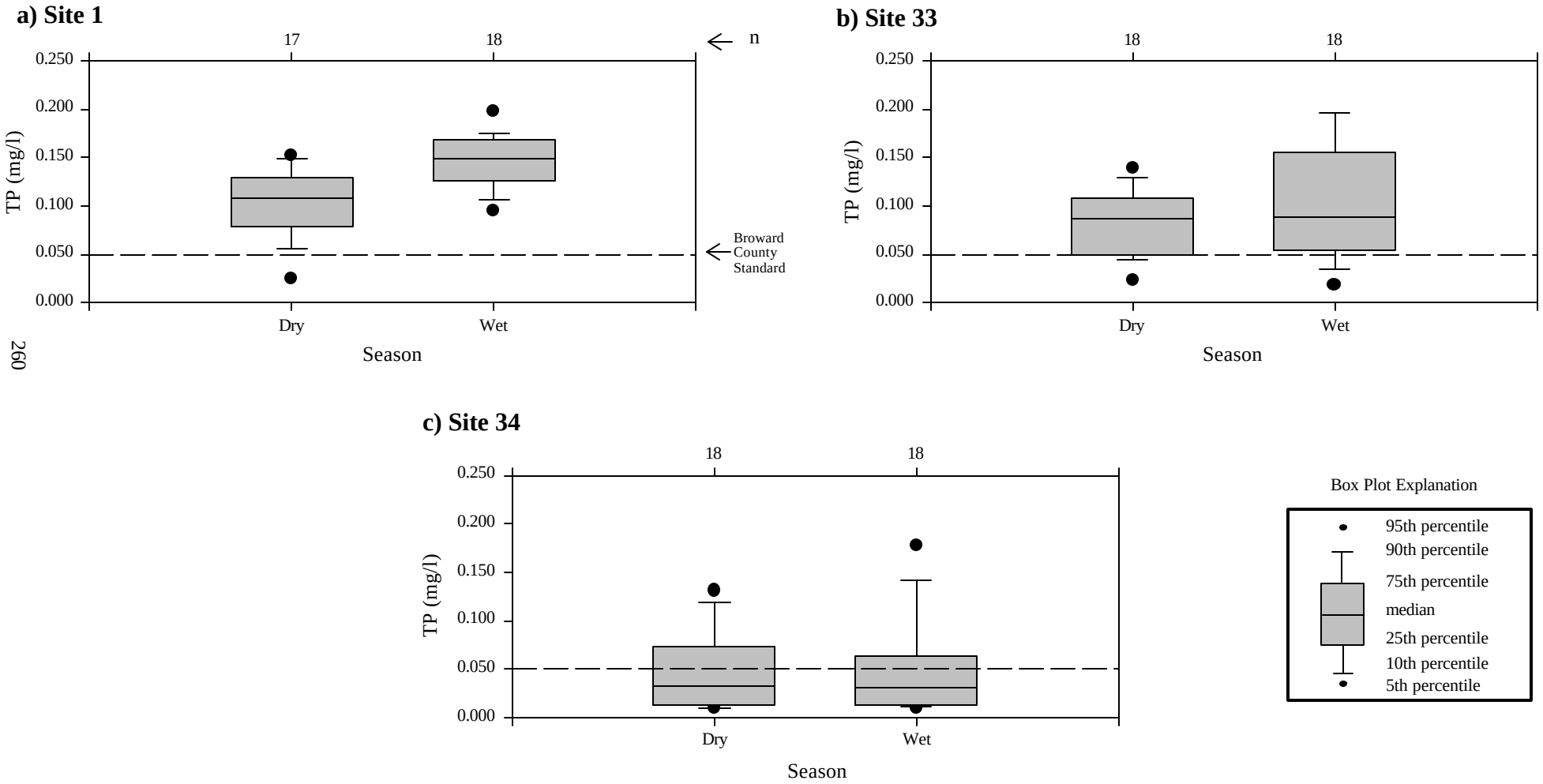


Figure IV.8 (Cont.). Northern Intracoastal Waterway Basin Total Phosphorus (TP) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. A statistically significant difference between wet and dry season means was only observed at Site 1 ($p < 0.001$, t-test).

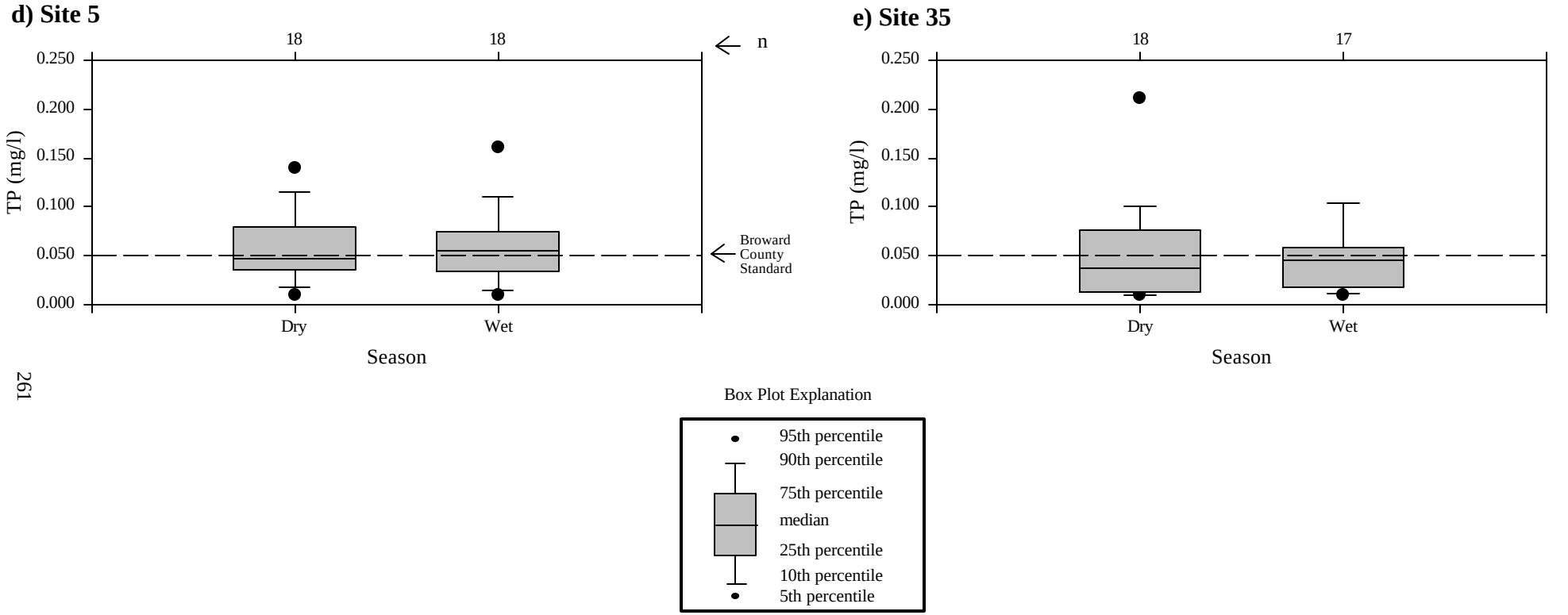


Table IV.5. Descriptive Statistics for Nitrite+Nitrate-Nitrogen (NO_2+NO_3), Ammonia-Nitrogen (NH_3), Total Kjeldahl Nitrogen (TKN), and Total Nitrogen (TN) in the NICW Basin. Total Nitrogen was calculated as the sum of TKN and NO_2+NO_3. All calculations represent seventeen years of sampling. However, the number of samples per year occasionally varied at each site 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).

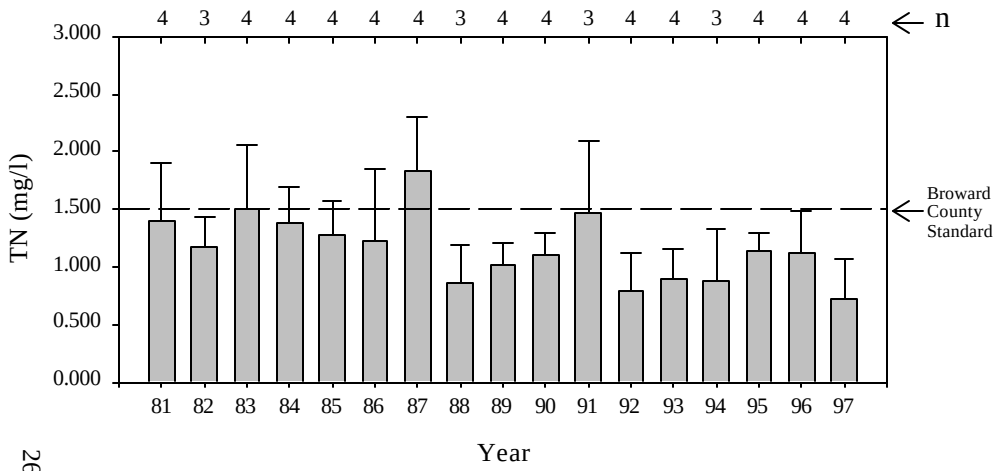
Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
1	NO_2+NO_3	mg/l	65	0.118	0.153	0.168	1.010	0.005	7
5	NO_2+NO_3	mg/l	67	0.104	0.117	0.087	0.400	0.005	4
33	NO_2+NO_3	mg/l	67	0.075	0.108	0.107	0.614	0.005	6
34	NO_2+NO_3	mg/l	66	0.047	0.076	0.104	0.601	0.005	12
35	NO_2+NO_3	mg/l	66	0.062	0.087	0.085	0.376	0.005	10
1	NH_3	mg/l	60	0.079	0.090	0.082	0.370	0.005	16
5	NH_3	mg/l	63	0.074	0.167	0.308	1.430	0.009	17
33	NH_3	mg/l	62	0.054	0.072	0.073	0.366	0.005	18
34	NH_3	mg/l	61	0.025	0.039	0.048	0.223	0.005	39
35	NH_3	mg/l	61	0.025	0.079	0.110	0.563	0.005	27
1	TKN	mg/l	64	1.013	1.018	0.354	1.940	0.342	0
5	TKN	mg/l	66	0.752	0.881	0.427	1.980	0.040	1
33	TKN	mg/l	66	0.726	0.796	0.409	3.230	0.134	0
34	TKN	mg/l	65	0.632	0.633	0.301	1.350	0.040	2
35	TKN	mg/l	65	0.686	0.683	0.290	1.320	0.054	1
1	TN	mg/l	64	1.115	1.172	0.439	2.380	0.477	Calc
5	TN	mg/l	66	0.887	0.998	0.474	2.162	0.144	Calc
33	TN	mg/l	66	0.804	0.905	0.437	3.283	0.165	Calc
34	TN	mg/l	66	0.690	0.699	0.336	1.591	0.048	Calc
35	TN	mg/l	66	0.790	0.759	0.324	1.658	0.033	Calc

Annual means revealed some decrease in TN content over the previous 17 years (Figure IV.9). In particular, the TN content from 1992-1997 at the inland sites (1 and 5) was generally lower and exhibited less variability then during 1981-1991. Annual total nitrogen levels in the ICW (Sites 33-35) were relatively consistent throughout the study period.

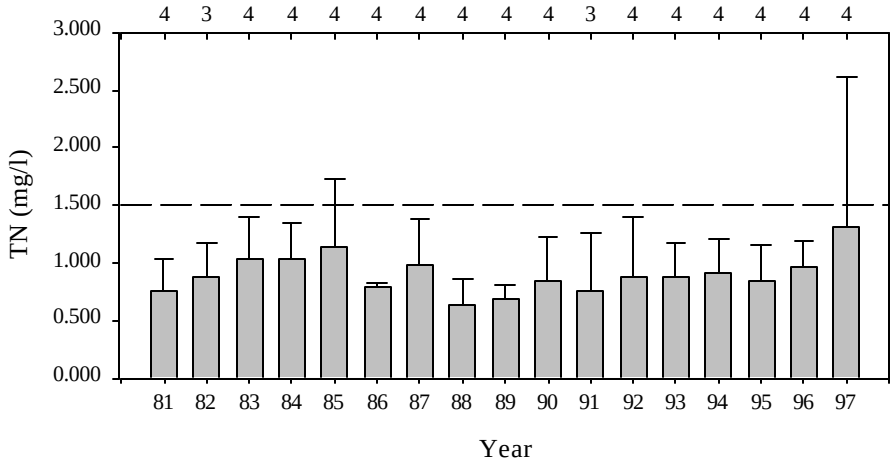
To further investigate compliance patterns within the basin, each TN sample was given a rating based on Broward County's water quality standard. Total nitrogen concentrations were designated as poor if they were over 2.500 mg/l which is 1.000 mg/l over the Broward County standard of 1.500 mg/l. A fair 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 IV.E.3.). Thus, the periods investigated were 1981-1986, 1987-1991, and 1992-1997.

Figure IV.9. Annual Mean Total Nitrogen (TN) Content Within the Northern Intracoastal Waterway Basin from 1981 to 1997. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. TN levels should be below the Broward County standard (1.500 mg/l) indicated by the dashed line.

a) Site 1



b) Site 33



c) Site 34

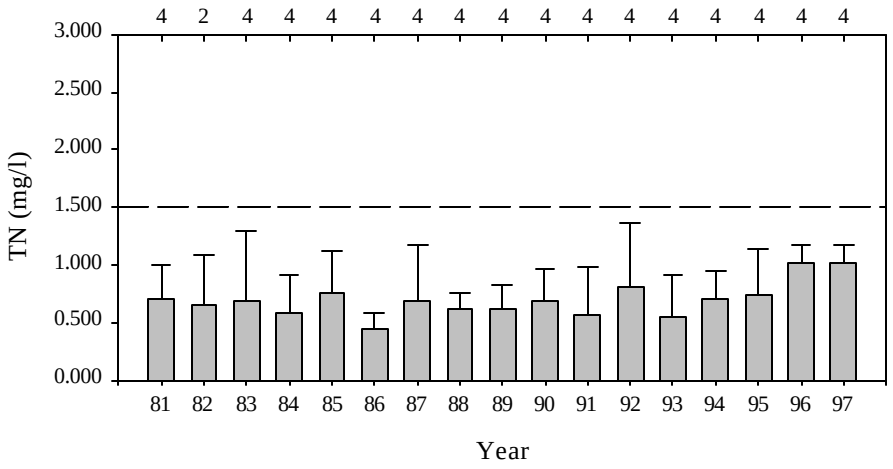
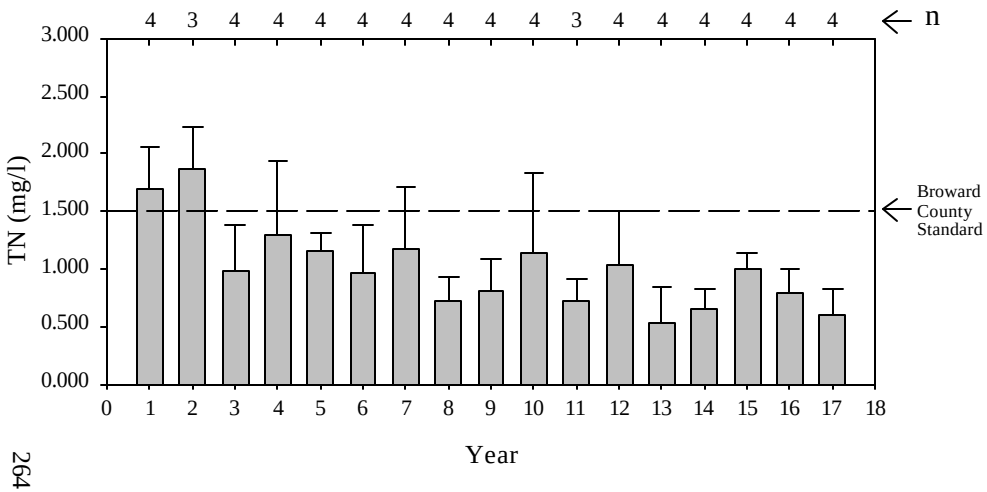
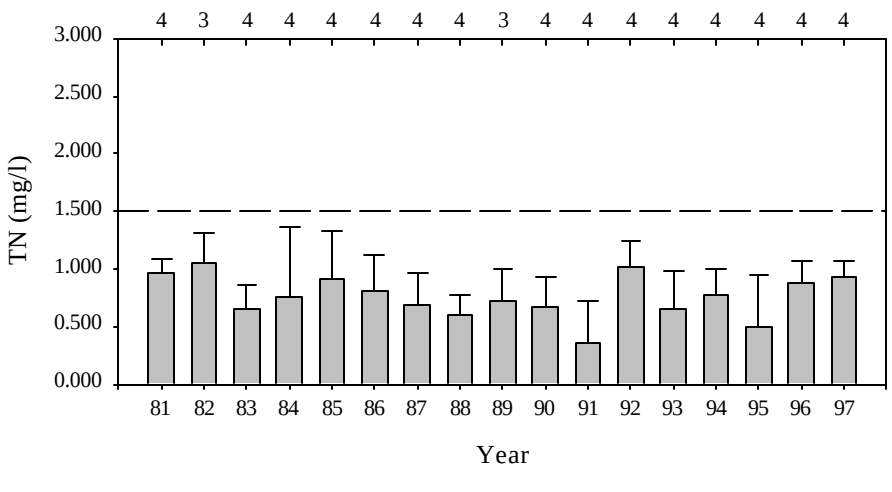


Figure IV.9 (cont.). Mean Annual Total Nitrogen (TN) Content Within the Northern Intracoastal Waterway Basin from 1981 to 1997. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. TN levels should be below the Broward County standard (1.500 mg/l) indicated by the dashed line.

d) Site 5



e) Site 35



A similar temporal pattern was observed with the percentage of TN samples achieving standard compliance (Figure IV.10) as seen with annual averages (Figure IV.9). Site 1 exhibited 60.9% and Site 5 exhibited 65.2% good ratings during the 1981-1986 period. By 1992-1997, the percent of good samples was up to 95.7% for Site 1 and 95.8% for Site 5 (Figure IV.10). Meanwhile, the ICW Sites 33 thru 35 were above 87.0% in all three periods, including 100% compliance at Sites 34 and 35.

Between 1989-1997, seasonal differences in TN content were not observed at any sampling site (Figure IV.11). Almost all values were within Broward County's compliance standard (i.e., 1.500 mg/l). The exceptions were either 90^{th} or 95^{th} percentile values measured in the dry season (Site 5) or the wet season (Sites 1 and 33).

f. Bacteriological Parameters

Bacteriological parameters measured from 1981-1997 included fecal coliform (FC), total coliform (TC), and fecal streptococcus (FS). The seventeen-year median FC values were typically low throughout the study (Table IV.6.). Fecal coliform means were higher than median values but bacteriological mean values are often skewed by outstanding high values (BCDNRP 1994a), as the high standard deviations illustrate (Table IV.6.). Sites 34 and 35 had the most FC samples below the method detection limit. Total coliform and FS values followed similar patterns between sampling sites as FC (Table IV.6).

Table IV.6. Descriptive Statistics for Fecal Coliform (FC), Total Coliform (TC), and Fecal Streptococcus (FS) in the NICW Basin. All calculations represent seventeen years of sampling. However, the number of samples per year occasionally varied at each site. 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
1	FC	col	74	155	494	1689	12000	5	1
5	FC	col	66	41	425	1654	11000	5	8
33	FC	col	66	110	298	835	6200	5	3
34	FC	col	65	20	76	274	2200	4	20
35	FC	col	65	20	97	231	1400	4	22
1	TC	col	73	450	1160	3616	30000	30	0
5	TC	col	66	275	601	876	4400	17	6
33	TC	col	66	338	668	1342	10000	17	1
34	TC	col	65	100	362	854	5500	12	11
35	TC	col	65	170	522	1632	13000	12	8
1	FS	col	75	200	582	1033	5700	17	3
5	FS	col	67	73	439	1722	14000	10	19
33	FS	col	67	100	382	944	6400	15	11
34	FS	col	66	47	200	432	2900	12	30
35	FS	col	66	29	157	243	1300	5	31

Figure IV.10. Total Nitrogen (TN) Concentrations Observed in the Northern Intracoastal Waterway Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County marine 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.

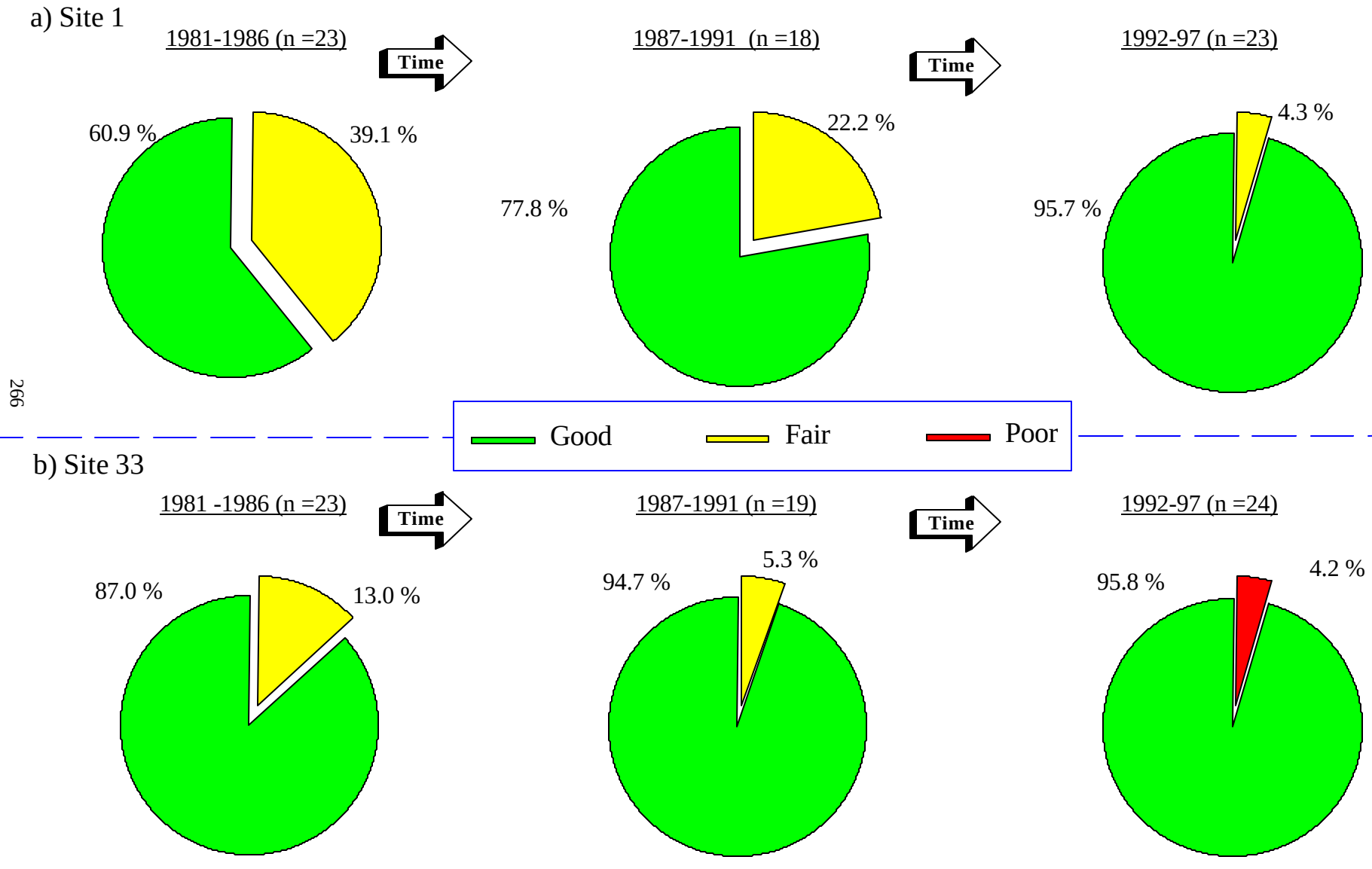


Figure IV.10 (Cont.). Total Nitrogen (TN) Concentrations Observed in the Northern Intracoastal Waterway Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County marine TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified 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.

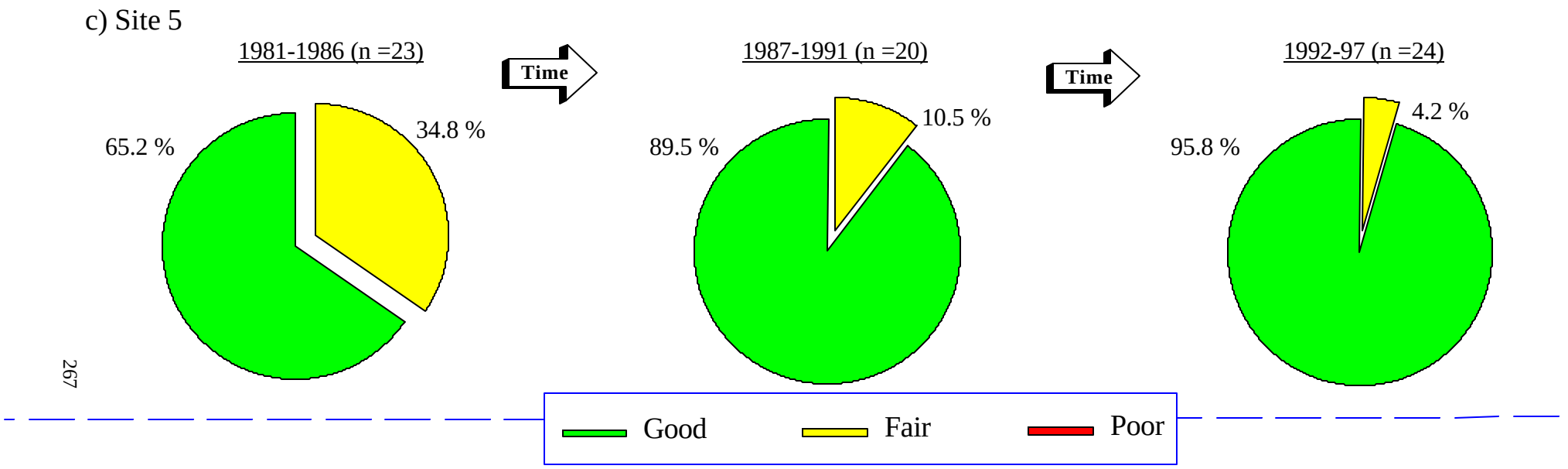


Figure IV.10 (Cont.). Total Nitrogen (TN) Concentrations Observed in the Northern Intracoastal Waterway Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified 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.

e) Site 34

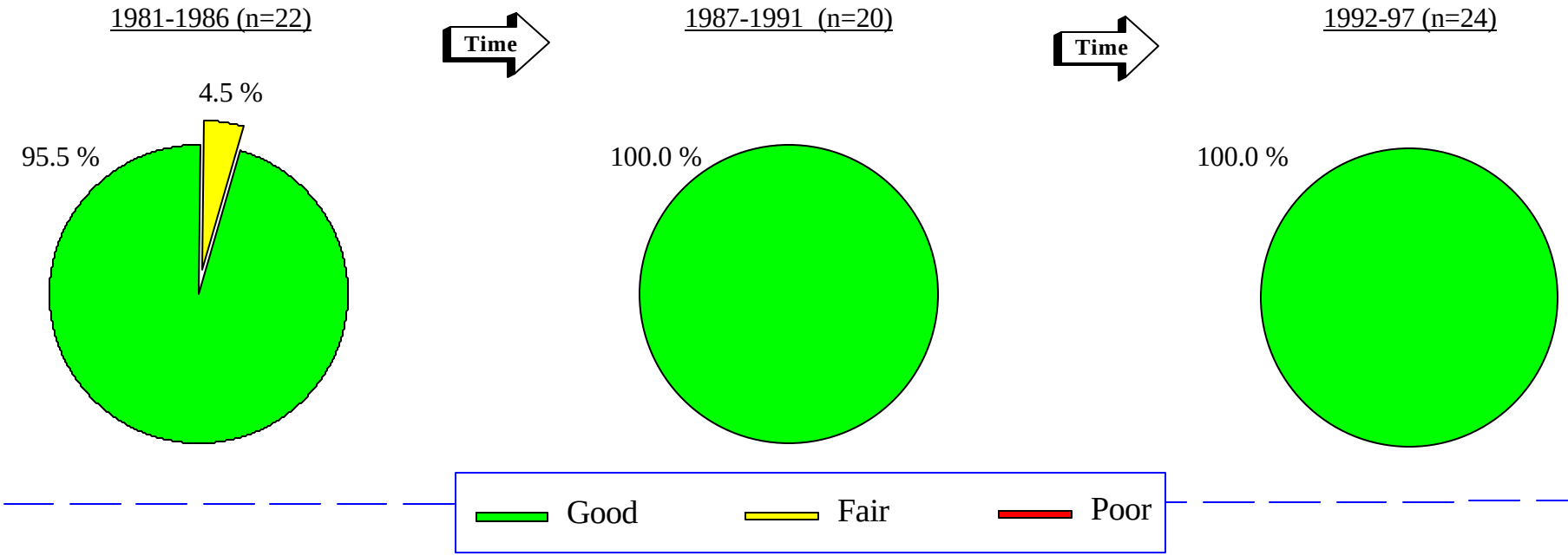


Figure IV.11. Northern Intracoastal Waterway Basin Total Nitrogen (TN) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season values were not observed at any sites.

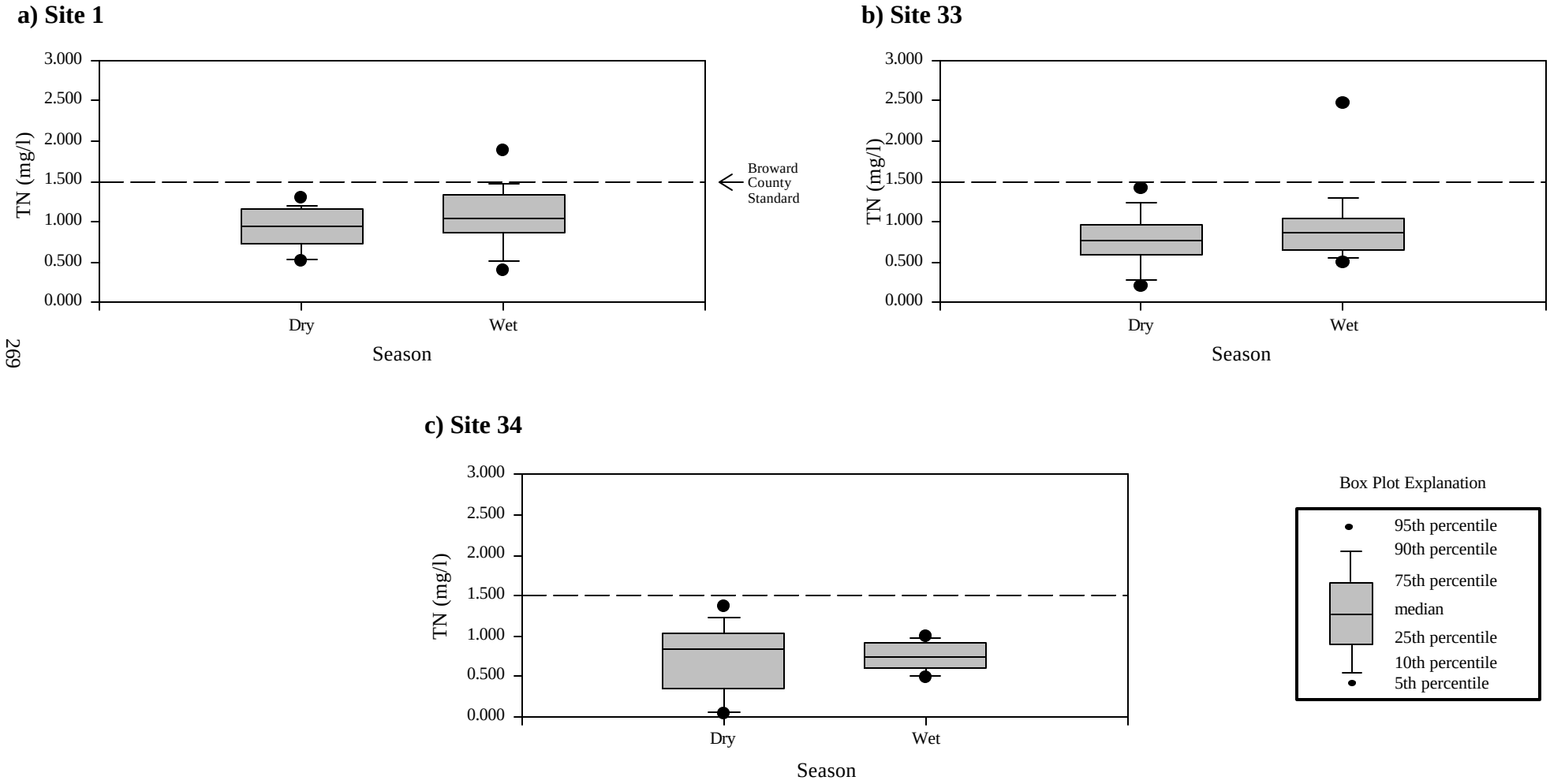
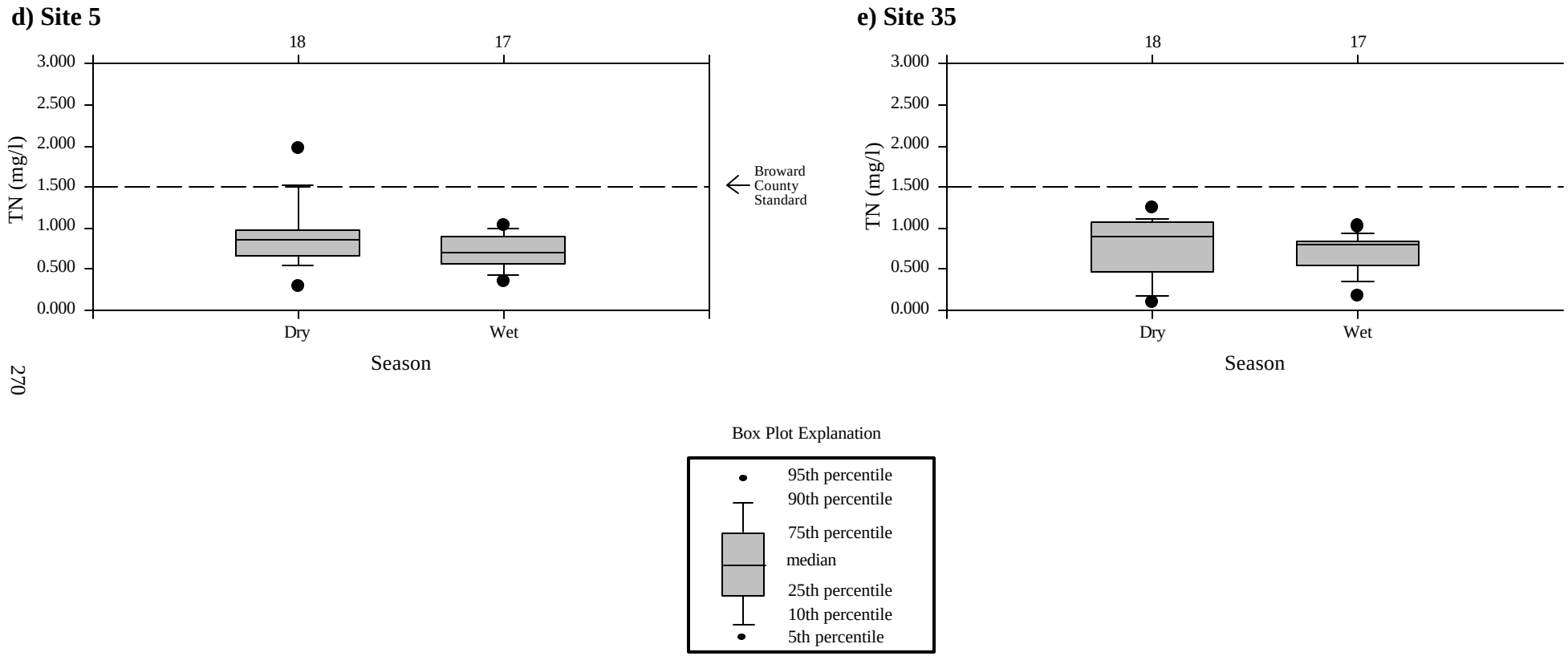


Figure IV.11 (Cont.). Northern Intracoastal Waterway Basin Total Nitrogen (TN) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season values were not observed at any sites.



Due to the large amount of variability around the mean, yearly box plots were plotted for FC instead of the mean (Figure IV.12). For example, three 1995 FC samples were obtained at Site 1. The results were 40, 140, and 12,000 colonies per 100/ml which yields a mean of 4,060 ± 6876 colonies/100 ml but a median of only 140 colonies/100 ml.

Yearly median values were below the one sample standard (800 colonies/100 ml) at all sites during all years (Figure IV.12). Occasional high FC concentrations were observed, particularly at Site 1 but clear trends over time were not apparent. However, the occurrence of the highest FC values were generally more frequent during the early 1980's for Sites 1, 33, and 34. Conversely, Site 5 experienced its maximum values during 1993 and 1996.

Basinwide compliance patterns were further analyzed by giving each specific FC sample 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. Fecal coliform values between 201 and 800 colonies/100 ml were designated fair. 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 IV.E.3). Thus, the periods investigated were 1981-1986, 1987-1991, and 1992-1997.

Fecal coliform compliance percentage was generally very high at all five sites (Figure IV.13). The lowest percentage of good samples at four of the five sites was observed during 1981-1986, however, the amount of poor samples never exceeded 15.0% at any site. Sites 34 and 35 had the highest percentage of good samples during all three periods, while Site 1 exhibited the lowest percentages. The three main ICW Sites 33 thru 35 had zero poor fecal coliform concentrations from 1987 through 1997.

Only Site 5 exhibited seasonal FC differences from 1989-1997 with the wet season median values being statistically higher than the dry season (Mann-Whitney Rank Sum Test; $p < 0.05$; Figure IV.14). A Mann-Whitney Rank Sum test was performed because the data was not normally distributed ($p < 0.001$). Overall, 1989 through 1997 FC values were relatively low during both seasons with the exception of a few high occurrences, particularly at the more inland monitoring Sites 1 and 5. Site 33 generally had the highest FC content observed among the three main ICW Sites 33 thru 35.

6. Basin Summary

The Northern Intracoastal Waterway Basin (NICW) is effectively divided by the Hillsboro Inlet. A primary freshwater canal discharges to a brackish tributary in both the northern (Hillsboro Canal) and southern (C-14 Canal) range of the basin. In this study, Sites 1 and 33, represent the northern extent of the basin while Sites 5 and 35 represent the southern reaches. Site 34 exists at the transition zone from the ICW to the oceanic inlet. The following will summarize the water quality characteristics of this basin's distinct sections. In addition, the influence of WWTP discharges and seasonal effects will also

Figure IV.12. Yearly Box Plots of Fecal Coliform (FC) Levels Within the Northern Intracoastal Waterway (NICW) Basin from 1981 to 1997. Medians and percentiles calculated from quarterly samples (n=4) unless noted on upper x-axis. FC levels should be below the Broward County single sample standard (800 colonies/100 ml) indicated by the dashed line. Numbers in parentheses represent 75th percentile values that extend beyond the y-axis scale.

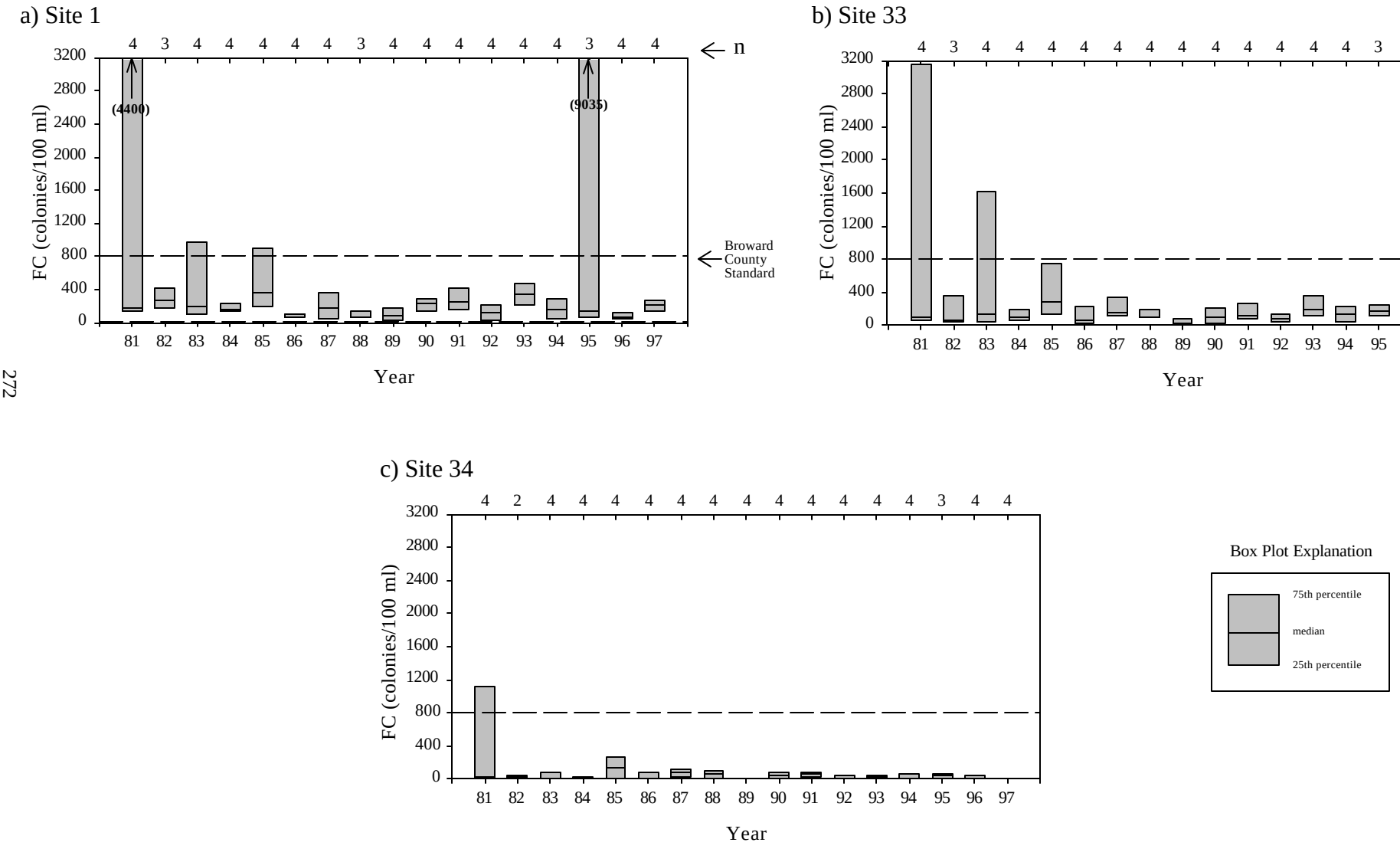
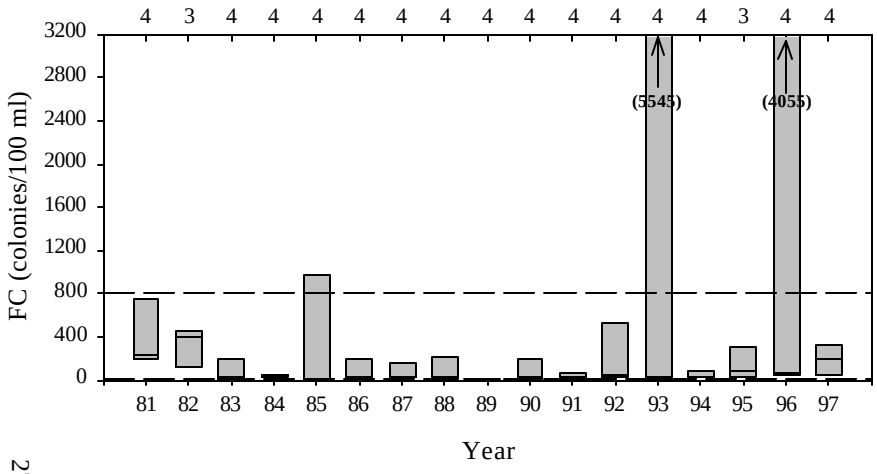
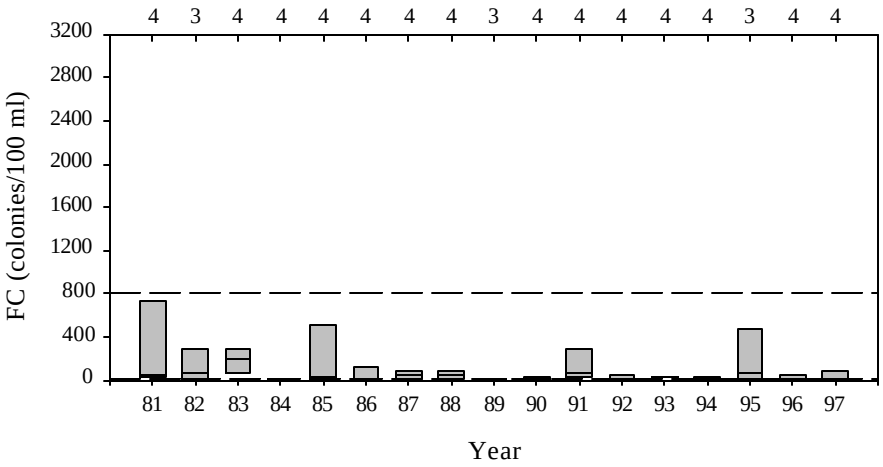


Figure IV.12 (Cont.). Yearly Box Plots of Fecal Coliform (FC) Levels Within the Northern Intracoastal Waterway (NICW) Basin from 1981 to 1997. Medians and percentiles calculated from quarterly samples (n=4) unless noted on upper x-axis. FC levels should be below the Broward County single sample standard (800 colonies/100 ml) indicated by the dashed line. Numbers in parentheses represent 75th percentile values that extend beyond the y-axis scale.

d) Site 5



e) Site 35



Box Plot Explanation

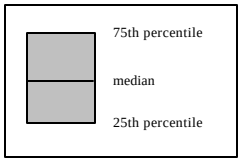


Figure IV.13. Fecal Coliform (FC) Concentrations Observed in the Northern Intracoastal Waterway Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100 ml (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.

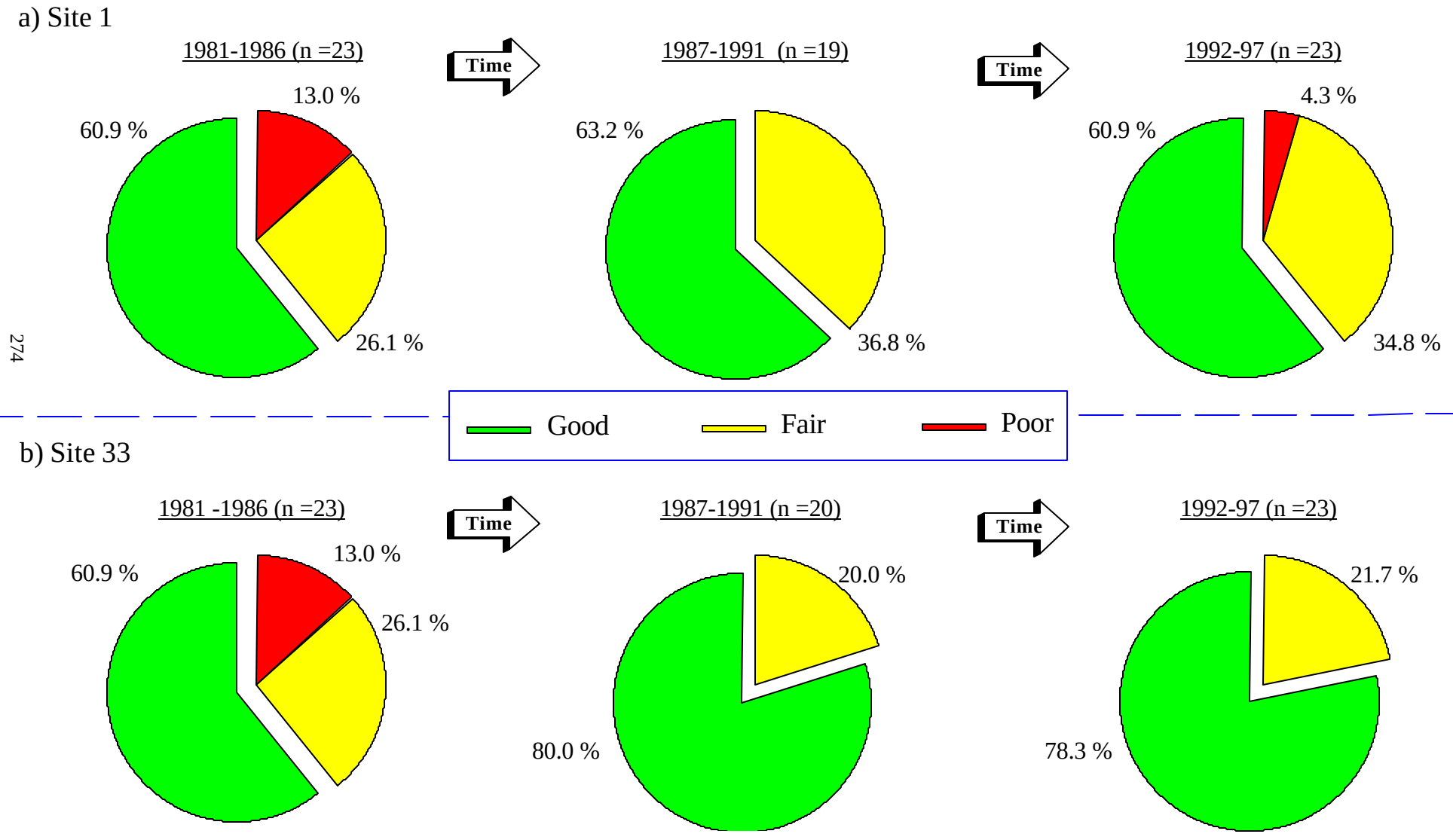


Figure IV.13 (Cont.). Fecal Coliform (FC) Concentrations Observed in the Northern Intracoastal Waterway Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100 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.

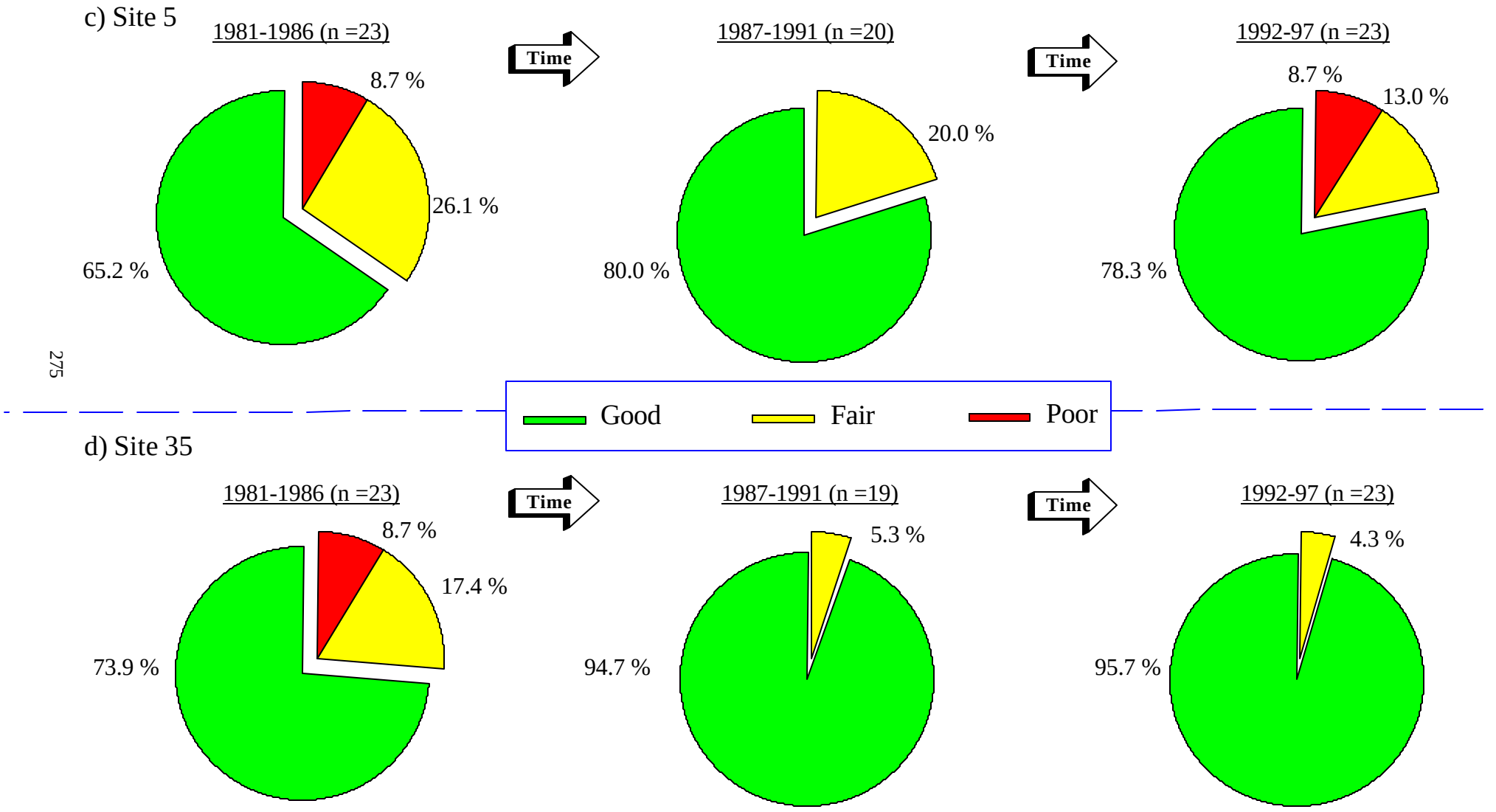


Figure IV.13 (Cont.). Fecal Coliform (FC) Concentrations Observed in the Northern Intracoastal Waterway Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100 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.

e) Site 34

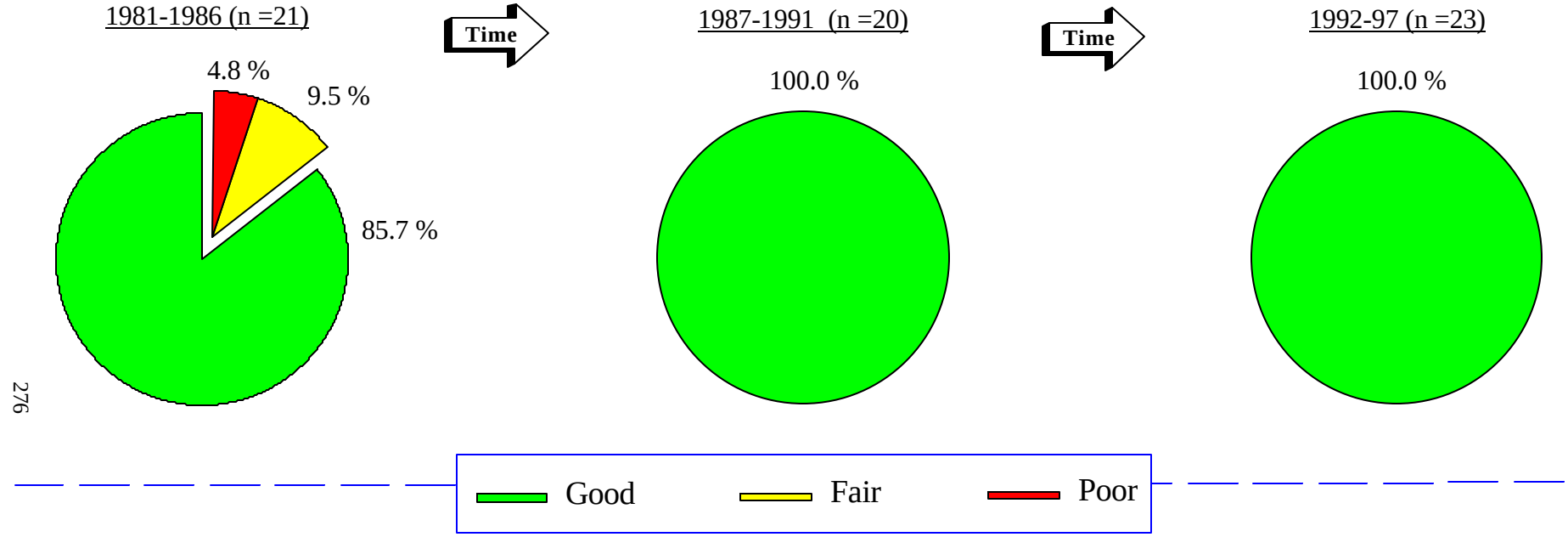


Figure IV.14. Northern Intracoastal Waterway Basin Fecal Coliform (FC) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. A statistically significant difference between wet and dry season medians was only observed at Site 5 ($p < 0.05$; Mann Whitney Rank Sum Test).

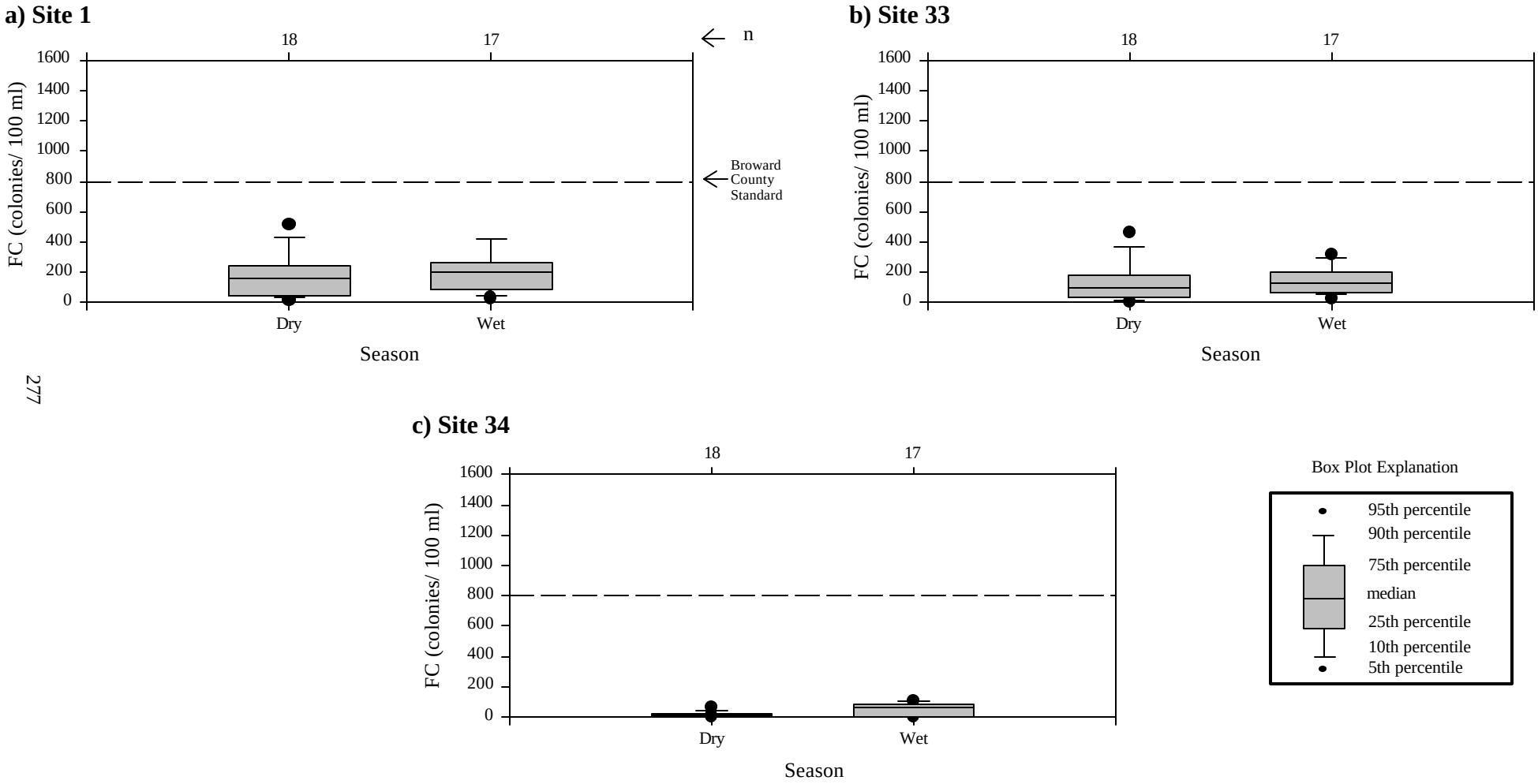
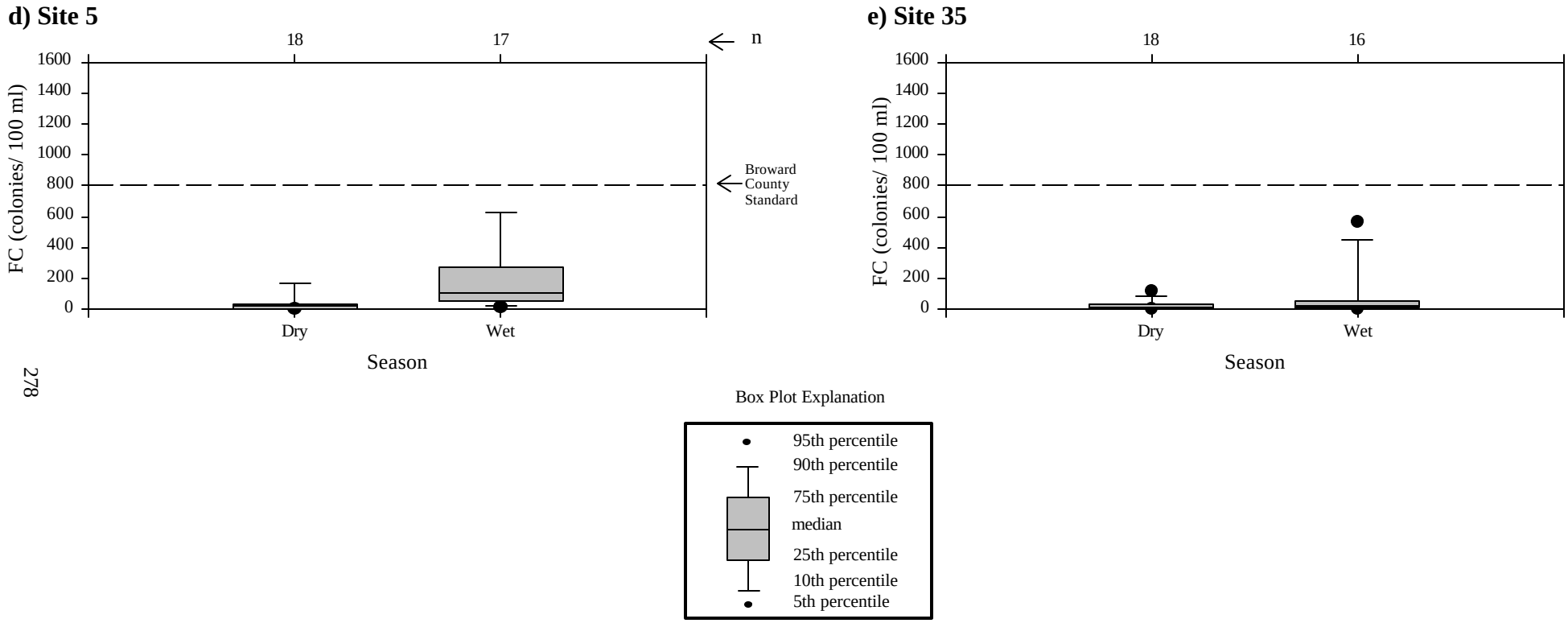


Figure IV.14 (Cont.). Northern Intracoastal Waterway Basin Fecal Coliform (FC) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. A statistically significant difference between wet and dry season medians was only observed at Site 5 ($p < 0.05$; Mann Whitney Rank Sum Test).



be discussed. Finally, questions about the NICW 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 southern portion of the basin (Sites 5 and 35) and the inlet area (Site 34). Based on TP concentrations, the northern Sites 1 and 33 did not show changes over time due to WTTP closures. However, improvements in TN content were observed at Sites 1 and 33. These results are consistent with the earlier analysis of the freshwater Hillsboro and C-14 freshwater canals (Section III.E and III.F) that intermittently discharge east towards the ICW and suggest a strong relationship exist between the eastern portion of the freshwater canals and the brackish tributaries of the ICW.

b. Basinwide Water Quality Characteristics (Post-WWTPs)

In general, Sites 1 and 33 exhibited the poorest water quality of the basin due to elevated TP concentrations after WWTP discharges to surface waters ceased in Broward County. The source of this high TP is largely from the "upstream" freshwater of the Hillsboro Canal that periodically is discharged to tide. As shown in the freshwater Section (III.E.5.d), high levels (> 0.100 mg/l) have been observed consistently in the Hillsboro Canal even after the closure of WWTPs and is most likely due to surrounding land use and/or secondary canal discharges.

The spatial extent of the Hillsboro Canal's influence on Broward's portion of ICW is not known at this time. Geographically, the Boca Raton Inlet in Palm Beach County is closer than the Hillsboro Inlet to the mouth of the Hillsboro Canal. Potentially, only the water quality at Site 33 is effected by Hillsboro Canal discharges and TP content at Sites 1 and 33 would appear to confirm a relationship between those two monitoring sites. Thus, Site 34's water quality may be more influenced by the numerous finger canals and associated stormwater discharges, as well as ICW water originating from south of the inlet. The dilution factor of coastal water is highly suggested by Site 34's relatively good water quality compared to main ICW channel (Sites 33 and 35) and tributary Sites 1 and 5. However, only discrete tidal sampling would confirm this observation. Furthermore, occasional high values were observed at Site 34 suggesting a potential for poorer water quality exists at different tidal and/or rain event conditions.

Other major water quality parameters (TN, FC, and DO) were relatively similar between all five sites and normally considered good based on water quality standards. Site 34 typically had the lowest TN and FC content as well as the highest DO concentrations again likely due to the close proximity to the Atlantic Ocean. The two inland Sites 1 and 5 exhibited at least one elevated FC concentration over the last ten years. Nonetheless, FC levels were normally low in the study area. The occasional high FC may represent storm events occurring on or near the sampling date.

c. Seasonal Differences

Statistical differences were observed for DO content at four of the five sites. As discussed in Section III, temperature changes alone between seasons can explain lower dissolved oxygen concentration in

a waterbody. Perhaps more importantly, almost all median values were above the 4.0 mg/l Broward County standard (i.e., within compliance) during both seasons at all sites.

For all other parameters, only the wet season TP content at Site 1 was observed at significantly higher levels than dry season concentrations. However, Site 1's dry season median was higher than any other sites' dry or wet season values. The exceptionally high wet season TP values are likely indicative of higher volumes of Hillsboro Canal water being discharged from the west during periods of excessive rainfall (i.e., wet season).

d. Future Monitoring Questions

A goal of this report is to establish the baseline water quality conditions in order 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 NICW Basin, several questions revolve around nutrient concentrations and potential transport. In particular, enhanced TP concentrations were observed in the north part of the basin. The fate of these and other chemical constituents is not well understood due, in part, to the lack of information on the basin's hydrological residence time and the ICW's main outgoing tide orientation (north or south) and flow patterns. Finally, the influence of estuarine water quality on the final "downstream destination", which is an offshore, coral reef system, needs to be quantified. Thus, the following questions are posed for the NICW basin.

- Are nutrient concentrations (primarily TP) in the north part of the basin creating an imbalance in water column biology (e.g., chlorophyll a) and/or macrophytes?

- Although TN levels are normally within compliance of the Broward County standard, are dissolved inorganic nitrogen levels (DIN, NO_2+NO_3-N plus NH_3) levels of more importance to water column biology?

- Are nutrient concentrations (primarily TP) in the north part of the basin primarily being transported north into the Palm Beach County ICW or south in the Broward County ICW to the Hillsboro Inlet?

- At low tides, does Site 34 have worse water quality than observed with an ambient monitoring effort (i.e., What is the poorest water being transported offshore)?

- As an estuarine waterbody, to what extent is the influence of a "salt wedge" from the east?

- How do intermittent discharges from the salinity structures influence water quality, as well as biology and estuarine residence time?

- How does stormwater quality influence the water quality of numerous finger canals and the NICW, particularly north of the Hillsboro Inlet where no permanent monitoring sites are located?

F. ICW - Central Basin

1. Geographic Locale

The Central Intracoastal Waterway (CICW) Basin is located in eastern Broward County (Figure IV.15) with freshwater originating primarily from the C-13 Canal/Middle River and North New River Canal/New River systems while oceanic water enters through the Port Everglades. The primary municipalities in this area are Pompano Beach, Sea Ranch Lakes, Lauderdale-by-the-Sea, and Ft. Lauderdale.

2. Land Use and Activities Impacting Water Quality

A majority of the shoreline is densely populated with residential (houses and condominiums) and commercial properties (hotels, restaurants, and marinas). Very few areas along the ICW are without some development with either a lawn and/or parking lot. One exception is Hugh Taylor Birch State Park north of Sunrise Boulevard which has a developed upland tree and remnant mangrove forests. Bulkheaded seawalls dominate the entire shoreline, including most of the state park. The waterway is used primarily by a large volume of boat (recreational and commercial) traffic less than 100 feet in length. However, some large vessels (greater than 100 feet) do utilize the channel. Very large (> 500) feet ocean going commercial oil tankers, cargo and cruise ships utilize Port Everglades. Port Everglades essentially divides the CICW from the Southern Intracoastal Waterway Basin (Figure IV.15).

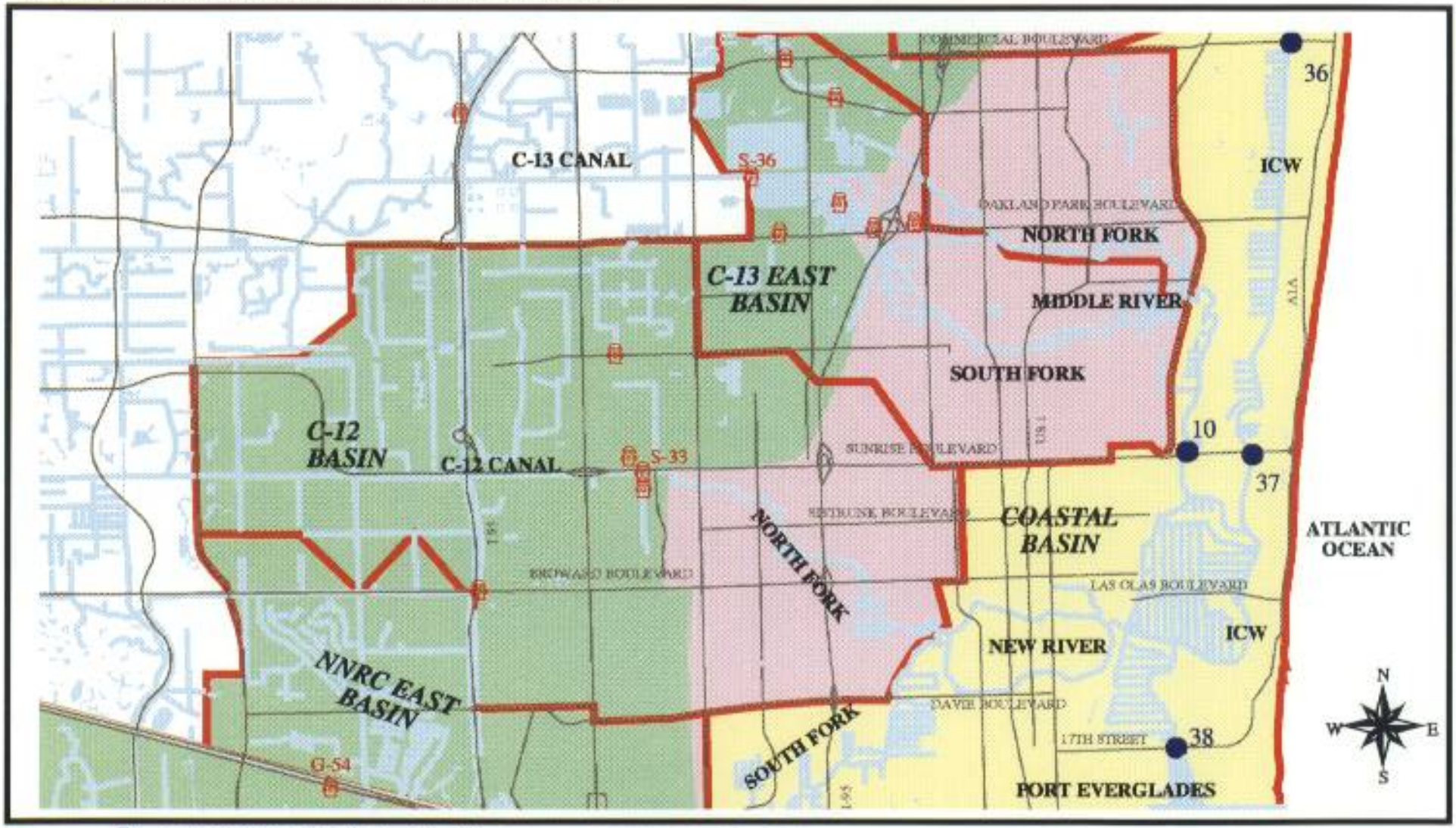
Stormwater outfalls exist throughout the area and represent the greatest potential source of contaminants. In some places, runoff occurs from the major roadways that run parallel to the ICW include Federal Highway and AIA. In addition, six major bridges with accompanying outfalls are present in this study area. However, the majority of stormwater outfalls are at the dead end of finger canals prominent throughout the area. The cumulative effect of all the outfalls (acute and/or chronic) on the CICW is not known at this time.

An area of septic tank systems exists north of the CICW basin as described for the NICW (Section IV.E.2). However, the area between the NICW and the CICW, as defined in this report, is not hydrologically separated (e.g., water control structure). Thus, waters north of the CICW undoubtedly interact to some extent with the southern area of the NICW. The influence of the septic tank area on the NICW or the CICW has not been investigated at this time. The New River system which flows into the CICW has extensive areas served by septic systems that will be described more fully in that basin's Section (IV.H.2).

3. Wastewater Treatment Plants Discharge History

A majority of the wastewater treatment plants (WWTPs) stopped directly discharging into the CICW before 1980. However, the City of Ft. Lauderdale's "B" plant had the capacity to discharge up to 8.0 million gallons per day (mgd) into the ICW until 1985. In addition, the City of Ft. Lauderdale's GT Lohmeyer plant dumped wastes (22.750 mgd capacity) into Port Everglades until 1984. The elimination of WWTP discharges into "upstream" tributaries such as the C-13 Canal and South Fork

Figure IV.15. The Central Intracoastal Waterway Basin and Broward County (BCDPEP) Sampling Sites Location Map. The brackish sections of the C-13, North Fork Middle River (NFMR), C-12, and North New River Basins are shown in pink. These areas were delineated by the United States Army Corps of Engineers as separate basins from the Coastal Basin (Cooper and Lane 1987). However, the respective receiving waterbodies are tidally connected and are downstream of the coastal water control structures (S-36, S-33, and G-54) operated by the South Florida Water Management District. Thus, the brackish waters (pink and yellow areas) within distinct basins are hydrologically connected within the overall estuarine system.



BCDPEP Water Quality Sampling Site

Water Control Structures (primarily SFWMD)

Waterbodies

Major Roadways

0 1 2 3 Miles

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

BROWARD COUNTY

New River occurred after 1986. The North New River Canal which eventually flows, via the Sewell Lock, to the South Fork of the New River received at least some WWTP discharges until 1988 when the City of Plantation halted discharges to the waterway. The City of Plantation similarly halted discharges in 1988 to the C-12 Canal which occasionally spills over to the North Fork of the New River.

4. Sampling Locations and Period

Latitude and longitude measurements were determined by Global Position System and specific site descriptions are given in Appendix 1. Located north (~100 feet) of the Commercial Boulevard Bridge, Site 36 is the northern most site of the CICW. This site represents a transition area between the NICW and CICW Basins and is normally sampled by boat. An investigation of the ICW's hydrological division (i.e., tidal) between the two oceanic inlets in Broward County has not been performed. Thus, waters from the NICW and the C-14 canal may influence the water quality of this site.

Site 37 is north of the Sunrise Boulevard Bridge on the ICW while Site 10 is also adjacent to Sunrise Boulevard but is on the Middle River (south of bridge). Site 38 is located in the basin's southern area and is heavily influenced by the Port Everglades oceanic inlet. All three sites are normally sampled by boat.

Sites 36 thru 38 have been sampled by BCDPEP since 1980, while Site 10 has been monitored since 1973. In order to investigate the basin's differences and similarities, the data analysis in this section is restricted to the previous 18 years (i.e., 1980-1997). Due to sampling logistics, Site 38 is normally sampled either one day before or after Sites 36, 37 and 10. Only temperature, dissolved oxygen, salinity, pH, and turbidity were measured during 1980. The remaining parameters (total Kjeldahl nitrogen, nitrite+nitrate-nitrogen, ammonia-nitrogen, total nitrogen [calculated], fecal coliform, total coliform, fecal streptococcus, total phosphorus, total organic carbon) were monitored beginning in 1981. Biochemical oxygen demand (seven-day test) monitoring occurred from 1981-1993 in the ICW. Data methodology and manipulation for this section were performed as detailed in the methodology section (Section II).

5. Results

a. Physical Characteristics

Median and mean water temperatures were relatively similar among all four sites with an overall range of 18.0°C to 34.0°C reflecting seasonal temperature changes (Table IV.7). Mean water temperatures from 1980-1997 ranged from 26.2 ± (standard deviation) 3.2°C at Site 38 to 26.5 ± 3.6°C for Site 37. Central ICW Basin pH levels were relatively similar between sites and showed little variability. The highest mean pH level was 7.9 ± 0.3 at Site 38 (Table IV.7). The lowest mean pH value, 7.6 ± 0.3, was observed at the inland Site 10.

Large salinity ranges were observed throughout the basin between 1980 and 1997 (Table IV.7). Salinities at the two main channel ICW Sites 36 and 37 were typically in the lower twenties but ranged

from 3.9 to 32.9 parts per thousand (ppt). At the north end of Port Everglades (oceanic inlet), Site 38 exhibited the basin's highest mean salinity (27.7 ± 6.0 ppt; Table IV.7). The lowest mean salinity was observed at the inland Site 10 (16.4 ± 8.6 ppt). Specific conductance was not consistently measured over the 18-year period but a wide range of values were also noted (2,000 to 52,800 Fmhos/per centimeter).

Table IV.7. Descriptive Statistics for Temperature (Temp, °C= degrees Celsius), pH, Specific Conductance (Cond; Fmhos = micromhos), and Salinity (Sal; ppt= parts per thousand) in the CICW Basin. With the exception of Cond, all calculations represent eighteen years of sampling (1980-1997). However, the number of samples per year occasionally varied at each site. 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
36	Temp	°C	70	26.8	26.3	3.6	32.4	18.0	0
37	Temp	°C	71	26.5	26.5	3.6	34.0	18.0	0
38	Temp	°C	72	26.5	26.2	3.2	31.6	19.0	0
10	Temp	°C	74	27.0	26.3	3.5	33.0	19.0	0
36	pH	units	73	7.7	7.7	0.2	8.2	7.1	0
37	pH	units	73	7.8	7.8	0.2	8.2	7.0	0
38	pH	units	73	7.9	7.9	0.3	8.4	6.7	0
10	pH	units	75	7.6	7.6	0.3	8.1	6.3	0
36	Cond	Fmhos	36	38000	34039	11772	48800	2100	0
37	Cond	Fmhos	36	35650	35344	9952	49500	2000	0
38	Cond	Fmhos	36	45000	43033	7619	52800	21000	0
10	Cond	Fmhos	31	26300	25954	13254	45700	2840	0
36	Sal	ppt	70	24.2	22.1	7.2	31.9	3.9	0
37	Sal	ppt	70	24.3	23.1	6.1	32.9	9.1	0
38	Sal	ppt	70	29.1	27.7	6.0	34.9	3.9	0
10	Sal	ppt	71	17.1	16.4	8.6	31.2	1.5	0

b. Total Organic Carbon and Turbidity

Site 10 exhibited the highest mean total organic carbon (TOC), 11.5 ± 3.7 mg/l, in the basin (Table IV.8). The remaining mean TOC levels were below 10.0 mg/l with the lowest average (6.4 ± 2.8 mg/l) observed at Port Everglades (Site 38). The basin's maximum TOC concentration (28.0 mg/l) was measured at Site 37.

Turbidity levels were relatively similar throughout the basin and always within compliance of water quality standards (Table IV.8). At Site 10, the basin's maximum turbidity value of 10.0 nephelometric turbidity units was recorded which is equal to Broward County's standard.

Table IV.8. Descriptive Statistics for Total Organic Carbon (TOC) and Turbidity (Turbid) Concentrations in the CICW Basin. TOC calculations represent seventeen years of sampling and Turbid (ntu = nephelometric turbidity units) measurements were obtained for eighteen years. However, the number of samples per year occasionally varied at each site. 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
36	TOC	mg/l	61	9.1	9.3	3.6	18.7	0.5	0
37	TOC	mg/l	61	8.6	8.9	3.9	28.0	0.5	0
38	TOC	mg/l	61	5.9	6.4	2.8	13.5	0.4	0
10	TOC	mg/l	58	10.6	11.5	3.7	18.8	4.6	0
36	Turb	ntu	72	1.4	1.5	1.0	7.8	0.3	1
37	Turb	ntu	73	1.5	1.9	1.3	7.5	0.3	2
38	Turb	ntu	73	1.9	2.2	1.2	7.6	0.5	0
10	Turb	ntu	75	1.5	1.8	1.3	10.0	0.3	1

c. Dissolved Oxygen and Biochemical Oxygen Demand

The lowest mean dissolved oxygen concentration was recorded at the most inland location (Site 10; Table IV.9). Site 38 exhibited the highest mean dissolved oxygen level (5.9 ± 0.9 mg/l) which was similar to Sites 36 and 37. All eighteen year averages were above (i.e., within compliance) the dissolved oxygen standard (single sample) of 4.0 mg/l (Broward County 2000) however each site's minimum values were below the regulatory level.

Biochemical oxygen demand (BOD) values were relatively similar for all four sites and typically near 1.0 mg/l (Table IV.9). The Broward County marine standard of 7.0 mg/l was never exceeded, indicating one hundred percent compliance.

Table IV.9. Descriptive Statistics for Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) Concentrations in the CICW Basin. Calculations for DO represent eighteen years of sampling. Measurements of BOD were taken from 1981 to 1993. However, the number of samples per year varied occasionally varied at each site. 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
36	DO	mg/l	72	5.6	5.6	1.4	8.6	0.3	0
37	DO	mg/l	71	5.6	5.6	1.1	8.0	2.9	0
38	DO	mg/l	72	5.8	5.9	0.9	8.3	3.2	0
10	DO	mg/l	74	5.0	4.9	1.1	7.1	2.9	0
36	BOD	mg/l	48	1.2	1.4	0.8	3.6	0.1	0
37	BOD	mg/l	48	1.3	1.2	0.7	3.1	0.1	0
38	BOD	mg/l	48	0.9	1.2	1.0	5.2	0.2	0
10	BOD	mg/l	48	1.1	1.1	0.4	2.2	0.4	0

Yearly DO averages revealed similar compliance with the single sample dissolved oxygen standard (4.0 mg/l) with one exception in 1995 at Site 10 (mean = 3.9 ± 0.5 mg/l; Figure IV.16). With ten of eighteen annual averages below 5.0 mg/l, Site 10 generally exhibited the basin's lowest oxygen levels. Conversely, ICW Sites 36-38 annual mean oxygen content dropped below 5.0 mg/l in only three of the fifty-four combined sampling years. The concentration of 5.0 mg/l represents the daily average standard for Broward County and state of Florida (1998, FAC 62-302), however all samples in this report are the results of single sampling events (i.e., 4.0 mg/l standard).

To further investigate the relationship to water quality standard compliance, CICW readings of DO were designated as poor, fair, and good based on local water quality standards (see Section IV.E.5.c). In addition, the changes over time are presented with special reference to the closing of WWTPs in the C-13/Middle River and New River basins, as well as, Port Everglades (see Section IV.F.3) Thus, the first period is from 1980-1986 and the remaining years were divided into two periods, 1987-1991 and 1992-1997.

Site 10 had the most oxygen samples depressed below Broward County compliance levels (Figure IV.17). Some improvements were observed at Site 10 over time, yet only 56.6% of samples between 1992-97 were over 5.0 mg/l. Samples rating poor were normally below twenty percent during the whole study period in the ICW (Sites 36-38, Figure IV.17). The Port Everglades location (Site 38) had the highest percentages of good dissolved oxygen values (85.7-91.7%).

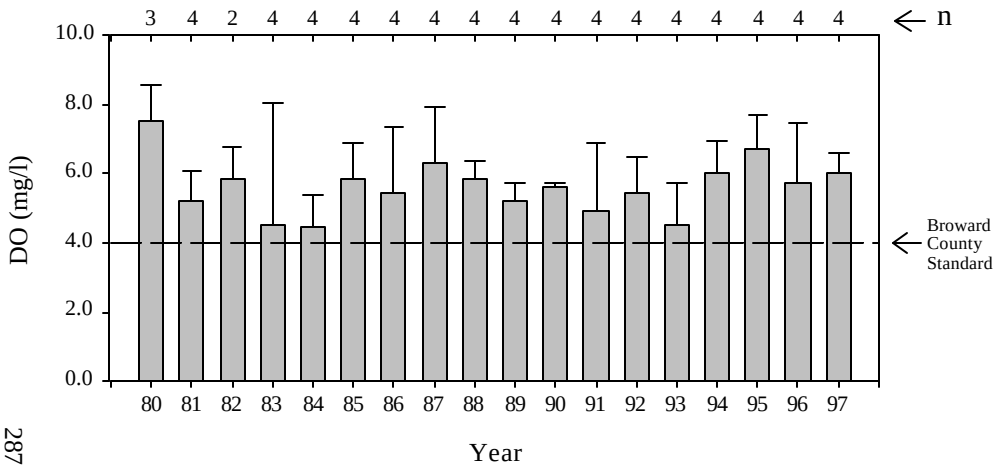
From 1989 to 1997, higher dissolved oxygen values were normally observed during the dry season (November through May) then during the wet season (Figure IV.18). Statistically significant seasonal differences were observed between wet and dry season data at Sites 10, 37, and 38 ($p < 0.001$, t-test), as well as Site 36 ($p < 0.01$, t-test). Almost all ICW seasonal values were at or above the 4.0 mg/l standard with the exception of Site 36's wet season 10^{th} percentile and lower values. Conversely, wet season median DO and lower values were below 4.0 mg/l at Site 10.

d. Total Phosphorus

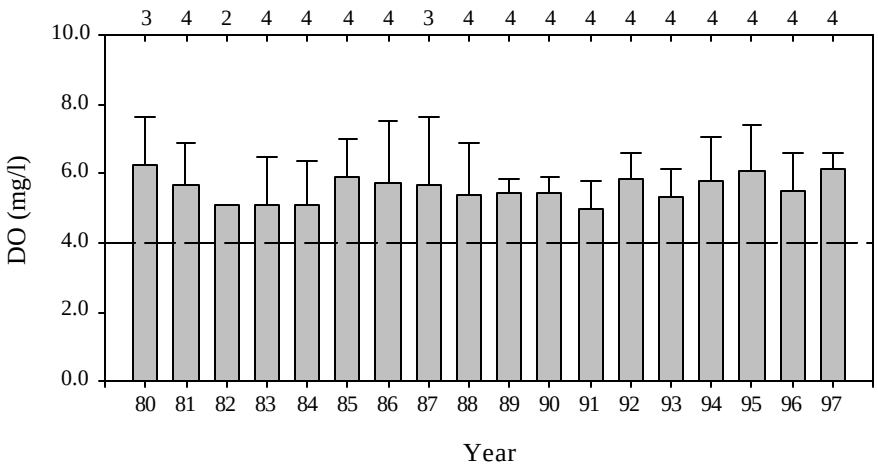
All four sites exhibited seventeen-year mean total phosphorus (TP) levels above the Broward County marine standard of 0.050 mg/l (Table IV.10). However, median values at Site 37 and 38 were below or near 0.050 mg/l. Sites 10 and 36 displayed the highest mean, median, and maximum values and lowest amount of samples below the method detection limit. However, variability around the mean was relatively high at all sites, particularly at Sites 10 and 36 (Table IV.10).

Figure IV.16. Annual Mean Dissolved Oxygen (DO) Content Within the Central Intracoastal Waterway Basin from 1980 to 1997. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. DO levels should be above the Broward County standard (4.0 mg/l) indicated by the dashed line.

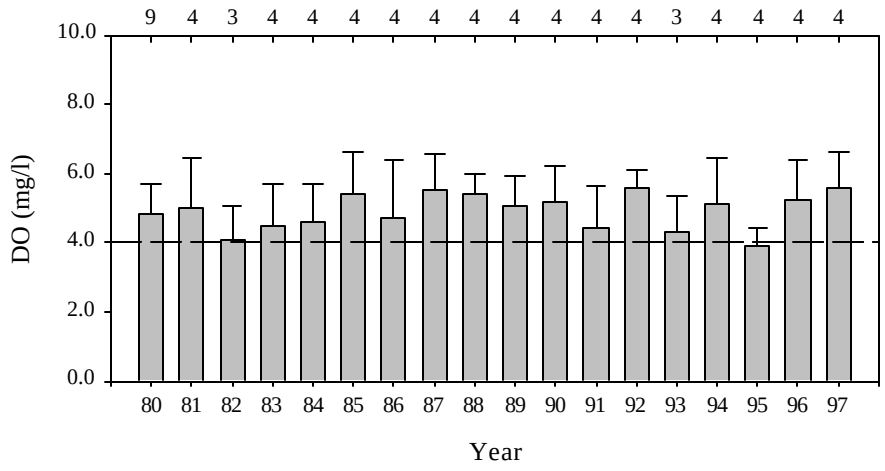
a) Site 36



b) Site 37



c) Site 10



d) Site 38

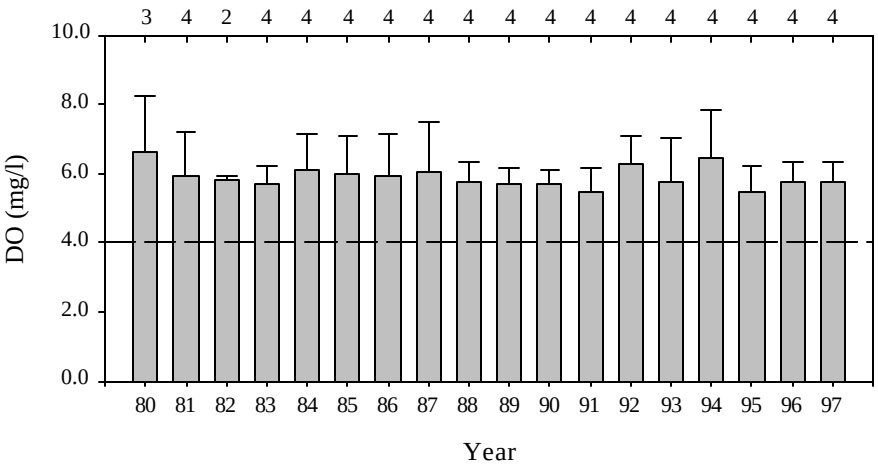


Figure IV.17. Dissolved Oxygen (DO) Concentrations Observed in the Central Intracoastal Waterway Basin over Three Time Periods. DO samples are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall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

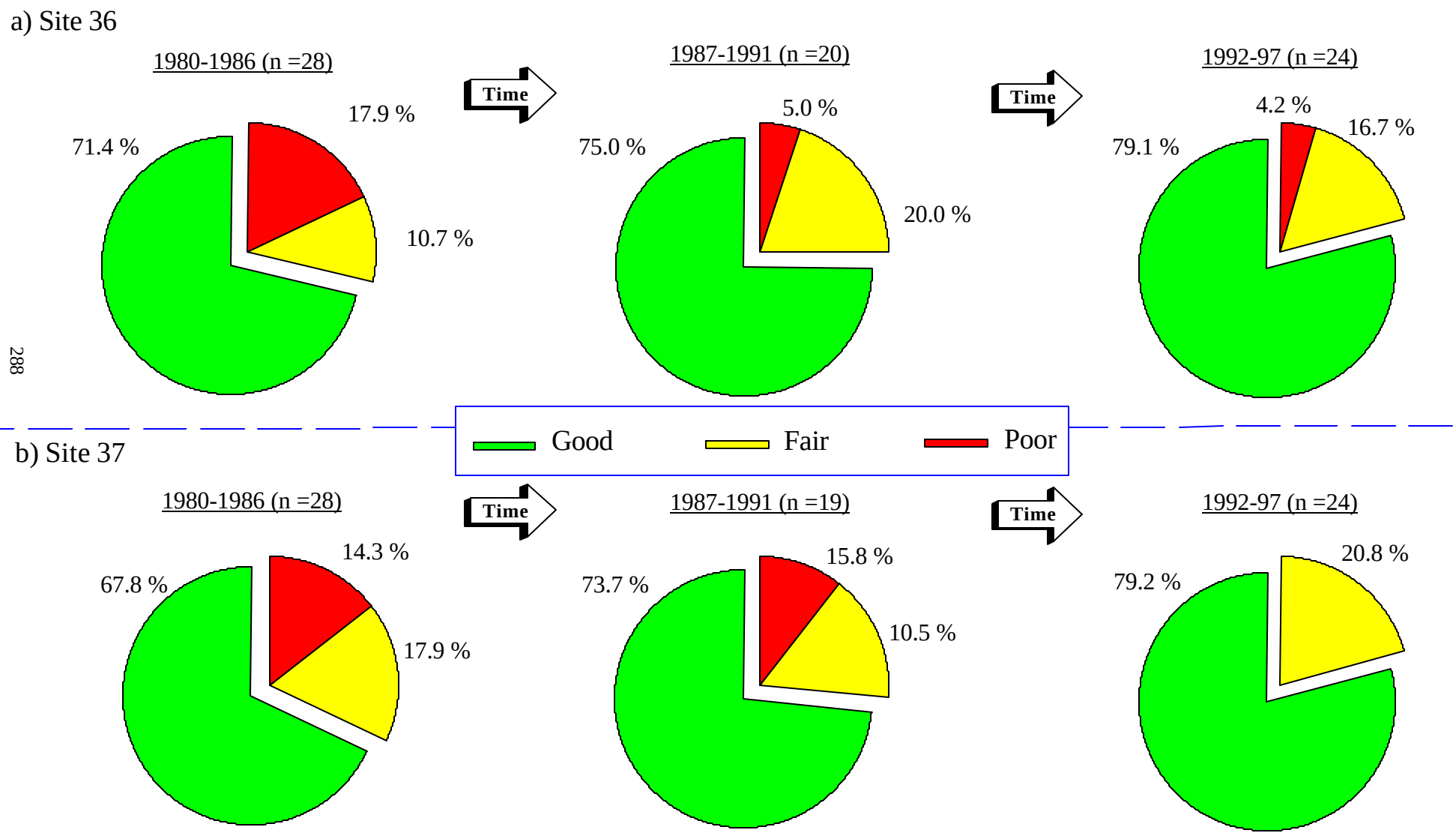
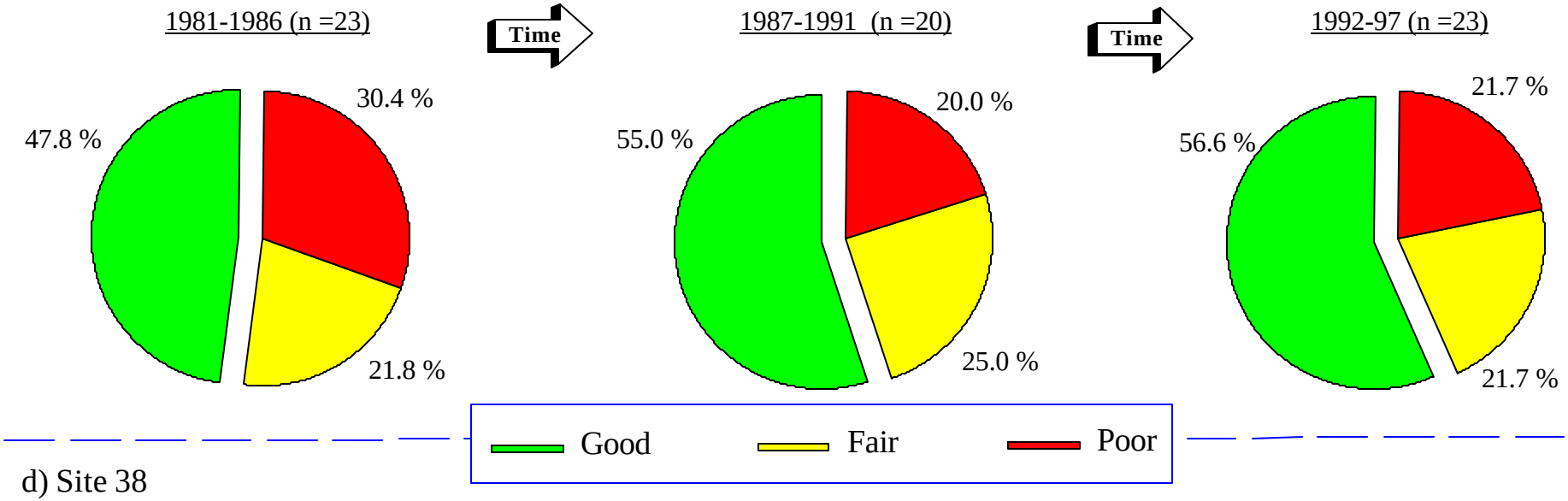


Figure IV.17 (cont.). Dissolved Oxygen (DO) Concentrations Observed in the Central Intracoastal Waterway Basin over Three Time Periods. DO samples are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading 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 levels between 4.0 to 4.9 mg/l are labeled fair. Readings below 4.0 mg/l are defined as poor.

c) Site 10



d) Site 38

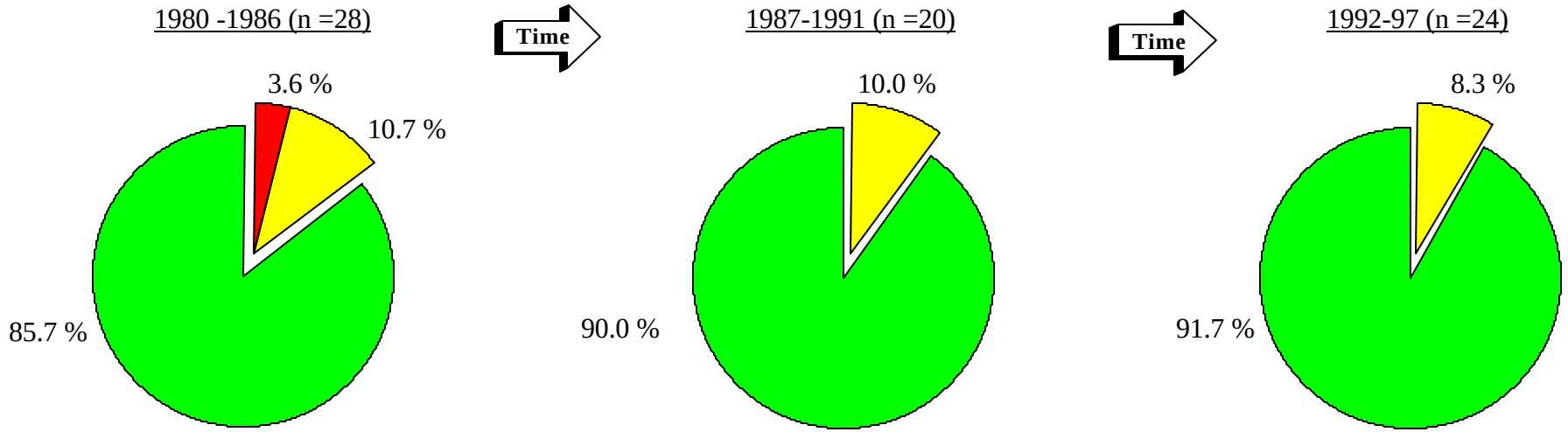


Figure IV.18. Central Intracoastal Waterway Basin Dissolved Oxygen (DO) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (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 10, 37, and 38 ($p < 0.001$, t-test), as well as Site 36 ($p < 0.01$, t-test).

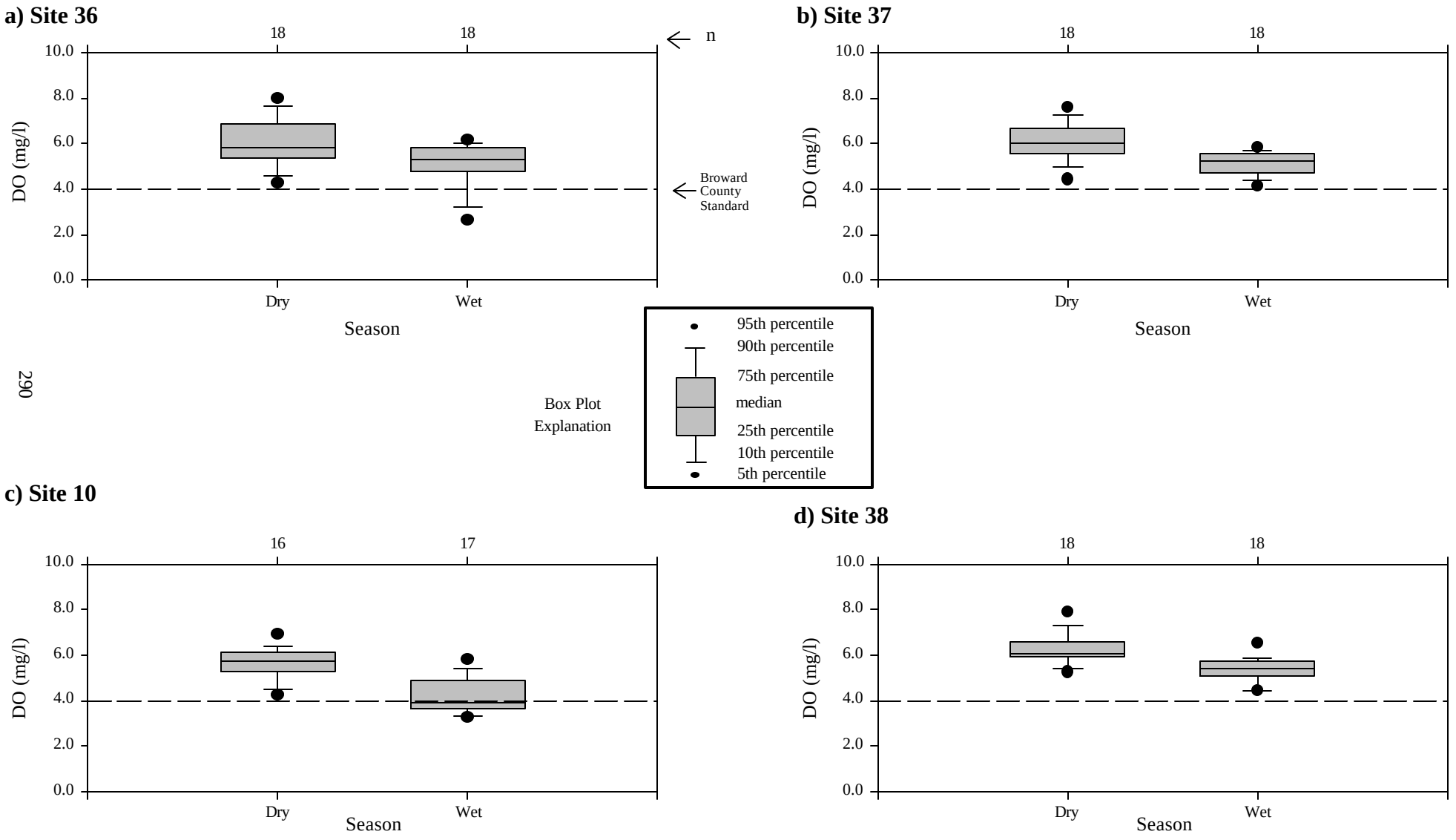


Table IV.10. Descriptive Statistics for Total Phosphorus (TP) Concentrations in the CICW Basin. All calculations represent seventeen years of sampling. However, the number of samples per year occasionally varied at each site. If a sample was below the method detection limit (MDL), half of the MDL value 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
36	TP	mg/l	67	0.070	0.125	0.228	1.860	0.010	4
37	TP	mg/l	67	0.056	0.078	0.060	0.294	0.010	10
38	TP	mg/l	67	0.044	0.054	0.044	0.239	0.010	14
10	TP	mg/l	74	0.072	0.121	0.270	2.150	0.010	4

High variability for long term means at Sites 10 and 36 is due primarily to a decreasing annual mean TP content over time (Figure IV.19). In particular, Site 36 displayed a general trend of TP concentration over 0.100 mg/l during the 1980s then changed to TP values near or within compliance in the 1990's. Site 10 yearly TP averages were 0.05 mg/l or higher eleven times from 1981 to 1992. Yet from 1993 to 1997, mean total phosphorus concentrations at Site 10 were near or below 0.050 mg/l four of the five years. Site 37 displayed a similar pattern as Site 10. The basin's lowest mean TP concentrations were typically measured at Site 38, especially from 1993 to 1997.

To further investigate TP values over time, all individual samples were rated in terms of Broward County's marine TP standard (0.050 mg/l; see (see IV.E.5.d). In addition, three periods (1981-1986, 1987-1991, and 1992-1997) were analyzed with special reference to the closing of WWTPs within the basin (see Section IV.F.3). The percentage of samples within compliance of the Broward County marine standard (0.050 mg/l) revealed elevated total phosphorus levels during early data collection, especially 1981-1986 (Figure IV.20). Sites 36, 37, and 10 went from 87.0%, 65.3%, and 52.2% poor rating, respectively during 1981-1986 to under 10.0% poor rating from 1992-1997. Overall, the highest percentage of good samples (87.5%) was observed at Site 38 from 1992 to 1997.

Statistical differences were not observed between wet and dry season median TP values from 1989-97 (Figure IV.21). Site 36 had the highest dry season TP values while Site 10 tended to exhibit the highest wet season measurements. Both Sites 37 and 38 had median values (wet and dry season) below 0.05 mg/l with Site 38 generally having the lowest TP levels in the basin.

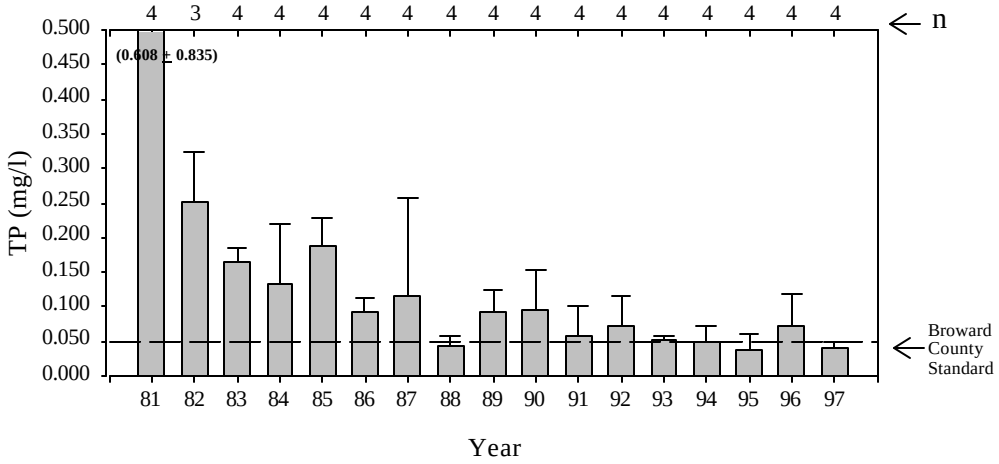
e. Total Nitrogen

Total Nitrogen (TN) levels are calculated from the total Kjeldahl nitrogen (TKN) and nitrate+nitrite-nitrogen (NO_2+NO_3) concentrations. Mean and median TN values over the 17-year period were at or below 1.000 mg/l at all sites and well within compliance of the Broward County marine standard (1.500 mg/l, Table IV.11). Site 10 exhibited the highest TN levels while Site 38 generally had the lowest TN content in the basin.

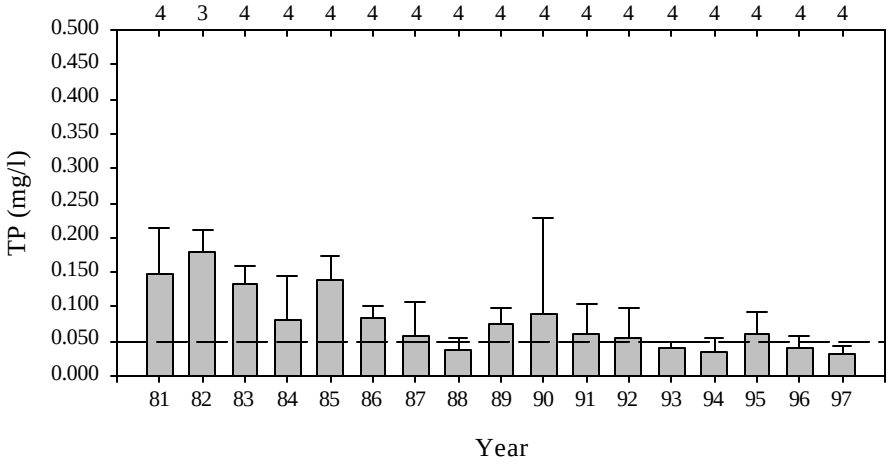
As with TN, the highest mean TKN, NH_3, and NO_2+NO_3 concentrations were observed at Site 10 and the lowest mean values for all nitrogen species were found at Site 38. Normally, the majority of

Figure IV.19. Annual Mean Total Phosphorus (TP) Content Within the Central Intracoastal Waterway (ICW) Basin from 1981 to 1997. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. TP levels should be below the Broward County marine standard (0.050 mg/l) indicated by the dashed line. Numbers in parentheses are mean and/or sd value outside y-axis range.

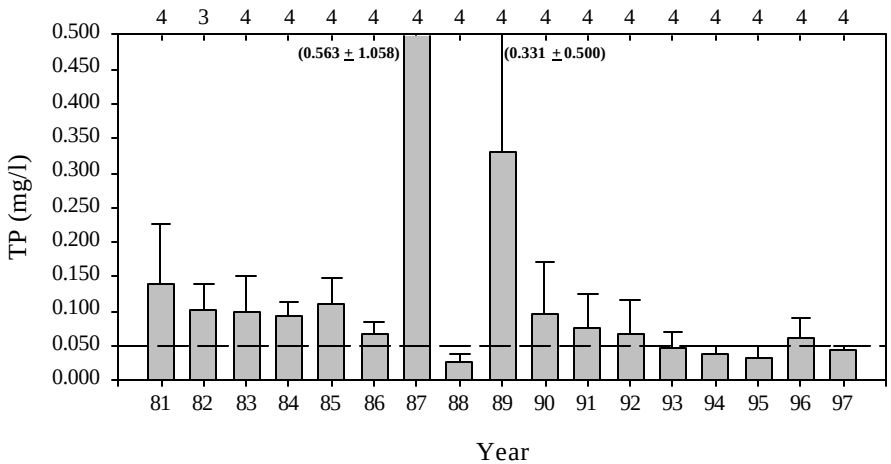
a) Site 36



b) Site 37



c) Site 10



d) Site 38

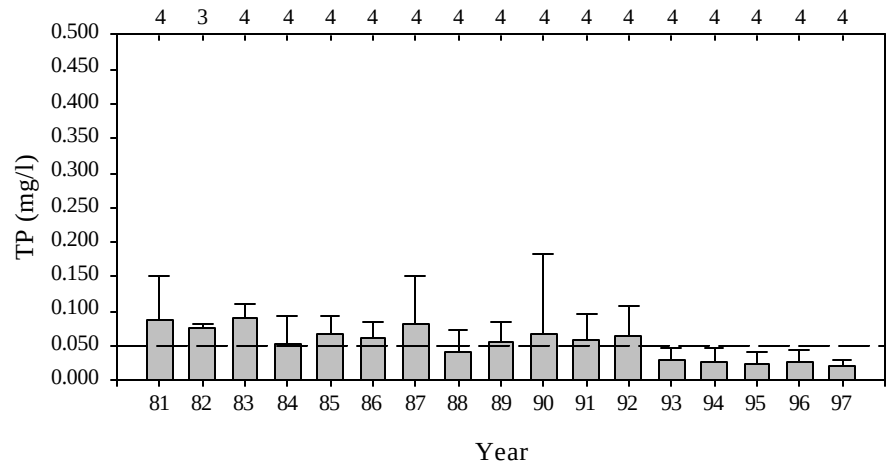


Figure IV.20. Total Phosphorus (TP) Concentrations Observed in the Central Intracoastal Waterway Basin over Three Time Periods. TP levels are categorized in terms of compliance with the Broward County marine standard of 0.050 mg/l. The percentage below 0.050 mg/l are classified as good. A fair rating was given to values between 0.051 mg/l to 0.099 mg/l. Values equal to or greater than twice the standard (i.e., 0.100 mg/l) are classified as poor.

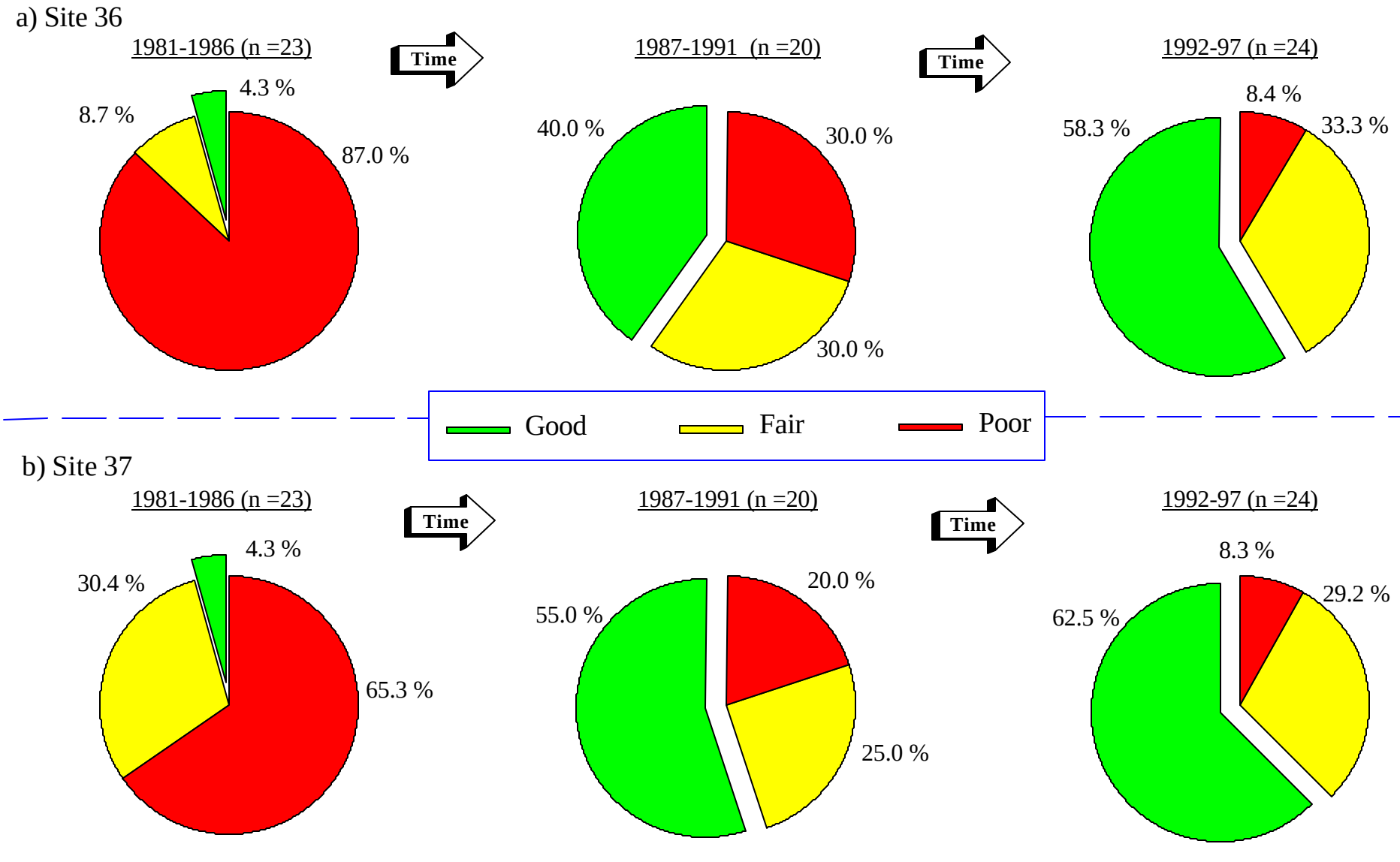
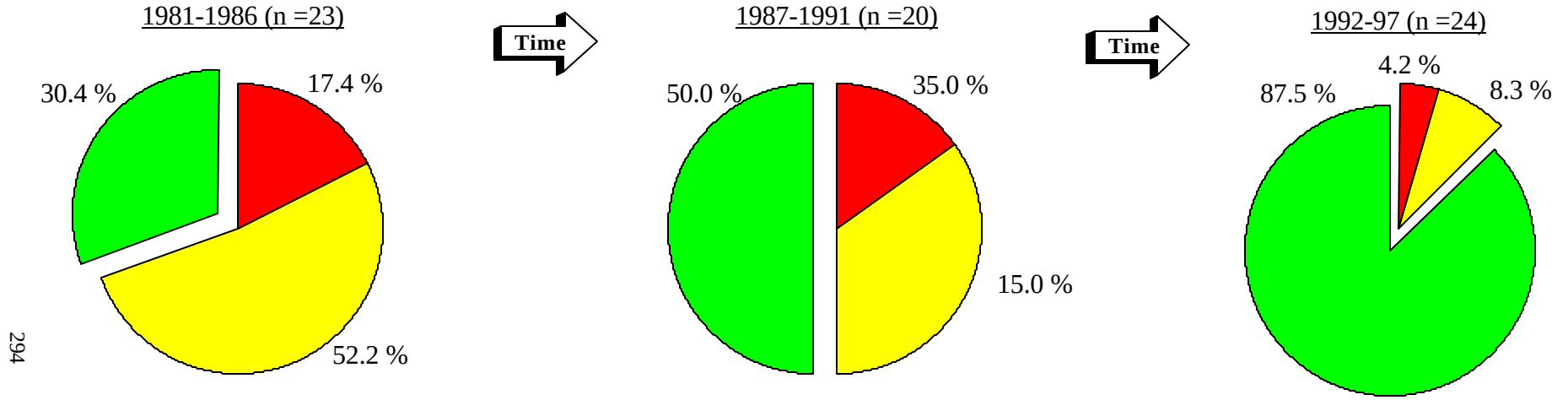


Figure IV.20 (Cont.). Total Phosphorus (TP) Concentrations Observed in the Central Intracoastal Waterway Basin over Three Time Periods. TP levels are categorized in terms of compliance with the Broward County marine standard of 0.050 mg/l. The percentage below 0.050 mg/l are classified as good. A fair rating was given to values between 0.051 mg/l to 0.099 mg/l. Values equal to or greater than twice the standard (i.e., 0.100 mg/l) are classified as poor.

c) Site 38



d) Site 10

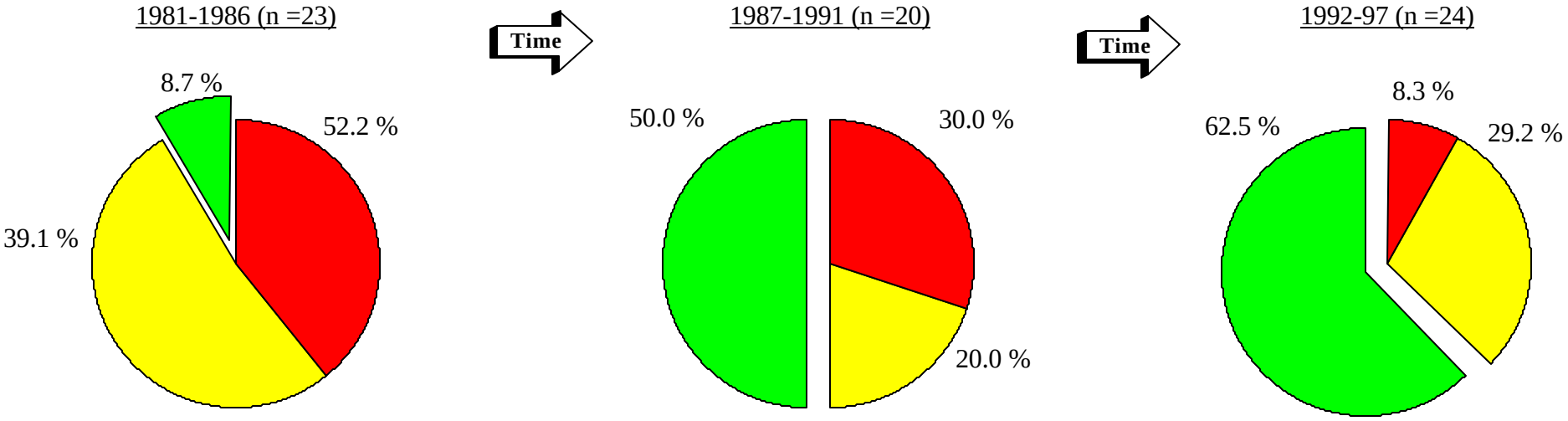
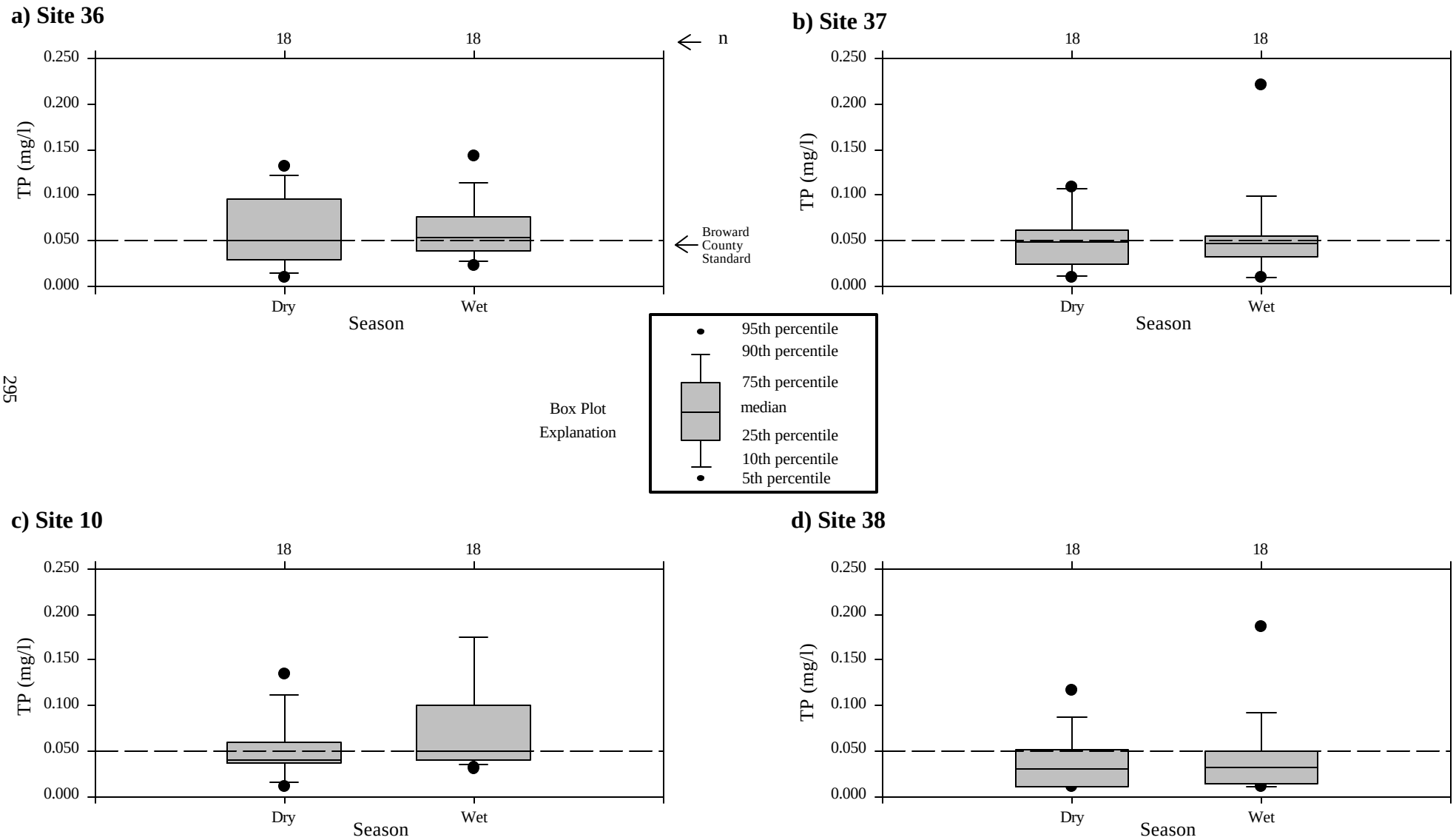


Figure IV.21. Central Intracoastal Waterway Basin Total Phosphorus (TP) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season values were not observed in the basin.



the TN (> 75%) was comprised of TKN which measures the total amount of organic nitrogen and ammonia-nitrogen (NH_3; Table IV.11). Ammonia-nitrogen levels were typically low with 31.4% of the basin's samples recorded below the method detection limit. Thus, organic nitrogen was the major form of the total nitrogen values observed during this study. Long term median NO_2+NO_3 concentrations, however, were slightly elevated throughout the basin (> 0.075 mg/l).

Table IV.11. Descriptive Statistics for Nitrite+Nitrate-Nitrogen (NO_2+NO_3), Ammonia-Nitrogen (NH_3), Total Kjeldahl Nitrogen (TKN), and Total Nitrogen (TN) in the CICW Basin. Total Nitrogen was calculated as the sum of TKN and NO_2+NO_3. All calculations represent seventeen years of sampling. However, the number of samples per year occasionally varied at each site. 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).

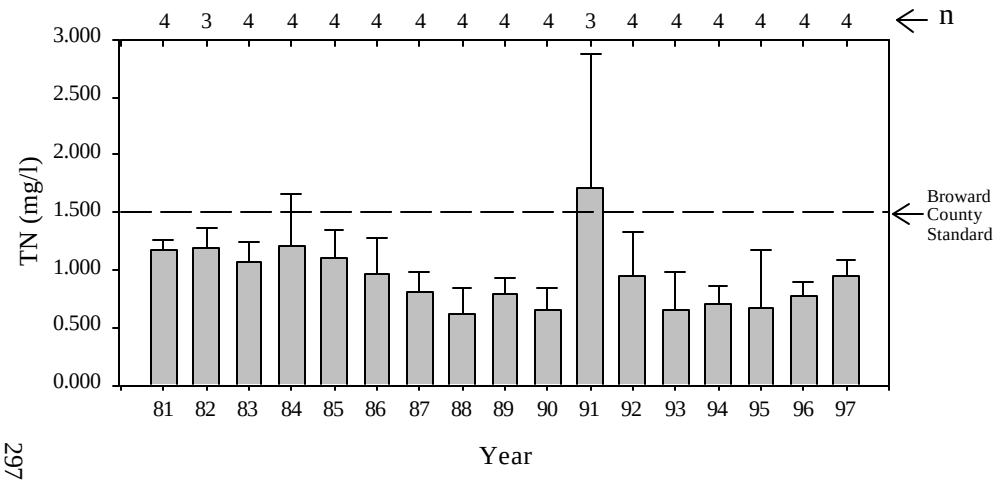
Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
36	NO_2+NO_3	mg/l	77	0.129	0.158	0.144	0.618	0.005	8
37	NO_2+NO_3	mg/l	76	0.154	0.163	0.123	0.563	0.005	3
38	NO_2+NO_3	mg/l	77	0.076	0.098	0.078	0.341	0.005	3
10	NO_2+NO_3	mg/l	65	0.160	0.233	0.381	3.120	0.005	1
36	NH_3	mg/l	61	0.039	0.090	0.114	0.598	0.005	21
37	NH_3	mg/l	62	0.041	0.072	0.077	0.313	0.005	15
38	NH_3	mg/l	62	0.025	0.047	0.059	0.221	0.005	23
10	NH_3	mg/l	60	0.068	0.101	0.117	0.590	0.005	18
36	TKN	mg/l	66	0.734	0.766	0.373	2.990	0.054	1
37	TKN	mg/l	66	0.664	0.656	0.276	1.460	0.020	2
38	TKN	mg/l	66	0.564	0.611	0.278	1.570	0.082	0
10	TKN	mg/l	66	0.788	0.790	0.273	1.500	0.020	1
36	TN	mg/l	67	0.851	0.925	0.402	3.049	0.142	calc
37	TN	mg/l	63	0.807	0.84	0.288	1.733	0.302	calc
38	TN	mg/l	66	0.665	0.709	0.287	1.635	0.147	calc
10	TN	mg/l	64	0.956	1.024	0.541	4.42	0.067	calc

Basinwide patterns were not apparent for annual TN concentrations. Site 10 annual mean TN values were occasionally elevated during the early 1980's but were normally below the Broward County standard (Figure IV.22). Mean TN values showed a slight trend upward at Site 38 but TN values were still within standard compliance (i.e., < 1.500 mg/l). With the exception of 1991, Site 36 showed a slight decreasing trend in annual TN values while Site 37 mean values remained fairly similar over time.

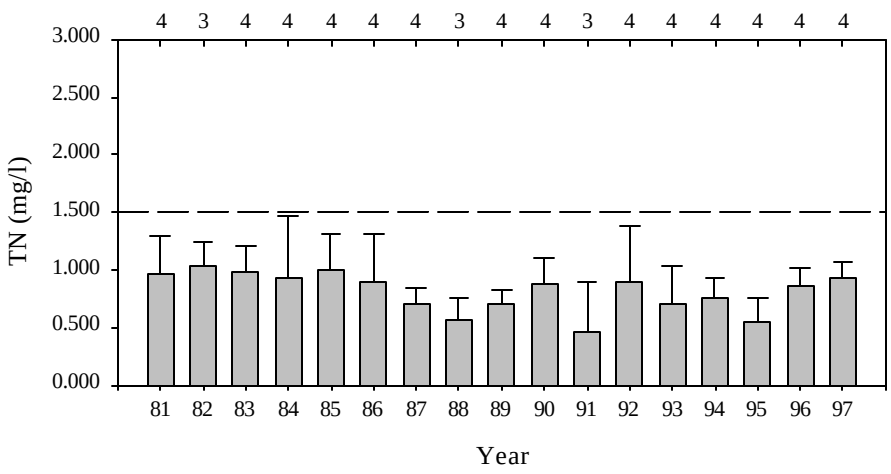
To more closely examine standard compliance, TN concentrations were designated poor, fair and good with the same methodology used for the NICW (see Section IV.E.5.e). In addition, changes over time are presented with special reference to the closing of WWTPs within the basin (see Section IV.F.3). The percentage of TN samples that achieved Broward County compliance (1.500 mg/l) was typically high (> 90.0%) throughout the sampling period at all sites (Figure IV.23). Only the 1981-1986 period

Figure IV.22. Annual Mean Total Nitrogen (TN) Content Within the Central Intracoastal Waterway (ICW) Basin from 1981 to 1997. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. TN levels should be below the Broward County standard (1.500 mg/l) indicated by the dashed line.

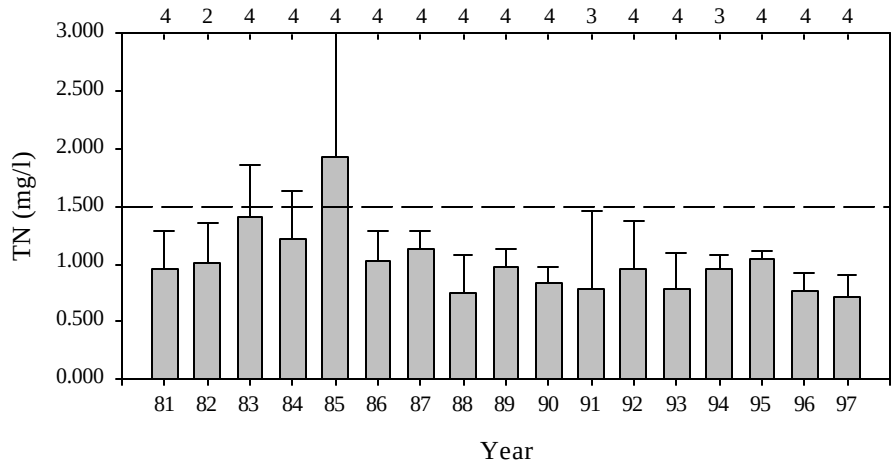
a) Site 36



b) Site 37



c) Site 10



d) Site 38

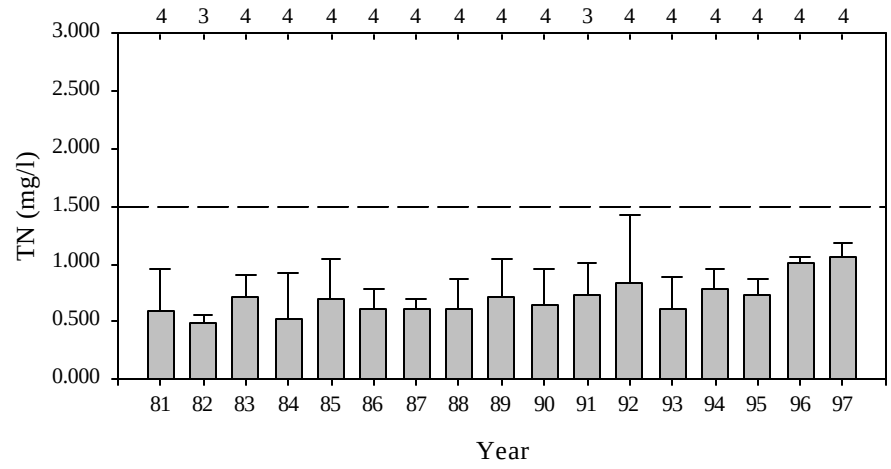


Figure IV.23. Total Nitrogen (TN) Concentrations Observed in the Central Intracoastal Waterway Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County marine TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified as 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.

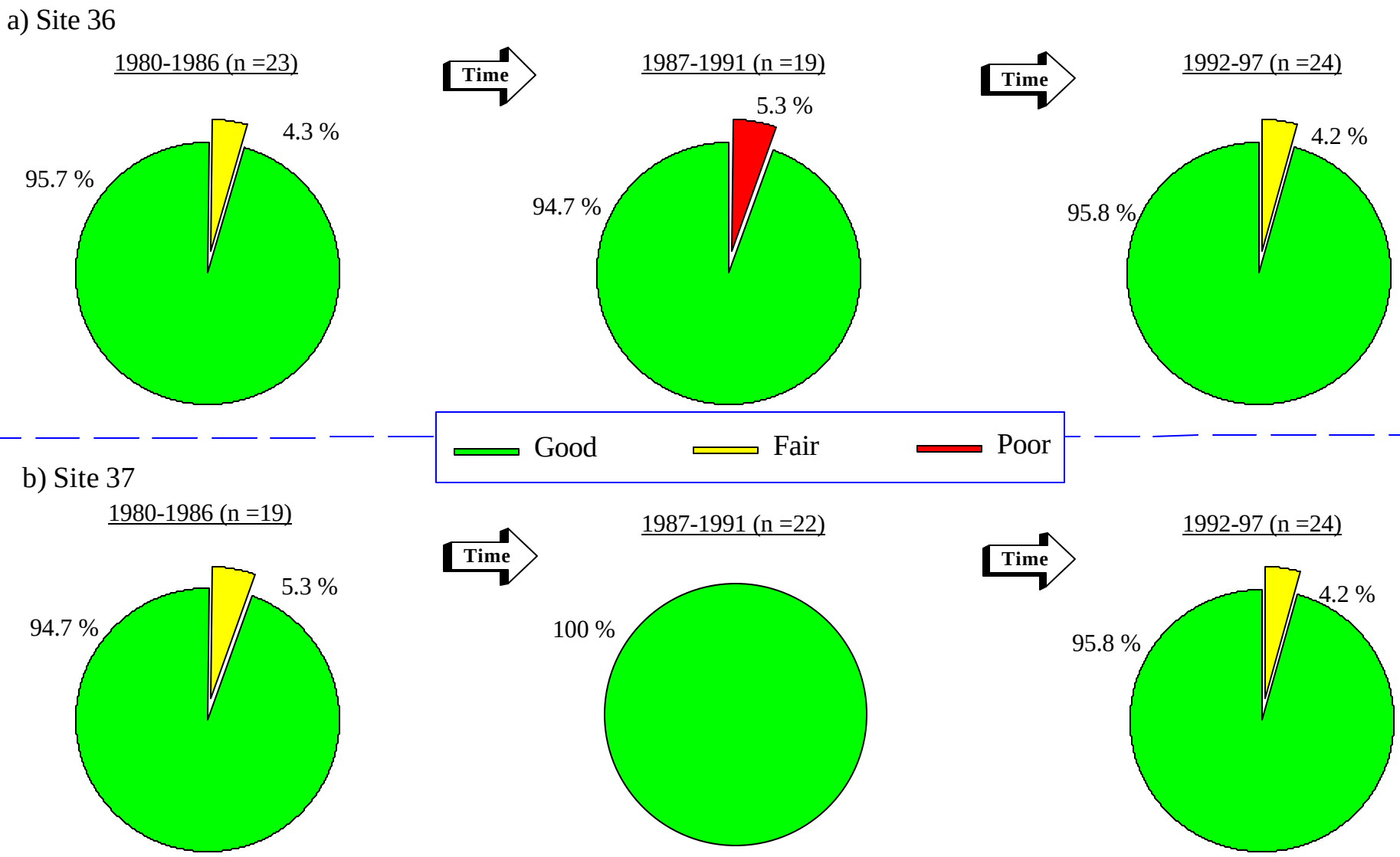
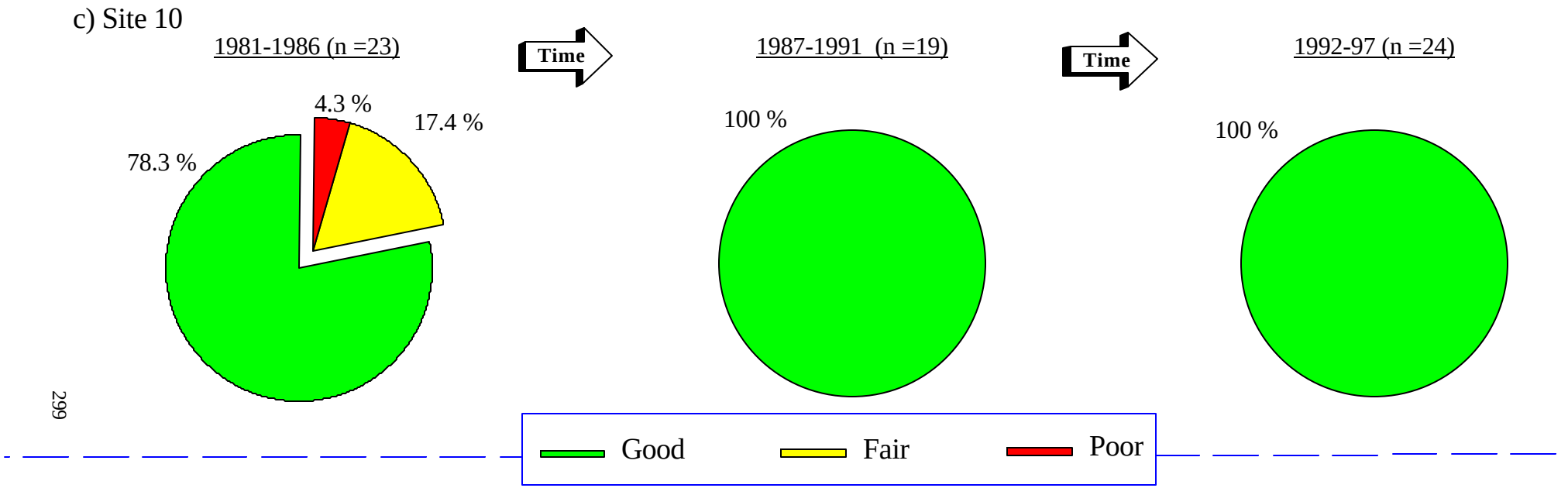
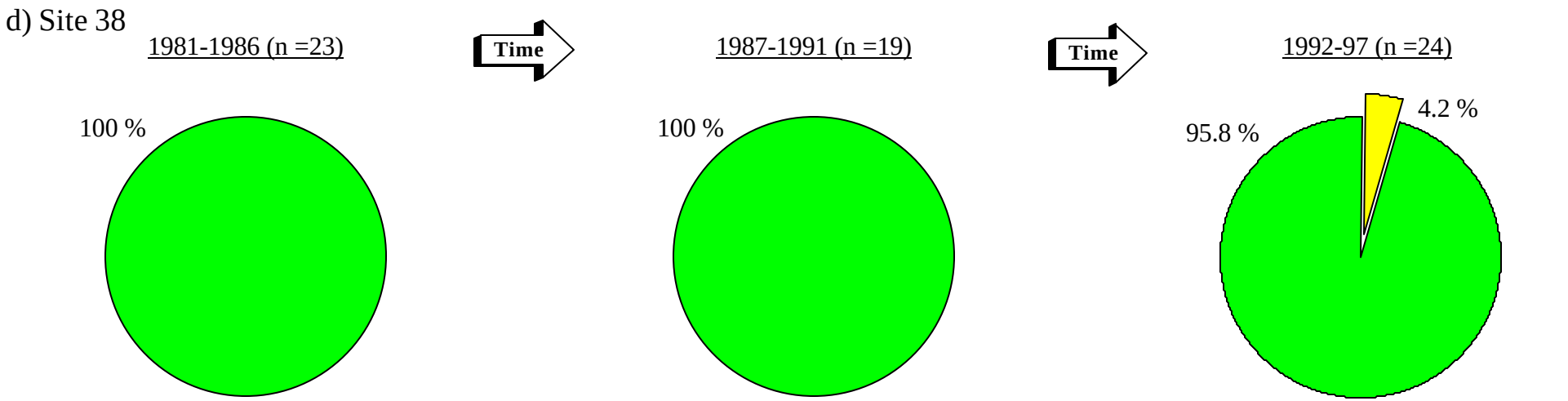


Figure V.23 (Cont.). Total Nitrogen (TN) Concentrations Observed in the Central Intracoastal Waterway Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County marine TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified 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.





for Site 10 revealed a good percentage below 90.0%.

Statistical differences were not observed between mean and/or median wet and dry season total nitrogen content at any CICW site (Figure IV.24). In addition, almost all TN values from 1989 to 1997 were within Broward County's compliance standard (i.e., 1.500 mg/l). Only Sites 36 and 38 had TN values (95th percentile) equal to or greater than 1.500 mg/l.

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, however, bacteriological mean values are often skewed by outlying high values (BCDNRP 1994a). The high standard deviations and large differences between maximum and minimum values (Table IV.12) attest to the occurrence of this pattern.

Site 10 exhibited the highest mean, median, maximum, and standard deviations for all bacteriological parameters and the least amount of samples below the method detection limit (Table IV.12). Relatively similar bacteriological median values were observed for the three ICW Sites 36 thru 38.

Table IV.12. Descriptive Statistics for Fecal Coliform (FC), Total Coliform (TC), and Fecal Streptococcus (FS) in the CICW Basin. All calculations represent seventeen years of sampling. However, the number of samples per year varied occasionally at each site. 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
36	FC	col	66	31	167	408	1800	3.5	14
37	FC	col	66	30	81	190	1400	3.5	19
38	FC	col	67	37	112	234	1300	3.5	12
10	FC	col	74	62	330	876	6600	3.5	10
36	TC	col	66	300	748	1592	11000	12	8
37	TC	col	66	170	355	688	5300	12	5
38	TC	col	66	280	522	823	4700	5	4
10	TC	col	74	450	2550	9541	80000	12	4
36	FS	col	7	33	234	825	6400	12	24
37	FS	col	7	49	137	282	2100	12	27
38	FS	col	7	49	246	722	5400	12	25
10	FS	col	75	100	726	3929	34000	12	19

Due to the large amount of variability around the mean, yearly box plots were plotted for FC instead of the mean (Figure IV.25). For example, four 1991 FC samples were obtained at Site 10. The results were 30, 50, 60 and 6,600 colonies/100 ml which yields a mean of 1,685 ± 3,277 colonies/100

Figure IV.24. Central Intracoastal Waterway 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 values were not observed in the basin.

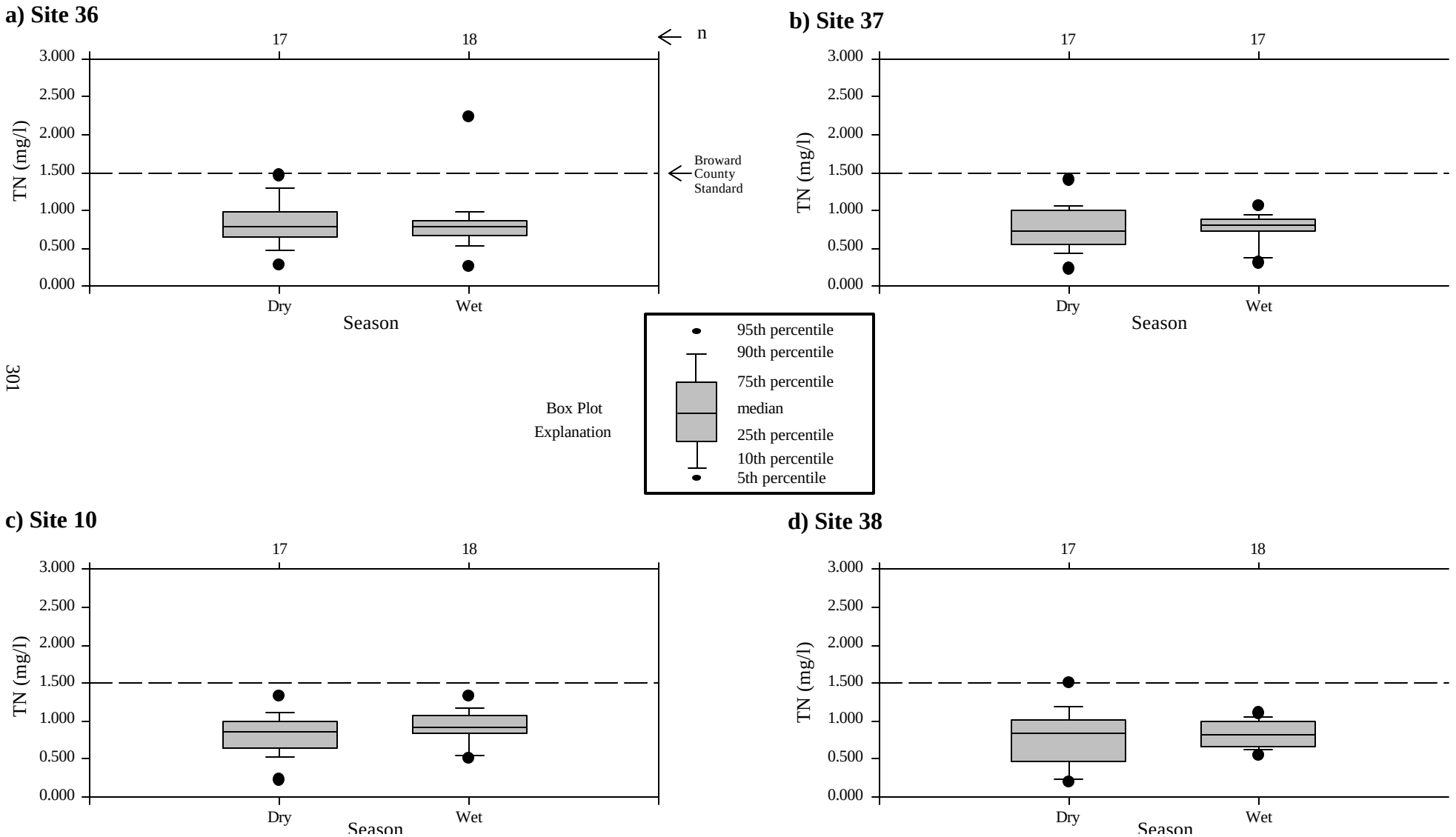
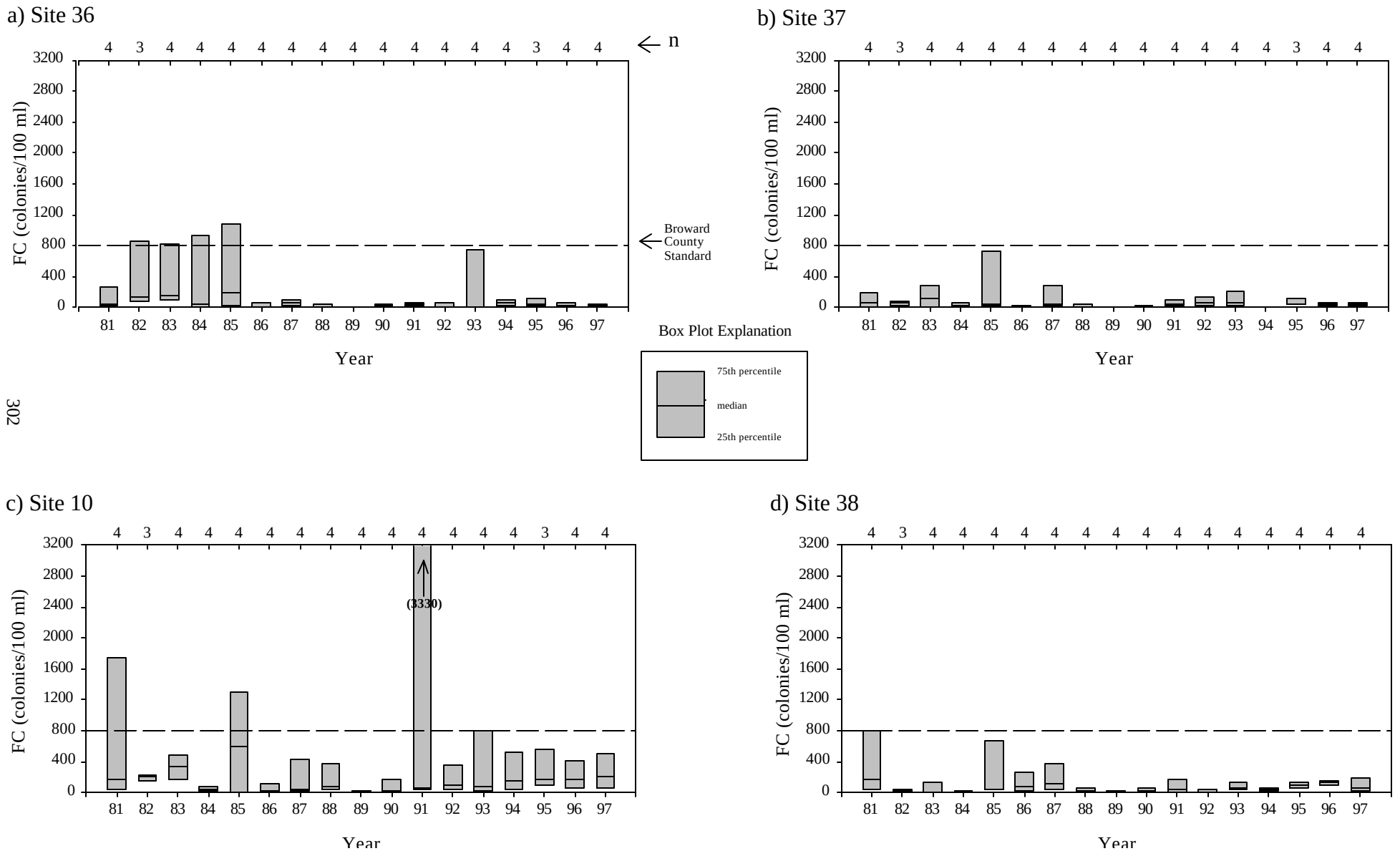


Figure IV.25. Yearly Box Plots of Fecal Coliform (FC) Levels Within the Central Intracoastal Waterway Basin from 1981 to 1997. Medians and percentiles calculated from quarterly samples (n=4) unless noted on upper x-axis. FC levels should be below the Broward County single sample standard (800 colonies/ 100 ml) indicated by the dashed line. Numbers in parentheses represent 75th percentile values that extend beyond the y-axis scale.



ml but a median of only 55 colonies/100 ml.

Yearly FC median values were below the single sample standard (800 colonies/100 ml) at all sites during all years (Figure IV.25). However, occasional high FC concentrations were observed, particularly at Site 10, which exhibited the highest annual medians and 75th percentile values during the 1990's. From 1981-85, some samples at Sites 36 thru 38 were above the 800 colonies/100 ml standard. However, the 1990's data revealed relatively lower FC content at Sites 36 thru 38 as compared to Site 10.

All FC samples were categorized based on three different Broward County water quality standards to better understand compliance levels (see Section IV.E.5.f). Special consideration was given to the closing of WWTPs within the basin (see Section IV.F.3). Thus, the periods compared were 1981-1986, 1987-1991, and 1992-1997. Fecal coliform compliance levels were generally very high at all four sites (Figure IV.26). The lowest percentage of good samples was observed during 1981-1986. However, Site 10 had identical good percentage (60.9%) during 1981-1986 as 1992-97, signifying a decrease from the 1987-91 sampling period. The three ICW Sites 36 thru 38 had at least ninety percent compliance (i.e., < 800 colonies/100ml) after 1986.

Seasonal (wet versus dry) FC differences were not observed in the basin (Figure IV.27). Site 10 showed the largest range of median to 95th percentile data for both seasons. Furthermore, an occasional (90th percentile) FC measurement was greater than the 800 colonies/100 ml standard. Site 36 also had some samples (95th percentile) above the 800 colonies/100 ml standard during the wet season, but ICW samples were normally low with medians never exceeding 100 colonies/100 ml for the nine-year period.

6. Basin Summary

The CICW Basin was divided more by geographical similarity than hydrological connectivity. The northernmost Site 36 is likely in a tidal transition zone between the NICW and the CICW basins. Two sites with similar latitude but different water sources (Sites 10 and 37) exist at two separate Sunrise Boulevard Bridges. Finally, the southernmost Site 38 exists at the northern border of Port Everglades and likely represents the area with the most interaction with coastal water. The following will summarize whether these hydrologically distinct but geographically similar sites have similar or different water quality characteristics. In addition, the influence of WWTP discharges and seasonal effects will also be discussed. Finally, questions about the CICW basin brought forth by this initial data analysis effort are listed to support future monitoring and resource planning.

a. Influence of WWTPs Discharge

Sites 36 and 37 showed the greatest response to the end of WWTP discharges. Annual nutrient concentrations, especially TP, substantially decreased after 1986. In addition, the number of low DO observations (< 4.0 mg/l) decreased at Sites 36 and 37 after WWTP closures. Site 10 also exhibited improvements in water quality after the closure of WWTPs, with the exception of FC content. Site 38 showed little trends when compared to the closing of the WWTP discharging into Port Everglades.

Figure IV.26. Fecal Coliform (FC) Concentrations Observed in the Central Intracoastal Waterway 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.

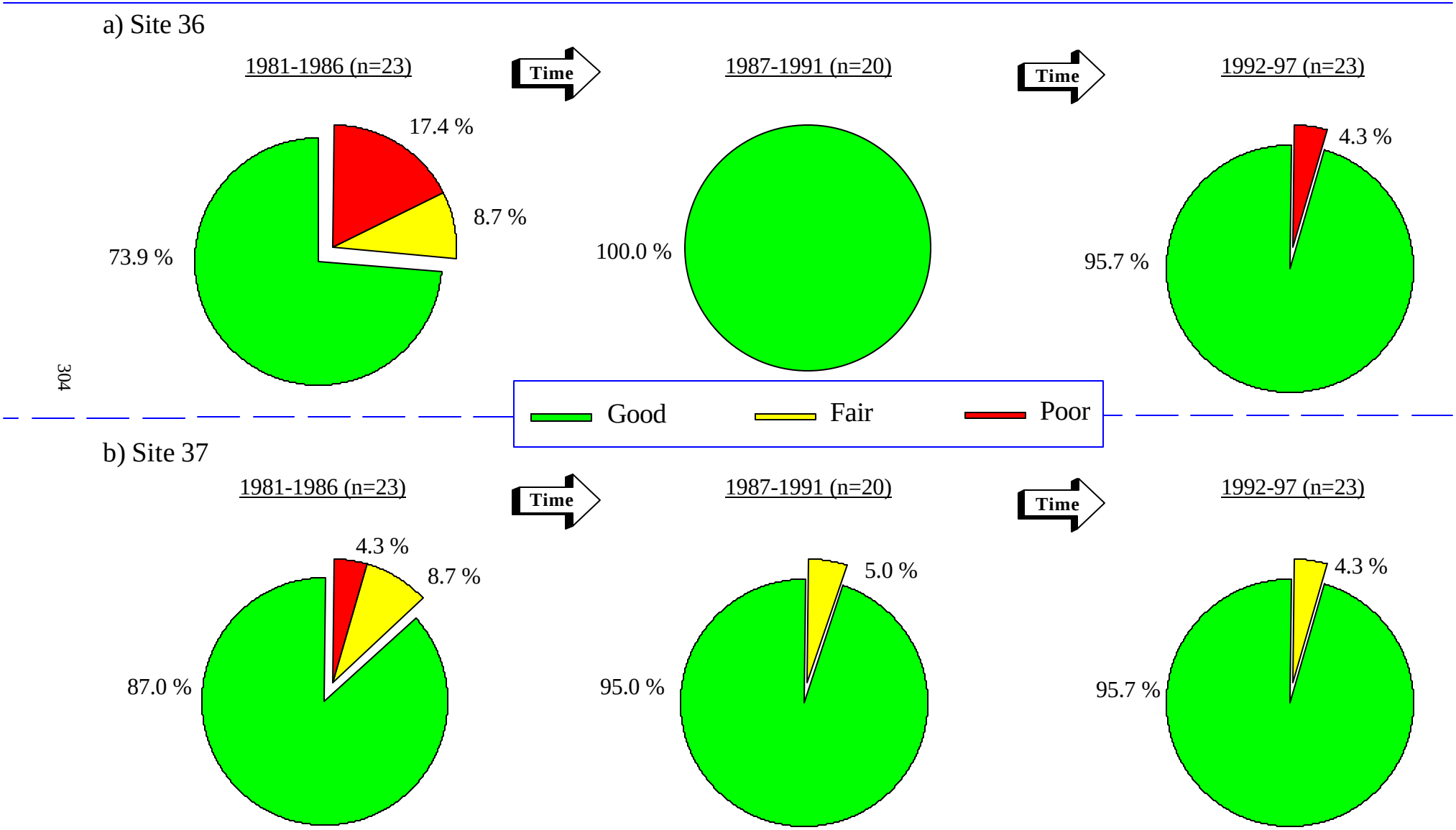


Figure IV.26 (Cont.). Fecal Coliform (FC) Concentrations Observed in the Central Intracoastal Waterway Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100 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.

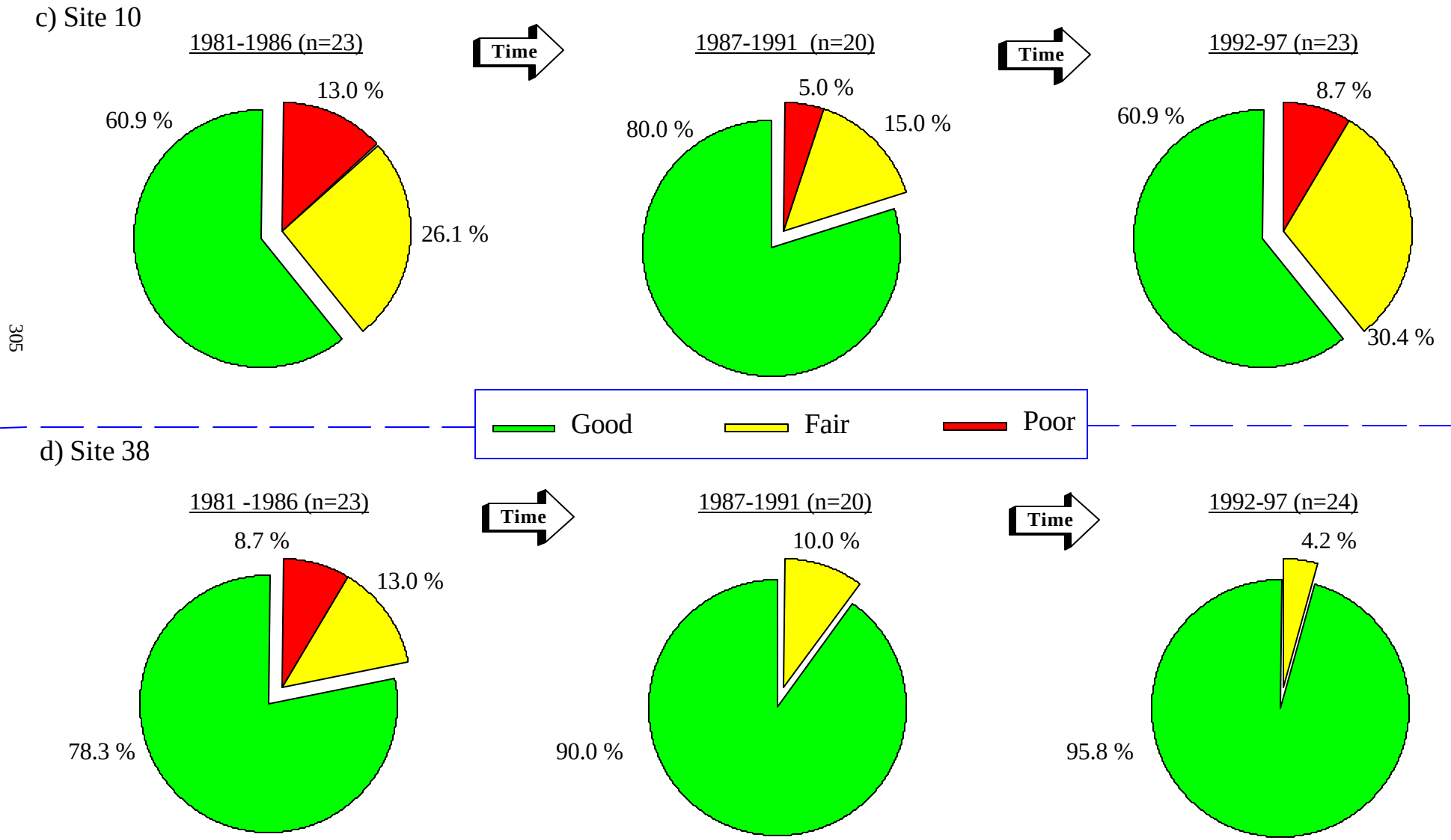
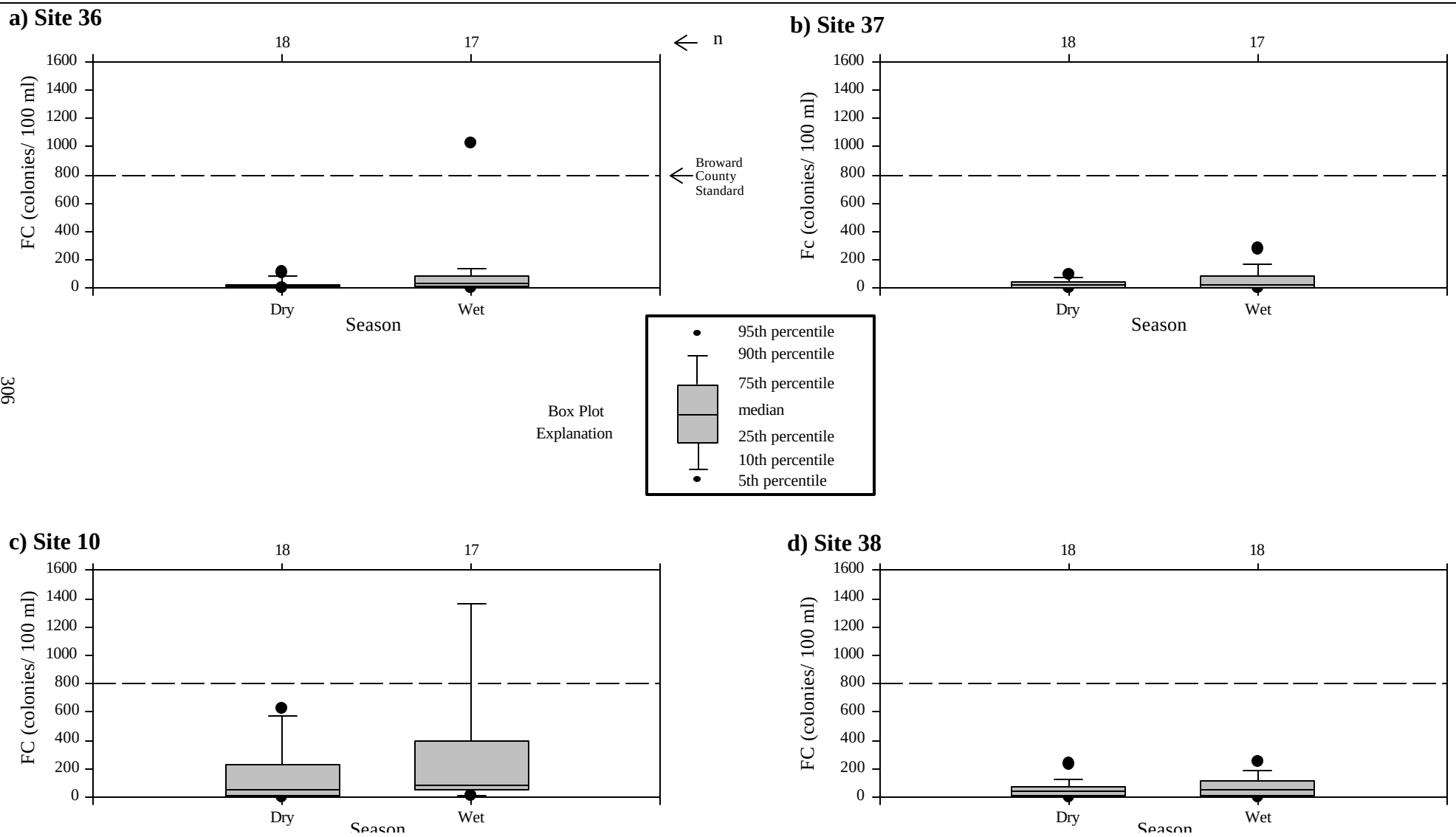


Figure IV.27. Central Intracoastal Waterway Basin Fecal Coliform (FC) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season values were not observed in the basin.



This may be due to the dynamic flushing (tidal) that takes place within Port Everglades. Interestingly, Site 38's TN values slightly increased in the 1990s as compared to the years when WWTPs discharged into surface waters (<1986), but values were still less than the 1.500 mg/l standard.

b. Basin Water Quality Comparison (Post-WWTPs)

Overall, the CICW Basin's ambient water quality was relatively good, particularly over the last five years. Only occasionally elevated TP concentrations were noted in the 1990's but the percentage of samples rated poor (i.e., 0.100 mg/l) was much lower than seen in the 1980's. Site 38, in close proximity to the Port Everglades Inlet, generally had the best water quality of the basin. Similar to Site 34 in the NICW, Site 38's water quality is heavily influenced by tidal flushing of coastal water which contributes to its relative good ambient water quality. Site 10, the inland-most site, typically exhibited the poorest water quality of the four sites, primarily due to occasional low DO content and relatively high FC concentrations. As the 'tributary' site, the area at Site 10 receives water from the western tributary (Middle River/C-13) directly. Thus, water quality decreases when moving from the coastal inlet to upstream tributaries. However, the major water quality parameters investigated (DO, TP, TN and FC) rarely ranked poor in the respective compliance level categories at Site 10.

Site 10's FC levels in the 1990s may warrant additional observations. Median FC levels were consistently around 200 colonies/100 ml even during the dry season (see Figure IV.27) and 75th percentile values were typically near or above 400 colonies/100 ml. Although the single sample standard is 800 colonies/100 ml, monthly averages are supposed to be below 200 colonies/100 ml. The current BCDPEP ambient monitoring network is not designed to collect the ten samples needed to define a monthly average (see state of Florida 1998, FAC 62-302). Potentially, some extra monitoring may be needed in this area but it should be emphasized the current single sample standard (800 colonies/100 ml) is rarely violated.

c. Seasonal Differences

Statistical differences were observed for DO content at all four sites. As discussed previously, temperature changes alone between wet and dry seasons can explain lower dissolved oxygen concentration in a waterbody. With the exception of Site 10's wet season, almost all wet and dry season samples were above the 4.0 mg/l Broward County standard (i.e., within compliance) at all sites.

For the other major parameters (TP, TN, and FC), wet season values were not significantly different than dry season concentrations. Potentially, this means the input of coastal water and/or freshwater may mask seasonal patterns and/or the sample size may reduce the power of this seasonal analysis. Unfortunately, residence time has not been computed for Broward's estuarine water. Mainly TP concentrations exceeded existing BC water quality standards during both seasons at all sites with Site 10 and 36 having the highest values. Dry season TN values tended to have more variability than wet seasons concentrations while TP values were characterized by slightly more scatter in the wet season.

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 CICW, the hydrologic flow regime needs to be better defined. Improved physical information would likely improve the understanding of possible nutrient transport (TP, TN and/or DIN [NO_2+NO_3-N plus NH_3-N) from western freshwater canals and offshore. It would also assist in defining the hydrological division between the NICW and CICW. Thus the following are proposed for the CICW:

- At low tide, does Site 38 have worse water quality than observed with an ambient monitoring effort (i.e., What is the poorest water being transported offshore?)

- As an estuarine waterbody, what extent is the influence of a "salt wedge" from the east and the freshwater from the west?

- What is stormwater quality like directly entering the numerous finger canals that reach the ICW?

- How does intermittent discharges from the salinity structures influence water quality, as well as overall estuarine hydraulic residence time?

- Are occasional high TP values indicative of western nutrient loading and is water column biology being effected?

- Although TN levels are normally within compliance the of Broward County standard, are DIN levels (DIN, NO_2+NO_3-N plus NH_3) of more importance to water column biology?

- Where is the physical division actually observed between the NICW and the CICW?

- Are the upper range (i.e., 75^{th} percentile) of fecal coliform observations at Site 10 anomalous or an indication of potential contamination?

- What is the water quality of the main Middle River (particularly east of I-95 to west of US 1)?

G. ICW - Southern Basin

1. Geographic Locale

The Southern Intracoastal Waterway (SICW) basin is located in the southeast corner of Broward County (Figure IV.28) and includes the municipalities of Ft. Lauderdale, Dania Beach, Hollywood, and Hallandale. Coastal ocean water primarily comes from the Port Everglades Inlet. In the north area of the basin, freshwater originates primarily from the eastern C-11 Canal which discharges into the Dania Cut-off Canal. The confluence of the Dania Cut-off Canal and SICW is approximately one and one half miles south of Port Everglades. The central and southern reaches do not have a major tributary. However, the basin's southern hydrology is likely influenced by Miami-Dade County's Haulover Inlet, ICW, and the C-9 Canal system.

2. Land Use and Activities Impacting Water Quality

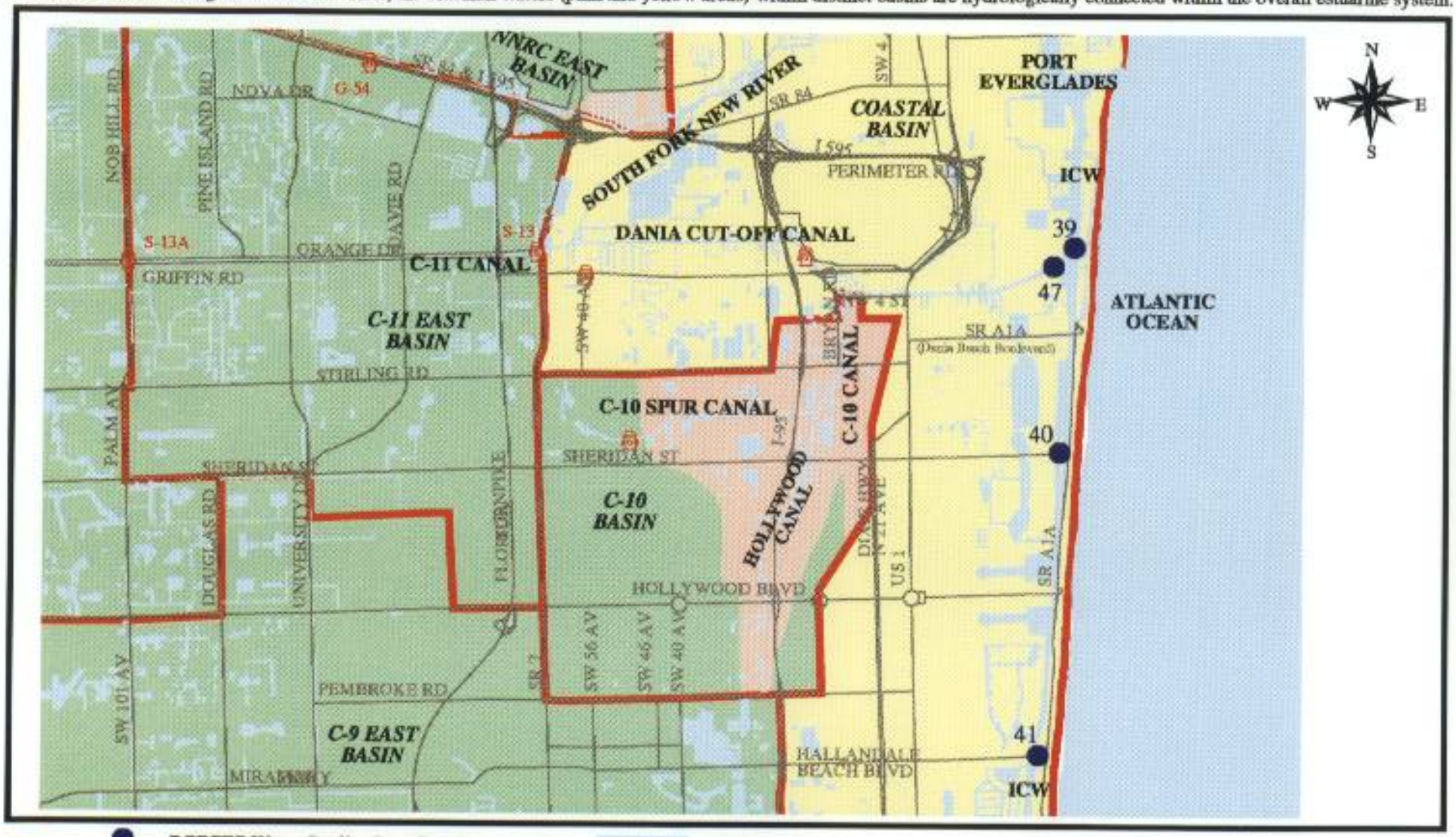
Three main areas divide the land use around the SICW. The north portion has both mangrove communities (John U. Lloyd State Park) along the eastern shore while the western shore is a major shipping port (Port Everglades). The central area is dominated by a 1,200 acre mangrove preserve (Broward County's West Lake Park). The southern region of the basin is densely populated with residential (houses and condominiums) and commercial properties (hotels, restaurants, and marinas). The SICW has relatively less finger canals then the NICW and CICW but has two large 'lakes' artificially cut into the ICW channel near Hollywood Boulevard. Overall, bulkheaded seawalls are not as prominent in the SICW as in the NICW and CICW due to the large areas of mangrove forests. The waterway is used primarily by a large volume of boat (recreational and commercial) traffic less than 100 feet (length) in the south and by very large (greater than 500 feet) ocean going commercial oil tankers, cargo and cruise ships that characterize Port Everglades and Port Dania Beach.

Stormwater outfalls in the area are primarily associated with major roadways and bridges, including State Road A1A, Dania Beach Boulevard, Sheridan Street, Hollywood Boulevard, and Hallandale Beach Boulevard (Figure IV.28). Septic tanks are not in the immediate study area but do exist upstream in the Dania Cut-off/C-10 Canal Basin and will be discussed more fully in Section IV.I.2.

3. Wastewater Treatment Plants Discharge History

Historically, few wastewater treatment plants (WWTPs) discharged directly into the SICW. The City of Ft. Lauderdale's GT Lohmeyer plant discharged waste (22.750 million gallons per day (mgd) capacity) into Port Everglades until 1984, which is just north of the SICW Basin. The elimination of WWTP discharges into the Dania Cut-off Canal occurred in 1980 when then Broward County Utilities 3A and 3B (1.095 mgd capacity) ceased dumping into the canal. The C-11 Canal, western freshwater canal tributary to the Dania Cut-off Canal (see Section III.J.3), still received some wastewater discharges from the Town of Davie and Hollywood Lakes Country Club until 1988.

Figure IV.28. The Southern Intracoastal Waterway Basin and Broward County (BCDPEP) Sampling Sites Location Map. The brackish sections of the North New River Canal (NNRC) and C-10 Basins are shown in pink. These areas were delineated by the United States Army Corps of Engineers as separate basins from the Coastal Basin (Cooper and Lane 1987). However, the respective receiving water bodies are tidally connected and are downstream of the coastal water control structures (G-54 and S-13) operated by the South Florida Water Management District. Thus, the brackish waters (pink and yellow areas) within distinct basins are hydrologically connected within the overall estuarine system.



BCDPEP Water Quality Sampling Site

Water Control Structures (primarily SFWMD)

Waterbodies

Major Roadways

0 1 2 3 Miles

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

4. Sampling Locations and Period

Latitude and longitude measurements were determined by Global Position System and specific site descriptions are given in Appendix 1. Site 39 is the northern most site in the basin and is heavily influenced by both Port Everglades and the Dania Cut-off Canal (Figure IV.28). Site 47 represents water quality at the mouth of the Dania Cut-off Canal, immediately west of the confluence with the ICW. Site 40 is located in the center of the basin just north of the Sheridan Street (Hollywood) bridge and surrounding land use is dominated by a mangrove preserve (West Lake Park). Site 41 is the southernmost sampling site along the ICW in Broward County and is at the Hallandale Beach Boulevard bridge. All sites are sampled by boat on the same day.

Sites 39 thru 41 have been sampled by BCDPEP since 1980, while Site 47 has been monitored since 1985. As Site 47 was only missing five years of observations, the data analysis in this section covers the previous 18 years (i.e., 1980-1997). However, only temperature, dissolved oxygen, salinity, pH, and turbidity were measured during 1980 at Sites 39 thru 41. The remaining parameters (total Kjeldahl nitrogen, nitrite+nitrate-nitrogen, ammonia-nitrogen, total nitrogen [calculated], fecal coliform, total coliform, fecal streptococcus, total phosphorus, total organic carbon) were monitored beginning in 1981 at Sites 39 thru 41. Biochemical oxygen demand (7-day test) monitoring occurred from 1981-1993 at Sites 39 thru 41.. Data methodology and manipulation for this section were performed as detailed in the methodology section (Section II).

5. Results

a. Physical Characteristics

Water temperatures throughout the basin were relatively similar and ranged between 18.0°C and 32.1°C (Table IV.13). Overall mean temperatures were nearly identical among the four sites with Sites 40 and 41 having a slightly larger standard deviation and median values. Basinwide pH levels were very similar between sites and showed little variability. Means and median pH values were almost identical at each site (Table IV.13). The lowest pH value recorded was 6.9 at Site 40 while the maximum (7.6) was seen at Site 39.

The highest mean and median salinity values of the entire ICW (northern, central, and southern basins) were observed in the southern basin (Table IV.13). The highest mean salinity (31.0 ± 4.0 ppt) was measured at Site 39 while the lowest mean salinity (28.4 ± 6.6 ppt) was observed in the Dania Cut-off Canal (Site 47) immediately west of the ICW. Three of the four sites exhibited minimum values above 15 ppt. Two SICW Sites 40 and 41 were nearly identical in salinity characteristics. Specific conductance was not consistently measured over the 17-year period but a smaller range of values were noted at the SICW sites than other (northern and central) basin areas.

Table IV.13. Descriptive Statistics for Temperature (Temp; °C = degrees Celsius), pH, Specific Conductance (Cond; Fmhos = micromhos), and Salinity (Sal; ppt= parts per thousand) in the SICW Basin. With the exception of Site 47, Temp, pH and Sal calculations represent eighteen years of sampling. However, the number of samples per year occasionally varied at each site. 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
39	Temp	°C	70.0	26.8	26.4	3.2	31.6	19.0	0
40	Temp	°C	72.0	27.0	26.5	3.6	32.1	18.0	0
41	Temp	°C	70.0	27.0	26.3	3.7	32.1	18.0	0
47	Temp	°C	46.0	26.7	26.5	3.0	31.4	19.0	0
39	pH	units	71	7.9	7.9	0.2	8.4	7.6	0
40	pH	units	73	7.9	7.9	0.2	8.4	6.9	0
41	pH	units	71	7.9	7.9	0.2	8.3	7.5	0
47	pH	units	46	7.8	7.8	0.2	8.3	7.3	0
39	Cond	Fmhos	34	49300	47500	5242	54400	31000	0
40	Cond	Fmhos	34	47150	45781	5721	53000	27500	0
41	Cond	Fmhos	36	45150	43422	6854	53200	25900	0
47	Cond	Fmhos	30	46800	44317	8759	52600	13300	0
39	Sal	ppt	68	32.4	31.0	4.0	36.2	19.1	0
40	Sal	ppt	70	30.7	29.5	4.4	36.0	16.8	0
41	Sal	ppt	69	30.1	29.2	4.3	35.4	15.7	0
47	Sal	ppt	46	30.3	28.4	6.6	35.2	6.8	0

b. Total Organic Carbon and Turbidity

Mean total organic carbon values were relatively similar between sites with Site 39 having the lowest average of 5.58 ± 5.49 mg/l (Table IV.14). The highest long term mean (7.36 ± 6.95 mg/l) was recorded at Site 41. Three sites (39-41) had maximum total organic carbon concentrations of 44.70, 44.20, and 44.50 mg/l, respectively that occurred on the same sampling day (February 16, 1982).

Turbidity levels within the NICW were typically low and within compliance of water quality standards. Although the maximum turbidity value was 230 nephelometric turbidity units (ntu; Site 39), 253 of the basin 's 257 samples (98.4%; raw data not shown) were within compliance (i.e., equal to or below) the Broward County standard of 10 ntus (Broward County 1996). Long term median values also indicate enhanced turbidity values were a rare occurrence.

Table IV.14. Descriptive Statistics for Total Organic Carbon (TOC) and Turbidity (Turbid) Concentrations in the SICW Basin. With the exception of Site 47, TOC calculations represent seventeen years of sampling and Turbid (ntu = nephelometric turbidity units) measurements were taken for eighteen years. However, the number of samples per year varied at each site. 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
39	TOC	mg/l	59	4.80	5.58	5.49	44.70	0.95	0
40	TOC	mg/l	61	5.50	6.47	5.60	44.20	1.33	0
41	TOC	mg/l	59	6.10	7.36	6.95	44.50	0.45	0
47	TOC	mg/l	44	5.35	6.48	4.61	27.00	1.41	0
39	Turb	ntu	71	2.8	6.6	27.0	230.0	0.250	1
40	Turb	ntu	73	2.8	2.9	1.3	7.8	0.600	0
41	Turb	ntu	71	1.8	2.1	1.2	7.7	0.250	1
47	Turb	ntu	46	3.2	3.7	2.7	14.0	0.500	0

c. Dissolved Oxygen and Biochemical Oxygen Demand

Mean, standard deviation, and median dissolved oxygen values for the entire eighteen year sampling period were nearly identical for Sites 39 thru 41 (Table IV.15). Site 47 had less samples and exhibited a thirteen-year mean (5.2 ± 1.0 mg/l) and median (5.3 mg/l) slightly lower than the ICW sites. All long term averages were above (i.e., within compliance) the dissolved oxygen standard (single sample) of 4.0 mg/l (Broward County 2000) although minimum values did fall out of compliance.

Biochemical oxygen demand (BOD) values were also nearly identical for all sites being at or near 1.0 mg/l (Table IV.15). Biochemical oxygen demand samples never exceeded the marine standard of 7.0 mg/l.

Table IV.15. Descriptive Statistics for Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) Concentrations in the SICW Basin. With the exception of Site 47, calculations represent eighteen years of sampling. However, the number of samples per year varied at each site. 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
39	DO	mg/l	70	5.6	5.7	1.3	13.6	3.7	0
40	DO	mg/l	72	5.6	5.6	1.0	8.7	3.4	0
41	DO	mg/l	70	5.8	5.6	1.2	8.5	2.1	0
47	DO	mg/l	46	5.3	5.2	1.0	7.8	2.6	0
39	BOD	mg/l	46	0.8	1.0	0.7	4.0	0.1	1
40	BOD	mg/l	48	0.9	1.1	0.9	5.4	0.2	0
41	BOD	mg/l	48	1.0	1.1	0.6	2.7	0.1	0
47	BOD	mg/l	28	0.8	0.9	0.7	3.8	0.2	0

Yearly DO means revealed a pattern similar to the long-term averages, including the relative consistency of dissolved oxygen compliance levels through time across all sites (Figure IV.29). Site 41 showed a slight general trend toward higher dissolved oxygen levels and lower variability with time. Only Site 47 had an annual mean near the county standard with 4.1 ± 2.1 mg/l recorded in 1991.

As with other basins (see IV.E.5.c), DO concentrations were designated as poor, fair, and good. In addition, the changes over time are presented with special reference to the closing of WWTPs within the basin (see IV.G.3). For the three ICW sites, samples rating good were normally above sixty percent during the whole study (Figure IV.30). Moreover, compliance with the 4.0 mg/l standard (good and fair samples) was at least 96.0% from 1992 to 1997. Site 41 exhibited the most improvement over the three periods by going from 61.5% compliance during 1980-1986 to 84.0% between 1992-1997. Site 39 and 40 exhibited an initial improvement in good ratings from 1987-1991 and then a decrease during 1992-1997. However, both sites experienced less than 5.0% poor samples. Site 47 good rating percentage was the lowest of the basin and remained fairly similar over time around 60%. All of the poor ratings for Site 47 occurred during 1987-1991.

From 1989 to 1997, higher dissolved oxygen values were normally observed during the dry season (November through May) than during the wet season (Figure IV.31). Statistically significant seasonal differences were observed at Sites 39, 40, and 47 between wet and dry season nine year means (t-test, $p < 0.001$) but not at Site 41. However, almost all values were at or above 4.0 mg/l at each site during both seasons. The only exception was Site 47's wet season 95th percentile value.

d. Total Phosphorus

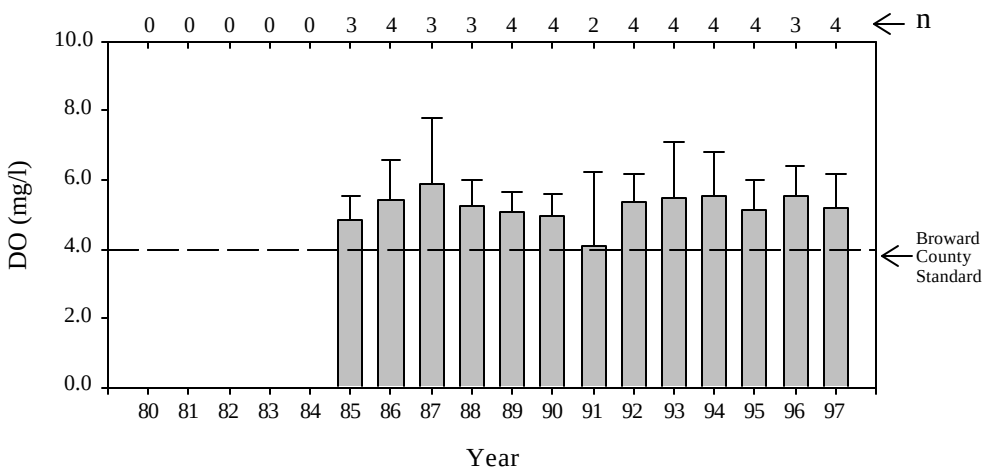
Mean and median total phosphorus (TP) levels were typically below the Broward County marine standard (0.050 mg/l) for the entire study (Table IV.16). Only Site 39 had a mean above 0.050 mg/l but this was influenced by an anomalous 0.809 mg/l maximum value. The number of basin samples below the TP method detection limit (MDL) ranged from 35.4 to 41.8%. During the study, TP MDL ranged between 0.020 to 0.026 mg/l (see Methodology, Section II).

Table IV.16. Descriptive Statistics for Total Phosphorus (TP) Concentrations in the SICW Basin. Except for Site 47, calculations represent seventeen years of sampling. However, the number of samples per year occasionally varied at each site. 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).

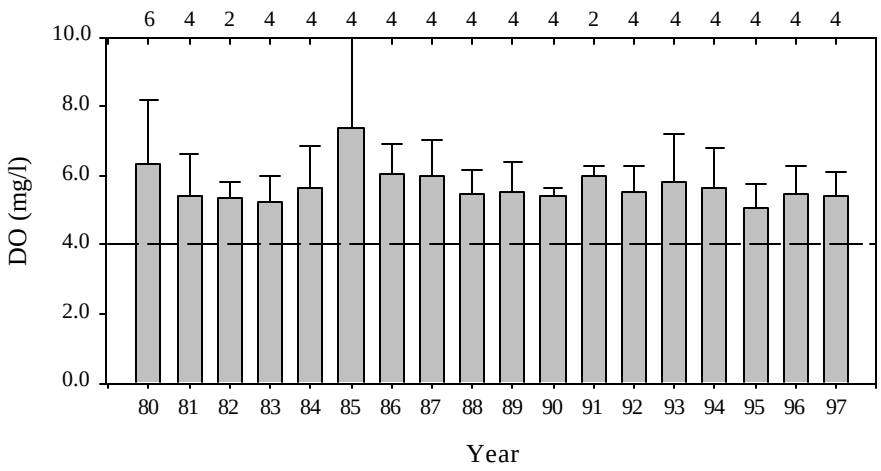
Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
39	TP	mg/l	65	0.033	0.056	0.106	0.809	0.010	24
40	TP	mg/l	67	0.026	0.036	0.038	0.224	0.010	28
41	TP	mg/l	65	0.025	0.038	0.041	0.239	0.010	23
47	TP	mg/l	47	0.028	0.046	0.047	0.190	0.010	18

Figure IV.29. Annual Mean Dissolved Oxygen (DO) Content Within the Southern Intracoastal Waterway (ICW) Basin from 1980 to 1997. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. DO levels should be above the Broward County standard (4.0 mg/l) indicated by the dashed line.

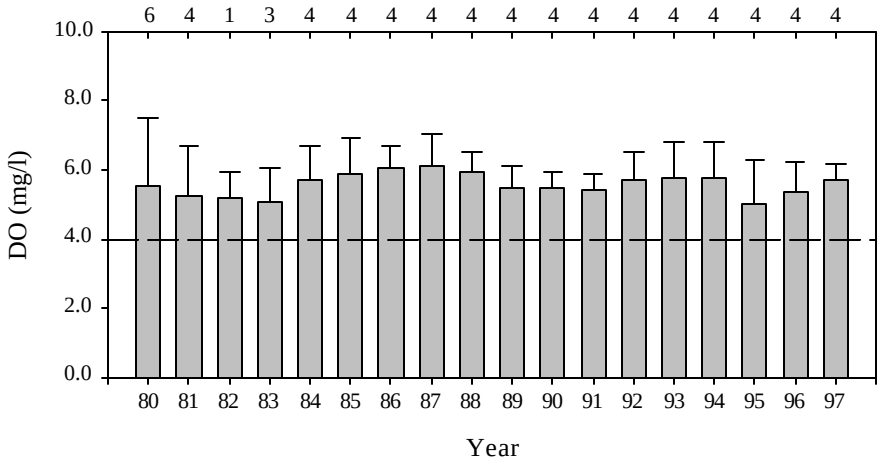
a) Site 47



b) Site 39



c) Site 40



d) Site 41

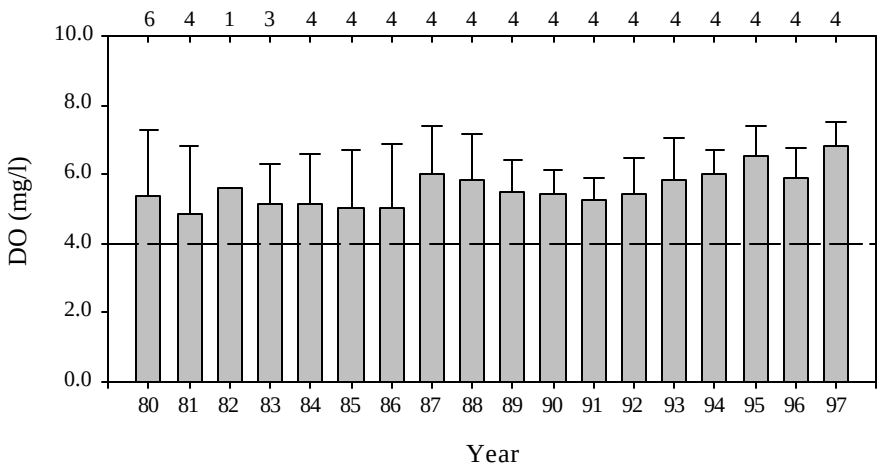


Figure IV.30. Dissolved Oxygen (DO) Concentrations Observed in the Southern Intracoastal Waterway Basin over Three Time Periods. DO samples are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall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

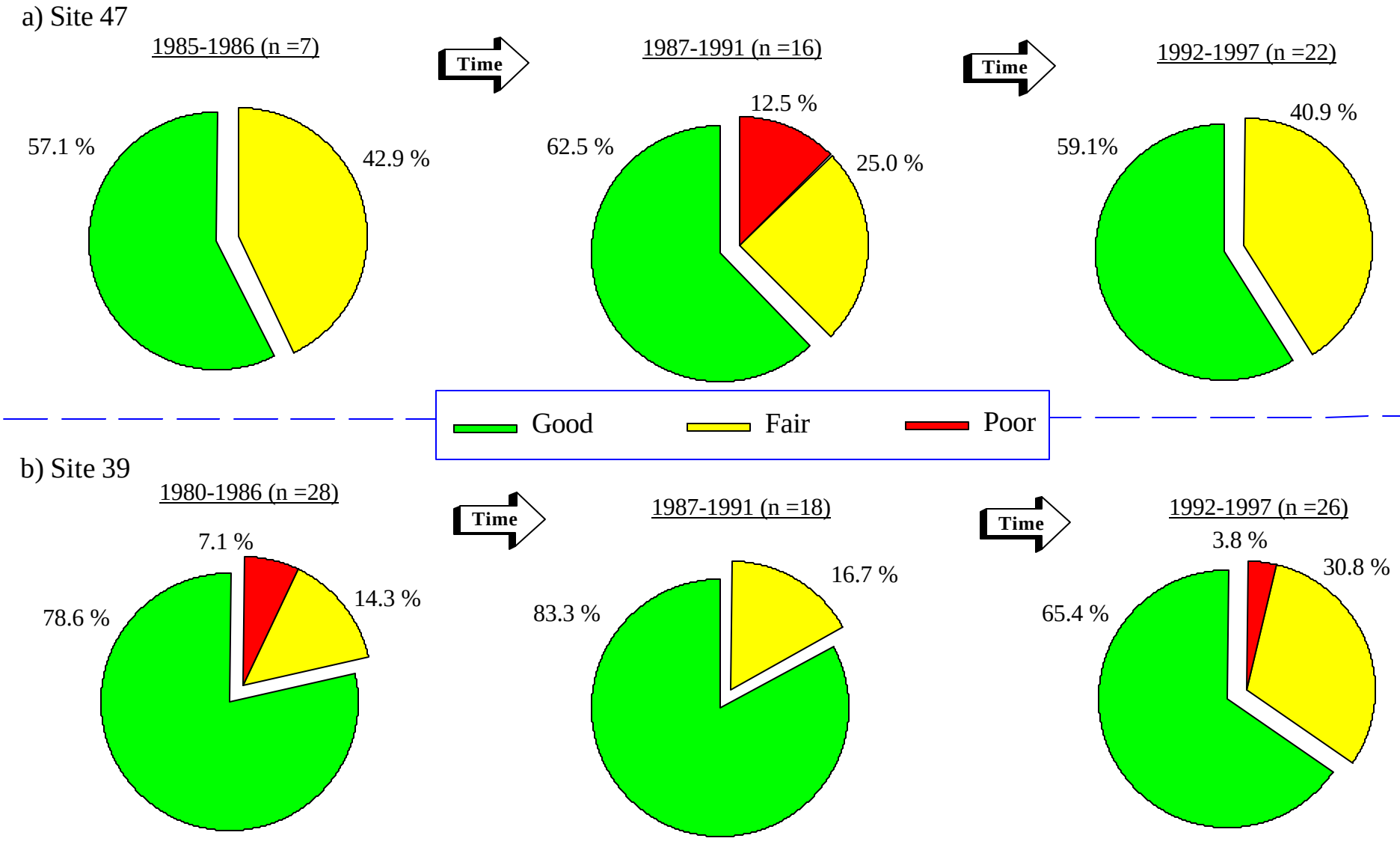
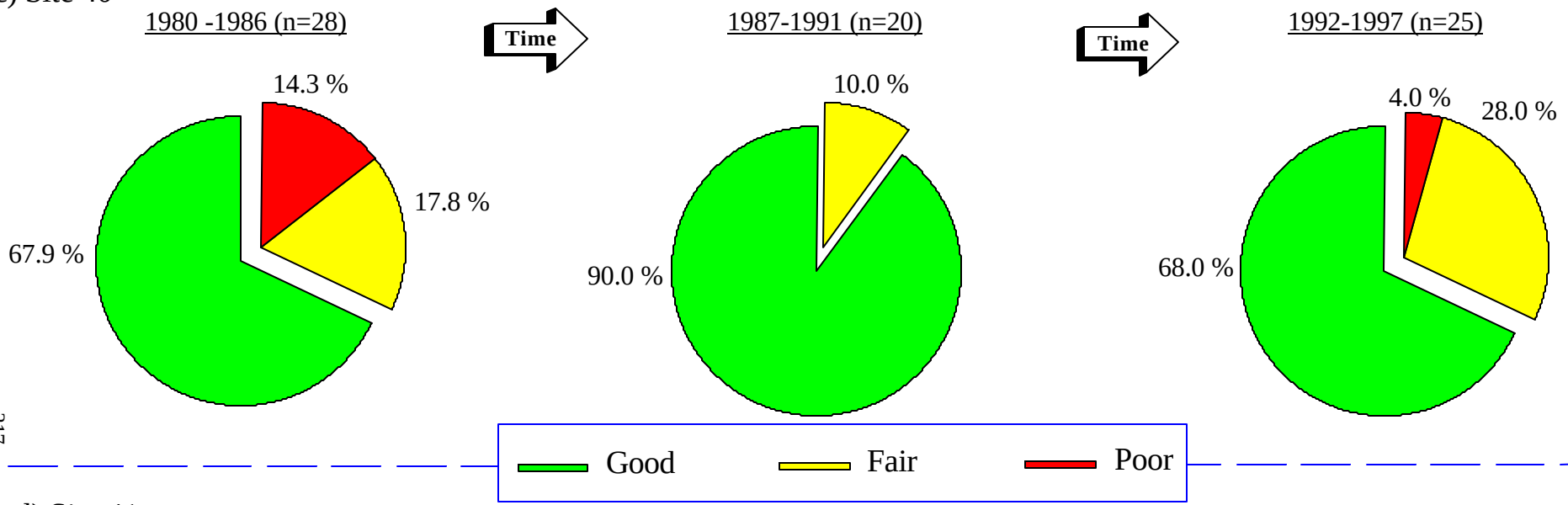


Figure IV.30 (Cont.). Dissolved Oxygen (DO) Concentrations Observed in the Southern Intracoastal Waterway Basin over Three Time Periods. DO samples are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading 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 levels between 4.0 to 4.9 mg/l are labeled fair. Readings below 4.0 mg/l are defined as poor.

c) Site 40



d) Site 41

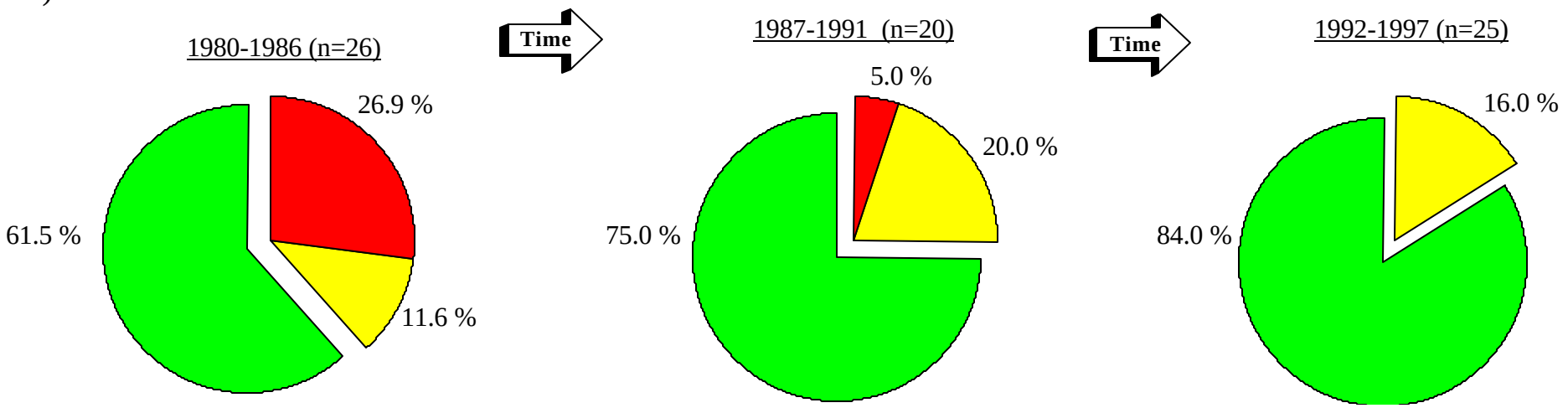
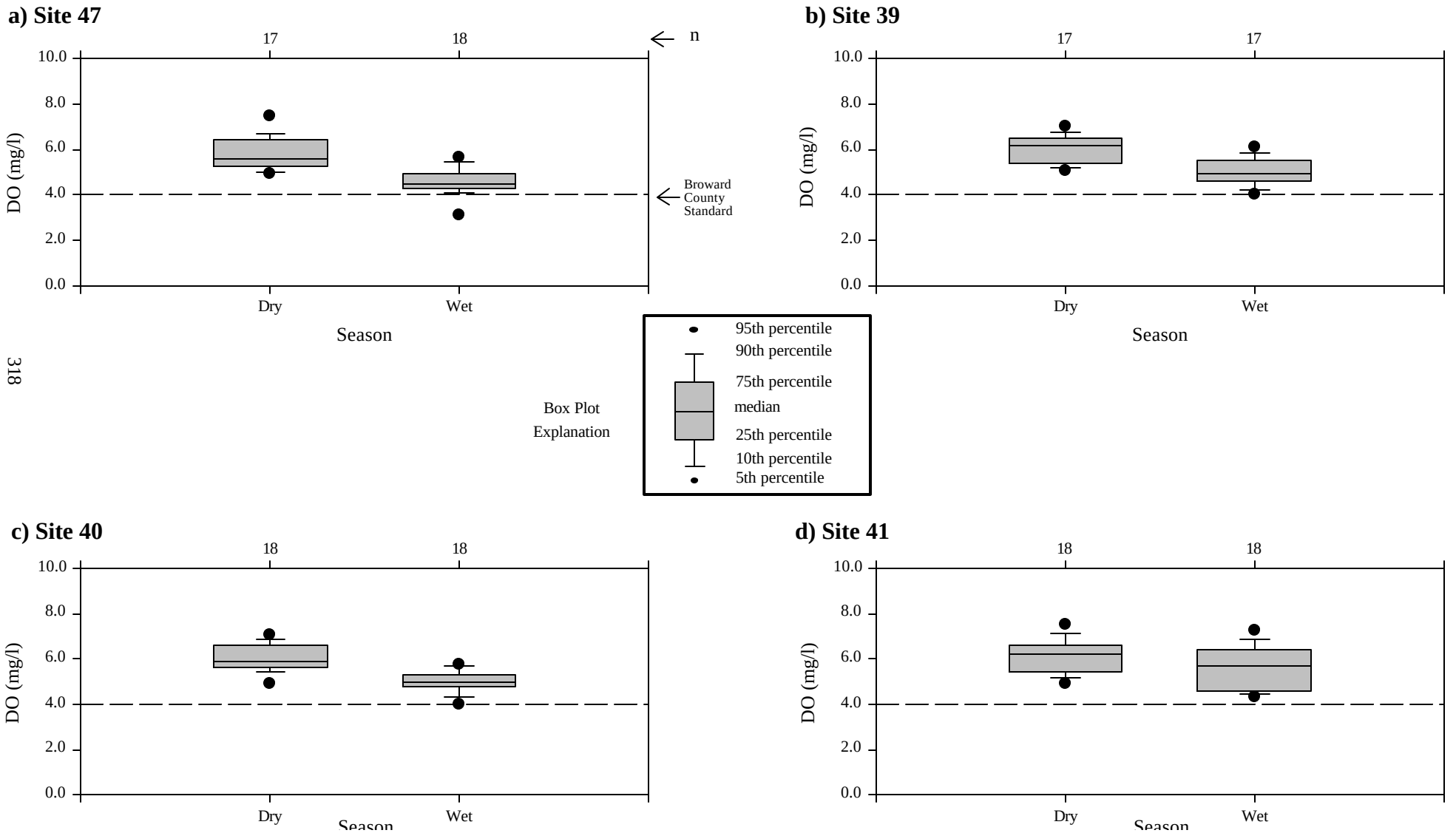


Figure IV.31. Southern Intracoastal Waterway Basin Dissolved Oxygen (DO) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (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 39, 40, and 47 ($p < 0.001$, t-test).



The basin's mean annual TP levels were at or below the Broward County standard a majority of the time (Figure IV.32). The highest TP values (> 0.050 mg/l) generally occurred from 1990 to 1992. However, the last four years (1994-1997) revealed the lowest TP values, with the exception of 1995 at Site 47.

To further investigate TP compliance patterns over time, all individual samples were rated in terms of Broward County's marine TP standard (see Section IV.E.5.d). In addition, changes over time are presented with special reference to the closing of WWTPs within the basin (i.e., 1981-1986, 1987-1991, and 1992-1997; see Section IV.G.3). The analysis of total samples within the Broward County marine standard (0.050 mg/l) revealed high compliance levels (> 80.0%) over the previous six years (1992-97, Figure IV.33). Conversely, 1987-1991 were characterized by the highest percentage of poor TP levels in the basin. Site 47 had the largest improvement with time, going from 50.0% (1987-1991) to 87.5% (1992-1997).

Statistical seasonal differences were not observed over the last nine years (1989-97) and all sites exhibited median values within compliance of the Broward County standard during this period. Variability was higher during the dry season than the wet season (Figure IV.34) and all sites had occasional TP concentrations (95^{th} percentile) greater than 0.100 mg/l. Only Site 47 had 75^{th} percentile and higher values substantially above 0.050 mg/l. Interestingly, this occurred in the dry season.

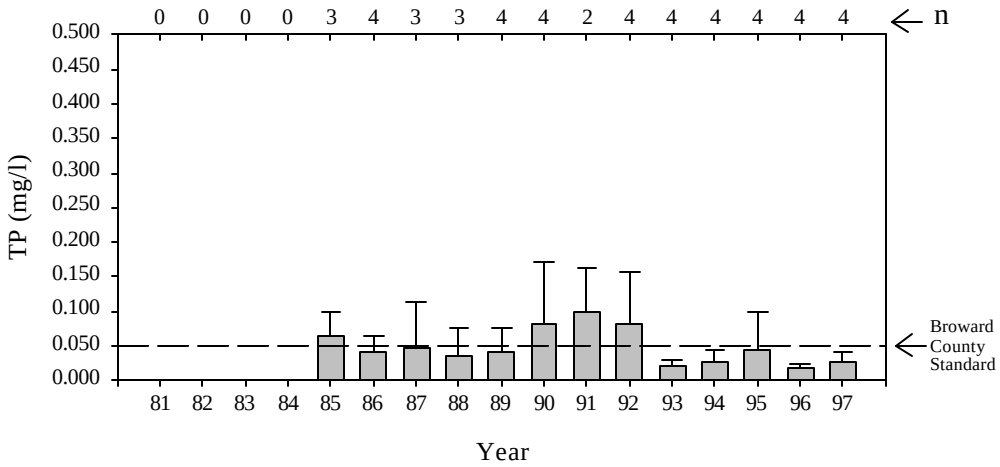
e. Total Nitrogen

Total nitrogen levels are calculated from the total Kjeldahl nitrogen (TKN) and nitrite+nitrate-nitrogen (NO_2+NO_3) concentrations. The SICW Sites 39 thru 41 had relatively similar seventeen-year mean values with Site 41 exhibiting the highest value (0.725 ± 0.537 mg/l) due to a unusually high maximum (4.16 mg/l). Site 47 had the least amount of samples but had the highest TN mean value of the basin (0.806 ± 0.358 mg/l). All medians and means were well within compliance of the Broward County standard (1.500 mg/l, Table IV.17).

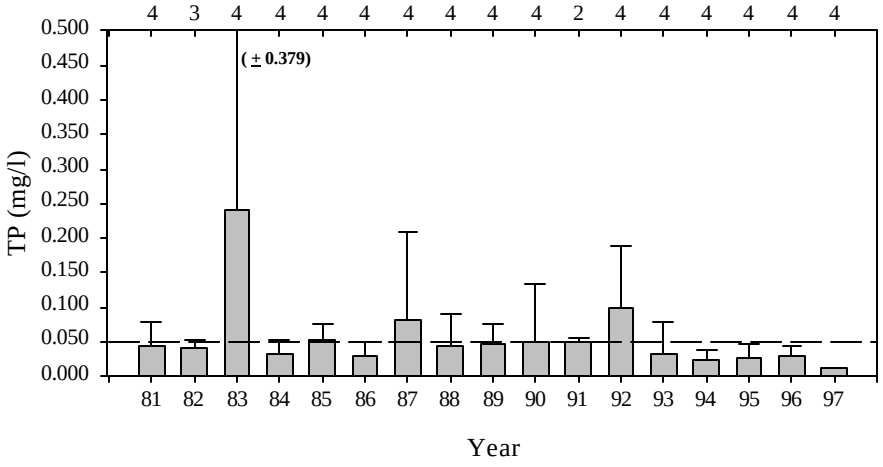
The vast majority of nitrogen was comprised of TKN which measures the total amount of organic nitrogen and ammonia-nitrogen (NH_3, Table IV.17). As seen in the other ICW basins, organic nitrogen was the major form of the total nitrogen values observed during this study. Basinwide, NH_3 levels were below the method detection limit in nearly two thirds of all sampling events. Long term median NO_2+NO_3 values were relatively low (< 0.075 mg/l) at all sites with Site 47 having the highest concentration (0.074 mg/l).

Figure IV.32. Annual Mean Total Phosphorus (TP) Content Within the Southern Intracoastal Waterway Basin from 1981 to 1997. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. TP levels should be below the Broward County marine standard (0.050 mg/l) indicated by the dashed line. Number in parentheses represents a sd outside the y-axis range.

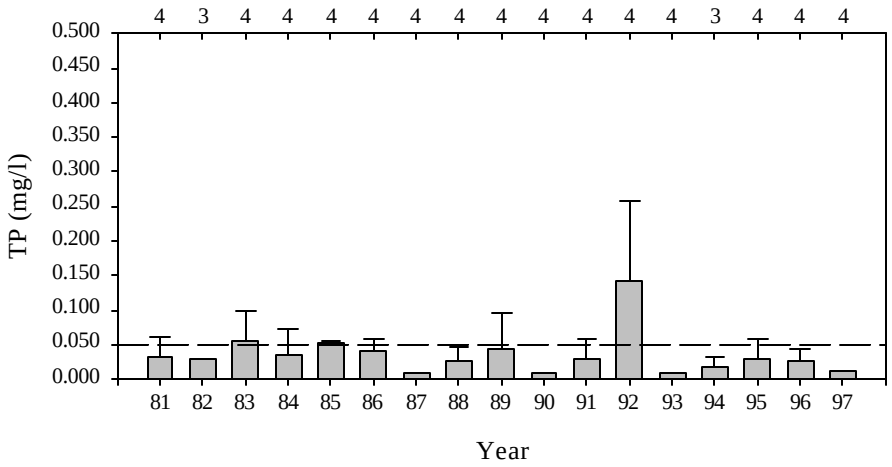
a) Site 47



b) Site 39



c) Site 40



d) Site 41

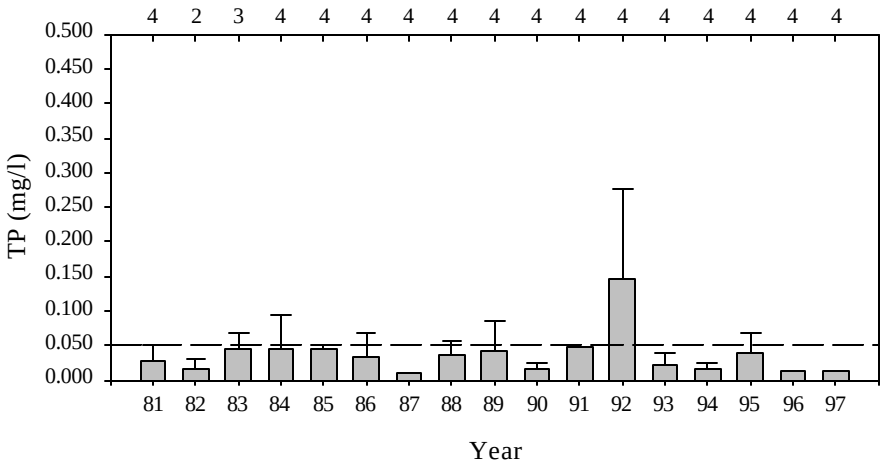


Figure IV.33. Total Phosphorus (TP) Concentrations Observed in the Southern Intracoastal Waterway Basin over Three Time Periods. TP levels are categorized in terms of compliance with the Broward County marine standard of 0.050 mg/l. The percentage below 0.050 mg/l are classified as good. A fair rating was given to values between 0.051 mg/l to 0.099 mg/l. Values equal to or greater than twice the standard (i.e., 0.100 mg/l) are classified as poor.

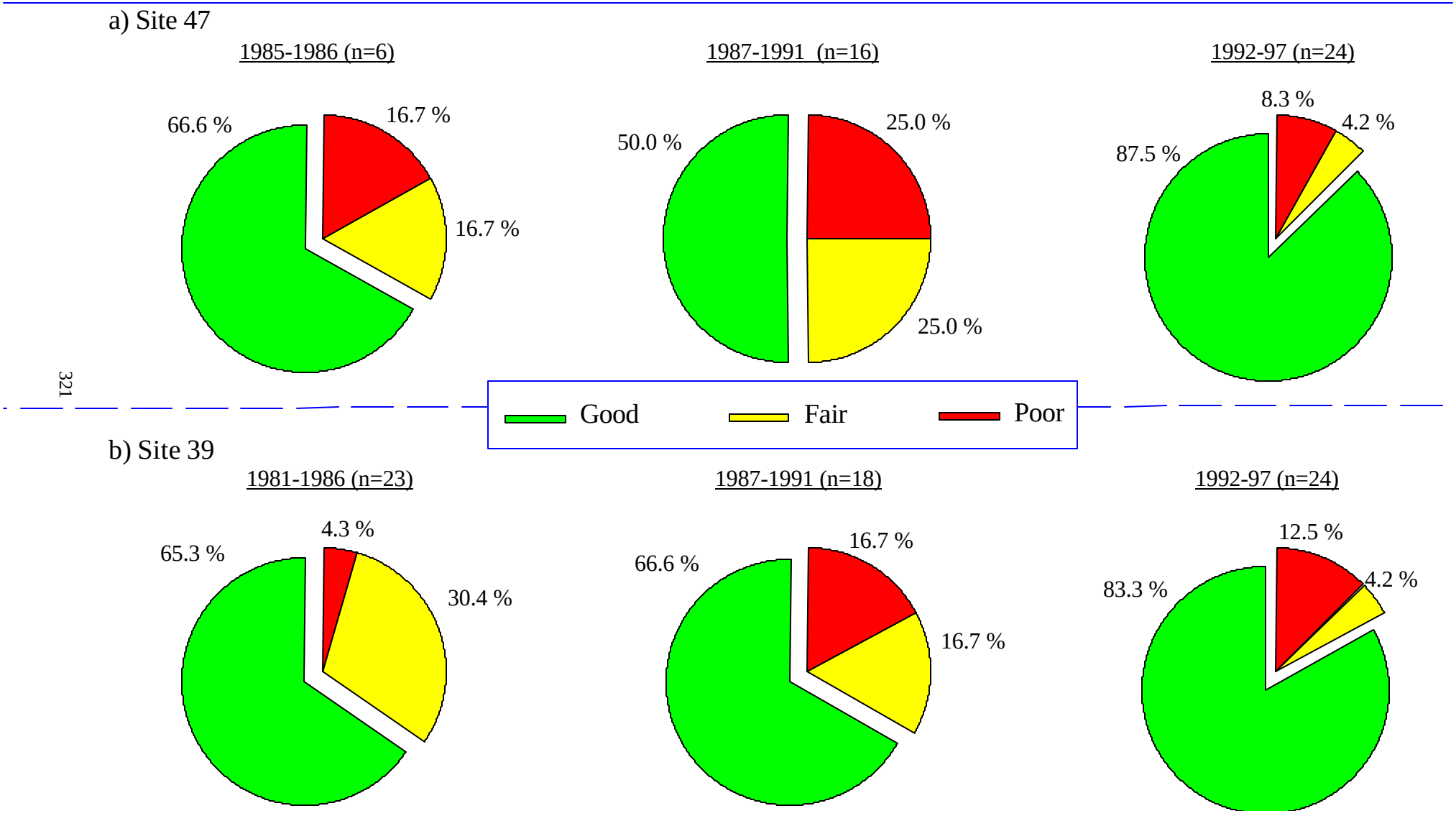
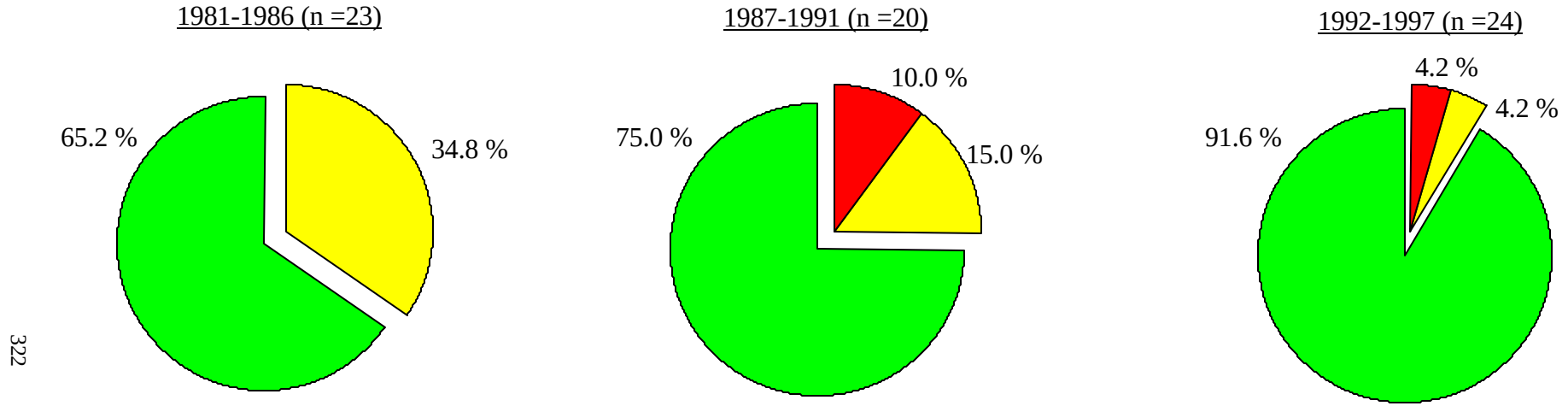


Figure IV.33 (Cont.). Total Phosphorus (TP) Concentrations Observed in the Southern Intracoastal Waterway (ICW) Basin over Three Time Periods. TP levels are categorized in terms of compliance with the Broward County marine standard of 0.050 mg/l. The percentage below 0.050 mg/l are classified as good. A fair rating was given to values between 0.051 mg/l to 0.099 mg/l. Values equal to or greater than twice the standard (i.e., 0.100 mg/l) are classified as poor.

c) Site 40



d) Site 41

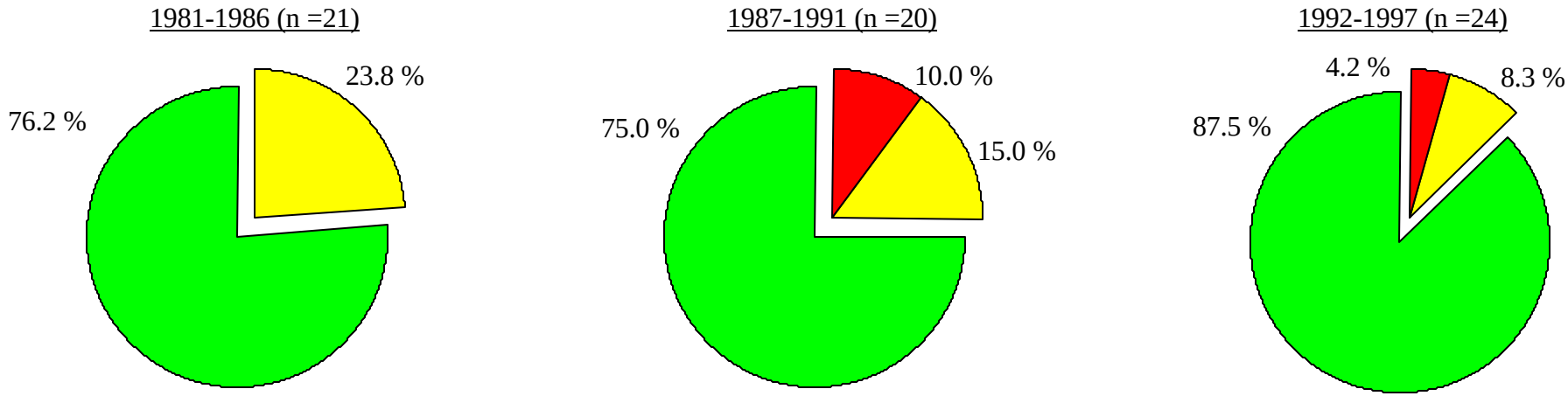


Figure IV.34. Southern Intracoastal Waterway Basin Total Phosphorus (TP) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. Th number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season values were not observed in the basin.

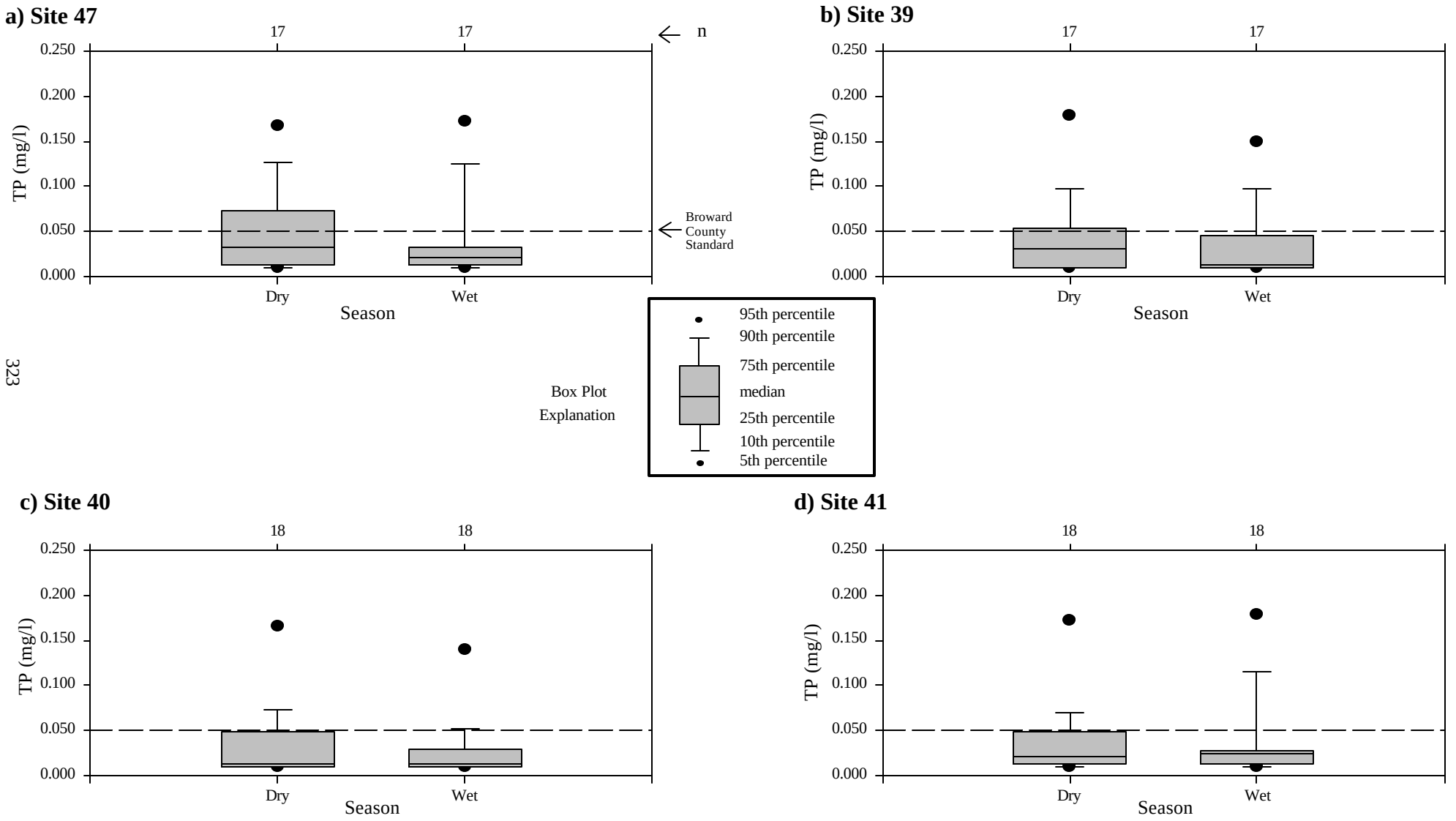


Table IV.17. Descriptive Statistics for Nitrite+Nitrate-Nitrogen (NO_2+NO_3), Ammonia-Nitrogen (NH_3), Total Kjeldahl Nitrogen (TKN), and Total Nitrogen (TN) in the SICW Basin. With the exception of Site 47, calculations represent seventeen years of sampling. However, the number of samples per year occasionally varied at each site. 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
39	NO_2+NO_3	mg/l	65	0.051	0.065	0.049	0.208	0.005	4
40	NO_2+NO_3	mg/l	67	0.050	0.067	0.057	0.278	0.005	8
41	NO_2+NO_3	mg/l	65	0.068	0.101	0.221	1.780	0.005	5
47	NO_2+NO_3	mg/l	47	0.074	0.085	0.065	0.276	0.005	3
39	NH_3	mg/l	60	0.025	0.037	0.041	0.178	0.005	40
40	NH_3	mg/l	62	0.025	0.029	0.030	0.134	0.005	41
41	NH_3	mg/l	60	0.025	0.023	0.021	0.112	0.005	41
47	NH_3	mg/l	42	0.025	0.058	0.092	0.442	0.008	21
39	TKN	mg/l	64	0.475	0.580	0.332	1.520	0.040	2
40	TKN	mg/l	66	0.550	0.589	0.298	1.220	0.040	2
41	TKN	mg/l	66	0.514	0.624	0.395	2.380	0.040	2
47	TKN	mg/l	65	0.677	0.736	0.328	1.510	0.020	1
39	TN	mg/l	64	0.556	0.646	0.331	1.546	0.086	Calc
40	TN	mg/l	66	0.599	0.655	0.287	1.243	0.025	Calc
41	TN	mg/l	66	0.585	0.725	0.537	4.160	0.090	Calc
47	TN	mg/l	66	0.776	0.806	0.358	1.716	0.064	Calc

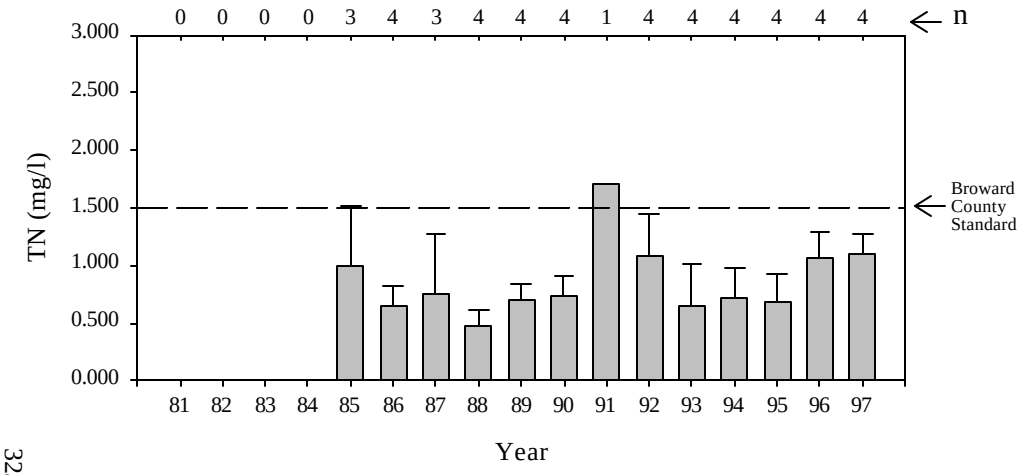
A general increase in annual TN means was observed over the previous 17 years at Sites 39 thru 41 (Figure IV.35). Site 47 TN averages did not show a consistent trend with time. However, all sites normally had TN values below the standard of 1.500 mg/l. Moreover, most annual averages were near or below 1.000 mg/l.

Poor, fair, and good designations were given to all TN based on the Broward County standard (1.500 mg/l, see Section IV.E.5.e). The periods analyzed were 1981-1986, 1987-1991, and 1992-1997 and were chosen based on WWTP discharge practices in the basin (see Section IV.G.3). Good TN samples were observed at the ICW Sites 39 thru 41 greater than 94% of the time (Figure IV.36). Furthermore, Site 40 showed 100% compliance from 1981-1997. Site 47 had the highest percentage of fair samples but poor TN levels were not seen at this location.

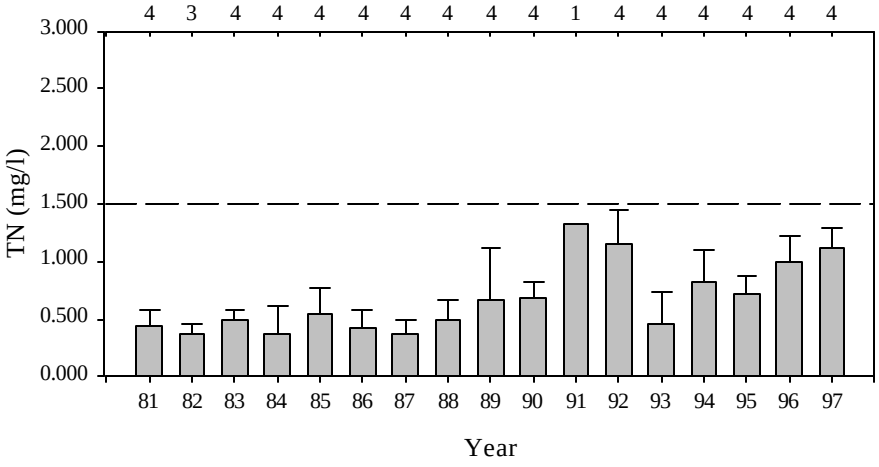
Seasonal differences in total nitrogen were not observed in the basin from 1989 to 1997 (Figure IV.37). Similar to TP, TN dry season values were characterized by more variability then wet season concentrations. However, only one 95th percentile value at Site 41 was above Broward's marine TN standard.

Figure IV.35. Annual Mean Total Nitrogen (TN) Content Within the Southern Intracoastal Waterway (ICW) Basin from 1981 to 1997. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. TN levels should be below the Broward County standard (1.500 mg/l) indicated by the dashed line. Number in parentheses represents a sd above x-axis scale.

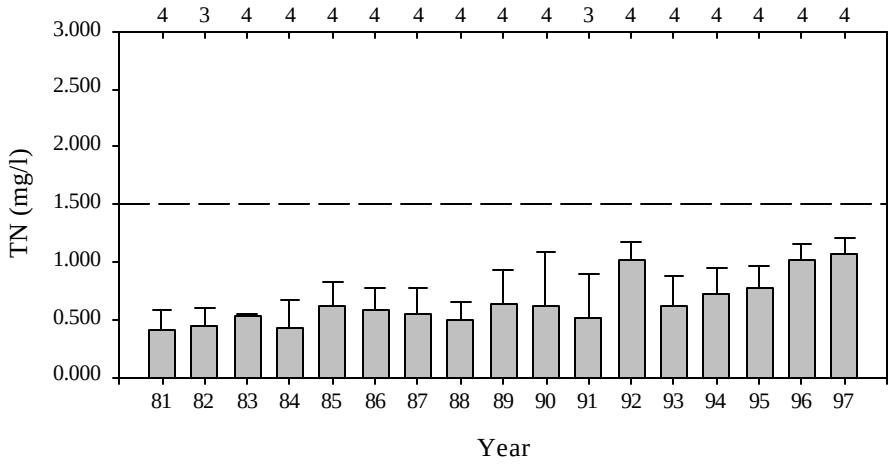
a) Site 47



b) Site 39



c) Site 40



d) Site 41

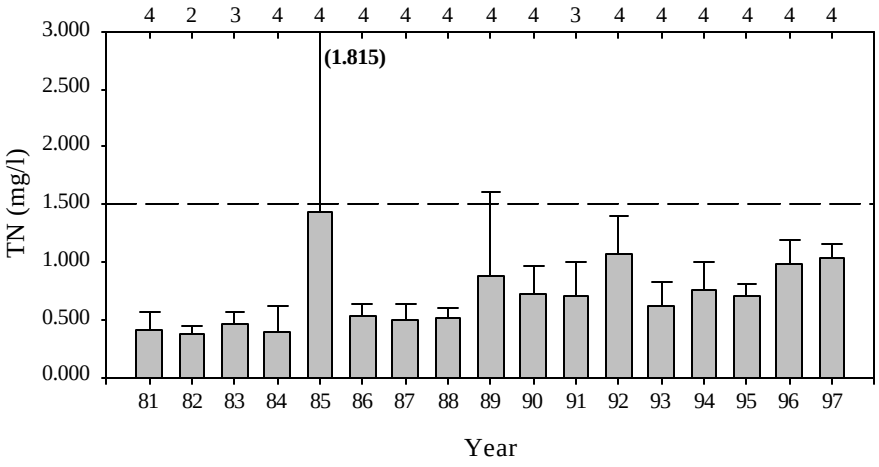


Figure IV.36. Total Nitrogen (TN) Concentrations Observed in the Southern Intracoastal Waterway Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County marine TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified 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.

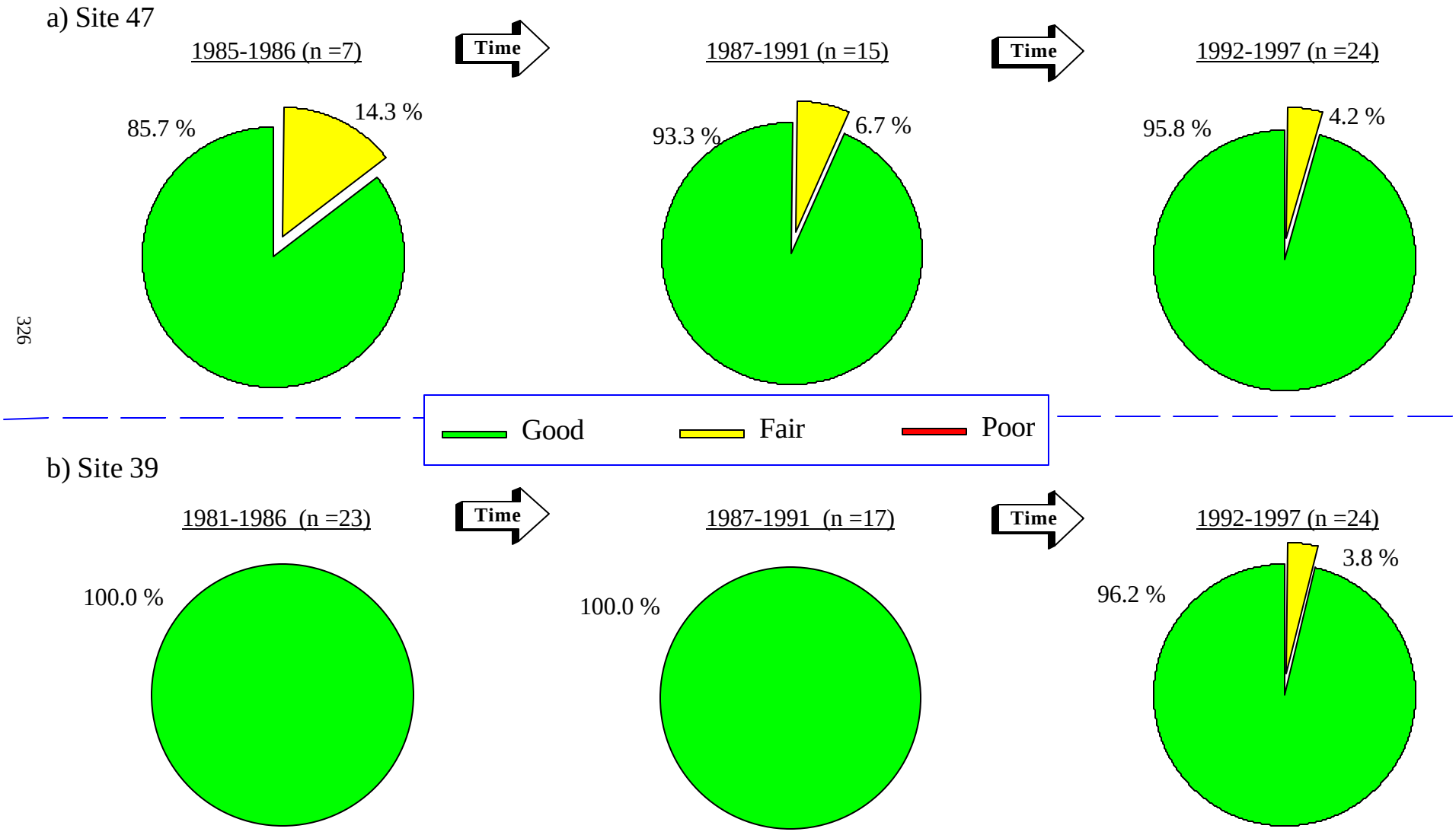
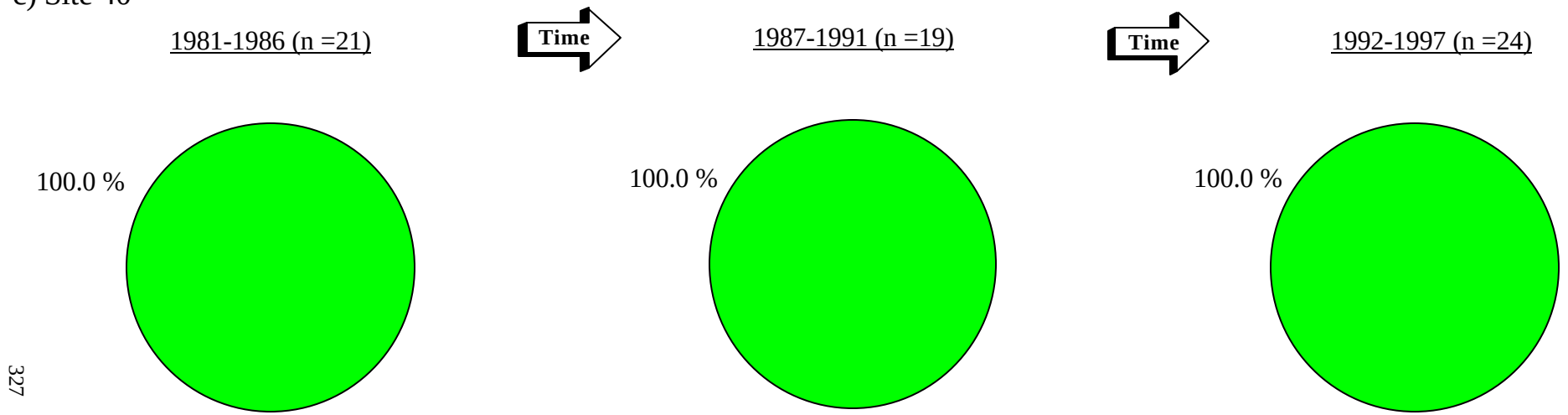
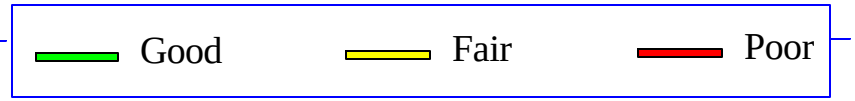


Figure IV.36 (Cont.). Total Nitrogen (TN) Concentrations Observed in the Southern Intracoastal Waterway (ICW) Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified 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 40





d) Site 41

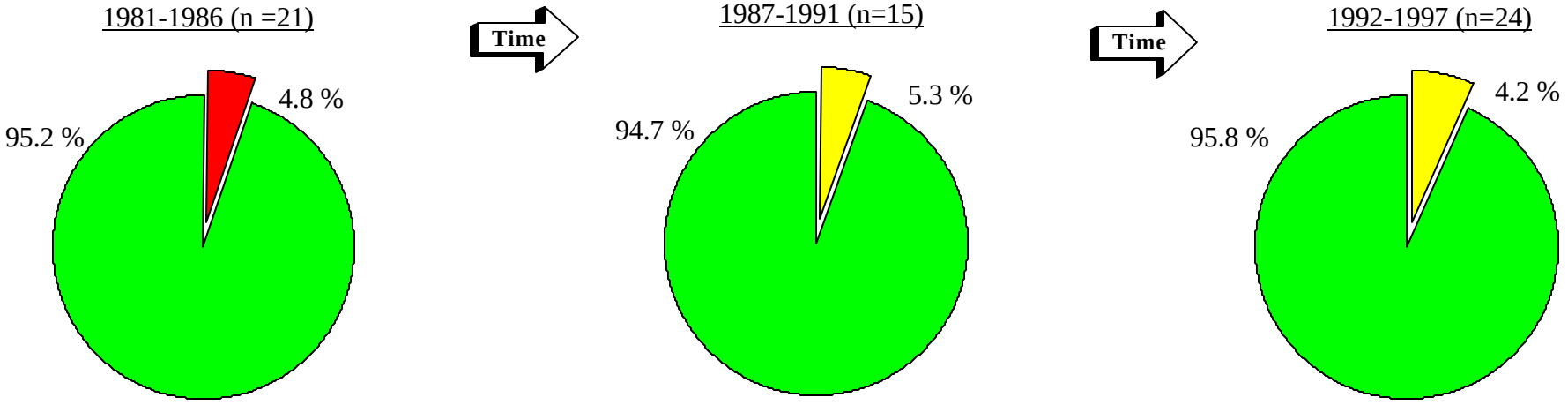
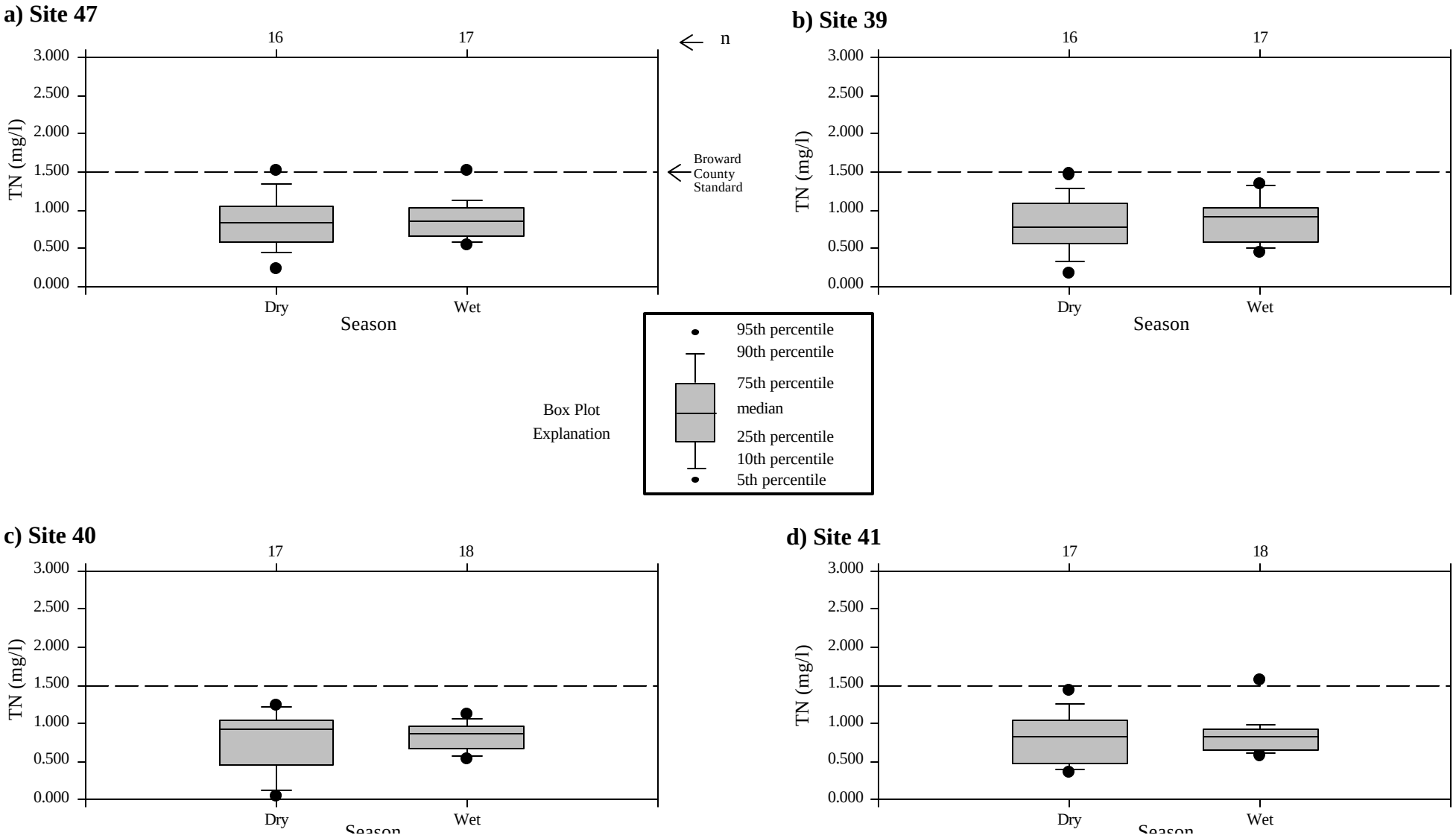


Figure IV.37. Southern Intracoastal Waterway Basin Total Nitrogen (TN) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples over the nine year period (n) is shown on the upper x-axis. Statistically significant differences between wet and dry season values were not observed in the basin.



f. Bacteriological Parameters

Bacteriological parameters measured from 1981-1997 included fecal coliform, total coliform, and fecal streptococcus. Seventeen-year median fecal coliform values were typically low throughout the study area and were well below the 800 colonies/100 ml single sample standard (Table IV.18). As discussed earlier, fecal coliform means were higher than median values but bacteriological mean values are often skewed by outlying high values (BCDNRP 1994a), as the high standard deviations illustrate.

Site 47 had the highest amount of fecal coliform samples above the method detection limit and the highest median value (70 colonies/100 ml). Site 40 and 41 samples were under the FC method detection limit 38.8% and 40% percent of the time, respectively. Median total coliform exhibited similar patterns as FC values while the amount of fecal streptococcus samples below the method detection limit was similar for Sites 40 and 41.

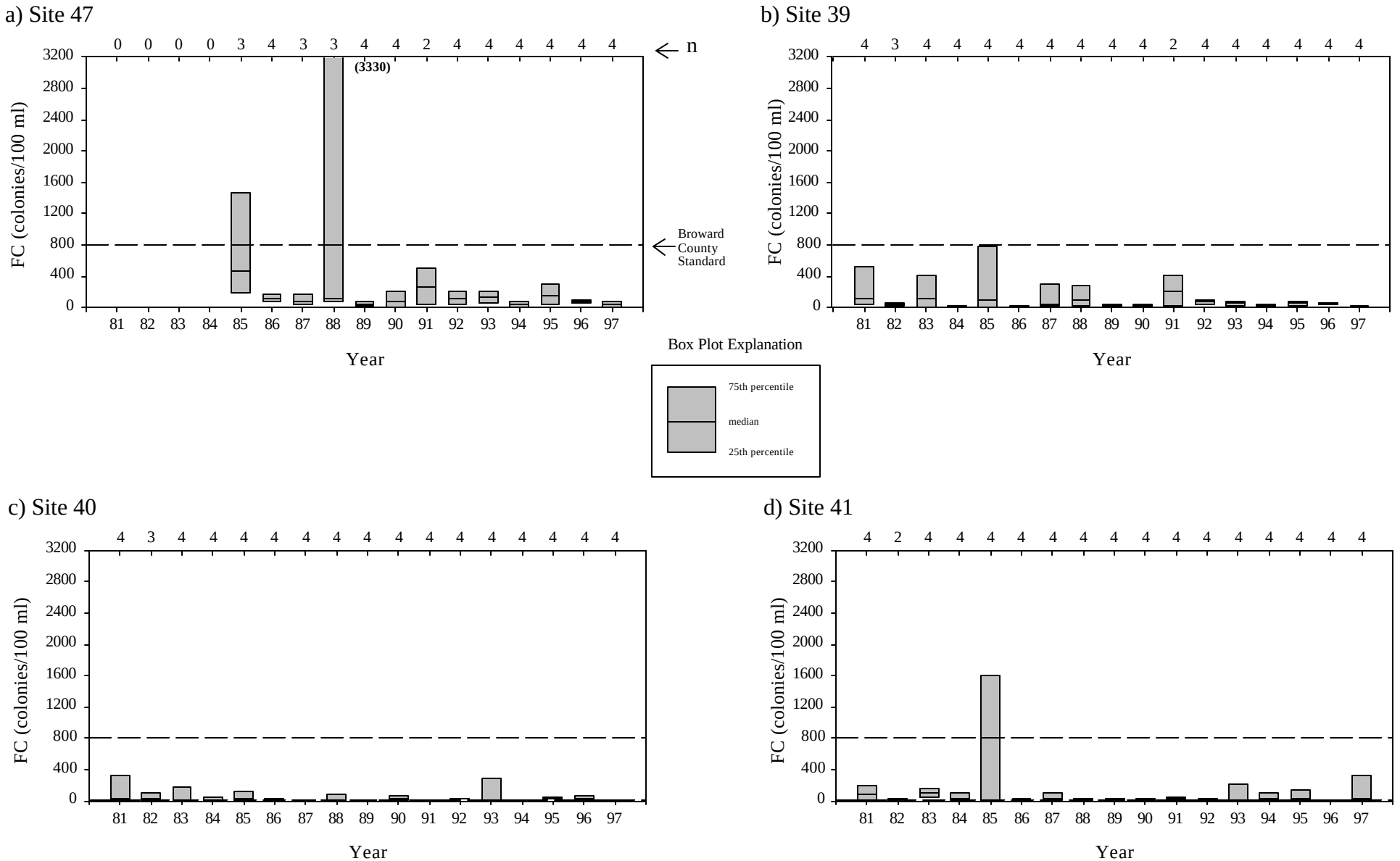
Table IV.18. Descriptive Statistics for Fecal Coliform (FC), Total Coliform (TC), and Fecal Streptococcus (FS) in the SICW Basin. With the exception of Site 47, calculations represent seventeen years of sampling. However, the number of samples per year occasionally varied at each site. If a sample was 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
39	FC	col	65	31	104	225	1400	4	11
40	FC	col	67	10	53	113	710	4	26
41	FC	col	65	10	100	404	3200	4	26
47	FC	col	47	70	249	730	4800	5	4
39	TC	col	64	190	357	627	4500	5	6
40	TC	col	66	100	239	328	1600	12	6
41	TC	col	64	100	222	323	2000	5	11
47	TC	col	46	450	878	2191	15000	17	1
39	FS	col	65	61	206	429	2600	12	16
40	FS	col	67	17	77	105	590	12	34
41	FS	col	65	24	1178	8922	72000	5	30
47	FS	col	47	70	191	526	3600	12	13

Due to the large amount of variability around the mean, yearly box plots were plotted for FC instead of the mean (Table IV.18). Yearly median values were well below the single sample standard of 800 colonies/100 ml at all sites during all years (Figure IV.38). Site 47 was characterized with the highest 75th percentile values but very few high values were observed in the basin, particularly since 1991.

All FC samples were categorized poor, fair or good (see Section IV.E.5.f) based on three different Broward County water quality standards and WWTP activity (see Section IV.G.3). High percentages

Figure IV.38. Yearly Box Plots of Fecal Coliform (FC) Levels Within the Southern Intracoastal Waterway Basin from 1981 to 1997. Medians and percentiles calculated from quarterly samples (n=4) unless noted on upper x-axis. FC levels should be below the Broward County single sample standard (800 colonies/ 100 ml) indicated by the dashed line. Numbers in parentheses represent 75th percentile values that extend beyond the y-axis scale.



of good samples typified the basin's compliance analysis (Figure IV.39). Site 47 was characterized by the lowest percentage of good samples 71.4% (1985-86) of any period but that value increased to 83.3% during 1992-97. The ICW monitoring Sites 39 thru 41 good sample percentage never reached below 80.0% during 1981-1997. Perhaps more importantly, no poor ratings were observed in the basin between 1992 and 1997.

The good quality of FC samples is further illustrated in the wet and dry season analysis where all values are below the Broward County standard line from 1989-1997 (Figure IV.40). Furthermore, wet and dry season medians were not significantly different at any site. The basin's highest median at Site 47 were still below 200 colonies/100 ml and 95th percentile values were normally less than 400 colonies/100 ml.

6. Basin Summary

The SICW basin is essentially separated from the CICW and NICW basins by Port Everglades. Only one major tributary system (C-11/C-10/Dania Cut-off Canals) discharges into the basin as compared to the CICW and the NICW which have two tributaries. Two sampling sites within the basin (39 and 47) are designed to look at ambient quality of the Port Everglades, ICW, and Dania Cut-off Canal confluence area. Site 40 is in the central area of a mangrove dominated region. Finally Site 41 is at the southern border of Broward County and likely has influence from SICW waters and Miami-Dade County waters. The following will summarize the water quality of the basin and discuss the influence of WWTP discharges and seasonal effects. Finally, questions about the SICW basin brought forth by this initial data analysis effort are listed to support future monitoring and resource planning.

a. Influence of WWTP Discharges

Of the three ICW basins, the SICW had the least response to the cessation of WWTP discharges. Small improvements were noted for DO levels in the southern end of the basin (Sites 40 and 41) but TP values actually increased after the closure of WWTPs from 1987 and 1991. In addition, TN values increased basinwide throughout the study's time period but not to levels above local water quality standards. The lack of relationship with WWTP discharge activity is likely due to the dynamic flushing (tidal) that takes place within Port Everglades and the fact that much of the basin was not directly receiving WWTP discharge and/or tributary discharge. Only the north portion of the basin, Port Everglades and the Dania Cut-off Canal area would have been influenced by WWTPs.

b. Basin Water Quality Comparison (Post-WTTPs)

Generally, water quality characteristics of each site in the basin was relatively similar. Total nitrogen content was most exemplary of the homogeneity at all four sites. A further example is the unusually high annual TP observed in 1992 at all four SICW sites. However, the one non-ICW channel Site 47 did exhibit slightly higher TP levels from 1989-1997, especially in the dry season. Additionally, annual FC medians were slightly higher at Site 47 where the largest concentrations were observed. This could suggest slightly lower quality at Site 47 which is consistent with the remaining ICW basins where inland sites typically had less quality.

Figure IV.39. Fecal Coliform (FC) Concentrations Observed in the Southern Intracoastal Waterway 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.

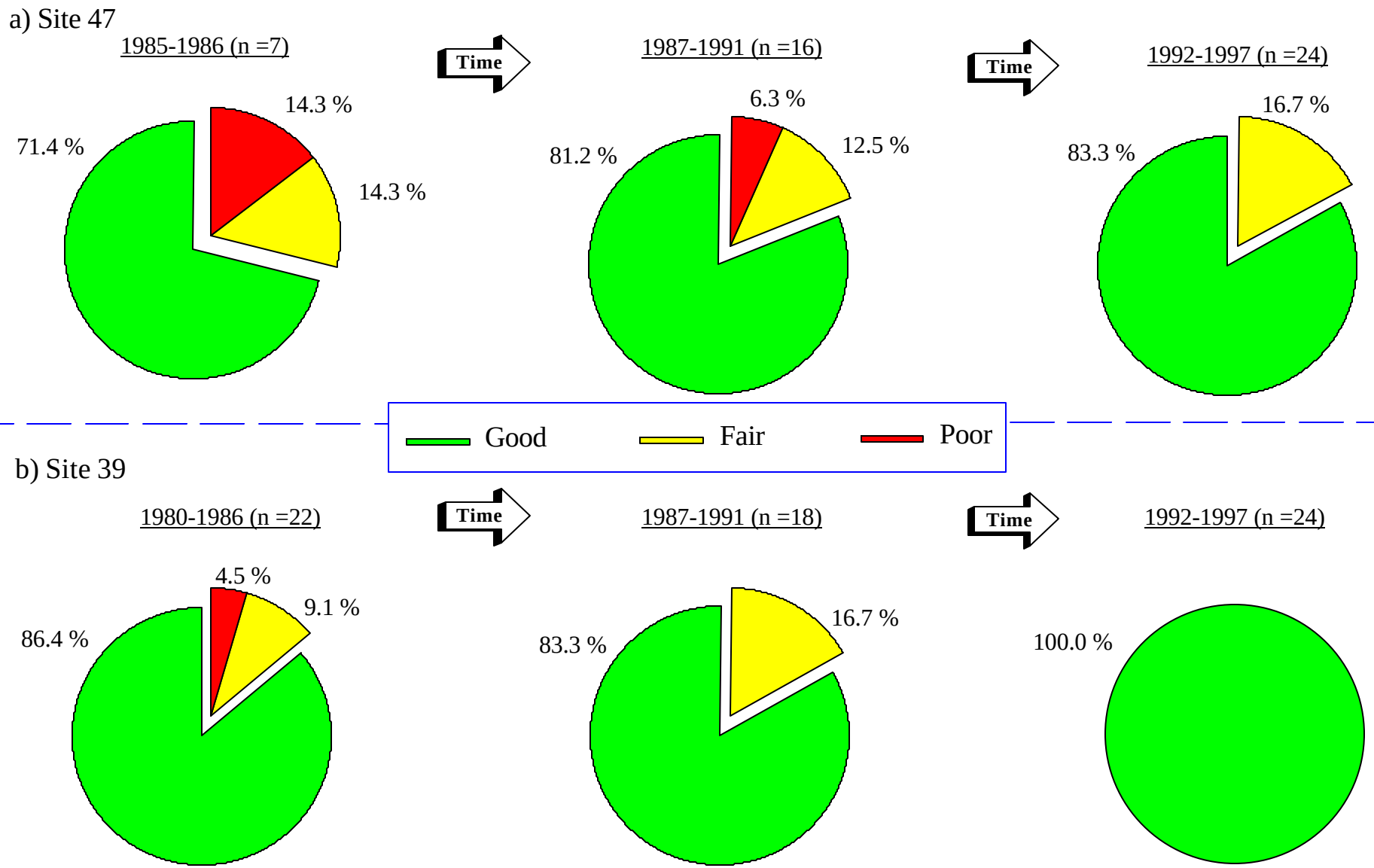
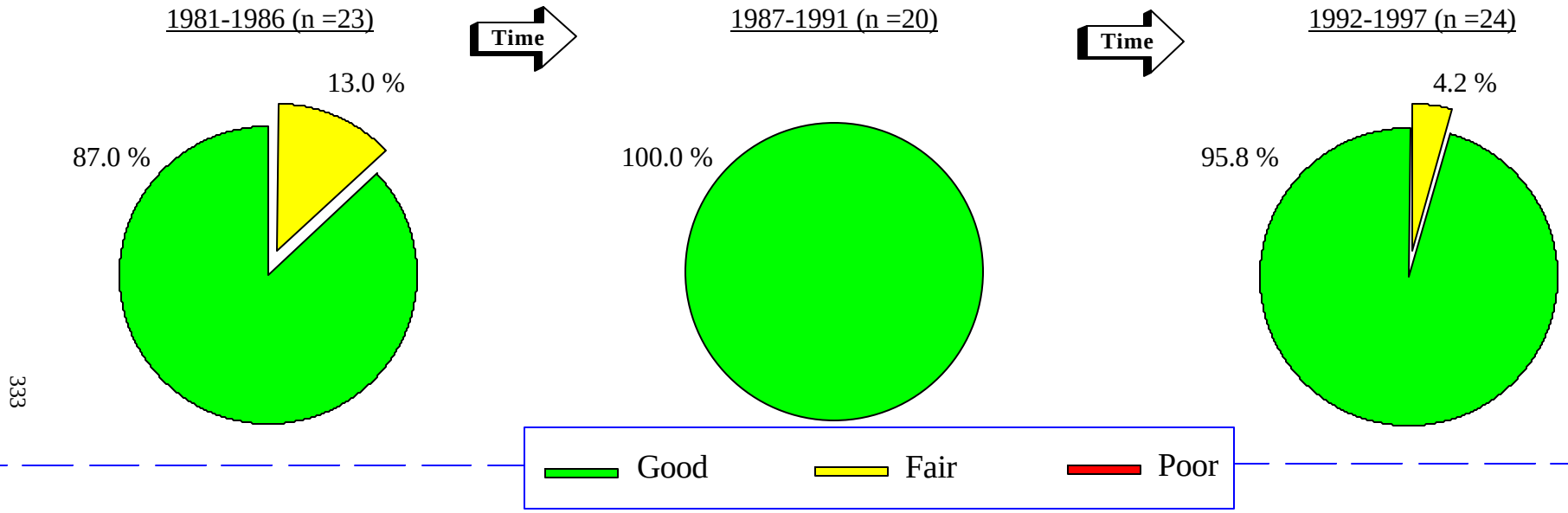


Figure IV.39 (Cont.). Fecal Coliform (FC) Concentrations Observed in the Southern Intracoastal Waterway Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100 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 40



d) Site 41

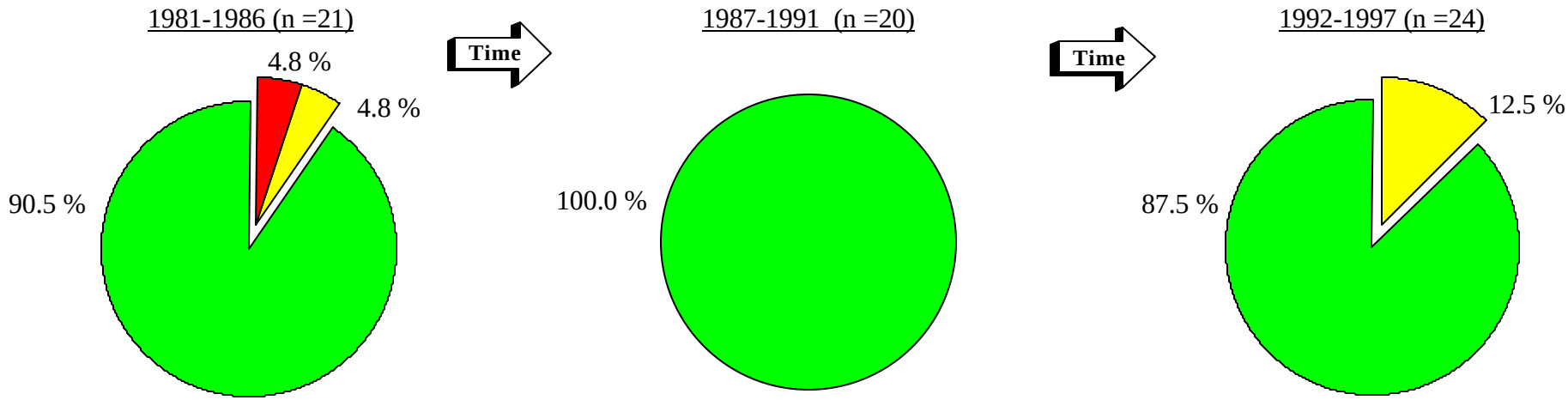
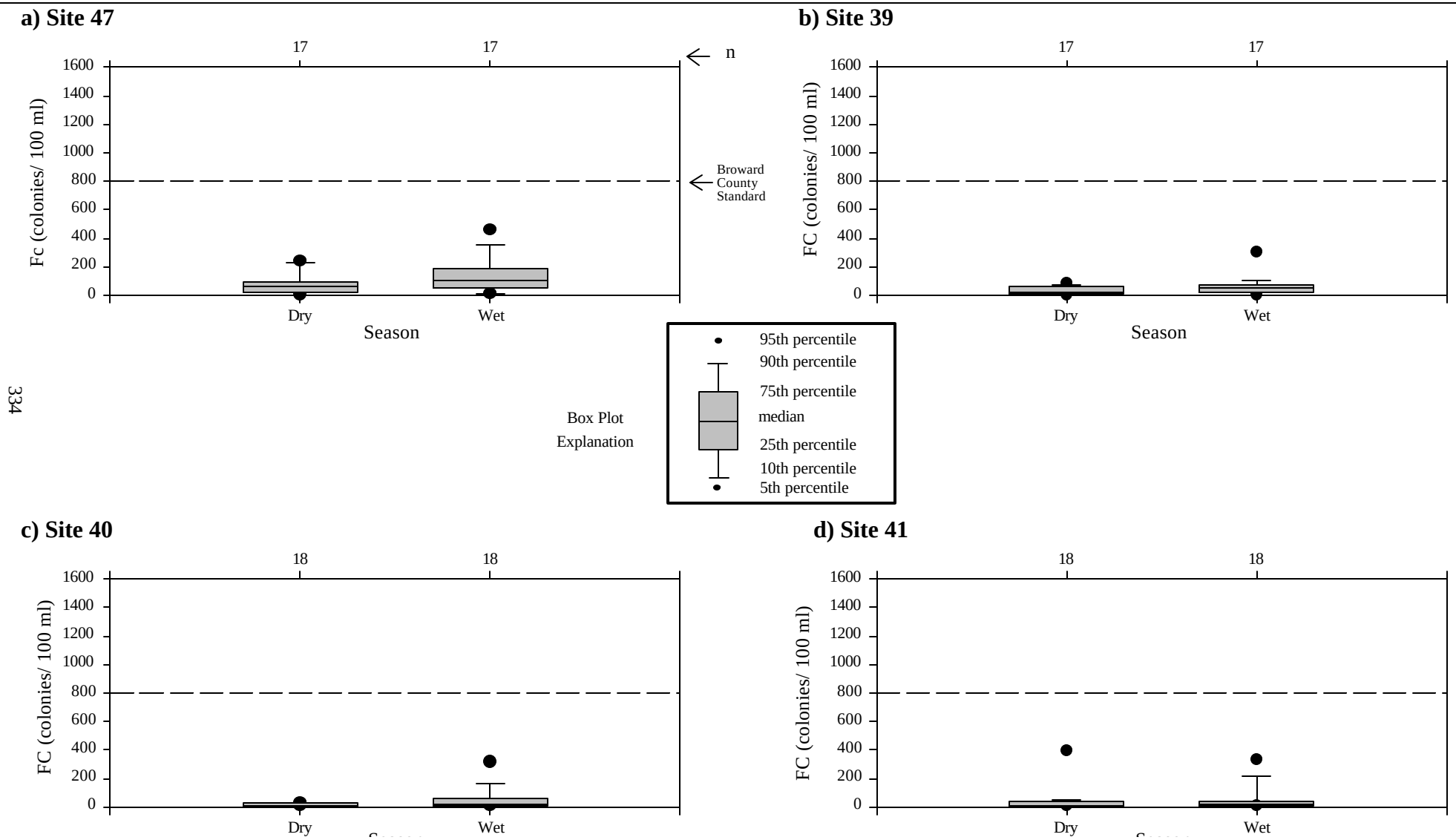


Figure IV.40. Southern Intracoastal Waterway Basin Fecal Coliform (FC) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) during the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season values were not observed in the basin.



An interesting pattern of basinwide DO levels was observed with Sites 39, 40, and 47 having slightly lower annual averages and more "fair" samples than Site 41. Potentially, this may reflect higher respiration rates in the adjacent mangrove communities and/or more influence of freshwater flow from the C-11/Dania Cut-off Canal. As discussed earlier, Site 41 is most removed from a western freshwater canal than any other site in the basin. The influence of the mangrove communities on DO levels would need to be investigated on much finer time and space scales. Although there are some slight differences between Site 41 and the other basin sites, it should be noted overall DO content in the basin was rarely poor (i.e., out of compliance).

c. Seasonal Differences

Statistical differences were observed for DO content at three of four sites. As discussed previously, temperature changes alone between wet and dry seasons can explain lower dissolved oxygen concentration in a waterbody. For the other major parameters (TP, TN, and FC), dry season values were not significantly different than wet season concentrations at all sites. Perhaps the most important feature of the 1989-1997 analysis was median, 25^{th}, and 75^{th} percentile values of DO, TP, TN, and FC, with one exception (Site 47 TP dry season 75^{th} percentile) were within compliance of water quality standards.

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 SICW, the hydrologic flow regime needs to be better defined and the potential impacts of pulses created by C-11/Dania Cut-off Canal and/or stormwater need to be better understood. Improved physical information would likely improve the understanding of possible nutrient (TP and/or TN, NH_3, and NO_2+NO_3) inflow and transport offshore. It would also assist in defining the hydrological division between the SICW and Miami-Dade County waters. Thus, the following are proposed for the SICW:

- At low tides, does Site 39 have worse water quality than observed with an ambient monitoring effort (i.e., What is the poorest water being transported offshore?)
- As an estuarine waterbody, what extent is the influence of a "salt wedge" from the east and the freshwater from the west?
- What is the impact of stormwater in the SICW, particularly Port Everglades?
- Are recent increases in TN a trend or anomalous and to what extent does DIN content influence overall TN values?
- Where is the physical division in the tides between the SICW and Miami-Dade County waters?

H. New River Basin

1. Geographic Locale

The New River Basin is located in east-central Broward County (Figure IV.41). The primary municipality in this area is Ft. Lauderdale with smaller portions located in the Town of Davie and unincorporated areas of Broward County. The basin is characterized by three distinct areas - the main New River, and its South and North Forks.

The South Fork receives freshwater primarily from the west or "upstream" North New River Canal that is controlled by releases through the SFWMD's Sewell Lock (Figure IV.41). Some eastern portions of the North New River Canal are tidally influenced. In addition, the South Fork receives approximately thirty-three million gallons per day via the Florida Power and Light cooling discharge lake system (BCDNRP 1993). Furthermore, the remnant natural channel interacts tidally with the Dania Cut-off Canal (Figure IV.41). Thus, freshwater flows from the C-11 Canal may have some influence in the southwest reaches of the basin.

The C-12 Canal rarely supplies freshwater flows (see BCDPEP 1999a) to the North Fork through the SFWMD S-33 control structure (Figure IV.41). Due, in part, to the South Fork's dynamic flow and relatively low volume of C-12 discharges, the North Fork primarily functions as a tidal "pond" characterized by restricted outflow to the main New River. The New River's main channel flows through downtown Ft. Lauderdale and receives most of its western flow from the South Fork and tidal (i.e., brackish) water from the ICW.

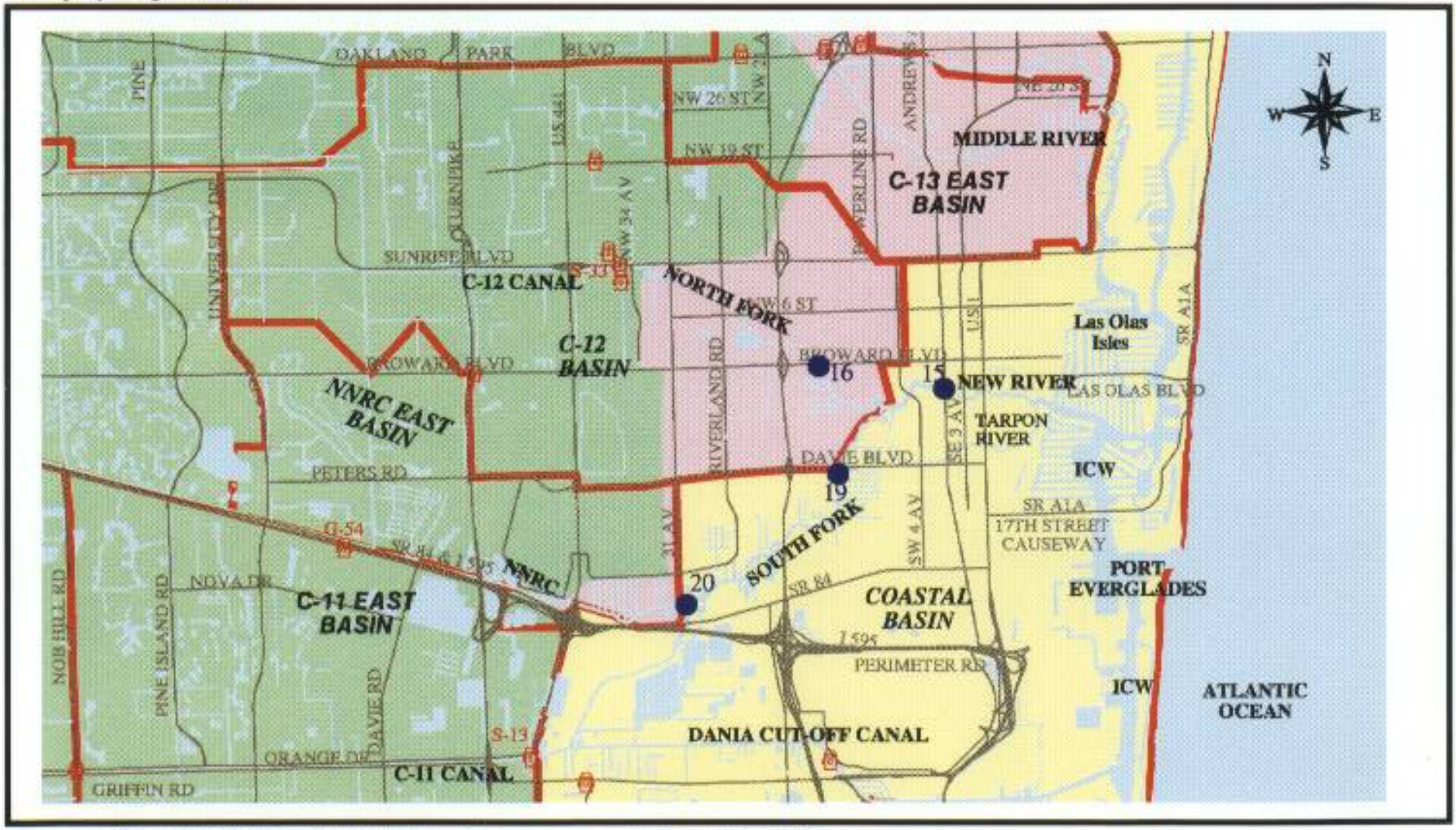
2. Land Use and Activities Impacting Water Quality

Diverse land uses exist along the New River. Residential areas with bulkheaded seawalls and well-groomed lawns line the South Fork and main New River. An extensive commercial marine industry exists throughout the South Fork and North New River Canal in areas known locally as Marina Mile and Marina Bay. In addition, consistent boat traffic occurs that at times can be congestive. The sizes of boats range from approximately twelve to one hundred feet although larger vessels do occasionally traverse the waterway.

The southwestern stretch (southwest of Interstate 595, see Figure IV.41)of the South Fork has a large (55 acres) natural area called Pond Apple Slough, as well as other extensive vegetation areas (Griffey Tract) that contain relatively large areas of mangrove forests and leatherfern stands. Much of this 'natural area' has rip-rap in place to protect against erosion due primarily from boat wake. In addition, the Broward County Parks and Recreation Division maintains the Secret Woods Nature Preserve that contains some mangrove forest shoreline. A large electrical plant (Florida Power and Light) and a trash burning facility (Wheelabrator) exist in close proximity to the South Fork's 'natural areas', however, only the FPL plant directly discharges into the waterway.

The North Fork land uses are primarily divided by the Broward Boulevard Bridge (Figure IV.41) that allows only small vessels (4 foot clearance at high tides) to access areas north of the bridge. South of

Figure IV.41. Broward County's New River Basin Sampling Sites. The brackish sections of the C-13, C-12, and North New River Canal Basins are shown in pink. These areas were delineated by the United States Army Corps of Engineers as separate basins from the Coastal Basin (Cooper and Lane 1987). However, the respective receiving waterbodies are tidally connected and are downstream of the coastal water control structures (S-36, S-33, and G-54) operated by the South Florida Water Management District. The brackish waters (pink and yellow areas) within distinct basins are hydrologically connected within the overall estuarine system. Thus, the geographic New River Basin overlaps hydrological basins.



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

the Broward Boulevard Bridge, bulkheaded seawalls and residential houses similar to the South Fork exists along the main North Fork channel and in an extensive finger canal system. North of the Broward Boulevard Bridge, a large majority of the shoreline has retained its natural state with areas of pond apples *(Annona glabra)*, leatherferns *(Acrostichum daneafolium)* and mangroves (*Laguncularia racemosa* and *Rhizophora mangle*). In addition, giant cutgrass *(Zizaniopsis miliacea)* has flourished over the last five years. Exotic and/or nuisance species are also prevalent and include Brazilian pepper *(Schinus terebinthifolius*), hygro *(Hygrophila polysperma)* and common reed *(Phragmites australis)*.

The main New River meanders through the center of downtown, urban Ft. Lauderdale which is characterized by many office centers, buildings, as well as shops and restaurants. A small tributary, called the Tarpon River (Figure IV.41) is tidally connected to the main waterway. Before reaching the ICW, the river again traverses a bulkheaded residential area that includes an extensive finger canal system, including the Las Olas Isles (Figure IV.41) that lies between the New River and Middle River basins. This area contains a large (> 500) population of live aboard boaters. The potential influence of these boats on fecal contamination has been the focal point of extensive BCDPEP studies and is covered elsewhere (BCDNRP 1993, 1994a, 1995, 1997).

Numerous roadways cross or run contiguous with the New River (Figure IV.41). Most of these roads have stormwater systems associated with them that eventually discharge into the New River. Due to the basin's development occurring before most stormwater management regulations, little to no treatment of first flush pollutants occurs before stormwater enters the river. Interstate 95 crosses over both the North and South Forks while Interstate 595 and State Road 7 traverse over the South Fork and North New River Canal, respectively. Other major roads that have bridges over some portion of the New River include, Broward Boulevard, Davie Boulevard, 11th Avenue, 7th Avenue, Andrews Avenue, and 3rd Avenue. In addition, a substantial amount of finger canals exist in the area with associated street end and stormwater outfalls. Thus, an abundance of stormwater outfalls exists in the basin. For example, a three-mile stretch of the North Fork was found to have thirty-five outfalls of various sizes and drainage areas (BCDPEP 1999a).

Septic tanks are prevalent in the basin where the North and South Forks meet the main channel of the New River, as well as in some portions of the Tarpon River. Currently, the City of Ft. Lauderdale is implementing a program to switch these areas to sanitary sewers. While the potential impacts of these systems have not been extensively studied, other South Florida studies indicate a high potential for such systems to impact adjacent surface waters (Harbor Branch Oceanographic Institute 1995).

3. Wastewater Treatment Plants Discharge History

The first WWTP plant to cease discharges was the Surfside 6 Floating Homes in 1975. Ft. Lauderdale Plant "C" halted its discharge (0.525 million gallons per day, mgd, capacity) to the North New River Canal in 1981. Four small WWTPs (less than 0.10 mgd capacity) stopped disposal to the South Fork between 1983 and 1984. The highest volume plant (5.06 mgd capacity) in the New River Basin, Fort Lauderdale Plant "A", stopped discharging to the North Fork in June of 1983 to the waterway which

generally has the least flow. Beyond direct discharges to the basin, the North New River Canal, C-12 Canal, and C-11 Canals also had WWTP discharge points (see Section III for details). Thus, during periods of water control structure discharges to the New River Basin, some indirect influence of these WWTPs may have occurred. Overall, the last year of direct or indirect WWTP influence was 1988.

4. Sampling Locations and Period

In the 1990s, the New River Basin was studied more extensively than any of Broward's waterways beginning with a basin wide study performed from 1991-1992 (BCDNRP 1993). From the initial study, numerous other water quality investigations have been performed by Broward County BCDPEP (BCDNRP 1994a,b,c, BCDNRP 1997a,b, BCDPEP 1999a,b) as well as other investigators (Solo-Gabriele et al. 2000). Many of these studies focused on the North Fork of the New River because initial studies indicated the waterway had the worst water quality in the basin, if not the entire county (see BCDNRP 1993, 1994c). In addition, the impact of moored vessels in the Las Olas Isles has been intensely investigated (BCDNRP 1994a, BCDNRP 1995, 1997a). Thus, numerous data sets exist beyond the ambient water quality network for the New River Basin.

For the purposes of this report, only ambient water quality network data will be used. This was done for two reasons. First, it allows for better comparison between the New River Basin and other basins sampled within the same countywide network. Second, many of the other studies have either focused on one parameter (e.g., fecal coliform, Las Olas Isles) or on finer temporal and spatial scales (e.g., North Fork Hydrolab® Study, BCDPEP 1999a) in order to address a known water quality problem.

All sites are located in tidally influenced waters in the southeast corner of Broward County. Latitude and longitude measurements were determined by Global Position System and specific site descriptions are given in Appendix 1. Site 20 represents water quality in the North New River Canal (tidal portion) immediately west of the confluence with the South Fork of the New River (Bradford Marina dock). Site 19 is located south (approximately 100 feet) of the Davie Boulevard Bridge and is indicative of ambient water quality of the eastern portion of the South Fork. Site 16 is located at the Broward Boulevard Bridge (north side) and is the North Fork's main water quality site. Located at the Andrews Avenue Bridge, Site 15 is in the main New River in the heart of downtown Ft. Lauderdale.

Sites 15, 16 and 20 have been sampled continuously by BCDPEP since 1973. However, only temperature, pH, dissolved oxygen, fecal coliform, and total coliform were sampled over the entire period. Salinity was measured from 1973-1997 at Sites 15, 19, and 20 but ranges from 1974 to 1997 at Site 16. Total phosphorus measurements were from 1974 to 1997. Turbidity readings began in 1975 and last until the 1997. Fecal streptococcus measurements began in 1976 until 1997. Ammonia-nitrogen, nitrite+nitrate-nitrogen, total Kjeldahl nitrogen, total nitrogen (calculated) and total organic carbon were not analyzed for until 1981. Biochemical oxygen demand monitoring occurred from 1973 until 1993 and included both the five and seven-day tests. Specific conductance recordings started in 1990. With the exceptions of nitrogen species, total organic carbon, fecal streptococcus, and specific conductance, Site 19 had two fewer years (1975 and 1976 missing) than the other sites in the basin. Data methodology and manipulation were performed as detailed in the methodology section (Section II).

5. Results

a. Physical Characteristics

A one degree (Celsius) difference was observed between long term mean water temperatures at Site 16 (26.0 ± 3.4ºC) and Sites 19 and 20 (27.0 ± 3.9ºC, 27.0 ± 3.6ºC), respectively (Table IV.19). Median temperatures were essentially the same at all sites. South Fork and main New River Sites 15,19,and 20 exhibited very comparable pH values, including maximum and minimum values (Table IV.19). Slightly lower pH values were observed in the North Fork (Site 16) than the rest of the basin.

Site 15, in the main New River, was the only site with mean and median salinity values over 10 parts per thousand (ppt). Sites 16 and 20 had the basin's freshest water with occasional salinity peaks that never exceeded 20 ppt. Site 19's intermediate salinity values mirrored its central location within the basin. All sites had the occurrence of salinity recordings below the method detection limit indicating a dynamic range of salinities existed in the area. Specific conductance values, though limited in number, reflected the same general trend as salinity recordings.

Table IV.19. Descriptive Statistics for Temperature (Temp, ºC= degrees Celsius), pH, Specific Conductance (Cond; Fmhos = micromhos), and Salinity (Sal; ppt= parts per thousand) in the New River Basin. Calculations represent twenty-five years of sampling for temperature and pH. Salinity measurements were performed for twenty-four years and specific conductance has been recorded for eight years. Site 19 had two less years of temperature, pH, and salinity measurements. However, the number of samples per year occasionally varied at each site. 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
15	Temp	ºC	170	27.2	27.0	3.6	34.0	19.0	0
16	Temp	ºC	148	27.0	26.0	3.4	32.0	17.8	0
19	Temp	ºC	117	27.0	27.0	3.9	34.0	19.0	0
20	Temp	ºC	138	27.1	26.6	3.6	34.0	17.8	0
15	pH	units	173	7.7	7.7	0.2	8.3	6.9	0
16	pH	units	118	7.5	7.5	0.3	8.0	6.7	0
19	pH	units	141	7.7	7.7	0.2	8.2	6.8	0
20	pH	units	150	7.7	7.7	0.3	8.2	6.8	0
15	Cond	Fmhos	32	18500	19095	13380	45300	921	0
16	Cond	Fmhos	32	4730	7176	7666	26400	448	0
19	Cond	Fmhos	32	9830	10924	9611	30900	820	0
20	Cond	Fmhos	32	2560	6595	7548	25700	600	0
15	Sal	ppt	151	11.9	12.8	8.8	30.2	0.25	6
16	Sal	ppt	136	2.1	3.7	4.0	16.3	0.25	31
19	Sal	ppt	110	3.9	6.7	6.7	28.0	0.25	11
20	Sal	ppt	136	1.4	3.2	3.8	15.7	0.25	24

b. Total Organic Carbon and Turbidity

The basin's westernmost Site 20 exhibited the highest TOC mean, median, and maximum values (Table IV.20). Furthermore, TOC content generally declined as moving east from the North New River Canal to the South Fork and ending in the main New River (i.e., Site 20 eastward to Site 15). However, Site 16, in the North Fork, had the basin's lowest median and mean TOC content.

At all sites, turbidity levels were typically low and normally within compliance of Broward County's standard of 10 nephelometric turbidity units (ntus, Table IV.20). Maximum values were above the standard at each site but these were rare occurrences based on the median, as well as standard deviation values.

Table IV.20. Descriptive Statistics for Total Organic Carbon (TOC) and Turbidity (Turb) Concentrations in the New River Basin. Calculations represent seventeen years of sampling for TOC and twenty-three years for Turb (ntu = nephelometric turbidity units). Only twenty-one years of turbidity readings were made at Site 19. However, the number of samples per year occasionally varied at each site. 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
15	TOC	mg/l	62	16.75	16.22	4.74	24.60	6.53	0
16	TOC	mg/l	62	14.15	14.98	4.99	29.00	1.35	0
19	TOC	mg/l	62	19.40	19.22	5.69	43.20	3.23	0
20	TOC	mg/l	61	21.40	20.93	5.98	46.80	3.18	0
15	Turb	ntu	132	2.8	3.1	2.1	19.0	0.7	0
16	Turb	ntu	132	4.0	4.2	1.9	15.0	0.7	0
19	Turb	ntu	101	2.8	3.6	3.1	23.0	0.7	0
20	Turb	ntu	133	3.1	3.8	3.8	42.0	0.7	0

c. Dissolved Oxygen and Biochemical Oxygen Demand

Mean and median dissolved oxygen concentrations were very comparable between the North New River Canal (Site 20), South Fork (Site 19), and the main New River (Site 15, Table IV.21). These three sites had values above the single sample standard of 4.0 mg/l but below the daily average standard of 5.0 mg/l. Minimum values were lower at Site 19 and 20 then at Site 15. Conversely, Site 16 (North Fork) mean and median oxygen concentrations were depressed below the 4.0 mg/l standard.

Site 16 had the highest biochemical oxygen demand (BOD) of the basin and its maximum value exceeded the 7.0 mg/l marine standard (Table IV.21). The other three sites in the basin were typified by BOD values near 2.0 mg/l, although Site 15's maximum value was equal to the standard.

Table IV.21. Descriptive Statistics for Dissolved Oxygen (DO) Concentrations in the New River Basin. Dissolved oxygen calculations represent twenty-five years of sampling. Biochemical oxygen demand (BOD) calculations are for twenty-one years. Site 19 had two less years of observations than the other sites. Overall, the number of samples per year occasionally varied at each site. 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
15	DO	mg/l	171	4.7	4.7	1.3	9.1	2.0	0
16	DO	mg/l	149	3.3	3.7	2.2	10.5	0.05	1
19	DO	mg/l	118	4.7	4.7	1.5	8.8	0.1	0
20	DO	mg/l	140	4.5	4.5	1.7	11.6	0.4	0
15	BOD	mg/l	141	1.5	1.6	0.8	7.0	0.5	0
16	BOD	mg/l	131	3.3	3.8	2.1	13.0	1.2	0
19	BOD	mg/l	93	1.6	1.7	0.8	5.0	0.4	0
20	BOD	mg/l	122	1.9	2.1	1.0	5.4	0.6	0

Yearly averages revealed a similar DO compliance patterns as the long term means for Sites 15, 19, and 20 (Figure IV.42). A more distinct temporal pattern occurred at Site 16 (North Fork), where annual DO values substantially improved after 1983 when the WWTP on the North Fork closed. Although improvements were observed at Site 16, relatively high variability around the means consistently occurred from 1984 to 1997.

To further investigate water quality standard compliance, DO concentrations were designated as poor, fair, or good (see Section IV.E.5.c) and changes over time were addressed with special reference to the closing of WWTPs in the basin (see Section IV.H.3). Site 16 exhibited the greatest increase in DO standard compliance (Figure IV.43) with an increase of good rated samples from 6.4% (1973-1983) to 58.3% (1989-1997). However, poor rated samples still existed 30.6% of the time in the North Fork (Site 16) in the final time period. Sites 15, 19, and 20 had relatively similar compliance patterns over all three periods. Some improvements were realized at all three sites but poor samples were in existence at least 22.9% of the time and as high as 35.2%, by the end period (1989-1997).

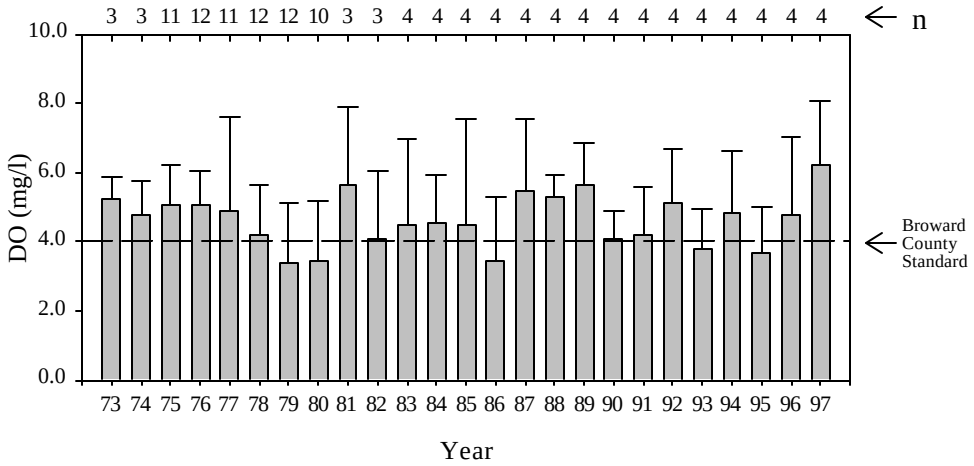
Significant statistical differences were observed between dry and wet season DO values at Sites 15, 19, and 20 ($p<0.001$, t-test) as well as Site 16 ($p<0.01$, t-test, Figure IV.44) between 1989 thru 1997. Site 16 exhibited a relatively wider range of values than observed at other New River sites. For all sites, at least the 75th percentile wet season value was below the 4.0 mg/l standard. At Sites 19 and 20, median wet season values were below the county standard.

d. Total Phosphorus

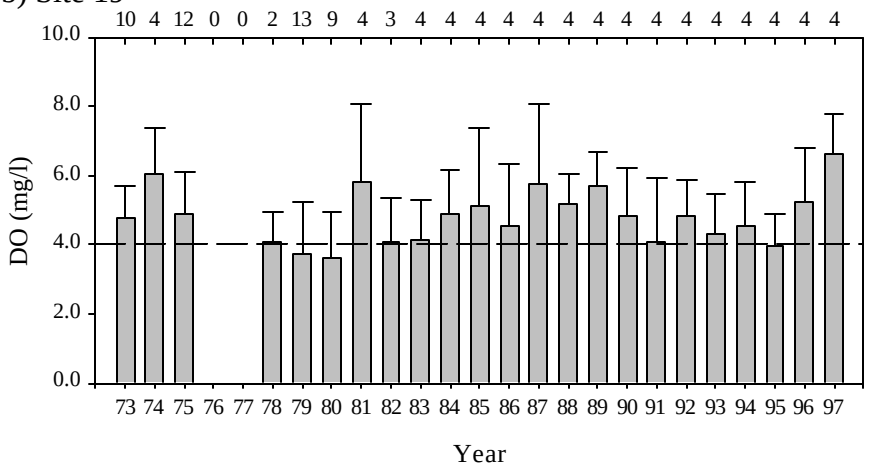
Long term mean and median total phosphorus (TP) levels were at least twice the Broward County marine standard of 0.050 mg/l standard (Table IV.22). Unusually high maxima were observed at all sites which likely contributed to high mean and standard deviations. Although variability was high, Site 16 was characterized by extraordinary high (greater than 0.500 mg/l) mean and median TP levels.

Figure IV.42. Annual Mean Dissolved Oxygen (DO) Content Within the New River Basin from 1973 to 1997. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. DO levels should be above the Broward County standard (4.0 mg/l) indicated by the dashed line.

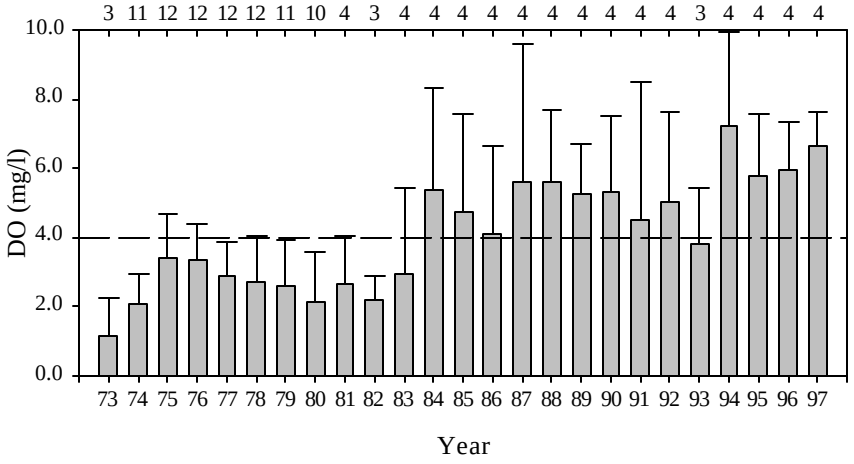
a) Site 20



b) Site 19



c) Site 16



d) Site 15

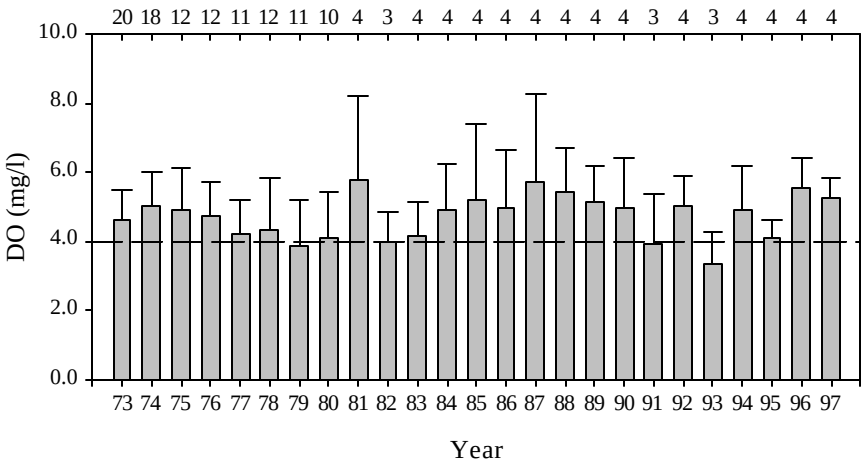


Figure IV.43. Dissolved Oxygen (DO) Concentrations Observed in the New River Basin over Three Time Periods. DO samples are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall be below 4.0 mg/l.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

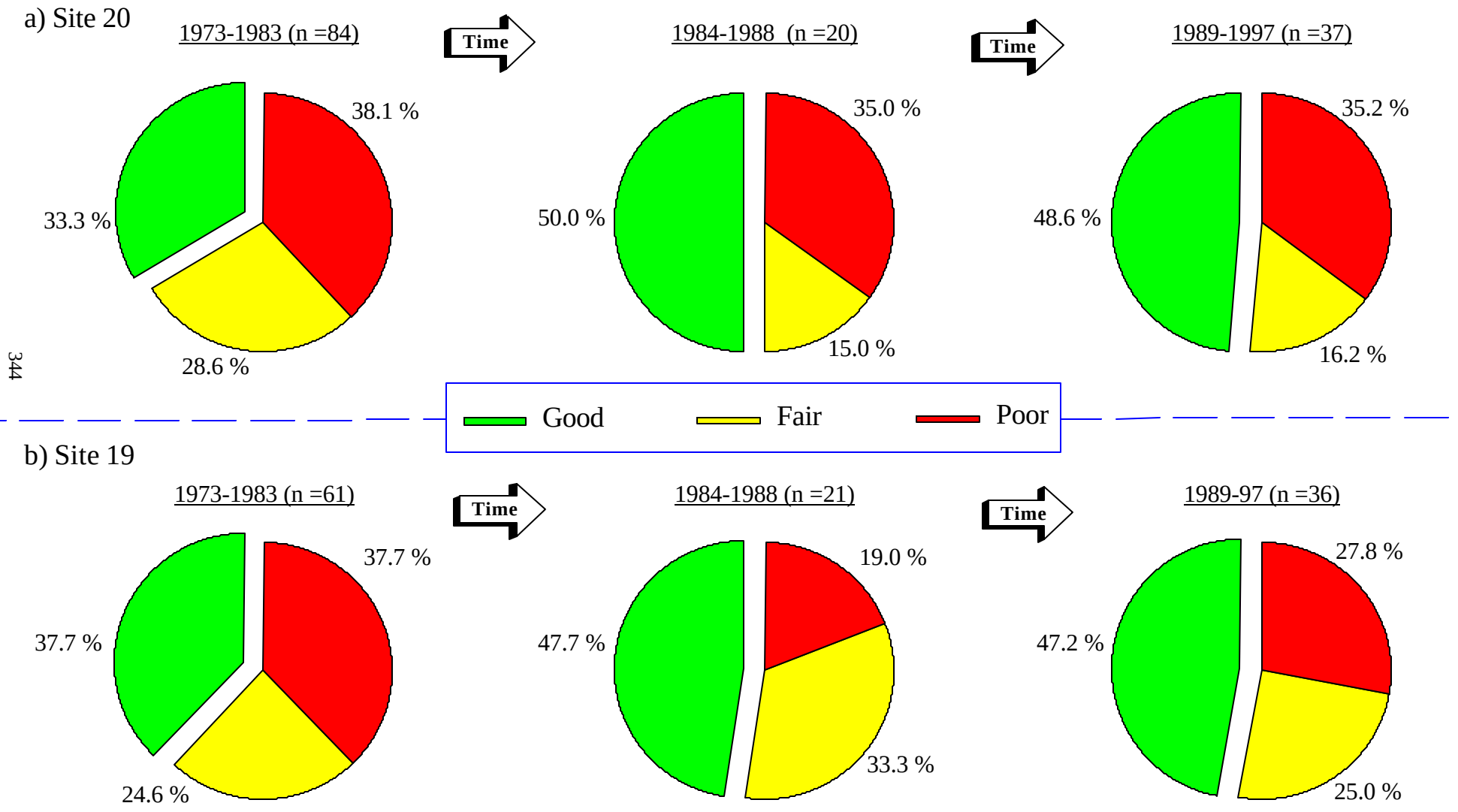
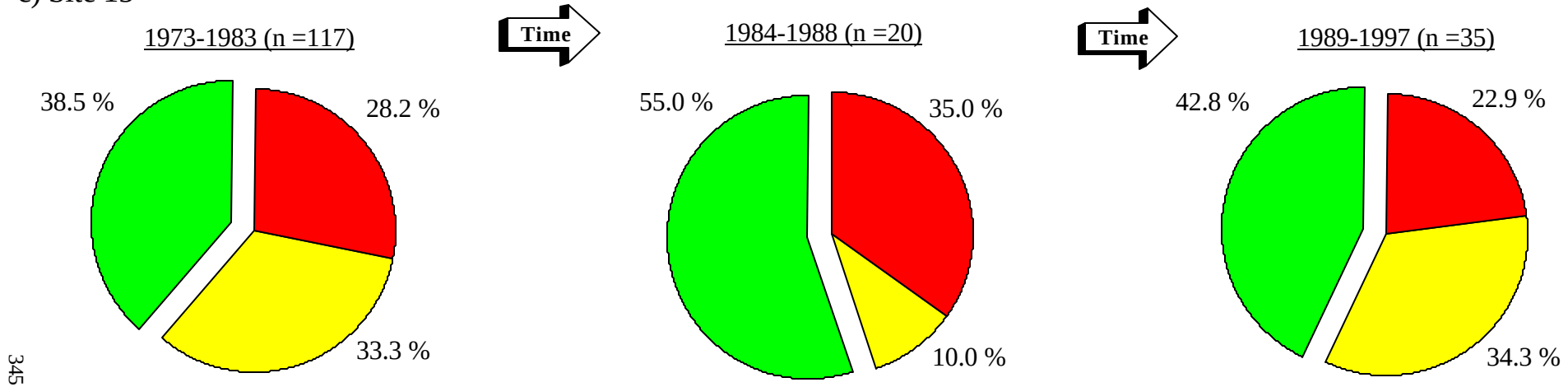


Figure IV.43 (Cont.). Dissolved Oxygen (DO) Concentrations Observed in the New River Basin over Three Time Periods. DO samples are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall be below 4.0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

c) Site 15



d) Site 16

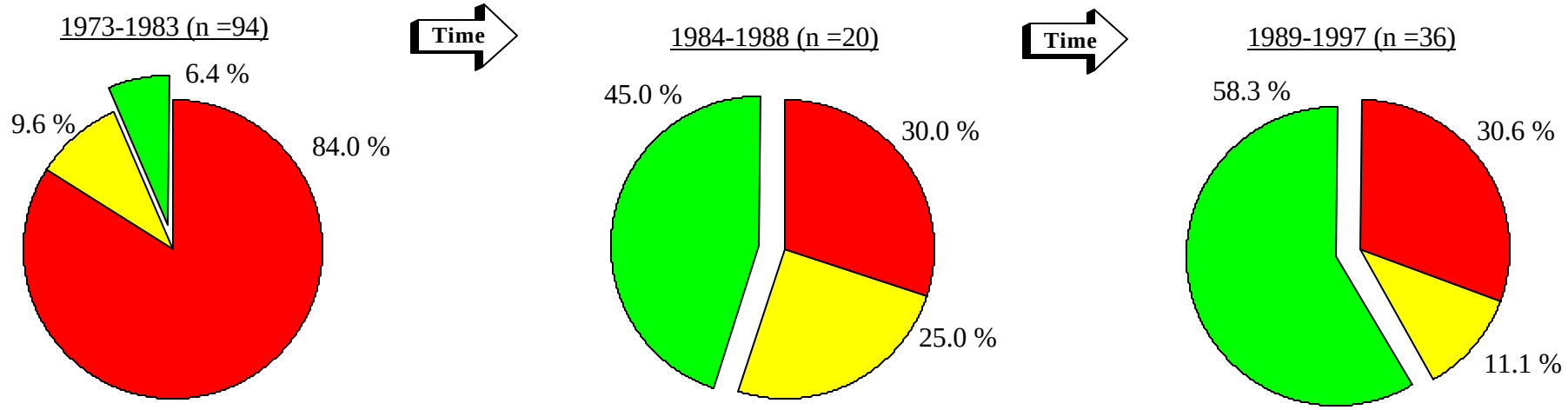


Figure IV.44. New River Basin Dissolved Oxygen (DO) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season means were observed at Sites 15, 19, and 20 ($p < 0.001$, t-test), as well as Site 16 ($p < 0.01$, t-test).

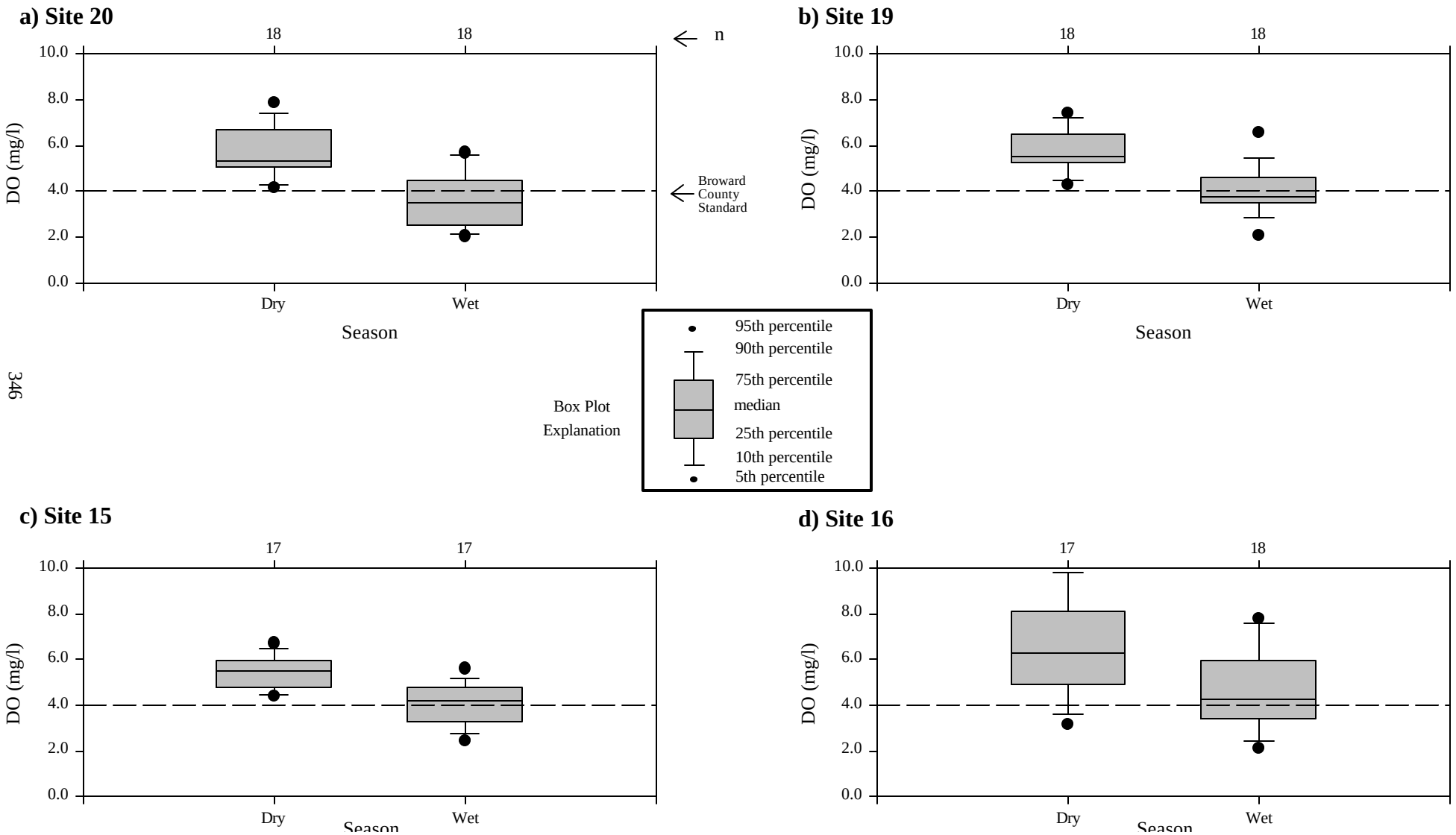


Table IV.22. Descriptive Statistics for Total Phosphorus (TP) Concentrations in the New River Basin. Calculations represent twenty-four years of sampling at Sites 15, 16, and 20 while Site 19 had twenty-two years of data. However, the number of samples per year occasionally varied at each site. If a 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
15	TP	mg/l	138	0.130	0.155	0.149	1.610	0.010	1
16	TP	mg/l	106	0.635	0.723	0.612	2.400	0.010	0
19	TP	mg/l	137	0.104	0.123	0.144	1.440	0.010	3
20	TP	mg/l	138	0.100	0.122	0.130	1.280	0.010	8

Annual averages demonstrated the high long term median and mean TP concentrations were due to levels primarily observed in the 1970's and 1980's (Figure IV.45). Recently (1994-1997), yearly TP means at Sites 15, 19, and 20 were below the 0.050 mg/l standard and exhibited relatively low variability. Site 16 showed the basin's sharpest decline in TP concentrations but annual averages were still typically over 0.100 mg/l.

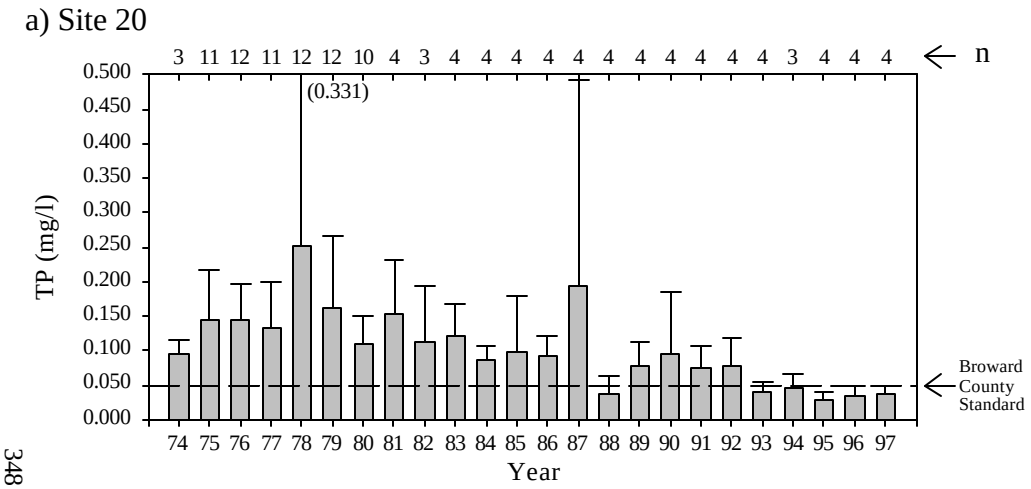
To further study TP compliance patterns over time, all individual samples were rated good, fair, or poor in terms of Broward County's marine TP standard (0.050 mg/l; see Section IV.E.5.d). In addition, the changes over time are presented with special reference to the closing of WWTPs in the basin (see Section IV.H.3). The southwest area of the basin (Sites 19 and 20) showed very similar changes with time (Figure IV.46) going from over 70.0% poorly rated samples in the first sampling period (1974-1983) to less than or equal to 20.0% in the final one (1989-1997). Site 15 also demonstrated improvements in the amount of poor samples but this occurred during the transition from the second to the third period. Although Site 16's annual averages showed a substantial decrease in TP values with time (Figure IV.45), compliance graphs (Figure IV.46) illustrate that poor rated samples (i.e., > 0.100 mg/l) were the dominant classification in the North Fork through all sampling years.

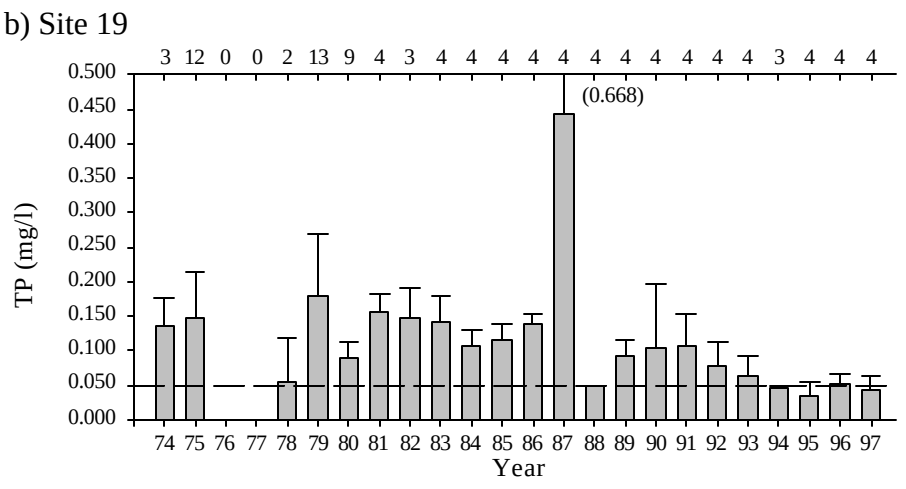
Observations from 1989-97 did not reveal statistically significant differences between wet and dry seasons (Figure IV.47). Interestingly, dry season TP median values were higher than wet season values at both Sites 19 and 20, though not statistically significant. Nearly all of Site 16's TP values (wet and dry season) were above the 0.050 mg/l standard and both medians were greater than 0.100 mg/l. All sites had at least one season with a median value above the 0.050 mg/l standard.

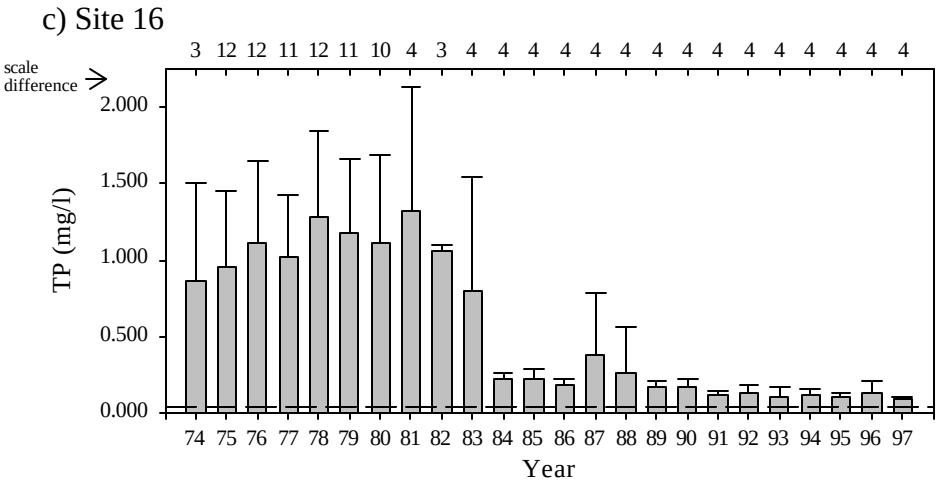
e. Total Nitrogen

Total Nitrogen levels are calculated from the total Kjeldahl nitrogen (TKN) and nitrate+nitrate-nitrogen (NO_2+NO_3) concentrations. Over the seventeen-year period, Site 20 had the basin's highest median value and Site 16 had the highest mean, due in part, to an extraordinarily high maximum value (11.454 mg/l, Table IV.23). Sites 15 and 19 exhibited long term median and mean TN values below the 1.500 mg/l standard.

Figure IV.45. Annual Mean Total Phosphorus (TP) Levels Within the New River 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 marine standard (0.050 mg/l) is indicated by the dashed line. Note Site 16 (c) has different y-axis scale than other three graphs.







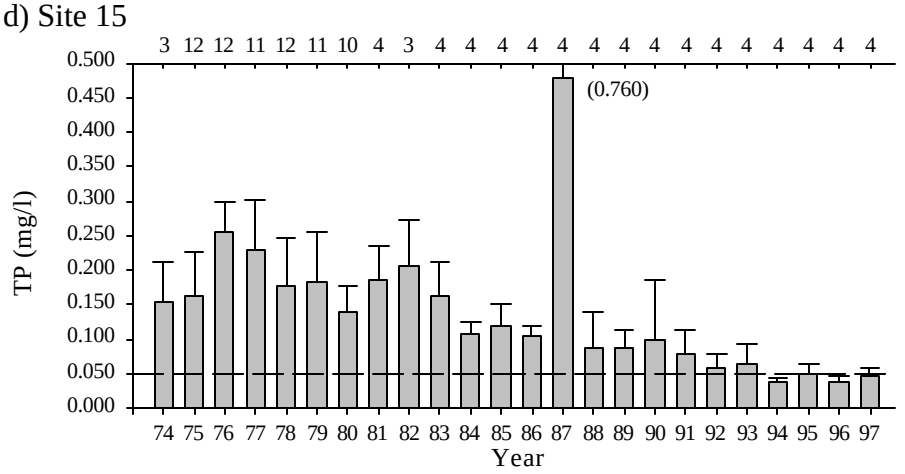


Figure IV.46. Total Phosphorus (TP) Concentrations Observed in the New River Basin over Three Time Periods. TP levels are categorized in terms of compliance with the Broward County marine standard of 0.050 mg/l. The percentage below 0.050 mg/l are classified as good. A fair rating was given to values between 0.051 mg/l to 0.099 mg/l. Values equal to or greater than twice the standard (i.e., 0.100 mg/l) are classified as poor.

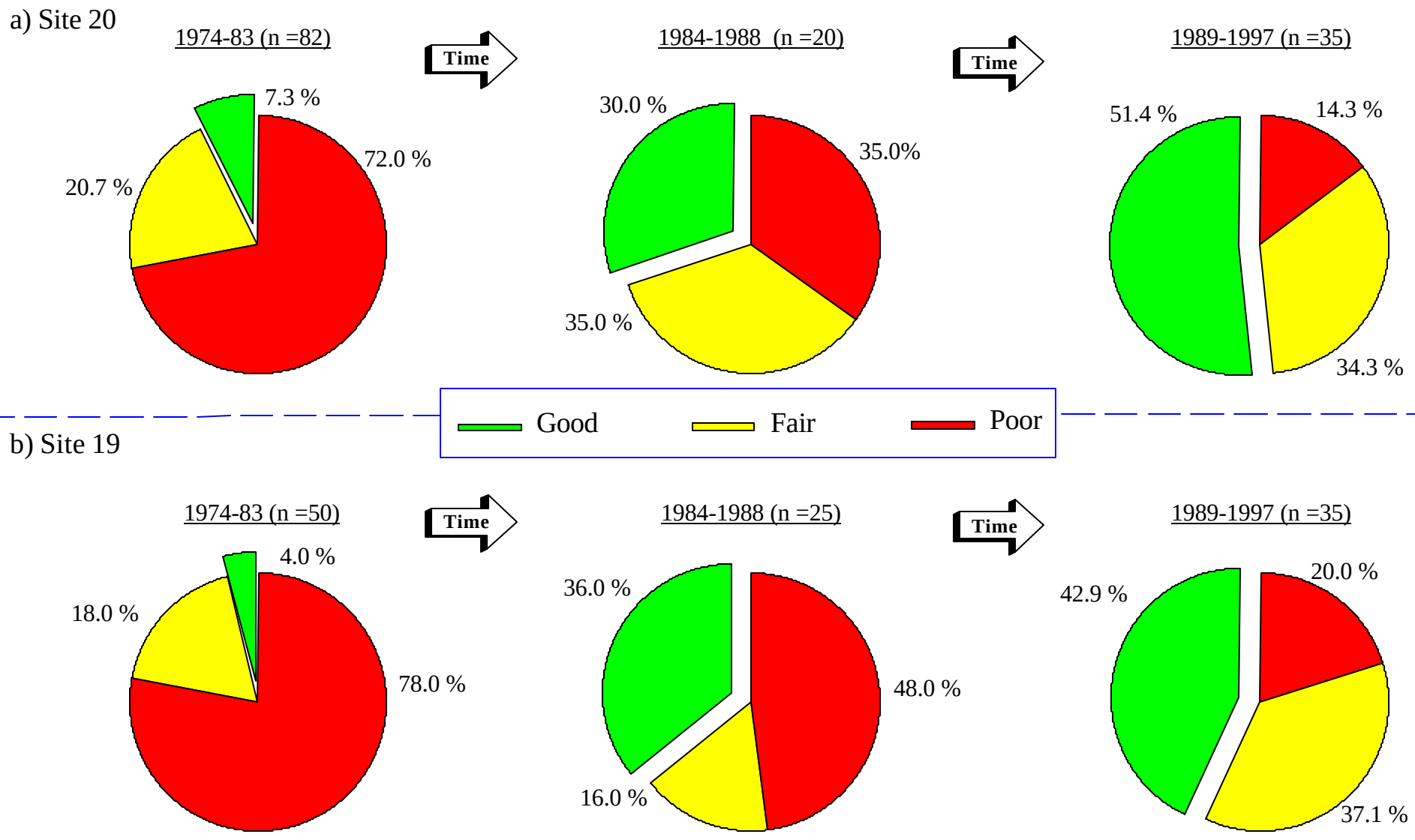
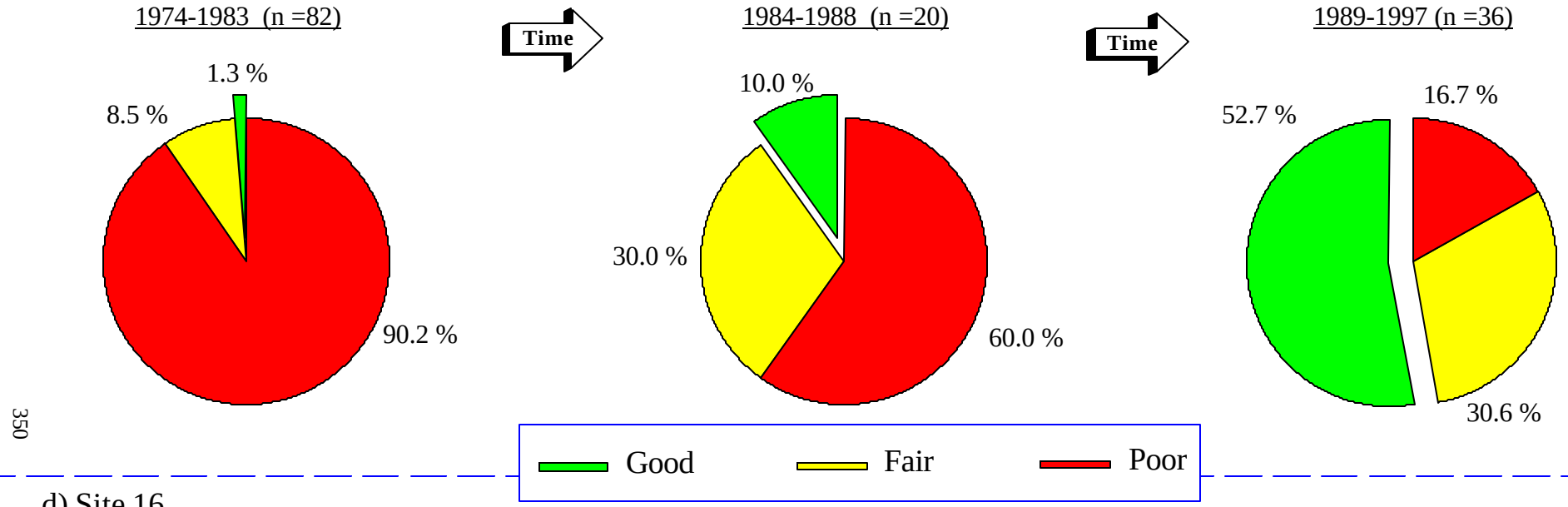


Figure IV.46 (Cont.). Total Phosphorus (TP) Concentrations Observed in the New River Basin over Three Time Periods. TP levels are categorized in terms of compliance with the Broward County marine standard of 0.050 mg/l. The percentage below 0.050 mg/l are classified as good. A fair rating was given to values between 0.051 mg/l to 0.099 mg/l. Values equal to or greater than twice the standard (i.e., 0.100 mg/l) are classified as poor.

c) Site 15



d) Site 16

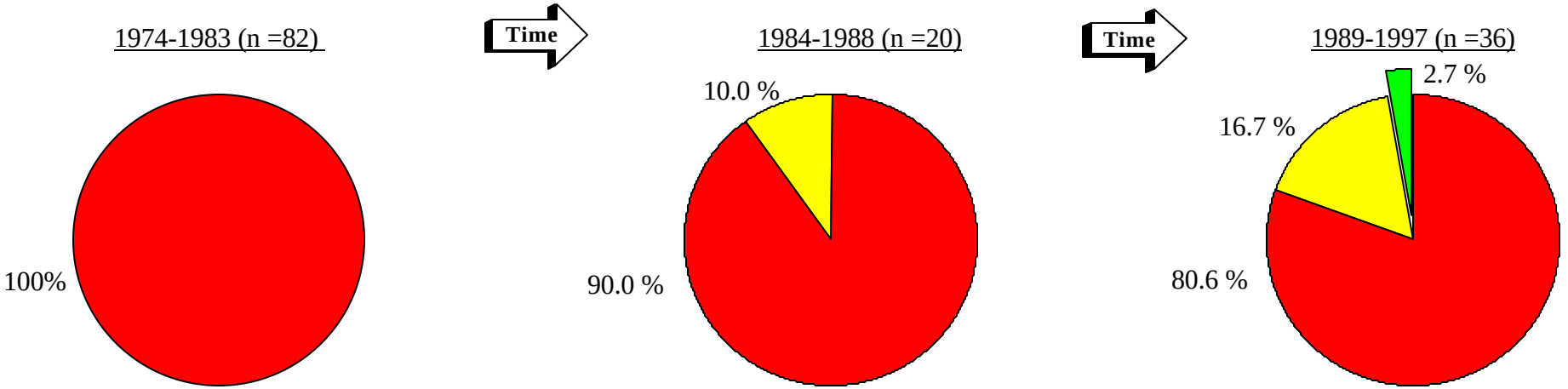
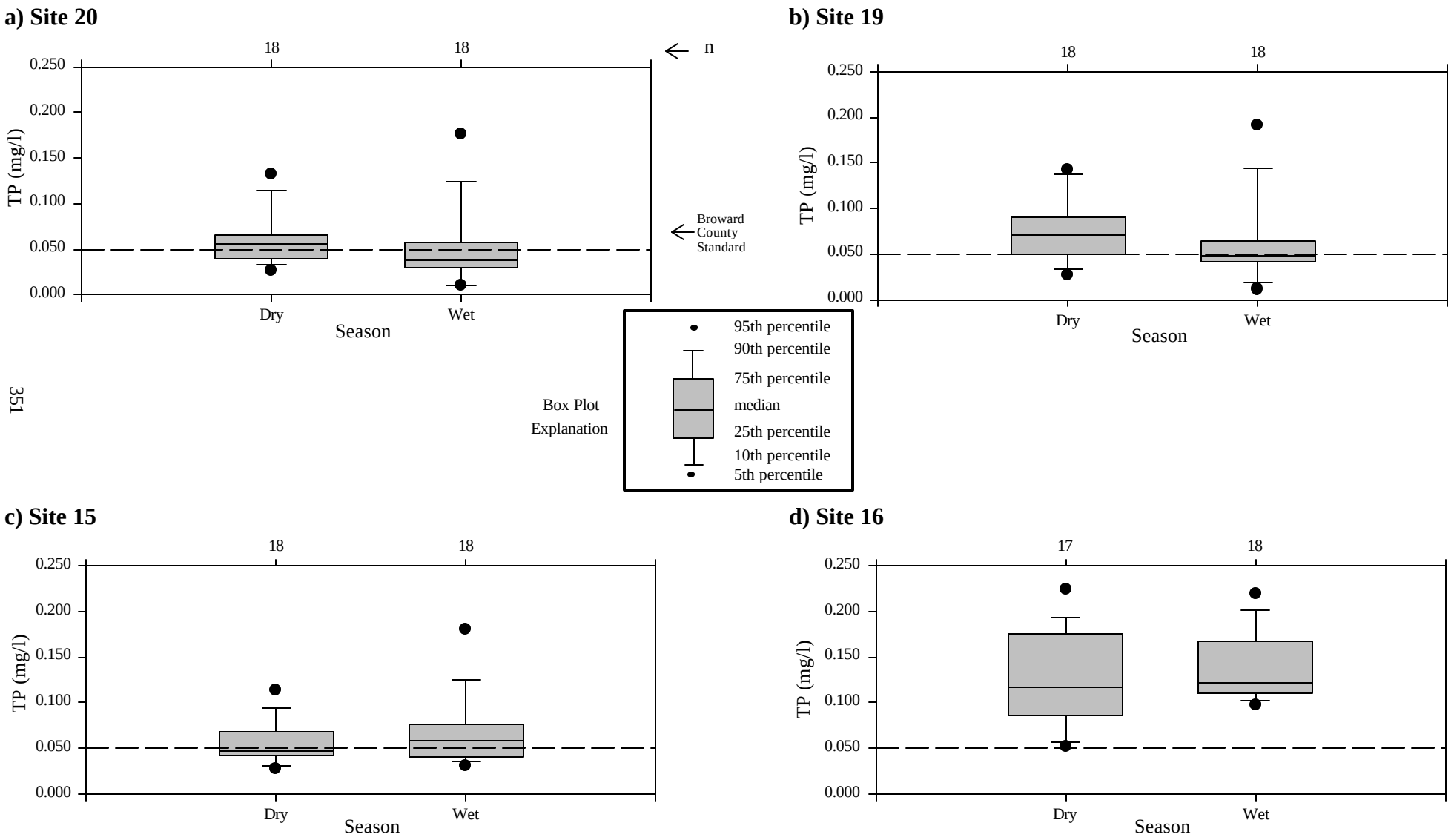


Figure IV.47. New River Basin Total Phosphorus (TP) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) collected over the nine year period are shown on the upper x-axis. Statistically significant differences between wet and dry season values were not observed in the basin.



Total Kjeldahl nitrogen represented at least 77% of median and mean TN levels. With the exception of Site 16's mean concentration, ammonia-nitrogen (NH_3) levels typically represented less than 15% of median and mean TKN content. Thus, organic nitrogen was the main nitrogen form observed in the basin. However, long term median and mean NO_2+NO_3 values were relatively enhanced (> 0.150 mg/l) and combined with NH_3 values, represent a high amount of dissolved inorganic nitrogen (DIN).

Table IV.23. Descriptive Statistics for Nitrite+Nitrate-Nitrogen (NO_2+NO_3), Ammonia-Nitrogen (NH_3), Total Kjeldahl Nitrogen (TKN), and Total Nitrogen (TN) in the New River Basin. All calculations represent seventeen years of sampling. However, the number of samples per year varied occasionally at each site. 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.

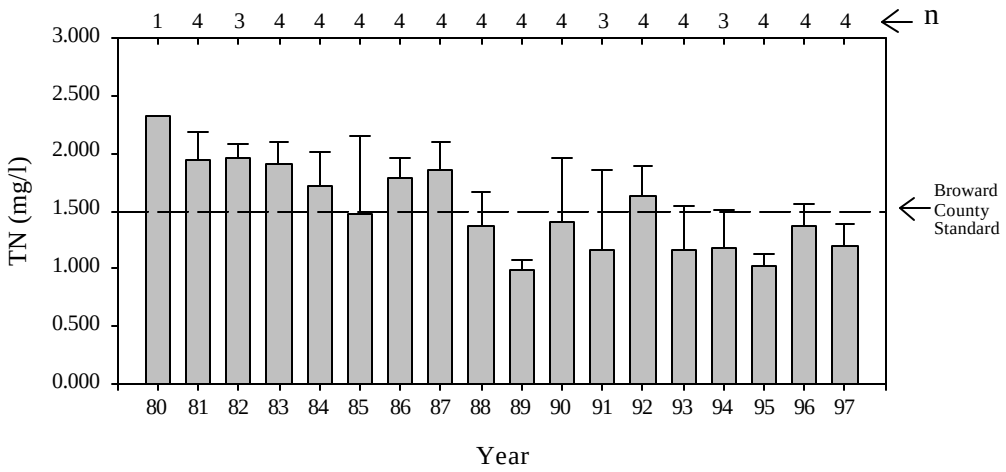
Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
15	NO_2+NO_3	mg/l	68	0.250	0.277	0.168	0.666	0.005	2
16	NO_2+NO_3	mg/l	68	0.162	0.238	0.338	1.750	0.005	8
19	NO_2+NO_3	mg/l	68	0.289	0.300	0.175	0.728	0.005	3
20	NO_2+NO_3	mg/l	67	0.193	0.249	0.164	0.705	0.005	0
15	NH_3	mg/l	63	0.076	0.127	0.135	0.619	0.005	11
16	NH_3	mg/l	63	0.108	0.533	1.213	6.350	0.005	18
19	NH_3	mg/l	63	0.120	0.137	0.118	0.500	0.009	9
20	NH_3	mg/l	62	0.110	0.173	0.147	0.770	0.019	3
15	TKN	mg/l	67	1.010	1.036	0.330	1.660	0.354	0
16	TKN	mg/l	67	1.010	1.598	1.912	11.300	0.139	0
19	TKN	mg/l	67	1.160	1.128	0.310	1.700	0.174	0
20	TKN	mg/l	66	1.303	1.248	0.382	2.170	0.184	0
15	TN	mg/l	67	1.296	1.313	0.432	2.245	0.528	Calc
16	TN	mg/l	67	1.197	1.836	2.097	11.454	0.144	Calc
19	TN	mg/l	67	1.385	1.427	0.050	2.162	0.179	Calc
20	TN	mg/l	66	1.533	1.495	0.055	2.332	0.365	Calc

Annual mean total nitrogen (TN) content was generally higher in the 1980's than during the 1990's at Sites 15, 19, and 20 (Figure IV.48). Site 16 exhibited a remarkable decline in TN values after 1983. Basinwide, all annual averages were below (i.e., compliant) the 1.500 mg/l Broward County standard since 1988.

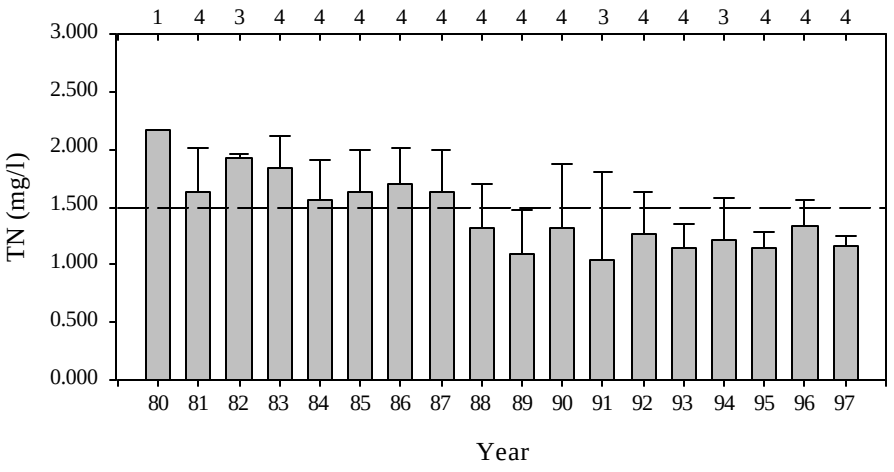
To look closely at standard compliance with time, TN concentrations were designated as poor, fair, and good based on the TN standard of 1.500 mg/l (see Section IV.E.5.e) and changes over time are presented with special reference to the closing of WWTPs in basin (see Section IV.H.3). Compliance patterns (Figure IV.49) were very similar to annual averages (IV.48), further illustrating the decadal difference observed at Sites 15, 19, and 20. In addition, the exceptional decrease of poor rated samples at Site 16 is clearly due to the closing in 1983 of the WWTP plant. In the post-WTTP years

Figure IV.48. Mean Annual Total Nitrogen (TN) Content Within the New River Basin from 1980 to 1997. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. TN levels should be below the Broward County standard (4.0 mg/l) indicated by the dashed line. Note Site 16 (c) has different y-axis scale than other three graphs.

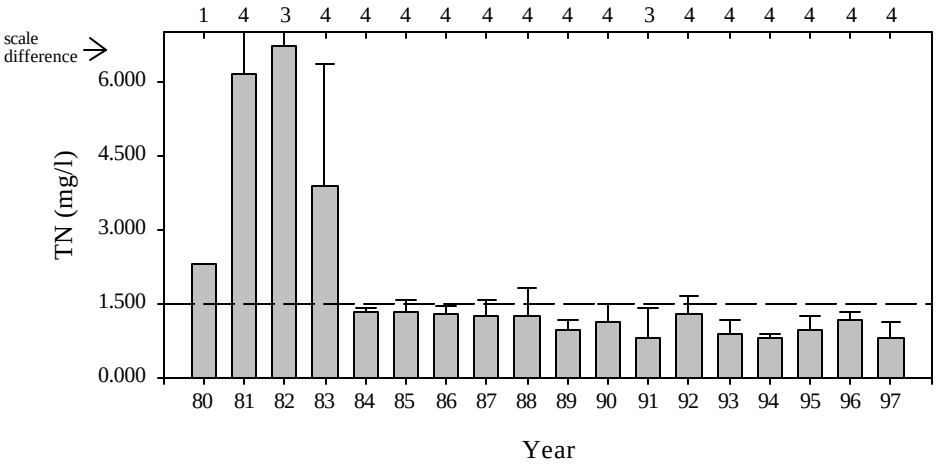
a) Site 20



b) Site 19



c) Site 16



d) Site 15

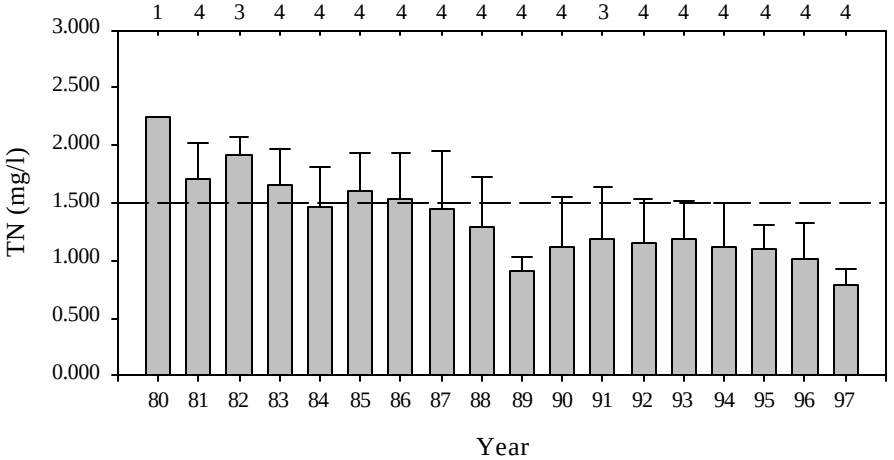


Figure IV.49. Total Nitrogen (TN) Concentrations Observed in the New River Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County marine TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified as good. A fair rating 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.

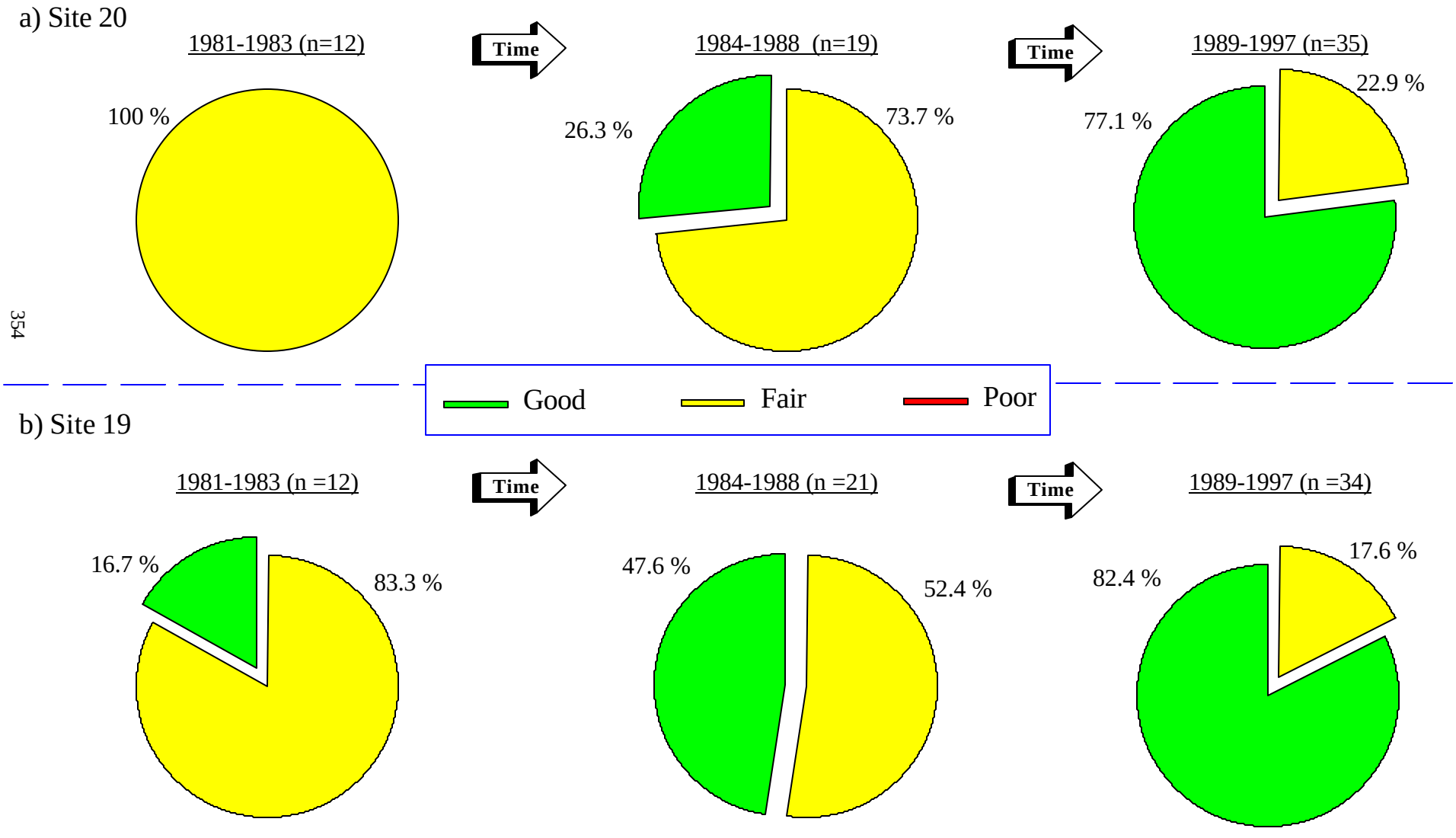
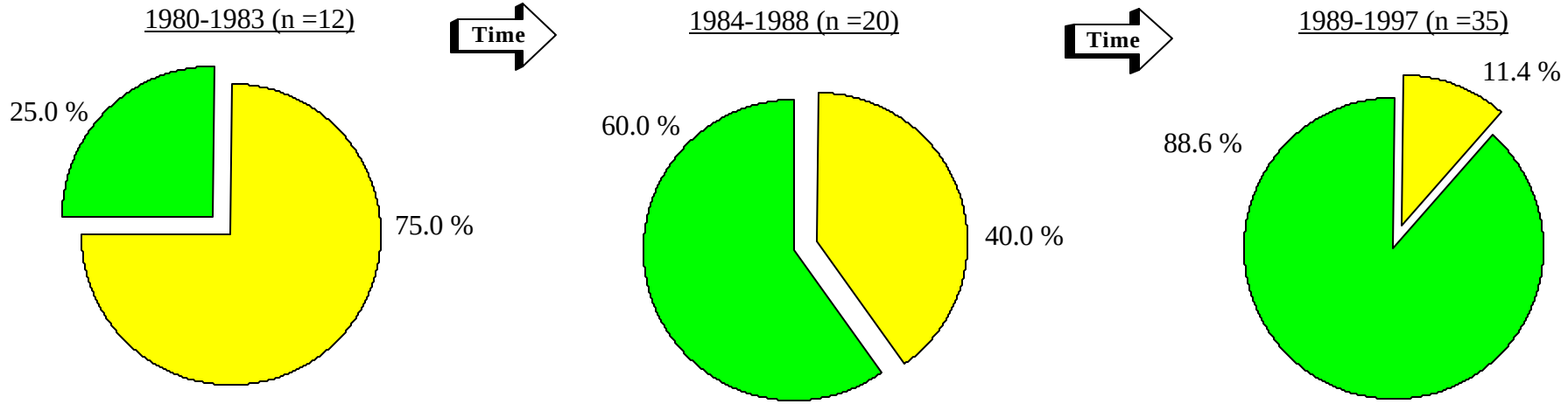
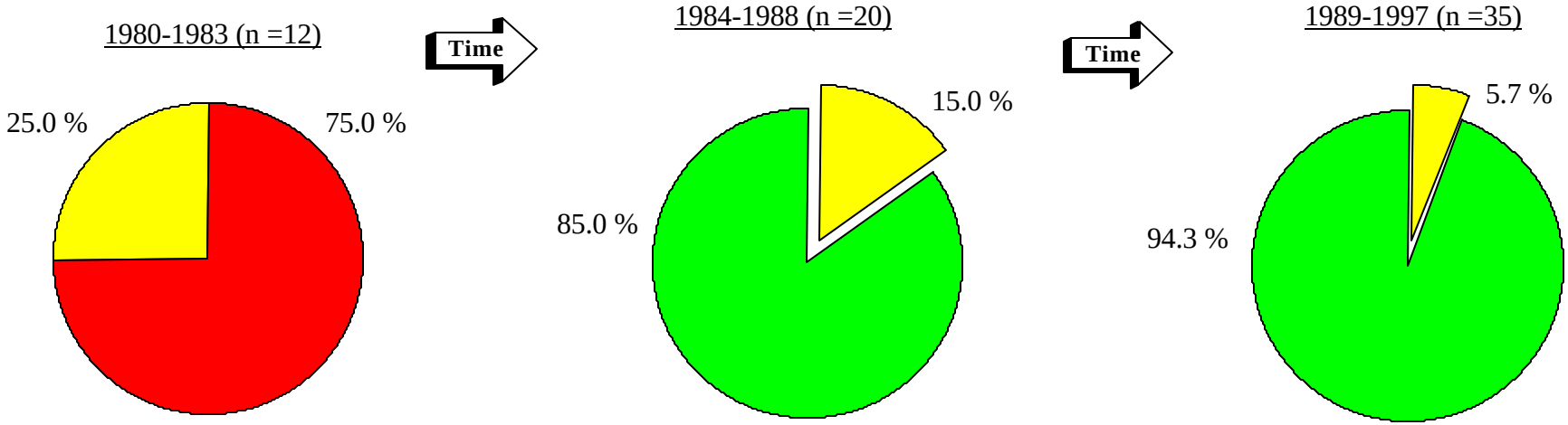


Figure IV.49 (Cont.). Total Nitrogen (TN) Concentrations Observed in the New River Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County marine TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified as good. A fair 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 15



d) Site 16



(i.e., 1989-1997), the highest TN values were observed in the southwest area at Sites 19 and 20 (17.6% and 22.9% fair samples, respectively).

From 1989-1997, statistical seasonal differences in TN content were observed in the western areas of the basin (Site 19, $p < 0.005$; Site 20, $p < 0.01$; t-test) with wet season values higher than dry (Figure IV.50). Furthermore, Sites 19 and 20 had 75th percentile values over 1.500 mg/l with both occurring in the wet season. Conversely Sites 16 and 15 had no statistical difference between seasons and only occasional (90th percentile) exceedances of the 1.500 mg/l standard were seen in the wet season.

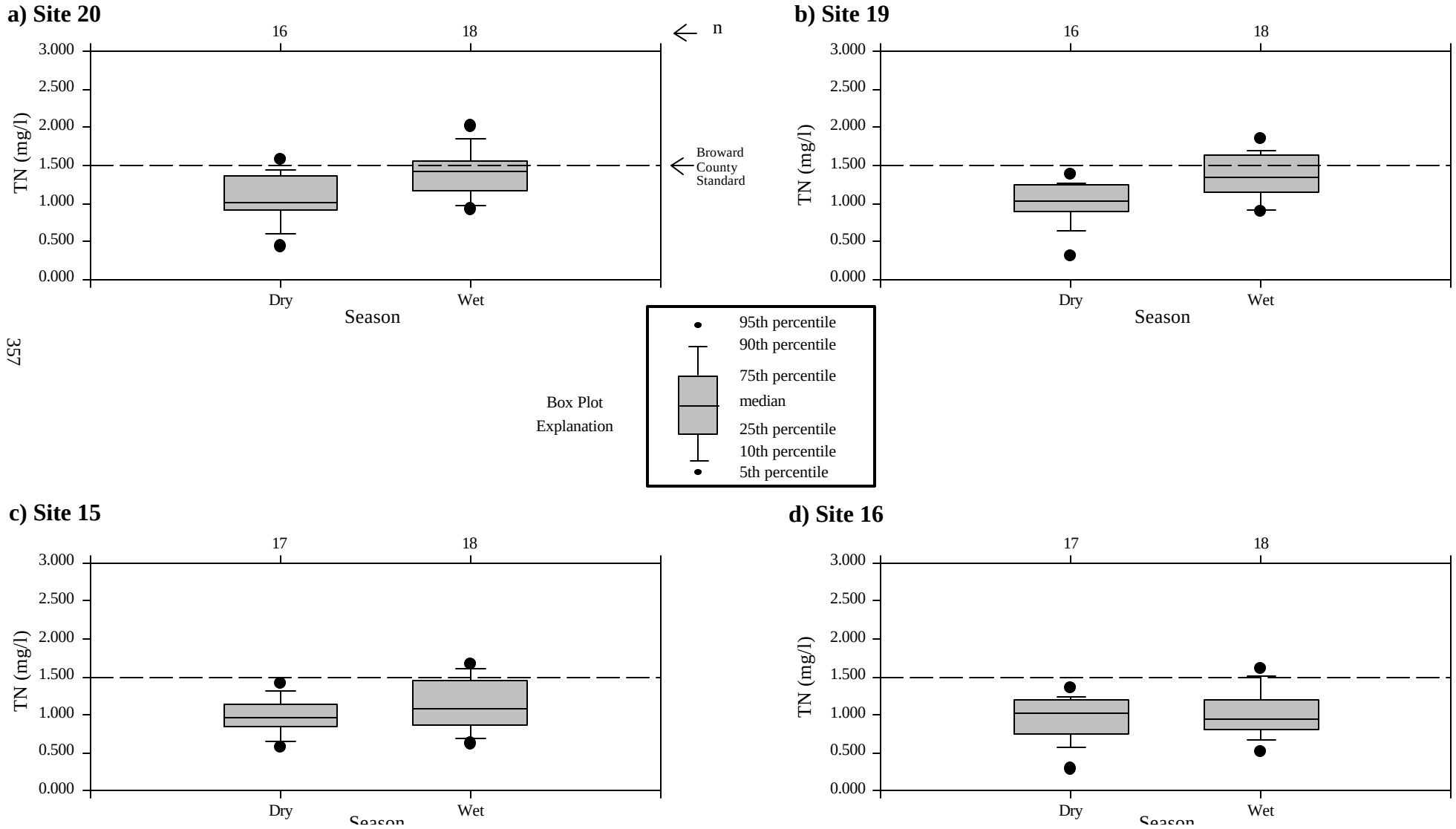
f. Bacteriological Parameters

Fecal coliform (FC), total coliform (TC), and fecal streptococcus (FS) levels were the bacteriological parameters measured from 1973 to 1997. Site 16 had the highest median fecal coliform value throughout the study area (370 colonies/100 ml, Table IV.24) that exceeded the monthly average standard (200 colonies/100 ml). Sites 15, 19 and 20 exhibited relatively similar medians between 170 and 200 colonies/100 ml. Maximum FC values well exceeded the Broward County single sample standard of 800 colonies/100 ml, particularly at Sites 15 and 16 and almost all samples were above the method detection limit. Median TC and FS showed similar spatial patterns as FC with Site 16 having the basin's highest median values.

Table IV.24 Descriptive Statistics for Fecal Coliform (FC), Total Coliform (TC), and Fecal Streptococcus (FS) in the New River Basin. Calculations for FC and TC represent twenty-five years of sampling with the exception of Site 19's twenty-three years of observations. Fecal streptococcus measurements were obtained over twenty-two years except for Site 19 (twenty-one years). However, the number of samples per year occasionally varied at each site. 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
15	FC	col	159	170	489	1331	12000	5	1
16	FC	col	150	370	1139	2091	12000	5	2
19	FC	col	111	190	234	184	1300	20	11
20	FC	col	139	200	139	376	2200	10	24
15	TC	col	172	1300	3438	9297	80000	67	0
16	TC	col	148	3000	8926	15453	80000	17	1
19	TC	col	117	900	1526	2341	19000	100	0
20	TC	col	137	1200	3278	7000	41000	73	0
15	FS	col	123	220	571	875	6700	15	7
16	FS	col	124	325	1030	2318	23000	12	7
19	FS	col	92	215	1341	8642	83000	12	6
20	FS	col	123	240	880	2756	24000	17	2

Figure IV.50. New River 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) during the nine year sampling period is shown on the upper x-axis. Statistically significant differences between wet and dry season means were observed at Sites 19 and 20 ($p < 0.005$ and $p < 0.01$, respectively t-test).



Due to the large amount of variability around the mean (Table IV.24), yearly box plots were plotted for fecal coliform instead of the mean (Figure IV.51). Site 16 consistently displayed annual median values above the single sample standard (800 colonies/100 ml). Site 15 had occasional 75th percentile concentrations exceeding the 800 colonies/100 ml. Interestingly, FC values have generally increased at Sites 15 and 16, beginning in 1980. Yearly medians in the southwest portion of the basin (Sites 19 and 20) were normally below the single sample standard but near the monthly average standard of 200 colonies/100 ml.

To better understand compliance levels, all FC samples were categorized good, fair, or poor based on three different Broward County water quality standards (see Section IV.E.5.f). In addition, the changes over time are presented with special reference to the closing of WWTPs in the basin (see Section IV.H.3). Figure IV.52 clearly illustrates the high (> 800 colonies/100 ml) fecal coliform levels in the North Fork (Site 16). Interestingly, 41.5% of FC samples at Site 16 were rated good during WWTPs operation (1973-1983) but by the final period (1989-1997), zero samples rated good while 45.9% ranked poor. Although not nearly as distinct, Site 15 also exhibited an increase in poor rated samples (8.7% to 19.4%) by the final period. Sites 19 and 20, in general, had better FC values than both Sites 15 and 16.

Between 1989-1997, all four sites' wet season medians were higher than corresponding dry season values but a statistically significant difference was only observed at Site 20 ($p < 0.005$, Mann Whitney Rank Sum Test, Figure IV.53). Site 16 exhibited an extremely high wet season median but variability in both seasons likely caused seasonal differences to be non-significant. Site 15 also demonstrated a large range of FC values with occasional (90th percentile) exceedances of the FC standard (i.e., 800 colonies/100 ml). Site 19 generally had the lowest FC values in the basin.

6. Basin Summary

Since 1990, BCDPEP has studied the New River Basin more extensively than any other basin in Broward County. However, the current historical analysis differs from earlier work by looking at nearly three decades of data. Site 20 represents the western area of the basin where the North New River Canal meets the South Fork of the New River. The South Fork's eastern range is described by Site 19. Site 16 represents the North Fork and Site 15 characterizes the main New River. Thus, the following will summarize the water quality of the four ambient water quality sites that exist at hydrologically different regions in the basin. In addition, the influence of WWTP discharges and seasonal effects will also be discussed. Finally, questions about the New River Basin brought forth by this historical data analysis are listed to support current restoration initiatives and monitoring, as well as future resource planning.

a. Influence of WWTP Discharge

A positive characteristic of the historic observations in the North Fork (Site 16) is the substantial improvement in water quality improved after the closure of the WWTP (Ft. Lauderdale Plant "A") in 1983. While other ambient sites in the county also showed water quality improvements after WWTP closure, the magnitude of change at Site 16 is striking. Annual TP levels decreased tenfold and TN

Figure IV.51. Yearly Box Plots of Fecal Coliform (FC) Levels within the New River 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 Site 16 (c) has different y-scale than other three graphs.

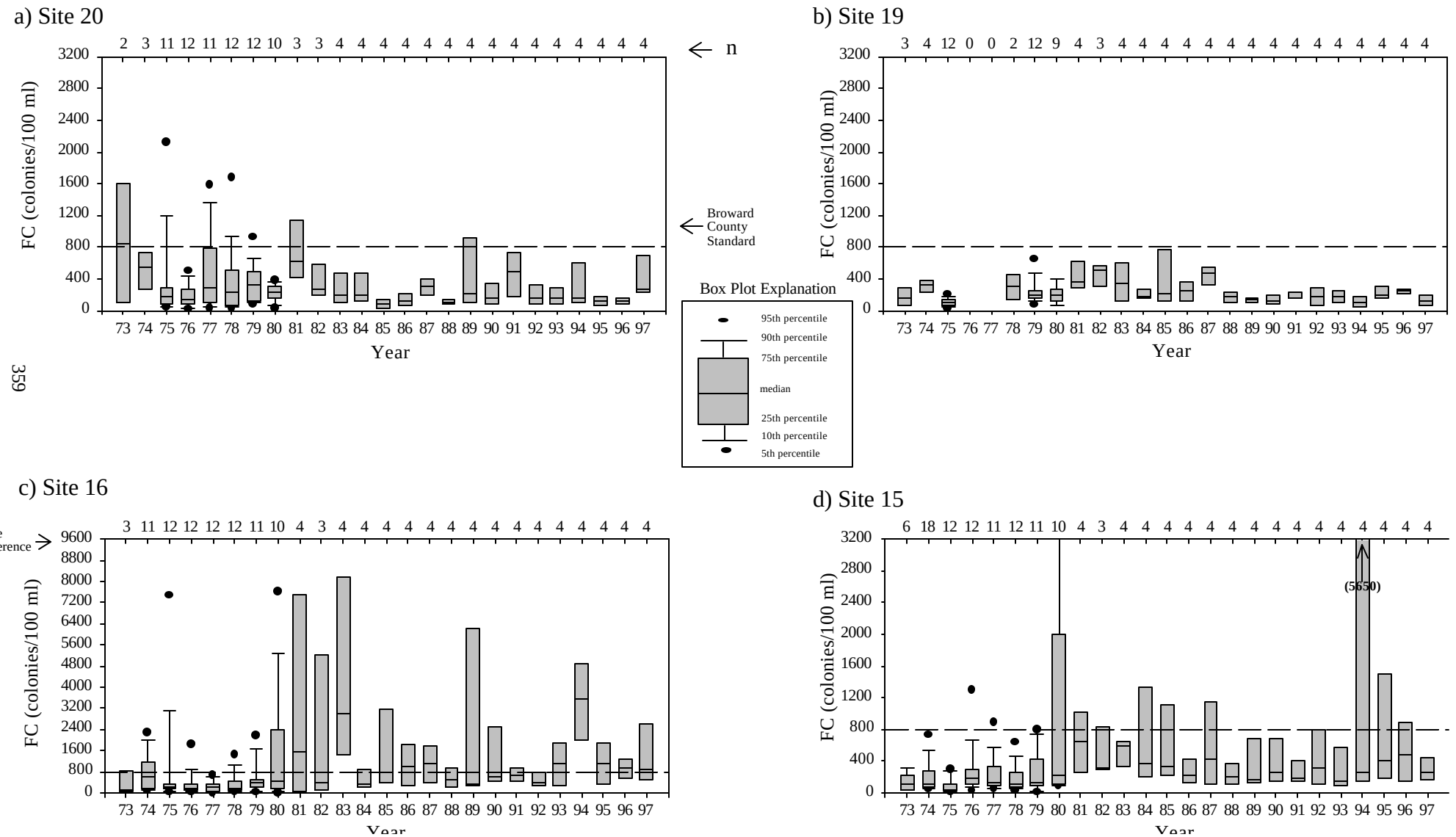


Figure IV.52. Fecal Coliform (FC) Concentrations Observed in the New River Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100 ml (good rating) and no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

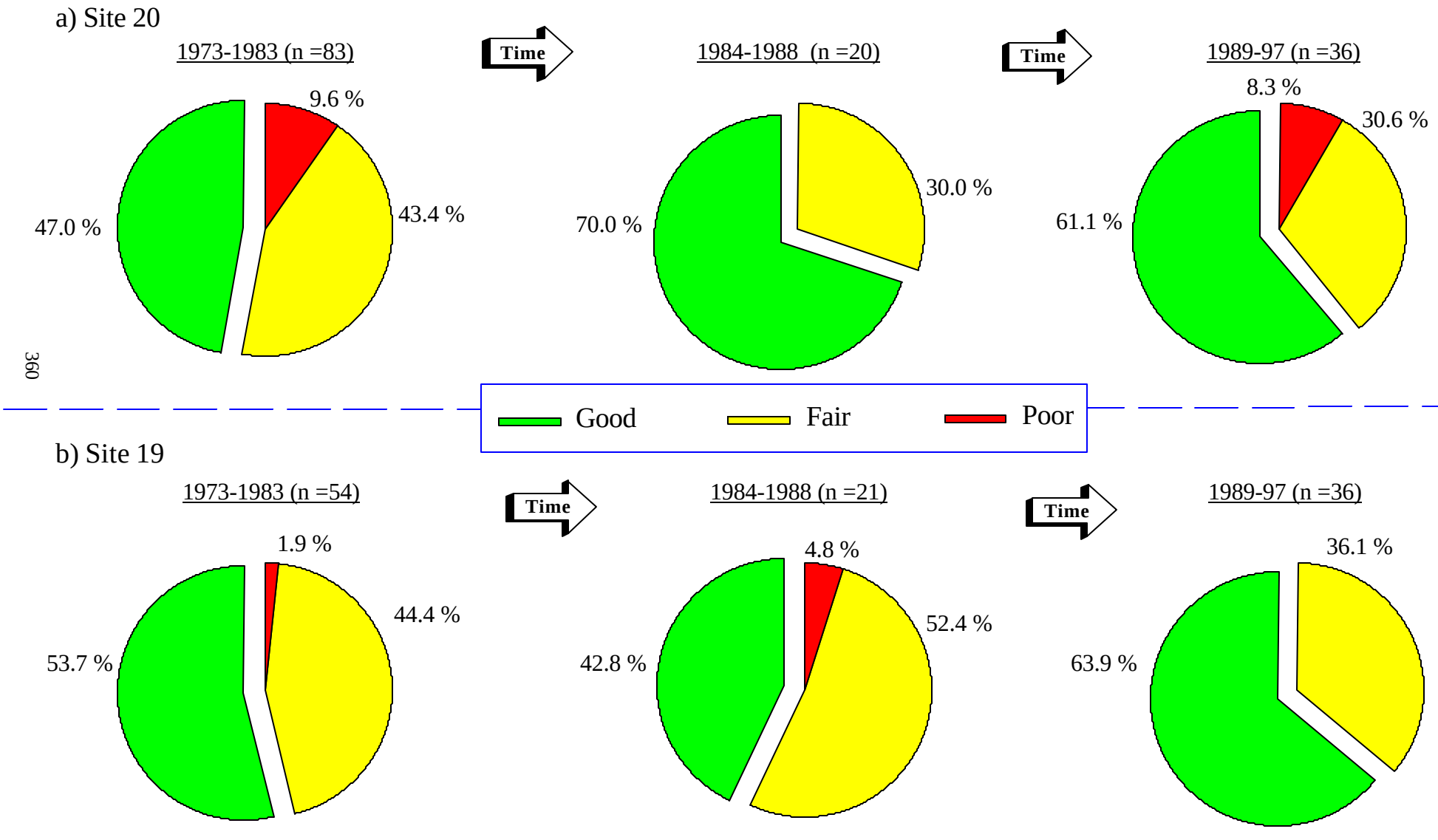


Figure IV.52 (Cont.). Fecal Coliform (FC) Concentrations Observed in the New River Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County marine FC standards which state the monthly average shall be equal to or less than 200 colonies/100 ml (good 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.

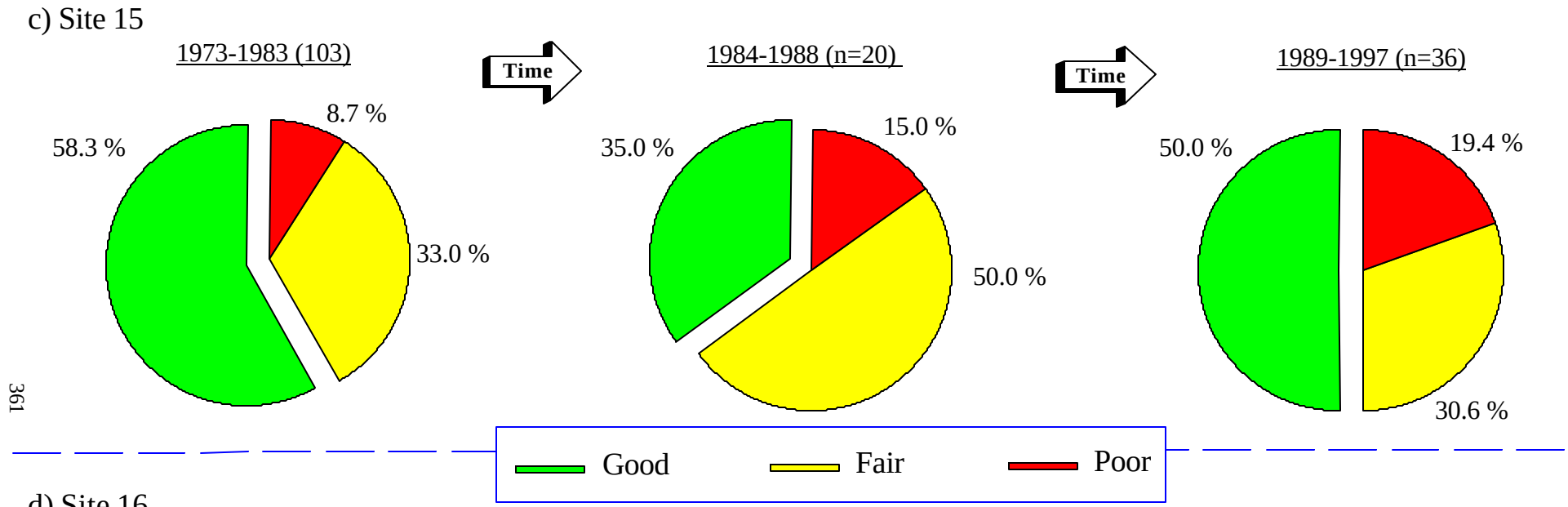
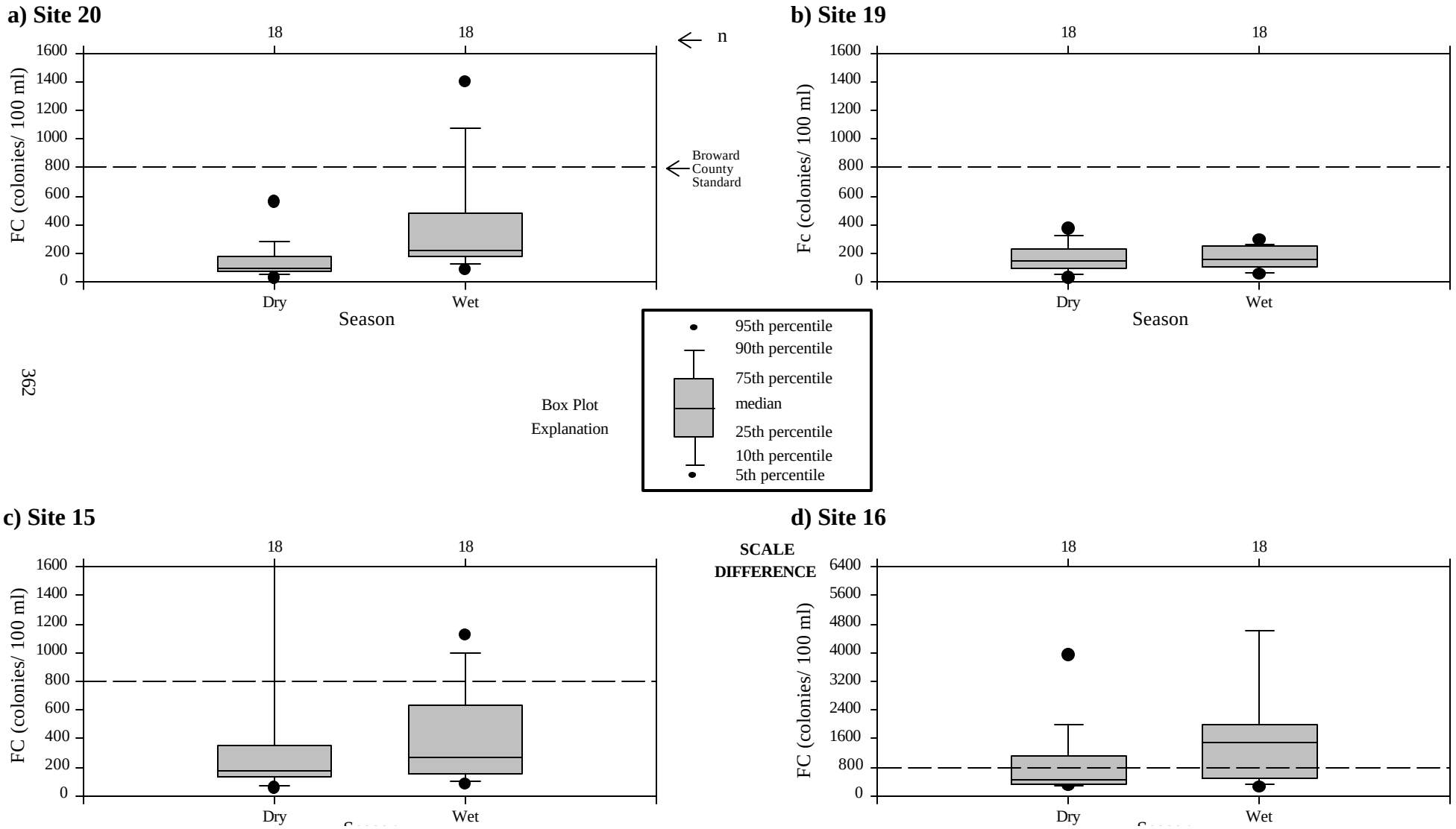


Figure IV.53. New River Basin Fecal Coliform (FC) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (n) during the nine year period is shown on the x-axis. A statistically significant difference between wet and dry season medians was observed at Site 20 ($p < 0.005$, Mann-Whitney Rank Sum Test).



concentrations decreased by over 50.0%. Dissolved oxygen levels, though variable, were at least near or above 4.0 mg/l after the closing of the WWTP.

Fecal coliform values increased after the WWTP closure. This may be due to the end of the release of chlorine laden waters associated with WWTP discharges. In sufficient concentrations, chlorine disinfects water. Fecal coliform observations after 1983 indicate a bacteriological source in the river not associated with the WWTP. The source of this FC is currently under investigation and may include stormwater, septic tanks, liveaboards, homeless populations, and/or wildlife, as well as regenerative bacteria populations in the soil and/or water (see BCDPEP 1999a and Solo-Gabriele et al. 2000).

The remaining three sampling points (15,19, and 20) also showed general improvements with the stoppage of WWTP disposal in the basin. Overall, nutrient concentrations were the best indicator of the improvements observed post-WWTP disposal in the basin. In particular, Sites 15, 19, and 20 showed substantial improvement in TP content.

b. Basin Water Quality Comparison (Post-WWTP)

As observed in the New River Study (BCDNRP 1993), the North Fork of the New River still has the worst water quality of the New River Basin despite the improvements seen with WWTP closures. In fact, based on the earlier freshwater analysis (Section III) and other estuarine water bodies (Section IV), Site 16 has arguably the worst water quality in the entire county (freshwater or estuarine). TP levels were exceptionally high (> 0.100 mg/l) and the site is the only one in this report where median FC values were consistently above 800 colonies/100 ml. Furthermore, DO levels appear to fluctuate greatly suggesting high levels of biological activity.

A lack of consistent flow from the western areas of the county (BCDPEP 1999a), as well as the relatively high flow rate of the South Fork (BCDNRP 1993) have been implicated as major reasons for the North Fork's stagnant waters. This lack of flow undoubtedly impacts water quality characteristics. Furthermore, at least 35 stormwater outfalls are along a three mile stretch of river north of Broward Boulevard (Figure IV.41), while to the south, dead-end finger canals (with stormwater outfalls) exists along with residential land use and septic tanks. Thus, the majority of the North Forks' main freshwater input is stormwater, although groundwater also contributes to the overall hydrology, likely on a seasonal basis.

Currently, improving regular freshwater flows and reducing stormwater impacts are part of a multi-agency effort, including BCDPEP (1999), SFWMD, and the state of Florida. In addition, the City of Ft. Lauderdale formed a Blue Ribbon Task Force that includes experts in the bacteriological, virological, and microbiological fields. Furthermore, the City of Ft. Lauderdale has begun to implement a changeover of septic tank to domestic wastewater service. These efforts, as well as the United States Environmental Protection's National Pollutant Discharge Elimination System, should begin to alleviate some of the North Fork's water quality problems.

Elsewhere in the basin, slightly higher TN values and lower DO concentrations observed at Site 20 are consistent with the more intensive basin analysis performed from 1991-1992 (BCDNRP 1993). This

pattern is likely due to localized groundwater interaction in the New River Basin, as well as inputs from the western, freshwater North New River Canal that is characterized by waters originating from the Water Conservation Areas (see Section III.I.1). Site 19 had similar attributes as Site 20, with slightly lower TN and higher DO values. Site 19 likely reflects a 'downstream' transition occurring from North New River Canal water (i.e., Site 20) to the eastern South Fork. Site 19 and 20 showed very similar FC content.

Site 15 appeared to have more independent characteristics from other areas of the basin likely due to its more eastern location and surrounding downtown land use. The salinity at Site 15 (11.9 ppt) was almost three times the other sampling locations. TN values were normally good from 1989-1997 and TP values were at the low range recorded in the basin. However, FC values were often elevated, although not to the extent of Site 16. An intensive tidal sampling project was completed in the summer of 1999 and the data are currently being compiled and analyzed (BCDPEP unpublished data). The results from that study should lead to a better understanding of tidal dynamics on water quality characteristics (e.g., FC) in the main New River.

c. Seasonal Differences

Statistical differences were observed for DO content at all four sites (15, 16, 19, and 20). As discussed previously, temperature changes alone between wet and dry seasons can explain lower dissolved oxygen concentration in a waterbody. Sites 19 and 20 had wet season median DO concentrations below the 4.0 mg/l standard. This occurrence may be due to more intensive groundwater inflow in both the western portion of the New River Basin as well as the freshwater North New River Canal Basin that discharges more water eastward, typically, during the wet season. Site 16 had extreme variation which suggests large swings in water column biology and possibly groundwater input as well. Low specific conductance and high chlorophyll a (> 75.0 mg/m^3) concentrations along with large swings in DO content have been observed further upstream in the North Fork (BCDPEP 1999a). Chlorophyll a is a pigment used to estimate the biomass or amount of plant life (primarily phytoplankton) in the water column. Large populations of plant life can impact the dissolved oxygen dynamics of a waterbody.

For nutrients, TP values were not significantly different between seasons but dry season values were higher than wet season concentrations at Sites 19 and 20. Conversely, median wet season TP content at Sites 15 and 16 was only slightly higher then the dry season. Total nitrogen concentrations were significantly higher in the wet season at Sites 19 and 20. This may represent more active structure (Sewell Lock, also named G-54) releases and/or groundwater interaction. This was suggested during the original New River assessment (BCDNRP 1993) and appears to be true for the long term ambient observations, as well. Potentially, fertilizer from the extensive residential population in the areas surrounding Sites 19 and 20 contribute to the higher wet season TN concentrations.

Site 20 also exhibited the only statistically significant seasonal difference in FC content with the wet season having higher values than the dry season, which is likely attributable to stormwater runoff. From 1989-1997, chronically high FC values were observed both seasons in the North Fork (Site 16) with the wet season having the only median above the single sample standard of 800 colonies/100 ml.

Recent investigations have pointed to the importance of stormwater (BCDPEP 1999a), as well as groundwater and tidal interaction (Solo-Gabriele 2000) to high FC values. Unfortunately, the ultimate source (s) of the FC is not definitively known at this time. Site 15 also had occasional high values of FC. A recent BCDPEP study (Fall of 1999) has been undertaken to understand water quality dynamics at the Andrews Avenue bridge (Site 15), in particular the influence of tidal stage on observed concentrations.

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. Some of these recommendations are either being investigated or are being considered for the New River. As with all other estuarine areas in the county, the hydrologic flow regime needs to be better defined and the potential impacts of pulses created by North New River Canal and/or stormwater need to better understood. Improved physical information would likely improve the understanding of possible nutrient (TP and/or TN, NH3, and NO_2+NO_3) input and transport to the ICW and offshore. It would also assist in defining the hydrological division between the North and South Forks. Thus the following are proposed for the New River Basin:

- As an estuarine waterbody, what extent is the influence of a "salt wedge" from the east and the freshwater from the west?
- How does stormwater quality effect the New River Basin both acutely and chronically?
- What is the main TP source in the North Fork and is sediment / water column interaction important to observed ambient values?
- What is the main FC source in the North Fork and main New River and is FC regeneration occurring (e.g., in stormwater catch basins)?
- Does the Sewell Lock discharge dissolved inorganic nitrogen at levels of concern?
- Are there water column imbalances because of nutrient inputs?
- What is the color gradient from the "tea" colored tannic waters of the west to the coastal water of the east basin?
- Would an increase in S-33 flows improve North Fork water quality?

I. Dania Cut-off/C-10 Canal Basin

1. Geographic Locale

The Dania Cut-off/C-10 Canal Basin is located in the southeast corner of Broward County (Figure IV.54). The primary municipalities in this area are Ft. Lauderdale, Dania Beach, and Hollywood. In addition, large areas of unincorporated Broward County exist in the area. Freshwater originates primarily from the C-11 Canal to the west or "upstream" of the Dania Cut-off Canal and is controlled by releases through the SFWMD's S-13 control structure. Ocean water primarily comes from the Port Everglades Inlet. Some tidal interaction also occurs with the South Fork of the New River in the western reaches of the Dania Cut-off Canal.

Originating in western Hollywood, the C-10 Canal connects to the Dania Cut-off Canal east of I-95. Stormwater is the main freshwater contribution to the C-10 Canal as no freshwater canals discharge from the west. Tidal interaction with the Dania Cut-off Canal provides the connection with that basin and likely increases the brackish environment in the north end of the canal.

2. Land Use and Activities Impacting Water Quality

Numerous and diverse land uses exist along the Dania Cut-off Canal. A natural mangrove forest borders a commercial port and several small marinas (Port Dania Beach) in the eastern section (east of US 1, Figure IV.54). The marina area contains some live aboard vessels. In addition, a small agricultural (primarily vegetable farming) operation is in the area A large airport (Ft. Lauderdale-Hollywood International) and two major roadways (Interstate 95 and US 1) are situated in the central area where the C-10 meets the Dania Cut-off Canal.

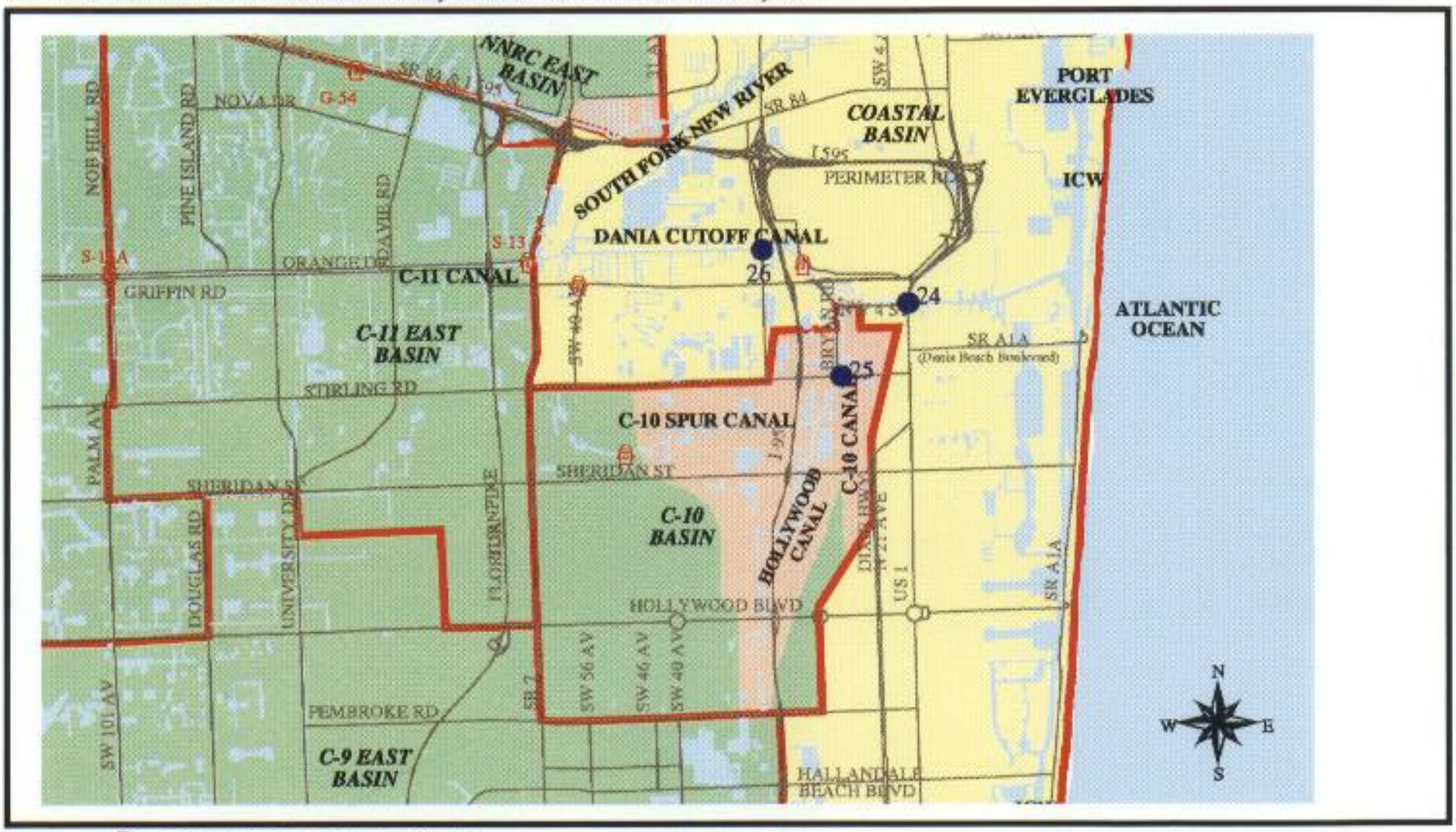
The western corridor has large areas of vegetative buffers along the shoreline, as well as, a large electrical plant (Florida Power and Light) that withdraws water from the canal that eventually discharges into the South Fork of the New River. Finally, residential housing with bulkheaded seawalls are interspersed throughout the canal with some neighborhoods served by septic systems.

The northern C-10 Canal has large tracts of natural shoreline, primarily Brazilian Pepper trees, mixed with marine industries (small vessels), and a large shopping complex, Oakwood Plaza. The C-10 splits into two separate "tributaries", the southern portion (Hollywood Canal) and the east-west oriented (C-10 Spur Canal). These tributaries are dominated by residential areas with bulkhead seawalls. The C-10 Spur Canal also has two golf courses at its western reach.

Interstate 95 crosses both the Dania Cut-off Canal, Hollywood Canal, and the C-10 Spur Canal. In addition, primary connector roads (e.g., Ravenswood Road) exist throughout the area with accompanying outfalls. Numerous finger canals also exist in both the Dania Cut-off and C-10 waterways which also have outfalls.

The Dania Cut-off Canal has two main residential areas that are served by septic tanks in both the western and eastern range. The influence of these septic systems on the waterway has not been investigated to date.

Figure IV.54. The Dania Cut-off Canal and C-10 Canal Basin Sampling Sites. The brackish sections of the North New River (NNRC) and C-10 Basins are shown in pink. These areas were delineated by the United States Army Corps of Engineers as separate basins from the Coastal Basin (Cooper and Lane 1987). However, the respective receiving water bodies are tidally connected and are downstream of the coastal water control structures (G-54) operated by the South Florida Water Management District. Thus, the brackish waters (pink and yellow areas) are hydrologically connected. The C-10 is its own distinct basin while the Dania Cut-off is part of the overall Coastal Basin. The C-10 and the Dania Cut-off Canals are also tidally connected within the same estuarine system.



BCDPEP Water Quality Sampling Site

Water Control Structures (primarily SFWMD)

Waterbodies

Major Roadways

0 1 2 3 Miles

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

3. Wastewater Treatment Plants Discharge History

WWTP discharges into the Dania Cut-off Canal occurred until 1980 when the Broward County Utility (1.095 million gallons per day capacity) stopped discharging treated wastewater into the canal. The C-11 Canal, western freshwater canal, still received some wastewater discharges from the Town of Davie and Hollywood Lakes Country Club until 1988.

4. Sampling Locations and Period

All sites are located in tidally influenced waters in the southeast corner of Broward County. Latitude and longitude measurements were determined by Global Position System and specific site descriptions are given in Appendix 1. The basins' three assessment sites are located in a geographical triangle (Figure IV.54). In the Dania Cut-off Canal, Site 24 is the eastern location and is sampled from the U.S. 1 bridge. The western Site 26 is also in the Dania Cut-off Canal at the Ravenswood Road bridge. Site 25 is the C-10 sampling located approximately 1 mile north of the confluence of C-10 Spur and the Hollywood Canal and is sampled from the Stirling Road bridge.

Site 26 has been sampled continuously by BCDPEP since 1973. While Site 24 measurements began in 1973, a hiatus occurred between October 1974 and October 1978 and then sampling continued in unison with Site 26. Site 25 monitoring ranged from 1980-1997. As two of the three sites had data acquisition periods in the seventies, all available data was used in this analysis. However, total Kjeldahl nitrogen and total organic carbon were not analyzed for until 1981. Additionally, biochemical oxygen demand monitoring occurred from 1981-1993 while specific conductance was recorded from 1990-1997. Data methodology and manipulation for this section was performed as detailed in the methodology section (Section II).

5. Results

a. Physical Characteristics

Mean water temperatures throughout the basin were relatively similar ranging from 26.5 ± 3.4°C to 26.9 ± 3.5°C (Table IV.25). The lowest minimum temperature (17.8°C) was observed at the inland most site (26), while maximum temperatures were comparable among the three sampling locations. Nearly identical mean and median pH values were observed at all three sites (Table IV.25).

Large salinity ranges were observed at all three sites with Site 24 having the highest median and mean values (Table IV.25). Sites 25 and 26 demonstrated similar median and mean salinities reflecting their more inland location. The maximum salinity value (33.9 ppt) was recorded at Site 24 while all three sites had samples that were below the method detection limit. Spatially, specific conductance recordings were similar to salinity observations with Site 24 having the highest readings.

Table IV.25. Descriptive Statistics for Temperature (Temp, °C= degrees Celsius), pH, Specific Conductance (Cond, Fmhos = micromhos), and, Salinity (Sal, ppt= parts per thousand) in the Dania Cut-off/C-10 Canal Basins. Temperature, pH, and salinity calculations represent 25, 22, and 18 years of sampling at Sites 26, 24, and 25, respectively. Conductance values obtained since 1990. However, the number of samples per year occasionally varied at each site. 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).

Site	Parameter	unit	n	Median	Mean	SD	Max	Min	# MDL
24	Temp	°C	99	27.5	26.8	3.5	33.5	20.0	0
25	Temp	°C	66	27.2	26.5	3.4	33.0	20.0	0
26	Temp	°C	165	27.5	26.9	3.5	33.5	17.8	0
24	pH	units	101	7.6	7.6	0.227	8.3	7.1	0
25	pH	units	68	7.5	7.5	0.231	7.8	6.8	0
26	pH	units	158	7.6	7.6	0.254	8.2	6.7	0
24	Cond	Fmhos	31	31200	28756	12225	51500	2190	0
25	Cond	Fmhos	32	17900	16929	9544	36800	1540	0
26	Cond	Fmhos	32	20550	21017	12964	46100	1208	0
24	Sal	ppt	88	16.6	16.3	8.7	33.9	0.5	1
25	Sal	ppt	65	10.6	10.5	6.5	24.2	0.25	2
26	Sal	ppt	144	10.5	11.5	8.6	31.9	0.25	4

b. Total Organic Carbon and Turbidity

With a mean of 15.56 ± 7.19 mg/l, Site 26 had the basin's highest total organic carbon (TOC) content and the largest range of values (Table IV.26). In addition, the basin's overall maximum TOC concentration (45.80 mg/l) was at Site 26. Sites 24 and 25 had very similar TOC averages and medians around 10.0 mg/l.

Turbidity levels within the Dania Cut-off Canal were typically low and normally within compliance of Broward County's standard of 10 nephelometric turbidity units (ntus; Table 1). Only Site 26 had a turbidity value (18.0 ntus) above the standard, however, the remaining 132 measurements were below 10 ntus.

Table IV.26. Descriptive Statistics for Total Organic Carbon (TOC) and Turbidity (Turb) Concentrations in the Dania Cut-off/C-10 Canal Basin. All TOC calculations were performed on 18 years of data. Turbidity (ntus = nephelometric turbidity units) calculations represent 23, 20, and 18 years of sampling at Sites 26, 24, and 25, respectively. However, the number of samples per year occasionally varied at each site. 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
24	TOC	mg/l	61	10.20	11.26	5.87	35.10	2.41	0
25	TOC	mg/l	62	10.20	10.28	4.82	41.20	1.60	0
26	TOC	mg/l	62	16.25	15.56	7.19	45.80	0.57	0
24	Turb	ntu	90	2.4	2.6	1.2	8.6	0.9	0
25	Turb	ntu	68	1.8	2.1	0.9	5.7	0.7	0
26	Turb	ntu	133	2.3	2.7	1.7	18.0	0.6	0

c. Dissolved Oxygen and Biochemical Oxygen Demand

Mean and median dissolved oxygen (DO) concentrations for the entire study period were very comparable between all sites and above (i.e., within compliance) the DO standard (single sample) of 4.0 mg/l (Table IV.27). However, mean and median DO values were below the daily average standard of 5.0 mg/l at each site.

Biochemical oxygen demand concentrations were slightly lower at Site 24 than Sites 25 and 26, however all mean and median values were below 2.0 mg/l. All values, including maxima, were below (i.e., within compliance) of the 7.0 mg/l standard.

Table IV.27. Descriptive Statistics for Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) Concentrations in the Dania Cut-off/C-10 Canal Basin. Calculations for DO represent 25, 22, and 18 years of sampling at Sites 26, 24, and 25, respectively. Biochemical oxygen demand calculations are for 21, 18, and 14 years of data at Sites 26, 24, and 25, respectively and include both BOD 5 and 7 day tests results. However, the number of samples per year occasionally varied at each site. 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
24	DO	mg/l	101	4.6	4.6	1.2	8.4	0.2	0
25	DO	mg/l	68	4.7	4.8	1.6	10.3	1.3	0
26	DO	mg/l	158	4.7	4.8	1.6	10.3	0.03	1
24	BOD	mg/l	82	1.3	1.5	0.9	5.0	0.6	0
25	BOD	mg/l	48	1.7	1.9	0.9	4.6	0.7	0
26	BOD	mg/l	132	1.8	1.8	0.9	6.0	0.3	0

Yearly DO averages revealed a similar compliance pattern as the long term means, however, clear temporal trends through the entire study period did not occur (Figure IV.55). In addition, obvious differences between the three sites were not apparent. Certain years (e.g., 1987) were characterized by relatively high variability in dissolved oxygen content. In addition, some years (e.g., 1991) yielded annual averages below the 4.0 mg/l standard.

To further investigate the relationship to water quality standard compliance, DO concentrations were designated as poor, fair, and good (see Section IV.E.5.c). In addition, the changes over time are presented with special reference to the closing of WWTPs in the basin (see Section IV.I.3). The percentage of dissolved oxygen samples achieving standard compliance revealed improvements at Sites 24 and 25 but little changes at Site 26 (Figure IV.56). Specifically, Site 25 realized a decrease in poor samples from 62.5% (1980-1982) to 8.3% (1992-1997). The percentage of good samples at Sites 24 and 25 increased from under 40.0% (1983-1991) to around 60.0% from 1992 to 1997. Although the good rating percentages remained similar for all three periods at Site 26 (range = 44.4% to 46.9%), samples below 4.0 mg/l (i.e., poor) decreased from 36.2% to 20.9% over the last two eras.

From 1989 to 1997, higher dissolved oxygen values were normally observed during the dry season (November through May) than during the wet season (Figure IV.57). Statistically significant seasonal differences were observed in the Dania Cut-off Canal at Sites 24 and 26 ($p < 0.001$, t-test), as well as the C-10 Canal at Site 25 ($p < 0.005$, t-test). Overall, Site 26 had the highest number of samples below 4.0 mg/l.

d. Total Phosphorus

Long term mean total phosphorus (TP) levels were above the Broward County marine standard of 0.050 mg/l standard (Table IV.28). Unusually high maxima were observed at Sites 24 and 26 but median values were either near (0.049 mg/l; Site 24) or well above (0.080 mg/l; Site 26) the 0.050 mg/l level. The number of samples below the method detection limit was relatively low for this basin.

Table IV.28. Descriptive Statistics for Total Phosphorus (TP) Concentrations in the Dania Cut-off/C-10 Basin. Calculations represent 24, 20, and 18 years of sampling at Sites 26, 24, and 25, respectively. However, the number of samples per year varied at each site. 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
24	TP	mg/l	90	0.049	0.090	0.266	2.540	0.010	11
25	TP	mg/l	68	0.053	0.067	0.065	0.498	0.010	5
26	TP	mg/l	138	0.080	0.098	0.132	1.470	0.010	7

Figure IV.55. Annual Mean Dissolved Oxygen (DO) Content Within the Dania Cut-off/C-10 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.

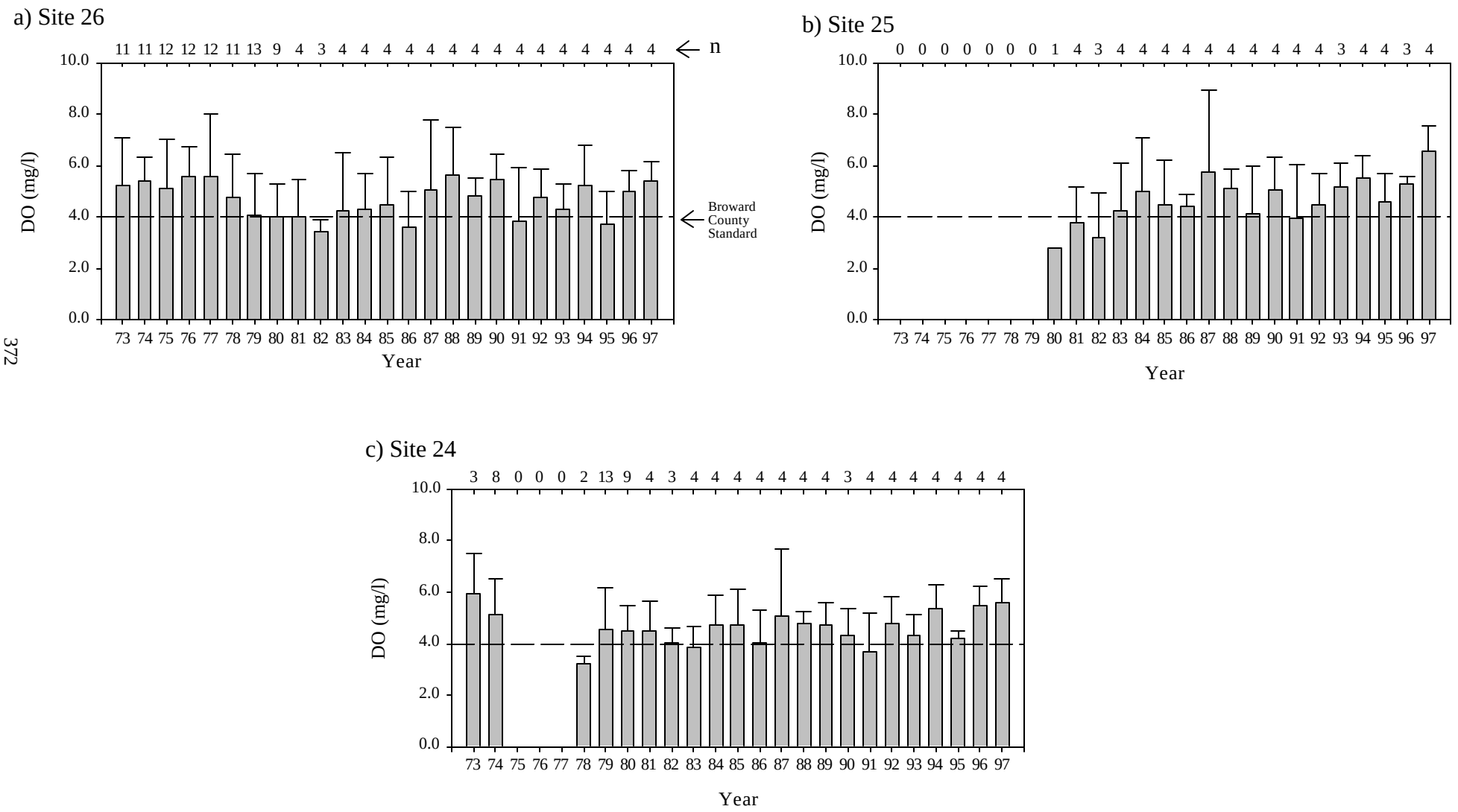


Figure IV.56. Dissolved Oxygen (DO) Concentrations Observed in the Dania Cut-off/C-10 Canal Basin over Three Time Periods. DO samples are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall be below 4.0 mg/l. Thus, all concentrations greater than or equal to 5.0 mg/l are classified as good and DO levels between 4.0 to 4.9 mg/l are labeled fair. Readings below 4.0 mg/l are defined as poor.

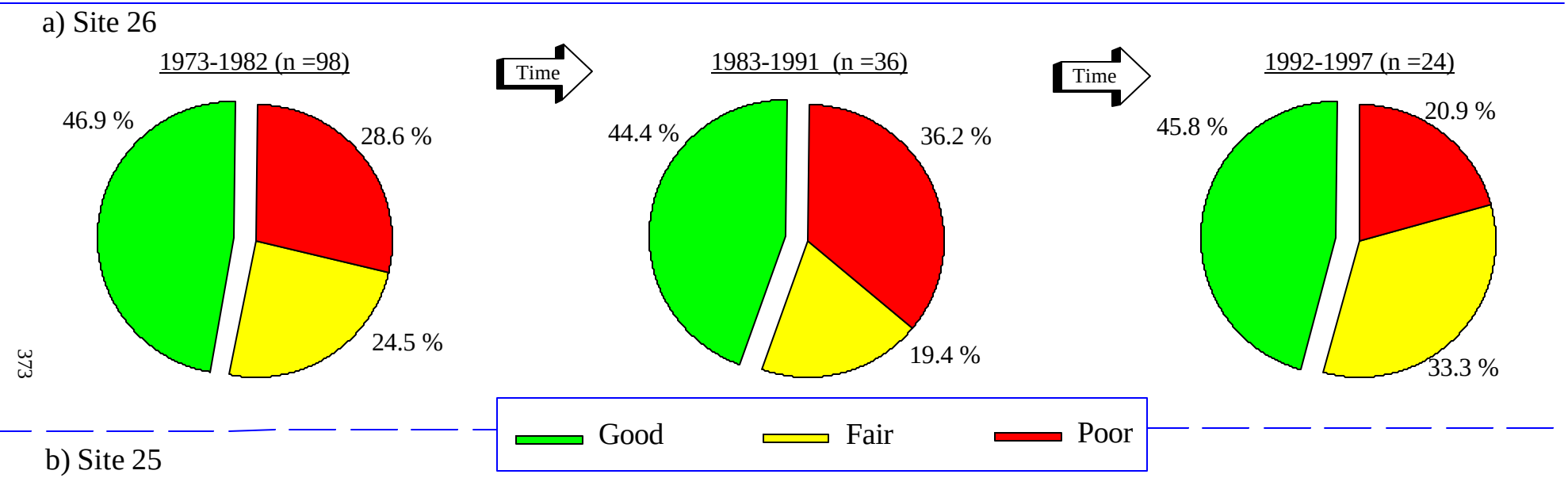


Figure IV.56 (Cont.). Dissolved Oxygen (DO) Concentrations Observed in the Dania Cut-off/C-10 Canal Basin over Three Time Periods. DO samples are categorized in terms of compliance with the Broward County standards which state the daily average shall not be less than 5.0 mg/l and no single reading shall be below 4.0 mg/l. Thus, all concentrations greater than or equal to 5.0 mg/l are classified as good and DO levels between 4.0 to 4.9 mg/l are labeled fair. Readings below 4.0 mg/l are defined as poor.

c) Site 24

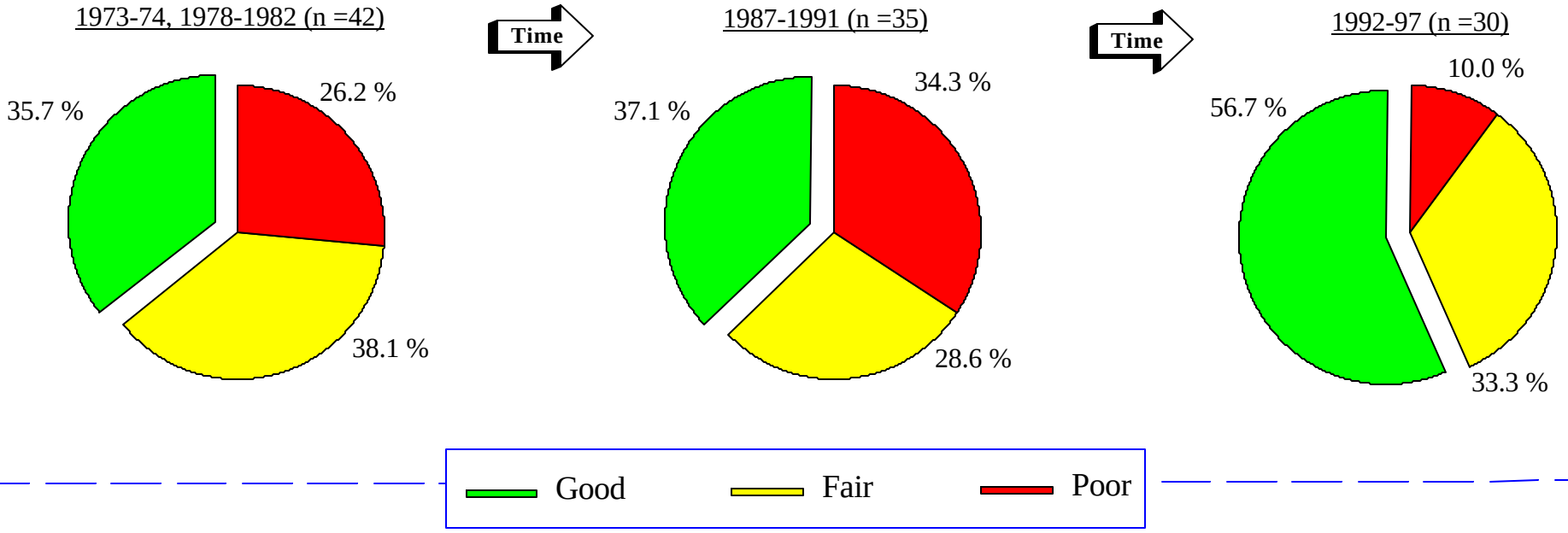
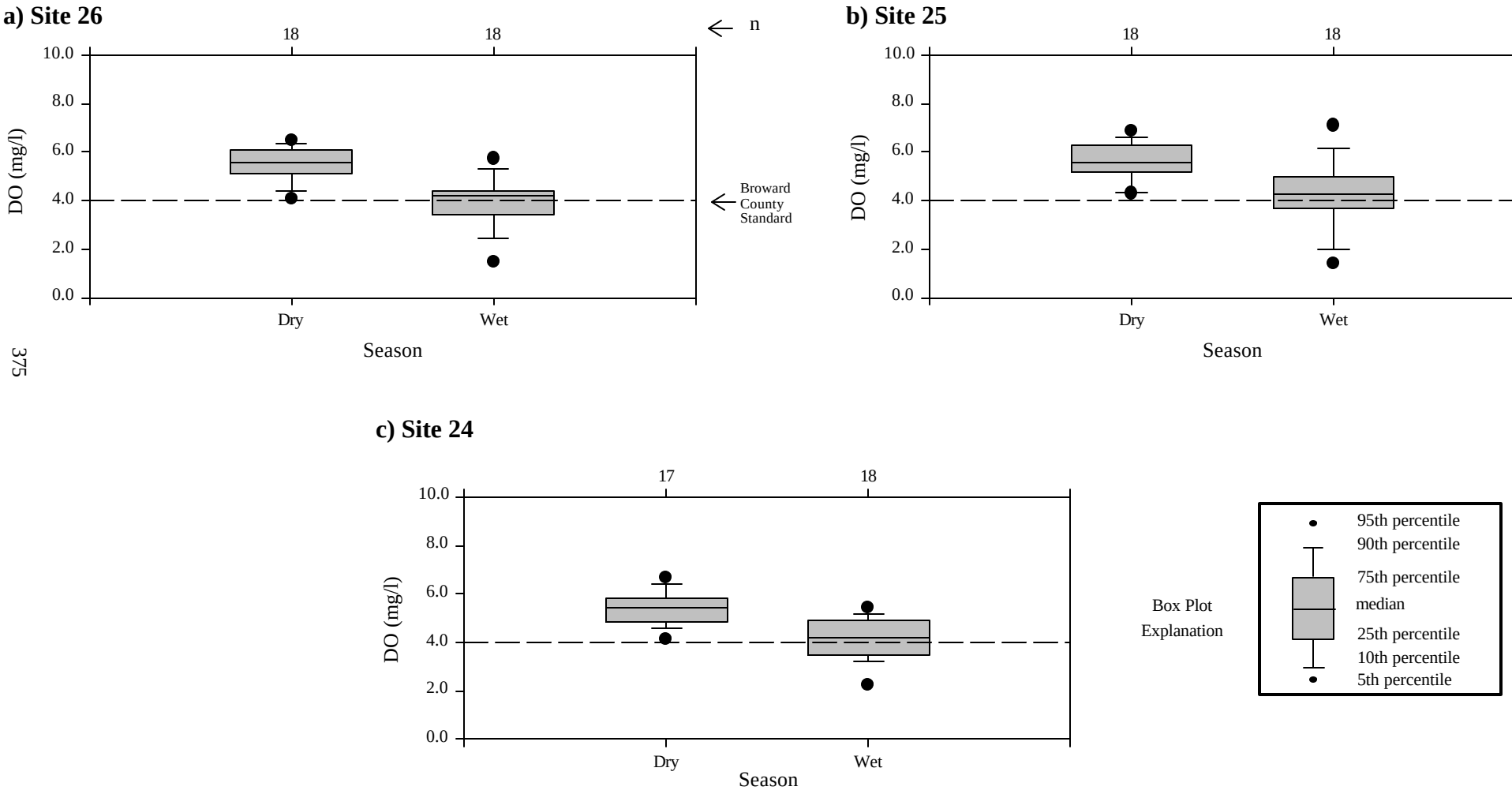


Figure IV.57. Dania Cut-off/C-10 Canal Basin Dissolved Oxygen (DO) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. The number of samples (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 24 and 26 ($p < 0.001$, t-test), as well as Site 25 ($p < 0.005$, t-test).



In general, Sites 24 and 26 annual TP levels have decreased from the 1970's to the 1990's (Figure IV.58). However, a distinct long term trend is not apparent due mostly to inter- and intra- annual variability. Overall, only twelve of sixty-two combined sampling years (all three sites) had an annual mean TP content below the Broward County standard 0.050 mg/l. The last five years of observations in the basin suggests a decrease in TP occurred in the basin as compared to the preceding years (i.e., 1974-1992). However, relatively low concentrations have been observed in earlier years (e.g., Site 26, 1988 and 1989) only to be followed by annual averages more typical of each site. Anomalously high values (see Table IV.28) occurred during in 1986 and/or 1987 at all sites (Figure IV.58).

To further study TP compliance patterns over time, all individual samples were rated in terms of Broward County's marine TP standard (0.050 mg/l; see Section IV.E.5.d). In addition, the changes over time are presented with special reference to the closing of WWTP in basin (see Section IV.I.3). The analysis of total samples within compliance of the Broward County marine standard (0.050 mg/l) revealed a more noticeable decrease in TP content with time than annual averages (Figure IV.59). Sites 24 and 26 demonstrated the most improvement, especially from 1992 through 1997 when 70.8% of samples rated good. Although compliance percentage (i.e., # 0.05 mg/l) only increased seven percent between the last two time spans, the amount of poor samples dropped below 10.0% at Site 25.

Observations from 1989-97 revealed no statistical differences between wet and dry seasons (Figure IV.60). Medians from all season and locations were at or below the Broward County standard. Site 26 had the most occurrences over the standard based on the large range between the median and 75^{th} (dry season) and 90^{th} (wet season) percentiles.

e. Total Nitrogen

Total nitrogen levels are calculated from the total Kjeldahl nitrogen (TKN) and nitrate+nitrate (NO_2+NO_3) concentrations (Table IV.29). Over the 17-year period, Site 26 had the basin's highest mean and median TN values which were very similar. Despite having the highest maximum TN value (8.585 mg/l), Site 25 exhibited the lowest mean and median TN concentrations. All long term mean and median TN values were below the Broward County marine standard (1.500 mg/l).

TKN represented over 80% of mean TN levels. As ammonia-nitrogen levels typically represented 20% of TKN content, organic nitrogen was the main nitrogen form observed in the basin. However, NO_2+NO_3 levels were above the method detection limit in nearly all samples and constituted 34% of the median TN at Site 25. Furthermore, enhanced long term median NO_2+NO_3 levels (> 0.100 mg/l) were observed throughout the basin and Site 26 had median and means over 0.200 mg/l.

Figure IV.58. Annual Mean Total Phosphorus (TP) Levels Within the Dania Cut-off/ C-10 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) noted on the upper x-axis. The Broward County single sample marine standard (0.05 mg/l) is indicated by the dashed line. The numbers in parentheses represents a mean and sd above the y-axis scale.

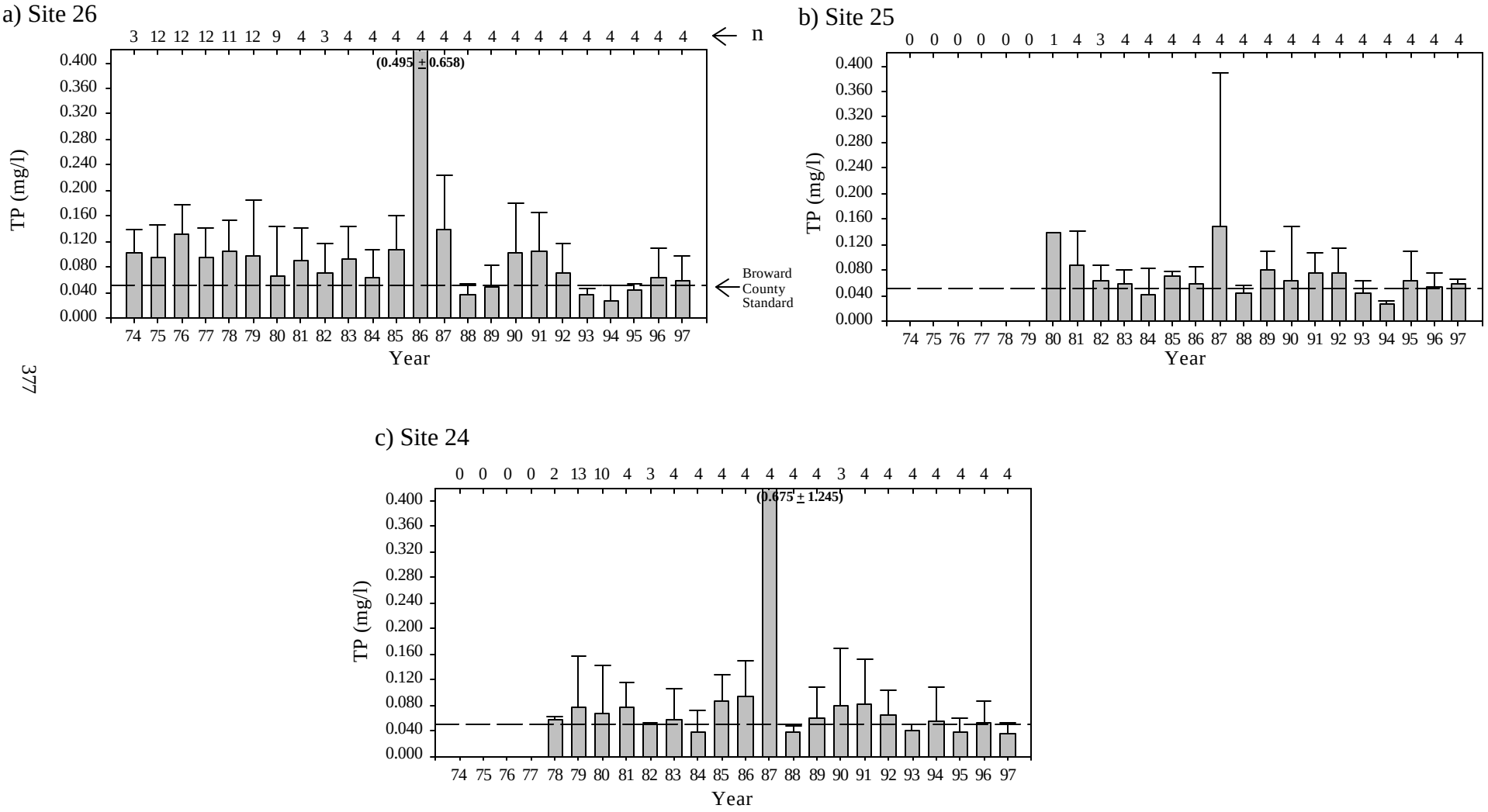


Figure IV.59. Total Phosphorus (TP) Concentrations Observed in the Dania Cut-off/C-10 Canal Basin over Three Time Periods. TP levels are categorized in terms of compliance with the Broward County marine standard of 0.050 mg/l. The percentage below 0.050 mg/l are classified as good. A fair rating was given to values between 0.051 mg/l to 0.099 mg/l. Values equal to or greater than twice the standard (i.e., 0.100 mg/l) are classified as poor.

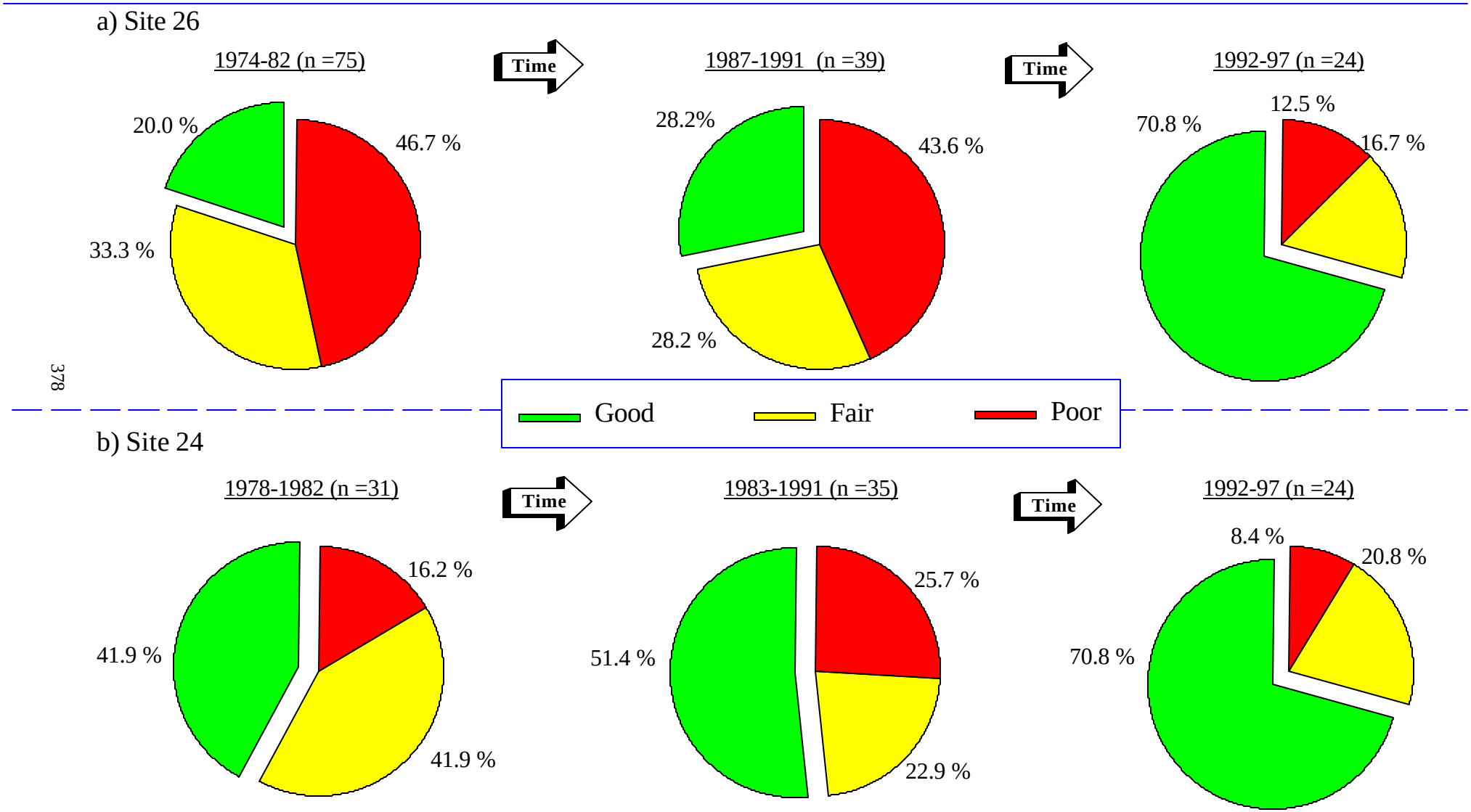


Figure IV.59 (Cont.). Total Phosphorus (TP) Concentrations Observed in the Dania Cut-off/C-10 Canal Basin over Three Time Periods. TP levels are categorized in terms of compliance with the Broward County marine standard of 0.050 mg/l. The percentage below 0.050 mg/l are classified as good. A fair rating was given to values between 0.051 mg/l to 0.099 mg/l. Values equal to or greater than twice the standard (i.e., 0.100 mg/l) are classified as poor.

c) Site 25

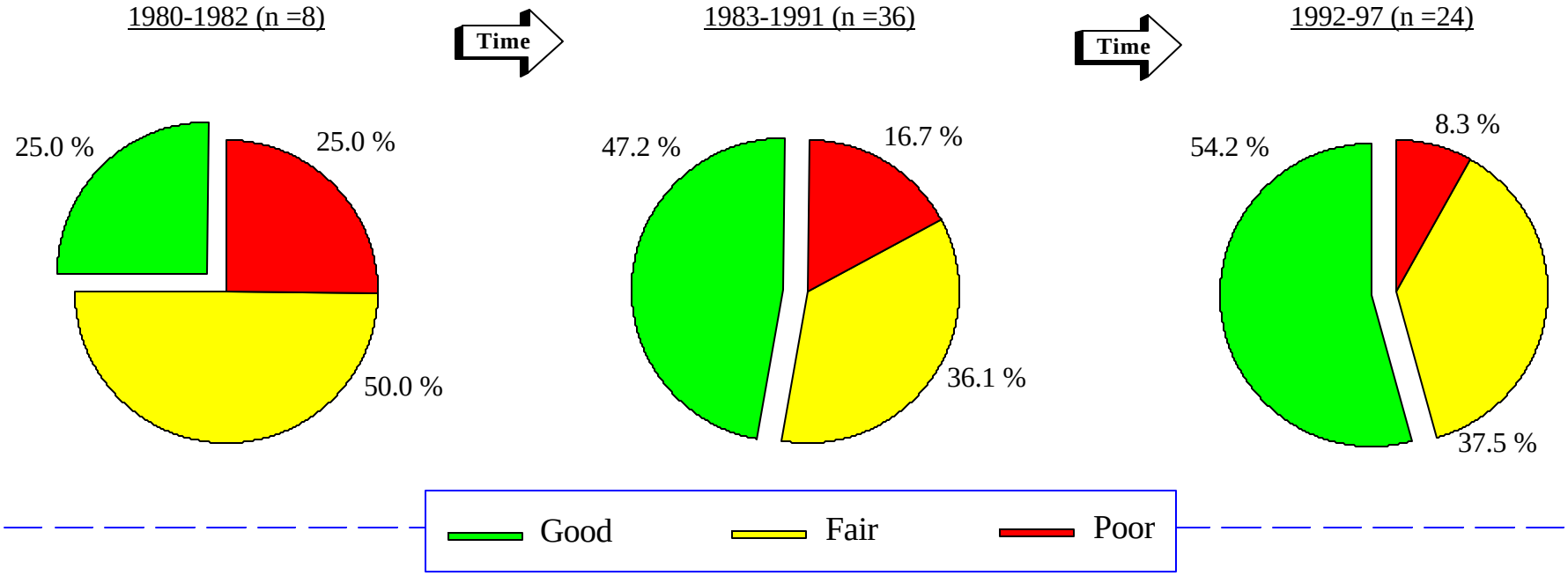


Figure IV.60. Dania Cut-off/C-10 Basin Total Phosphorus (TP) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. Statistically significant differences between wet and dry season values were not observed in the basin.

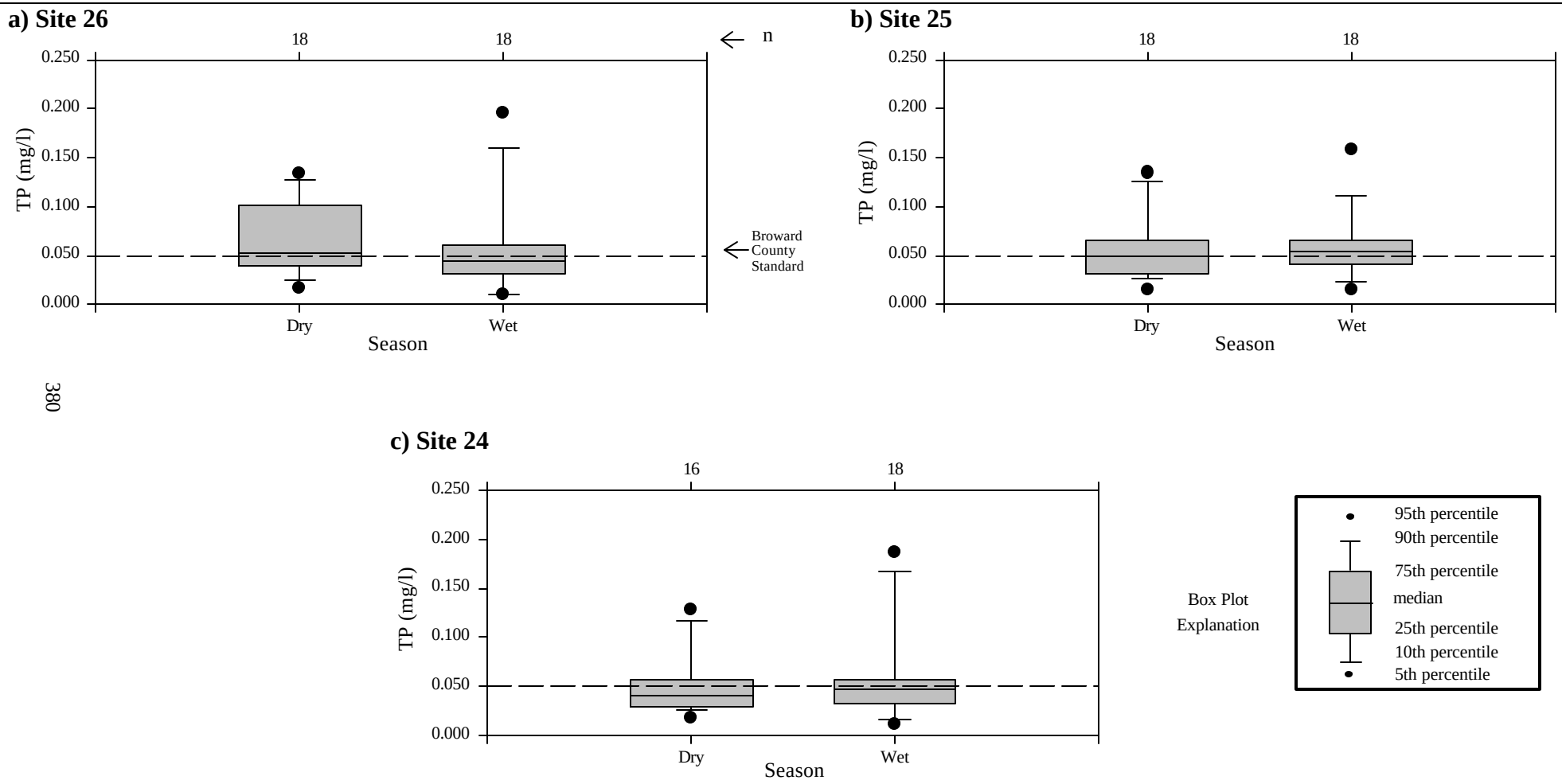


Table IV.29. Descriptive Statistics for Nitrite+Nitrate-Nitrogen (NO_2+NO_3), Ammonia-Nitrogen (NH_3), Total Kjeldahl Nitrogen (TKN) , and Total Nitrogen (TN) in the Dania Cut-off Canal/C-10 Canal Basin. All calculations represent seventeen years of sampling, however, the number of samples (n) varied per year at each site. 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
24	NO_2+NO_3	mg/l	67	0.175	0.181	0.111	0.449	0.005	1
25	NO_2+NO_3	mg/l	68	0.130	0.145	0.100	0.585	0.005	2
26	NO_2+NO_3	mg/l	68	0.216	0.223	0.131	0.589	0.005	1
24	NH_3	mg/l	63	0.085	0.158	0.199	0.972	0.005	17
25	NH_3	mg/l	62	0.148	0.168	0.142	0.661	0.009	10
26	NH_3	mg/l	63	0.145	0.214	0.244	1.400	0.005	11
24	TKN	mg/l	66	0.841	0.864	0.385	2.040	0.020	1
25	TKN	mg/l	66	0.577	0.862	0.936	8.000	0.139	0
26	TKN	mg/l	67	1.050	1.066	0.462	2.210	0.289	0
24	TN	mg/l	66	0.980	1.046	0.451	2.236	0.108	Calc
25	TN	mg/l	66	0.887	1.008	0.995	8.585	0.324	Calc
26	TN	mg/l	67	1.280	1.290	0.550	2.535	0.325	Calc

Annual mean total nitrogen (TN) content was generally higher in the 1980's than during the 1990's at all three sites with Site 26 exhibiting the most obvious decrease with time (Figure IV.61). All annual averages were within the 1.500 mg/l Broward County standard since 1990. Site 25 was characterized by the lowest mean content over the last eight years, while Site 26 normally had the highest annual averages in the basin. In addition, Site 26 had the most TN concentrations above 1.500 mg/l based on standard deviations of the yearly means.

To look more closely at standard compliance with time, TN concentrations were designated as poor, fair, and good based on the county standard of 1.500 mg/l (see Section IV.E.5.e). In addition, the changes over time are presented with special reference to the closing of WWTPs in the basin (see Section IV.I.3). The percentage of total nitrogen samples that achieved Broward County compliance revealed a similar pattern as the annual averages. Site 26 compliance percentage increased from 54.3% during 1983-1991 to 91.7% through 1992-1997 (Figure IV.62). Site 24 and 25 also showed incremental increase over time to 95.8% and 100% compliance, respectively. Basin-wide TN samples did not achieve a poor rating between 1992-1997.

Statistical seasonal differences in TN content were observed at Site 26 ($p < 0.05$, t-test) with the wet season mean content being higher than the dry season (Figure IV.63). Site 26's wet season 90th percentile value was the only one in the basin that exceeded the 1.500 mg/l standard. In addition, Site 26's wet season TN median content (1.236) was the only one over 1.000 mg/l. The lowest median TN values from 1989-1997 were the dry season values for Site 25.

Figure IV.61. Annual Mean Total Nitrogen (TN) Levels Within the Dania Cut-off/C-10 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. The number in parentheses represents a sd above the y-axis.

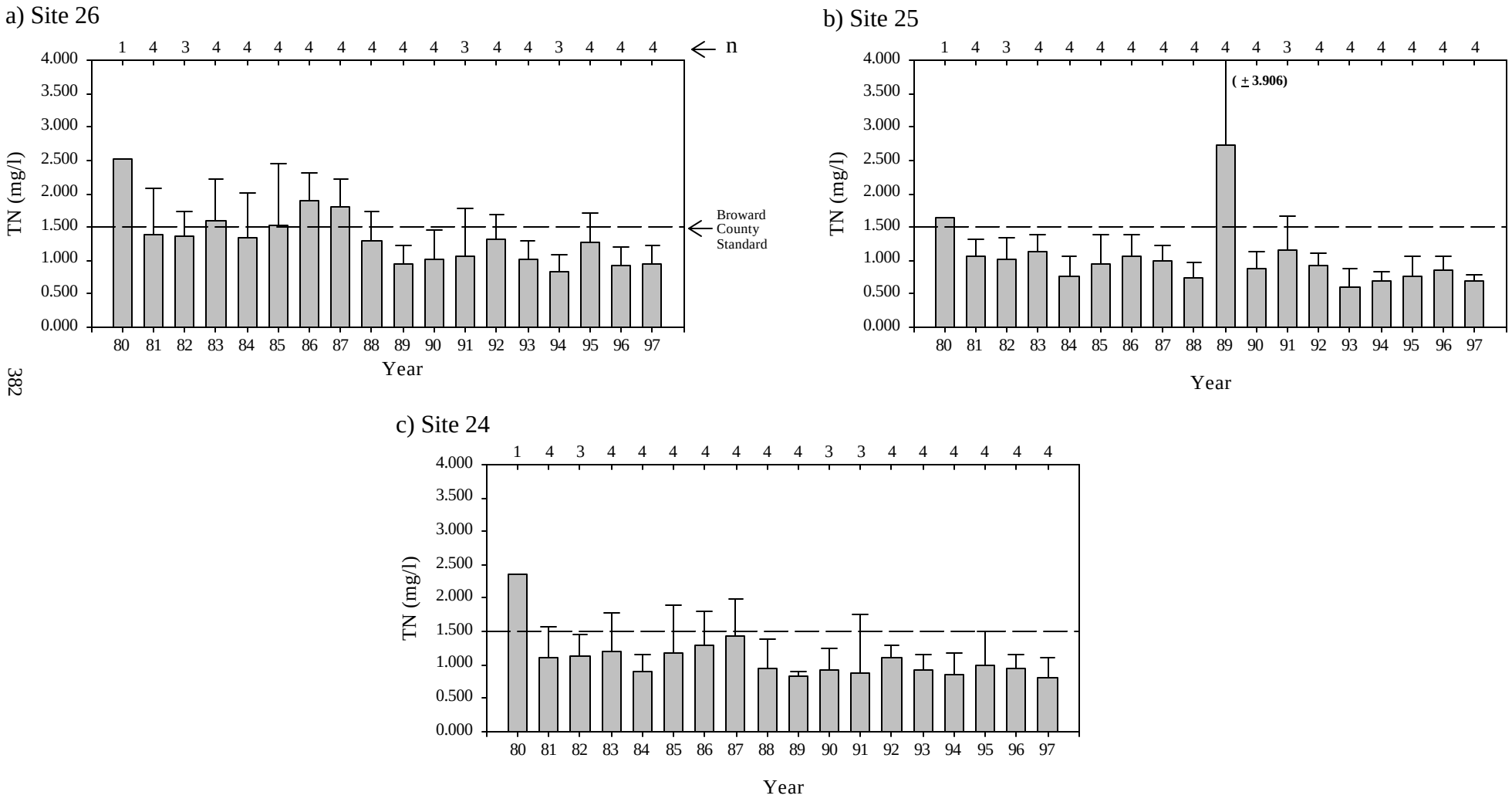


Figure IV.62. Total Nitrogen (TN) Concentrations Observed in the Dania Cut-off/C-10 Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified as good. A fair rating 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.

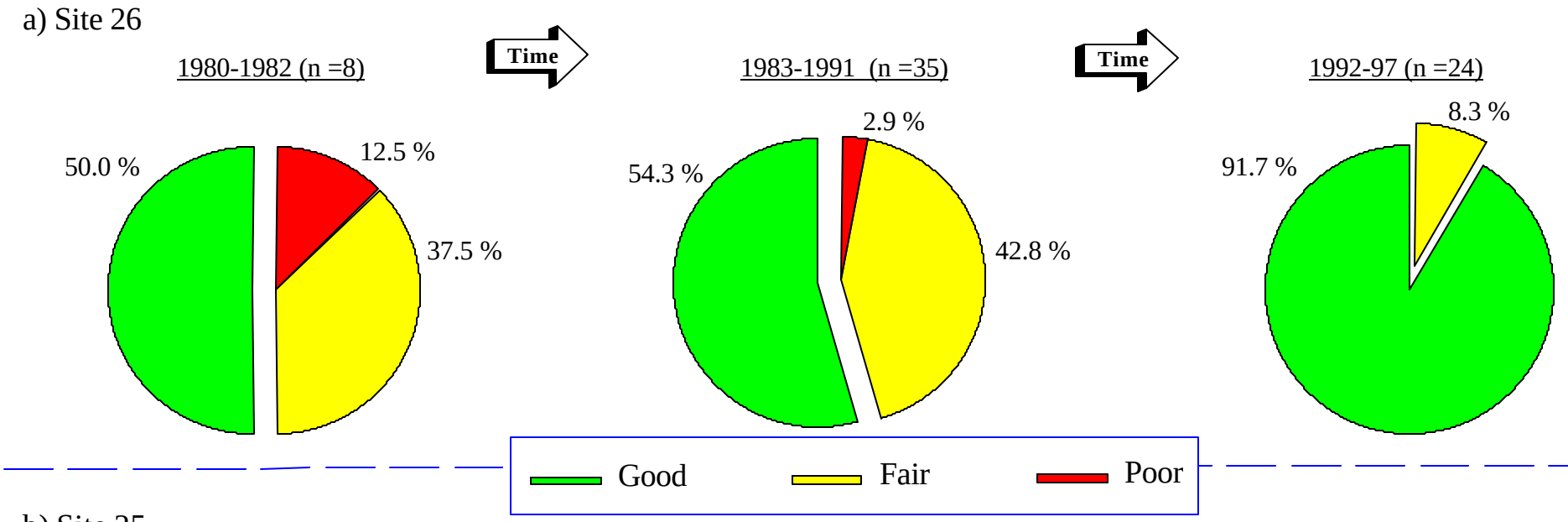


Figure IV.62 (Cont.). Total Nitrogen (TN) Concentrations Observed in the Dania Cut-off/C-10 Basin over Three Time Periods. Values are categorized in terms of compliance with the Broward County TN standard of 1.500 mg/l. The percentage of samples equal to or below 1.500 mg/l are classified as good. A 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 24

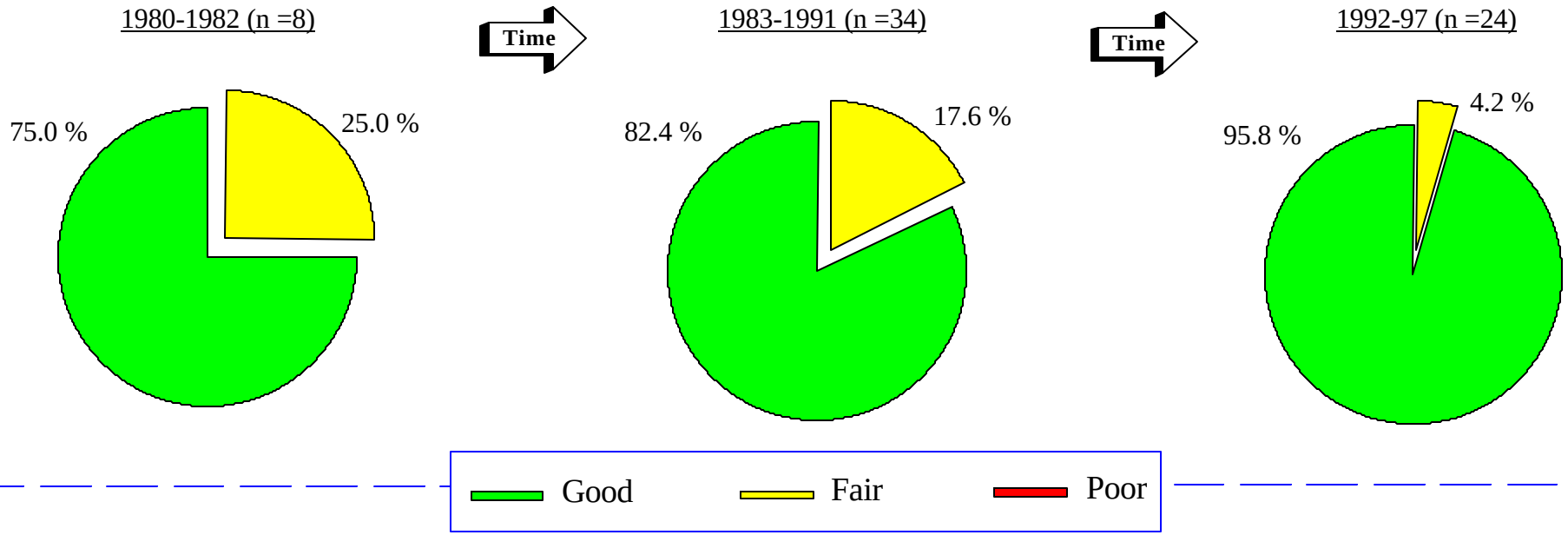
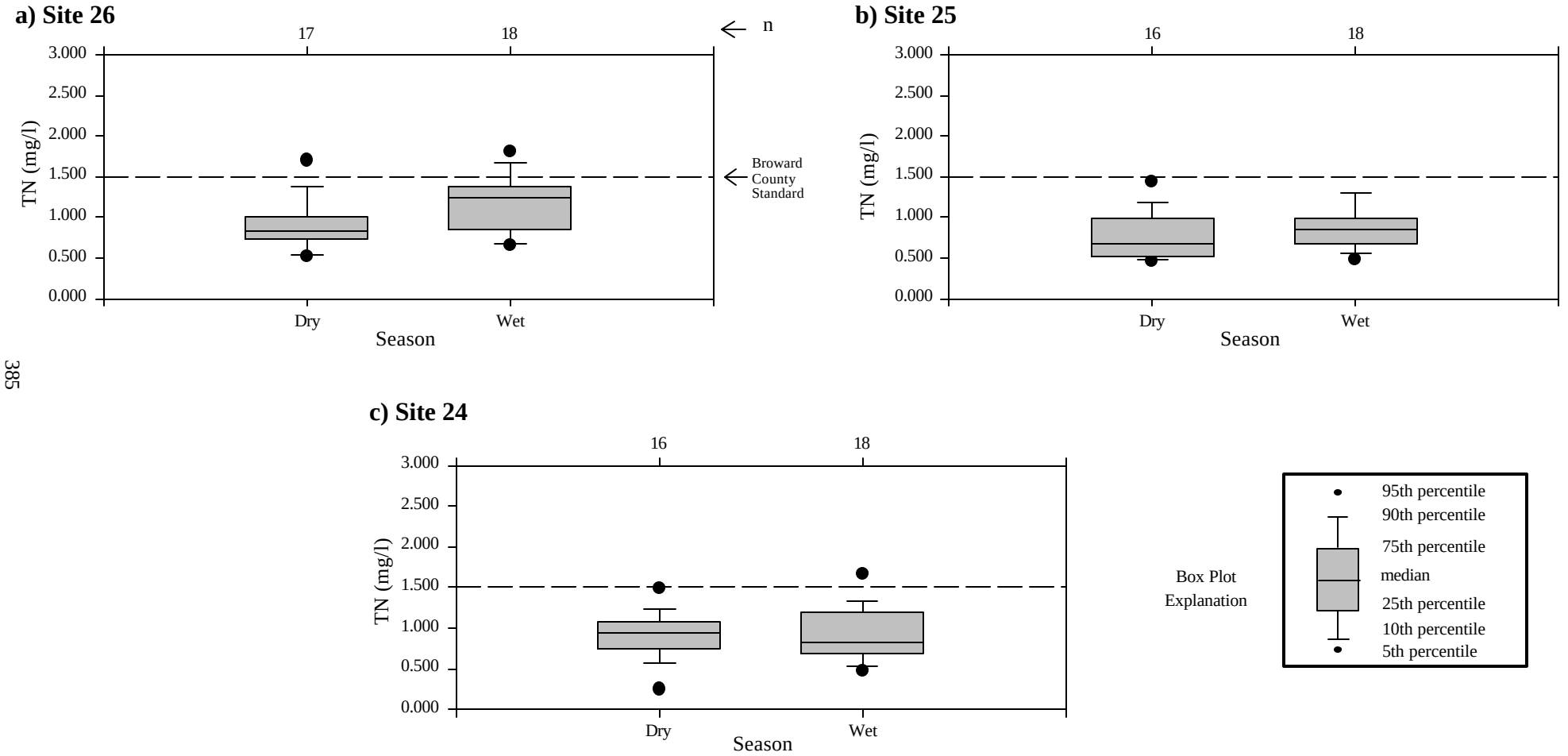


Figure IV.63. Dania Cut-off/C10 Canal Basin Total Nitrogen (TN) Levels During Wet (June-October) and Dry (November-May) Seasons from 1989 thru 1997. Wet season sampling normally occurred during July and October while dry season sampling was performed during January and April. A statistically significant difference between wet and dry season means was observed at Site 26 ($p < 0.05$, t-test).



f. Bacteriological Parameters

Fecal coliform (FC), total coliform (TC), and fecal streptococcus (FS) levels were observed over different periods at all three sites. Median FC values were relatively similar throughout the study area (Table IV.30). The highest median FC value was 200 colonies/100 ml (Site 26) that is the Broward County monthly average standard. Maximum FC values well exceeded the Broward County single sample standard of 800 colonies/100 ml and almost all samples were above the method detection limit. Site 26 exhibited the highest total coliform counts and the maximum fecal streptococcus value (44,000 colonies/100 ml) while Site 24 had the highest median FS content (Table IV.30).

Table IV.30. Descriptive Statistics for Fecal Coliform (FC), Total Coliform (TC), and Fecal Streptococcus (FS) in the Dania Cut-off/C-10 Canal Basin. Calculations represent 25, 22, and 18 years of sampling at Sites 26, 24, and 25, respectively. However, the number of samples per year varied occasionally. 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
24	FC	col	101	170	597	2885	29000	10	0
25	FC	col	66	180	299	1047	8400	10	0
26	FC	col	152	200	414	1094	12000	5	3
24	TC	col	100	600	2236	8178	60000	67	0
25	TC	col	65	500	1199	2828	21000	33	0
26	TC	col	157	800	2871	9785	80000	33	0
24	FS	col	90	250	1413	4232	33000	12	9
25	FS	col	67	100	273	458	3000	12	10
26	FS	col	124	220	1152	4547	44000	12	8

Due to the large amount of variability around the mean (Table IV.30), yearly box plots were plotted for fecal coliform instead of the mean (Figure IV.64). Only one annual median value (990 colonies/100 ml; Site 24) was above the standard (800 colonies/100 ml) due, in part, to the highest maximum single sample (29,000 colonies/100ml) detected in the basin (Table IV.30). However, an additional high fecal concentration (1700 colonies/100 ml) was observed at Site 24 in 1997 (raw data not shown). In addition, Site 25's highest annual median (685 colonies/100 ml) was observed in 1997. Beyond 1997, Sites 26 and 24 yearly median FC concentrations were generally characterized by higher values in the eighties than in the nineties. Differences between the two decades were not readily observed at Site 25.

To better investigate compliance levels, all FC samples were categorized based on three different Broward County water quality standards and good, fair, or poor rating was given to each sample (see Section IV.E.5.f.). In addition, the changes over time are presented with special reference to the closing of WWTP in basin (see Section IV.I.3). Each site was characterized by a unique FC compliance percentage pattern (Figure IV.65). Site 26 showed a small increase in the percentage of

Figure IV.64. Yearly Box Plots of Fecal Coliform (FC) Levels within the Dania Cut-off/C-10 Canal Basins from 1972 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.

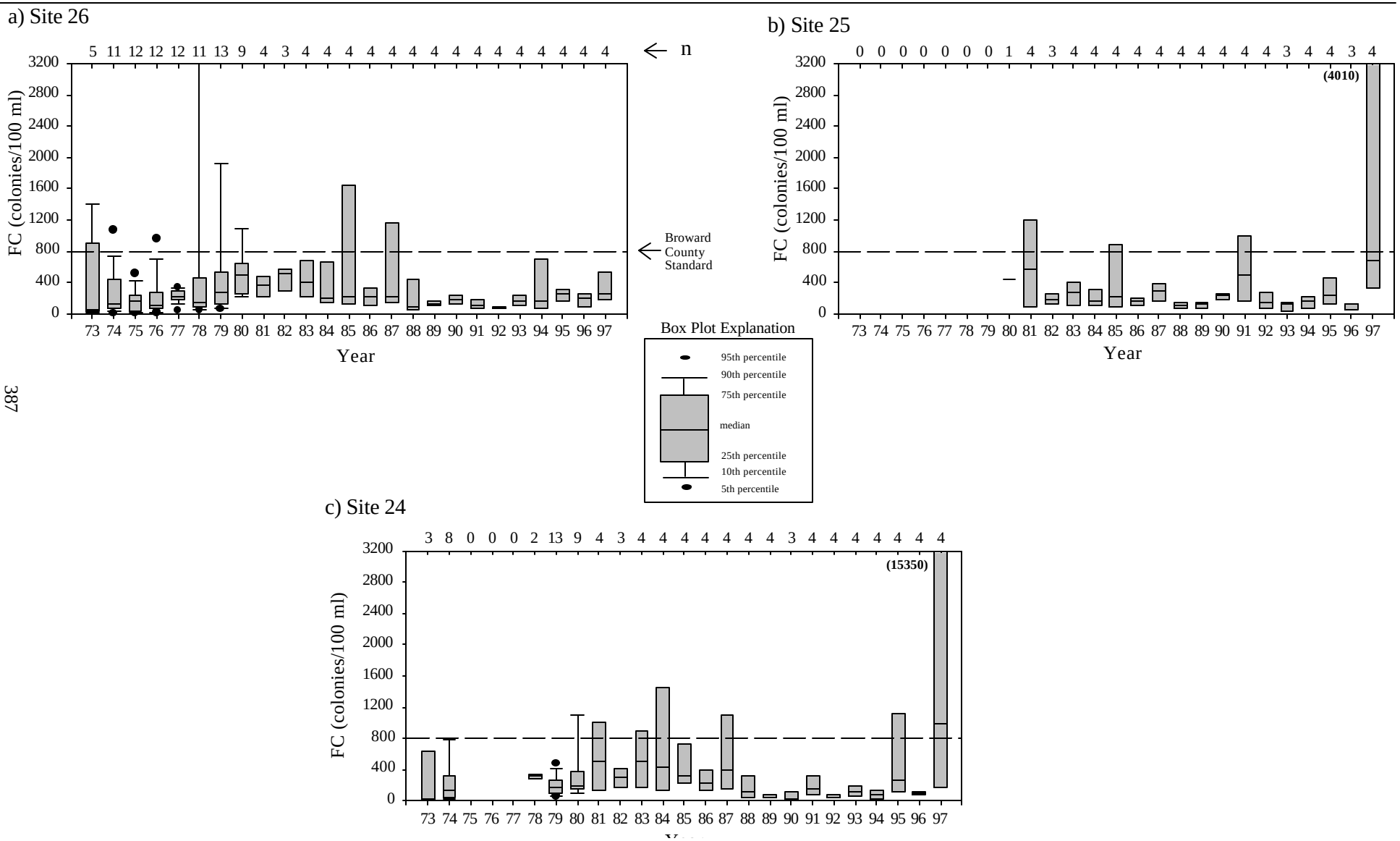


Figure IV.65. Fecal Coliform (FC) Concentrations Observed in the Dania Cut-off/C-10 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100 ml (good 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.

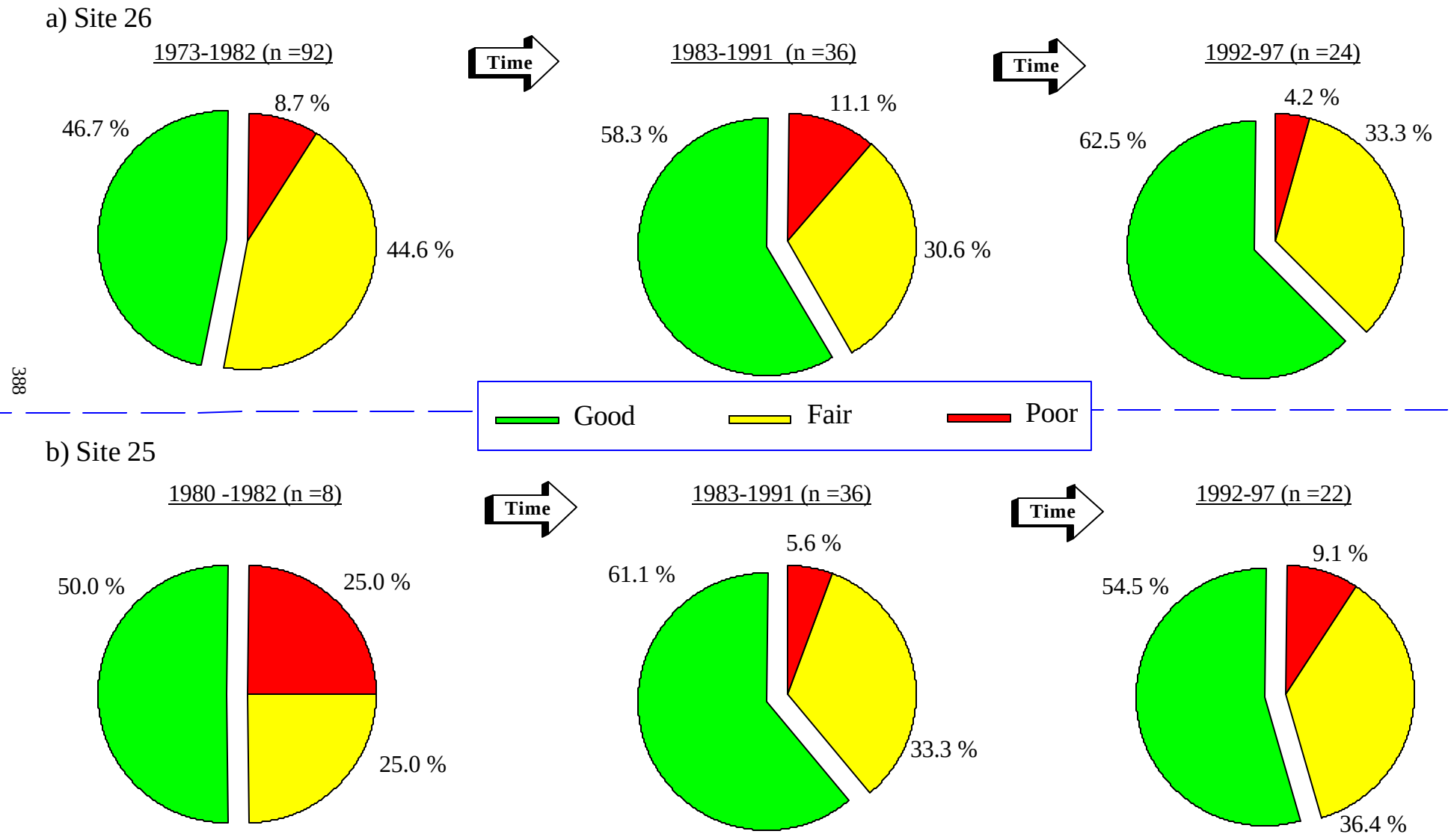
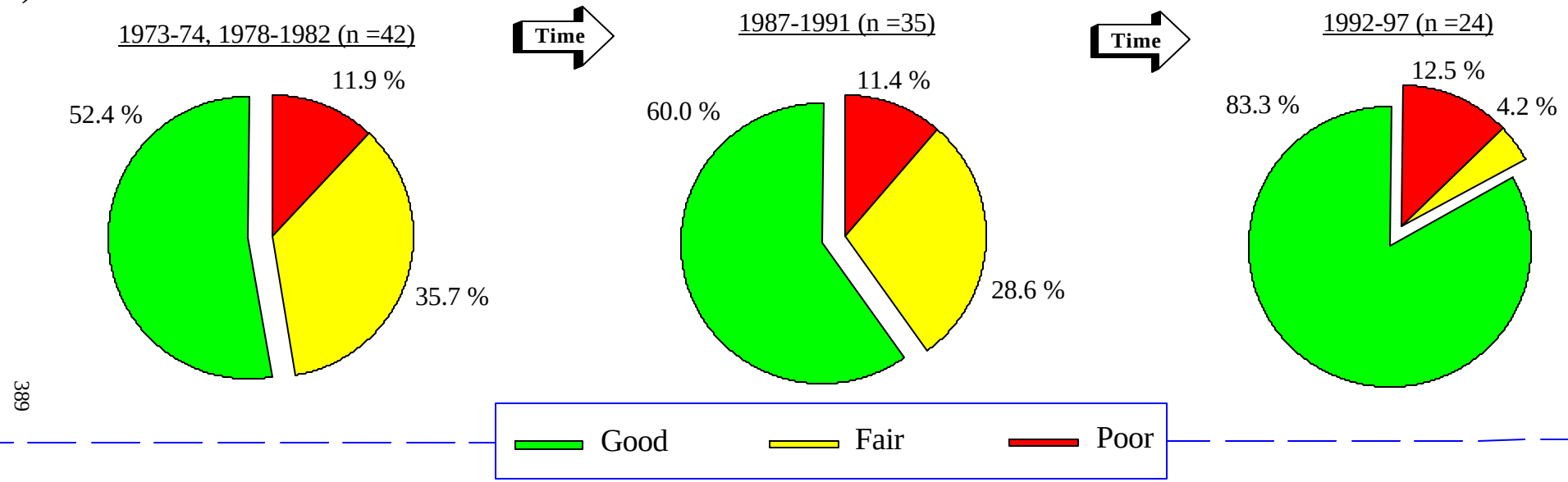


Figure IV.65 (Cont.). Fecal Coliform (FC) Concentrations Observed in the Dania Cut-off/C-10 Canal Basin over Three Time Periods. Concentrations are categorized in terms of compliance with the Broward County FC standards which state the monthly average shall be equal to or less than 200 colonies/100 ml (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.

c) Site 24



good samples since 1973 and had the least amount of poor ratings during 1992-1997. Site 25 exhibited the least amount of good samples during 1992-1997 but exhibited a decrease to 9.1% poor samples (1992-1997) from the 25% observed during 1980-1982. The low number of samples during 1980-82 may have influenced the initial value at Site 25. Site 24 displayed the greatest increase in good samples over time, yet the percentage of poor ratings was similar throughout the study period (11.4-12.5%).

Statistical differences were not observed between 1992-1997 wet and dry season values (Figure IV.66). Extending above the single sample standard, the data's upper range (i.e., 90^{th} and 95^{th} percentiles) was highest in the wet season for Sites 25 and 26 and the dry season at Site 24.

6. Basin Summary

The Dania Cut-off/C-10 Canal basin is actually two sub-basins that meet and flow eastward (outgoing tide) through the main Dania Cut-off Canal waterbody. The Dania Cut-off Canal receives freshwater from the C-11 East basin and some tidal input through the South Fork of the New River. In the present study, Site 26 characterizes this region. The C-10 Canal is directly connected to the eastern region of the Dania Cut-off Canal and Site 25 represents the water quality of the northern extent of that waterbody. Site 24 is east of the confluence of the Dania Cut-off and C-10 Canals and thus, is geographically downstream of both Sites 25 and 26. However, surrounding land uses at Site 24 (i.e., commercial port) undoubtedly influence to some extent the area's water quality.

The following discussion will summarize similarities and differences between the three sites which exist in different areas of the basin. In addition, the influence of WWTP discharges and seasonal effects will also be discussed. Finally, questions about the Dania Cut-off/ C-10 Canal Basin brought forth by this historical data analysis are listed to support current initiatives and monitoring, as well as future resource planning.

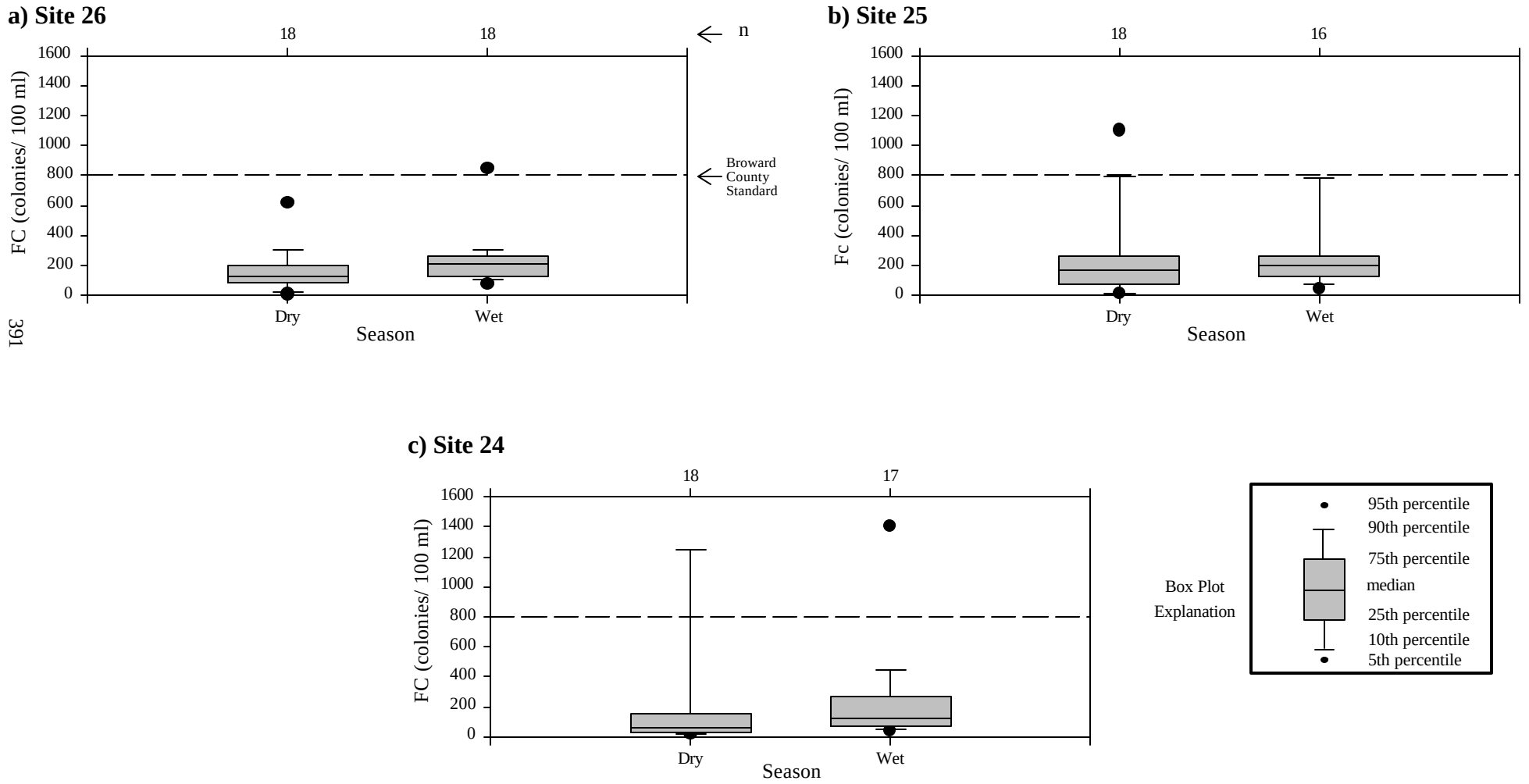
a. Influence of WWTP Discharge

The end of WWTP discharges ushered in a general improvement in the four major water quality parameters (DO, TP, TN, and FC) examined. However, the magnitude of changes for different parameters tended to be site specific. For example, nutrient levels at Site 26, though the highest in the basin, have decreased for the most part since 1989, with the exception of 1990 and 1991. The other two sites (24 and 25) did not show as much of a dramatic change. Proximity to the WWTP itself most likely contributes to this observation. Site 26 is the closet site to the C-11 Canal which still received wastewater until 1988 (see Section IV.J.3). Thus, it would be expected that Site 26 would exhibit the greatest improvements in water quality after a WWTP discharging into the C-11 Canal went offline.

b. Basin Water Quality Comparison (Post-WWTPs)

Extreme basinwide trends (similarities or differences) did not readily exist for any of the major parameters. In general, Sites 24 and 25 water quality characteristics reflected each other and were

Figure IV.66. Dania Cut-off/C-10 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 over the nine year period is shown on the upper x-axis. Statistically significant differences between wet and dry season values were not observed in the basin.



better than Site 26's values. An important exception were occasional enhanced FC concentrations observed at Sites 24 and 25 but not at Site 26. It should be noted that salinity regimes were more similar between Sites 25 and 26 (fresher) as compared to Site 24 (more saline).

However, differences within the basin are more readily seen during the period of WWTP discharges (see below). For the post-WWTPs years (i.e., 1989-1997), the major difference between sites appears to be in nutrient content with Site 26 exhibiting the highest TN and TP values in the basin for almost every year after 1988. The 1989-1997 seasonal box plots, especially for TN (Figure IV.63), further demonstrate higher nutrient levels at Site 26 than Sites 24 and 25.

As described in Section III.J, the C-11 east (Site 27) has among the highest nutrient concentrations in the county. In fact, DIN levels at Site 27 are consistently above all other freshwater sites. Site 26 is influenced by the C-11's waters more readily than other canal sampling sites, thus higher nutrient levels exist there. In addition, Site 26 had the highest long term total organic carbon values in the Dania Cut-off Canal which were also more indicative of the C-11 Canal than the ICW.

Sites 25 and 24 showed dramatic turnarounds in DO content going from mostly poor water quality samples to a majority of good samples. Conversely, Site 26 showed a relatively consistent pattern during all eras. However, the percentage of poor samples decreased after 1991 by over 15.0% at Site 26.

Good rated FC values were relatively the same throughout time at Site 25, slightly increased at Site 26, and increased substantially (approximately 30.0%) at Site 24. Ironically, Site 24 also had the highest percentage of poor samples by the final analysis period (12.5%, 1992-1997) and the only single year in the basin (1997) with a FC median greater than 800 colonies/100 ml. The influences of tidal action, as well as sporadic marine vessel discharges and septic tank failures may in part, explain why the FC values are normally good with occasional poor measurements.

c. Seasonal Differences

Statistical differences were observed for DO content at three sites. As discussed previously, temperature changes alone between wet and dry seasons can explain lower dissolved oxygen concentration in a waterbody. The 5^{th} and 10^{th} percentile were quite depressed at Sites 25 and 26 during the wet season (below 2.0 mg/l). This may either indicate localized groundwater seepage and/or input of freshwater from the eastern C-11 Canal for Site 26 which was characterized by DO values below 4.0 mg/l (Section III.J.6.c). Based on long term BOD values, ambient water quality does not appear impaired by oxygen demand. Potentially, storm events, more prevalent in the wet season, may increase BOD levels periodically and have a depressing influence on ambient DO content.

For nutrients, only Site 26's wet season TN content was significantly different than the corresponding dry season. This also suggests an increased input from the C-11 Canal through the S-13 salinity structure because of the very enhanced levels of TN observed at Site 27 (Section III.J.6.e). Interestingly, the dry season 75^{th} percentile TP value at Site 26 was much higher than the wet season.

However, 90th percentile and higher TP values at Site 26 were higher in the wet season which may reflect extreme storm and/or flow events from the C-11 Canal. Sites 24 and 25 also had rare samples that well exceeded the 0.050 mg/l standard but TN concentrations tended to be less variable within each season. For FC content, the highest values in the basin were observed during the dry season at Site 24.

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. As with all other estuarine areas in the county, the hydrologic flow regime should be better defined and the potential impacts of pulses created by the eastern C-11 Basin and/or stormwater need to better understood. Improved physical information would likely improve the understanding of possible nutrient (TP and/or TN, NH_3-nitrogen, and NO_2+NO_3-nitrogen) inflow and export to the ICW and offshore. It would also assist in defining the hydrological connection between the C-10 and Dania Cut-off Canals. Thus, the following are proposed for the Dania Cut-off/C-10 Basin:

- Does the S-13 located on the C-11 Canal consistently discharge nutrients at levels of concern to the Dania Cut-off Canal, particularly TP and DIN?

- If high levels of nutrients are entering the system what is the effect on water column biology and/or macrophytes?

- Are occasional FC standard exceedances, particularly at Site 24, anomalous or evidence of a human health concern?

- As an estuarine waterbody, what extent is the influence of a "salt wedge" from the east and the freshwater from the west?

- How does stormwater quality effect the Dania Cut-off/C-10 Canal Basin both acutely and chronically?

- Do large areas of natural shoreline help maintain significantly better water quality in both the C-10 and Dania Cut-off Canal than the bulkheaded sea walled areas serviced by septic tanks?

- What is the water quality in the upper reaches of the C-10 Spur and Hollywood Canal?

J. Discussion - Estuarine Waters

Four major objectives constituted the framework for this study and included:

- Determine water quality conditions (long-term and current) at each estuarine 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 estuary.

The preceding sections on each basin addressed these objectives, especially the first three. The following text will primarily discuss the last two objectives by focusing on the entire Broward estuary.

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

Generally, wastewater treatment plant (WWTP) discharges negatively impacted water quality at a majority of the estuarine sites. In some locations, the influence of coastal waters in the Intracoastal Waterway (ICW) appeared to dilute the influences of WWTPs when compared to inland freshwater canals (See Section III). However, upper estuarine sites within the tributaries of the ICW (e.g., New River) saw noticeable improvements when WWTPs ceased discharge to surface water. Furthermore, a major improvement in water quality was observed in the northern portion of the CICW after the Ft. Lauderdale "B" plant halted substantial discharges (8.0 mgd capacity) to the waterway (see Figure IV.19; Site 36).

The analysis on the entire data set, before and after WWTP discharges, 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 constituents starting in 1989 (i.e., after WWTPs). 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 estuarine-wide similarities and differences, 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 estuarine sediments. In particular, sediment and water column nutrient interaction can occur particularly in shallow (< 50 meters) waters such as most of Broward's estuarine waters.

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 their modeling purposes. Thus the 1989-1997 time frame contains all three weather scenarios (dry, average, and wet).

2. Salinity Regime

Chemical and biological components of estuaries are often defined by the associated salinity regime (Kennish 1990, cited in Chamberlain and Hayward 1996). As such, Broward County's estuarine salinity regime was analyzed for the period 1989-1997 and compared to Bulger et al.'s (1990, cited in Chamberlain and Hayward 1996) five estuarine zones (Table IV.31).

With the exception of the Hillsboro Inlet (Site 34), the highest median salinity values of the entire ICW basin (northern, central, and southern) were observed in the SICW. In addition, three of the four SICW sites exhibited minimum values above 15 ppt while all other sites showed minimums below 10 ppt. This suggests the SICW may be influenced more consistently by coastal ocean water than the other two ICW basins. In addition, the SICW has the least amount of pulsed freshwater input from both inland tributaries and stormwater outfalls.

The lowest salinities were observed in the western, upper estuarine reaches (Table IV.31). For example, Site 11 had a median of 0.5 ppt which is the minimum detection limit for salinity measurements. Low salinity levels were one reason Site 11 was discussed in the C-13 Canal Basin (see Section III.G). The North New River Canal (Site 20), South Fork (Site 19), and North Fork (Site 16) of the New River also had median values from 1989-1997 below 5.0 ppt.

An important criterion for biological and chemical functions is the range of salinity observed at a location. With the exception of Sites 11, and 39-41, most sites had minimum and/or maximum values characteristic of at least three estuarine zones. In fact, five sites had salinities within all five zones. This is most likely the result of the artificially manipulated hydrology of the main western freshwater sources. Fortunately, the area with the most natural habitat (i.e., SICW) also appears to have the most stable salinity regime.

The feasibility of salinity management targets, to reduce the extreme ranges observed at some sites, is a Broward County research need. Other South Florida estuarine managers are investigating the potential of doing this through a system of dikes and ponds to better manage freshwater releases from coastal salinity structures (Indian River Lagoon Feasibility Study, http://www.evergladesplan org/ projects/ irl_main.htm). Figure IV.67 illustrates the extent of inter and intra- annual fluctuation for discharges from the freshwater Hillsboro Canal and explains, in part, why Sites 1 and 33 have a relatively large salinity range. A more consistent flow pattern could provide a more stable salinity regime and potentially contribute to better water quality characteristics in the area. For example the annual TP loading that likely occurs from the western Hillsboro Canal (see Section III.L.2) to the estuarine side may decrease and not occur in large pulses.

Table IV.31. Summary of the Salinity Regime within Broward County Estuarine Waters. Salinity values were collected from 1989 to 1997 for the inland sites and the ICW. Maxium and minimum values for each site were compared to Bulger *et al. 's** five estuarine zones. The number of Bulger *et al. 's* zones refers to the occurrence of maximum and minimum values for each site to the corresponding five (I-V) zone values. Median concentrations provide a reference for the maximum and minimum.

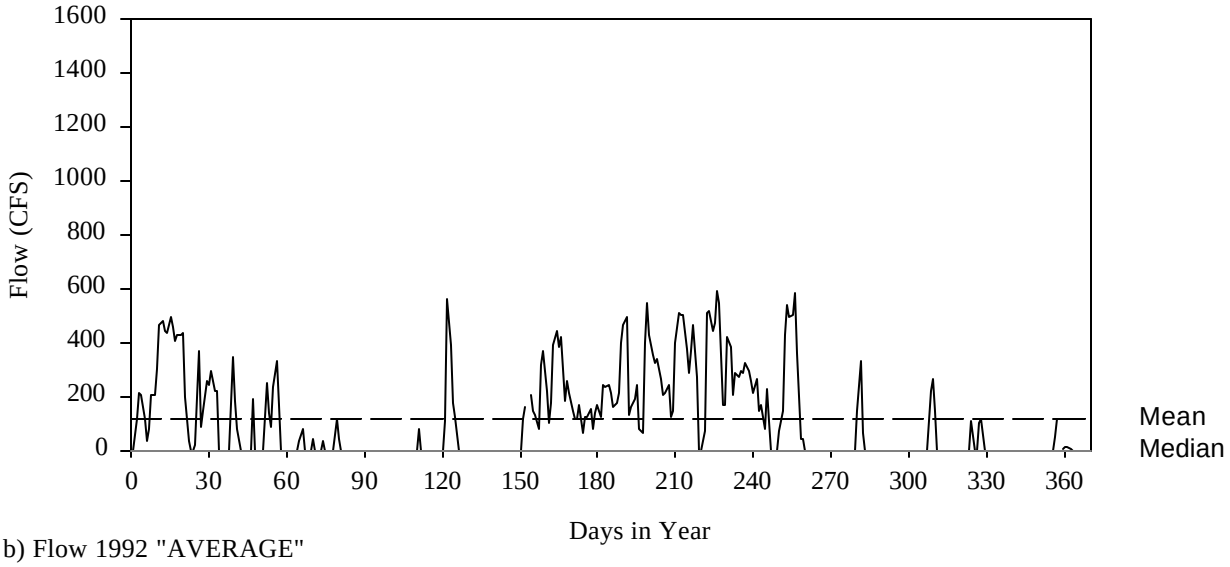
Site or Zone	Median Salinity (ppt)	Maximum Salinity (ppt)	Minimum Salinity (ppt)	# Bulger *et al. 's* Zones*
Bulger *et al. 's* Zone I*	N/A	4.0	Fresh	I
Bulger *et al. 's* Zone II*	N/A	15.0	2.0	II
Bulger *et al. 's* Zone III*	N/A	19.0	11.0	III
Bulger *et al. 's* Zone IV*	N/A	28.0	15.0	IV
Bulger *et al. 's* Zone V*	N/A	Marine	23.0	V
BCDPEP Site 1	7.4	22.8	0.25	I-IV
BCDPEP Site 5	16.9	29.8	0.25	I-V
BCDPEP Site 33	26.4	34.5	1.4	I-V
BCDPEP Site 34	32.1	36.2	9.0	II-V
BCDPEP Site 35	29.5	36.5	8.3	II-V
BCDPEP Site 36	24.3	31.9	3.9	II-V
BCDPEP Site 37	24.3	32.7	9.1	II-V
BCDPEP Site 38	29.9	34.8	3.9	II-V
BCDPEP Site 10	17.7	31.0	1.5	I-V
BCDPEP Site 39	32.5	36.2	19.1	IV-V
BCDPEP Site 47	31.5	35.2	6.8	II-V
BCDPEP Site 40	31.0	36.0	16.8	IV-V
BCDPEP Site 41	30.0	35.4	15.7	IV-V
BCDPEP Site 15	11.3	25.3	0.25	I-IV
BCDPEP Site 16	3.6	15.9	0.25	I-III
BCDPEP Site 19	3.9	19.2	0.25	I-III
BCDPEP Site 20	1.6	15.7	0.25	I-III
BCDPEP Site 24	19.8	33.9	0.5	I-V
BCDPEP Site 25	10.7	23.3	0.25	I-IV
BCDPEP Site 26	12.6	30.1	0.25	I-V
BCDPEP Site 11**	0.5	9.5	0.25	I-II

* Bulger *et al.* refers to Bulger, A.J, B.P. Hayden, M.G. McCormick-Ray, M. E. Monaco, and D.M. Nelson (1990) estuarine classification scheme as reported in Chamberlain and Hayward (1996, see their Table 4).

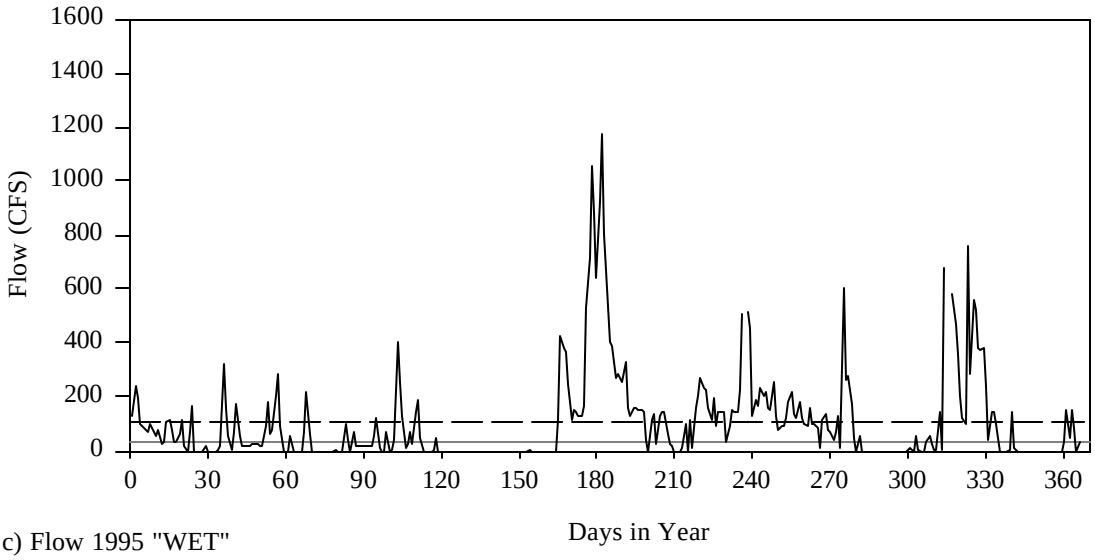
** Site 11 was primarily described in the Freshwater Chapter (see Section III).

Figure IV.67. Calculated Flow Rates for the South Florida Water Management District's (SFWMD) Coastal Salinity Structure G-56. Flow data (cubic feet per second; cfs) obtained from the SFWMD and annual means and medians are also shown. Dry, average and wet years were defined based on the SFWMD's Water Preserve Feasibility definitions (see Section IV.J.1).

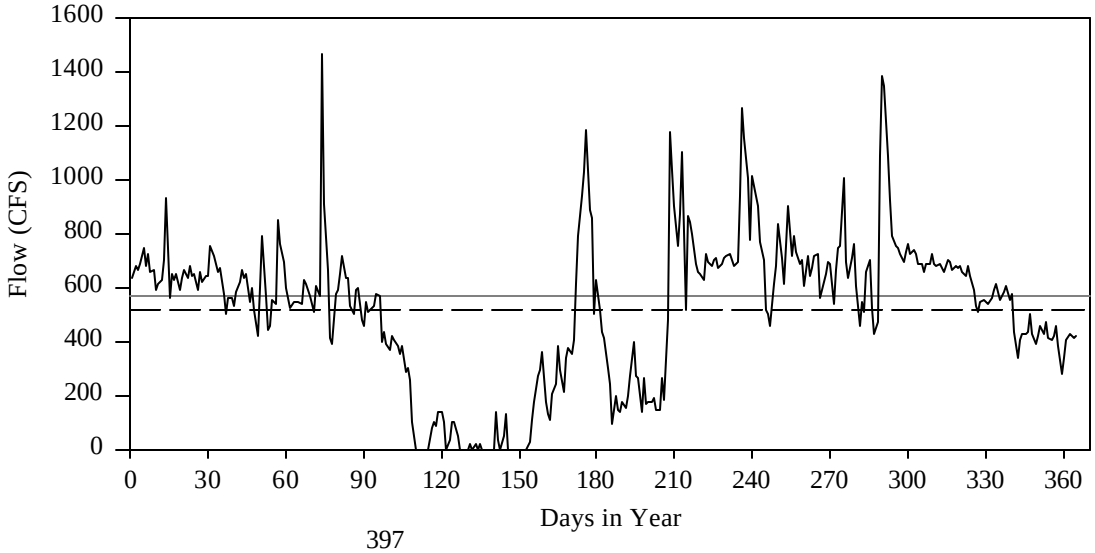
a) Flow 1988 "DRY"



b) Flow 1992 "AVERAGE"



c) Flow 1995 "WET"



3. Ambient Nutrient Concentrations

Nutrient observations form the broad base of this investigation and estuarine-wide differences were observed for TN (Figure IV.68) and TP (Figure IV.69) from 1989-1997. For TN, the western areas of the New River Basin (Sites 19 and 20) exhibited the highest median values and along with the North Fork of the New River (Site 16) were the only estuarine sites with median values greater than 1.000 mg/l. Most sites had median values near 0.800 mg/l and the overall median for all sites was 0.886 mg/l (n=691).

Statistical differences between sites were mainly seen for the New River sites (Table IV.32). Sites 19 and 20's median TN values were each statistically different (higher) than thirteen other estuarine sites (Kruskal-Wallis One Way Analysis of Variance of Ranks, Dunn's Method All Pairwise Multiple Comparison Procedure, $p < 0.05$). Site 15 had a statistically higher median TN concentration than Site 35.

Although each site showed a large range of values, TN concentrations above (i.e., out of compliance) the 1.500 mg/l standard were rare. Potentially, the Broward County TN standard is too high for today's ambient conditions having been formulated during the period of WWTP discharges. Currently, the state of Florida does not have a numerical TN or TP standard but instead a narrative nutrient water quality standard exists that states nutrient concentrations should not be at levels which cause an ecological imbalance (state of Florida 1998, FAC. 62-302). However, FDEP has used a TN content of 1.220 mg/l as a screening level to indicate possible poor water quality (Paulic et al. 1996). Only Sites 19 and 20 had median TN values equal to or barely over 1.220 mg/l. A likely reason for the relatively high TN values at these sites is the upstream freshwater source (North New River Canal) that transports large volumes of water from the Water Conservation Areas.

As with TN, TP values were also quite variable within and between sampling locales (Figure IV.69). Three sites (1, 33, and 16) were prominently higher than the remaining sites with median values greater than the county-wide 75^{th} percentile value of 0.086 mg/l (n=711). The lowest concentrations were typically observed in the ICW, particularly the SICW. Sites 1, 16, and 33 median TP values had the most statistically different observations between all estuarine sites (Table IV.33, Kruskal-Wallis One Way Analysis of Variance of Ranks, Dunn's Method All Pairwise Multiple Comparison Procedure, $p < 0.05$). A few other sites also displayed significant differences but typically with three or less sites (e.g., Site 19, Table IV.33).

For all samples, compliance with the Broward County TP standard was not as high as observed for TN. However, median TP values were near or below the 0.050 mg/l standard at fifteen of the twenty sites. The FDEP uses 0.070 mg/l as a screening level for the potential existence of poor water quality (Paulic et al. 1996). Site 16 (North Fork New River), as well as two NICW Sites 1 and 33 had median TP values exceeding the 0.070 mg/l level (Figure IV.69). The sources of North Fork TP levels have been described elsewhere (BCDNRP 1993, BCDPEP 1999a) and include stormwater. In addition, remediation measures such as dredging TP laden sediments are planned for this area. For the NICW, the discharges (see Figure IV.67) from the Hillsboro Canal which is characterized by TP

Figure IV.68. Total Nitrogen Values at Each Estuarine Water Quality Site from 1989-1997. Box plots describe data from the Northern, Central, and Southern Intracoastal Waterway Basins (NICW, CICW, and SICW), as well as the New River and Dania Cut-off/C-10 Canal Basins. The number of samples (n) per site is shown on the upper x-axis. Individual sites are also compared to the median, 25th, and 75th percentile values for all Broward County sites through the time period (n=691).

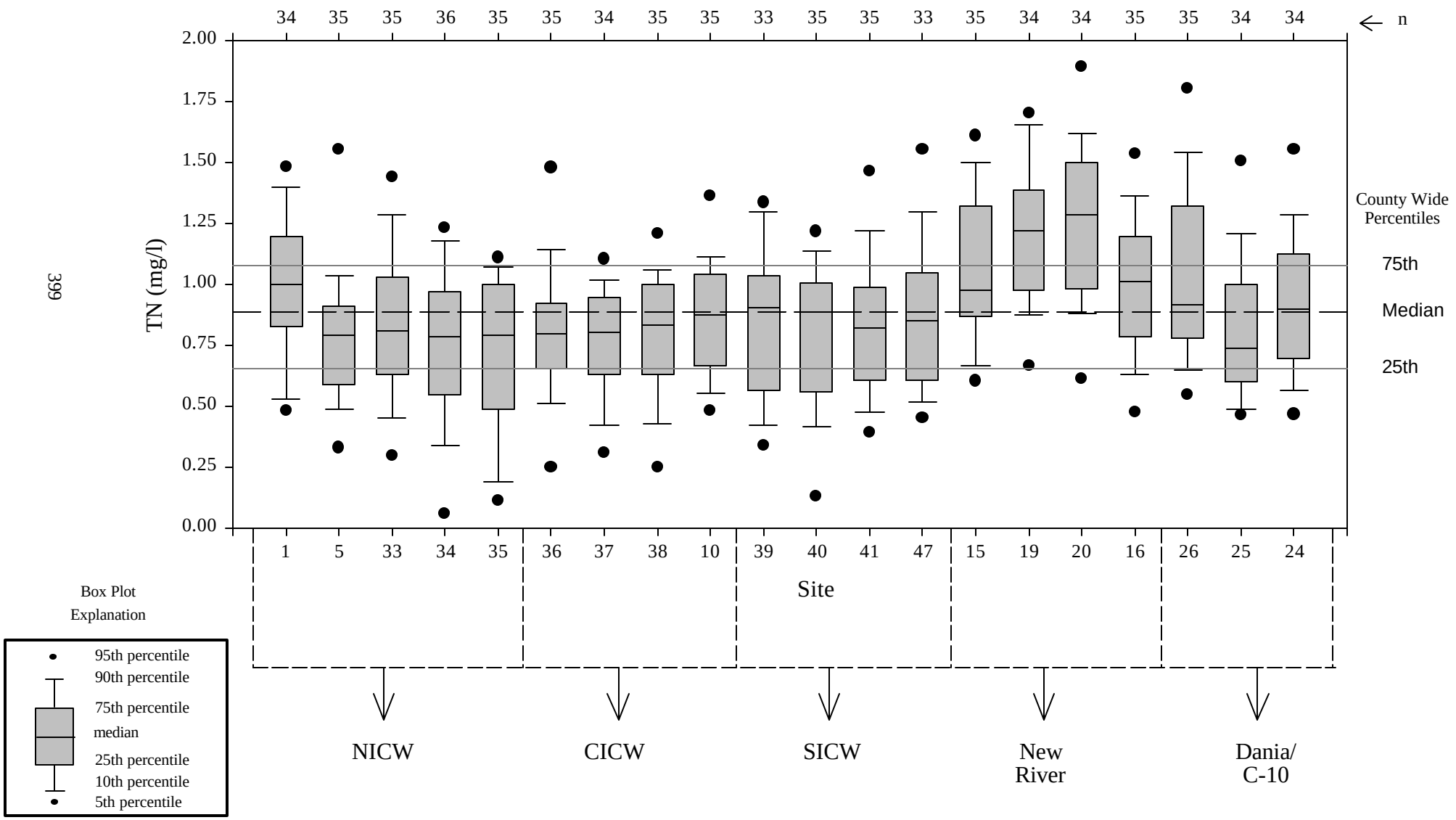


Table IV.32. Statistical Differences Observed Between Estuarine Sampling Site Median Total Nitrogen Values (1989-1997). A black box indicates the difference between the medians of two sites was statistically significant based on a Kruskal-Wallis One Way Analysis of Variance on Ranks and an isolated analysis with Dunn's Method ($p < 0.05$). Median and percentile values for the all sampling sites within the Northern Intracoastal Waterway (NICW), Central Intracoastal Waterway (CICW), Southern Intracoastal Waterway (SICW), New River (NEW), and Dania Cut-off/C-10 Canal Basins (DAN) are shown in Figure IV.68.

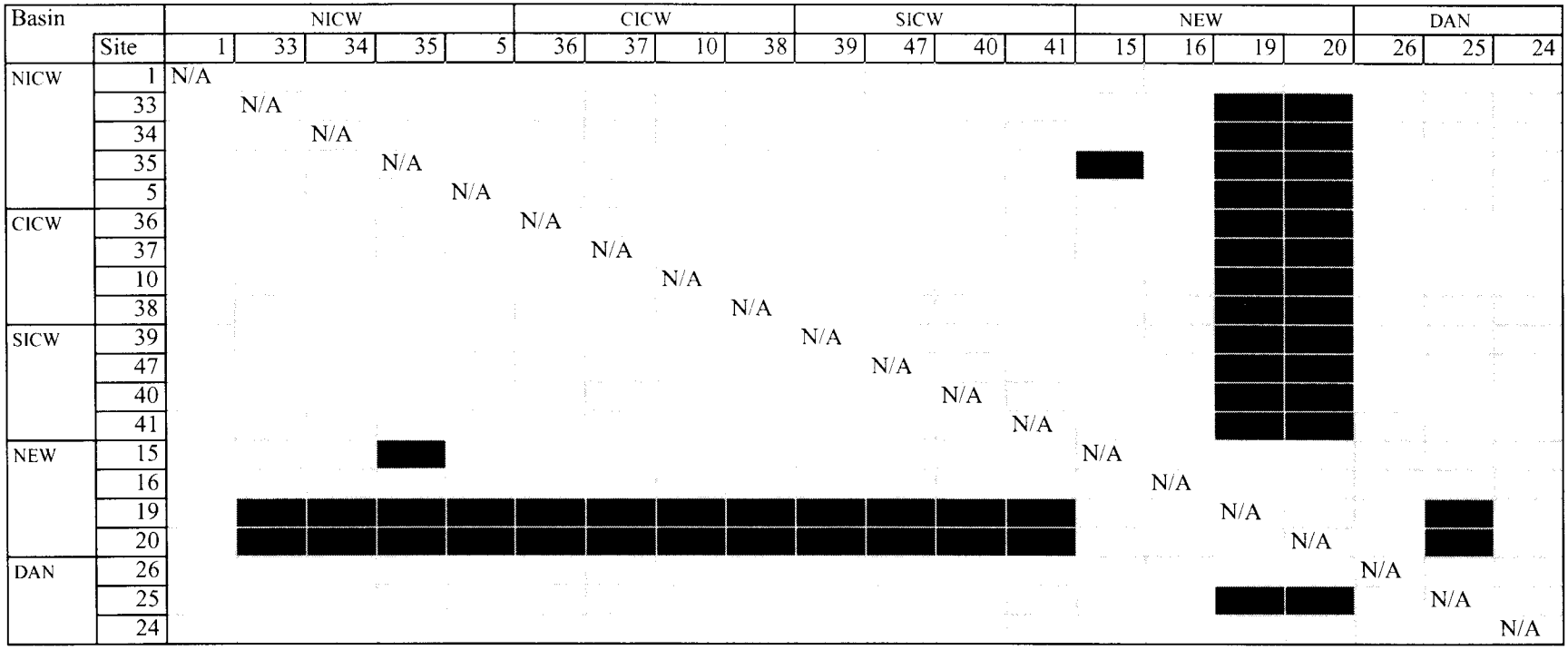


Figure IV.69. Total Phosphorus Values at Each Estuarine Water Quality Site from 1989-1997. Box plots describe data from the Northern, Central, and Southern Intracoastal Waterway Basins (NICW, CICW, and SICW), as well as the New River and Dania Cut-off Canal/C-10 Basins. The number of samples (n) per site is shown on the upper x-axis. Individual sites are also compared to the median, 25th, and 75th percentile values for all Broward County sites through the time period (n=711).

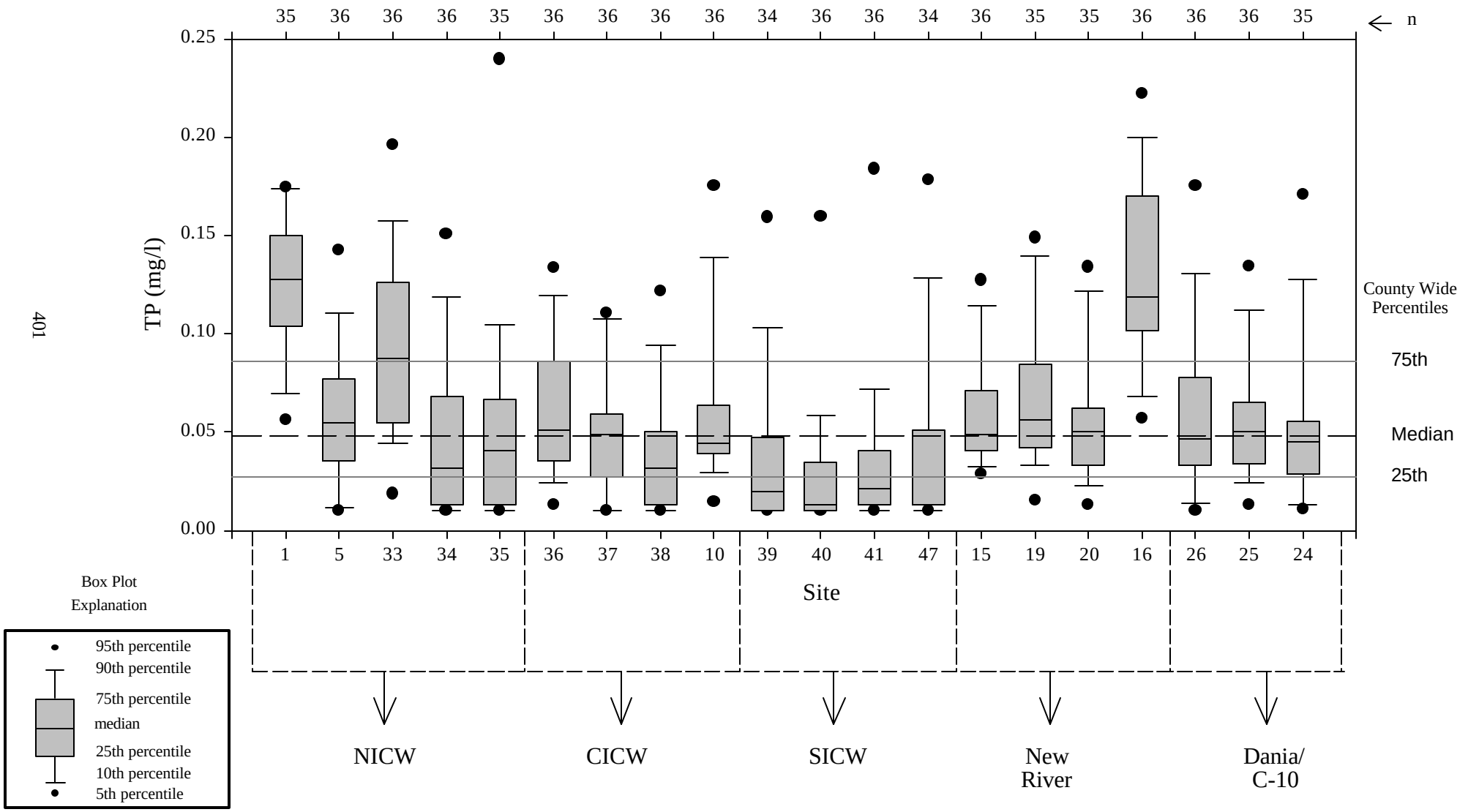
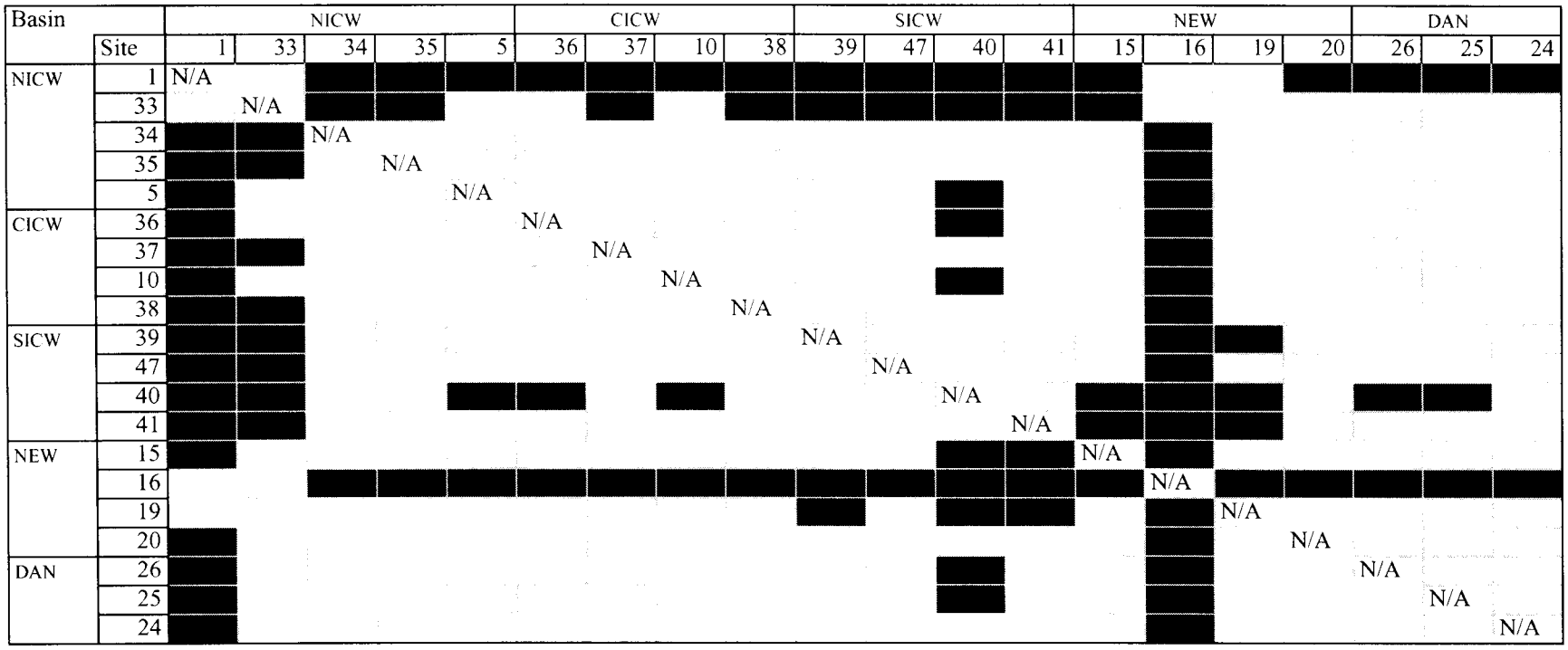


Table IV.33. Statistical Differences Observed Between Estuarine Sampling Site Median Total Phosphorus Values (1989-1997). A black box indicates the difference between the medians of two sites was statistically significant based on a Kruskal-Wallis One Way Analysis of Variance on Ranks and an isolated analysis with Dunn's Method ($p < 0.05$). Median and percentile values for the all sampling sites within the Northern Intracoastal Waterway (NICW), Central Intracoastal Waterway (CICW), Southern Intracoastal Waterway (SICW), New River (NEW), and Dania Cut-off/C-10 Canal Basins (DAN) are shown in Figure IV.69.



concentrations over 0.100 mg/l (see Site 2, Figure III.6) undoubtedly contributed to the enhanced levels downstream of the G-56 salinity structure. Site 2's median TP content (0.138 mg/l) is the highest in Broward County (Figure III.93) and represents the upstream TP content discharged through G-56. For comparison, median TP concentrations were less than 0.050 mg/l at fourteen of the fifteen Miami-Dade County coastal salinity structure discharge points during a year of intensive sampling (Lietz 1999).

The dynamic salinities (Table IV.31) observed in the tributaries of the New River, Hillsboro Canal, Middle River, C-14 and the Dania Cut-off Canal suggest that oligohaline (less than 5.0 ppt) waters exist throughout the county. An intensive year long study in a freshwater tidal region (North Fork of the New River) suggested TP levels over 0.100 mg/l were contributing to ecological imbalances based on chlorophyll a concentrations as high as 120 mg/m^3 (BCDPEP 1999a). The continued enhancement of the BCDPEP chlorophyll a database will allow for better assessment of any ecological imbalances due to nutrients throughout the estuary.

To better characterize estuarine-wide nutrient content and designate areas of most concern, a table was constructed (Table IV.34) that ranked each site individually for TN and TP, as well as a combined ranking. A low ranking (e.g., 1) indicates the highest concentration of a respective nutrient category or the worst quality. Sites 1 (NICW) and 16 (North Fork New River) had the highest nutrient concentrations in the county (Table IV.34). Overall, the New River Basin had the highest values for a basin with all four sites ranked in the top five. Conversely, the SICW had the lowest nutrient content in the Broward County estuarine system. The most disjunct basin was the NICW which had the lowest (34) and highest ranked sites (1). The driving mechanism behind the rankings differed between sites (Table IV.34). Sites 20 and 33 were ranked relatively high because of either high TN or TP, respectively. Other sites had high (1 and 16) or low (Sites 34 and 35) rankings for both nutrient parameters.

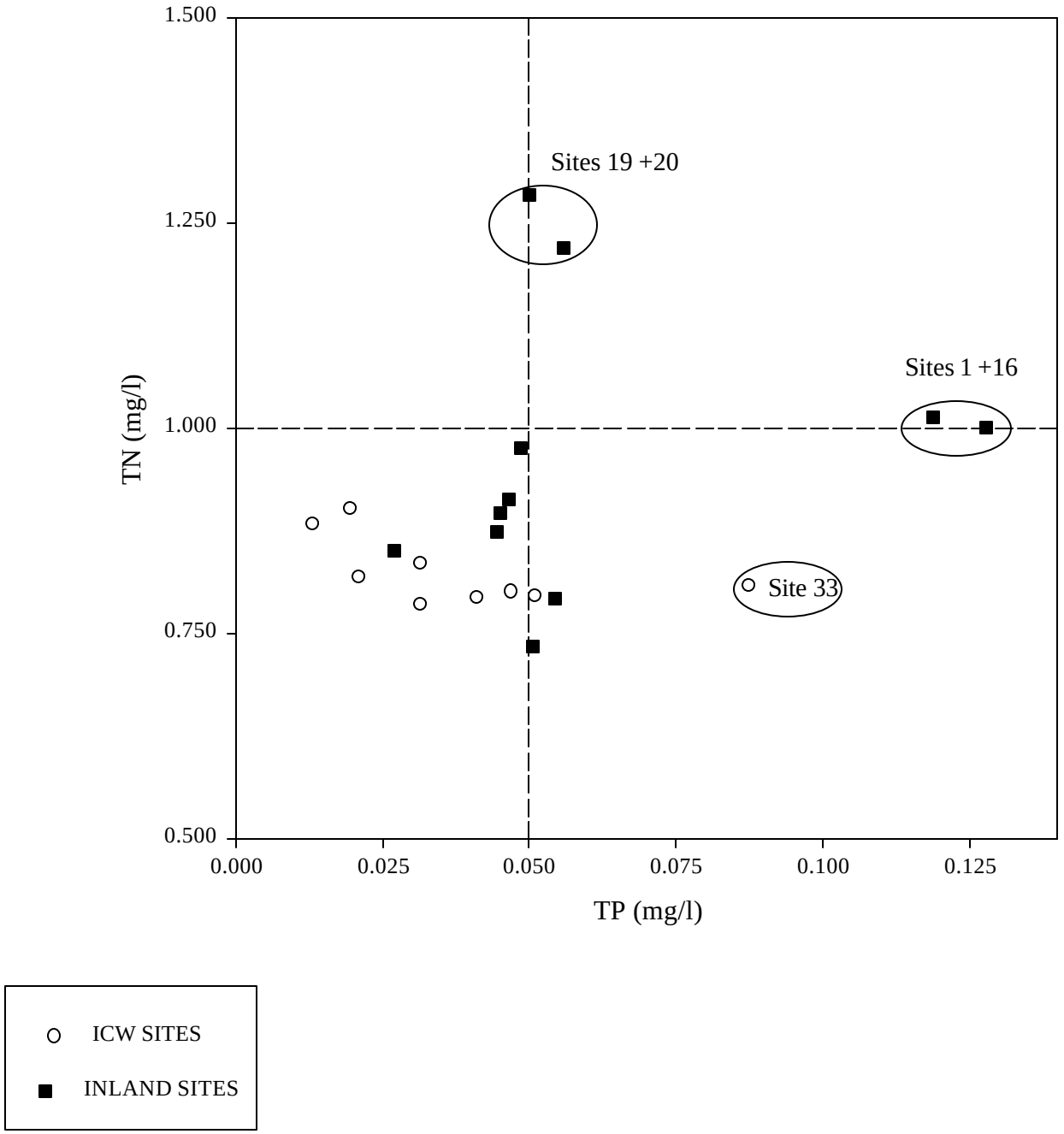
Inland sites typically had higher concentrations of nutrients (Figure IV.70). As seen in the rank analysis, Sites 1 and 16 cluster together when TP is plotted against TN values. In addition, the high TN values at Sites 19 and 20 are reflected on the plot as well. The close proximity of the oceanic waters, most notably the Gulf Stream (Florida Current), would dictate west to east decrease in water chemistry. Furthermore, inland waters are surrounded by relatively higher land use drainage area to water body volume than the ICW. Thus, waters, such as the New River, typically have less volume to assimilate nutrient loads than the wider ICW.

The basin with best nutrient quality, SICW, also has the most compatible land use for good water quality. The relatively large mangrove preserves within that basin likely contribute to the relative good ambient water quality by decreasing the area of impervious surfaces. Impervious surfaces (e.g., asphalt) contribute to an increase in pollutant loads. Furthermore, salinity values indicated that this has the highest values in the estuary likely related to coastal water. Thus, relatively cleaner coastal water, lower volumes of stormwater and freshwater pulses, and larger areas of natural land uses contribute to the basin's relatively good ambient water quality.

Table IV.34. Ranking Table of Nutrient (TN and TP) Content for Broward County's Estuarine Monitoring Sites. Sites were in the Northern Intracoastal Waterway (NICW), Central Intracoastal Waterway (CICW), Southern Intracoastal Waterway (SICW), New River (NEW), and the Dania Cut-off/C-10 Canal (DANIA) Basins. Ranks were based on median (MED) values from 1989-1997. The TP +TN rank is the average of TN rank and TP rank. The highest concentrations correspond to the number one.

BASIN	ST	TN MED	TN RANK	TP MED	TP RANK	TP+TN RANK	FINAL RANK
NICW	1	1.000	4	0.128	1	2.5	**1**
NEW	16	1.013	3	0.119	2	2.5	**1**
NEW	19	1.219	2	0.056	4	3	**3**
NEW	20	1.284	1	0.050	8	4.5	**4**
NEW	15	0.976	5	0.048	9	7	**5**
DANIA	26	0.914	6	0.046	11	8.5	**6**
NICW	33	0.809	14	0.088	3	8.5	**6**
DANIA	24	0.896	8	0.045	12	10	**8**
CICW	36	0.795	16	0.051	6	11	**9**
NICW	5	0.792	18	0.054	5	11.5	**10**
CICW	10	0.874	10	0.044	13	11.5	**10**
CICW	37	0.801	15	0.047	10	12.5	**12**
SICW	39	0.902	7	0.019	19	13	**13**
DANIA	25	0.735	20	0.050	7	13.5	**14**
CICW	38	0.835	12	0.031	15	13.5	**14**
SICW	47	0.851	11	0.027	17	14	**16**
SICW	40	0.884	9	0.013	20	14.5	**17**
NICW	35	0.793	17	0.041	14	15.5	**18**
SICW	41	0.819	13	0.021	18	15.5	**18**
NICW	34	0.785	19	0.031	16	17.5	**20**

Figure IV.70. Relationship Between Total Phosphorus and Total Nitrogen at Inland and Intracoastal Waterway (ICW) Estuarine Sites. Median total phosphorus (TP) and total nitrogen (TN) values from 1989 through 1997 were used in the analysis with the number of samples normally near thirty-six. Sites with the highest concentrations of either nutrient are circled and ranked highest in the estuary for nutrient content (see Table IV.34).



4. Nutrient Fate and Transport

The BCDPEP water quality network has created a excellent database to understand ambient or "typical' nutrient conditions. The determination of what the measured nutrient concentrations mean to a given environment is the next logical step beyond ambient data collection. In particular, an area that needs to be further addressed is the fate and transport of nutrients. Some efforts have already begun, especially in the North Fork of the New River (BCDPEP 1999a) but more is needed throughout the county.

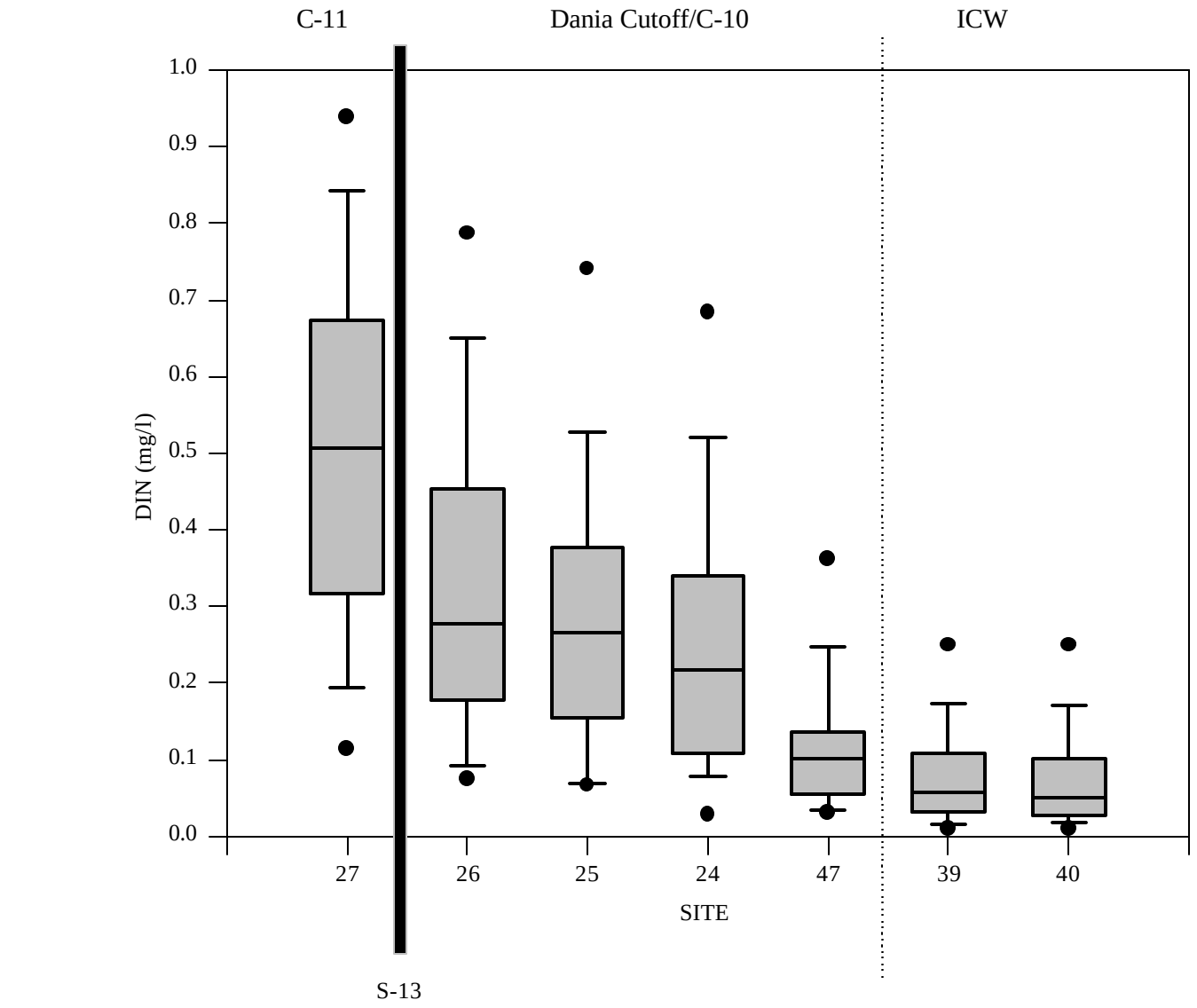
Nutrients undergo biogeochemical cycling (see Doering 1996) on different time and space scales which influence the ambient levels measured by BCDPEP. In turn, sampling on a quarterly basis may allow for the development of a good average or median value but can miss the details of nutrient cycling which may occur on finer time scales than quarterly dates (Doering 1996). Additionally, the artificial discharges from the western canals further complicate understanding nutrient dynamics in the south Florida watershed (see Chamberlain and Hayward 1996, Doering 1996). Finally, the number of stormwater outfalls within the urban Broward County corridor add complexity to the origin of nutrient inputs into water bodies. Thus, comprehensive sampling programs are needed to pinpoint areas with potential water quality problems. As comprehensive programs are expensive in both time and money, a rationale and/or need (e.g., water quality standard violation) is usually developed before sampling begins.

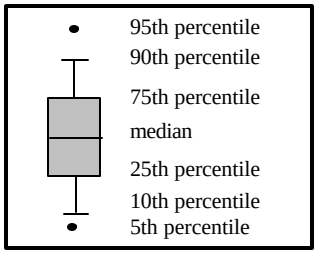
One of the main reasons for investigating nutrient cycling is understanding the biological utilization of the chemicals. Excessive phosphorus and nitrogen concentrations can cause ecological imbalances such as in phytoplankton (microscopic algae) population that may form harmful blooms. Chlorophyll a (chl a) measurements are an indicator of the abundance of phytoplankton and excessive concentrations (e.g., 50 mg/m^3, SFWMD 1999) may indicate blooms which reflect an imbalanced system. The BCDPEP began measuring chl a in 1995 at quarterly intervals. The continued growth of this database will help establish if nutrients are causing an imbalance. If more intensive sampling is performed, other factors that also effect chl a levels, including light, color, temperature, and grazing should be considered (see Doering 1996).

Furthermore, the composition of TN and TP is also important to chl a. The inorganic form of phosphorus (orthophosphate) is utilized more readily by phytoplankton and more knowledge about potential phosphorus origin can also be gained. The BCDPEP began monitoring orthophosphate in 1995 and the continued collection of data will be very useful. Fortunately, the major species of TN have been measured by BCDPEP since 1981. While this report has focused on TN, primarily because of local water quality standards, it should be noted the composition of TN is also important. Phytoplankton preferentially utilize dissolved inorganic nitrogen (DIN, nitrite+nitrate-nitrogen plus ammonia-nitrogen) over other forms of nitrogen during photosynthesis activity (See Appendix 2). For the Broward estuary, most of the TN appears to be in the form of organic nitrogen. However, some areas had relatively elevated levels (> 0.100 mg/l) of dissolved inorganic nitrogen, primarily nitrite+nitrate-nitrogen.

One area with relatively high DIN levels was the Dania Cut-off Canal. Furthermore, this area appears to receive a source of DIN from an upstream waterbody (C-11 Canal, Figure IV.71) and may be a

Figure IV.71. Distribution of Dissolved Inorganic Nitrogen (DIN) in the C-11 Canal (Freshwater), Dania Cut-off/C-10 Canal (Brackish), and the Intracoastal Waterway (ICW). Nitrate+Nitrite-Nitrogen plus Ammonia-Nitrogen make up the DIN concentrations shown from 1989-1997. The S-13 line refers to the salinity control structure that separates the C-11 Canal from the Dania Cut-off Canal. The Dania Cut-off Canal joins with the C-10 Canal and flows to the ICW.





Box Plot Explanation

good example of nutrient transport dynamics. The eastern C-11 Canal (Site 27) has the highest dissolved inorganic nitrogen (DIN, nitrite+nitrate-nitrogen plus ammonia-nitrogen) content in the county (refer to Figure III.95). The C-11's DIN concentrations are actually at levels considered very high (greater than 0.500 mg/l) for South Florida, in general (see Paulic et al. 1996).

At Site 26, DIN values appear to reflect input from the C-11 Canal to some extent (Figure IV.71). However, the C-10 Canal (Site 25) and the eastern Dania Cut-off Canal location (Site 24) have similar medians and range of percentiles. Potentially, Site 25 is influenced to some extent hydrologically by the Dania Cut-off Canal and receives some DIN input. Median salinity values between Sites 25 and 26 are relatively similar (10.7 and 12.6 ppt, respectively, see Table IV.31).

The remaining downstream DIN content, such as at Site 47, suggest that dilution effect occurs with ICW water and estuarine land uses are not contributing at least to ambient nitrogen values. This analysis, however, carries the caveat of using ambient data, though long term, in trying to describe fate and transport of nutrients. It would be preferred to have residence times and /or study a segment of water as it travels through the estuarine reach in order to more accurately determine the fate of nutrients. Nonetheless, the current discussion at least points to the importance of understanding the fate of discharged nutrients in the estuary such as has been performed in the St. Lucie Estuary (Chamberlain and Hayward 1996, Doering 1996), including hydrodynamical modeling (Morris 1987).

Beyond the estuarine ecosystem, the potential export of nutrients to offshore waters is an important issue. The Broward County marine system includes a coral reef community and several offshore recreational and commercial fisheries which have ecological, as well as economical significance. The water quality either at or near inlets (Sites 34, 38 and 39) was typically the best in the estuary. However, some variability did exist for TN (Figure IV.68), TP (Figure IV.69), and DIN (Figure IV.71). Thus, an important question is how often these relatively rare ambient measurements (i.e., 75^{th} percentile and higher) exist on finer time scales and space.

To date, BCDPEP has not performed water quality testing to any great extent outside of the ocean inlets. Qualitative observations of periodic macroalgal blooms (e.g., *Codium* sp.) have occurred offshore (Hazen and Sawyer, P.C. 1994). Additionally, a large scale investigation was performed on the potential impacts of wastewater outfalls (Hazen and Sawyer, P.C. 1994). Potentially, other agencies and universities have collected nutrient information. A literature search, as well as communication with appropriate research entities should be performed to see if a need exists for nutrient characterization of the inlets and offshore waters.

5. Other Parameters

While most of the discussion has revolved around nutrients and salinity, other important findings were observed with other parameters. Ambient fecal coliform levels for the most part, were at compliance levels (i.e., less than 800 colonies/100 ml). Exceptions were typically observed at inland Sites 10 (Middle River, CICW), 15 (New River), 16 (North Fork New River), 20 (North New River Canal), 24 (Dania Cut-off Canal), and 25 (C-10 Canal). The North Fork of the New River has the worst FC values but as discussed in that section has been and continues to be comprehensively investigated (see BCDPEP 1999a, Solo-Gabriele et al. 2000). In addition, Site 15 has recently been sampled as part of a tidal water quality study (BCDPEP, unpublished data).

For Sites 10, 20, 24, and 25 the exceedances of the single sample standard were rare (90^{th} percentile, see Figures IV.27 c and IV.66 c). Interestingly, the highest FC levels in the Dania Cut-off Canal were observed during the dry season (see Figure IV.66). However, median values were below the monthly average standard of 200 colonies per 100 ml. Thus, prior to any extensive investigation of these areas, a land and water use survey should be performed to understand potential FC sources. Furthermore, the development and implementation of new fecal contamination techniques (BCDNRP 1998a, Solo-Gabriele et al. 2000, Parveen et.al, in prep.) should be continued to assess possible human health risks.

Dissolved oxygen values were almost always less during the wet season than the dry season due, in part, to seasonal temperatures. However, the influence of increased stormwater flows may be a factor as well. Furthermore, groundwater and surface water interaction may likely influence DO values, particularly in the western areas (e.g., Site 20, North New River Canal) depending on whether a waterway is "gaining" water from groundwater or "losing" it to groundwater (see Lietz 1999, their Figure 6). Thus, several factors influence DO readings including time of day and depth of measurement. Sampling technologies allow DO levels to be remotely monitored at extremely fine time scales (minutes). For areas (e.g., Site 20 and 26) that consistently have low DO concentration (i.e., below 4.0 mg/l), these DO instruments may be deployed to obtain more discrete information.

Although total organic carbon (TOC) was not graphically presented in this report TOC values generally decrease from the western freshwater areas of the county (see Section III) to the ICW. The higher values in the western areas is most likely due to water originating in the Everglades and Everglades canal system. The inclusion of color measurements would assist the tracking of this water east. Color was observed to be an important constituent in the St. Lucie Estuary (Chamberlain and Hayward 1996, Doering 1996).

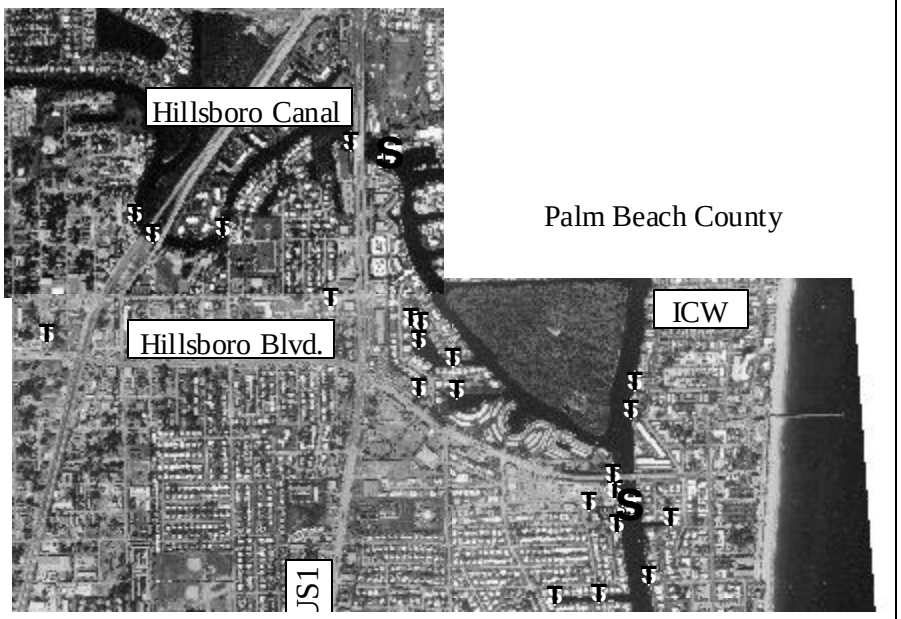
6. Physical and Meteorological Information

Understanding how freshwater flow direction, groundwater levels, and tidal stage influence water quality throughout the estuary is a research need for Broward County. For example, an analysis of flows through the major salinity structures (available from the SFWMD) would be useful in understanding the extreme salinity fluctuations observed at several sites. In addition, residence time calculations that quantify how long a specific water mass exists in the estuary would be very useful in understanding fate and transport of specific water quality parameters (e.g., dissolved inorganic nitrogen).

A major mechanism driving hydrology is rainfall. Thus, future investigation of flow patterns should also include rainfall, which is also available from the SFWMD. Rainfall information would also be useful in understanding the relationship between stormwater and ambient water quality conditions. Currently, BCDPEP is formulating loading rates as part of their National Pollutant Discharge Elimination System (NPDES) permit with the United States Environmental Protection Agency. Understanding these rates and how well the waterways can assimilate pollutants will be an important aspect of both BCDPEP's regulatory and policy working groups. The aerials in Figure IV.72 illustrate how important this information will be because of the large number of stormwater outfalls that exist within the county.

Figure IV.72. Aerial Photos of the Northern Intracoastal Waterway Basin Sampling Sites and Adjacent Stormwater Outfalls. Outfalls are shown with white triangles and differ in size and drainage area throughout the basin.

a)



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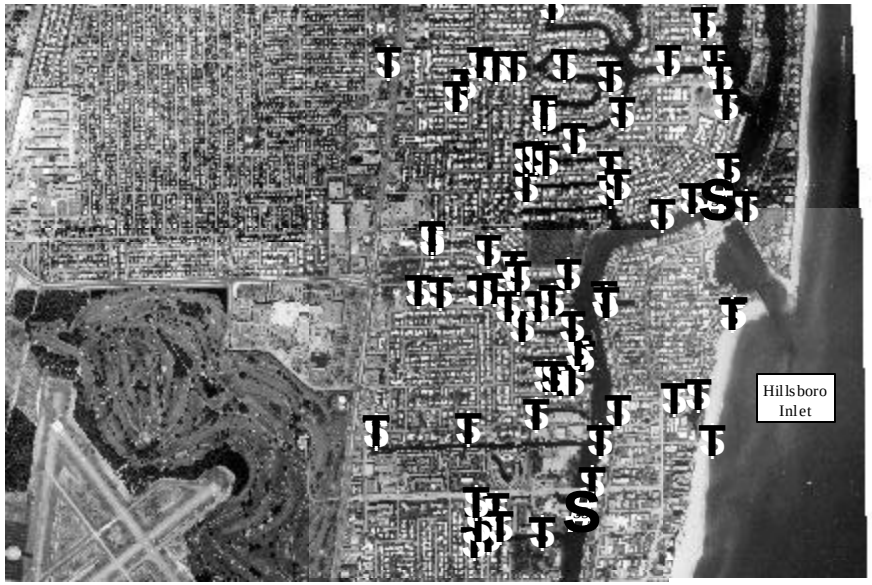

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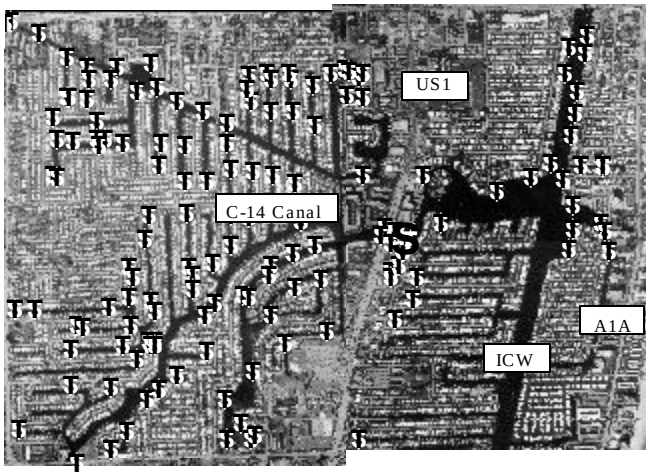

K. Conclusions and Recommendations

The Broward County estuary has several diverse geographical and hydrological areas. Variability exists in water quality within and between water sampling sites. However, some key conclusions can be made and some recommendations for future research and management directions.

- The best overall water quality was normally observed in the Southern Intracoastal Waterway (SICW; Sites 39-41, and 47) which also had the most consistent salinity regime, as well as natural (pervious) land uses (e.g., mangrove forests).

- Beyond the SICW, most of the estuary is characterized by large salinity fluctuations that are likely caused by artificially manipulated freshwater flows and an urban watershed dominated by impervious surfaces leading to substantial runoff.

- In general, inland (upper estuarine) locales exhibited the poorest water quality when compared to the ICW due, in part, to coastal water diluting the influence of land based runoff in the ICW. In addition, the inland waterways have a lower assimilation capacity of pollutants than the ICW due to their smaller channel widths and shallower depths.

- The basin with the poorest water quality was typically the New River Basin. In particular Site 16 (North Fork) had the poorest water quality of the whole county (freshwater and estuarine). Current remediation efforts (e.g., dredging) are underway in the North Fork of the New River to address the poor water quality.

- Another area of concern was the brackish reach of the Hillsboro Canal and its confluence with the NICW (Sites 1 and 33). This area's water quality, particularly total phosphorus (TP) levels, was consistent with the upstream (freshwater) Hillsboro Canal and illustrates the need for a better understanding of the influence of freshwater flows on estuarine water quality.

- The western Dania Cut-off Canal also showed some evidence of nutrient transport (e.g., dissolved inorganic nitrogen) through coastal salinity structures from an upstream waterbody (eastern C-11 Canal).

- Almost all sites showed improvements in water quality after wastewater treatment plants (WTTP) stopped discharging into Broward County's surface waters. The major exception was the TP levels in the NICW and Hillsboro Canal. Other areas which did not exhibit changes in water quality were either near oceanic inlets and/or did not have WWTPs in close proximity (e.g., SICW).

- Beyond the influence of WWTPs, long term annual trends were not readily observed, with the exception of a slight increase in total nitrogen (TN) content at the SICW basin. Some high nutrient levels were observed at other sites during a period known to have low rainfall totals (1988 to early 1990), but this relationship was not quantified in the current study.

- Nutrient levels were variable and total phosphorus content was the parameter with the most exceedances of a county water quality county standard. However, the effect of both the variability and high concentrations is not known at this time.

- Although TN levels were consistently within compliance of the county standard after the closure of WWTPs, the overall influence of TN concentrations on the environment is not known. For example, the DIN content may be more important to water column biology than TN although there is not a particular water quality standard for it.

- Fecal coliform levels were typically low in the estuarine region with the exception of Site 16. The remaining estuarine sites had occasionally high values but only the inland Sites 10, 15, 20, 24, and 25 had fecal coliform values (90^{th} percentile) above the standard (800 colonies/100 ml).

- Seasonal differences were mostly seen in dissolved oxygen content that is likely due, in part, to seasonal temperature patterns. However, some upper estuarine sites showed significantly higher levels of total nitrogen in the wet season which may be due to water control structure release and/or stormwater runoff.

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

- Continue ambient water quality program to build up overall post-WWTP database.

- Determine flow characteristics of all major salinity structures along with rainfall over time and compare with water quality.

- Understand the fate and transport of nutrients in the estuary, including hydrological residence times and discharge characteristics to coastal systems.

- Investigate flow information and residence times, the feasibility of salinity targets needs to be investigated similar to other Florida estuaries (e.g., Indian River Lagoon).

- Determine the sources and fate of total phosphorus in the Hillsboro Canal and NICW basin. Also, characterize orthophosphate concentrations in that basin first and then other areas of the county as well.

- Determine the importance of nitrogen species to water column biology throughout estuary, in particular chlorophyll a concentrations. This initially should start with dissolved inorganic nitrogen dynamics in the C-11 eastern basin and Dania Cut-off Canal.

- Continue ambient chlorophyll a monitoring but consider increasing sampling periodicity to understand if areas of high nutrients are causing ecological imbalances.

- Perform biological characterization (phytoplankton, zooplankton, fish, and macroinvertebrates, see Messing and Dodge 1997) to understand what types of organisms are living in the estuary and if ecological imbalances have been and/or are occurring.

- The continued protection of large natural areas (e.g., West Lake Park) which have large areas of permeable ground cover should be considered a high priority for future water quality management.

- Compile available information on water quality studies in the coastal waters to better understand the influence of estuarine water quality on those systems.

- Continue the development and use of better fecal contamination indicators to understand potential human health concerns.

- Consider deploying remote recorders to better understand diel and seasonal patterns.

- Compile available data on groundwater and surface water interaction (e.g., seepage rates) to understand the extent of inflows and outflows. This may also include using the current soil characterization maps.

- Ascertain the chronic and acute effects of overall stormwater input, particularly in the New River basin and the Northern Intracoastal/Hillsboro area.

- Determine to what extent petroleum by-products and heavy metals exist in stormwater in the different basins and their fate and transport characteristics (see BCDNRP 1997c, 1998b, 1999).

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