

BROWARD COUNTY, FLORIDA WATER QUALITY ATLAS: FRESHWATER CANALS 1998 – 2003



Sawgrass Expressway dividing western Everglades and eastern, urban Broward County (view is to the north).



East C-11 Canal with view east towards Davie Road.



South Florida Water Management District G54 at east end of freshwater North New River Canal (view is to northeast)

**BROWARD COUNTY
ENVIRONMENTAL PROTECTION DEPARTMENT**

TECHNICAL REPORT SERIES

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**BROWARD COUNTY, FLORIDA WATER QUALITY
ATLAS: FRESHWATER CANALS 1998 - 2003**

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**ENVIRONMENTAL MONITORING DIVISION
(954) 519-1240**

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EXECUTIVE SUMMARY

The Broward County Freshwater Canal Water Quality Atlas summarizes six years of surface water quality network observations from 1998 through 2003 by the Broward County Environmental Protection Department (BCEPD). This document is a follow up investigation for the freshwater canal section contained in an earlier publication (Broward County Department of Planning and Environmental Protection, [BCDPEP 2001](#)) that investigated water quality from 1972 through 1997.

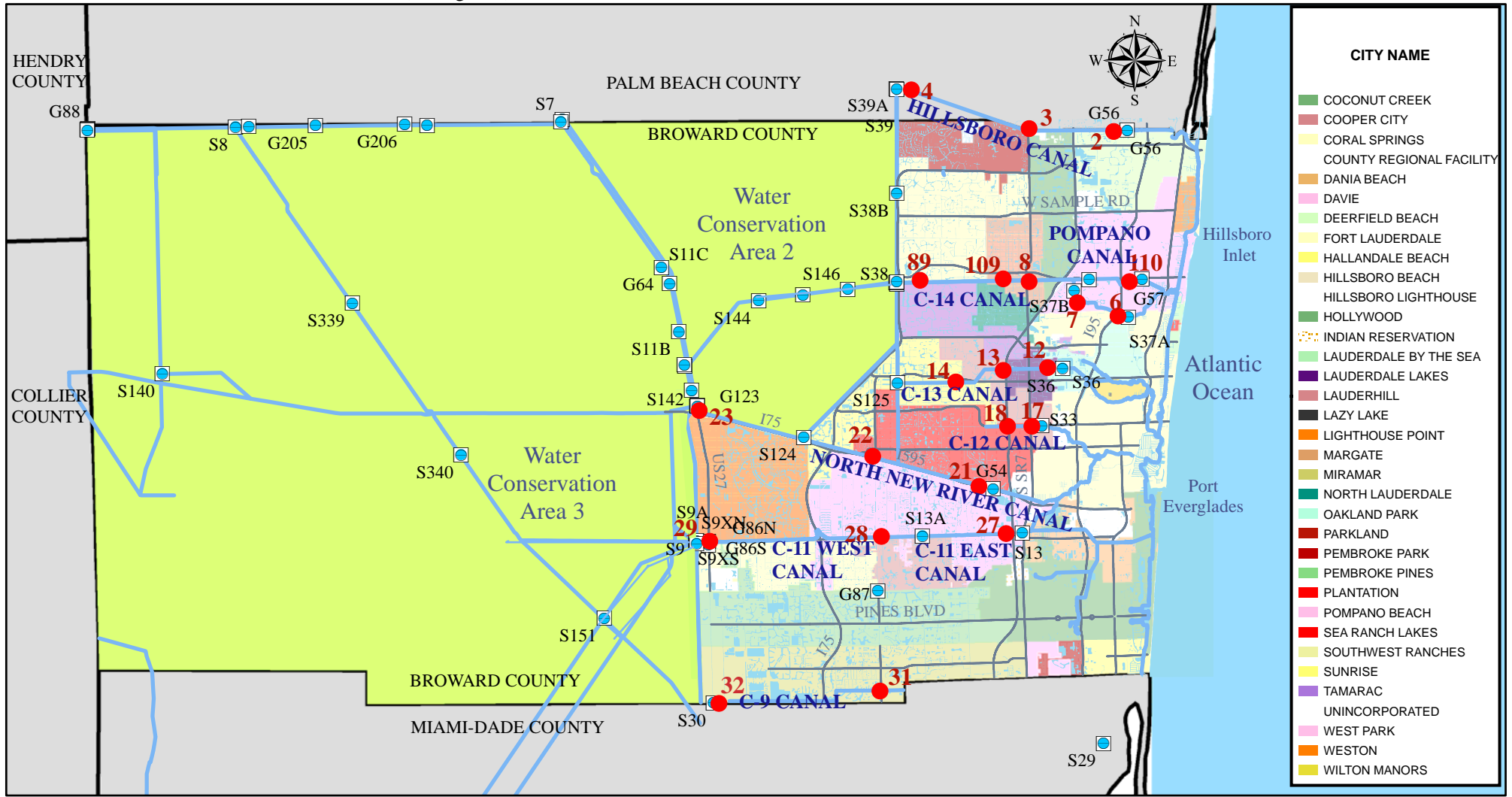
Twenty-one BCEPD freshwater canal sampling sites are located on the South Florida Water Management District's (SFWMD) primary canal system within the county's urban core (Figure X-1). Both temporal and spatial water quality patterns are investigated within and between the primary canals countywide. Water quality data are also compared to both county and state water quality standards, as well as the state of Florida's total maximum daily loads (TMDL) thresholds to understand compliance characteristics of local water bodies.

Located in Southeast Florida, USA, Broward County was established in 1915 and contains thirty-one municipalities, as well as some unincorporated neighborhoods. Geographically, the populated region of Broward County is tucked between the Everglades to the west and the Atlantic Ocean to the east and now has over 1.6 million residents ([Broward County Public Communications Office 2007](#)). Connecting these two large aquatic systems are more than 266 miles of primary natural and dredged canals that traverse the county's urban corridor ([Broward County Public Communications Office 2007](#)). Overall, the hydrology of Broward County's major canals are highly manipulated by a series of water control structures and levees operated by the SFWMD (Cooper and Lane 1987) that have altered the natural hydro-periods and flows of the South Florida watershed.

The SFWMD primary drainage system consists of nine major canals and their corresponding drainage basins: Hillsboro Canal (Florida Department of Environmental Protection [FDEP] Water Body Identification Number [WBID] 3264), C-14 (Cypress Creek Canal WBID 3270), Pompano Canal (WBID 3271), C-13 (Middle River, WBID 3273) Canal, C-12 (Plantation, WBID 3276) Canal, North New River Canal (WBID 3277), C-11 (South New River, WBIDs 3279 and 3281) Canal, C-9 (Snake Creek, WBIDs 3283 and 3284) Canal, and the C-10 (also called Hollywood Canal (WBID 3282, Cooper and Lane 1987).

These nine major canals, along with secondary and tertiary canals, eventually drain eastward to the estuarine areas (e.g., Intracoastal Waterway, ICW) when meteorological and hydrological conditions necessitate water management activity particularly for flood protection. One important exception is the Western C-11 Canal that is normally back pumped (westward) into the Water Conservation Area (WCA) 3B when flood protection measures are necessary. The C-10 Canal is an estuarine water body and will not be covered in this freshwater canal document.

Figure X-1. Broward County Environmental Protection Department's Freshwater Canal Surface Water Quality Monitoring Network. The South Florida Water Management District's (SFWMD) control structures are shown by the blue squares and manage water levels and flow throughout the watershed. Major cities are shown by the various colors in the eastern third of the county. Two thirds of Broward County is located in the portion of the Everglades known as the Water Conservation Areas (lime green).



Legend

- Canals
- Major Roads
- BCEPD Monitoring Sites
- SFWMD Water Control Structures
- Other Waterbodies
- Water Conservation Areas

Miles
0 1 2 3 4

The BCEPD has monitored the canal system since 1972 with varying number of sampling sites and frequency ([BCDPEP 2001](#)). Water quality parameters covered in this report include specific conductance, total organic carbon, dissolved oxygen (DO), total phosphorus (TP), ortho-phosphate, total nitrogen (TN), ammonia-nitrogen, nitrite+nitrate-nitrogen, chlorophyll a, and fecal coliform. The main objectives of this study were to:

1. Determine (long-term and current) basin specific water quality conditions by analyzing data from each sampling site.
2. Determine similarities and differences existing within each basin or region.
3. Determine compliance patterns with Broward County Code, Chapter 27 water quality standards ([Broward County 1996](#)).
4. Determine compliance patterns with the state of Florida's water quality criteria in Florida Administrative Code, FAC, 62-302 ([FDEP 2006a](#)) and the Impaired Waters Rule (IWR, FAC 62-303, [FDEP 2006b](#)); and
5. Formulate monitoring questions, needs, and direction for better water quality management and protection of Broward County's surface waters.

The following summary text will discuss the major findings for individual canals within the context of objectives 1 through 4. Tables X-1 and X-2 summarize medians from the discussion section where variability within the data sets is displayed. Table X-3 shows overall Broward County compliance levels (i.e., objective 3) for each site over the previous six years. In addition, a countywide perspective will be used to address objectives 3 and 4 (Table X-4). A final summary section will address future county monitoring needs and directions (objective 5).

A. Hillsboro Canal (WBID 3264)

As observed previously ([BCDPEP 2001](#)), the Hillsboro Canal continued to exhibit elevated nutrients (TP and TN) as compared to other freshwater canals countywide (Table X-1). Nutrient concentrations varied between the western and eastern portions of the waterway (Table X-1), yet non-compliance levels with the Broward County TN and TP standards were relatively high throughout the waterway (Table X-3). In addition, the canal's ortho-phosphate concentrations were orders of magnitude higher than any other freshwater canal in the county (see IV. Discussion, page 140). The Hillsboro Canal exhibited some of the highest chlorophyll a content countywide (Table X-1) yet only a few samples were above the IWR impairment threshold of 20 micrograms per liter (ug/l, [FDEP 2006b](#)). This canal was not listed for nutrient impairment by the FDEP.

Table X-1. Nutrient (Total Nitrogen, TN and Total Phosphorus, TP) and Chlorophyll a (Chl a) Median Concentrations Ranked for Broward County’s Freshwater Canal Monitoring Sites. Final ranking is where a specific canal ranked after the average of all three categories combined was calculated. Median (MED) values and individual category rankings are also shown. Sampling sites were in all county canals including Hillsboro (Hills), C-14, Pompano (Pomp), C-13, C-12, North New River (NNR), C-11 West, C-11 East, and C-9. The lowest median concentrations correspond to the number one ranking for each category.

Canal	Site	FINAL RANK		TN MED (mg/l)	TN RANK	TP MED (mg/l)	TP RANK	Chl <u>a</u> MED ug/l	Chl <u>a</u> RANK
C-9	32	1		1.063	4	0.0103	2	0.865	1
C-9	31	2		1.125	5	0.006	1	0.958	2
C-13	12	3		1.301	7	0.013	3	2.565	6
C-14	6	4		1.136	6	0.0375	13	1.78	3
NNR	21	5		1.391	9	0.024	8	2.795	5
C-11 West	28	6		1.543	16	0.0215	6	2.565	4
C-12	17	7		0.89	2	0.0388	14	4.67	12
C-13	14	8		1.488	12	0.019	4	4.93	14
C-14	109	9		1.395	10	0.0278	11	4.42	10
C-13	13	10		1.532	14	0.0216	7	4.515	11
C-11 West	29	11		1.543	16	0.0265	10	3.105	7
C-14	7	12		1.303	8	0.0522	18	3.467	8
C-12	18	13		0.915	3	0.0398	16	5.87	17
NNR	23	13		1.544	18	0.02	5	4.715	13
Pomp	110	14		0.69	1	0.0595	19	5.095	18
C-14	89	15		1.552	19	0.0334	12	3.505	9
NNR	22	16		1.596	20	0.024	8	5.715	16
Hills	4	17		1.541	15	0.039	15	6.365	19
Hills	3	18		1.433	11	0.0628	20	6.485	20
C-11 East	27	19		1.82	21	0.05	17	5.005	15
Hills	2	20		1.493	13	0.0734	21	7.55	21

Table X-2. Summary of Dissolved Oxygen (DO) and Fecal Coliform (FC) Concentrations Ranked for Broward County's Freshwater Canal Monitoring Sites. Median (MED) values and individual category rankings are also shown. Sampling sites were in all county canals including Hillsboro (Hills), C-14, Pompano (Pomp), C-13, C-12, North New River (NNR), C-11 West, C-11 East, and C-9. The highest DO median concentrations correspond to the number one ranking while the lowest median FC concentrations relate to the number one ranking for each category.

Canal	Site	DO MED (mg/l)	DO RANK		Canal	Site	FC MED (mg/l)	FC RANK
C-12	18	6.875	1		C-9	32	7	1
C-14	109	6.52	2		Hills	4	22	2
C-12	17	6.41	3		C-12	18	30	3
C-14	6	6.305	4		NNR	23	30	3
C-13	12	6.26	5		C-14	89	31.5	5
C-14	7	6.197	6		Pomp	110	46.5	6
C-14	89	6.175	7		C-14	7	48.25	7
NNR	21	5.78	8		C-14	109	59	8
C-13	13	5.635	9		Hills	2	63	9
Hills	4	5.393	10		Hills	3	66.5	10
C-13	14	5.345	11		C-9	31	66.5	10
C-11 East	27	4.97	12		C-12	17	67	12
Pomp	110	4.915	13		C-13	12	74	13
Hills	2	4.825	14		C-13	14	77.5	14
C-11 West	28	4.51	15		NNR	21	77.5	14
Hills	3	4.237	16		C-13	13	81	16
NNR	23	4.17	17		C-11 West	29	96	17
NNR	22	3.55	18		C-11 West	28	140	18
C-11 West	29	3.35	19		NNR	22	160	19
C-9	31	3	20		C-14	6	170	20
C-9	32	2.14	21		C-11 East	27	175	21

Table X-3. Summary of Broward County Local Water Quality Standard Compliance at each Freshwater Canal Sampling Site from 1998-2003. Nine canals are shown including Hillsboro (Hills), C-14, Pompano, C-13, C-12, North New River (NNR), C-11 East, C-11 West, and C-9 listed north to south. The four major parameters investigated for standard percent compliance (%) were dissolved oxygen (DO), total phosphorus (TP), total nitrogen (TN), and fecal coliform (FC). Numbers represent the percentage of samples above 4.0 mg/l (single sample standard, Broward County 1996) for DO. For TP, percentages are the number of samples below the 0.020 mg/l TP standard. The TN numbers represent the percentage of samples under 1.500 mg/l, while the FC values are the percent of samples under the 800 colonies/100 ml single sample standard.

		Percent Compliance			
Canal	Site	DO	TP	TN	FC
Hills	2	77.2	0.0	50.0	100.0
Hills	3	59.0	4.1	58.3	100.0
Hills	4	68.2	20.8	45.8	100.0
C-14	6	91.7	20.8	79.2	100.0
C-14	7	91.7	12.5	62.5	100.0
C-14	109	100.0	33.0	57.1	100.0
C-14	89	100.0	25.0	45.8	95.8
Pompano	110	70.0	10.0	100.0	90.0
C-13	12	88.0	66.7	75.0	95.8
C-13	13	91.7	37.5	41.7	83.3
C-13	14	79.0	50.0	50.0	91.7
C-12	17	96.0	16.7	95.8	87.5
C-12	18	100.0	8.3	91.7	91.3
NNR	21	71.0	37.5	75.0	95.8
NNR	22	42.0	37.5	29.2	95.7
NNR	23	52.0	50.0	50.0	95.8
C-11 East	27	71.0	12.5	16.7	95.8
C-11 West	28	67.0	45.8	45.8	100.0
C-11 West	29	33.0	37.5	41.7	95.8
C-9	31	42.0	66.7	87.5	95.8
C-9	32	21.0	62.5	91.7	100.0
County wide Median		71.0	33.0	57.1	95.8

Table X-4. Summary Statistics of Broward County Freshwater Canal Surface Water Quality Monitoring Network. The data shown for each parameter are from all Broward County freshwater sites within nine distinct canals from 1998 through 2003 with the exception of ortho-phosphate that is from 2000 through 2003 due to a change in detection limits. The standard and threshold compliance are percentages of the sample number listed on the table and include Broward County Code Chapter 27, Florida Administrative Code (FAC) 62-302 and FAC 62-303.

Parameter	Sample Numbers	Units	10 th percentile	25 th percentile	Median	75 th percentile	90 th percentile	Standard/Threshold Compliance ^a
Specific Conductance	492	umhos ^b	465	559	651	739	817	100%
Total Organic Carbon	493	mg/l ^c	10.4	13.9	17.1	20.6	23.9	NA ^d
Dissolved Oxygen	490	mg/l	2.35	3.71	5.09	6.65	7.88	71.8% ^e / 52.0%
Total Phosphorus	497	mg/l	0.0061	0.017	0.031	0.054	0.082	31.6%
Ortho-phosphate	307	mg/l	0.00174	0.00174	0.00174	0.0120	0.0310	NA
Total Nitrogen	493	mg/l	0.871	1.11	1.40	1.64	1.90	61.1%
Ammonia-N	497	mg/l	0.012	0.0387	0.0800	0.181	0.314	NA
Nitrite+Nitrate-N	497	mg/l	0.009	0.0265	0.0740	0.164	0.268	NA
Chlorophyll <u>a</u>	496	ug/l	0.960 ^f	1.94	3.78	6.63	12.69	96.2%
Fecal Coliform	493	col/100 ml ^g	7	22	67	170	361	95.9% ^h / 91.5%/ 77.9%

^a Broward County and FAC Water Quality Standards are for Specific Conductance, Dissolved Oxygen, Total Phosphorus, Total Nitrogen, and Fecal Coliform. Chlorophyll a percentage is based on threshold value in FAC 62-303.

^b umhos/cm = micromhos per centimeter at 25 degrees Celsius

^c mg/l = milligrams per liter

^d NA = not applicable

^e Top percentage (71.8%) refers to compliance with Broward County Chapter 27 single dissolved oxygen reading standard. Bottom percentage (52%) refers to compliance with Broward County Chapter 27 daily average standard and FAC 62-302 single sample standard.

^f ug/l = micrograms per liter

^g col/100 ml = colonies per 100 milliliters

^h Top percentage (95.9%) refers to the single sample compliance standard of 800 col/ 100 ml in both Broward County Chapter 27 and FAC 62-302. The monthly average standard compliance (200 col/100 ml) is indicated by the bottom percentage (77.9%) for both local and state standards. The middle percentage (91.5%) refers to the state and local standard which states only ten percent of monthly samples may exceed 400 col/100 ml. Note the Florida Department of Environmental Protection utilized the 400 colonies/ 100 ml standard when implementing the Total Maximum Daily Load process through FAC 62-303.

B. C-14 Canal (WBID 3270)

The C-14 Canal generally exhibits some of the best water quality within Broward County freshwater canals when all parameters are considered together (Tables X-1 and X-2). For example, the highest dissolved oxygen concentrations within the county are typically observed in this waterway (Table X-2). In addition, total nitrogen values throughout most of the canal are typically within compliance of the county standard (Table X-3) with the western areas being the exception (Table X-1). Many TP exceedances were observed, however, overall levels were not as high as seen for the Hillsboro Canal (WBID 3264) or even the adjacent Pompano Canal (WBID 3271). Chlorophyll *a* concentrations were normally low throughout the waterway (Table X-1) and were well within the IWR threshold. Fecal coliform levels were also within state and county standards (Table X-3) although an occasional high observation was seen at the canal's eastern extent (Table X-2).

C. Pompano Canal (WBID 3271)

The Pompano Canal exhibited some of the highest TP and orthophosphate concentrations countywide, yet had the lowest TN values for all waterways (Table X-1). Chlorophyll *a* values were among the highest in the county (Table X-1) and the FDEP has listed this waterway as impaired for nutrients because of two annual means greater than 20 ug/l (note one of those years was 2004 which is not reported in this document). As such, a draft TMDL for nutrients has been proposed by the FDEP ([Wu et al. 2007](#)). Fecal coliform values were occasionally enhanced but generally within county and state standards (Table X-2). Dissolved oxygen concentrations were quite variable but the median value from 1998 through 2003 was near the state and local standard of 5.0 mg/l (Table X-3).

D. C-13 Canal (WBID 3273)

Dissolved oxygen and fecal coliform were generally within Broward County water quality criteria with some exceptions within the C-13 Canal (Table X-3). C-13 Canal TP levels were very low as compared to other county canals (Table X-1) but still exceeded the county standard of 0.02 mg/l on many observations (Table X-3). Total nitrogen was the C-13 Canal parameter which had relatively high concentrations as compared to other county water bodies (Table X-1), particularly in the western portions of the waterway.

E. C-12 Canal (WBID 3276)

Two of the three highest median dissolved oxygen concentrations countywide were observed in the C-12 Canal (Table X-2) and it nearly achieved perfect compliance with the county standard (Table X-3). In addition, the C-12 Canal had nearly the lowest total nitrogen values in the county yet its TP content was among the highest in the county (Table X-1). Chlorophyll *a* values were slightly high as compared to other canals (Table X-1) but absolute values rarely exceeded the IWR threshold for nutrient

impairment. The C-12 Canal's fecal coliform levels were normally within compliance of county standards (Table X-3).

F. North New River Canal (WBID 3277)

The North New River Canal TP content was in the low range from a countywide perspective (Table X-1). Conversely, the western part of the canal had some of the highest median TN values (Table X-1) seen in the county and lowest dissolved oxygen content (Table X-2). Chlorophyll *a* was quite variable within the central region of canal (Site 22) having the highest concentrations (Table X-1).

G. C-11 East Canal (South New River, WBID 3281)

The C-11 East Canal's water quality typically ranks among the Broward County's poorest for freshwater canals. While many canals have one nutrient (TN or TP) with high concentrations, the C-11 East had very high ranking across all categories in Table X-1. In addition, the C-11 East also had the highest median fecal coliform content countywide (Table X-2). The C-11 East Canal's relatively high nitrite+nitrate-nitrogen concentrations are a potential concern in terms of transport to estuarine waters via discharges via the SFWMD's S13 coastal salinity structure (see IV. Discussion, page 144).

H. C-11 West Canal (South New River, WBID 3279)

Due primarily to discharges west to the Everglades (Water Conservation Area 3B), phosphorus levels are the major water quality parameter of interest within the western C-11 Canal. From an urban canal perspective, the waterway ranks in the top fifty percent of the county for median total phosphorus concentrations (0.0265 mg/l, Site 29 Table X-1) and its median chlorophyll *a* value is low (3.105 ug/l; Site 29 Table X-1). The main challenge is the Everglades requires TP levels at 0.010 mg/l or lower (Florida Administrative Code 62-302.540, [FDEP 2005a](#)). Fortunately, many initiatives are underway to improve stormwater quality locally (e.g., Broward Everglades Working Group, see [BCEPD 2007a](#)). In addition the Comprehensive Everglades Restoration Plan has a component, Water Preserve Areas, that should reduce discharges west into WCA 3B by up to ninety-five percent of the current rate ([United States Army Corps of Engineers, USACOE and SFWMD 2007a](#)).

I. C-9 Canal (Snake Creek, WBIDs 3283 and 3284)

Historically, the C-9 Canal's nutrient content has been the lowest observed for the county's freshwater canals ([BCDPEP 2001](#)). The trend of low nutrient concentrations continued over the period of 1998 through 2003 and also included new observation of low chlorophyll *a* content (Table X-1). Despite low nutrient and chlorophyll *a* concentrations, the C-9 Canal had the lowest dissolved oxygen concentrations countywide (Table X-2) as was also observed from 1972 through 1997 ([BCDPEP 2001](#)). The exceptionally low land and water elevations of the C-9 basin contribute to

consistent mixing of groundwater and surface waters and historically have explained the low dissolved oxygen levels in this waterway (SFWMD 1976). Thus, pollutant loading does not appear to be the reason for depressed dissolved oxygen in this basin.

J. Summary of Broward County Canals

While individual variability exists within and between canal systems, data was combined from all canals to better understand the waterways as one ecotype within the state of Florida. Table X-4 summarizes the descriptive statistics when all canals are analyzed together. Selected graphics from this analysis are shown in the discussion section of this document. For several parameters (e.g., total organic carbon), a water quality standard or threshold does not exist. However, these parameters may be used to understand such processes as water movements across the county.

The overall county dissolved oxygen median was 5.09 mg/l which is within compliance of both state and county water quality standards (Table X-4). To be within compliance of county water quality standards, a sample should be equal to or above 4.0 mg/l at all times and have a daily average greater than or equal to 5.0 mg/l. For all canals, 71.8% of samples were within compliance of the county's 4.0 mg/l standard. However, state water quality criteria mandate all samples must be greater than or equal to 5.0 mg/l. Thus, the compliance number is reduced to 52.0% of all individual samples (n=490) that were within compliance of both state and county standard of 5.0 mg/l from 1998 through 2003.

Groundwater and surface water are intricately linked in the South Florida watershed. From Fish's (1988) description of Broward County water resources, "Surface water and ground water are considered the visible and hidden components of a continuous water body." Importantly, groundwater is typically low in dissolved oxygen. For example, Bradner et al. (2004) reported median dissolved oxygen concentration in South Florida groundwater as 0.15 milligrams per liter. Thus, groundwater interaction with surface water can be a significant reason for relatively low dissolved oxygen levels in South Florida canals as compared to the state's numeric criteria.

Total nitrogen (TN) compliance for the 1.5 mg/l county standard ([Broward County 1996](#)) was 61.1% of 493 samples (Table X-4). The median TN value for the county's water was 1.40 mg/l that did fall within compliance of the standard. However, values from the 75th percentile and upward exceeded county water quality standards. Based on the relatively low proportion of inorganic nitrogen content (ammonia-nitrogen and nitrite+nitrate-nitrogen, Table X-4), most of the total nitrogen within Broward County's freshwater canals appears to be organic nitrogen.

For total phosphorus (TP), Broward County has a numeric standard of 0.020 mg/l in its county code ([Broward County 1996](#)). A total of 31.6% of TP samples collected from Broward County freshwater canals from 1998 through 2003 were within compliance of the 0.020 mg/l criteria (Table X-4). Of the 68.4% of non compliant

samples, 30.2% were less than twice the standard while 38.2% were twice the criteria (see Discussion). The median orthophosphate value for the county was half the detection limit of Broward County's analytical capability (0.00348 mg/l). Thus most of the ambient TP concentrations measured in Broward County's waterways are generally not in the inorganic form (orthophosphate) most readily used by aquatic plants.

The state of Florida does not currently have a numeric nutrient standard within its water quality criteria ([FDEP 2006a](#)) although efforts have been underway by the FDEP to establish both numeric total nitrogen and total phosphorus standards ([FDEP 2007a](#)). The FDEP has nutrient thresholds within FAC 62-303 ([FDEP 2006b](#)) to determine if a water body is impaired for nutrients. The chlorophyll *a* value for canals is 20 micrograms per liter (ug/l) and is the same as established for streams and rivers statewide. In addition, if annual means in a specific water body increase by 50 percent within an assessment period, the water body may also be determined to be impaired and slated for a total maximum daily load for nutrients ([FDEP 2006b](#)).

The vast majority of Broward County's waterways do not have ambient chlorophyll *a* concentrations at levels near the Impaired Waters Rule threshold value of 20 ug/l (Table X-4). The Broward County freshwater canal median chlorophyll *a* of 3.78 ug/l and even the 75th percentile value of 6.63 ug/l are well below the 20 ug/l threshold. The 90th percentile (12.69 ug/l) is almost half of 20 ug/l. In addition, a weak relationship was observed between chlorophyll *a* content and nutrient (TN and TP) concentrations (see IV. Discussion, page 146).

Other factors beyond nutrients such as color (note high TOC median value Table X-4), flow, and aquatic plant management are likely affecting the phytoplankton populations and influencing overall chlorophyll *a* content. This also suggests the main potential water quality challenge of nutrients in canals may not be the "in-canal" biological response but instead downstream fate of the nutrient pools. The United States Environmental Protection Agency ([2007a](#)) often defines this as 'far-field' effects and any future water quality criteria development in Broward County should take this into serious considerations for estuarine, coastal, and Everglades discharges.

K. Future Monitoring Questions and Needs

Over the last five years, the most critical use of the BCEPD water quality database has been its utilization by FDEP in the IWR process which is the state's total maximum daily load (TMDL) program ([FDEP 2007b](#)). As the FDEP or SFWMD do not regularly monitor water quality within the urban third of Broward County, the BCEPD network constituted almost the entire database from which the FDEP made their assessments. The next five to ten years will see a continued need for BCEPD's Freshwater Canal Surface Water Quality Monitoring Network for the second round of FDEP assessments, as well as any Basin Management Action Plan implementation.

Also within the next five to ten years, several Comprehensive Everglades Restoration Plan (CERP) and related projects are slated to begin construction that will directly influence water quality (e.g., Broward County Water Preserve Areas, [USACOE and SFWMD 2007a](#)). These projects are both regional and local in scale and may provide water quality benefits or potentially cause unintended local water quality challenges. The BCEPD monitoring sites, especially within the western most parts of the county, will continue to be important to monitor these effects.

Through Chapter 27, the Broward County Environmental Protection Department's Water Resources Division has several regulatory programs that protect the county's surface water quality ([BCEPD 2007b](#)). The BCEPD surface water quality network helps track part of the successes of this program in two specific basins (C-13 and C-14) where the county has the most jurisdiction in a series known as the BCEPD Environmental Benchmarks Report (for example see [BCEPD 2007c](#)). As eastern Broward County continues to redevelop its urban core, the implementation of the BCEPD regulations should continue to improve surface water quality. This will likely be most evident in some smaller, older basins such as the Pompano Canal.

The BCEPD also has enforcement powers under Broward County Code - Chapter 27 ([Broward County 1996](#)). The availability of a long and continuous background water quality database allows for an understanding of the severity of pollutant discharges and assists in determining potential penalties. In particular, turbidity violations during construction activities have often exceeded 100 nephelometric turbidity units (ntus) while ambient values are typically near 2 ntus. This background information has assisted the BCEPD in levying fines exceeding \$100,000 in previous cases.

The FDEP ([2007c](#)) began a process to examine the designated uses and classifications of the state's waterways including South Florida canals. The FDEP formed a policy advisory committee (PAC) to discuss the main issues and make recommendations. However, some concerns did arise suggesting this effort would lead to a lowering of water quality standards and the Broward County Board of County Commissioners passed a resolution ([Broward County Board of County Commissioners 2006](#)) at its December 5, 2006 Board meeting to ensure water quality would not be diminished in Broward County. The FDEP has since written a letter ([FDEP 2007d](#)) stating this is not the intended purpose of the PAC. However, there remains a possibility for many interested stakeholders to have different opinions on canals and their designated uses. The collection of water quality data by BCEPD can only benefit this process by providing accurate scientific information to support policy and regulatory decisions.

Another statewide process is the FDEP Numeric Nutrient Criteria ([FDEP 2007a](#)). Much of the freshwater canal data used to date has been from BCEPD's network. For example, Broward County urban freshwater canals tended to have much lower TP levels than reference streams (i.e., little human impact from development) from the northern part of the state ([FDEP 2005b](#)). This was somewhat unexpected based on the different land uses (i.e., urban vs. "pristine"). Yet, part of the explanation is the exceptionally different geological and even climatic conditions of two systems

situated at the broad geographical spectrum of a large state. Future numeric nutrient criteria efforts will benefit from the continued collection of nutrients and chlorophyll *a* in Broward County's freshwater canals to help understand these variable and complex relationships.

Broward County's population in 2000 was over 1.6 million people and it is expected to grow to over 2.3 million people by 2030 ([Broward County Office of Urban Planning Services Division 2007](#)). Thus, augmentation of traditional methods of providing public water supplies (i.e., Biscayne Aquifer withdrawals) and the added volume of human wastewater are significant challenges for the South Florida watershed, including Broward County. Many alternative water supplies have been and are being investigated in particular by the SFWMD ([2006](#)).

Some of these technologies do pose potential surface water quality concerns; in particular direct discharges to canals (see [FDEP 2006c](#)). Policy and regulatory decision makers will need water quality datasets such as provided by the BCEPD surface water quality monitoring network to give good background ambient information on the primary canals. In addition, the BCEPD has also begun pilot sampling on secondary canal systems to better understand the water quality of these waterways that are generally smaller and shallower than the primary canal systems.

Most of the freshwater canal water quality network exists in waterways that discharge into tidal estuarine reaches through a SFWMD water control structure (e.g., G54, North New River Canal). Many of these water control structures are approximately five to seven miles west of the oceanic inlets. It is important to understand the connectivity between the freshwater and estuarine systems. A future project should consider looking at flow rates with the observed chemical concentrations for an estimate of estuarine loads. The proposed loading calculations would be coarse scale as the flow data are not measured by Acoustic Doppler Current Profiler (ADCP) but are estimates by the SFWMD due in part to the large expense of ADCP deployments.

Future monitoring should consider tracking water masses entering the estuary from the freshwater canals to understand the fate and transport of water quality parameters more quantitatively. As BCEPD has also initiated a Coastal Water Quality Monitoring Program, the connectivity of the 'Glades to the Sea' may be more accurately described by this type of sampling strategy. Future tracking studies would also help determine the extent that freshwater discharges influence the coastal waters. This area of study is of particular importance in terms of the CERP projects mentioned above which may affect the future freshwater flows to the estuary. Although all freshwater quality sites are important, the freshwater sites immediately west of the control structures are particularly important for understanding of estuarine loadings.

L. Conclusions and Recommendations

- Distinct differences in water quality were observed between and even within the same freshwater canals despite the canals having relatively similar morphology, climate, and surrounding land use (on a state-wide scale).
- Hydrologic variability and proximity to the western two thirds of the county (i.e., Water Conservation Areas) are two likely factors in the different water quality patterns. However, this relationship needs to be further quantified by looking at water quantity and quality values together in the future.
- In general, the western sampling sites (particularly the central to southern areas of the county) in a canal are more likely influenced by the Water Conservation Areas and have the highest specific conductance, highest total organic carbon, highest total nitrogen, and highest ammonia-nitrogen content. In addition, these canal areas typically had the lowest nitrite+nitrate nitrogen, lowest total phosphorus, and lowest chlorophyll a across the county.
- The eastern sampling sites generally had the opposite characteristics of the western most areas, with exceptions for some parameters (e.g., total nitrogen in Eastern C-11 Canal). The lowest specific conductance, lowest total organic carbon, lowest total nitrogen, and lowest ammonia-nitrogen levels were generally observed in the eastern areas of canals. In addition, these canal areas tended to have the highest nitrite+nitrate-nitrogen, highest total phosphorus, highest dissolved oxygen, and highest chlorophyll a.
- The three canals (Pompano Canal, C-12 Canal, Eastern C-11) with no direct connection to the WCAs tended to have the poorest water quality in the county. The exception to this is the Hillsboro Canal (with connections to the WCAs) that continues to have the highest nutrient content in the county as observed previously ([BCDPEP 2001](#)).
- The new monitoring site on the Pompano Canal also revealed elevated total phosphorus levels yet the canal had the lowest total nitrogen values in the county.
- Chlorophyll a values are typically low in the county and well within compliance of the state of Florida Impaired Waters Rule threshold value of 20 ug/l ([FDEP 2006b](#)). The Pompano Canal is one important exception and has been determined to be impaired by the FDEP based on exceedance of the IWR chlorophyll a threshold for nutrients.
- Water flow, color, and aquatic plant management are likely major factors causing a weak relationship between nutrient levels and chlorophyll a concentrations.

- Fecal coliform values tended to be low throughout the county and no freshwater canals have been listed as impaired for fecal coliform by the FDEP during their IWR assessments. Despite the relatively high level of fecal coliform standard compliance, swimming is still not recommended by the Broward County Health Department due, in part, to sampling intervals being on a quarterly basis and not weekly.
- In general, no strong temporal patterns were observed with most constituents. One exception was seen in the C-9 basin where dissolved oxygen content was at some of the highest ever recorded for the canal over the six year period.
- Several state, regional, and local regulatory, management, and policy initiatives are either presently occurring (e.g., IWR) or will be in the near future (e.g., CERP) that necessitate the continued implementation of the BCEPD Surface Water Quality Network.

The following are proposed to continue the development of enhanced water quality monitoring in Broward County in the future.

- An analysis of water flow and meteorological data should be performed in the future with concurrent water quality data to better understand some of the variability observed within and between different canals.
- In addition, the BCEPD should determine if aquatic plant management activities are influencing the water quality observations by coordinating with local and regional managers on their activities.
- The probability assessment for chlorophyll a should be continued to understand at what nutrient concentrations the impaired waters rule threshold is being crossed.
- The Eastern C-11 Canal and Hillsboro Canal continue to have some of the highest nutrient content in the county. While these water bodies were not listed for impairment through the first IWR assessment, they are still possible candidates during the FDEP's second IWR assessment that is currently being performed.
- Furthermore, the potential impact of all freshwater canal discharges into estuarine waters needs to be completed with an emphasis on the Eastern C-11 Canal and the Hillsboro Canal.
- BCEPD should continue consultation with CERP water quality teams (e.g., RECOVER) to see where our current water quality sites can augment information on the progress and effects of CERP on local water quality.
- The BCEPD should consider joining the Regional Ambient Monitoring Program (RAMP) program of Southwest Florida which was initiated by the Tampa Bay Estuarine Program in 1992, but is now coordinated by the local governments that

run the monitoring programs. RAMP participants meet quarterly to collect water samples from a common container and has its own laboratory run the samples for a core group of parameters (TN, nitrite+nitrate-nitrogen, ammonia-nitrogen, TSS, TP, orthophosphate, color, turbidity, and chlorophyll a), and compare the results ([Tampa Bay Estuary Program 2006](#)). This program has led to regional data comparability and better management and protection of Southwest Florida water resources.

- The BCEPD should continue to coordinate with Palm Beach and Miami-Dade Counties, particularly investigating how comparable our concurrent data collection sites are with each other. In addition, the TMDL process and CERP necessitate good regional coordination.
- The BCEPD should begin to post data on the Internet and investigate a University of South Florida Water Atlas approach to reporting water quality data and other important watershed information ([University of South Florida 2007](#)).

I. Introduction

Located in Southeast Florida (United States of America), Broward County was established in 1915 with a charter government developed in 1975. Currently, thirty-one municipalities and several small areas of unincorporated neighborhoods exist within the eastern 409.8 square miles of the county's total of 1,196.9 square miles ([Broward County Public Communications Office 2007](#)). The county exists within the South Florida Watershed and approximately two-thirds of its area (787.1 square miles) exists in the Everglades (regionally termed the Water Conservations Areas, Figure 1). The Atlantic Ocean lies to the east of the urbanized portion of the county and includes a unique coral reef habitat coupled with a major oceanographic feature, the Gulf Stream.

Connecting these two large aquatic systems are over 266 miles of major canals that traverse the county's urban corridor ([Broward County Public Communications Office 2007](#)). The primary uses of these canals include flood protection, water supply enhancement, and fishing. Although it is not recommended by the local Health Department, many of the canals are utilized for swimming and water sports such as jet skiing by local residents. Canal aesthetics are also an important component of water-front property and water quality in Broward County.

Overall, Broward County's hydrology is highly manipulated by a series of water control structures and levees that have altered the natural hydro periods and flows of the South Florida watershed on regional to local scales. Freshwater and estuarine reaches of water bodies are delineated by coastal salinity structures operated by the South Florida Water Management District (Cooper and Lane 1987) for the purposes of flood protection and water supply (Figure 2). Thus, freshwater and estuarine connectivity is highly altered. During the wet season (approximately June thru October), discharges to tide thru coastal salinity structures may be frequent and large while during the dry season (approximately November thru May) discharges are less frequent and may be of smaller volume.

The Broward County Department of Environmental Protection Department (BCEPD) is an environmental agency working under the Broward County Board of County Commissioners. Originally the Broward County Pollution Control Board (BCPCB), the agency has undergone numerous name changes but since 1972 has maintained a surface water quality network (Figure 2). A large synopsis of this work (1972 thru 1997) was compiled in an earlier publication (Broward County Department of Planning and Environmental Protection, [BCDPEP 2001](#)).

A. Objectives

This assessment study will lead to enhanced management and protection of Broward County surface waters by providing an update of the primary freshwater canal system's water quality. In addition, a large amount of the data in this report was assessed by the Florida Department of Environmental Protection (FDEP) in their Impaired Waters Rule (IWR) process (Florida Administrative Code, FAC, 62-303, [FDEP 2006b](#)) which is the state's

Figure 1. The Lower East Coast Region of the South Florida Watershed as Managed and Operated by the South Florida Water Management District (SFWMD). The blue-green areas represent the Water Conservations Areas and the white represent urban and agricultural areas. Numerous water control structures are shown (black symbols). Canals are depicted by blue lines and some major roadways are also shown in black. This figure was adapted from an original SFWMD (2007) map or the SFWMD's phone number is 561-686-8800.

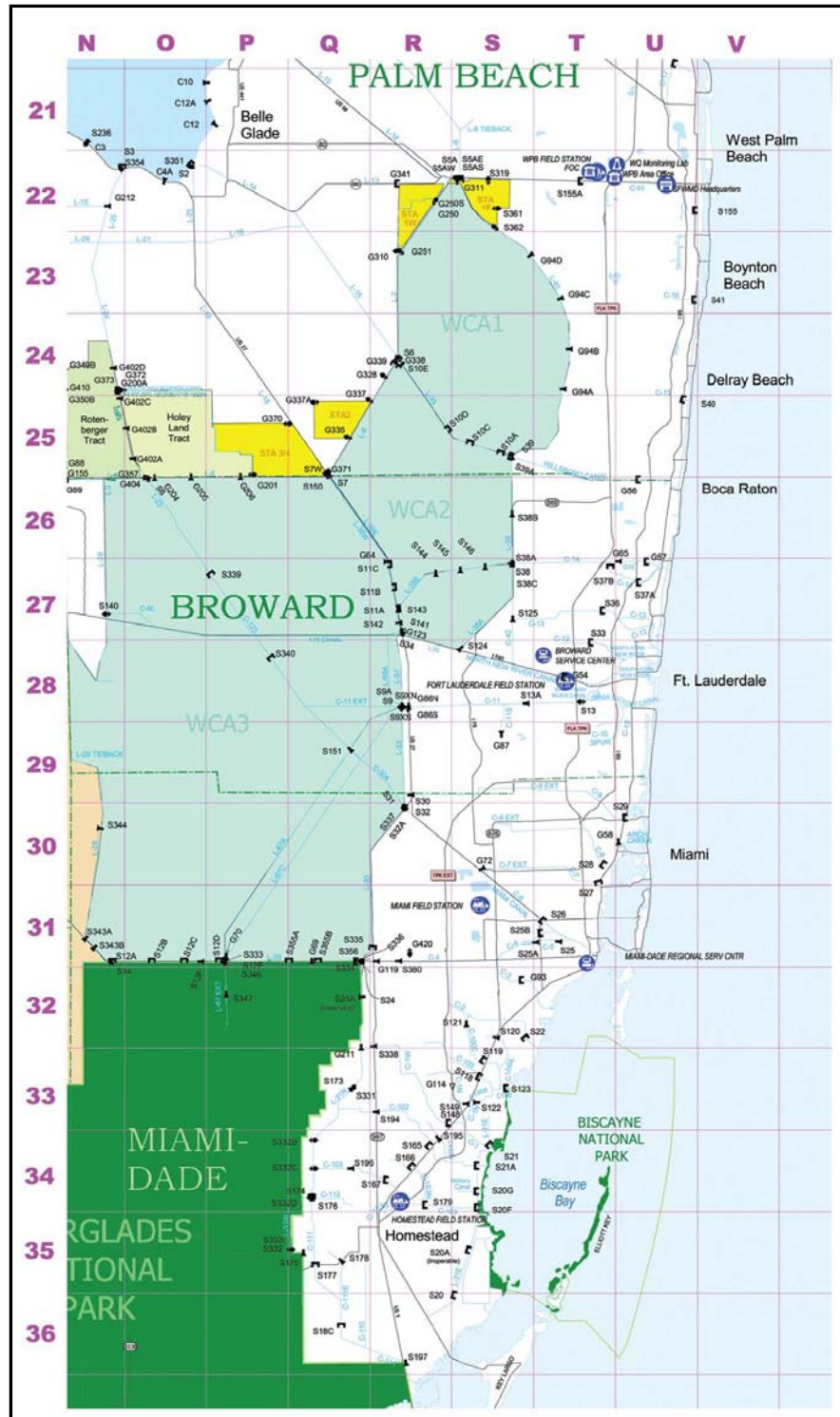
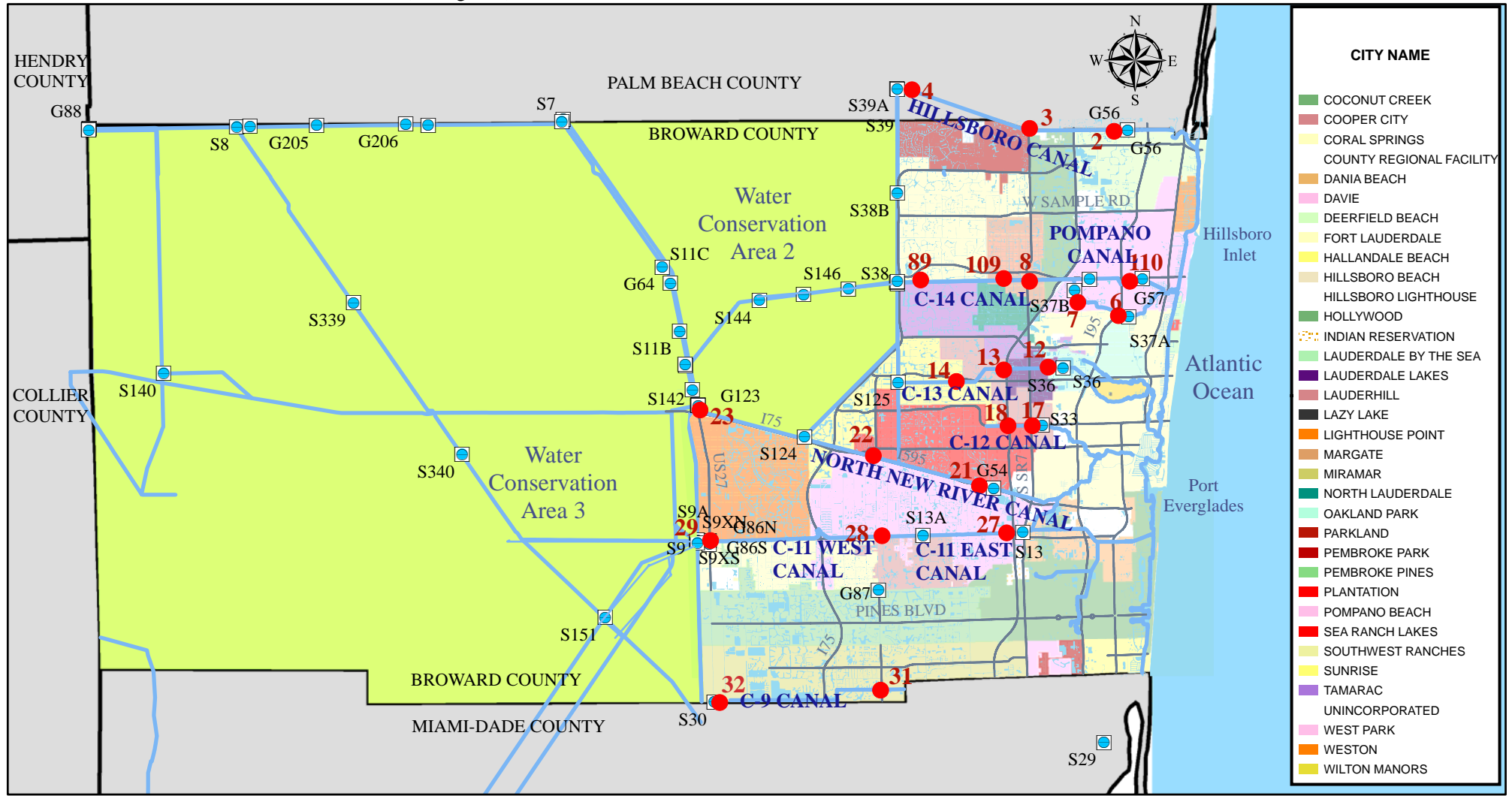


Figure 2. Broward County Environmental Protection Department's Freshwater Canal Surface Water Quality Monitoring Network. The South Florida Water Management District's (SFWMD) control structures are shown by the blue squares and manage water levels and flow throughout the watershed. Major cities are shown by the various colors in the eastern third of the county. Two thirds of Broward County is located in the portion of the Everglades known as the Water Conservation Areas (lime green).



- CITY NAME**
- COCONUT CREEK
 - COOPER CITY
 - CORAL SPRINGS
 - COUNTY REGIONAL FACILITY
 - DANIA BEACH
 - DAVIE
 - DEERFIELD BEACH
 - FORT LAUDERDALE
 - HALLANDALE BEACH
 - HILLSBORO BEACH
 - HILLSBORO LIGHTHOUSE
 - HOLLYWOOD
 - INDIAN RESERVATION
 - LAUDERDALE BY THE SEA
 - LAUDERDALE LAKES
 - LAUDERHILL
 - LAZY LAKE
 - LIGHTHOUSE POINT
 - MARGATE
 - MIRAMAR
 - NORTH LAUDERDALE
 - OAKLAND PARK
 - PARKLAND
 - PEMBROKE PARK
 - PEMBROKE PINES
 - PLANTATION
 - POMPANO BEACH
 - SEA RANCH LAKES
 - SOUTHWEST RANCHES
 - SUNRISE
 - TAMARAC
 - UNINCORPORATED
 - WEST PARK
 - WESTON
 - WILTON MANORS

Legend

- Canals
- Major Roads
- BCEPD Monitoring Sites
- SFWMD Water Control Structures
- Other Waterbodies
- Water Conservation Areas
- Miles
- 0 1 2 3 4

approach to the Clean Water Act's Total Maximum Daily Load (TMDL, [FDEP 2007b](#)) section. The following are the study's five major objectives:

1. Determine (long-term and current) basin specific water quality conditions by analyzing data from each sampling site;
2. Determine compliance patterns with Broward County Code, Chapter 27 Article V water quality standards ([Broward County 1996](#));
3. Determine compliance patterns with the state of Florida's water quality criteria (Florida Administrative Code, FAC, 62-302, [FDEP 2006a](#)) and the Impaired Waters Rule (IWR, FAC 62-303, [FDEP 2006b](#));
4. Determine similarities and differences existing within each basin or region; and
5. Formulate monitoring questions, needs, and direction for better water quality management and protection of Broward County's surface waters.

II. Methodology

A. Field and Laboratory

The Broward County Environmental Protection Department's Environmental Monitoring Division has a Florida Department of Health certified laboratory (#E46053) and follows a comprehensive quality assurance plan (#870191G). The first certification procedure occurred in 1977 when the agency was known as the Broward Environmental Quality Control Board.

Sampling of freshwater canals was primarily performed from bridge crossings across specific canals (Figure 2). Appendix I describes the geographical location of all sites. Sub-surface (0.5 meters) grab samples were mainly collected via a Kemmerer/Niskin bottle which was lowered to collect water from a canal. Samples for individual constituents were then placed into clean glass bottles, plastic bottles and/or whirlpaks depending on the parameter to be analyzed. Samples were placed on ice and brought back to the laboratory within four hours of collection. Table 1 describes the parameters and methodologies used over time for each parameter. All of the parameters were not sampled through the entire study. Thus, the overall sampling years for each parameter will be presented with each specific basin. All of the data presented here is available in the USEPA's ([2007b](#)) national STORET and FDEP ([2007e](#)) state STORET databases.

Table 1. Broward County's Laboratory Methodologies for Water Quality Parameters. Total nitrogen was calculated by adding nitrite+nitrate-nitrogen and total Kjeldahl nitrogen concentrations.

Parameter	Technique	Method
Specific Conductance	Whetstone bridge or equivalent	USEPA 120.1
Dissolved Oxygen	Membrane electrode (1972-present) Winkler titration (1972-present)	USEPA 360.1 USEPA 360.2
Total Organic Carbon	Thermal oxidation, NDIR (1981-1994) Persulfate oxidation, NDIR (1994-present)	USEPA 415.1 USEPA 415.2
Total Phosphorus	Acid, block digestion, automated, ascorbic acid	USEPA 365.4
Ortho-phosphate	Automated, low level	USEPA 365.1
Nitrite+Nitrate-Nitrogen	Cadmium reduction, automated	USEPA 353.2
Ammonia-Nitrogen	Specific ion electrode (1980) Automated phenate (1981-present)	USEPA 350.2 USEPA 350.1
Total Kjeldahl Nitrogen	Acid, block digestion, automated phenate	USEPA 351.2
Chlorophyll <u>a</u> (corrected)	Membrane filtered in field/ 90% acetone extraction	SM 10200H
Fecal Coliform	Membrane filter	SM 909C
USEPA 1983 Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, March 1983 SM =. APHA 1975, 1989, and 1999 Standard Methods for the Examination of Water and Waste Water, 14 th , 17 th , and 20 th eds., APHA, Washington, D.C.		

B. Data Analysis

At the core of this investigation is a graphical analysis performed to investigate inter- and intra- annual variation. This also allowed for inter- and intra- drainage basin comparison. Furthermore, for four parameters, dissolved oxygen, total phosphorus, total nitrogen, and fecal coliform graphical analyses was available from a previous publication ([BCDPEP 2001](#)) that demonstrated the influence of wastewater treatment plant (WWTP) discharges to surface waters to both the observed concentrations and water quality standard compliance.

For data manipulation, concentrations below the method detection limit (MDL) were transformed to half of the MDL. Concentrations below the practical quantitation limit but above the MDL were retained at their observed values. Data manipulation was primarily performed with Excel[®] for Windows. Graphical analysis was performed with Sigmaplot[®] and the statistical package used was SigmaStat[®] that are both Windows based software.

III. Results

A. Hillsboro Canal (Florida Department of Environmental Protection, FDEP, WBID 3264)

1. Basin Description and Sampling Locations

The Hillsboro Canal has several distinct segments within the regional South Florida Water Management District system extending from Lake Okeechobee to the Intracoastal Waterway (Figure 3). For this chapter, all water quality sampling sites are located in the freshwater section of the Hillsboro Canal between South Florida Water Management District (SFWMD) structures S-39 and G56, without direct tidal influence by surface waters (Figure 3). Global Position System coordinates and specific site descriptions are given in Appendix 1.

Broward County Environmental Protection Department's (BCEPD) Site 4 is in Palm Beach County at the bridge to Southeast Growers' Association and is immediately east of the S-39 control structure. Site 4 represents water quality discharged to the Hillsboro Canal from the L-39 (Hillsboro Canal, northwest of S-39) and L-40. Both the L-39 and L-40 are influenced by the hydrodynamics of Water Conservation Area 1 (Arthur Loxahatchee Natural Wildlife Refuge). Site 3 is the central site along the waterway at the State Road 7 Bridge. Site 2 is located immediately west (approximately 100 feet) of the SFWMD coastal salinity structure G56 and represents the final discharge point into the brackish regions of the canal.

2. Specific Conductance

Sites 2 through 4 showed relatively similar annual specific conductance values (Figure 4). In addition, all three sites showed similar fluctuations between maximum and minimum annual means over the six years. The highest (874 micromhos per centimeter, umhos/cm) and lowest annual mean (537 umhos/cm) were observed at Site 4 over two consecutive years (2002 and 2003).

3. Total Organic Carbon

Annual total organic carbon (TOC) values decreased from west to east within the Hillsboro Canal (Figure 5). All Site 4 annual TOC means were greater than 20.0 milligrams per liter (mg/l) and the maximum for the canal (26.2 mg/l) was observed in 2003 at this location. Conversely, Site 2 only exhibited one annual mean above 20 mg/l (Figure 5) and had the canal's lowest annual average of 16.8 mg/l in 1998.

4. Dissolved Oxygen

Dissolved oxygen (DO) values from 1973 to 2003 are shown as these graphs (Figure 6) were available in the BCEPD's first water quality atlas (Broward County Department of Planning and Environmental Protection, [BCDPEP 2001](#)). Annual DO averages have generally increased to compliance levels at Sites 2 through 4 from 1996 until 2003 (Figure 6) with 1999 being the exception to this trend for all

Figure 3. Broward County Environmental Protection Department's Surface Water Quality Monitoring Sites on the Freshwater Hillsboro Canal. Freshwater sampling site numbers 2 through 4 are west of the South Florida Water Management District's coastal salinity structure, G56. The southern portion of the Hillsboro Canal drainage basin is depicted by the yellow color. The northern sub-basin is in Palm Beach County. Major cities in both sub-basins are labeled.

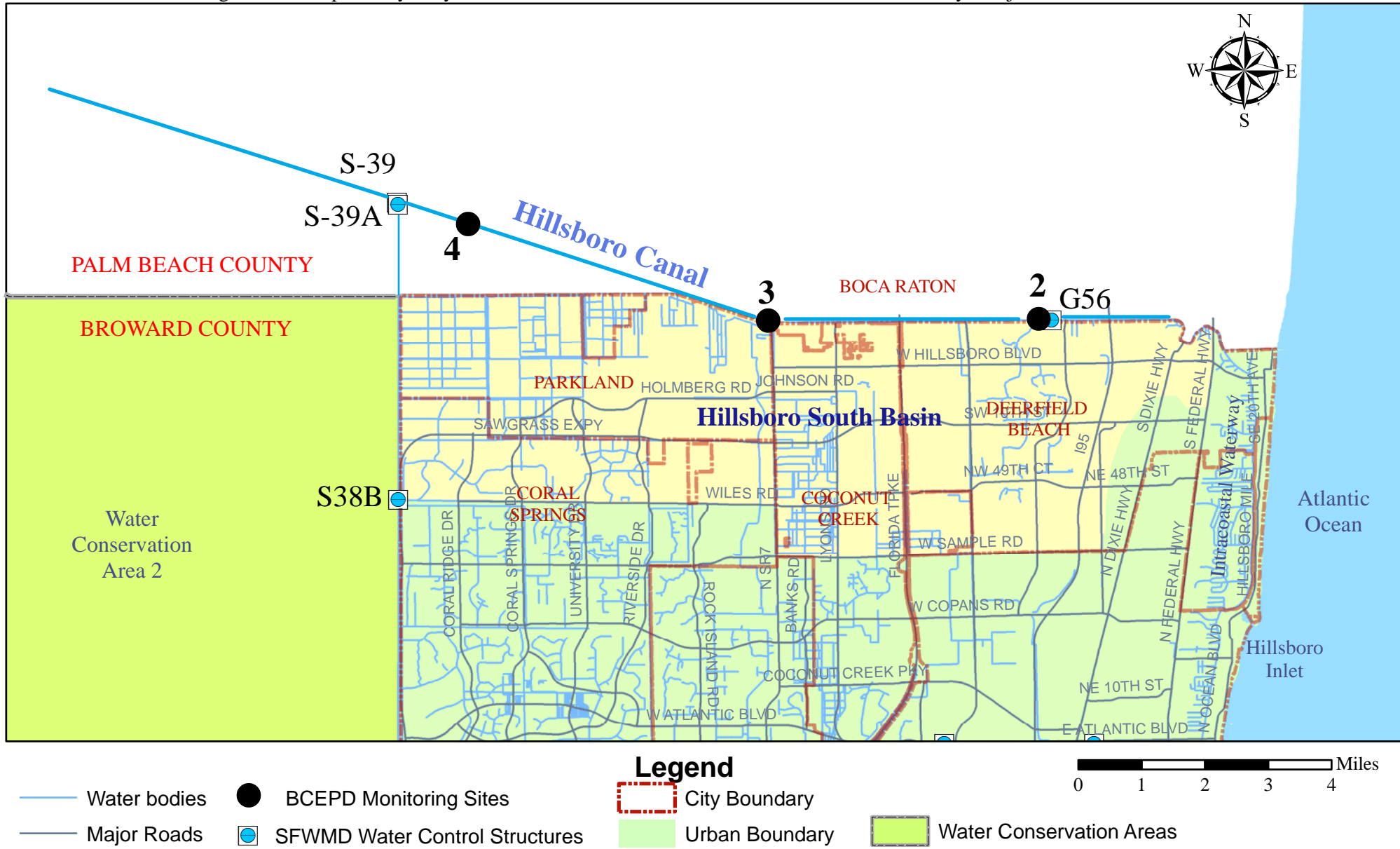


Figure 4. Annual Mean Specific Conductance (Cond) Levels within the Hillsboro Canal Basin (Florida Department of Environmental Protection WBID 3264) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis and values are shown in micromhos per centimeter (umhos/cm) at 25 degrees Celsius. Sites are shown in a west to east orientation to show the typical direction of the canal during periods of flow.

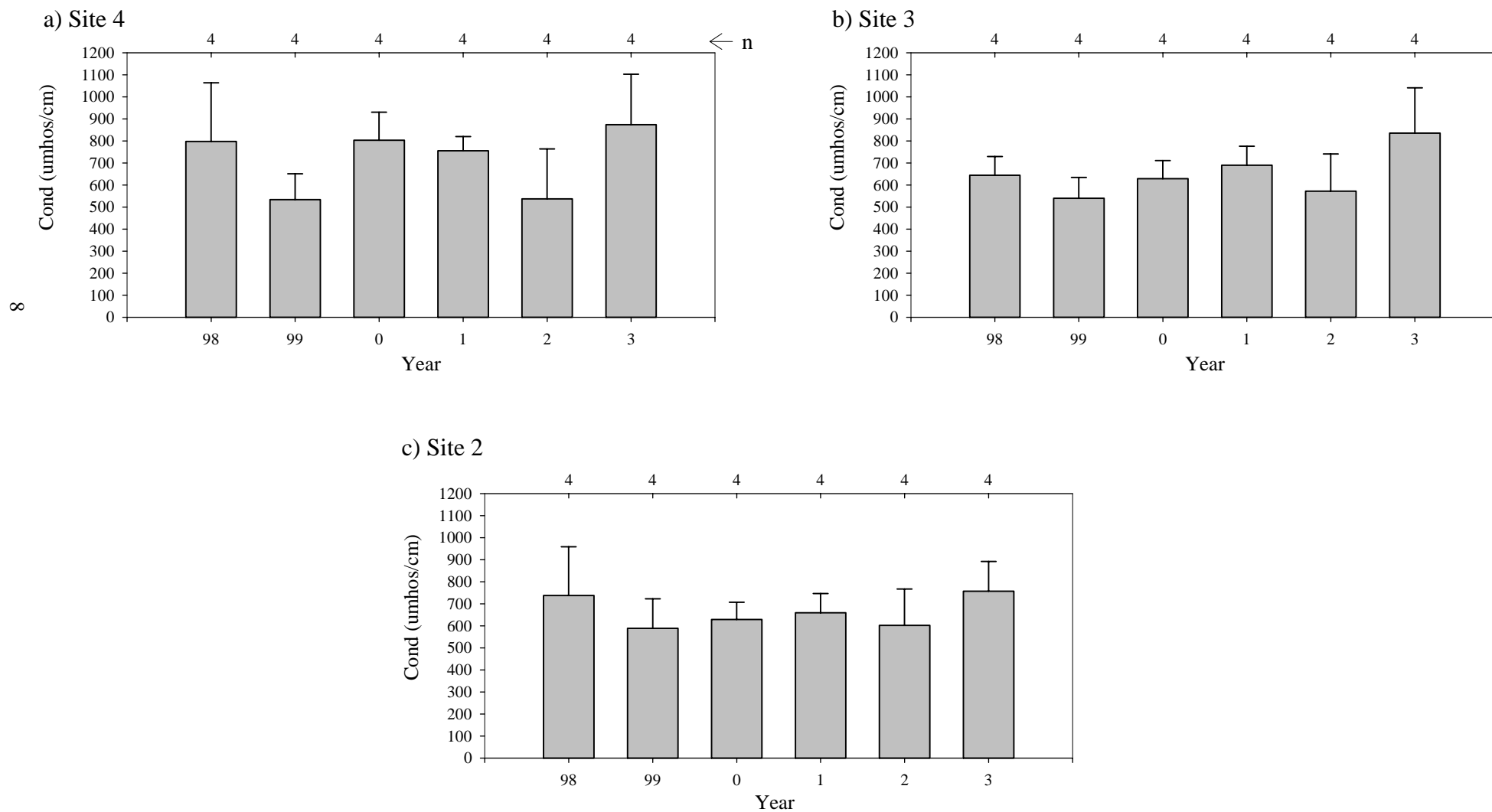


Figure 5. Annual Mean Total Organic Carbon (TOC) Content within the Hillsboro Canal Basin (Florida Department of Environmental Protection WBID 3264) from 1998 to 2003. Yearly means and standard deviations (error bars, concentrations are in milligrams per liter, mg/l) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. Sites are shown in a west to east orientation to show the typical canal flow direction when water control structures are operating.

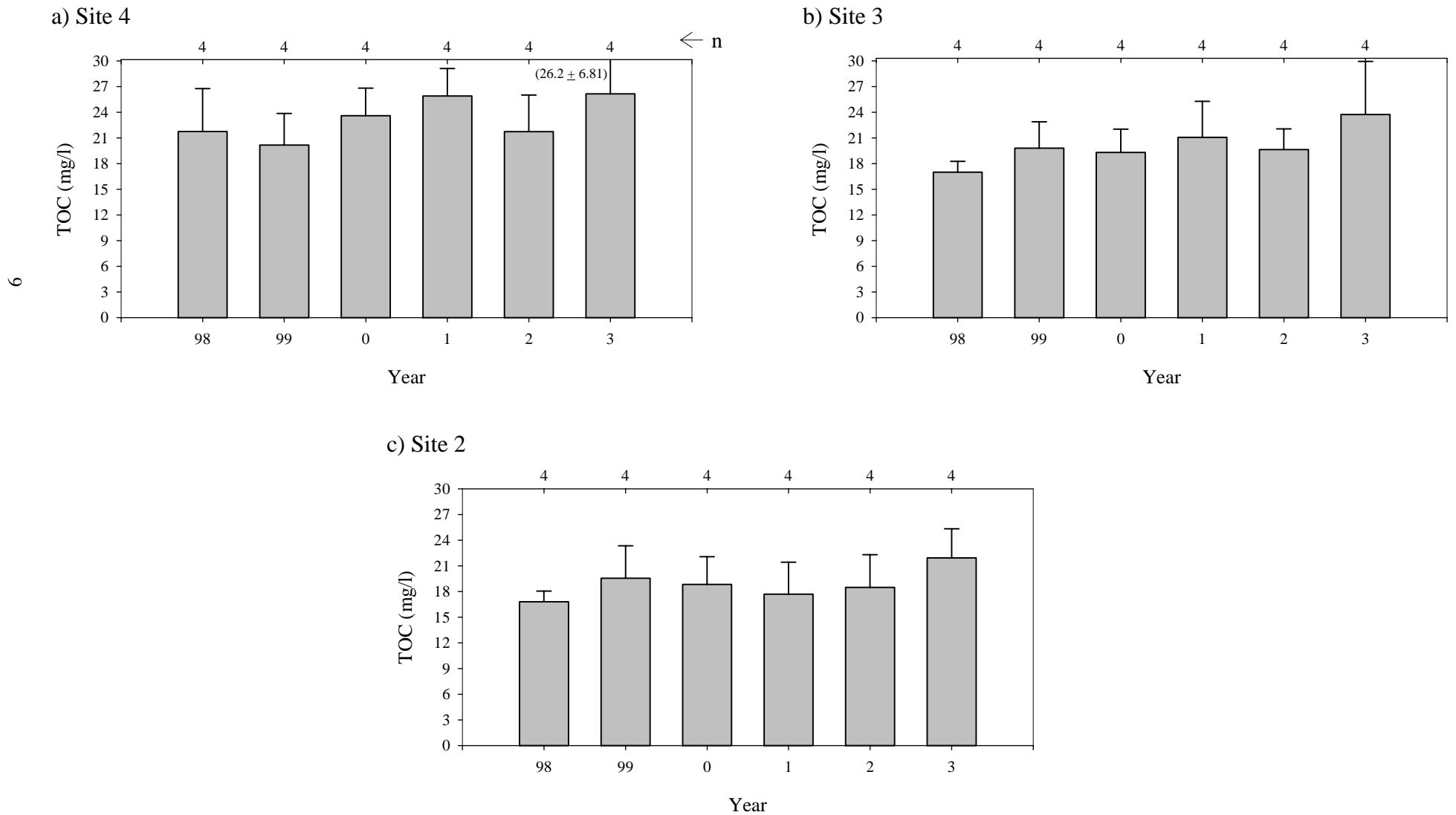
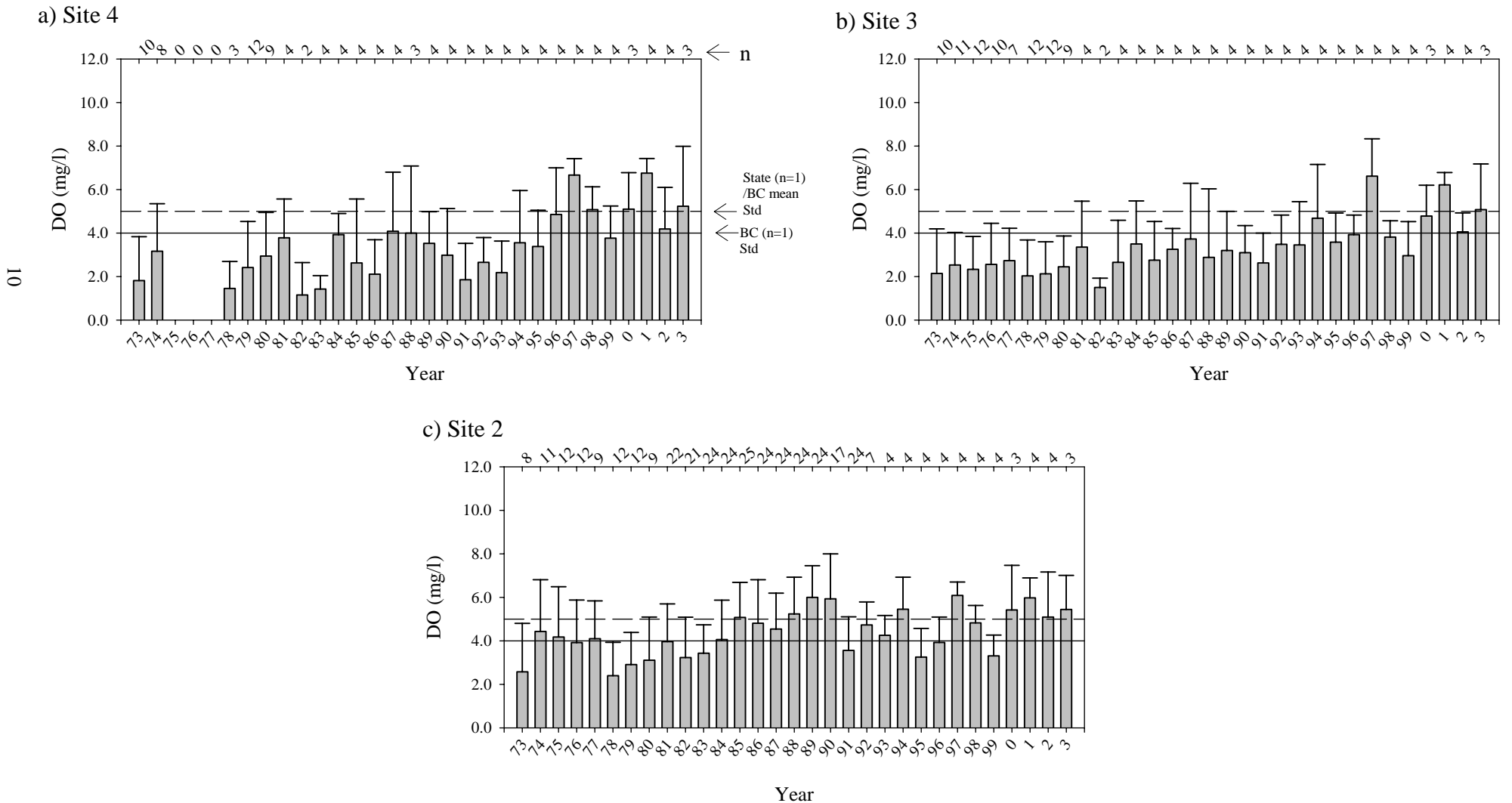


Figure 6. Annual Mean Dissolved Oxygen (DO) Content within the Hillsboro Canal Basin (Florida Department of Environmental Protection WBID 3264) from 1973 to 2003. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county (BC) water quality standards, any sample should be equal to or above 4.0 mg/l (milligrams per liter, solid line), while the daily average should be greater than or equal to 5.0 mg/l (dashed line). State water quality criteria mandate all samples must be greater than or equal to 5.0 mg/l (dashed line). Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.



sites. For Sites 2 and 3 only, depressed DO content was observed in 1998 in that section of the canal (i.e., State Road 7 east to G56, Figure 6). Conversely, Sites 3 and 4 (west of SR 7) showed depressed DO (means near 4.0 mg/l) in 2002 while Site 2 did not.

5. Total Phosphorus

Total phosphorus (TP) values from 1974 to 2003 are shown as these graphs (Figure 7) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). A distinct increase in TP content was observed in the Hillsboro Canal moving from Site 4 to Site 3 (Figure 7). Site 4 had the lowest annual average (0.022 mg/l) for the waterway nearly within compliance of the Broward County surface water quality standard of 0.020 mg/l in 2003 ([Broward County 1996](#)). Site 3 had the maximum annual average (0.122 mg/l) for the Hillsboro Canal from 1998 through 2003. Overall, Site 2 TP concentrations were very similar to Site 3. Since 1995, annual TP levels, at all sites, have generally been lower than observed over the six year period from 1989 until 1994.

6. ortho-Phosphate

The ortho-Phosphate (o-OP₄) observations are made more complex because BCEPD changed its method detection limit (mdl) from 0.030 mg/l to 0.00348 mg/l in 2000. Thus, the use of half the detection limit for samples which were below the mdl in 1998 and 1999 are an order of magnitude higher in concentration than mdls for 2000 through 2003. In addition, the practical quantitation limit, which is the mdl multiplied by four, was also higher by default because of a higher mdl.

For the Hillsboro Canal, Site 4 had three of twelve observations below the mdl in 1998 and 1999 (Figure 8). These were the only occurrence of samples below the mdl in 1998 and 1999 for the entire canal. From 2000 through 2003, eight of the fifteen observations were below the mdl at Site 4, while at Sites 2 and 3 five of the fifteen observations were below the mdl. The o-OP₄ spatial patterns in the canal are similar to TP (see Figure 7) with higher values in the central to eastern stretch (i.e., Sites 2 and 3, Figure 8). Sites 2 and 3 annual averages are also associated with higher variability than Site 4 based on the standard deviations.

7. Total Nitrogen

Total nitrogen (TN) values from 1981 to 2003 are shown as these graphs (Figure 9) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). The TN spatial pattern (Figure 9) over twenty-three years was opposite of the TP pattern (Figure 7) with the highest values being observed at Site 4 and the lowest ones at Site 2. Over the last six years, Sites 2 and 3 had the most consistent compliance of the 1.5 mg/l Broward County water quality standard ([Broward County 1996](#)). Conversely, Site 4 had the highest standard exceedance and typically had higher standard deviations reflecting more intrannual variability than observed at the other

Figure 7. Annual Mean Total Phosphorus (TP) Levels within the Hillsboro Canal Basin (Florida Department of Environmental Protection WBID 3264) from 1974 to 2003. Means and standard deviations (error bars) calculated from biweekly, monthly, and/or quarterly samples with the number of samples (n) noted on the upper x-axis. Numbers in parentheses represent standard deviation outside range of graph. To be within compliance of county environmental regulations, TP levels should be below the Broward County standard (0.02 mg/l) indicated by the dashed line. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

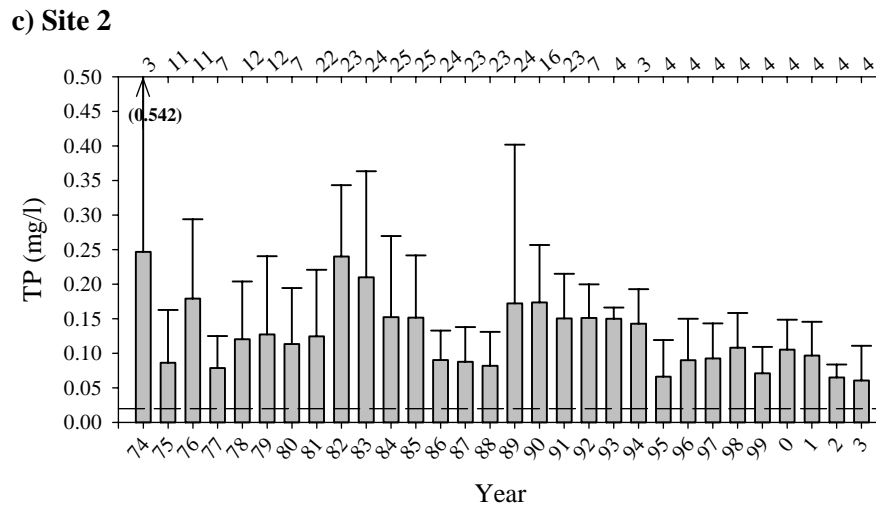
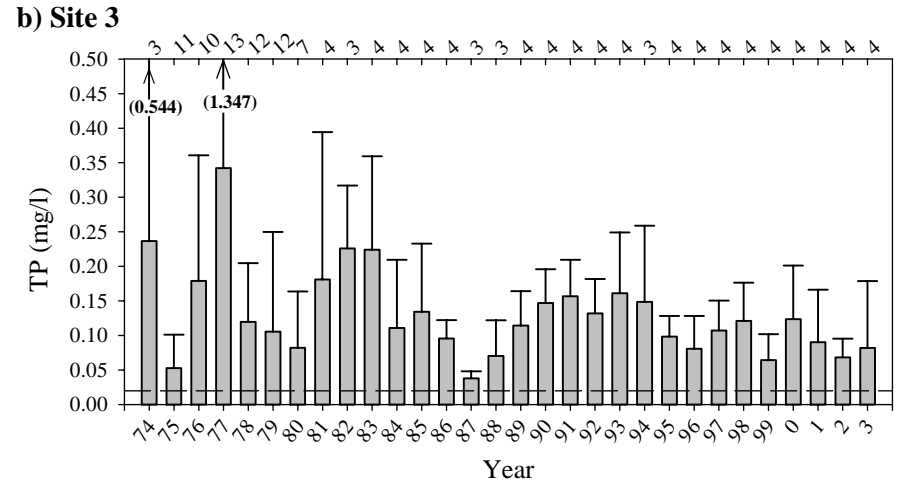
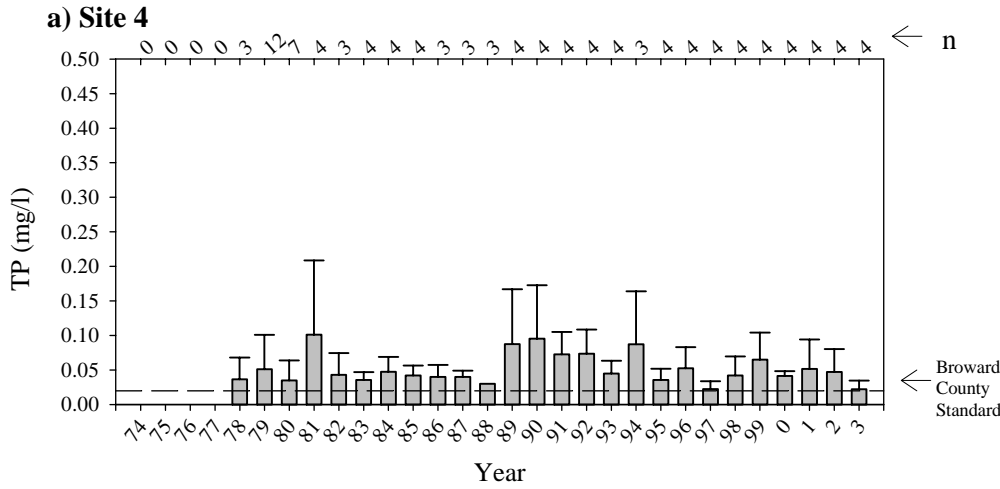


Figure 8. Annual Mean ortho-Phosphate (o-PO₄) Content within the Hillsboro Canal Basin (Florida Department of Environmental Protection WBID 3264) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. The method detection limit changed from 0.030 mg/l to 0.00348 mg/l in 2000. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

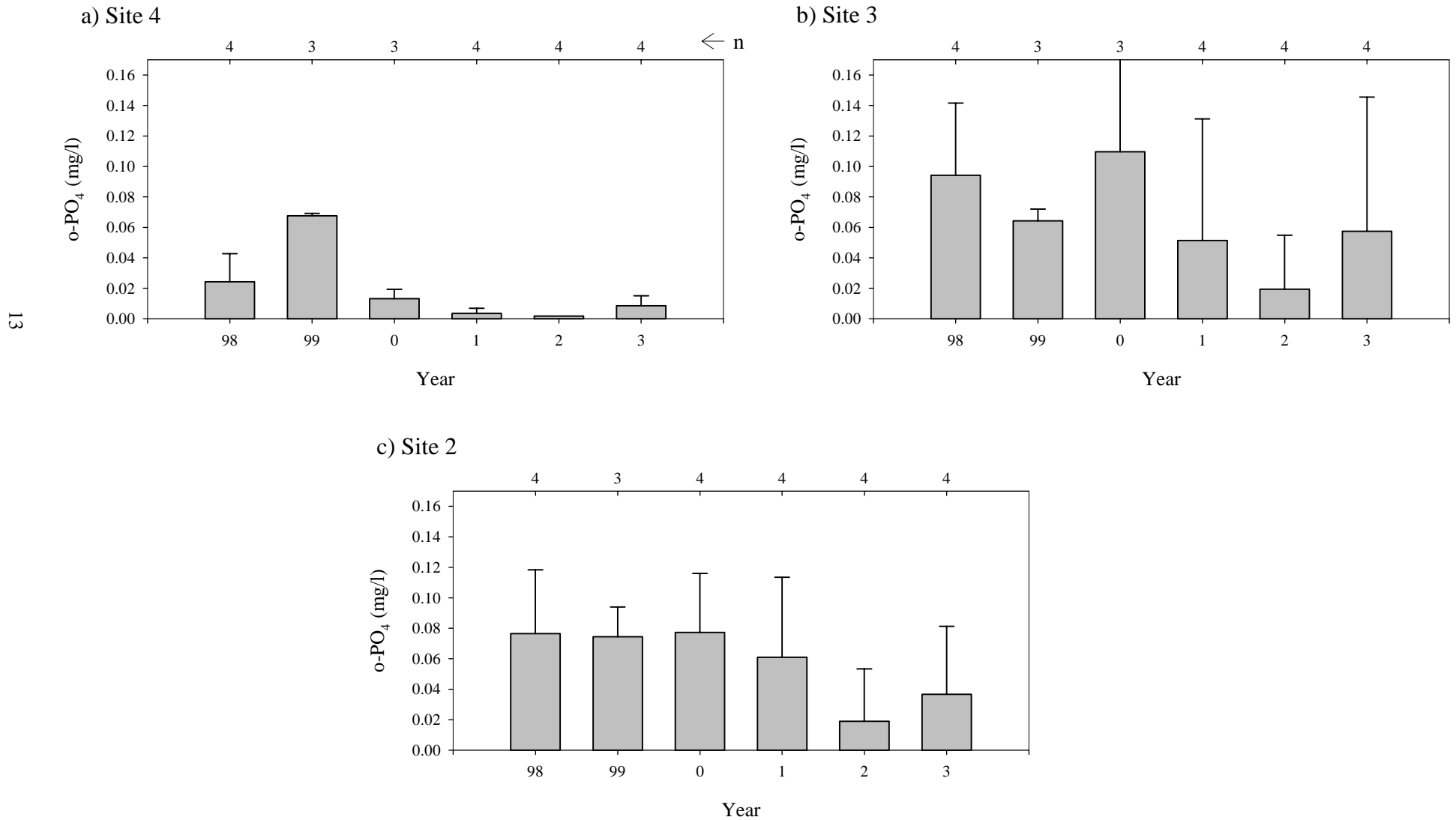
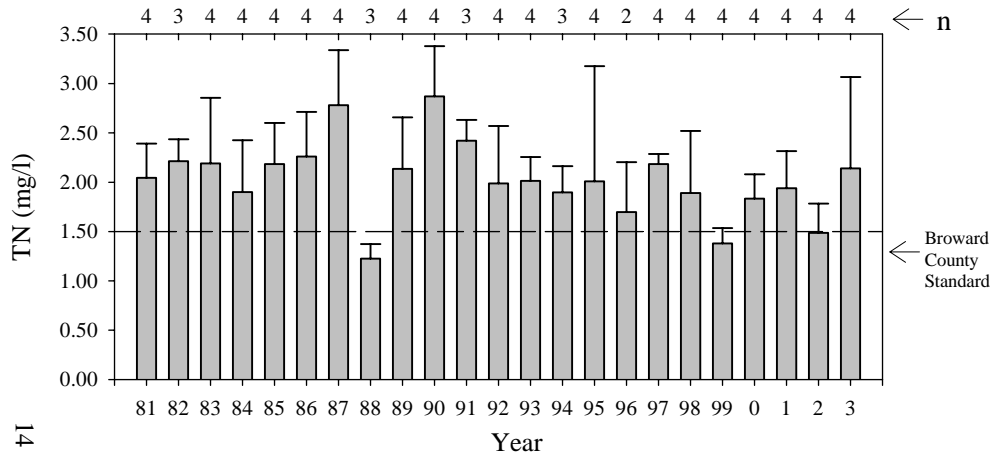
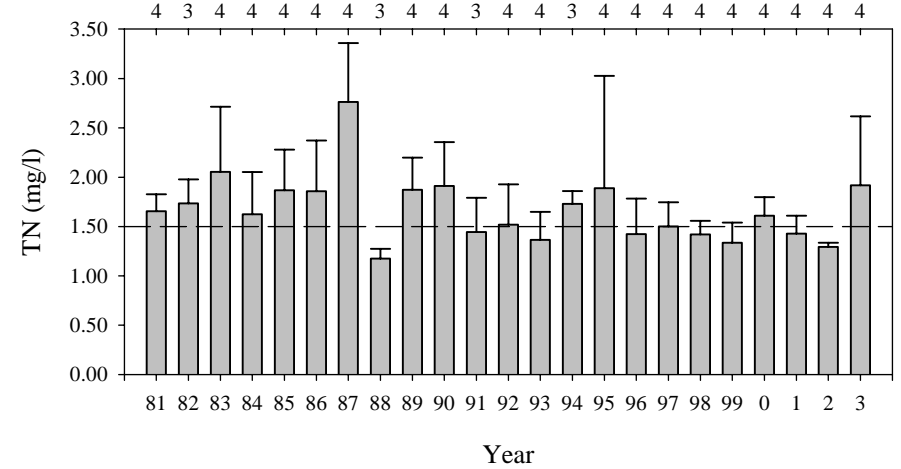


Figure 9. Annual Mean Total Nitrogen (TN) Levels within the Hillsboro Canal Basin (Florida Department of Environmental Protection WBID 3264) from 1981 to 2003. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county environmental regulations, TN levels should be below the Broward County standard (1.50 mg/l) indicated by the dashed line. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

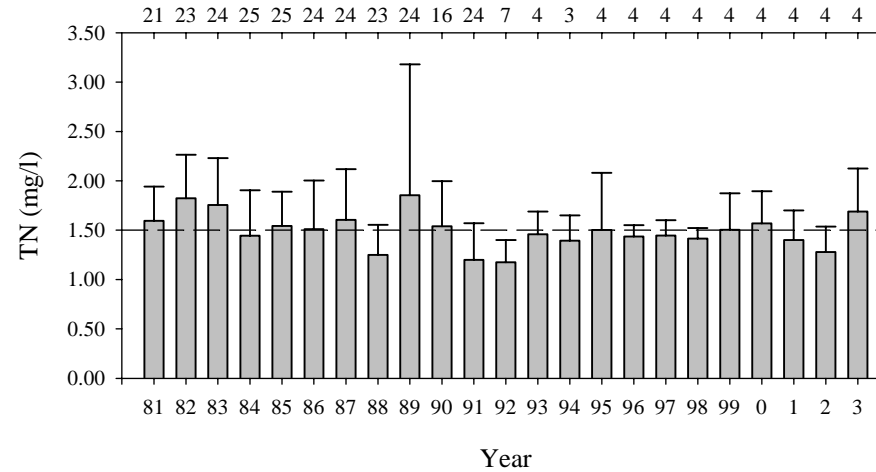
a) Site 4



b) Site 3



c) Site 2



sites. In 1999 and 2002, the entire canal had annual averages within the water quality standard for TN. This had only occurred once (1988) in the previous seventeen years (1981 through 1997).

8. Ammonia-Nitrogen

Ammonia-Nitrogen (NH₃-N) annual averages and variability were higher at Site 4 than the other two Hillsboro Canal sites (Figure 10). The highest annual averages throughout the waterway were observed in 2000 and the lowest was seen in 2002. A clear temporal trend was not observed at any site in NH₃-N content.

9. Nitrite+Nitrate-Nitrogen

Nitrite+Nitrate-Nitrogen (NO₂₊₃) concentrations (Figure 11) were generally higher than corresponding NH₃-N values at Sites 2 and 3 but not Site 4 (see Figure 10). In addition, Sites 2 and 3 exhibited higher inter-annual variability for NO₂₊₃ content than NH₃-N. The lowest annual concentration for NO₂₊₃ was observed in 2002 (similar to TN and NH₃-N) while 1998 and 2003 were characterized by the highest values. However, the 2003 sampling year was characterized by unusually high NO₂₊₃ concentrations (range 0.449 mg/l to 0.517 mg/l) at all three sites on August 8, 2003.

10. Chlorophyll a

Annual chlorophyll a values were typically below the Impaired Waters Rule threshold value for freshwater canals (20 micrograms per liter, ug/l; Florida Department of Environmental Protection, [FDEP 2006b](#), Figure 12). Water bodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients. An exception was observed in 2001 at Site 4 which had an annual average of 40.0 ug/l due in large part to an observation of 91.65 ug/l on July 18, 2001. Intra-annual variability was relatively high at all three sites for most years which suggests seasonal effects and/or water management operations are influencing chlorophyll a content within the canal.

11. Fecal Coliform

Fecal coliform (FC) content from 1973 to 2003 is shown as these graphs (Figure 13) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Most fecal coliform samples were within compliance of county ([Broward County 1996](#)) and state ([FDEP 2006a](#)) environmental regulations with a few exceptional events (e.g., 1995). In particular, 1998 through 2003 was a period of consistently low fecal coliform values throughout the waterway.

Figure 10. Annual Mean Ammonia (NH₃) within the Hillsboro Canal Basin (Florida Department of Environmental Protection WBID 3264) from 1998 to 2003. Means and standard deviations (error bars, concentrations are in milligrams per liter, mg/l) calculated from quarterly sampling with number of samples (n) for each year noted on upper x-axis. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

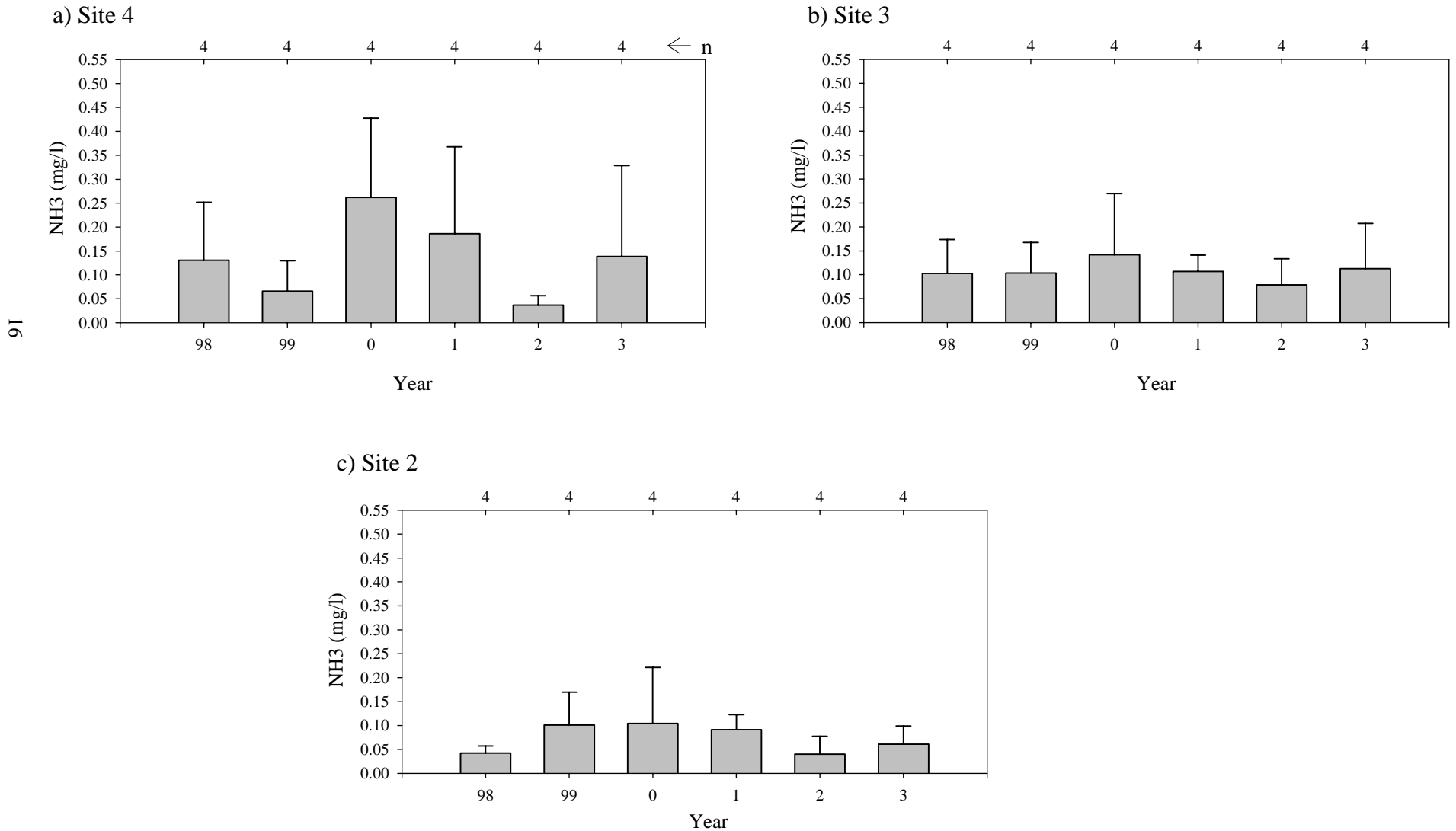


Figure 11. Annual Mean Nitrite+Nitrate-Nitrogen (NO_2+NO_3) Content within the Hillsboro Canal Basin (Florida Department of Environmental Protection WBID 3264) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., $n=4$) unless noted on upper x-axis. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

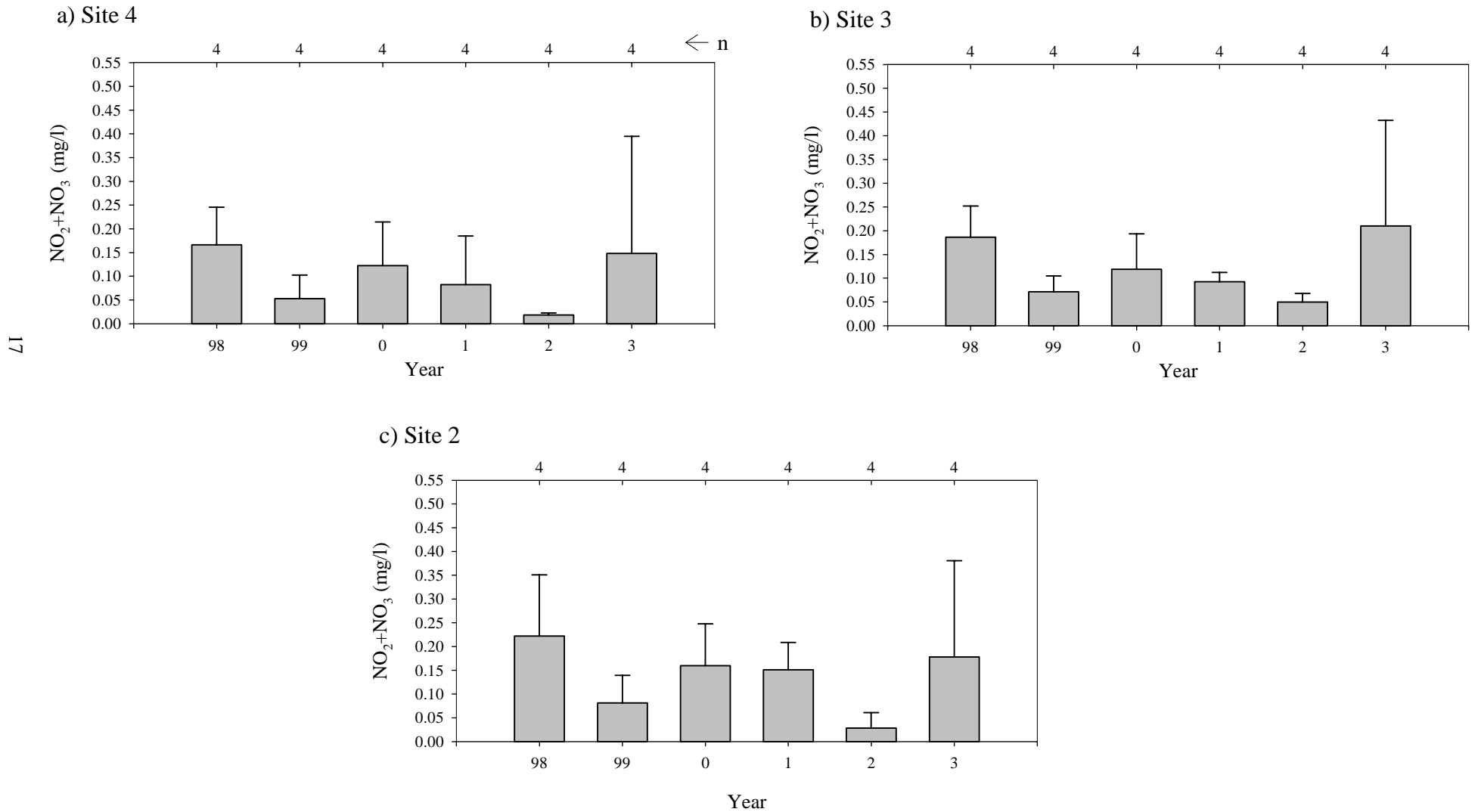
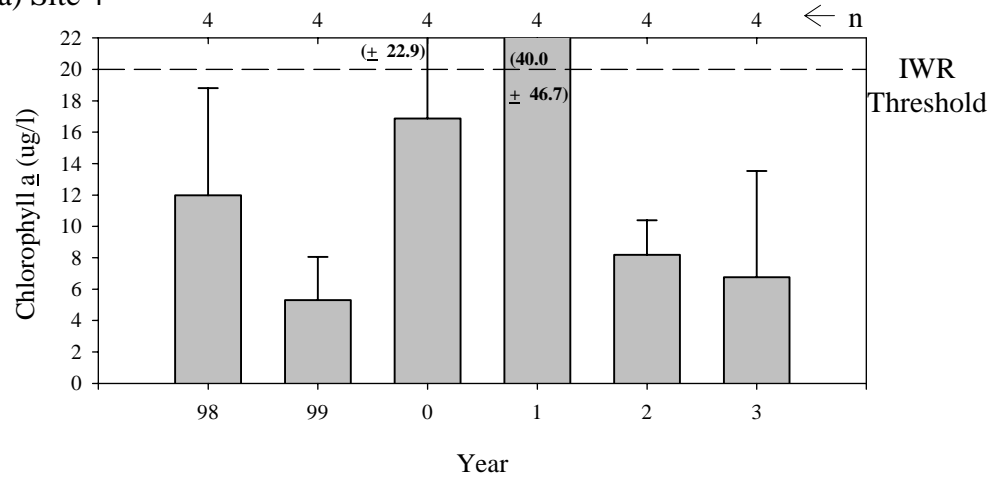
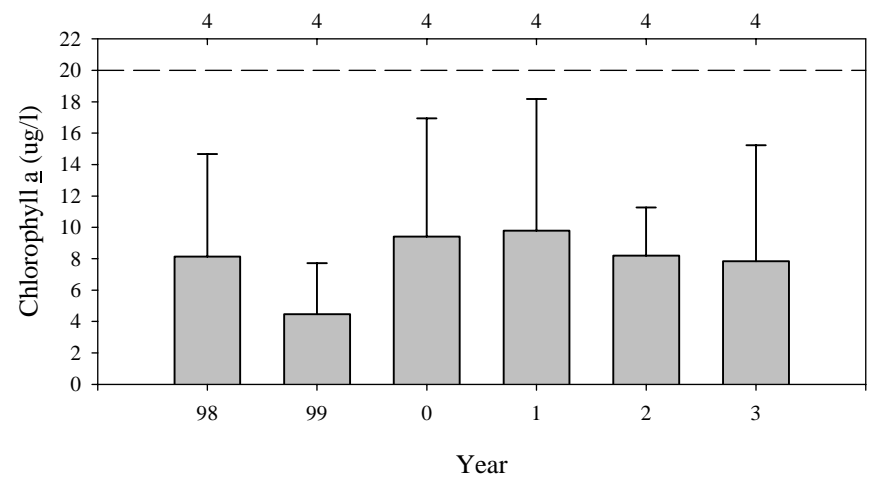


Figure 12. Annual Mean Chlorophyll *a* Levels within the Hillsboro Canal Basin (Florida Department of Environmental Protection, FDEP, WBID 3264) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. The FDEP Impaired Waters Rule (Florida Administrative Code 62-303) chlorophyll *a* threshold value of 20 micrograms per liter (ug/l) is shown by the dashed line. Waterbodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

a) Site 4



b) Site 3



c) Site 2

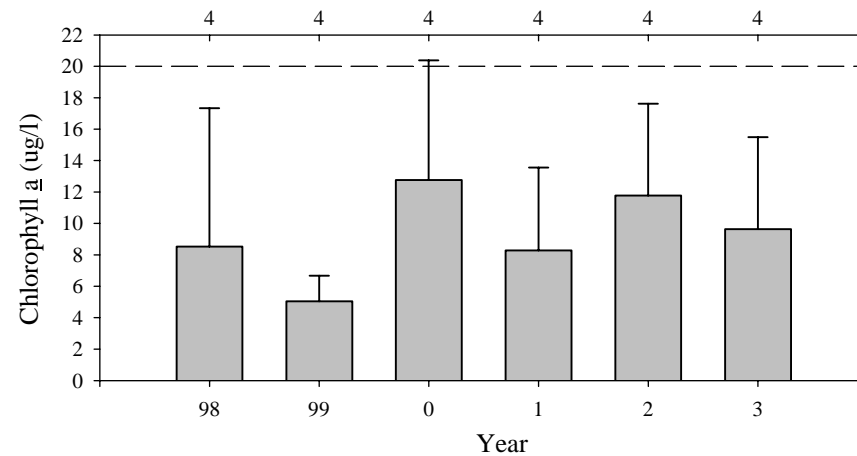
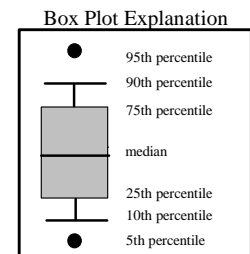
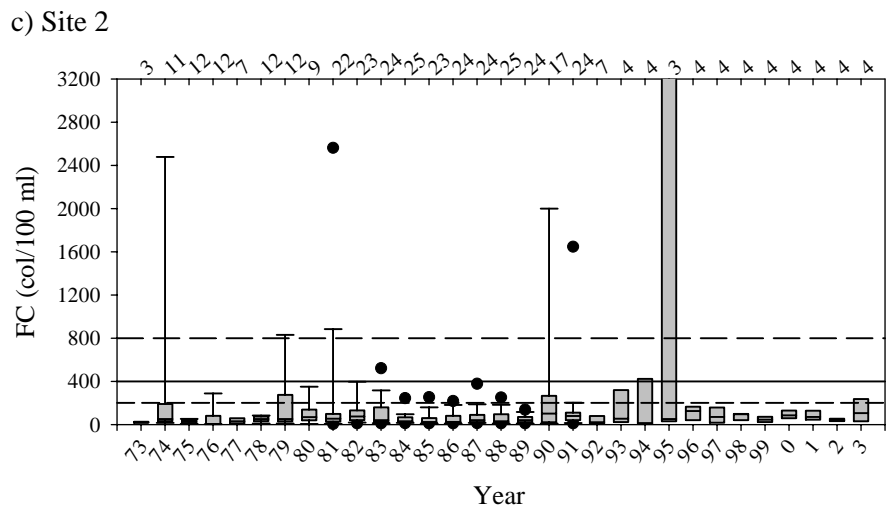
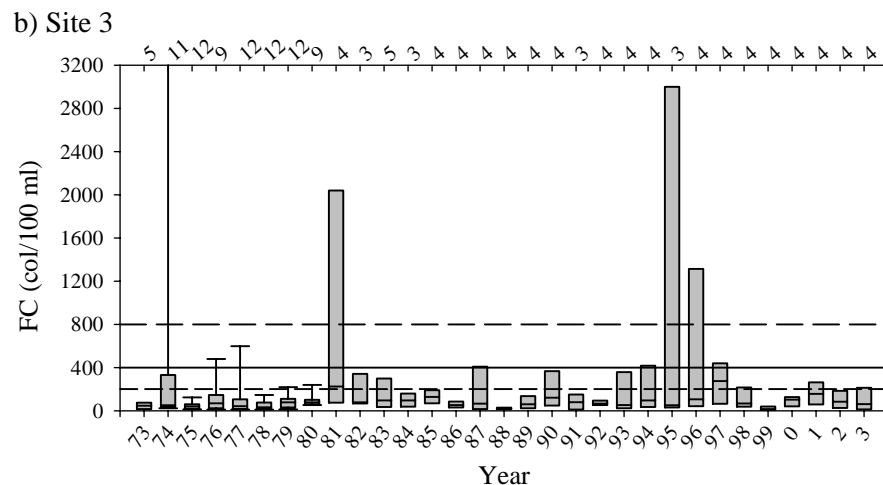
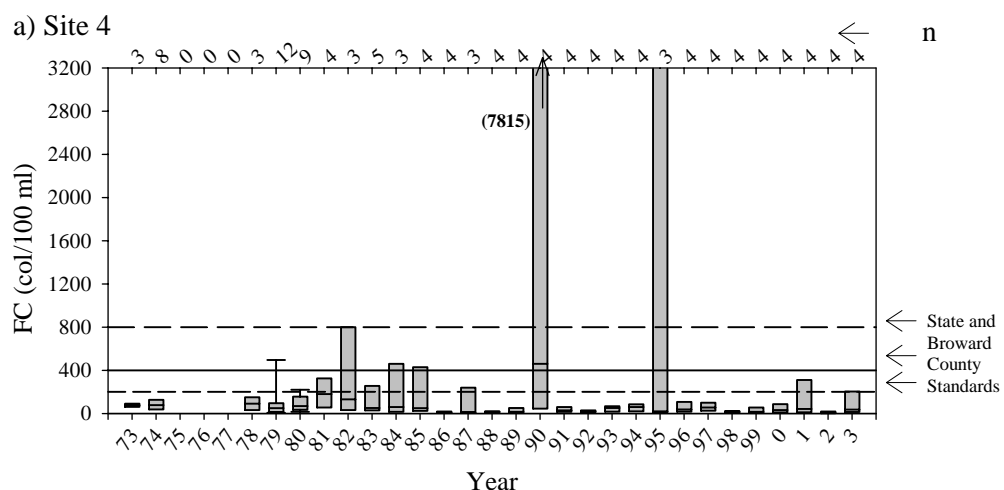


Figure 13. Annual Box Plots of Fecal Coliform (FC) Levels within the Hillsboro Canal Basin (Florida Department of Environmental Protection WBID 3264) from 1973 to 2003. Medians and percentiles calculated from bi-weekly, monthly, and quarterly samples with the number of samples (n) noted on the upper axis. To be within compliance of state and county environmental regulations, levels shall not exceed a monthly average of 200 colonies per 100 milliliters (col/100 ml), nor exceed 400 col/100 ml in 10% of the samples, nor exceed 800 col/100 ml on any one day. Numbers in parentheses represent 75th percentile values that extend beyond y-axis. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.



B. C-14 (Cypress Creek) Canal; Florida Department of Environmental Protection, FDEP, WBID 3270)

1. Basin Description and Sampling Locations

For this chapter, all water quality sampling sites are located in the freshwater section of the C-14 Canal between SFWMD structures S38A and S37A without direct tidal influence by surface waters (Figure 14). The C-14 Canal is divided into two freshwater segments by the S37B. Global Position System coordinates and specific site descriptions are given in Appendix 1.

Broward County Environmental Protection Department's (BCEPD) Site 89 represents the western portion of the C-14 study area and monitors the influence of incoming water from Water Conservation Area 2. Due to bridge construction at Site 8, BCEPD started to monitor Site 109 in October 1998. Site 9 monitoring was halted in 1998 as Site 109 was seen as suitable for covering this geographical area. Site 7 represents the first site downstream of S37B and is also surrounded by a golf course. Site 6 lies directly west of the coastal salinity structure S37A and monitors the water quality eventually discharged during times of flow to the estuary.

2. Specific Conductance

Annual mean specific conductance values generally ranged from 600 to 800 micromhos per centimeter (Figure 15). The year of 2003 had the highest peak for three sites (6, 7 and 109) and also had the highest standard deviation. The lowest values downstream of S37B were observed in 1999 while the lowest concentrations upstream were seen in 2000.

3. Total Organic Carbon

Annual total organic carbon (TOC) values decreased from west to east within the C-14 Canal (Figure 16). In general, annual means upstream of S37B were greater than 20.0 milligrams per liter (mg/l) while values below S37B (Sites 6 and 7) were typically below 20 mg/l. In 2001, the highest TOC values were observed in the western extent of the canal (Sites 89 and 109) but this year also showed the highest variability.

4. Dissolved Oxygen

Dissolved oxygen (DO) values from 1973 to 2003 are shown as these graphs (Figure 17) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Annual DO averages have generally shown compliance with local and state water quality standards. The state water quality criteria states no values should be below 5.0 mg/l while Broward County standards state no single value should be below 4.0 mg/l and the daily average 5.0 mg/l. Some of the highest values for the C-14 Canal were seen in 2001 and 2002 while the lowest annual averages below state criteria were observed in 1999.

Figure 14. Broward County Environmental Protection Department's Surface Water Quality Monitoring Sites on the Freshwater C-14/Cypress Creek Canal. The western portion of the C-14 Canal drainage basin is depicted by white and the eastern basin by the yellow color. Freshwater sampling site numbers 8, 9, 89, and 109 are northwest of the South Florida Water Management District's (SFWMD) water control structure, S37B. Sampling Sites 6 and 7 are south and east of S37B and west of the SFWMD coastal salinity structure S37A. Major cities in both sub-basins are labeled and depicted with the orange outline.

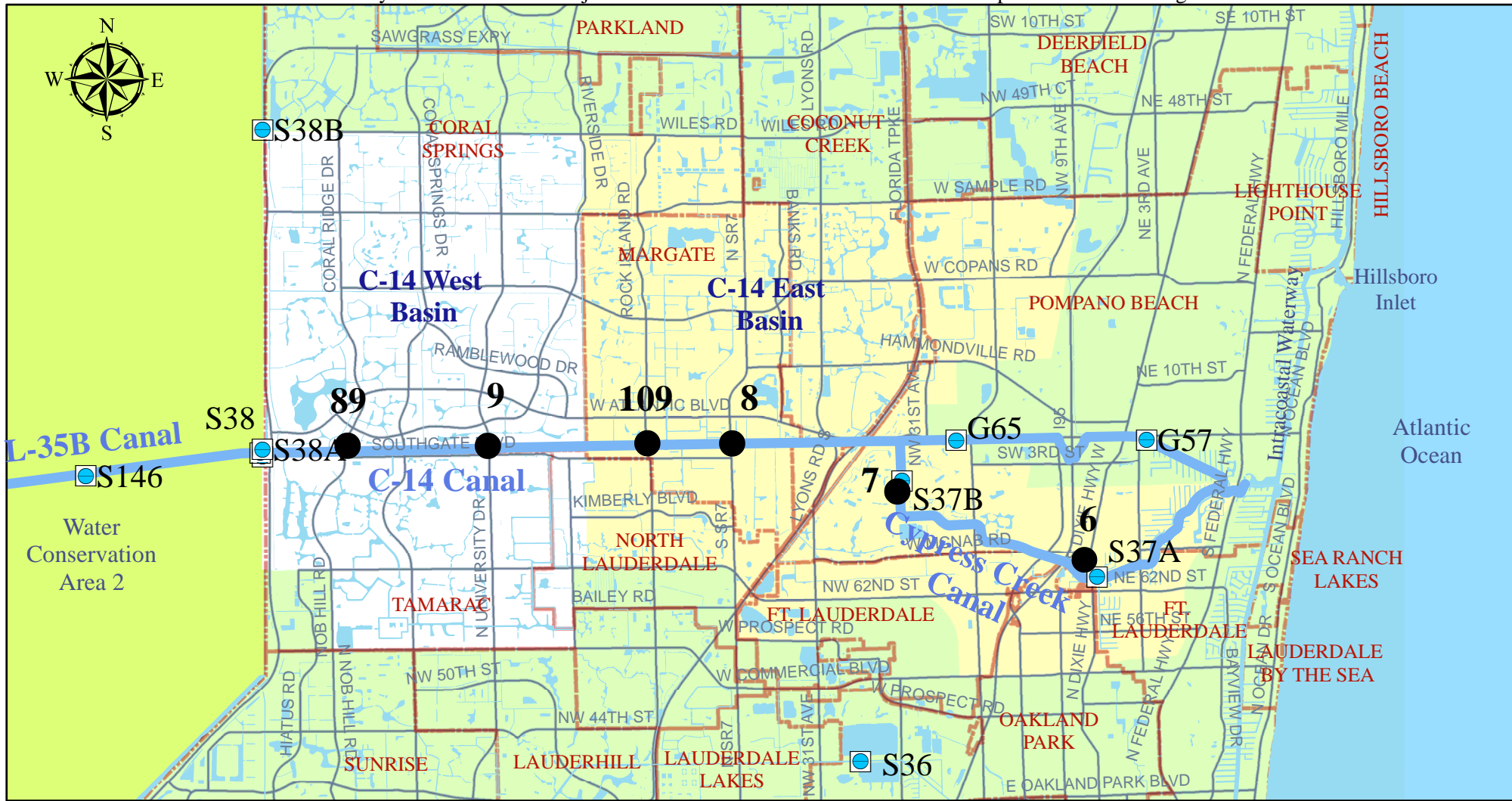


Figure 15. Annual Mean Specific Conductance (Cond) Levels within the C-14 Canal Basin (Florida Department of Environmental Protection WBID 3270) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis and values are shown in micromhos per centimeter (umhos/cm) at 25 degrees Celsius. Sites are shown in a west to east orientation to show the typical canal flow direction when water control structures are operating. Sampling halted at Sites 8 and 9 after 1998.

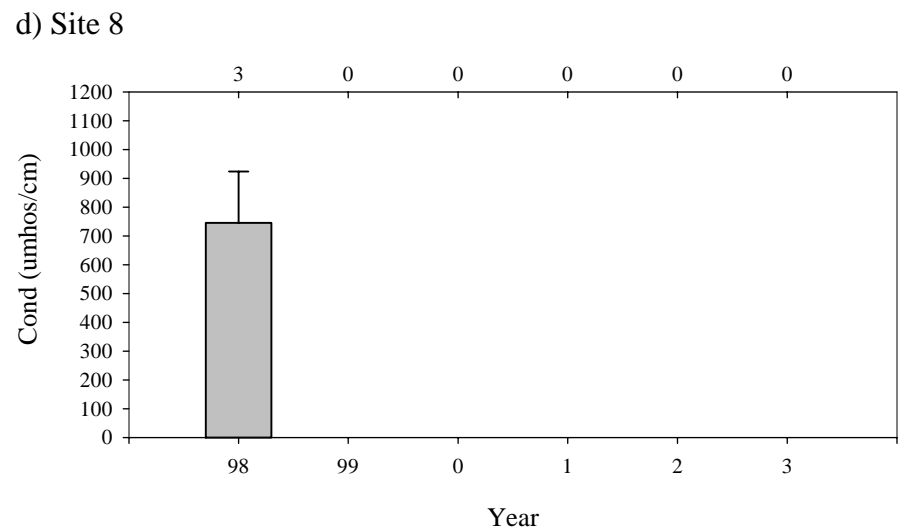
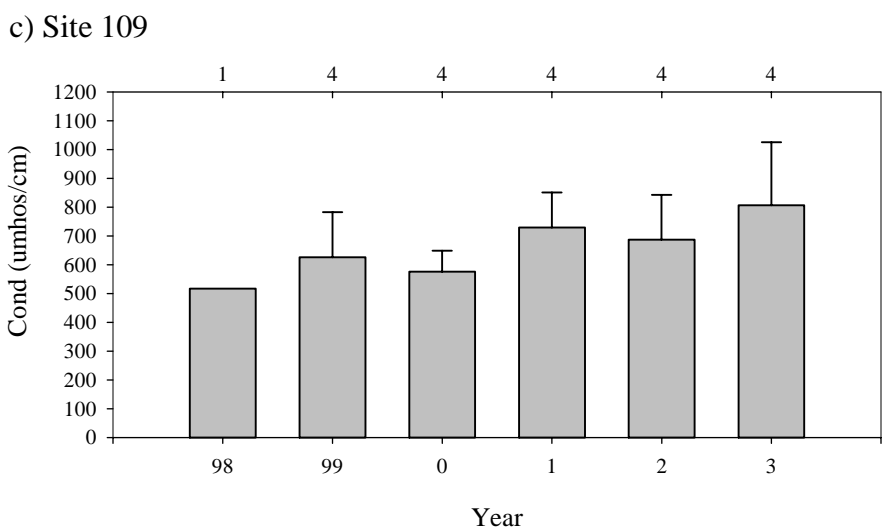
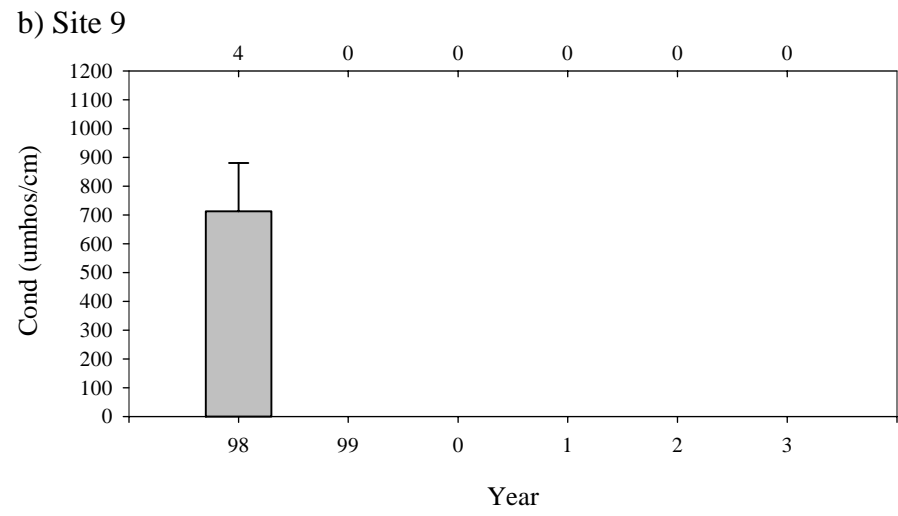
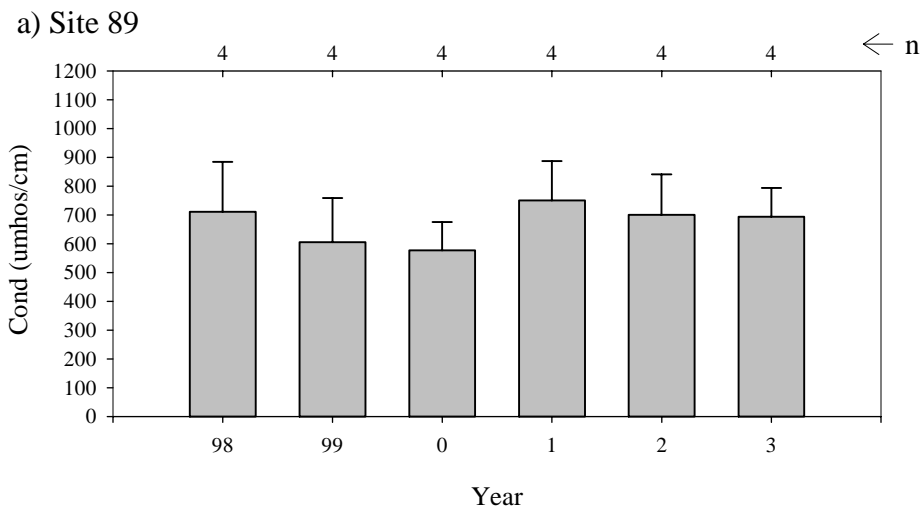
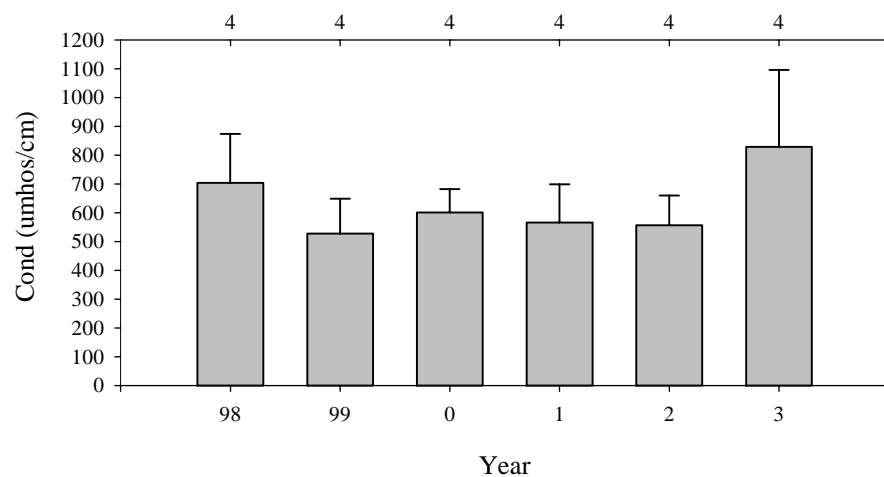


Figure 15 (cont.). Annual Mean Specific Conductance (Cond) Levels within the C-14 Canal Basin (Florida Department of Environmental Protection WBID 3270) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis and values are shown in micromhos per centimeter (umhos/cm) at 25 degrees Celsius. Sites are shown in a west to east orientation to show the typical canal flow direction when water control structures are operating.

e) Site 7



f) Site 6

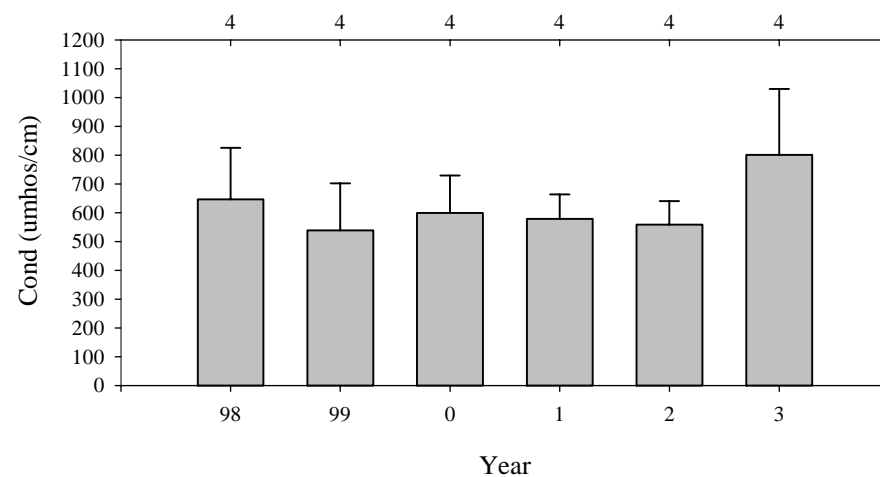


Figure 16. Annual Mean Total Organic Carbon (TOC) Content within the C-14 Canal Basin (Florida Department of Environmental Protection WBID 3270) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. Sites are shown in a west to east orientation to show the typical canal flow direction when water control structures are operating. Sampling halted at Sites 8 and 9 after 1998.

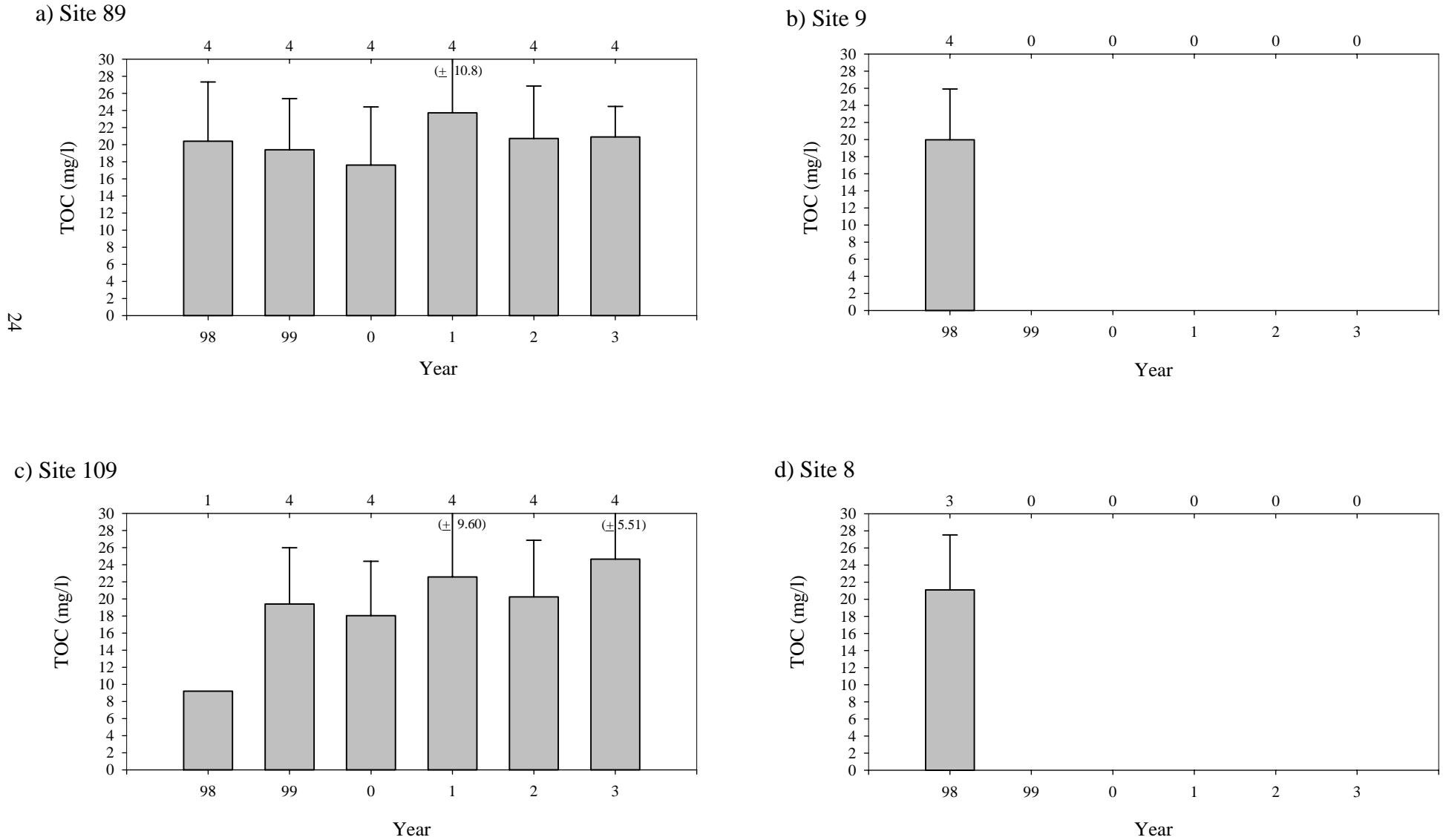
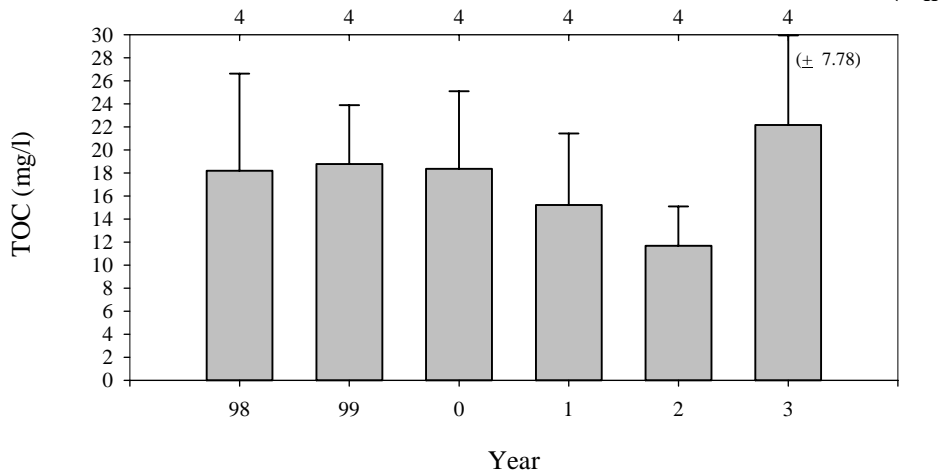


Figure 16 (cont.). Annual Mean Total Organic Carbon (TOC) Content within the C-14 Canal Basin (Florida Department of Environmental Protection WBID 3270) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. Sites are shown in a west to east orientation to show the typical canal flow direction when water control structures are operating. Sampling halted at Sites 8 and 9 after 1998.

e) Site 7



f) Site 6

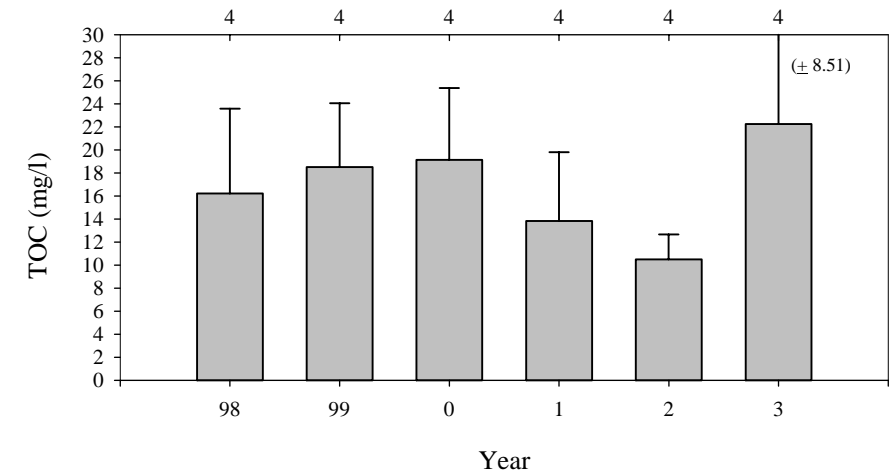
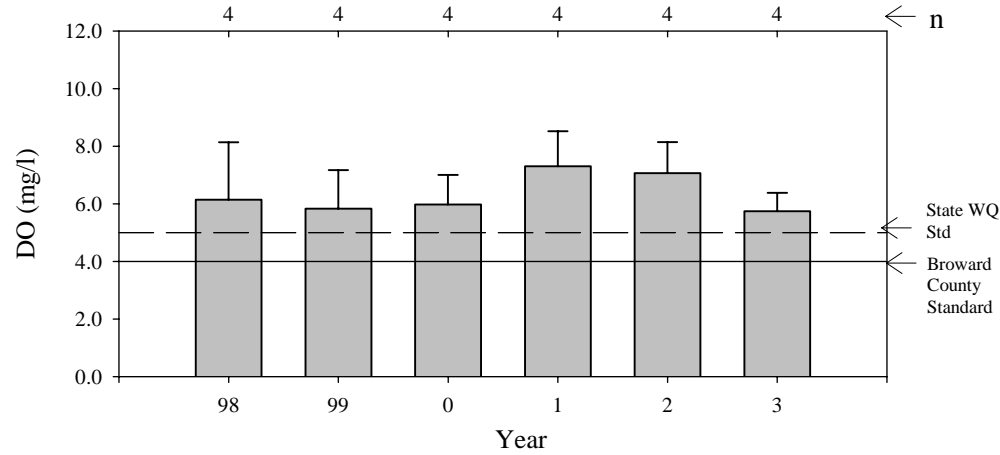
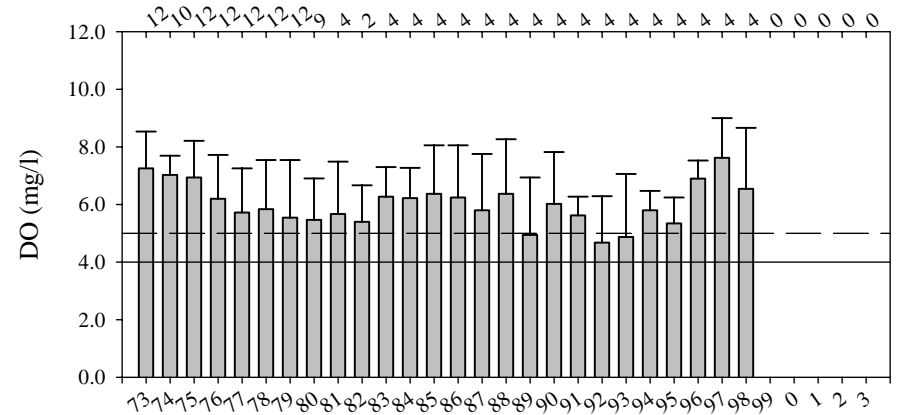


Figure 17. Annual Mean Dissolved Oxygen (DO) Content within the C-14 Canal Basin (Florida Department of Environmental Protection WBID 3270) from 1973 to 2003. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county (BC) water quality standards, any sample should be equal to or above 4.0 mg/l (solid line), while the daily average should be greater than or equal to 5.0 mg/l (dashed line). State water quality criteria mandate all samples must be greater than or equal to 5.0 mg/l (dashed line). Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

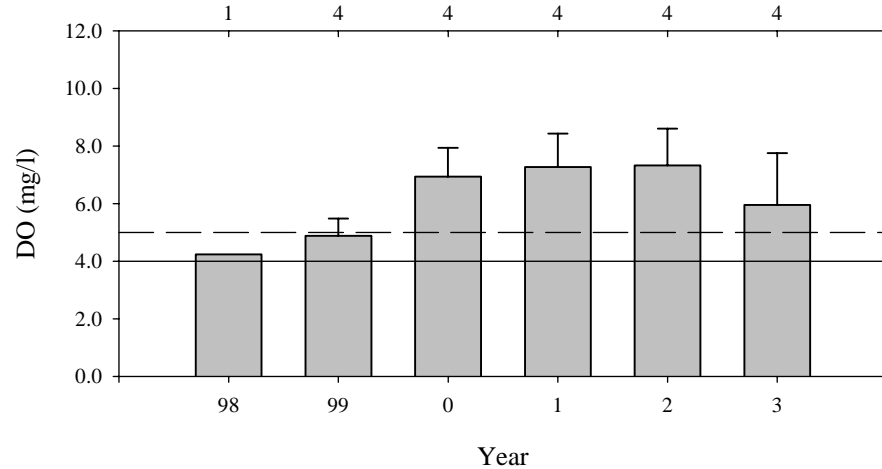
a) Site 89



b) Site 9



c) Site 109



d) Site 8

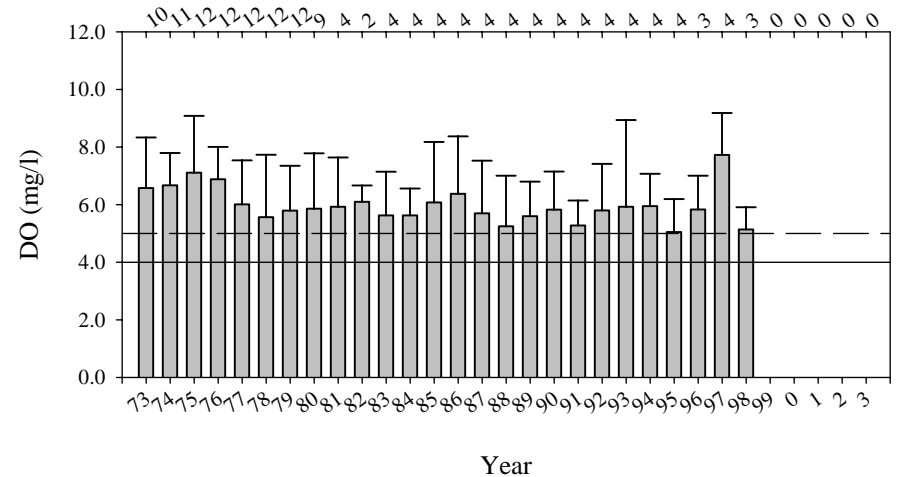
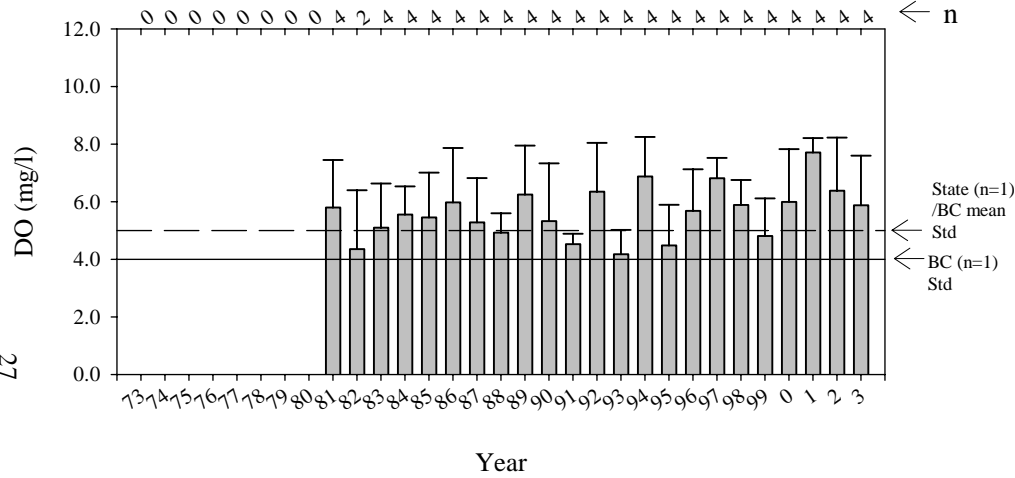
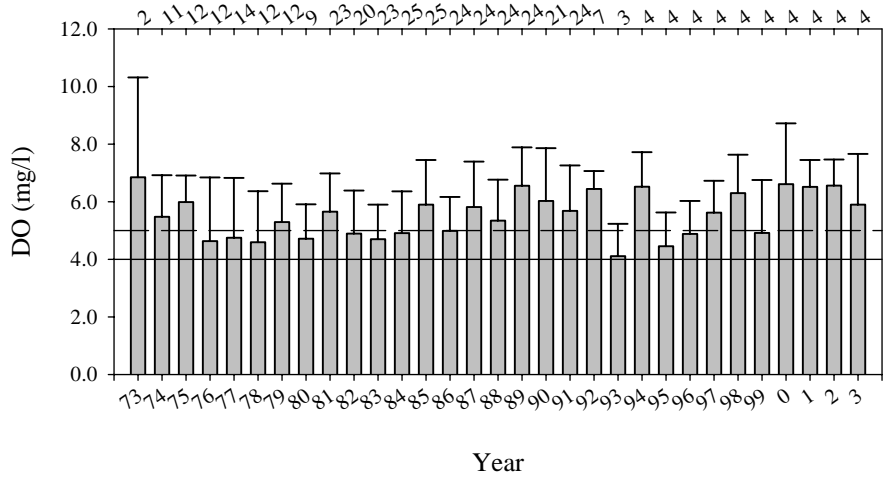


Figure 17 (cont.). Annual Mean Dissolved Oxygen (DO) Content within the C-14 Canal Basin (Florida Department of Environmental Protection WBID 3270) from 1973 to 2003. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county (BC) water quality standards, any sample should be equal to or above 4.0 mg/l (solid line), while the daily average should be greater than or equal to 5.0 mg/l (dashed line). State water quality criteria mandate all samples must be greater than or equal to 5.0 mg/l (dashed line). Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

e) Site 7



f) Site 6



5. Total Phosphorus

Total phosphorus (TP) values from 1974 to 2003 are shown as these graphs (Figure 18) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). These data show the distinct change in C-14 canal TP levels 1987 when the practice of discharging secondarily treated human wastewater to the canal ceased. Since 1998, TP values upstream of S37B were typically lower than values downstream. Site 109 was the only site exhibiting annual averages below or nearly below the compliance level of 0.02 mg/l. In contrast, Sites 6 and 7 annual TP means were typically twice the local standard.

6. ortho-Phosphate

The ortho-Phosphate (o-OP₄) observations (Figure 19) are made more complex because BCEPD changed its method detection limit (mdl) from 0.030 mg/l to 0.00348 mg/l in 2000. Thus, the use of half the detection limit for samples which were below the mdl in 1998 and 1999 are an order of magnitude higher in concentration than mdls for 2000 through 2003. In addition, the practical quantitation limit, which is the mdl multiplied by four, was also higher by default because of a higher mdl.

Even with the change of detection limits, the o-OP₄ values (Figure 19) generally tracked the same pattern as TP (Figure 18) with the highest values observed downstream of S37B. In fact after the change in methodology, o-PO₄ content upstream of S37B was almost nonexistent. Downstream of S37B (Sites 6 and 7) detectable concentrations were seen more often than at the upstream sites.

7. Total Nitrogen

Total nitrogen (TN) values from 1981 to 2003 are shown as these graphs (Figure 20) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Similar to TP, the total nitrogen (TN) pattern over these twenty-three years reflects the influence of secondarily treated human wastewater discharges (pre-1988) with higher TN concentrations existing before 1987. The year 2003 showed a relative spike in TN content at all sites. The annual increase was most dramatically observed at sites downstream of S37B (Sites 6 and 7). Besides 2003, the whole waterway had annual averages typically within the water quality standard for TN (1.5 mg/l), however, the standard deviations around the mean demonstrate exceedances do occur almost every year.

8. Ammonia-Nitrogen

Ammonia-Nitrogen (NH₃-N) annual averages and standard deviations (i.e., variability) were higher downstream of S37B than upstream (Figure 21). Over time, the NH₃-N content was fairly consistent at each site, however slight elevations were observed at Sites 6 and 7 in 2003.

Figure 18. Annual Mean Total Phosphorus (TP) Levels within the C-14 Canal Basin (Florida Department of Environmental Protection WBID 3270) from 1974 to 2003. Means and standard deviations (error bars) calculated from biweekly, monthly, and/or quarterly samples with the number of samples (n) noted on the upper x-axis. Numbers in parentheses represent standard deviation outside range of graph. To be within compliance of county environmental regulations, TP levels should be below the Broward County standard (0.02 mg/l) indicated by the dashed line. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow. Sampling halted at Sites 8 and 9 after 1998.

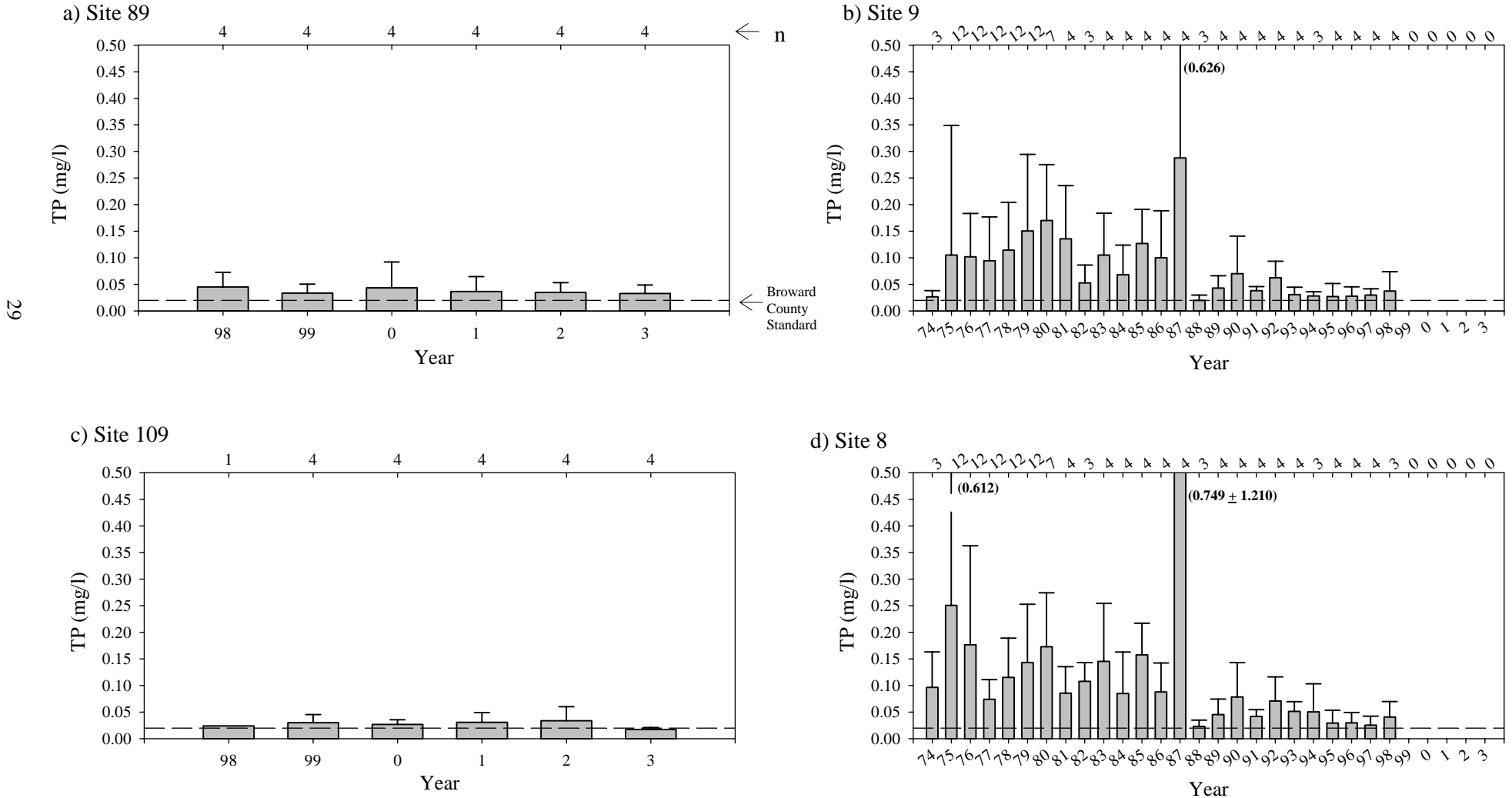
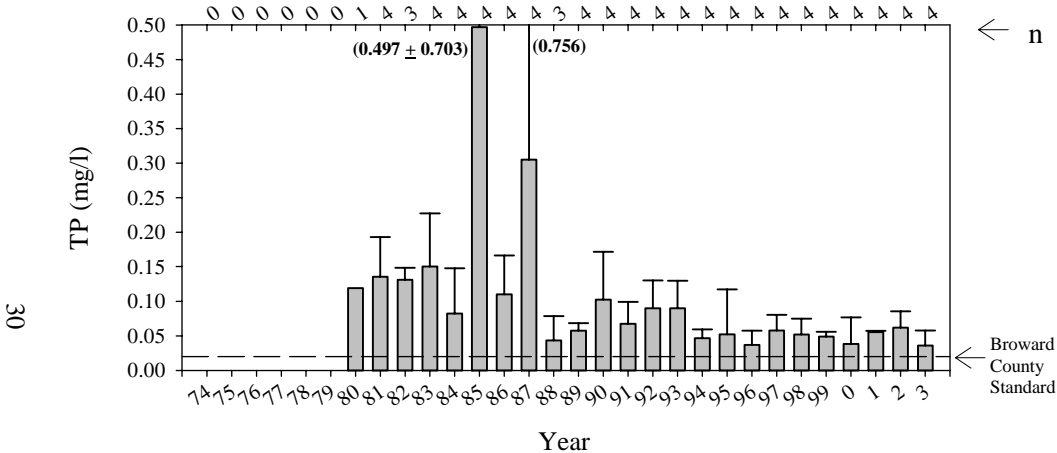


Figure 18 (cont.). Annual Mean Total Phosphorus (TP) Levels within the C-14 Canal Basin (Florida Department of Environmental Protection WBID 3270) from 1974 to 2003. Means and standard deviations (error bars) calculated from biweekly, monthly, and/or quarterly samples with the number of samples (n) noted on the upper x-axis. Numbers in parentheses represent standard deviation outside range of graph. To be within compliance of county environmental regulations, TP levels should be below the Broward County standard (0.02 mg/l) indicated by the dashed line. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

e) Site 7



f) Site 6

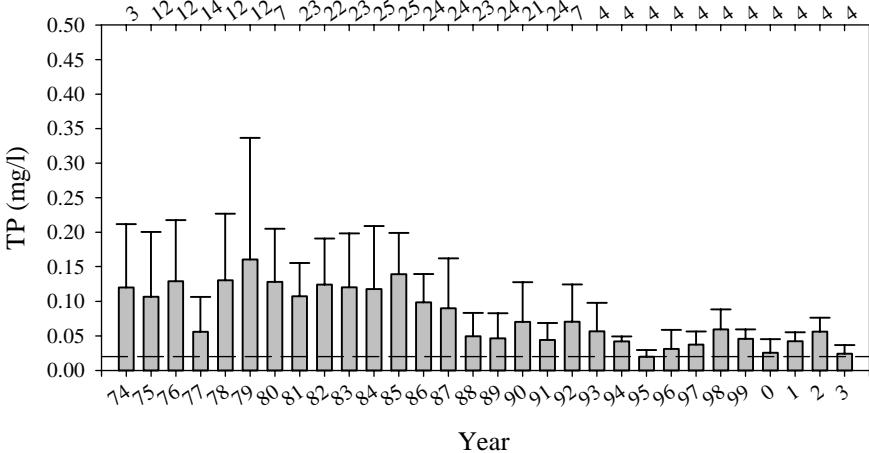
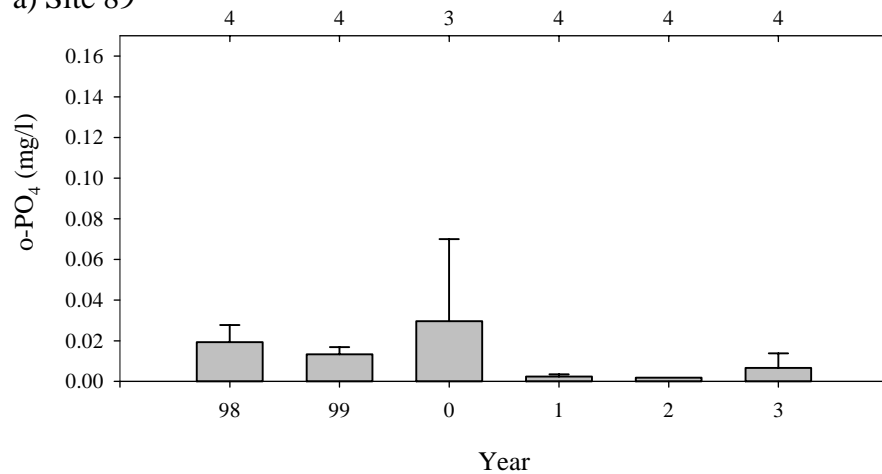
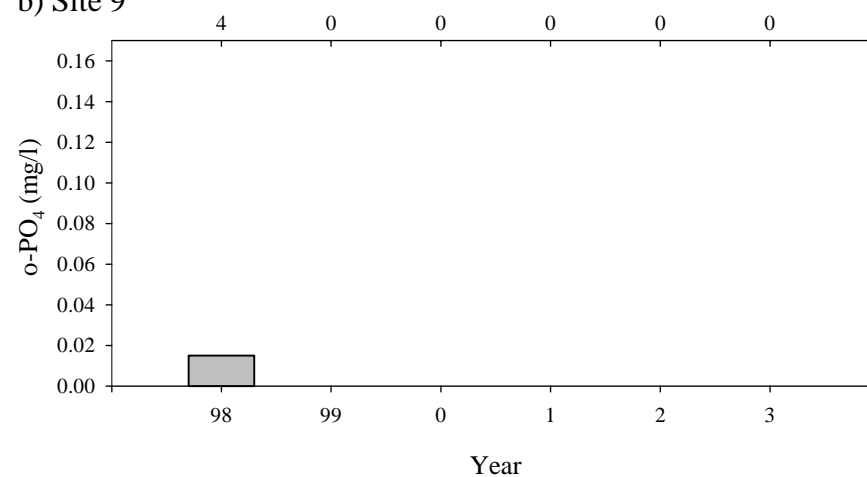


Figure 19. Annual Mean ortho-Phosphate (o-PO₄) Content within the C-14 Canal Basin (Florida Department of Environmental Protection WBID 3270) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. The method detection limit changed from 0.030 mg/l to 0.00348 mg/l in 2000. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow. Sampling halted at Sites 8 and 9 after 1998.

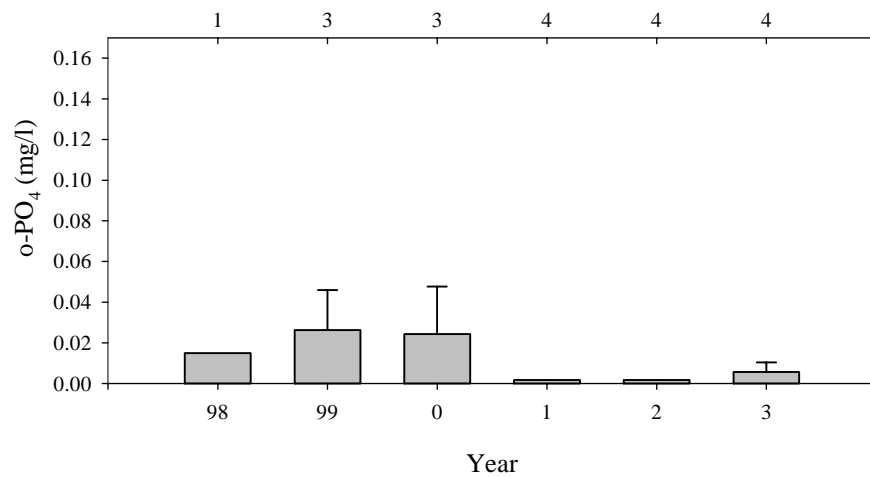
a) Site 89



b) Site 9



c) Site 109



d) Site 8

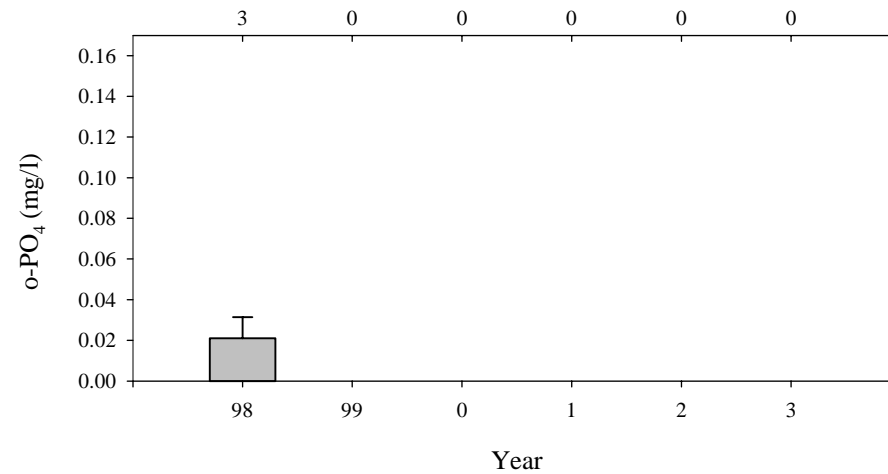
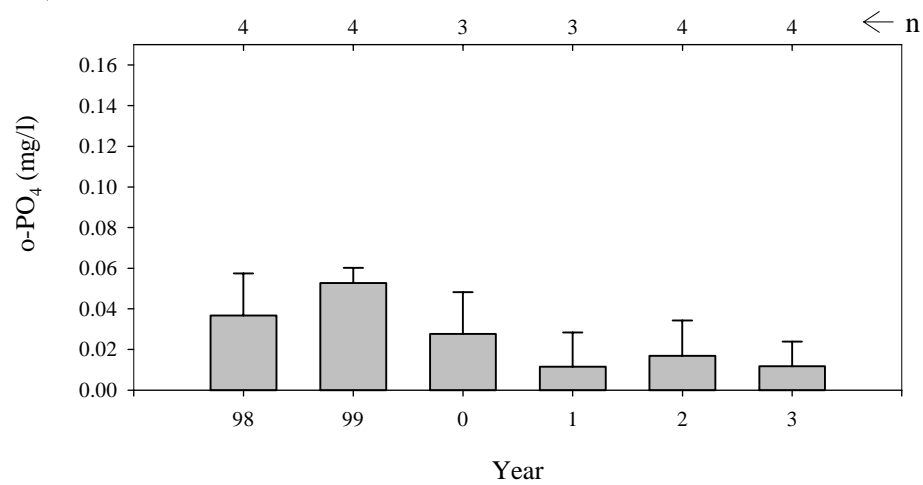


Figure 19 (cont.). Annual Mean ortho-Phosphate (o-PO₄) Content within the C-14 Canal Basin (Florida Department of Environmental Protection WBID 3270) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. The method detection limit changed from 0.030 mg/l to 0.00348 mg/l in 2000. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

e) Site 7



f) Site 6

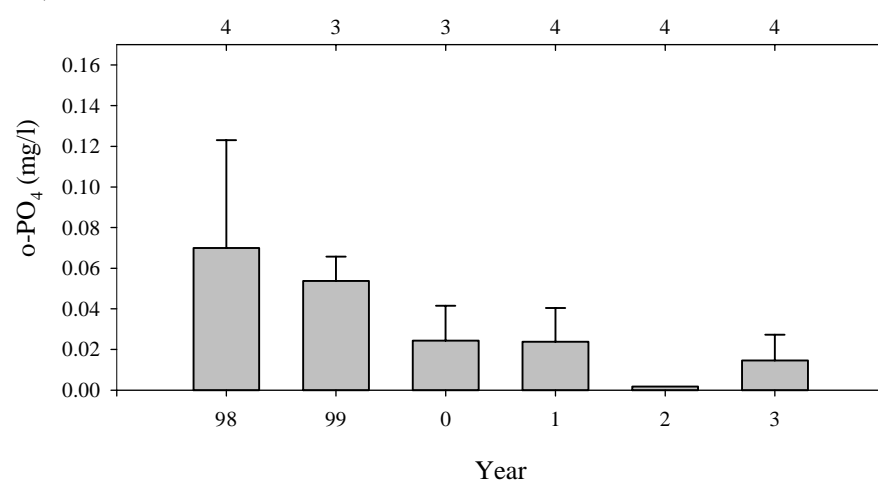


Figure 20. Annual Mean Total Nitrogen (TN) Levels within the C-14 Canal Basin (Florida Department of Environmental Protection WBID 3270) from 1981 to 2003. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county environmental regulations, TN levels should be below the Broward County standard (1.50 mg/l) indicated by the dashed line. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow. Sampling halted at Sites 8 and 9 after 1998.

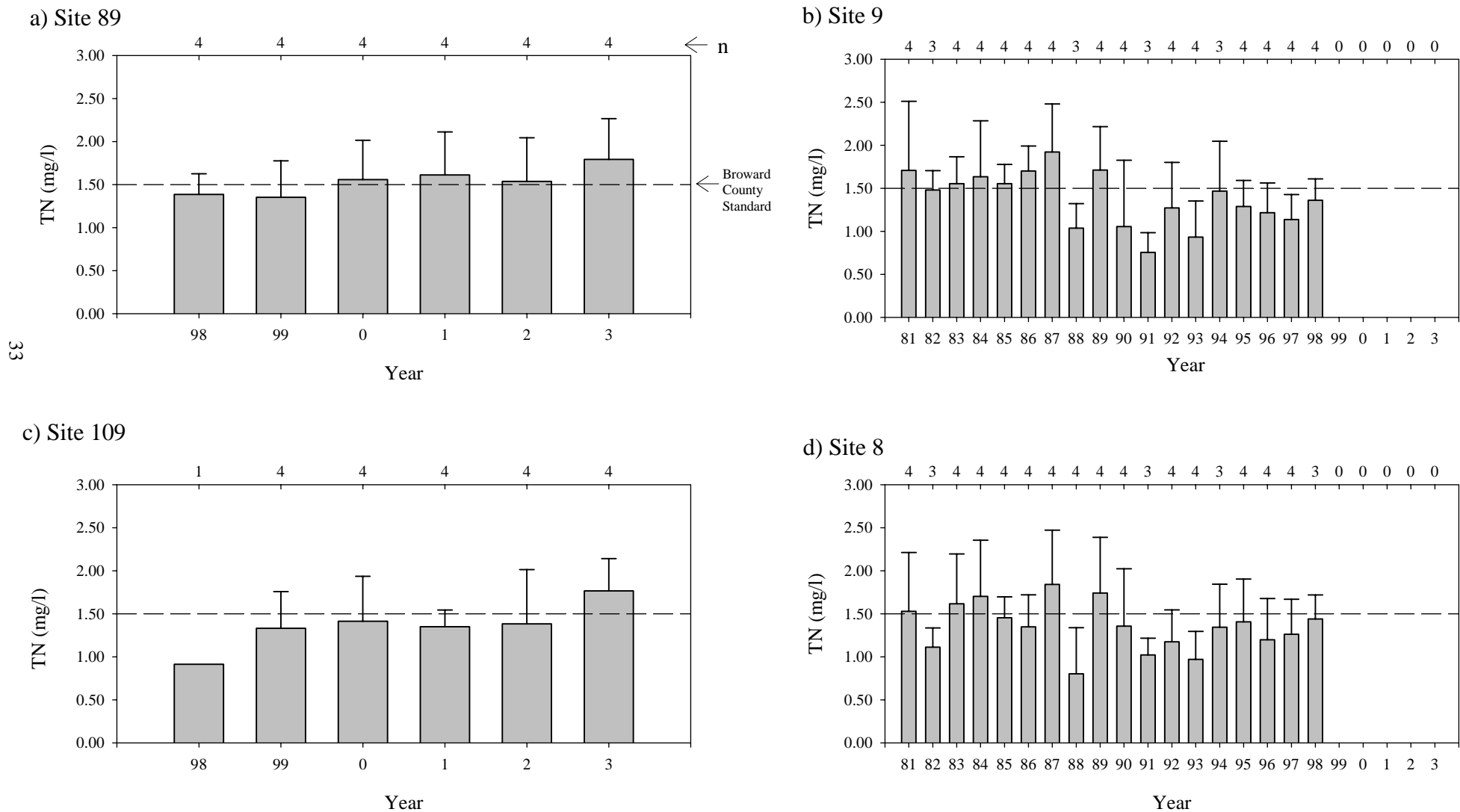


Figure 20 (cont.). Annual Mean Total Nitrogen (TN) Levels within the C-14 Canal Basin (Florida Department of Environmental Protection WBID 3270) from 1981 to 2003. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county environmental regulations, TN levels should be below the Broward County standard (1.50 mg/l) indicated by the dashed line. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow. Sampling halted at Sites 8 and 9 after 1998.

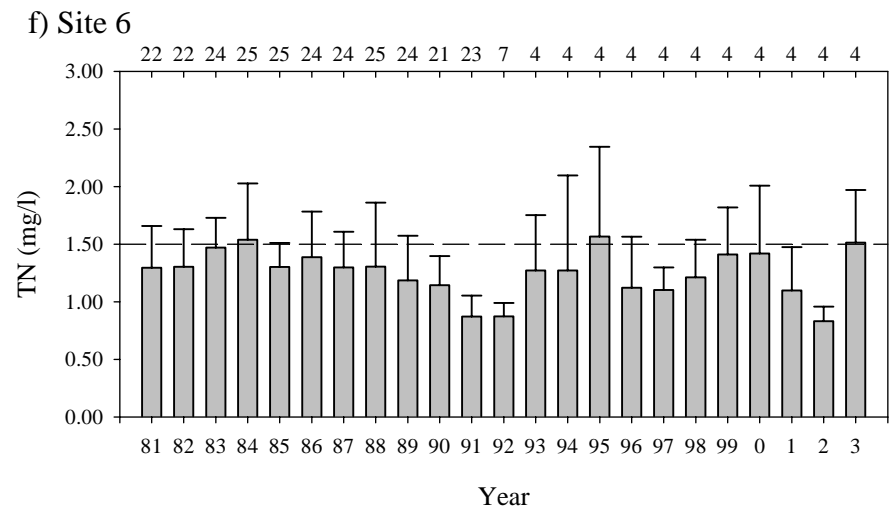
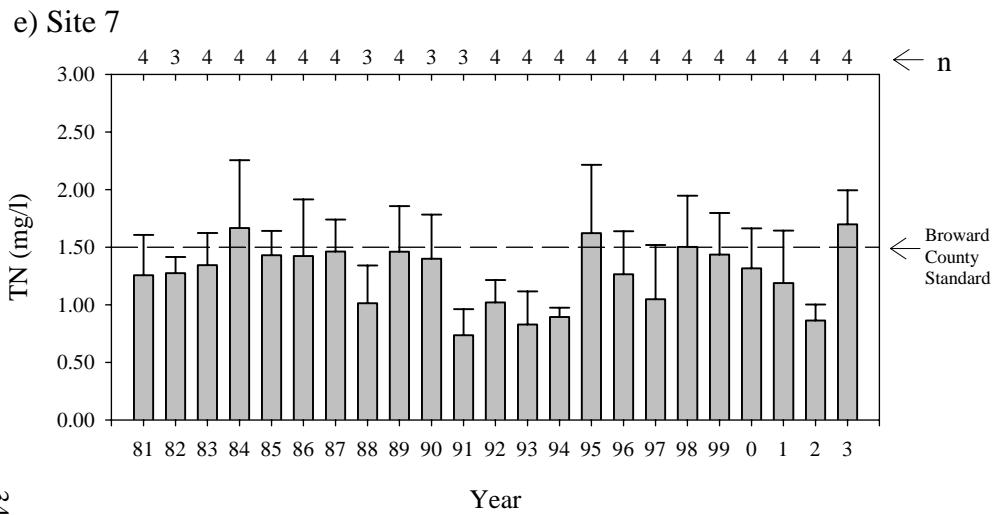
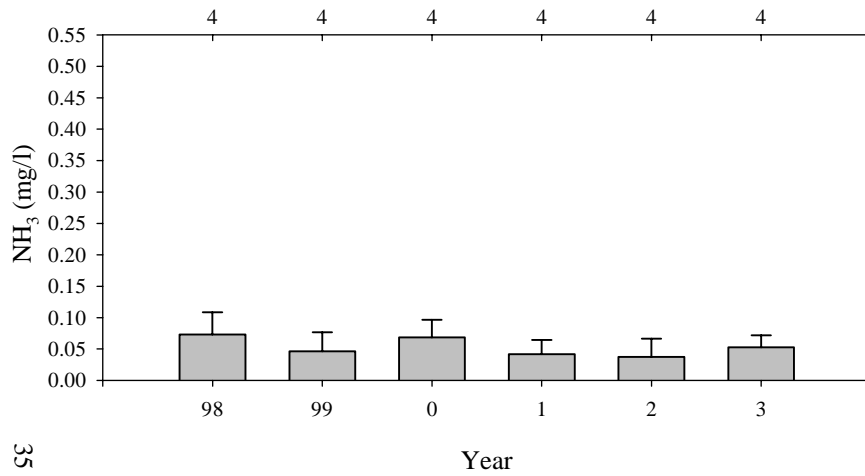
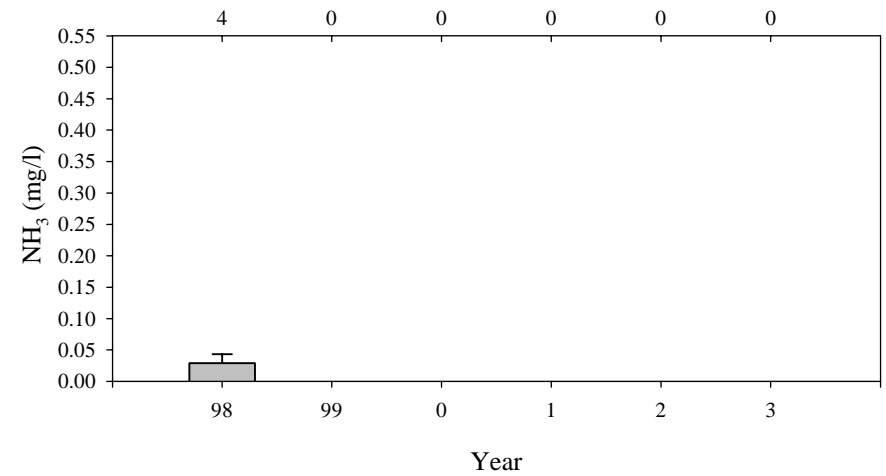


Figure 21. Annual Mean Ammonia (NH₃) within the C-14 Canal Basin (Florida Department of Environmental Protection WBID 3270) from 1998 to 2003. Means and standard deviations (error bars) calculated from quarterly sampling with number of samples (n) for each year noted on upper x-axis. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow. Sampling halted at Sites 8 and 9 after 1998.

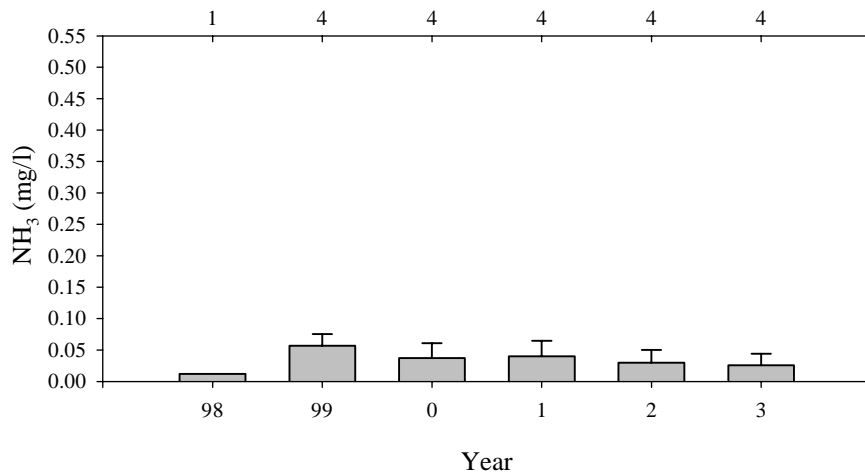
a) Site 89



b) Site 9



c) Site 109



d) Site 8

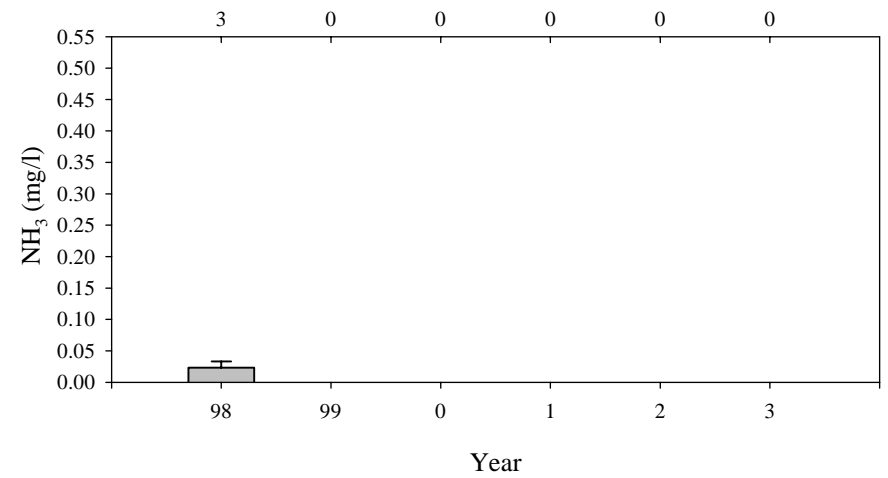
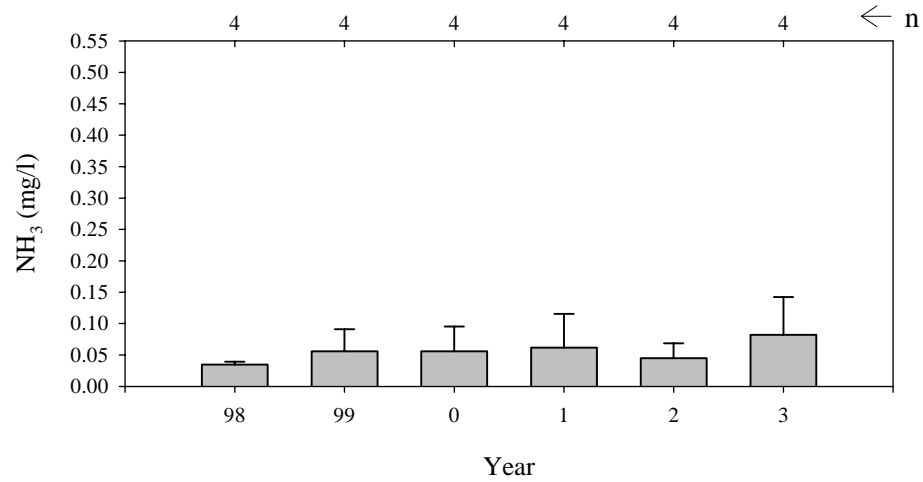
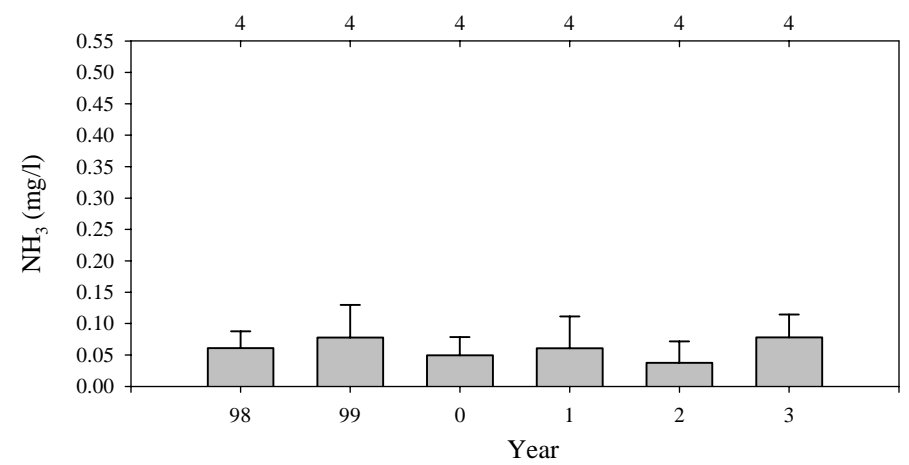


Figure 21 (Cont.). Annual Mean Ammonia (NH₃) within the C-14 Canal Basin (Florida Department of Environmental Protection WBID 3270) from 1998 to 2003. Means and standard deviations (error bars) calculated from quarterly sampling with number of samples (n) for each year noted on upper x-axis. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

e) Site 7



f) Site 6



9. Nitrite+Nitrate-Nitrogen

Nitrite+Nitrate-Nitrogen (NO_{2+3}) concentrations (Figure 22) were generally higher than corresponding $\text{NH}_3\text{-N}$ values at Sites 6 and 7 (see Figure 21). These downstream sites of S37B also had at times considerably higher NO_{2+3} values than upstream sites (Sites 8, 9, 89, and 109). Temporally each site showed relatively consistent values with the exception of Site 6's 2000 annual average.

10. Chlorophyll a

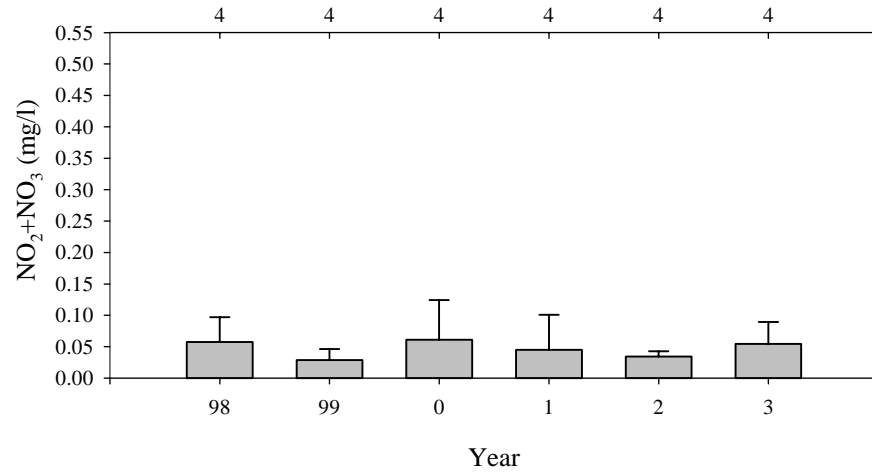
Annual chlorophyll a values were typically below the Impaired Waters Rule threshold value for freshwater canals (20 micrograms per liter; [FDEP 2006b](#), Figure 23). Water bodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients. An extraordinary exception was observed in 2001 at Site 89 which had a standard deviation higher than the annual average reflecting an anomalously high concentration. Site 7 also had elevated chlorophyll a during 2001 though not as high as Site 89. Interestingly, these high values were not observed at Sites 109 and 6 in 2001 and this suggests that elevated chlorophyll a values may not always be observed throughout a whole canal reach but instead are more localized events.

11. Fecal Coliform

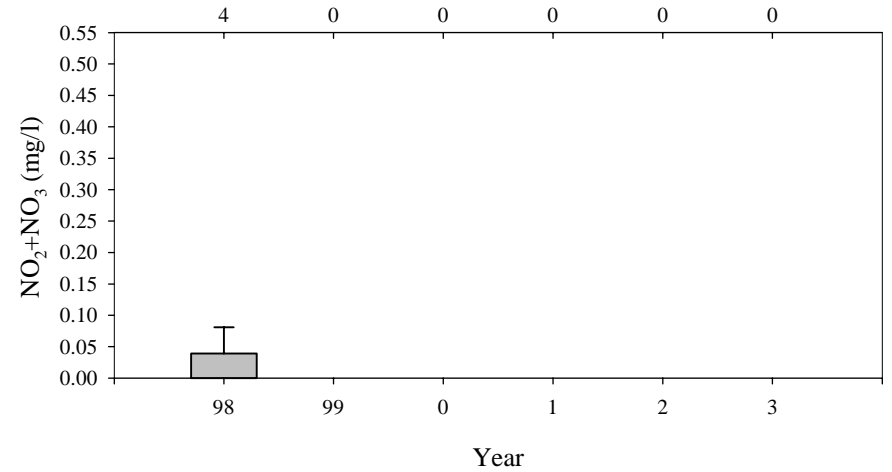
Fecal coliform (FC) content from 1973 to 2003 is shown as these graphs (Figure 24) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Most fecal coliform samples were within compliance of county ([Broward County 1996](#)) and state ([FDEP 2006a](#)) environmental regulations with a few exceptional events being observed at specific sites (e.g., 1994 and 1995). In general, 1998 through 2003 was a period of consistently low fecal coliform values throughout the waterway with Sites 109 and 7 exhibiting the lowest values.

Figure 22. Annual Mean Nitrite+Nitrate-Nitrogen (NO_2+NO_3) Content within the C-14 Canal Basin (Florida Department of Environmental Protection WBID 3270) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., $n=4$) unless noted on upper x-axis. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow. Sampling halted at Sites 8 and 9 after 1998.

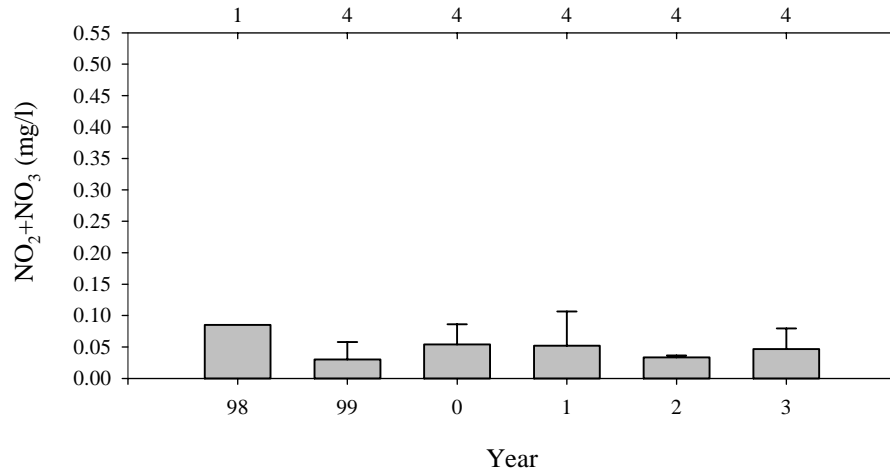
a) Site 89



b) Site 9



c) Site 109



d) Site 8

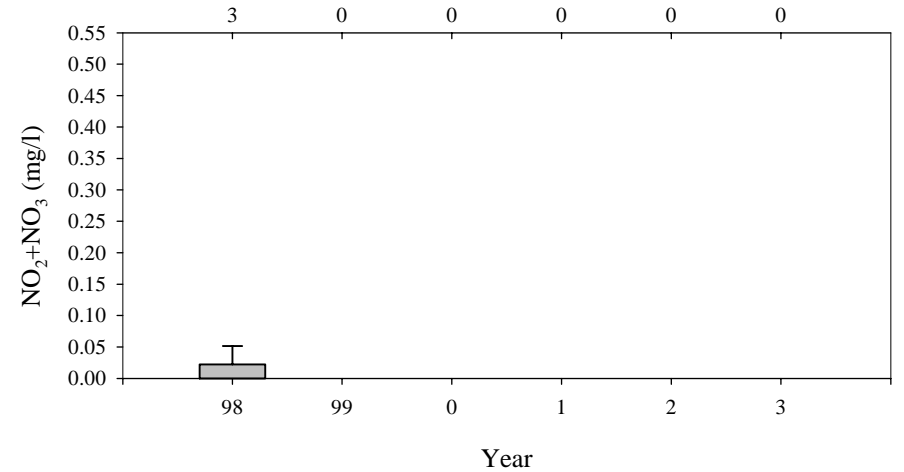
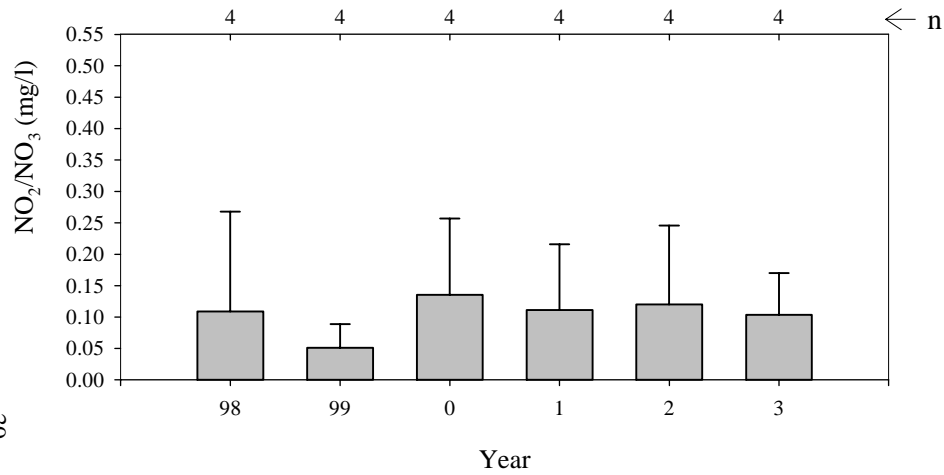


Figure 22 (cont.). Annual Mean Nitrite+Nitrate-Nitrogen (NO_2+NO_3) Content within the C-14 Canal Basin (Florida Department of Environmental Protection WBID 3270) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., $n=4$) unless noted on upper x-axis. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

e) Site 7



f) Site 6

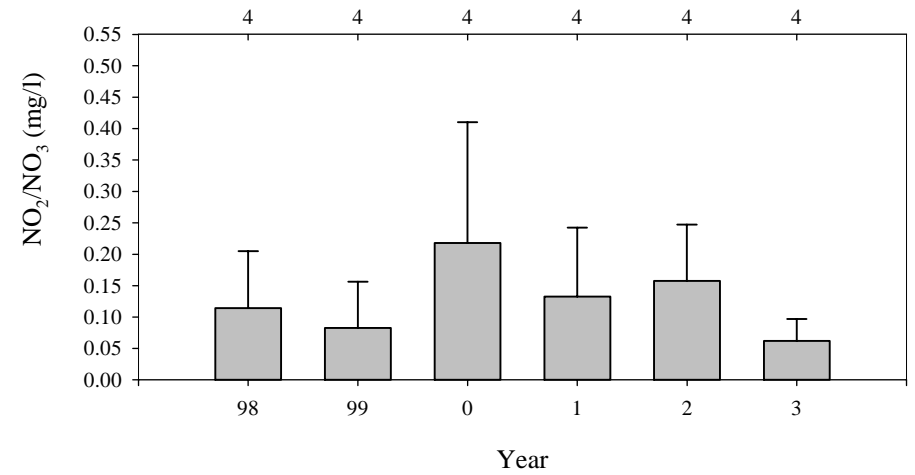
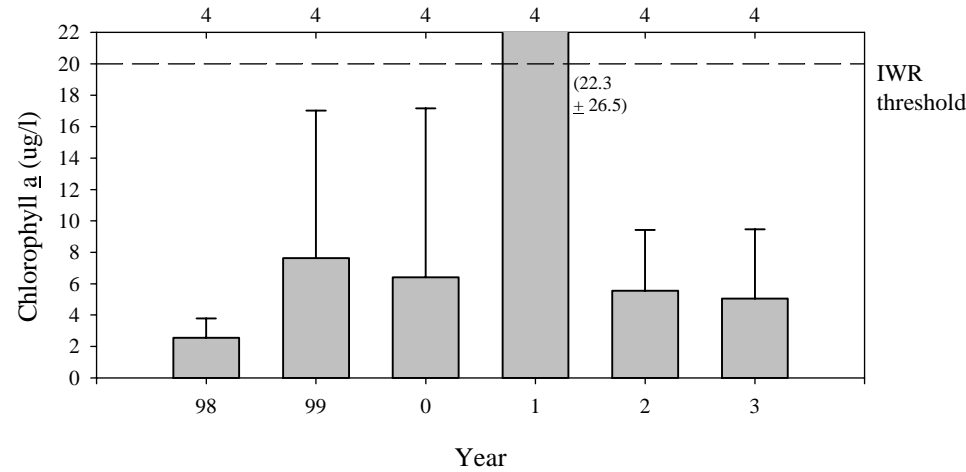
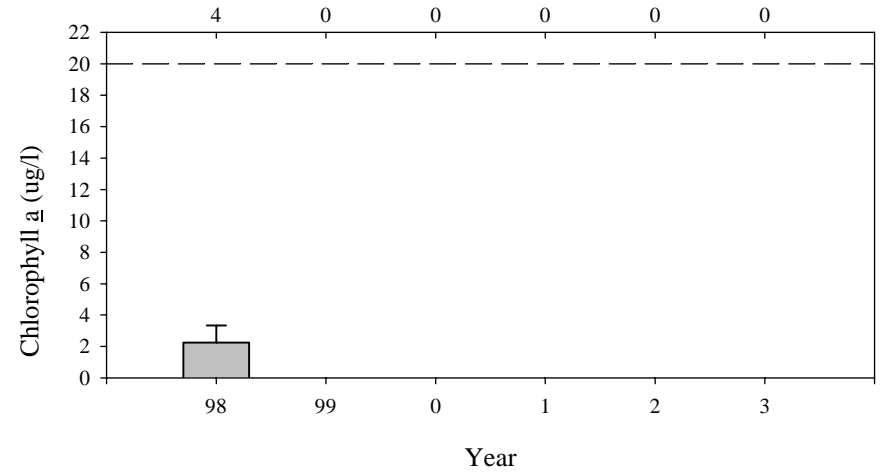


Figure 23. Annual Mean Chlorophyll *a* Levels within the C-14 Canal Basin (Florida Department of Environmental Protection, FDEP, WBID 3270) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. The FDEP Impaired Waters Rule (Florida Administrative Code 62-303) chlorophyll *a* threshold value of 20 micrograms per liter (ug/l) is shown by the dashed line. Waterbodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow. Sampling halted at Sites 8 and 9 after 1998.

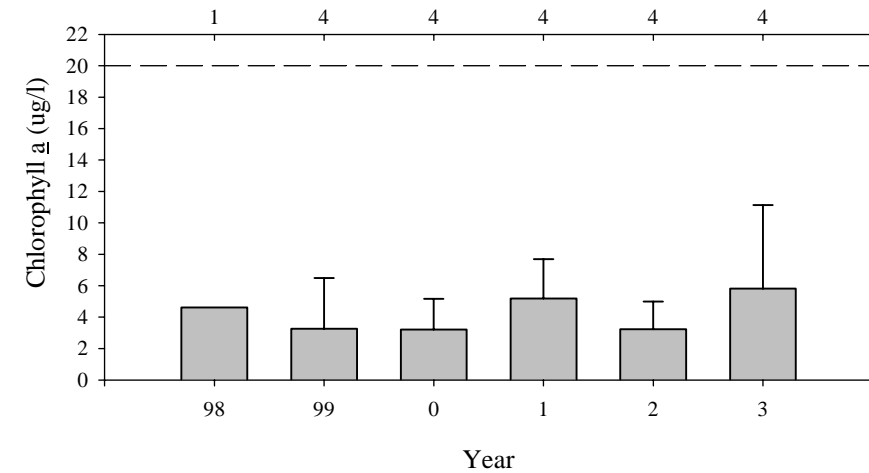
a) Site 89



b) Site 9



c) Site 109



d) Site 8

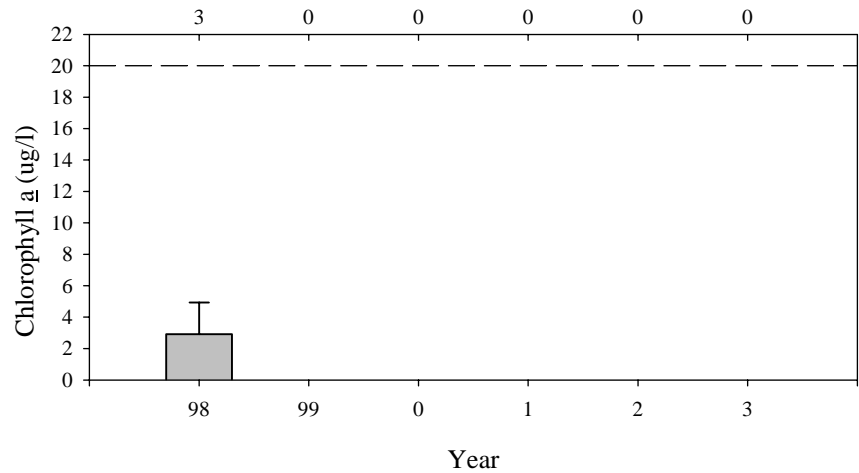
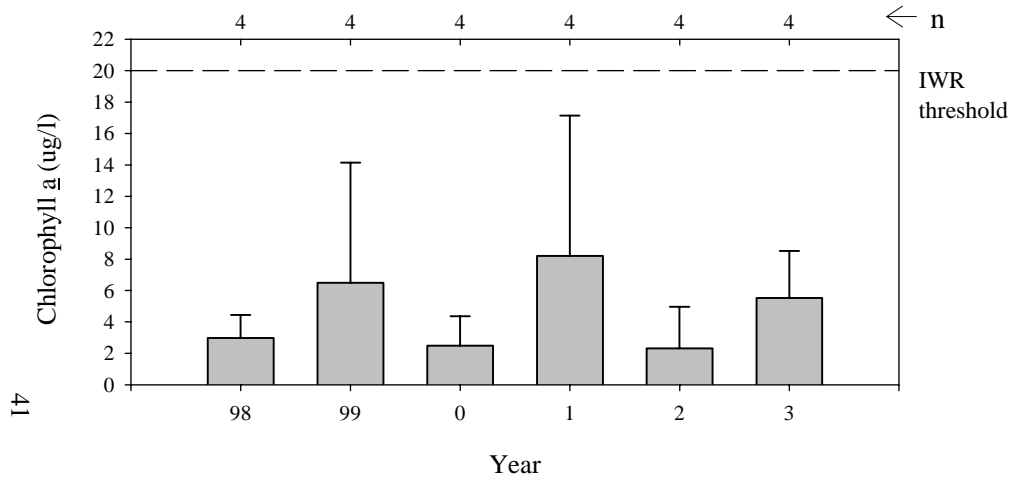


Figure 23 (cont.). Annual Mean Chlorophyll *a* Levels within the C-14 Canal Basin (Florida Department of Environmental Protection, FDEP, WBID 3270) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. The FDEP Impaired Waters Rule (Florida Administrative Code 62-303) chlorophyll *a* threshold value of 20 micrograms per liter (ug/l) is shown by the dashed line. Waterbodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow. Sampling halted at Sites 8 and 9 after 1998.

e) Site 7



f) Site 6

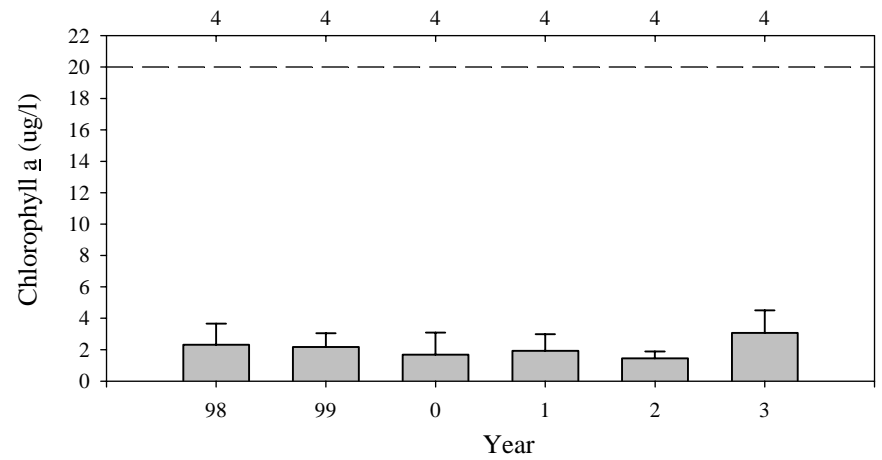
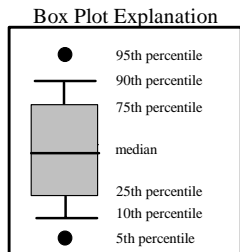
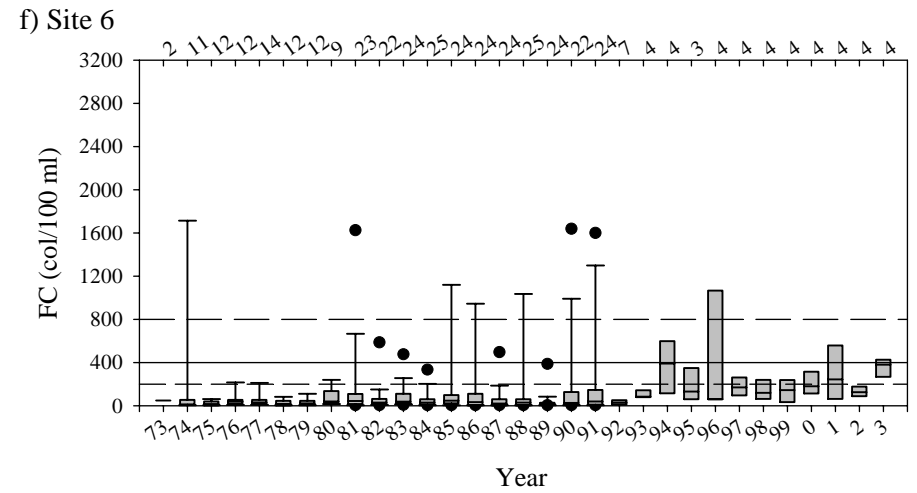
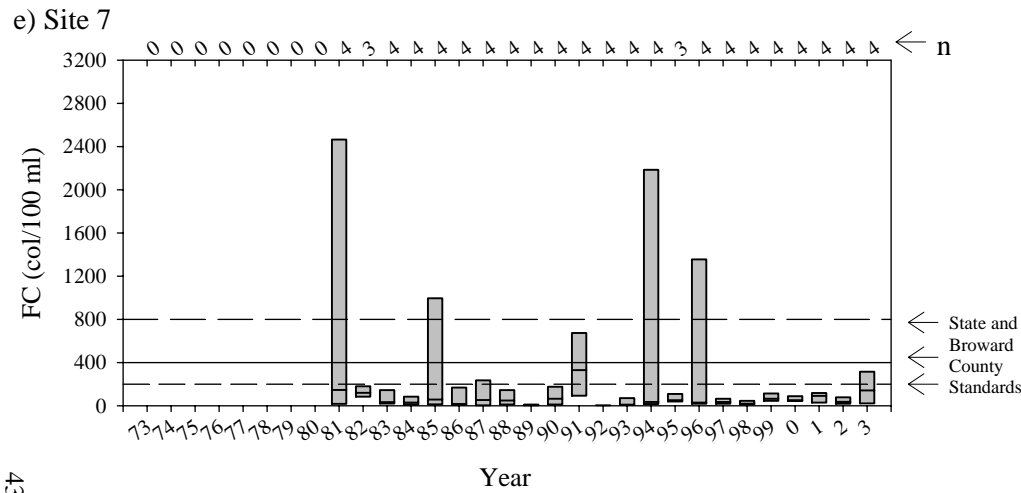


Figure 24 (cont.). Annual Box Plots of Fecal Coliform (FC) Levels within the C-14 Canal Basin (Florida Department of Environmental Protection WBID 3270) from 1973 to 2003. Medians and percentiles calculated from bi-weekly, monthly, and quarterly samples with the number of samples (n) noted on the upper axis. To be within compliance of state and county environmental regulations, levels shall not exceed a monthly average of 200 colonies per 100 milliliters (col/100 ml), nor exceed 400 col/100 ml in 10% of the samples, nor exceed 800 col/100 ml on any one day. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.



C. Pompano Canal (Florida Department of Environmental Protection, FDEP, WBID 3271)

1. Basin Description and Sampling Locations

With an area of 7.2 mi², the Pompano Canal is one of the smallest basins within the county (Figure 25). The freshwater portion of the canal is entirely within the City of Pompano Beach and extends from west of Powerline Road east to Cypress Road. The South Florida Water Management District's (SFWMD) G65 blocks C-14 Canal water from moving east into the Pompano Canal and represents the western hydrological extent of the canal in terms of surface water inputs. The G65 has not been operated in over 10 years (SFWMD Field Station, personal communication).

The canal has three long covered, culverted reaches and its easternmost point discharges occasional low volumes of water to the estuary at the G57. The BCEPD has monitored one site (Site 110) on the canal's eastern extent since 1999. Site 110 is located immediately west of Dixie Highway at the western edge of one the three large culverted areas.

2. Specific Conductance

Site 110 yearly means ranged from 450 to 550 micromhos/centimeters (umhos/cm) over the last six years (Figure 26). Two annual (2000 and 2003) means were characterized by high variability caused by two unusually high (> 1400 umhos/cm) sampling observations observed during the dry seasons of each year.

3. Total Organic Carbon

Annual total organic carbon (TOC) means were fairly consistent at Site 110 in the Pompano Canal over time with the lowest values being seen in 1999 (Figure 27). The maximum annual mean and standard deviation was observed in 2001. Overall, the annual values were low (less than 6 mg/l) especially compared to other canals in the county.

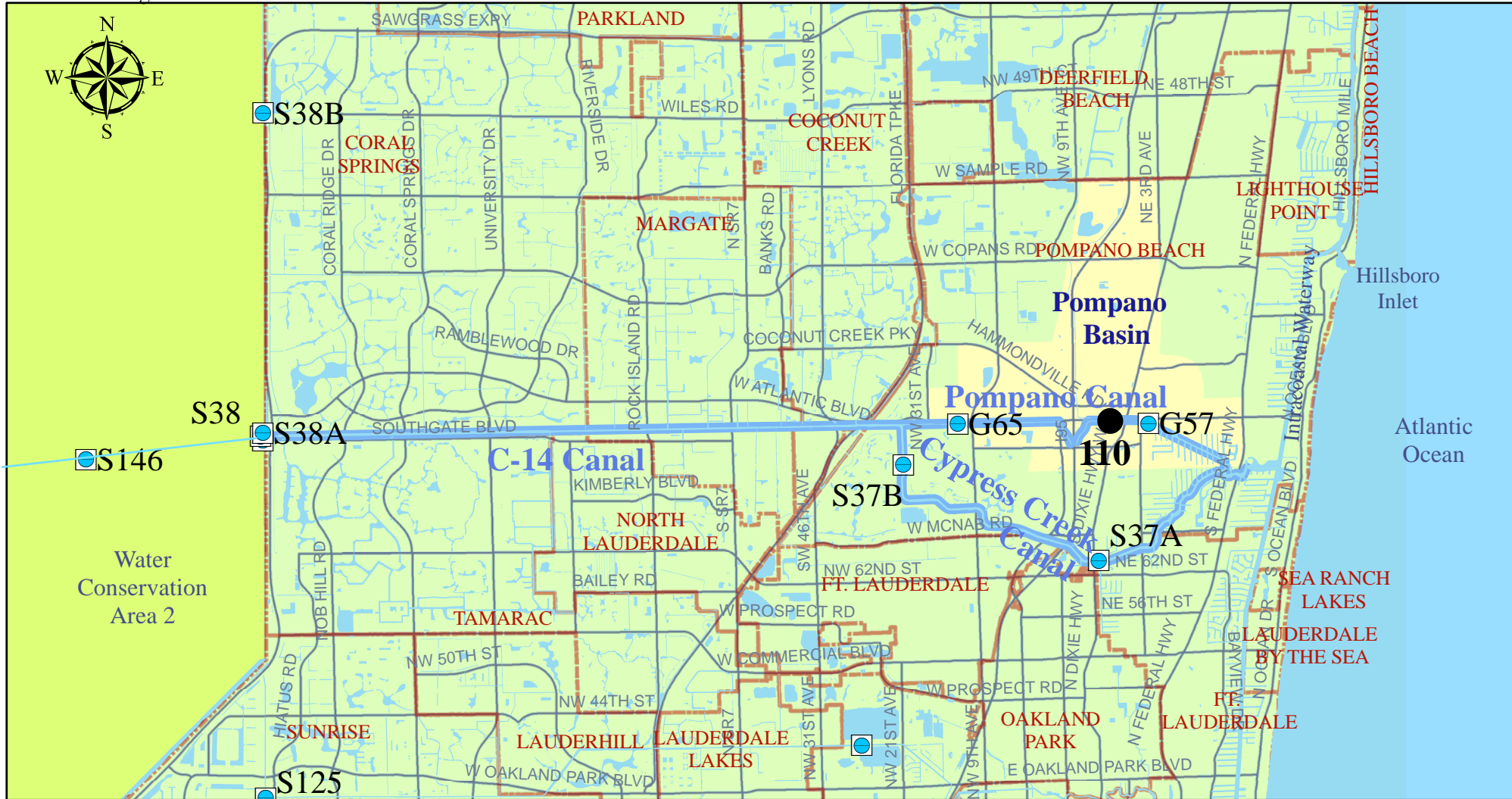
4. Dissolved Oxygen

After 1999, annual DO averages have generally increased to Broward County and state compliance levels from 2000 through 2003 (Figure 28). However, the relatively high standard deviations over the last three years illustrate some single sample values are falling below the both state and county criteria. As of this writing, the FDEP is only placing the Pompano Canal on the Impaired Waters list for nutrient impairment requiring total maximum daily load development but not for DO.

5. Total Phosphorus

The Broward County numeric standard of 0.02 mg/l was exceeded each year Site 110 has been monitored (Figure 29). The maximum annual mean total phosphorus (TP)

Figure 25. Broward County Environmental Protection Department's Surface Water Quality Monitoring Site on the Freshwater Pompano Canal. The Pompano Canal basin is shown by the yellow color and the sampling site is number 110 west of the South Florida Water Management District coastal salinity structure G57. The connection to the C-14 Canal (G65) is currently dormant and has not been operated for over a decade. Major cities in both sub-basins are labeled and depicted with the orange outline.



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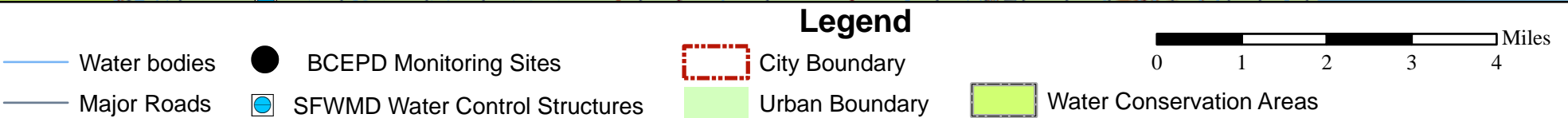


Figure 26. Annual Mean Specific Conductance (Cond) Levels within the Pompano Canal Basin (Florida Department of Environmental Protection WBID 3271) from 1999 to 2003 (no sampling in 1998). Yearly means and standard deviations (error bars) for Site 110 calculated from quarterly samples (i.e., n=4) and values are shown in micromhos per centimeter (umhos/cm) at 25 degrees Celsius.

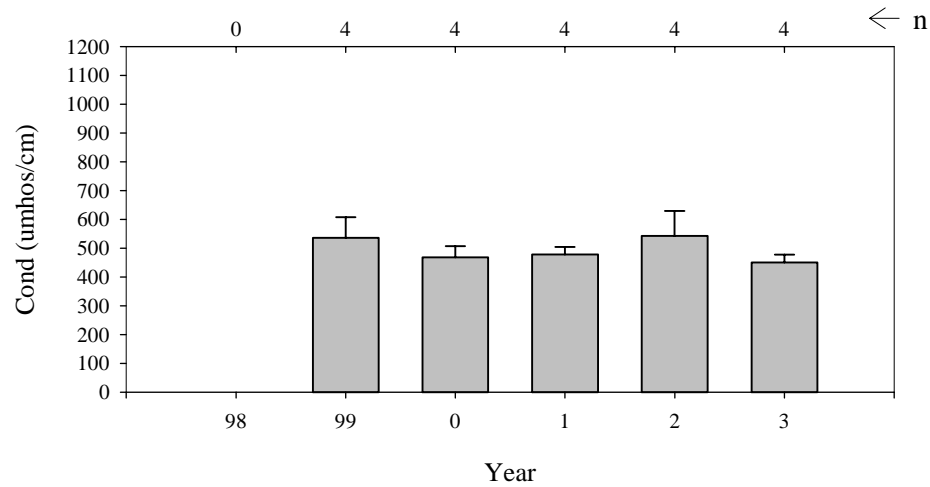


Figure 27. Annual Mean Total Organic Carbon (TOC) Content within the Pompano Canal Basin (Florida Department of Environmental Protection WBID 3271) from 1999 to 2003 (no sampling in 1998). Yearly means and standard deviations (error bars) from Site 110 calculated from quarterly samples (i.e., n=4).

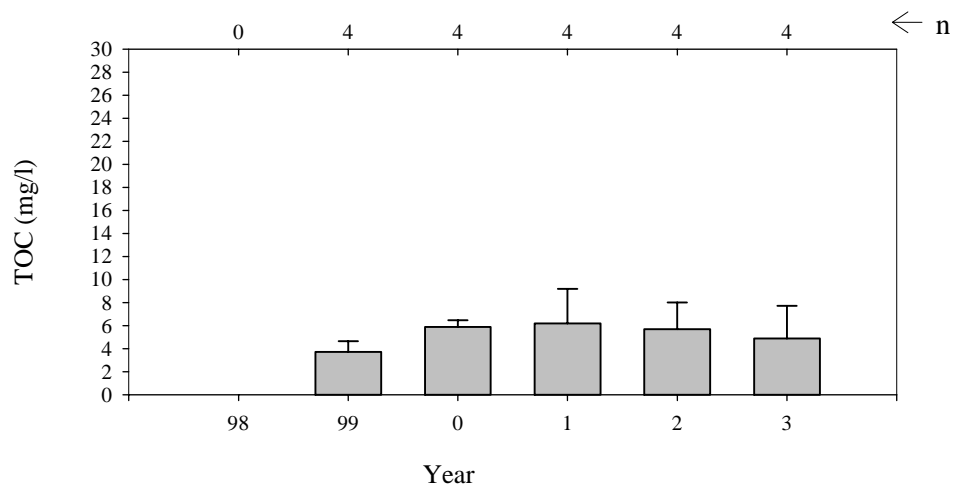


Figure 28. Annual Mean Dissolved Oxygen (DO) Content within the Pompano Canal Basin (Florida Department of Environmental Protection WBID 3271) from 1999 to 2003 (no sampling for 1998). Means and standard deviations (error bars) calculated for Site 110 from quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county (BC) water quality standards, any sample should be equal to or above 4.0 mg/l (solid line), while the daily average should be greater than or equal to 5.0 mg/l (dashed line). State water quality criteria mandate all samples must be greater than or equal to 5.0 mg/l (dashed line).

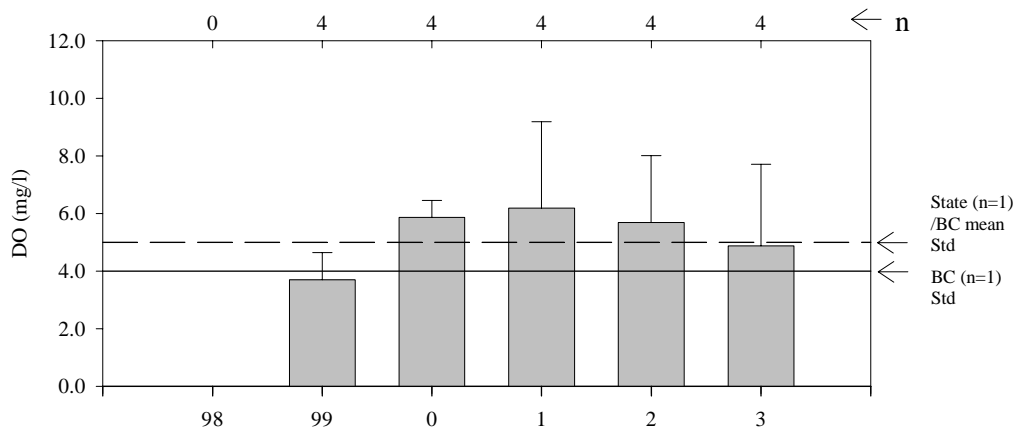
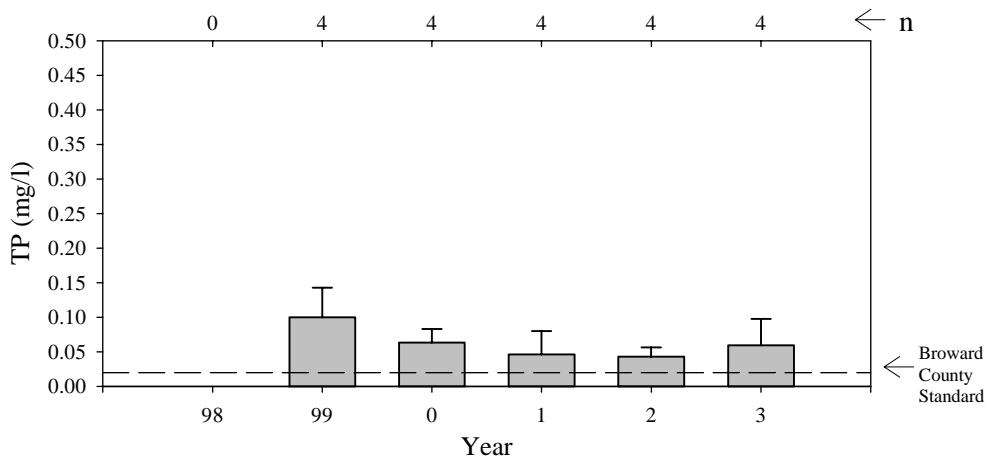


Figure 29. Annual Mean Total Phosphorus (TP) Levels within the Pompano Canal Basin (Florida Department of Environmental Protection WBID 3271) from 1999 to 2003 (no sampling for 1998). Means and standard deviations (error bars) calculated for Site 110 from quarterly samples with the number of samples (n) noted on the upper x-axis. To be within compliance of county environmental regulations, TP levels should be below the Broward County standard (0.02 mg/l) indicated by the dashed line.



value was observed in 1999 and the minimum was seen in 2002. However, no clear increasing or decreasing trend was seen over time for Pompano Canal TP levels.

6. ortho-Phosphate

The ortho-Phosphate ($o\text{-OP}_4$) observations (Figure 30) are made more complex because BCEPD changed its method detection limit (mdl) from 0.030 mg/l to 0.00348 mg/l in 2000. Thus, the use of half the detection limit for samples which were below the mdl in 1999 are an order of magnitude higher in concentration than mdls for 2000 through 2003. In addition, the practical quantitation limit, which is the mdl multiplied by four, was also higher by default because of a higher mdl.

The annual $o\text{-OP}_4$ concentrations at Site 110 were relatively similar in 2001 and 2003. Interestingly, the mean $o\text{-OP}_4$ concentrations in 2002 were much lower than all years as all four observations in 2002 were below the detection limit.

7. Total Nitrogen

Site 110's annual total nitrogen (TN) means values were well within compliance of the Broward County 1.50 mg/l standard for all years (Figure 31). The years 2001 and 2002 were characterized by particularly low values (near 0.50 mg/l). Average values and standard deviation were very similar for 1999, 2000, and 2003 ranging between 0.80 and 0.89 mg/l.

8. Ammonia-Nitrogen

Ammonia-nitrogen (NH_3) annual averages and standard deviations increased and decreased over alternating years from 1998 through 2003 at Site 110 (Figure 32). In 1999 and 2003, yearly means were greater than 0.150 mg/l with both years having large standard deviations. The 1999 observation was measured 10 days after Hurricane Irene's landfall (October 15, 1999). The two lowest annual averages were seen in 2000 and 2002.

9. Nitrite+Nitrate-Nitrogen

Site 110's nitrite+nitrate-nitrogen (NO_{2+3}) concentrations only exceeded 0.100 mg/l once over five years (Figure 33) in 2000 when a high standard deviations was also noted. The minimum annual NO_{2+3} averages were observed in 2002.

Figure 30. Annual Mean ortho-Phosphate (o-PO₄) Content within the Pompano Canal Basin (Florida Department of Environmental Protection WBID 3271) from 1999 to 2003 (no sampling in 1998). Yearly means and standard deviations (error bars) from Site 110 calculated from quarterly samples (i.e., n=4). The method detection limit changed from 0.030 mg/l to 0.00348 mg/l in 2000.

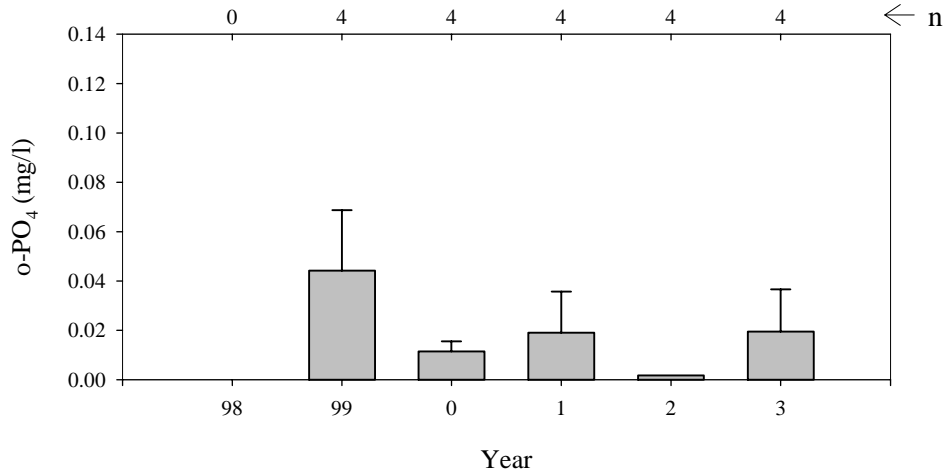


Figure 31. Annual Mean Total Nitrogen (TN) Levels within the Pompano Canal Basin (Florida Department of Environmental Protection WBID 3271) from 1999 to 2003 (no sampling in 1998). Means and standard deviations (error bars) calculated for Site 110 from quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county environmental regulations, TN levels should be below the Broward County standard (1.50 mg/l) indicated by the dashed line.

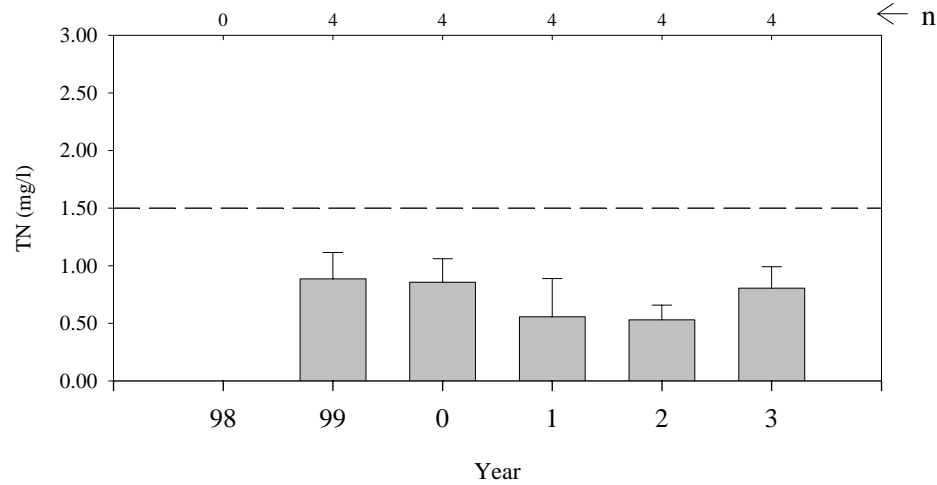


Figure 32. Annual Mean Ammonia (NH₃) within the Pompano Canal Basin (Florida Department of Environmental Protection WBID 3271) from 1999 to 2003 (no sampling in 1998). Yearly means and standard deviations (error bars) for Site 110 calculated from quarterly samples (i.e., n=4).

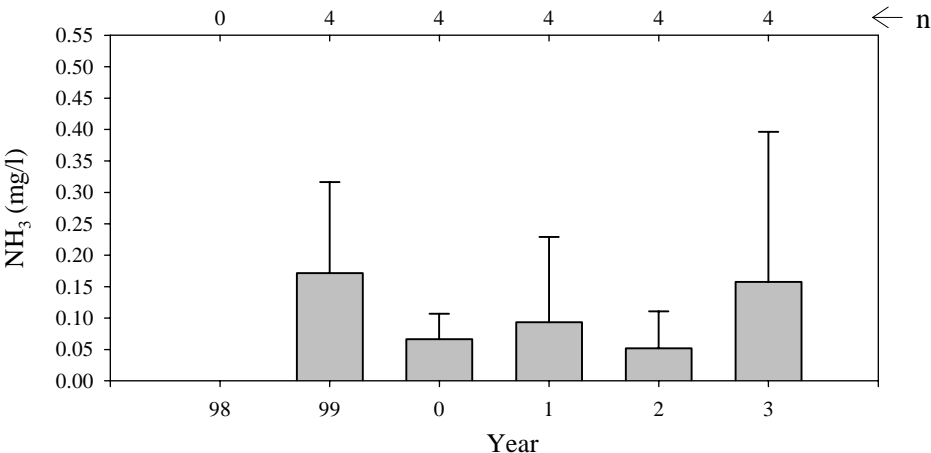
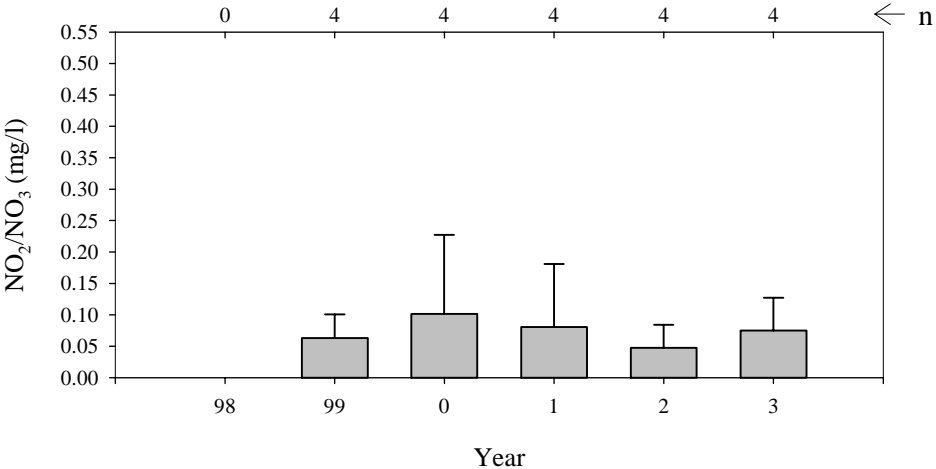


Figure 33. Annual Mean Nitrite+Nitrate-Nitrogen (NO₂+NO₃) Content within the Pompano Canal Basin (Florida Department of Environmental Protection WBID 3271) from 1999 to 2003 (no sampling in 1998). Yearly means and standard deviations (error bars) for Site 110 calculated from quarterly samples (i.e., n=4).



10. Chlorophyll a

The annual chlorophyll a mean values were above the Impaired Waters Rule (IWR) threshold value for freshwater canals (20 ug/l; [FDEP 2006b](#), Figure 34). Water bodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients. As of this writing, the Pompano Canal was listed by the FDEP for nutrient impairment.

The exceptionally high standard deviation observed in 1999, 2000, and 2003 are the result of high values observed in the wet season (raw data not shown). The year 2002 had the lowest annual average for chlorophyll a, well below the threshold value of 20 ug/l.

11. Fecal Coliform

Most fecal coliform samples were within compliance of county (Broward County 2005) and state ([FDEP 2005a](#)) environmental regulations for single sample (800 colonies/ 100 ml) and 'ten percent rule' (400 colonies/ 100 ml) with a few exceptional events (1997 and 2003, Figure 35). Please note the monthly average must be computed with 10 samples within a month and the annual medians shown in Figure 35 are primarily calculated from four samples a year. In addition, the state of Florida DEP is using the 400 colonies/ 100 ml criteria ([FDEP 2005a](#)) for inclusion of a waterway on the Impaired Waters Rule list ([FDEP 2006b](#)). The Pompano Canal is not currently on the FDEP draft list for fecal coliform impairment.

Figure 34. Annual Mean Chlorophyll *a* Levels within the Pompano Canal Basin (Florida Department of Environmental Protection, FDEP, WBID 3271) from 1999 to 2003 (no sampling in 1998). Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4). The FDEP Impaired Waters Rule (Florida Administrative Code 62-303) chlorophyll *a* threshold value of 20 ug/l is shown by the dashed line. Waterbodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients.

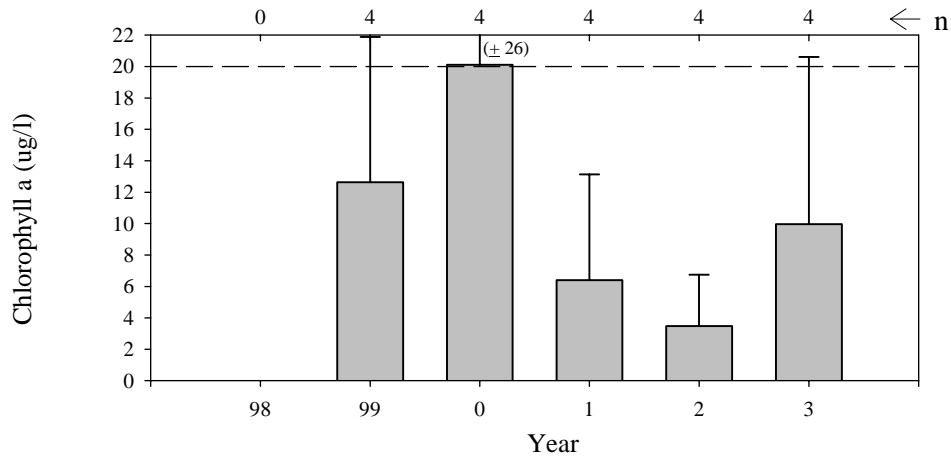
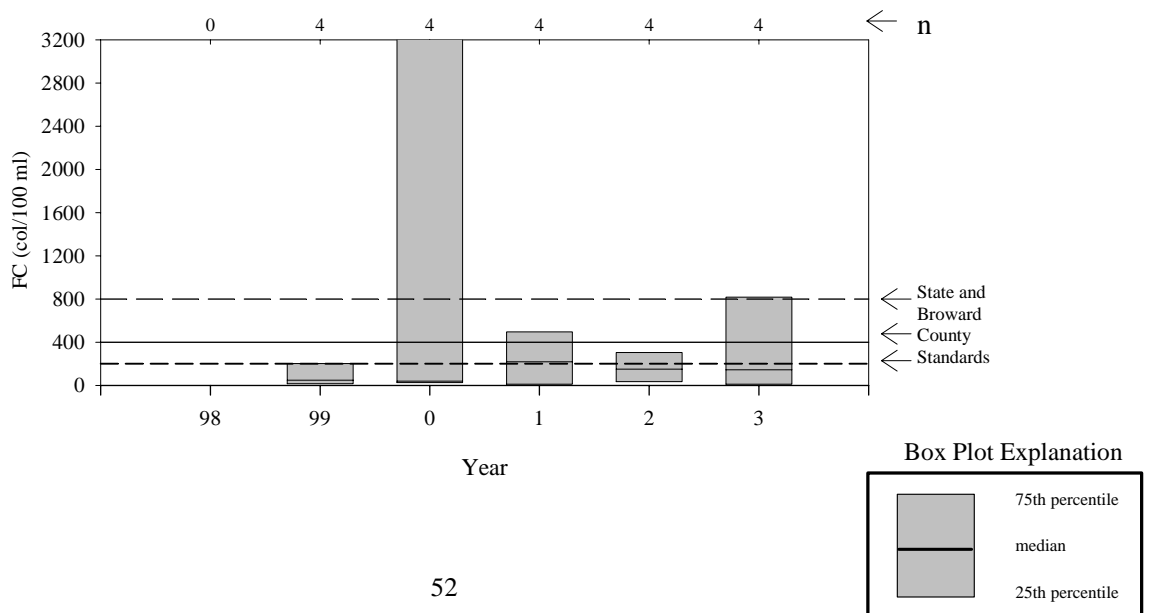


Figure 35. Annual Box Plots of Fecal Coliform (FC) Levels within the Pompano Canal Basin (Florida Department of Environmental Protection WBID 3271) from 1999 to 2003 (no sampling 1998). Medians and percentiles calculated from quarterly samples with the number of samples (n) noted on the upper axis. To be within compliance of state and county environmental regulations, levels shall not exceed a monthly average of 200 colonies per 100 milliliters (col/100 ml), nor exceed 400 col/100 ml in 10% of the samples, nor exceed 800 col/100 ml on any one day. Numbers in parentheses represent 75th percentile values that extend beyond y-axis.



D. C-13 Canal (Florida Department of Environmental Protection, FDEP, WBID 3273)

1. Basin Description and Sampling Locations

The C-13 Canal Basin is a medium-sized basin with an area of thirty-nine mi² (Cooper and Lane 1987). The basin is located in north-central Broward County and is divided into eastern (nine mi², Figure 36) and western basins (thirty mi²). The western C-13 Basin includes the entire freshwater section of the C-13 Canal which represents the headwaters of the S-36. The SFWMD controls the water management of the primary canals and structures within the basin. Independent or dependent drainage districts do not exist in the C-13 Basin, thus Broward County has permit jurisdiction of the basin's drainage into the primary C-13 Canal and maintains the basin along with local municipalities such as Sunrise.

Western inputs of water occur from the L-36 Canal south of the S38C structure via the C-42 Canal. Both the L-36 and C-42 Canals are oriented in a north-south direction. The C-42 Canal has an open connection to the east-west oriented C-13 Canal. The S125 structure effectively divides the C-13 and North New River Canal (NNRC) Basins south of the confluence of the C-42 and the C-13 Canals.

In addition, portions of the western NNRC Basin may drain seepage and runoff water into the C-13 Canal via the L-35A Canal except during times of flooding (Cooper and Lane 1987). Operation of the S124 determines if water from the L-35A Canals flows to the C-13 Canal or the North New River Canal.

The Broward County Environmental Protection Department (BCEPD) maintains three water quality monitoring sites (12 through 14) along the C-13 Canal in its western basin (Figure 36). These include the easternmost freshwater Site 12 that is immediately west of the S-36 at the Martin Luther King Boulevard (NW 31st Avenue) Bridge. Site 13 is approximately two miles west of Site 12 at the Rock Island Road Bridge. Site 14 is the westernmost sampling locale at the University Drive Bridge and is approximately two and one half miles east of the S125 control structure.

2. Specific Conductance

Sites 12 through 14 showed relatively similar annual specific conductance values (Figure 37). In addition, all three sites showed similar fluctuations between maximum and minimum annual means over the six years. The highest and lowest annual values in the canal were relatively similar ranging from near 600 micromhos per centimeter (umhos/cm) to just above 700 umhos/cm.

Figure 36. Broward County Environmental Protection Department's Surface Water Quality Monitoring Sites on the Freshwater C-13 Canal. The western portion of the C-13 Canal drainage basin is depicted by white color. Freshwater sampling site numbers 12, 13, and 14 are west of the South Florida Water Management District's (SFWMD) coastal salinity control structure, S36. The eastern portion of the C-13 Canal Basin (shown in yellow) primarily drains to tidal C-13 Canal and portions of the Middle River. Major cities in both sub-basins are labeled and depicted with the orange outline.

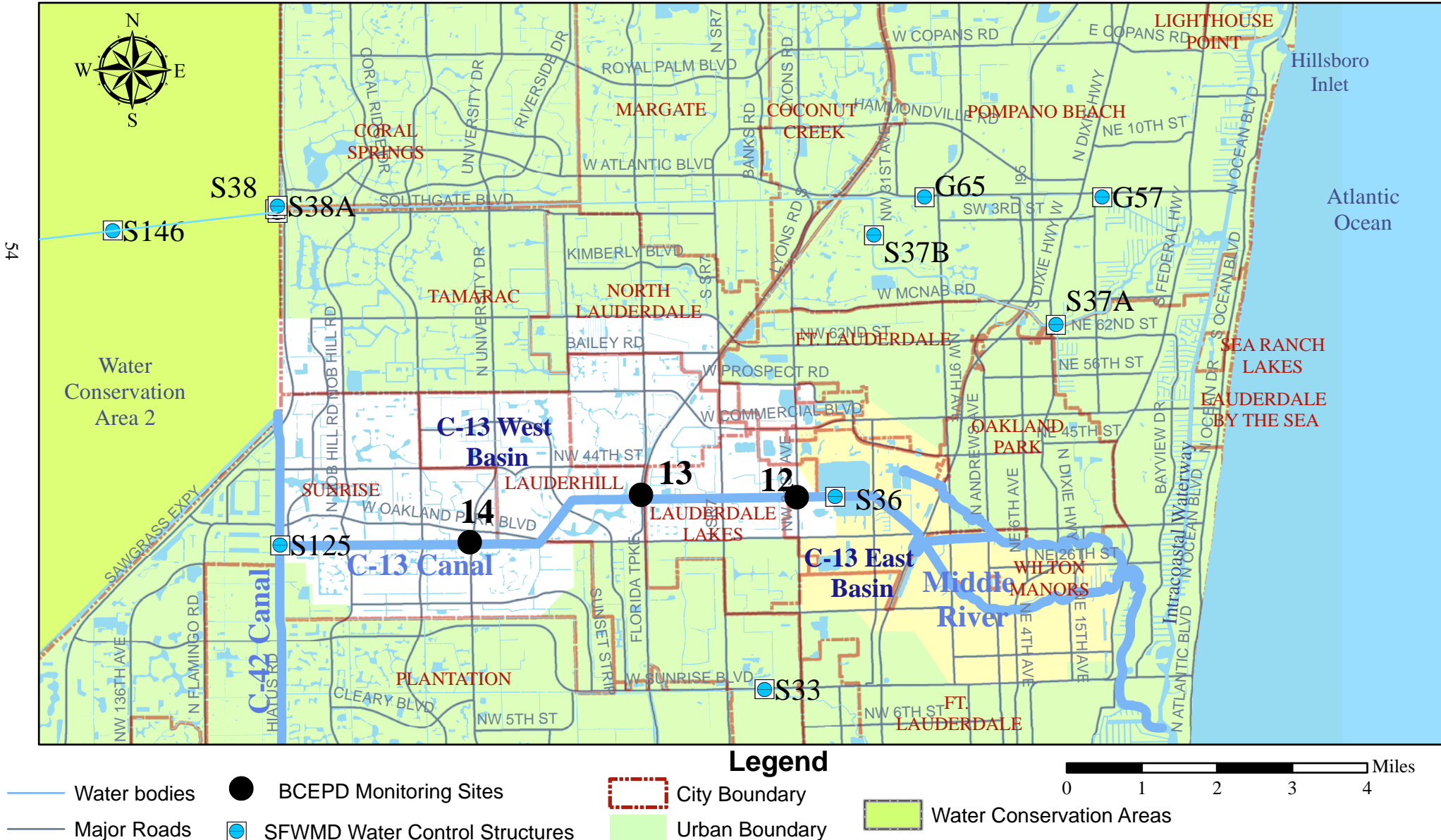
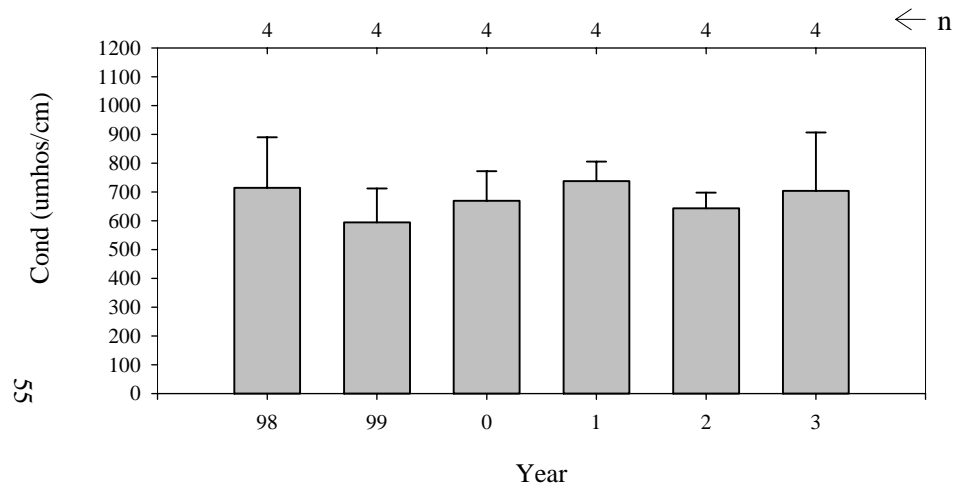
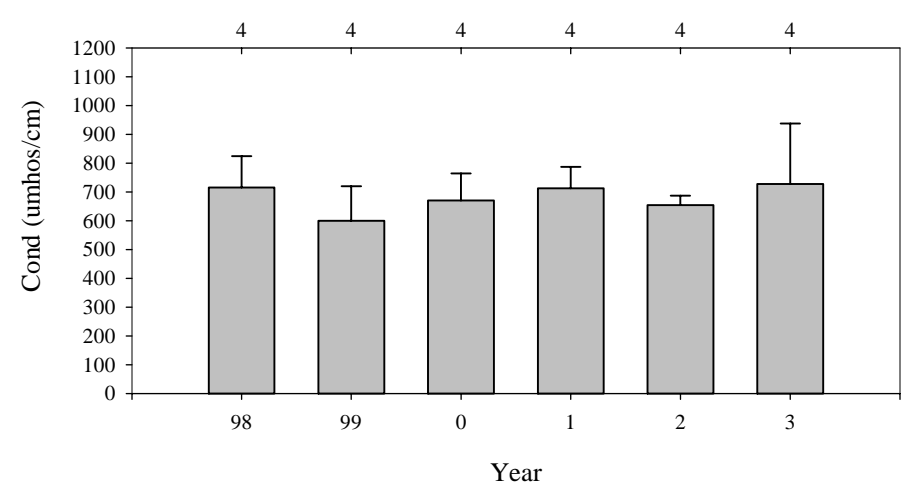


Figure 37. Annual Mean Specific Conductance (Cond) Levels within the C-13 Canal Basin (Florida Department of Environmental Protection WBID 3273) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) and values are shown in micromhos per centimeter (umhos/cm) at 25 degrees Celsius. Sites are shown in a west to east orientation to show the typical canal flow direction when water control structures are operating.

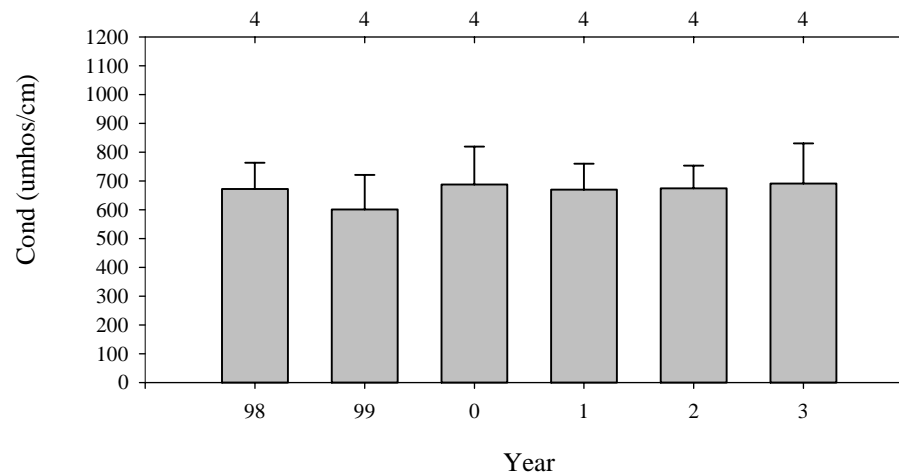
a) Site 14



b) Site 13



c) Site 12



3. Total Organic Carbon

Annual total organic carbon (TOC) means decreased very slightly from west to east within the C-13 Canal (Figure 38). The yearly means ranged from 15.5 to 19.7 mg/l at all sites, with Site 14 exhibiting the highest annual averages. The lowest annual TOC means were observed in 2002 at all sites. The following year, 2003, revealed the most variable TOC data throughout the canal.

4. Dissolved Oxygen

Dissolved oxygen (DO) values from 1973 to 2003 are shown as these graphs (Figure 39) were available in the EPD's first water quality atlas ([BCDPEP 2001](#)). Annual DO averages have generally increased to compliance levels at Sites 12 through 14 from 1997 until 2003 (Figure 39). This increase in DO values is especially noticed when compared to the previous five years of monitoring (1991 through 1996) when annual levels were depressed below the 5.0 mg/l standard and often below the 4.0 mg/l Broward County single sample standard.

5. Total Phosphorus

Total phosphorus (TP) values from 1974 to 2003 are shown as these graphs (Figure 40) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Since 1993, annual TP levels have remained close or within compliance of the Broward County standard of 0.02 mg/l with a few exceptional years (e.g., Site 14 in 1998). Variability was also relatively low around the annual means at all sites over this ten year period suggesting the canal maintains a relatively consistent TP concentration throughout the year.

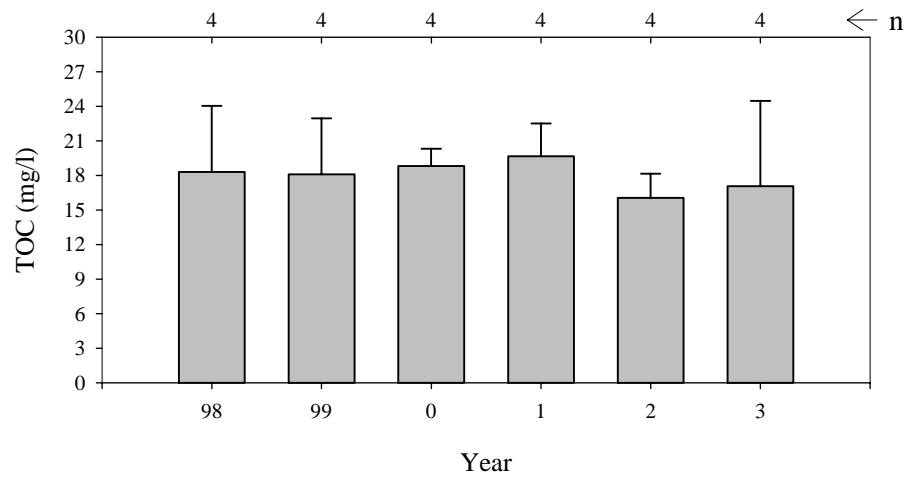
6. ortho-Phosphate

The ortho-Phosphate (o-OP₄) observations are made more complex because BCEPD changed its method detection limit (mdl) from 0.030 mg/l to 0.00348 mg/l in 2000. Thus, the use of half the detection limit for samples which were below the mdl in 1998 and 1999 are an order of magnitude higher in concentration than mdls for 2000 through 2003. In addition, the practical quantitation limit, which is the mdl multiplied by four, was also higher by default because of a higher mdl.

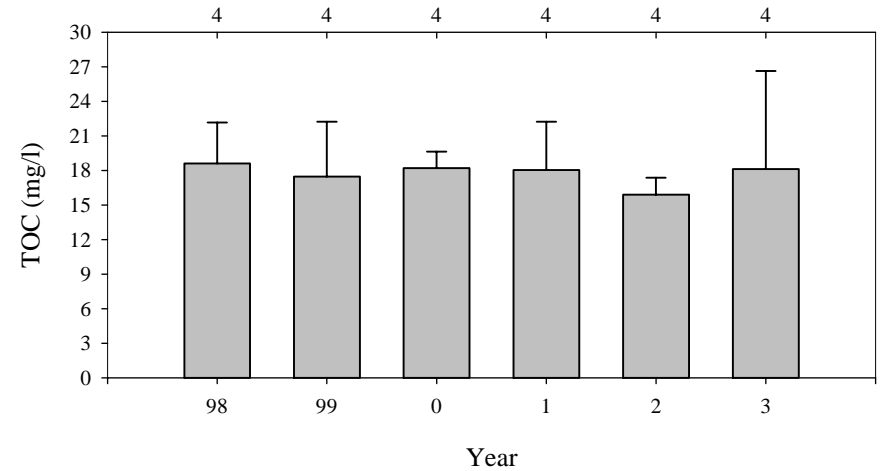
Since the detection limit change, Site 12 was the only site to exhibit annual o-OP₄ values greater than 0.01 mg/l with highest annual means observed in 2000 and 2001 (Figure 41). The year of 2000 also revealed the highest levels at Sites 13 and 14. The lowest annual average was seen during 2002 at all three sites.

Figure 38. Annual Mean Total Organic Carbon (TOC) Content within the C-13 Canal Basin (Florida Department of Environmental Protection WBID 3273) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. Sites are shown in a west to east orientation to show the typical canal flow direction when water control structures are operating.

a) Site 14



b) Site 13



c) Site 12

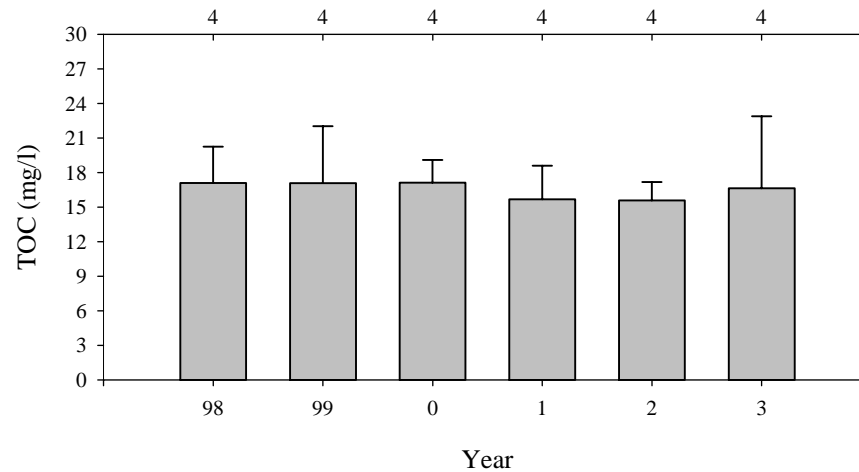


Figure 39. Annual Mean Dissolved Oxygen (DO) Content within the C-13 Canal Basin (Florida Department of Environmental Protection WBID 3273) from 1973 to 2003. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county (BC) water quality standards, any sample should be equal to or above 4.0 mg/l (solid line), while the daily average should be greater than or equal to 5.0 mg/l (dashed line). State water quality criteria mandate all samples must be greater than or equal to 5.0 mg/l (dashed line). Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

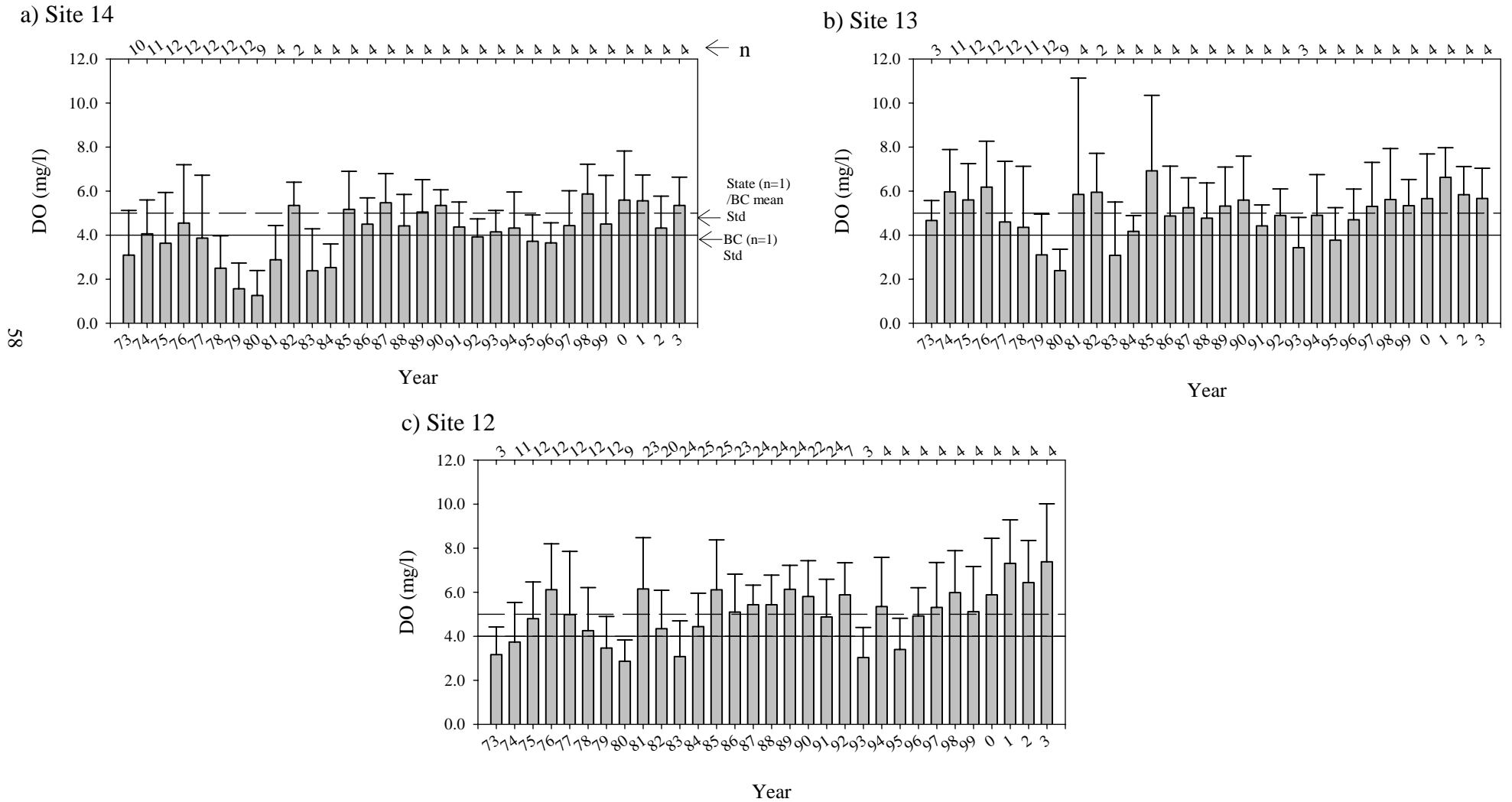


Figure 40. Annual Mean Total Phosphorus (TP) Levels within the C-13 Canal Basin (Florida Department of Environmental Protection WBID 3273) from 1974 to 2003. Means and standard deviations (error bars) calculated from biweekly, monthly, and/or quarterly samples with the number of samples (n) noted on the upper x-axis. Numbers in parentheses represent standard deviation outside range of graph. To be within compliance of county environmental regulations, TP levels should be below the Broward County standard (0.02 mg/l) indicated by the dashed line. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

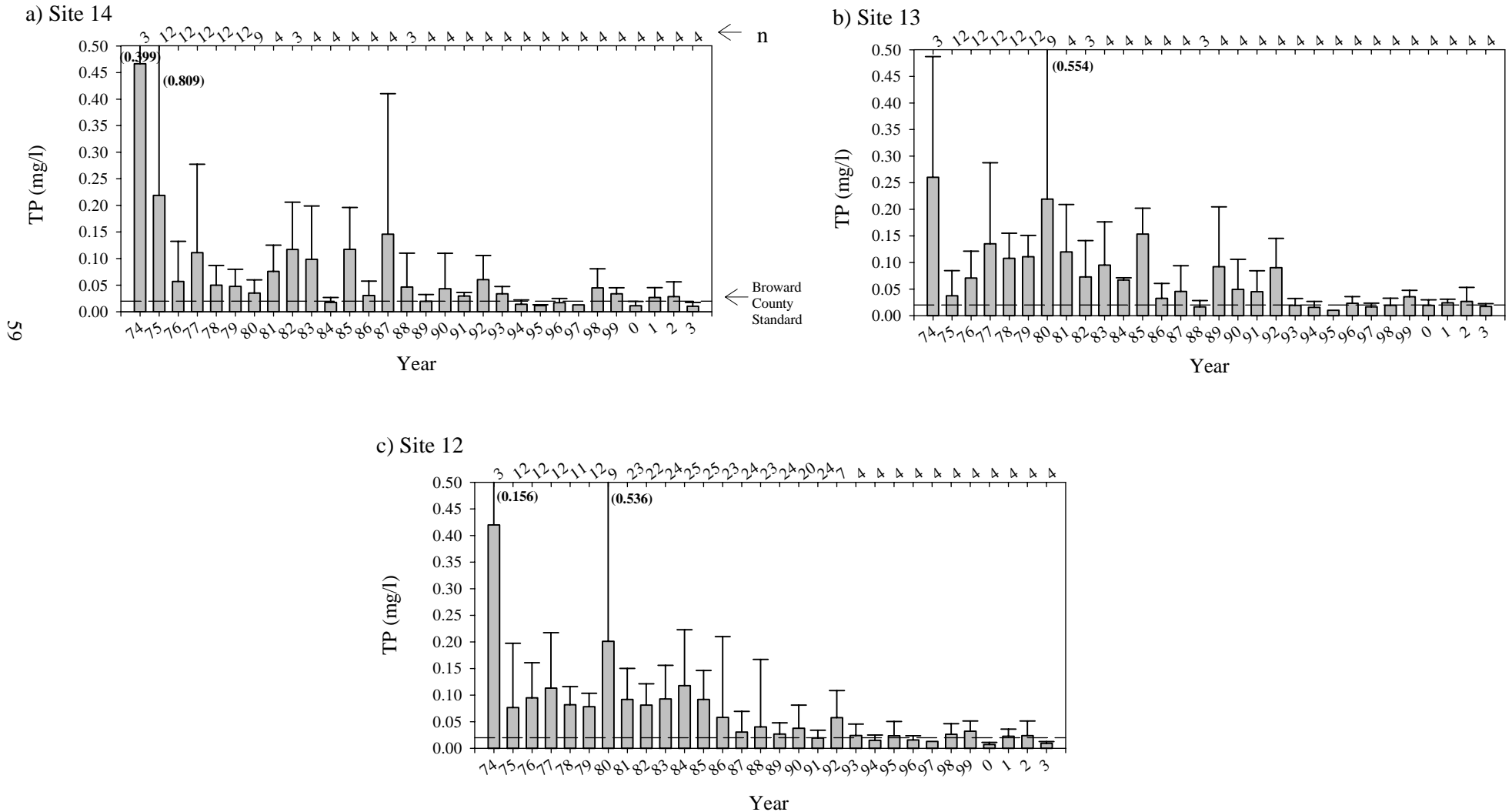
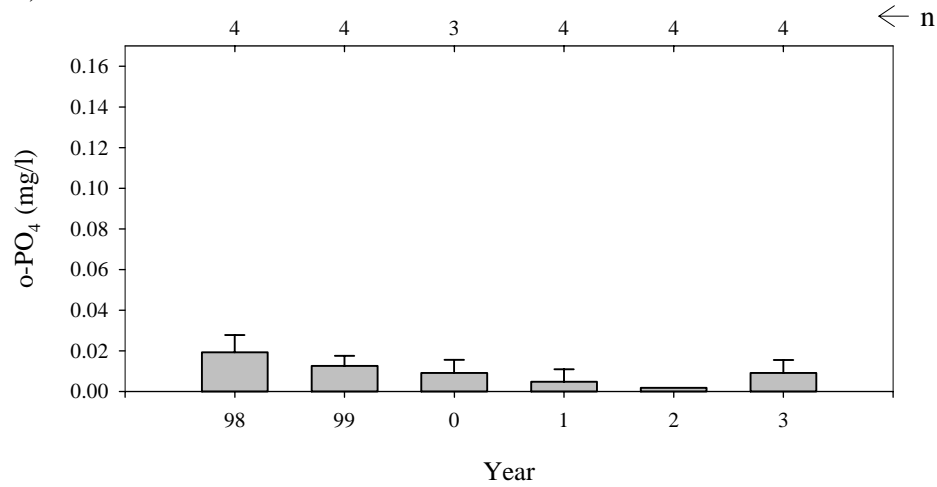
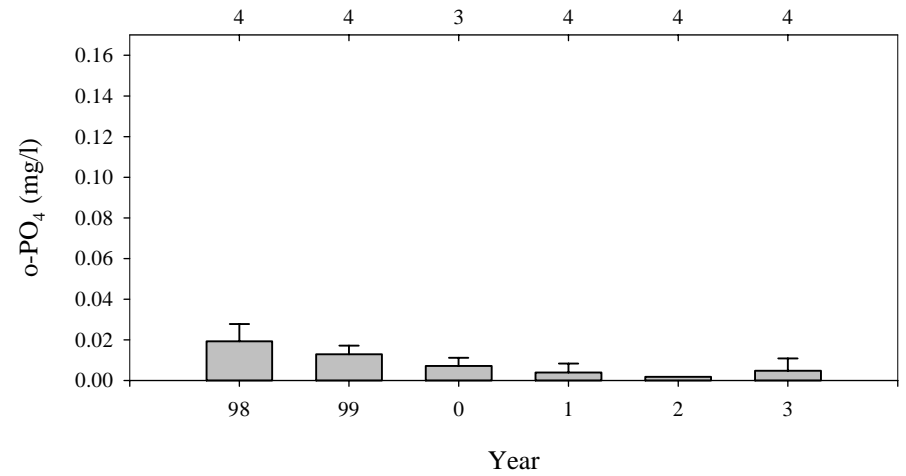


Figure 41. Annual Mean ortho-Phosphate (o-PO₄) Content within the C-13 Canal Basin (Florida Department of Environmental Protection WBID 3273) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. The method detection limit changed from 0.030 mg/l to 0.00348 mg/l in 2000. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

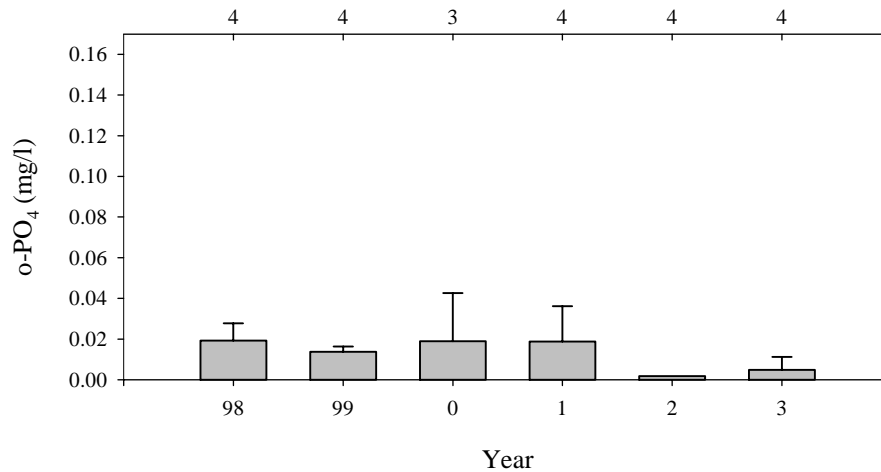
a) Site 14



b) Site 13



c) Site 12



7. Total Nitrogen

Total nitrogen (TN) values from 1981 to 2003 are shown as these graphs (Figure 42) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Since 1994, Site 14 was the only C-13 Canal site where yearly TN averages exceeded the Broward County TN standard of 1.5 mg/l. Sites 13 and 12 nearly mirrored each other over the last 6 years in terms of the years of highest and lowest annual averages. The year 2002 revealed the lowest TN concentrations at all sites in the canal.

8. Ammonia-Nitrogen

Ammonia-nitrogen (NH₃) annual averages and variability were higher at Site 14 than the other two C-13 Canal sites (Figure 43). In particular, Site 14 exhibited a relatively high annual average above 0.30 mg/l in 2003 and the highest annual averages at Sites 13 and 12 were also observed that year. With Site 12 having the lowest NH₃ values, there appears to be a western to eastern decrease in ammonia content within the canal.

9. Nitrite+Nitrate-Nitrogen

The spatial pattern of nitrite+nitrate-nitrogen (NO₂₊₃) concentrations in the C-13 Canal (Figure 44) was generally opposite the pattern observed for the NH₃ concentrations (see Figure 43). Site 14 exhibited the lowest annual concentration for NO₂₊₃ while the highest yearly means for NO₂₊₃ were observed at Site 12 (the easternmost site). The highest NO₂₊₃ concentrations were seen in 2002 and 2003 at Sites 13 and 12.

10. Chlorophyll a

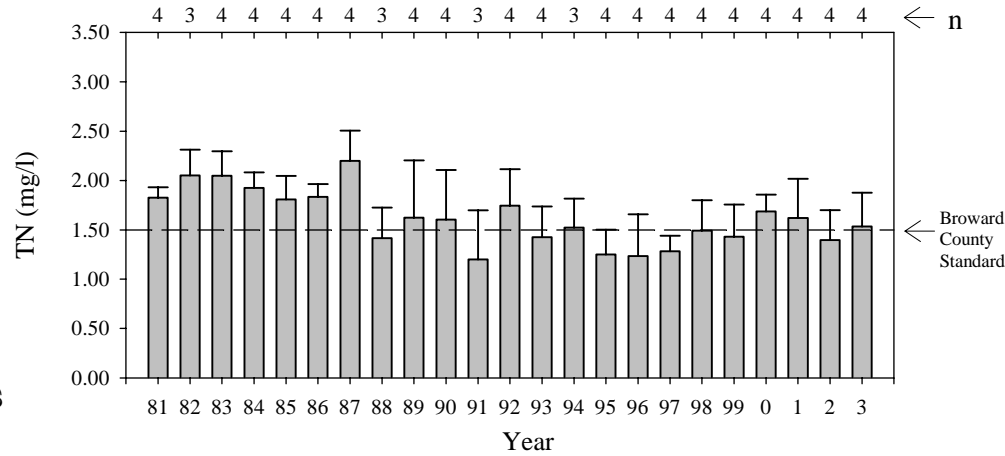
All annual chlorophyll a values were below the Impaired Waters Rule threshold value for freshwater canals (20 ug/l; [FDEP 2006b](#), Figure 45). Waterbodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients. In fact, all chlorophyll a values from the canal were below 20 ug/l (individual data not shown). Generally, Site 14 exhibited the highest annual averages but also had the highest variability around the mean suggesting single samples were influencing the average. Site 12 displayed the lowest annual values for the canal, typically below 5 ug/l.

11. Fecal Coliform

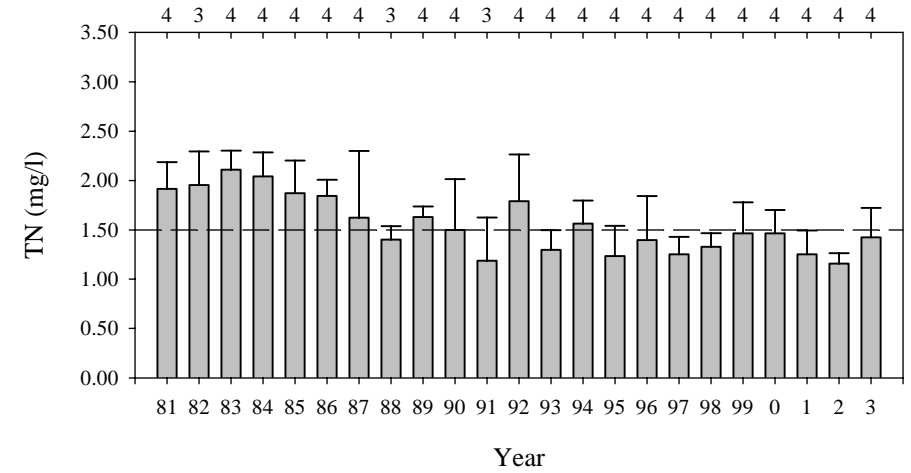
Fecal coliform (FC) content from 1973 to 2003 are shown as these graphs (Figure 46) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Most fecal coliform samples were within compliance of county ([Broward County 1996](#)) and state ([FDEP 2006a](#)) environmental regulations with a few exceptional events (e.g., 1995). However, 2001 appeared to be an atypical year of high fecal coliform content at all three sampling sites. Sites 13 and 14 also had an unusually high range but not median in 2003.

Figure 42. Annual Mean Total Nitrogen (TN) Levels within the C-13 Canal Basin (Florida Department of Environmental Protection WBID 3273) from 1981 to 2003. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county environmental regulations, TN levels should be below the Broward County standard (1.50 mg/l) indicated by the dashed line. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

a) Site 14



b) Site 13



c) Site 12

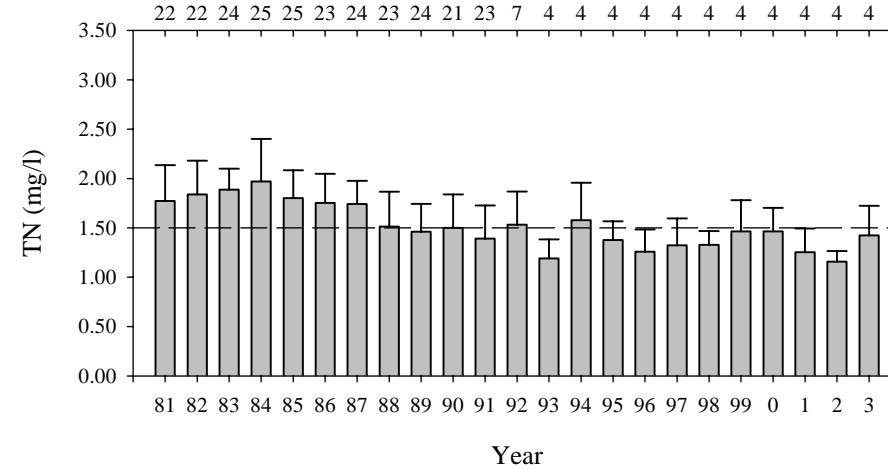
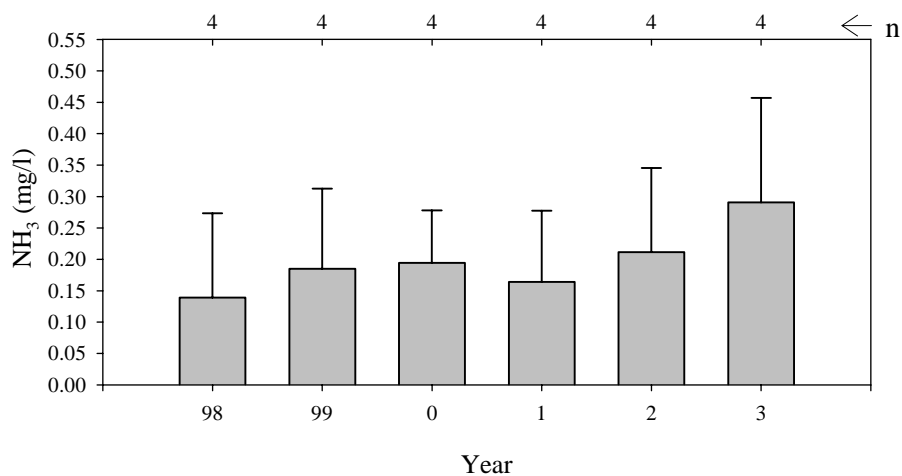
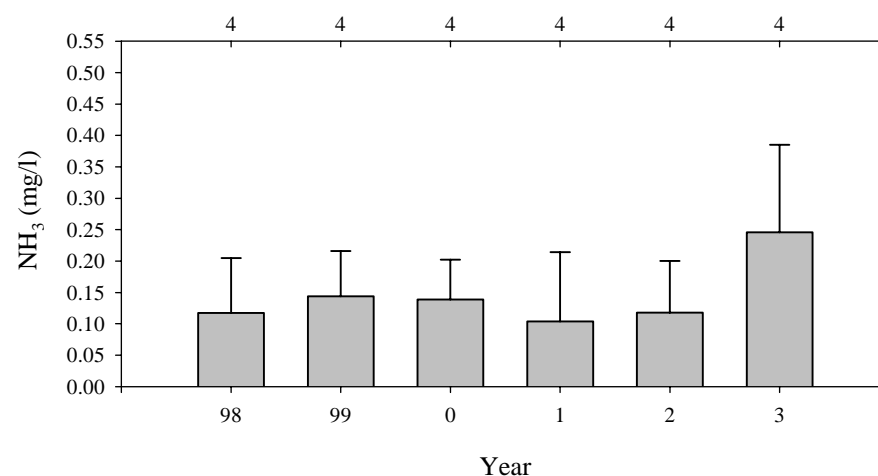


Figure 43. Annual Mean Ammonia (NH₃) within the C-13 Canal Basin (Florida Department of Environmental Protection WBID 3273) from 1998 to 2003. Means and standard deviations (error bars) calculated from quarterly sampling with number of samples (n) for each year noted on upper x-axis. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

a) Site 14



b) Site 13



c) Site 12

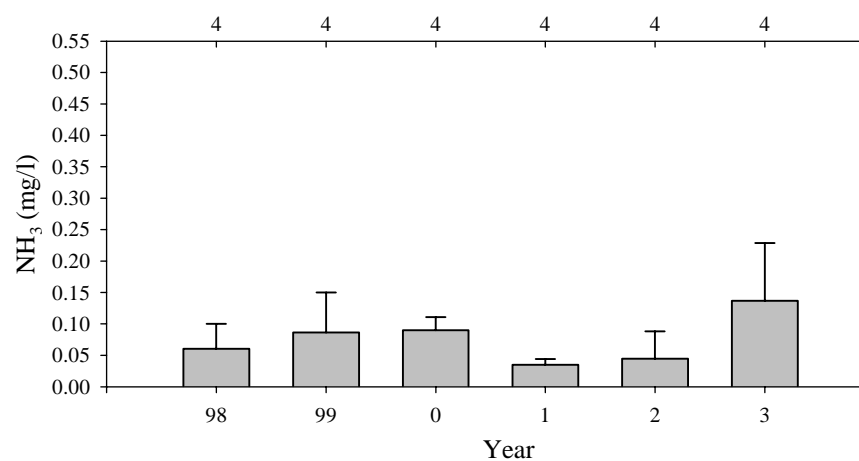


Figure 44. Annual Mean Nitrite+Nitrate-Nitrogen (NO_2+NO_3) Content within the C-13 Canal Basin (Florida Department of Environmental Protection WBID 3273) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., $n=4$) unless noted on upper x-axis. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

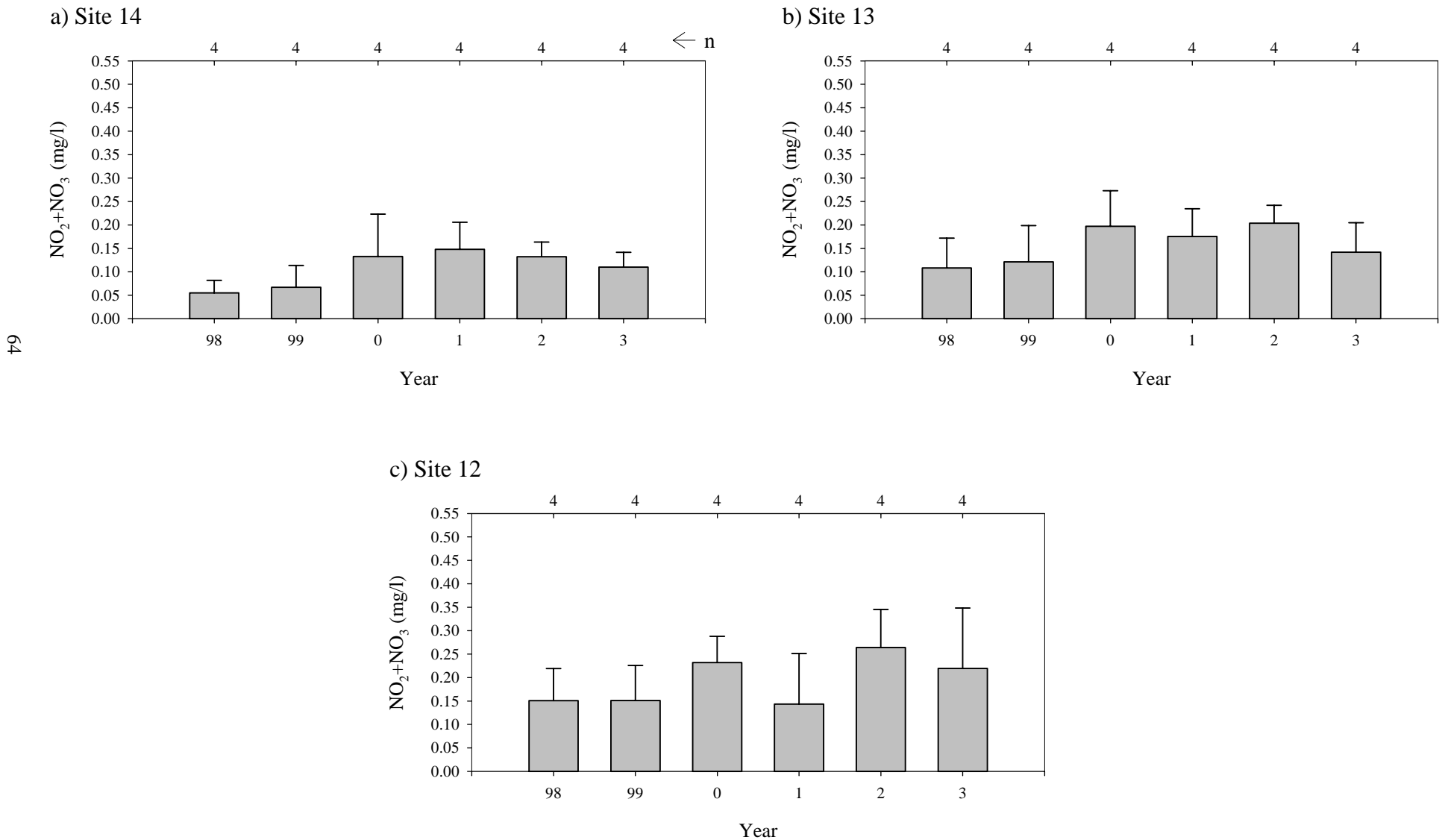


Figure 45. Annual Mean Chlorophyll a Levels within the C-13 Canal Basin (Florida Department of Environmental Protection, FDEP, WBID 3273) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. The FDEP Impaired Waters Rule (Florida Administrative Code 62-303) chlorophyll a threshold value of 20 ug/l is shown by the dashed line. Waterbodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

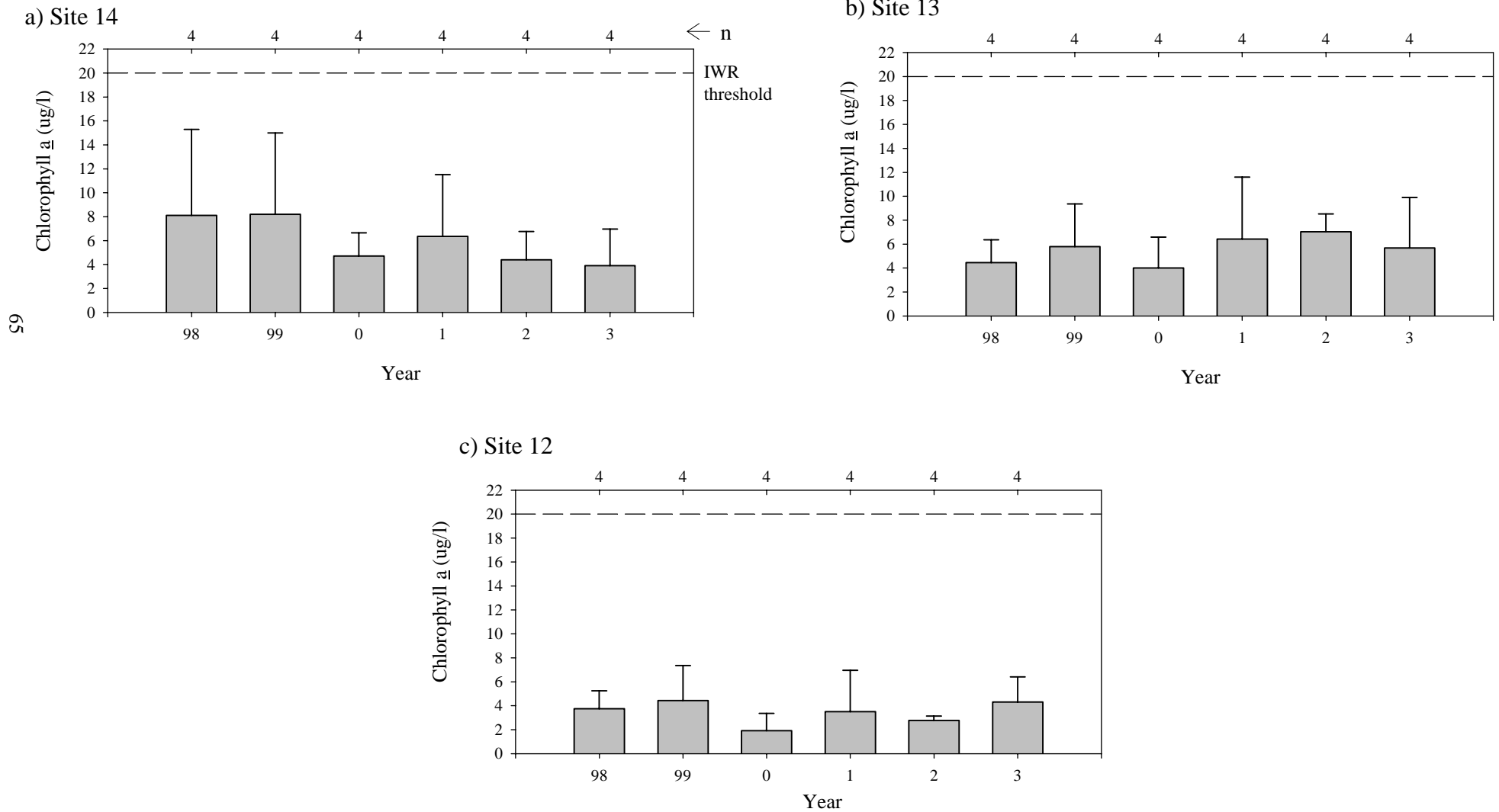
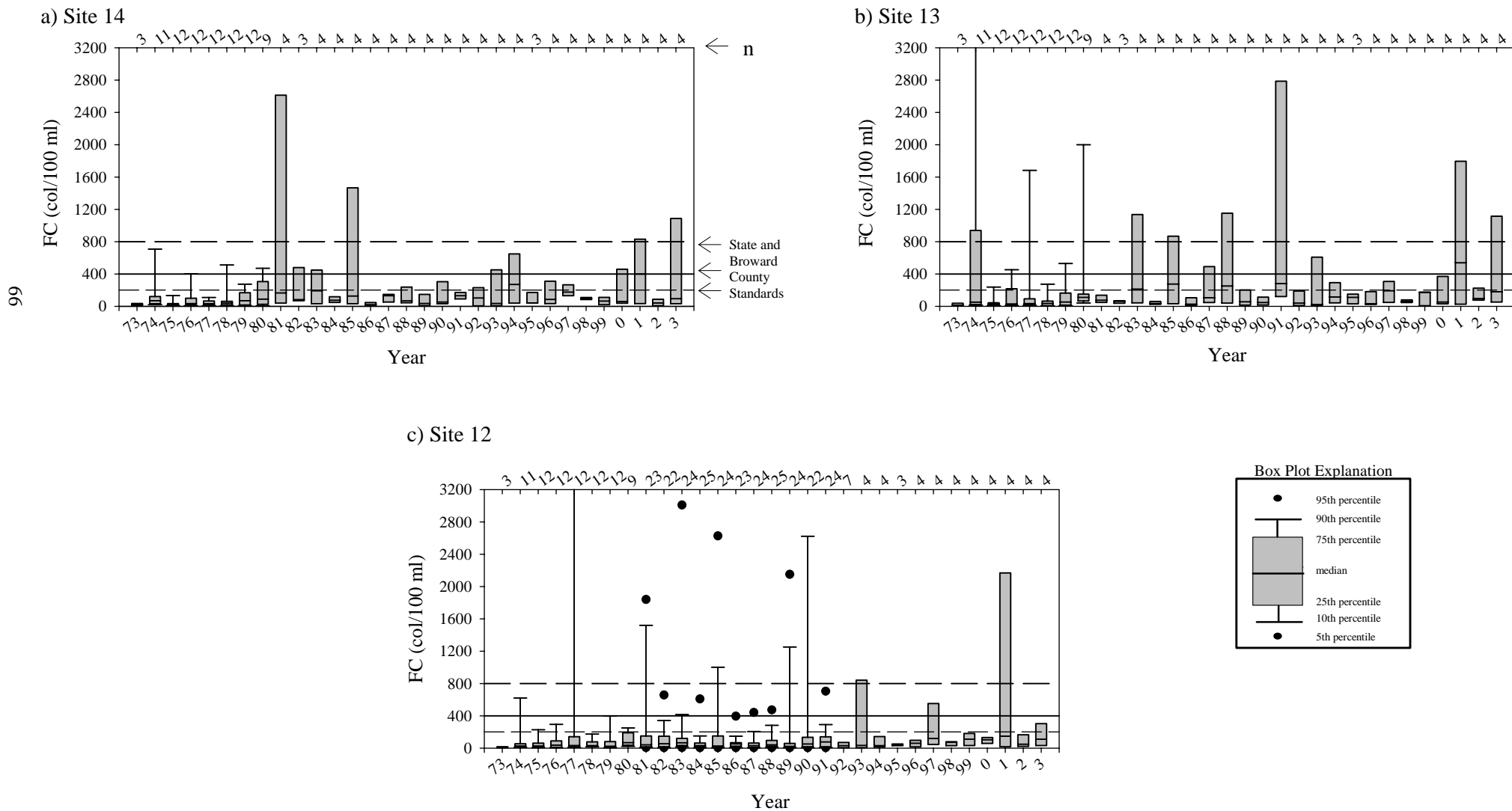


Figure 46. Annual Box Plots of Fecal Coliform (FC) Levels within the C-13 Canal Basin (Florida Department of Environmental Protection WBID 3273) from 1973 to 2003. Medians and percentiles calculated from bi-weekly, monthly, and quarterly samples with the number of samples (n) noted on the upper axis. To be within compliance of state and county environmental regulations, levels shall not exceed a monthly average of 200 colonies per 100 milliliters (col/ml), nor exceed 400 col/100 ml in 10% of the samples, nor exceed 800 col/100 ml on any one day. Numbers in parentheses represent 75th percentile values that extend beyond y-axis. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.



E. C-12 Canal (Florida Department of Environmental Protection, FDEP, WBID 3276)

1. Basin Description and Sampling Locations

The C-12 Basin has a relatively small drainage area of nineteen mi² and is located in east-central Broward County (Cooper and Lane 1987, Figure 47). The C-12 Canal forms the headwaters of the S33 control structure. Within the C-12 Basin, the tail waters of the S33 exist in the North Fork New River, an estuarine water body. The C-12 Basin is unique among the major basins because no temporary or permanent flow originates from WCA seepage and water supply to the basin is limited to rainfall (Cooper and Lane 1987). The Old Plantation Water Control District has a pump site at the western end of the canal that is relatively inactive. Thus, overall flow in the canal is basically limited to major storm events. For example, a BCDPEP study (1999) compiled SFWMD S33 flow data and zero flow occurred 85% of the time from December 1998 through January 1999.

The Broward County Environmental Protection Department (EPD) has maintained sampling sites on the C-12 since 1973. Site 17 is situated immediately west of the S33 control structure and has been sampled since 1973. Site 18 is located at the Northwest 9th Drive bridge and sampling commenced there in 1980 (Figure 47).

2. Specific Conductance

Sites 17 and 18 showed relatively similar annual specific conductance values (Figure 48) typically below 500 micromhos per centimeter. In addition, both sites exhibited similar levels over time with one apparent outlier in 2002 at Site 17.

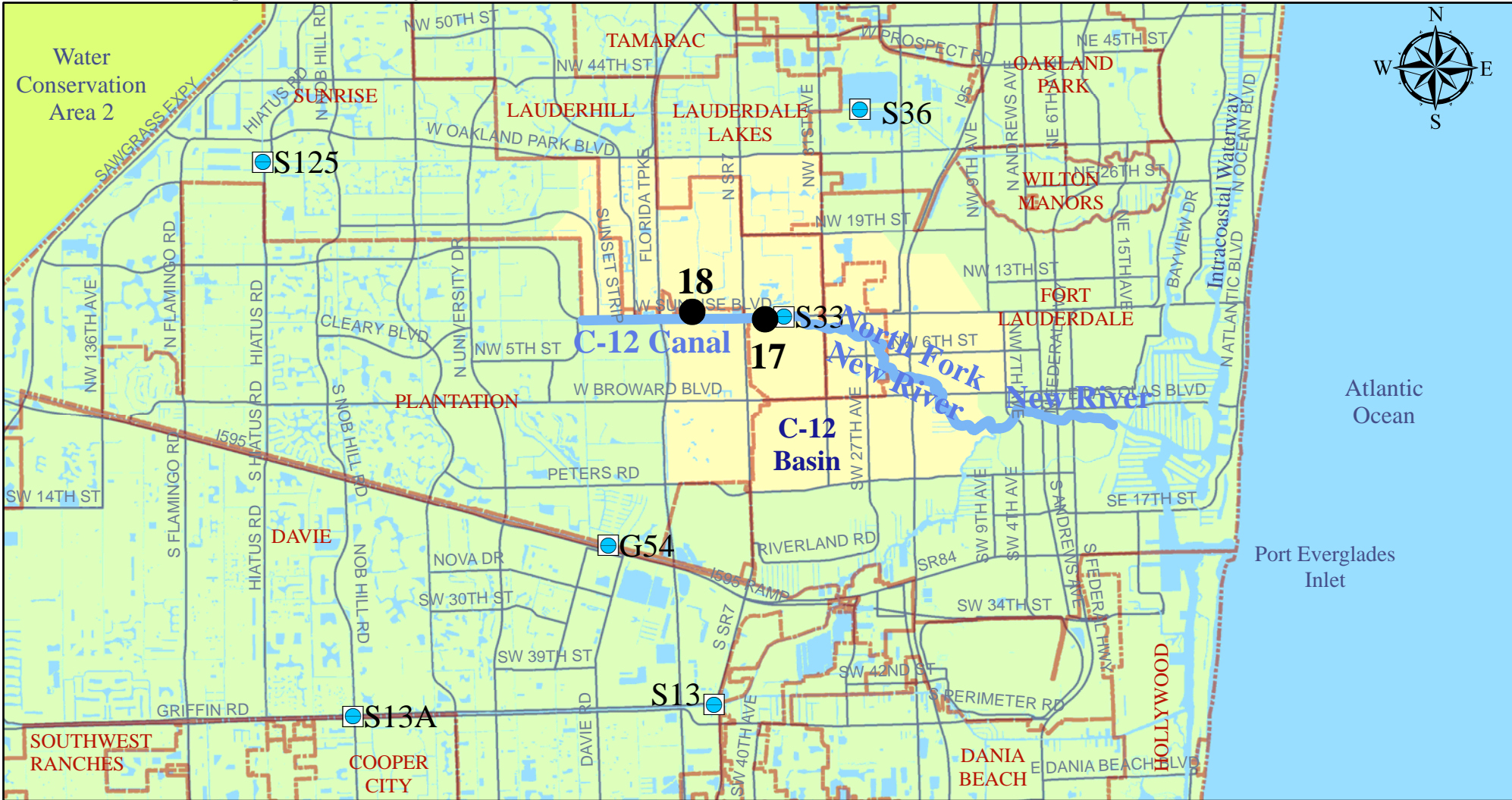
3. Total Organic Carbon

Annual total organic carbon (TOC) concentrations were slightly higher at Site 18 as compared to Site 17 (Figure 49). Generally, yearly means ranged from 9.0 to 12.0 milligrams per liter (mg/l) at both sites from 1998 and 2002. The highest averages were observed in 2003 at each site with Site 18 exhibiting the maximum of 14.3 mg/l.

4. Dissolved Oxygen

Dissolved oxygen (DO) values from 1973 to 2003 are shown as these graphs (Figure 50) were available in the EPD's first water quality atlas (Broward County 2001). Annual DO averages have generally increased to compliance levels at Sites 17 through 18 from 1997 until 2003 (Figure 50). This increase in DO values occurred after a period of depressed values was occasionally seen in the canal (1993 through 1996). The period from 1997 through 2003 was actually more comparable to the period of 1988 through 1992. Although annual averages are above the standard, it is important to note the variability around the mean was high on occasion ranging between \pm 1.7 and 4.1 mg/l from 2001 until 2003.

Figure 47. Broward County Environmental Protection Department's Surface Water Quality Monitoring Sites on the Freshwater C-12 Canal. The C-12 Canal drainage basin is depicted by yellow color and includes both the freshwater C-12 Canal and the estuarine North Fork New River which begins east of the South Florida Water Management District's (SFWMD) coastal salinity control structure, S33. Sampling Sites 17 and 18 are west of the S33. Major cities in both sub-basins are labeled and depicted with the orange outline.

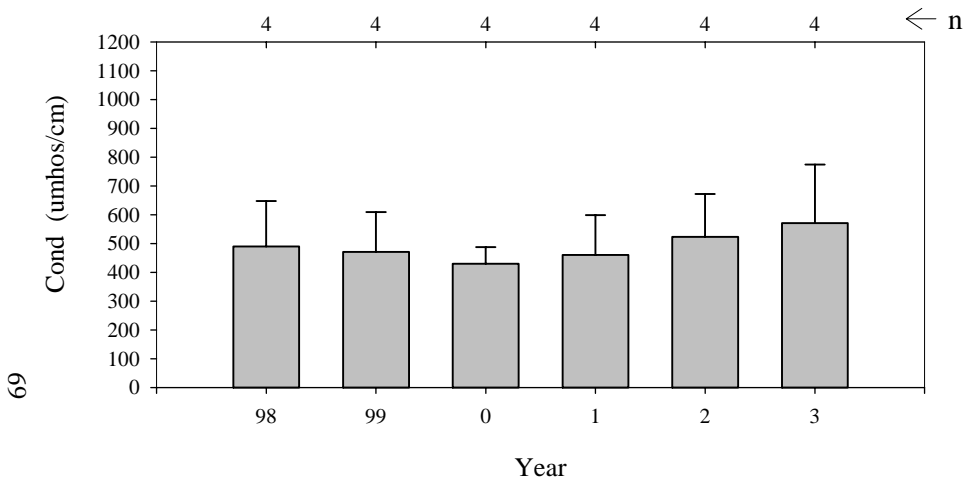


89

Water bodies	BCEPD Monitoring Sites	Legend	Urban Boundary	Miles 0 0.75 1.5 2.25 3
Major Roads	SFWMD Water Control Structures		City Boundary	

Figure 48. Annual Mean Specific Conductance (Cond) Levels within the C-12 Canal Basin (Florida Department of Environmental Protection WBID 3276) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) and values are shown in micromhos per centimeter (umhos/cm) at 25 degrees Celsius. Sites are shown in a west to east orientation to show the typical canal flow direction when water control structures are operating which is rare for the C-12 .

a) Site 18



b) Site 17

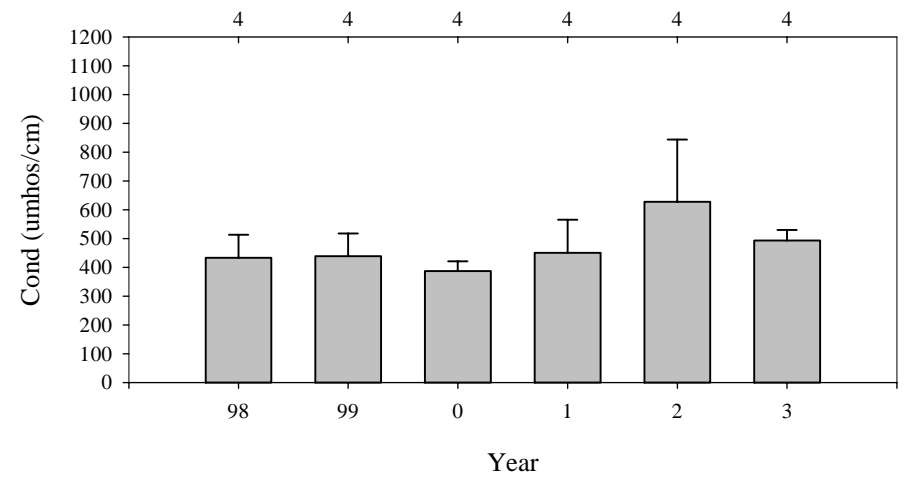


Figure 49. Annual Mean Total Organic Carbon (TOC) Content within the C-12 Canal Basin (Florida Department of Environmental Protection WBID 3276) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4). Sites are shown in a west to east orientation to show the typical canal flow direction when water control structures are operating which is rare in C-12 Canal (see text).

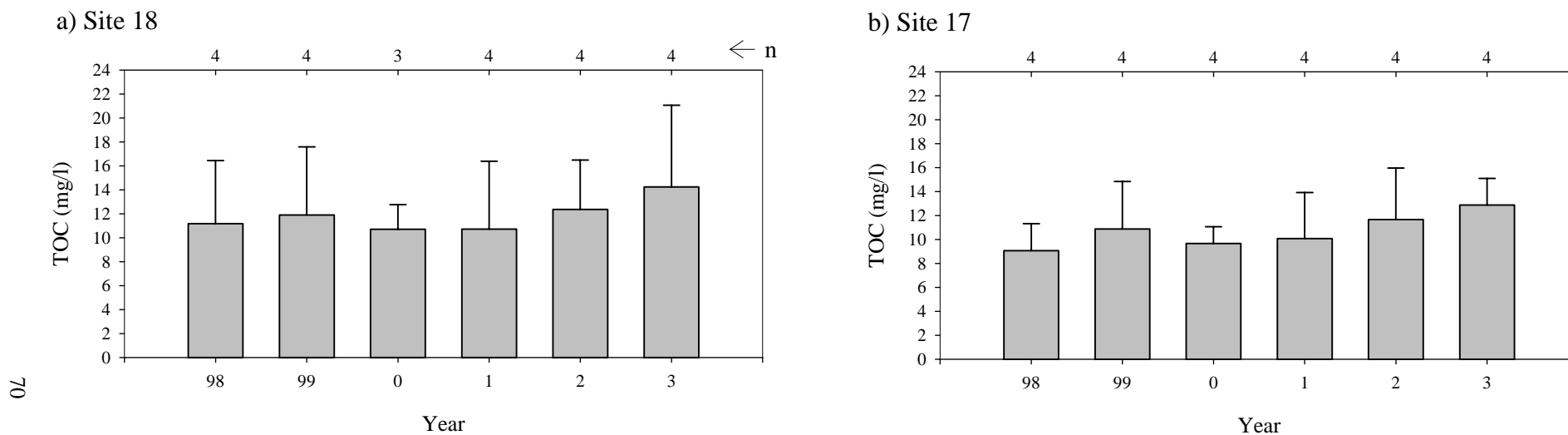
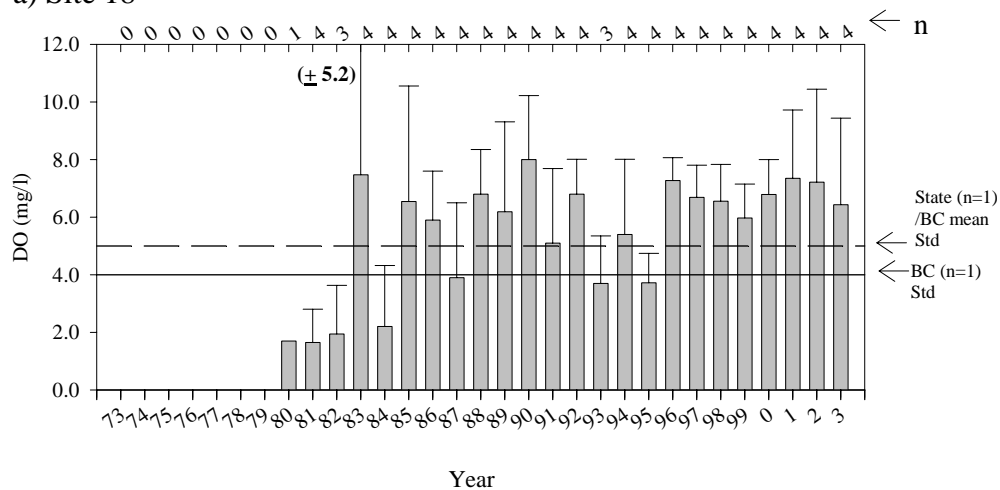
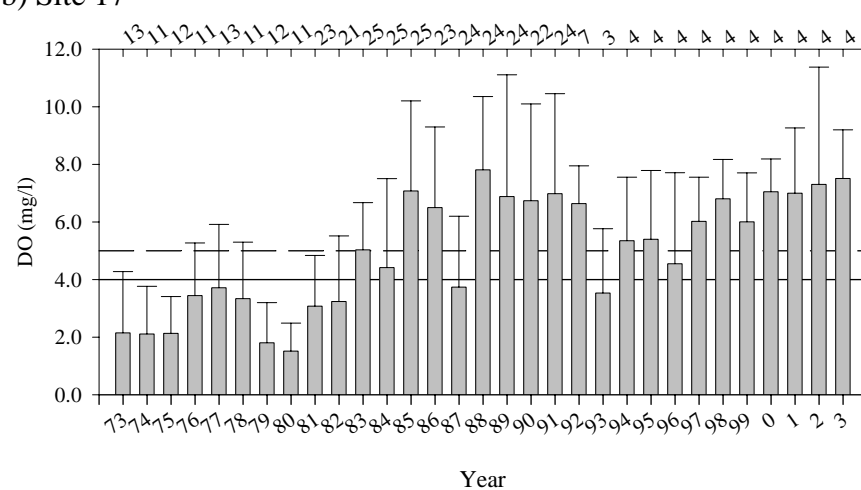


Figure 50. Annual Mean Dissolved Oxygen (DO) Content within the C-12 Canal Basin (Florida Department of Environmental Protection WBID 3276) from 1973 to 2003. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county (BC) water quality standards, any sample should be equal to or above 4.0 mg/l (solid line), while the daily average should be greater than or equal to 5.0 mg/l (dashed line). State water quality criteria mandate all samples must be greater than or equal to 5.0 mg/l (dashed line). Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow which is rare in C-12 Canal (see text).

a) Site 18



b) Site 17



5. Total Phosphorus

Total phosphorus (TP) values from 1974 to 2003 are shown as these graphs (Figure 51) were available in the EPD's first water quality atlas ([BCDPEP 2001](#)). The long term data shows four distinct shifts in TP concentrations over time. The first two shifts occurred in 1980 and 1987 after secondarily treated human wastewater discharges to the waterway ceased. Ambient levels remained around 0.075 mg/l from 1988 through 1999 with an occasional deviation at both Sites 17 and 18. The most recent shift has TP annual values ranging from 0.026 to 0.042 mg/l and the canal is now closer to compliance with the Broward County standard of 0.02 mg/l.

6. ortho-Phosphate

The ortho-Phosphate (o-OP₄) observations are made more complex because BCEPD changed its method detection limit (mdl) from 0.030 mg/l to 0.00348 mg/l in 2000. Thus, the use of half the detection limit for samples which were below the mdl in 1998 and 1999 are an order of magnitude higher in concentration than mdls for 2000 through 2003. In addition, the practical quantitation limit, which is the mdl multiplied by four, was also higher by default because of a higher mdl. Since the detection limit change, Site 18 has exhibited slightly higher annual o-OP₄ averages but also higher variability than Site 17 (Figure 52). Annual o-OP₄ values throughout the waterway were rarely greater than 0.020 mg/l and more typically below 0.01 mg/l.

7. Total Nitrogen

Total nitrogen (TN) values from 1981 to 2003 are shown as these graphs (Figure 53) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). With few exceptions (e.g., 1996), TN values at Site 17 and 18 were relatively similar each year. Overall, TN values were typically less than 1.0 mg/l in the canal since 1988.

8. Ammonia-Nitrogen

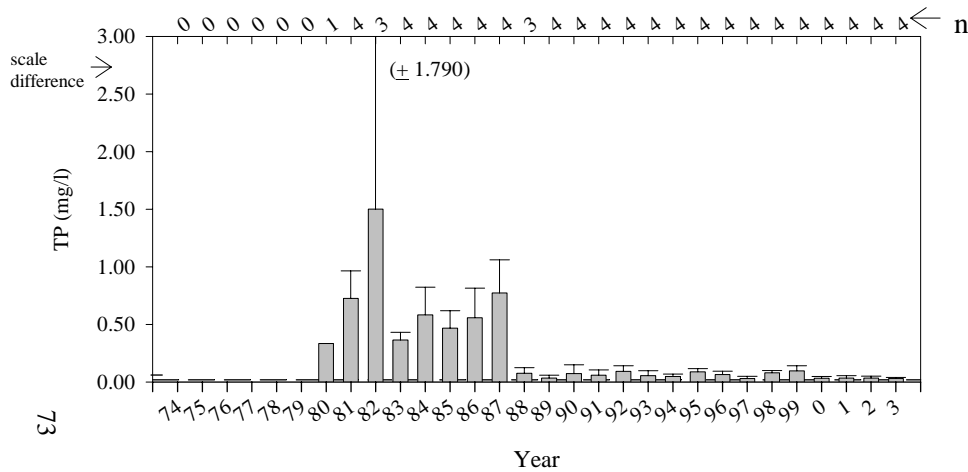
Ammonia-nitrogen (NH₃) annual averages and variability were higher at Site 18 during 1998 and 1999 and then the opposite pattern was observed from 2000 through 2003 (Figure 54). At both sites, NH₃ values were typically below 0.05 mg/l over the six years of measurements.

9. Nitrite+Nitrate-Nitrogen

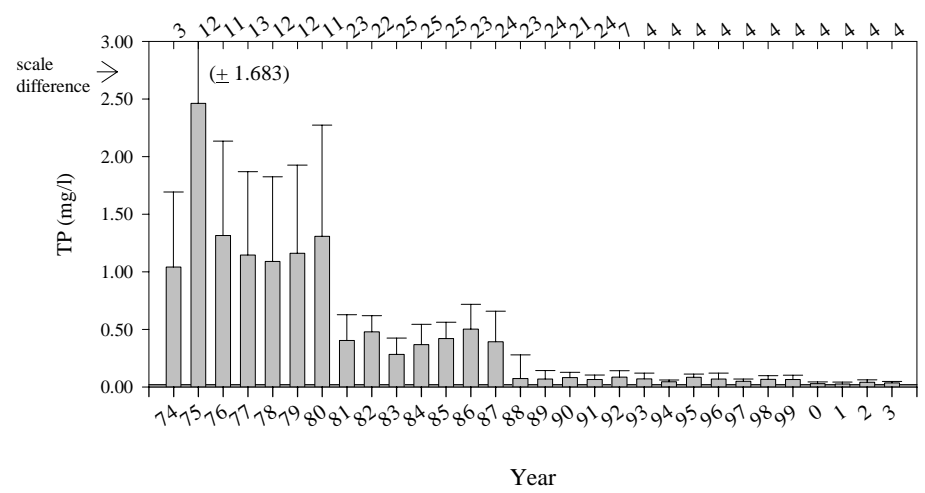
Nitrite+nitrate-nitrogen (NO₂₊₃) annual averages and variability were essentially the same at Sites 17 and 18 from 1998 through 2000 (Figure 55) but each site showed differing patterns in NO₂₊₃ content during 2001 through 2003. Site 17 had a spike in NO₂₊₃ concentrations in 2002 while Site 18 displayed a general decrease in NO₂₊₃ from 2001 through 2003. Maximum yearly averages were either above or near 0.100 mg/l while the minimum annual means centered around 0.025 mg/l.

Figure 51. Annual Mean Total Phosphorus (TP) Levels within the C-12 Canal Basin (Florida Department of Environmental Protection WBID 3276) from 1974 to 2003. Means and standard deviations (error bars) calculated from biweekly, monthly, and/or quarterly samples with the number of samples (n) noted on the upper x-axis. Numbers in parentheses represent standard deviation outside range of graph. To be within compliance of county environmental regulations, TP levels should be below the Broward County standard (0.02 mg/l) indicated by the dashed line. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow which is rare in C-12 Canal (see text).

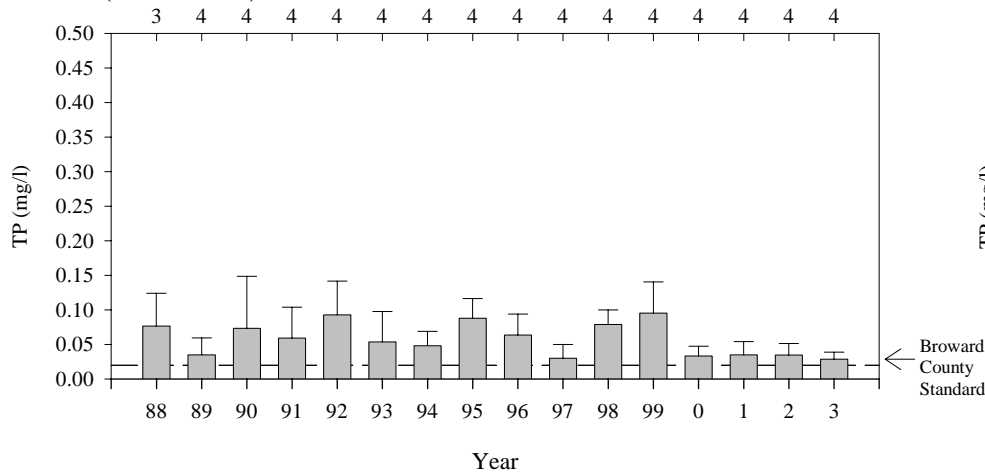
a) Site 18



b) Site 17



c) Site 18 (1988-2003)



d) Site 17 (1988-2003)

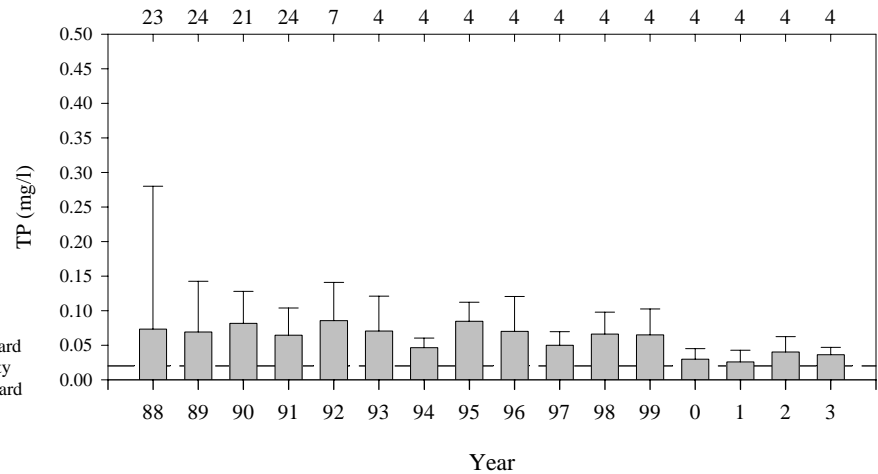


Figure 52. Annual Mean ortho-Phosphate (o-PO₄) Content within the C-12 Canal Basin (Florida Department of Environmental Protection WBID 3276) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. The method detection limit changed from 0.030 mg/l to 0.00348 mg/l in 2000. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow which are rare in the C-12 Canal.

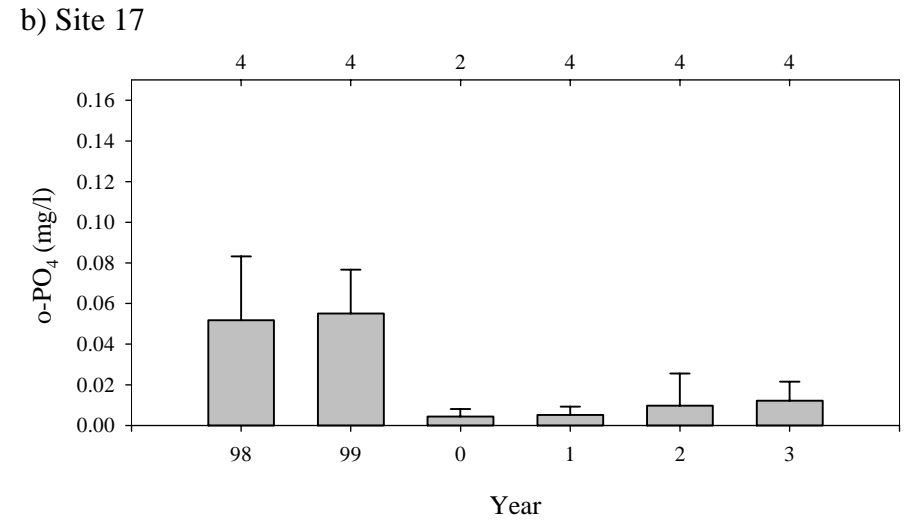
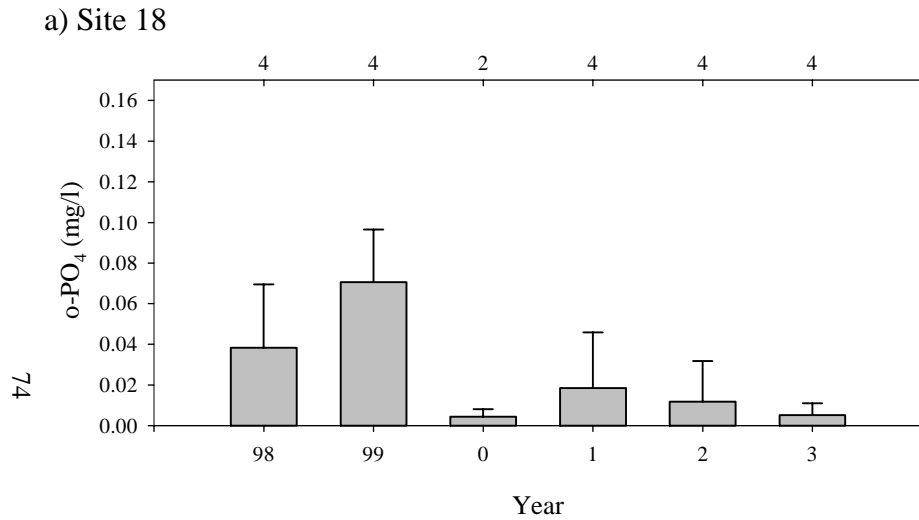


Figure 53. Annual Mean Total Nitrogen (TN) Levels within the C-12 Canal Basin (Florida Department of Environmental Protection WBID 3276) from 1981 to 2003. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county environmental regulations, TN levels should be below the Broward County standard (1.50 mg/l) indicated by the dashed line. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow which is rare in the C-12 Canal.

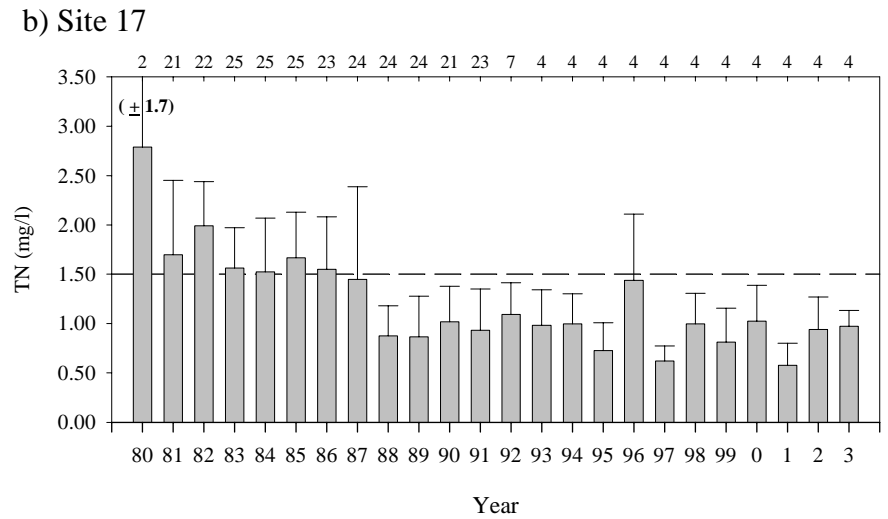
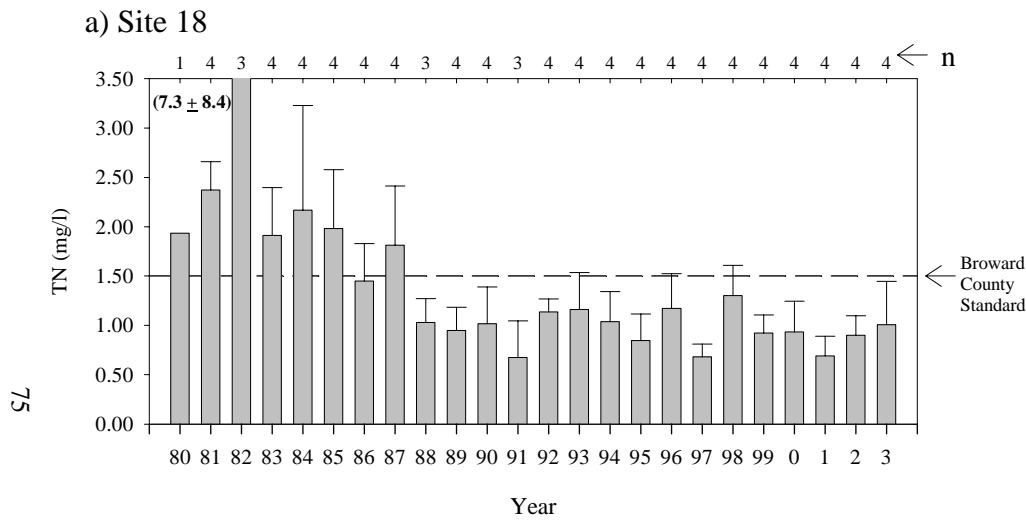
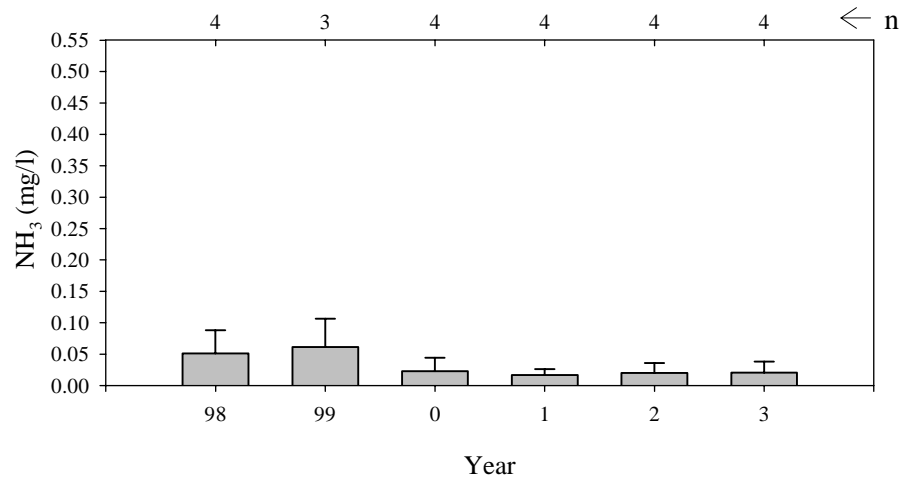


Figure 54. Annual Mean Ammonia (NH₃) within the C-12 Canal Basin (Florida Department of Environmental Protection WBID 3276) from 1998 to 2003. Means and standard deviations (error bars) calculated from quarterly sampling with number of samples (n) for each year noted on upper x-axis. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow which is rare in C-12 Canal (see text).

a) Site 18



b) Site 17

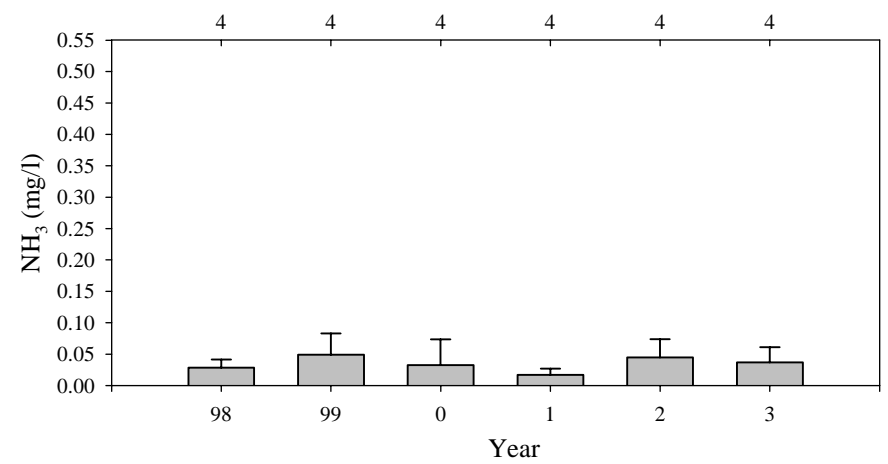
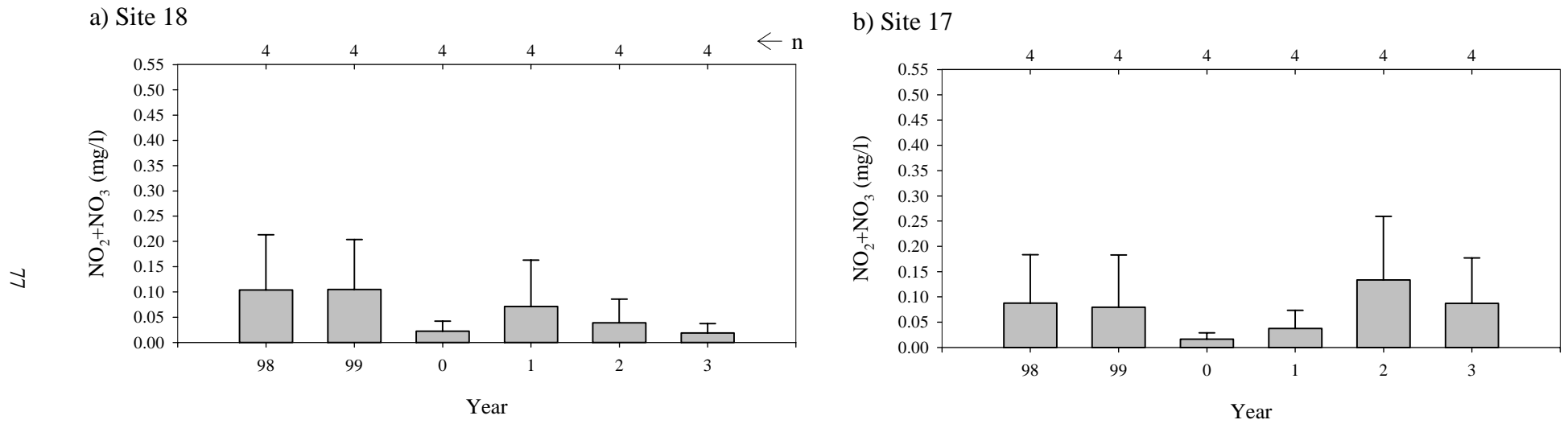


Figure 55. Annual Mean Nitrite+Nitrate-Nitrogen (NO₂+NO₃) Content within the C-12 Canal Basin (Florida Department of Environmental Protection WBID 3276) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow which is rare in C-12 Canal.



10. Chlorophyll a

All annual chlorophyll a (chl a) values were below the Impaired Waters Rule threshold value for freshwater canals (20 micrograms per liter, ug/l; [FDEP 2006b](#), Figure 56). Waterbodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients. Both sites had peaks in chl a observations in 1998 with Site 17 having a single observation greater than 20 ug/l. From 1999 through 2003, annual chl a concentrations in the C-12 were typically between 4 and 6 ug/l throughout the waterway.

11. Fecal Coliform

Fecal coliform (FC) content from 1973 to 2003 is shown as these graphs (Figure 57) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Most fecal coliform samples were within compliance of county ([Broward County 1996](#)) and state ([FDEP 2006a](#)) environmental regulations with a few exceptional events (e.g., Site 18 in 1998). However, in 2003, high fecal coliform concentrations were observed at both sampling sites. Although the median value was just below 400 colonies per 100 ml, Site 17 did have two observations greater than the 800 colonies per 100 ml standard in 2003. In addition, Site 17 had one observation over 800 colonies per 100 ml in 2002.

Figure 56. Annual Mean Chlorophyll a Levels within the C-12 Canal Basin (Florida Department of Environmental Protection, FDEP, WBID 3276) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. The FDEP Impaired Waters Rule (Florida Administrative Code 62-303) chlorophyll a threshold value of 20 ug/l is shown by the dashed line. Waterbodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow which is rare in the C-12 Canal.

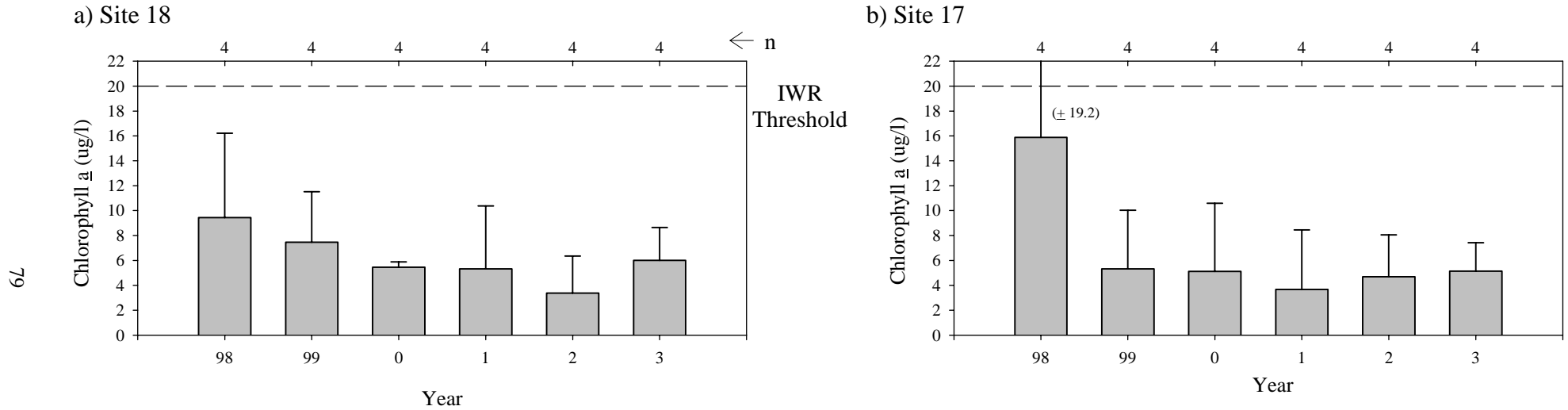
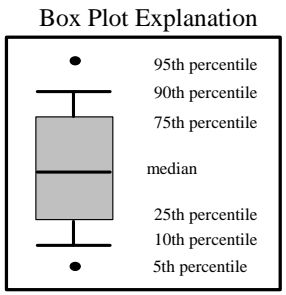
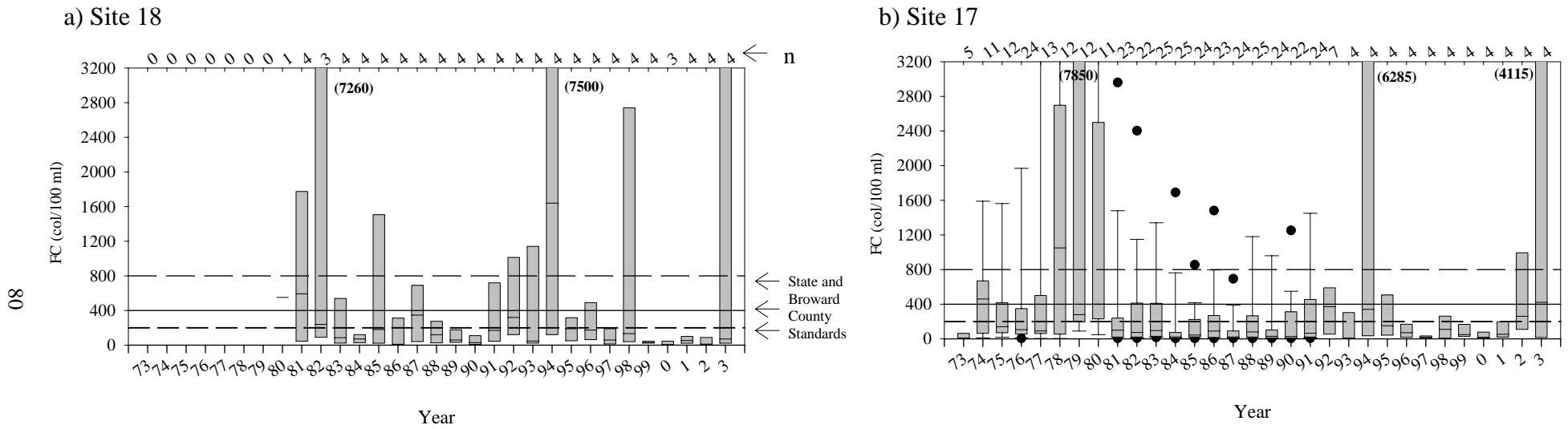


Figure 57. Annual Box Plots of Fecal Coliform (FC) Levels within the C-12 Canal Basin (Florida Department of Environmental Protection WBID 3276) from 1973 to 2003. Medians and percentiles calculated from bi-weekly, monthly, and quarterly samples with the number of samples (n) noted on the upper axis. To be within compliance of state and county environmental regulations, levels shall not exceed a monthly average of 200 colonies per 100 ml (col/100 ml), nor exceed 400 col/100 ml in 10% of the samples, nor exceed 800 col/100 ml on any one day. Numbers in parentheses represent 75th percentile values that extend beyond y-axis. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.



F. North New River Canal (Florida Department of Environmental Protection, FDEP, WBID 3277)

1. Basin Description and Sampling Locations

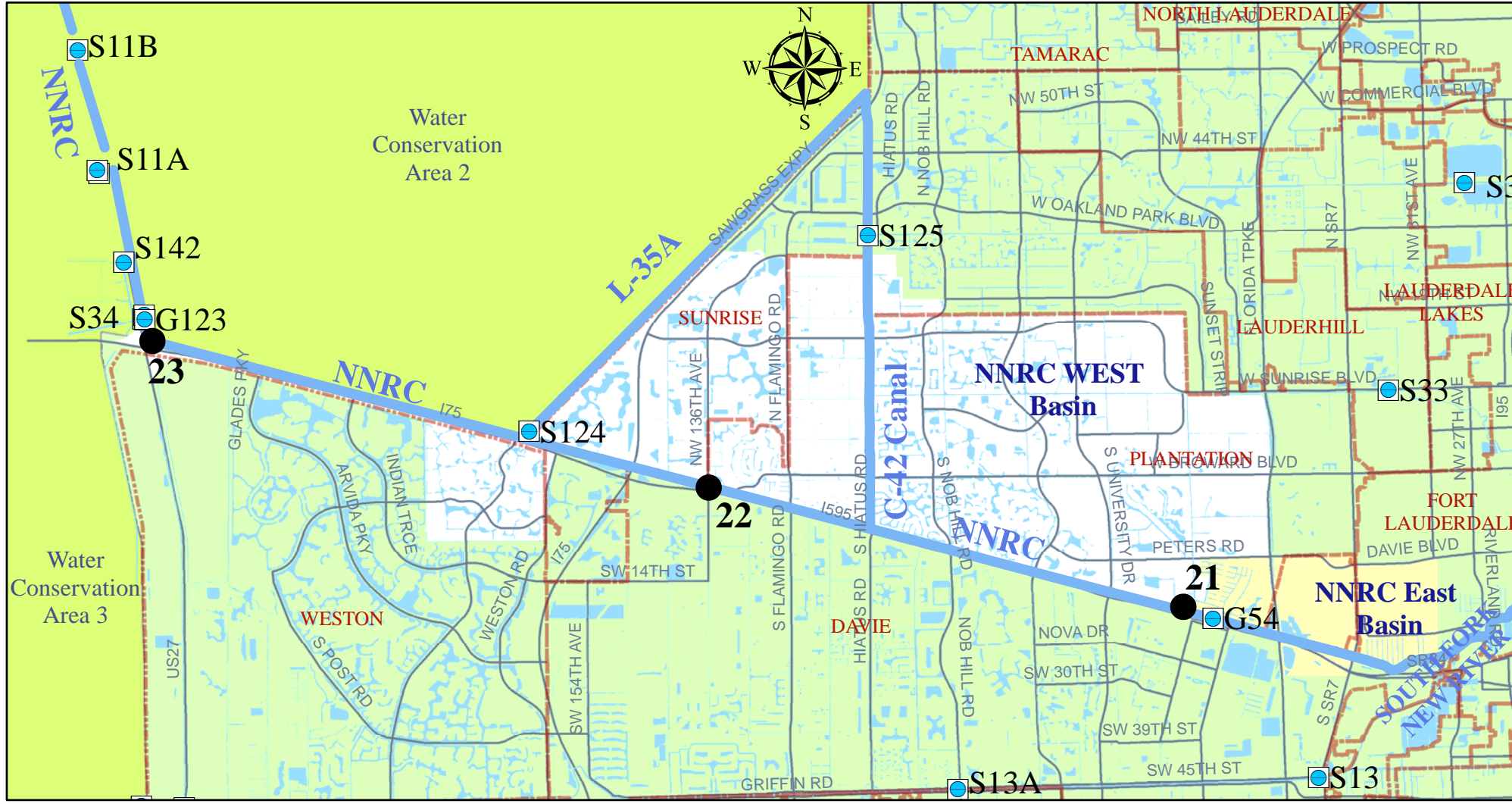
The North New River Canal (NNRC) Basin is a medium-sized drainage area of approximately thirty mi². The NNRC is divided into a western (twenty-three mi²) and an eastern (seven mi²) sub-basin with the approximate dividing boundary at University Drive (SR 817, Cooper and Lane 1987, Figure 58). Construction of the NNRC began in 1906 and was completed in 1912. The waterway was the first in Broward County to connect to Lake Okeechobee through a series of levees and water control structures.

Due, in part, to the convergence of two Water Conservation Areas (WCA), the South Florida Water Management District (SFWMD) has a complex set of water control structures including, S141, S142, S34, and G123, northwest near the US-27 and I-75 interchange (i.e., where populated Broward County begins). The main western inflow of water is from WCA 2 via the S143 and S34 (Cooper and Lane 1987). Additional water from WCA 2B and/or WCA 3A may be discharged to the NNRC by S141 and S142, respectively through the S34 depending on specific water elevations (Cooper and Lane 1987). In certain hydrological conditions (see Cooper and Lane 1987), NNRC water may be discharged through G123 and S142 into WCA 3A.

East of S34, the NNRC becomes the headwaters of the Sewell Lock (G54) which separates the fresh and estuarine sections of the waterway. The tidal NNRC meets the South Fork of the New River approximately four miles east of the Sewell Lock. The freshwater NNRC is a contiguous waterway through the western NNRC Basin. However, important hydrological connections occur in this segment. In the western NNRC Basin, the S124 normally allows water in the L-35A to be discharged to the C-13 Basin. However, during periods of flooding, the S124 allows water to flow southwest into the NNRC. In addition, the C-42 generally flows south of S125 (see C-13 Basin, Section III.D.1) and has a direct open connection to the NNRC at Hiatus Road. Most of the land area to the south of the NNRC drains to the C-11 Canal Basin (see III.F.1). However, Bonaventure is within the NNRC Basin and the Shenandoah development drains north to the NNRC during storm events (Cooper and Lane 1987).

Since 1972, The Broward County Environmental Protection Department (BCEPD) has maintained water quality monitoring sites along the NNRC and currently has three sites along the waterway (Figure 58). Site 23 is located at the US 27 and Interstate 75 interchanges and primarily represents water quality from the L-38 Canal system to the north. Site 22 is at the Southwest 125th Avenue Bridge approximately eight miles east of Site 23. Site 21 is immediately west of the Sewell Lock, five miles east of Site 22. Sampling site location information (e.g., coordinates) is shown in Appendix 1.

Figure 58 Broward County Environmental Protection Department's Surface Water Quality Monitoring Sites on the Freshwater North New River Canal (NNRC). The western portion of the NNRC Canal drainage basin is depicted by white color. Freshwater sampling site numbers 21, 22, and 23 are west of the South Florida Water Management District's (SFWMD) coastal salinity control structure, G54. The eastern portion of the NNRC Canal Basin (shown in yellow) primarily drains estuarine NNRC and portions of the South Fork New River to the east. Major cities in both sub-basins are labeled and depicted with the orange outline.



Water bodies	BCEPD Monitoring Sites	Legend	Urban Boundary	Miles 0 0.5 1 1.5 2
Major Roads	SFWMD Water Control Structures		City Boundary	

2. Specific Conductance

Sites 21 through 23 showed relatively similar annual specific conductance values from 1998 until 2003 (Figure 59). Site 23 typically had the highest annual averages in the NNRC but there were exceptions (e.g., Site 21 in 2003). Yearly means ranged from 650 to 850 micromhos/centimeters (umhos/cm) in the canal and variability was typically low with a few minor exceptions.

3. Total Organic Carbon

Annual total organic carbon (TOC) means were generally higher moving from the western most Site 23 to the eastern Site 21 within the NNRC (Figure 60). In addition, the maximum overall annual TOC mean was observed at Site 23 in 2003. Sites 21 and 22 had similar TOC content and generally tracked each other over time. The lowest annual mean (15.65 milligrams per liter, mg/l) was seen at Site 22 in 2002.

4. Dissolved Oxygen

Dissolved oxygen (DO) values from 1973 to 2003 are shown as these graphs (Figure 61) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Annual DO averages have generally increased to compliance levels at Site 23 from 1996 through 2003 but are typified by high variability (Figure 61). For example, the 1998 sampling year standard deviation almost equals the water quality criteria of 5 mg/l at Site 23. This high variability means that some samples are either extremely low, high, or a combination of the two when compared to the average. Sites 22 and 21 also were characterized by relatively high variability around the mean. Site 22 also has had a few years (e.g., 1999) with exceptionally low DO as compared to the rest of the canal.

5. Total Phosphorus

Total phosphorus (TP) values from 1974 to 2003 are shown as these graphs (Figure 62) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Over the last ten years, TP annual values at all NNRC sites were generally similar in content over time with the highest values observed from 1998 through 2000. In addition, a majority of the annual averages were typically within or close to compliance of the TP criteria of 0.02 mg/l. One exception was observed at Site 21 which exhibited the highest annual TP content for the NNRC in ten years in 2002 due to one anomalously high sample of 0.161 mg/l.

Figure 59. Annual Mean Specific Conductance (Cond) Levels within the North New River Canal Basin (Florida Department of Environmental Protection WBID 3277) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis and values are shown in micromhos per centimeter (umhos/cm) at 25 degrees Celsius. Sites are shown in a west to east orientation to show the typical canal flow direction when water control structures are operating.

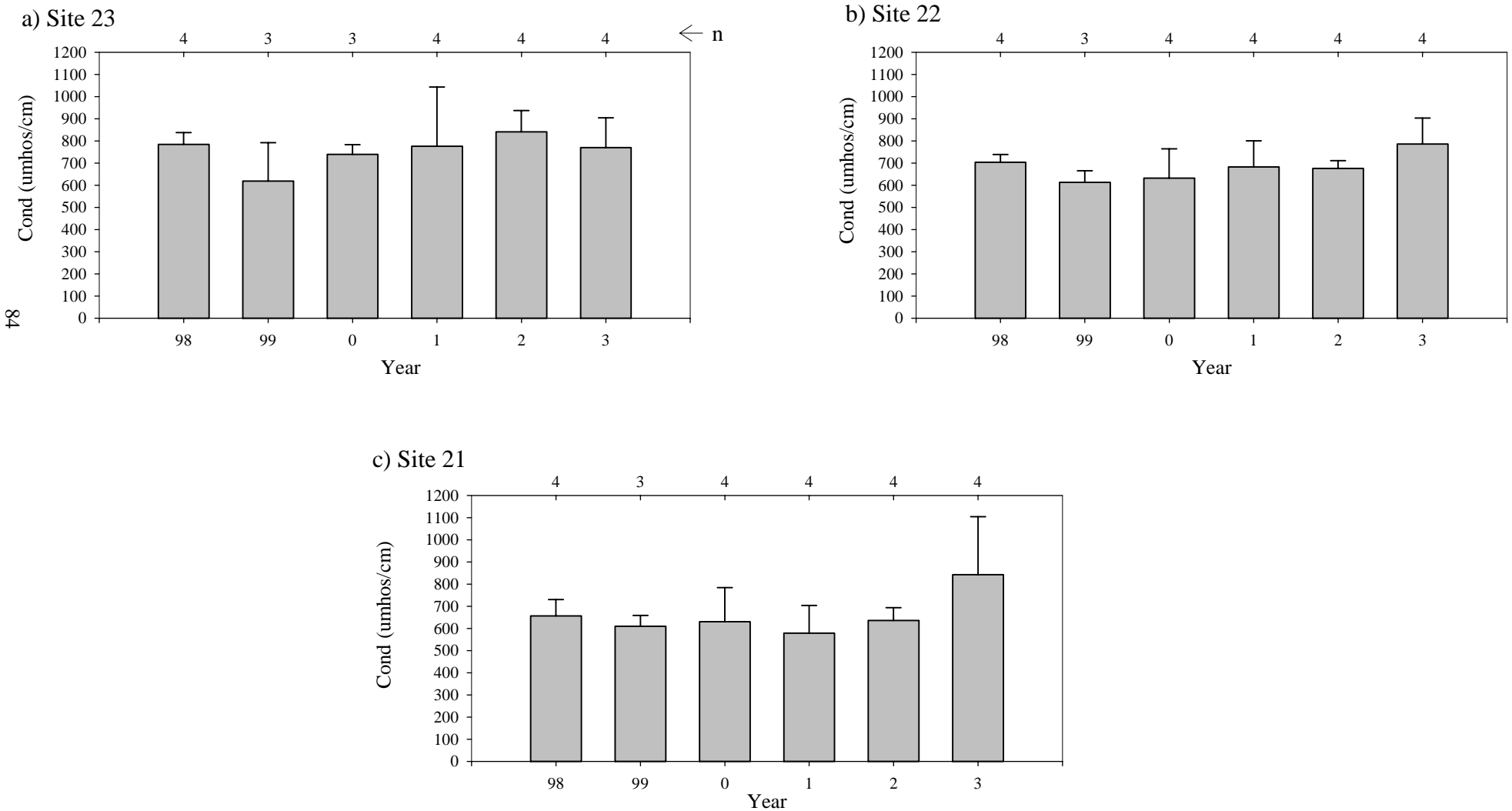
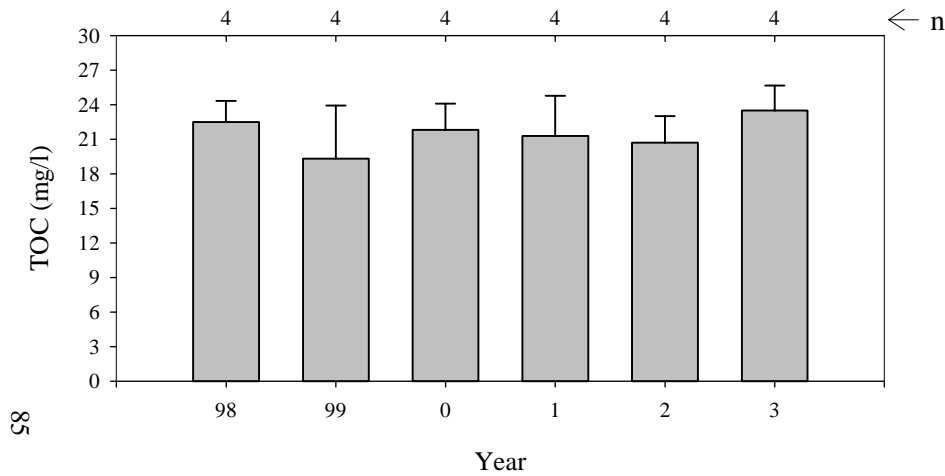
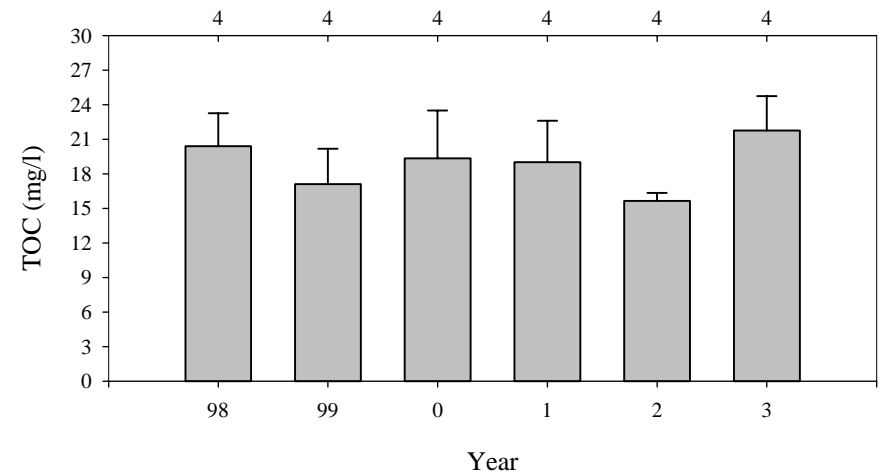


Figure 60. Annual Mean Total Organic Carbon (TOC) Content within the North New River Canal Basin (Florida Department of Environmental Protection WBID 3277) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. Sites are shown in a west to east orientation to show the typical canal flow direction when water control structures are operating.

a) Site 23



b) Site 22



c) Site 21

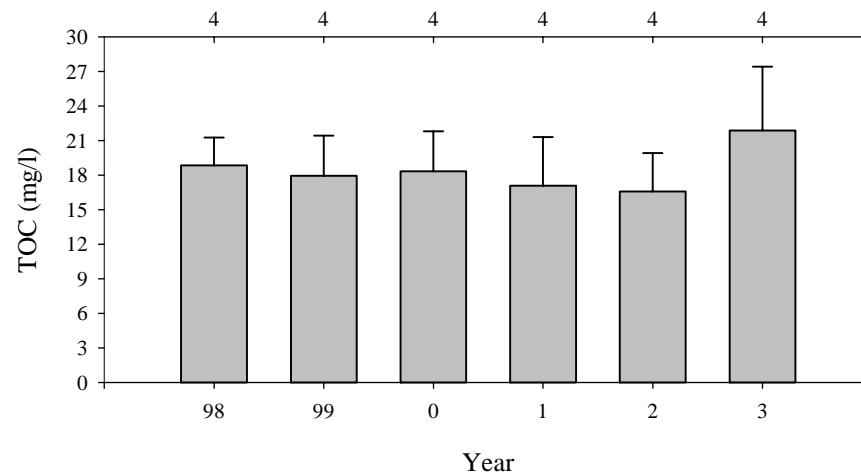
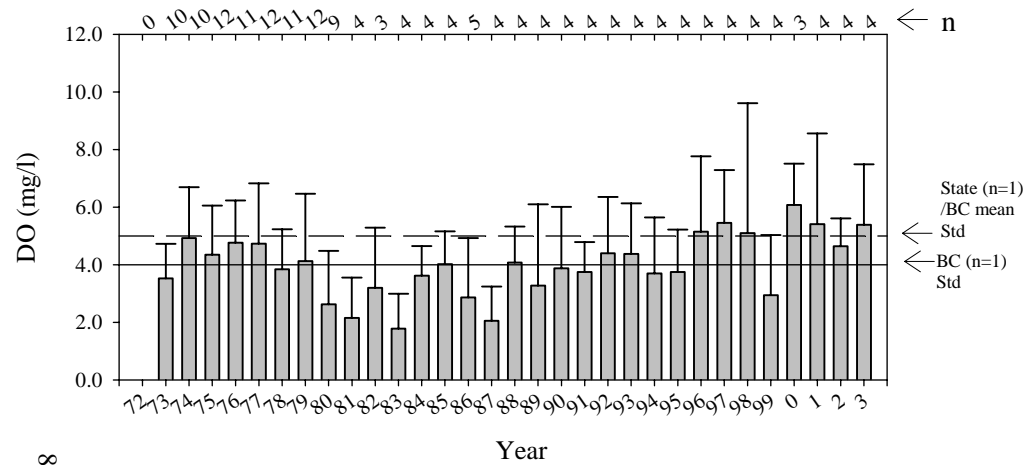
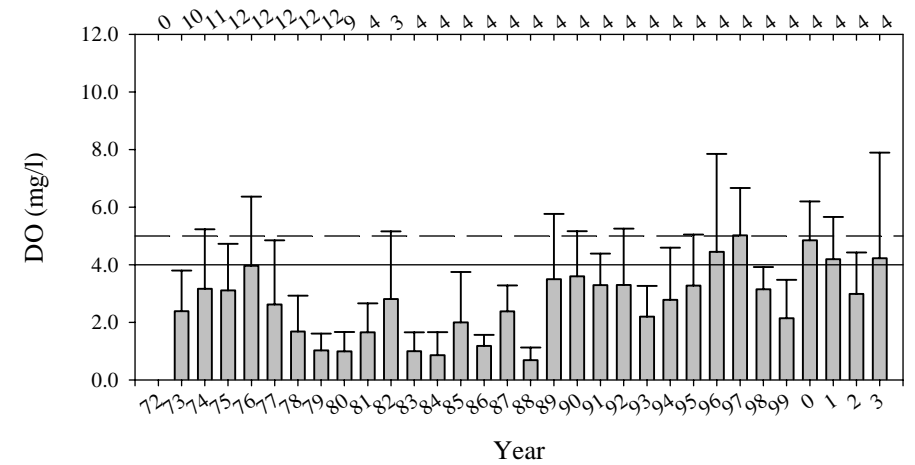


Figure 61. Annual Mean Dissolved Oxygen (DO) Content within the North New River Canal Basin (Florida Department of Environmental Protection WBID 3277) from 1972 to 2003. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county (BC) water quality standards, any sample should be equal to or above 4.0 mg/l (solid line), while the daily average should be greater than or equal to 5.0 mg/l (dashed line). State water quality criteria mandate all samples must be greater than or equal to 5.0 mg/l (dashed line). Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

a) Site 23



b) Site 22



c) Site 21

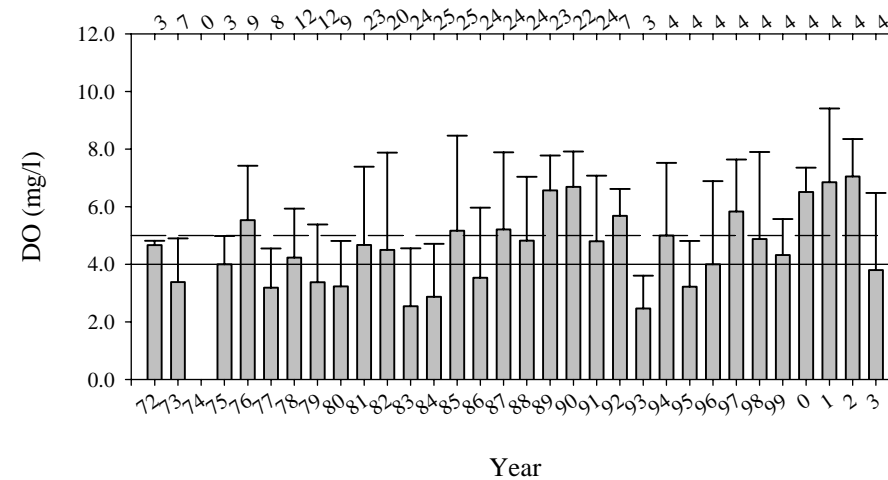
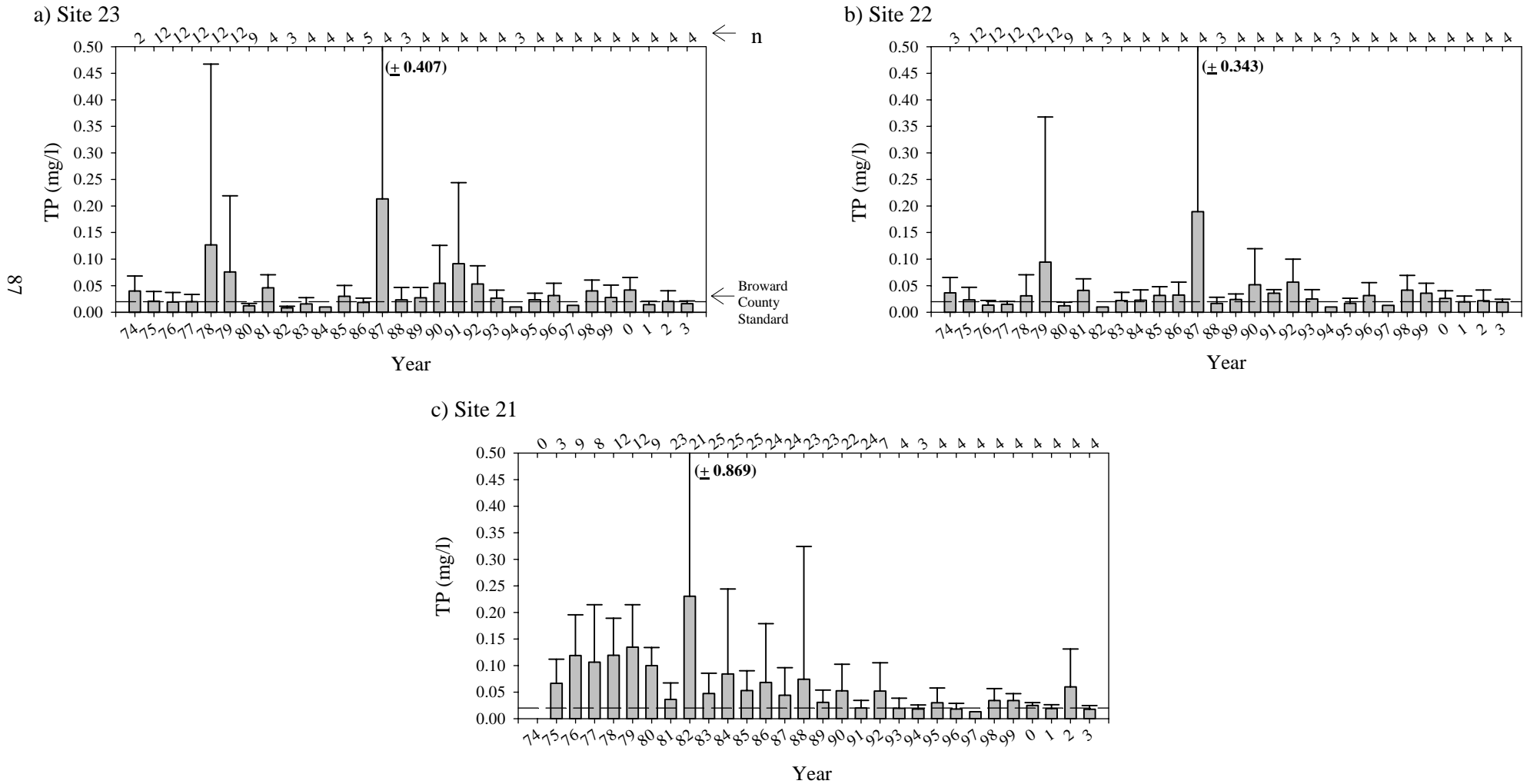


Figure 62. Annual Mean Total Phosphorus (TP) Levels within the North New River Canal Basin (Florida Department of Environmental Protection WBID 3277) from 1974 to 2003. Means and standard deviations (error bars) calculated from biweekly, monthly, and/or quarterly samples with the number of samples (n) noted on the upper x-axis. Numbers in parentheses represent standard deviation outside range of graph. To be within compliance of county environmental regulations, TP levels should be below the Broward County standard (0.02 mg/l) indicated by the dashed line. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.



6. ortho-Phosphate

The ortho-Phosphate (o-OP₄) observations are made more complex because BCEPD changed its method detection limit (mdl) from 0.030 mg/l to 0.00348 mg/l in 2000. Thus, the use of half the detection limit for samples which were below the mdl in 1998 and 1999 are an order of magnitude higher in concentration than mdls for 2000 through 2003. In addition, the practical quantitation limit, which is the mdl multiplied by four, was also higher by default because of a higher mdl. Annual o-OP₄ values throughout the NNRC were rarely greater than 0.010 mg/l and more typically below 0.005 mg/l (Figure 63). In fact, over fifty percent of samples taken between 2000 and 2003 were below the 0.00348 mg/ detection limit.

7. Total Nitrogen

Total nitrogen (TN) values from 1981 to 2003 are shown as these graphs (Figure 64) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Since the early 1990s, NNRC TN values have been relatively similar at Sites 23 and 22 with higher and lower values generally occurring during the same years. Values at Site 23 and 22 also tend to be over the Broward County standard of 1.5 mg/l since a three year record of compliance from 1995 through 1997. Overall, Site 21 had lower concentrations than the western portion of the canal and had the most annual averages within compliance of the Broward County TN water quality criteria of 1.5 mg/l.

8. Ammonia-Nitrogen

Ammonia-nitrogen (NH₃) annual averages and variability were exceptionally higher at Site 22 than the other two NNRC Canal sites (Figure 65). In particular, the annual means in 2001 and 2002 were greater than 0.400 mg/l at Site 22. Site 23 also exhibited relatively high NH₃ but not at the levels seen at Site 22. With the exception of 2003, Site 21 had the lowest NH₃ values seen in the canal.

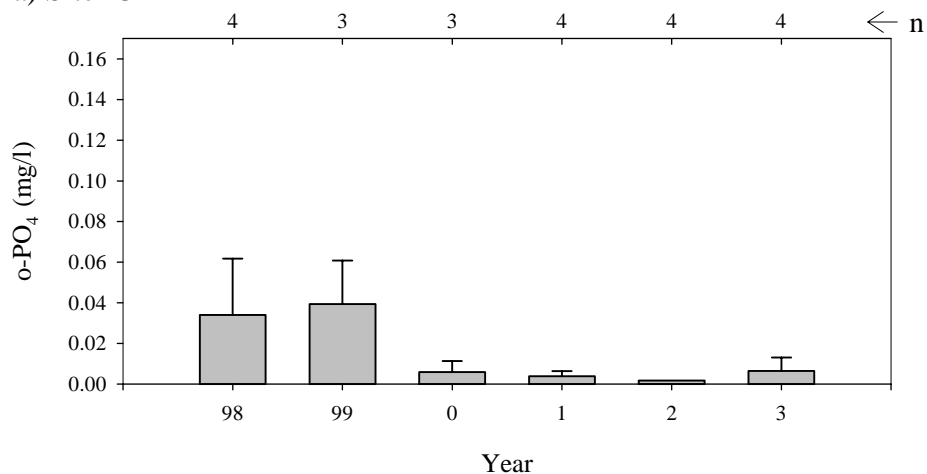
9. Nitrite+Nitrate-Nitrogen

The spatial pattern of nitrite+nitrate-nitrogen (NO₂₊₃) concentrations in the NNRC Canal (Figure 66) was generally opposite the pattern observed for the NH₃ concentrations (see Figure 65). The highest NO₂₊₃ concentrations were observed at Site 21 in the eastern portion of the canal, with some variability around the mean, while lower NO₂₊₃ values (less than 0.100 mg/l) were seen at Sites 22 and 23.

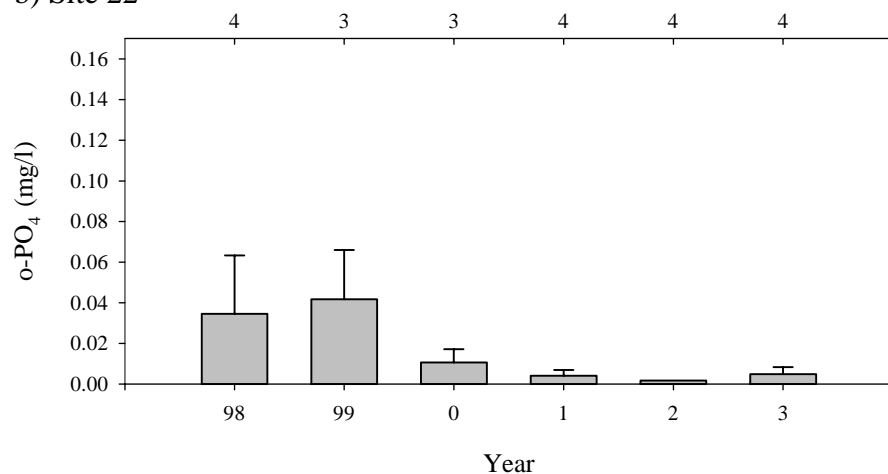
Figure 63. Annual Mean ortho-Phosphate (o-PO₄) Content within the North New River Canal Basin (Florida Department of Environmental Protection WBID 3277) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. The method detection limit changed from 0.030 mg/l to 0.00348 mg/l in 2000. Sites are shown in a western to eastern geographical orientation to show the normal direction of the canal during flow periods.

68

a) Site 23



b) Site 22



c) Site 21

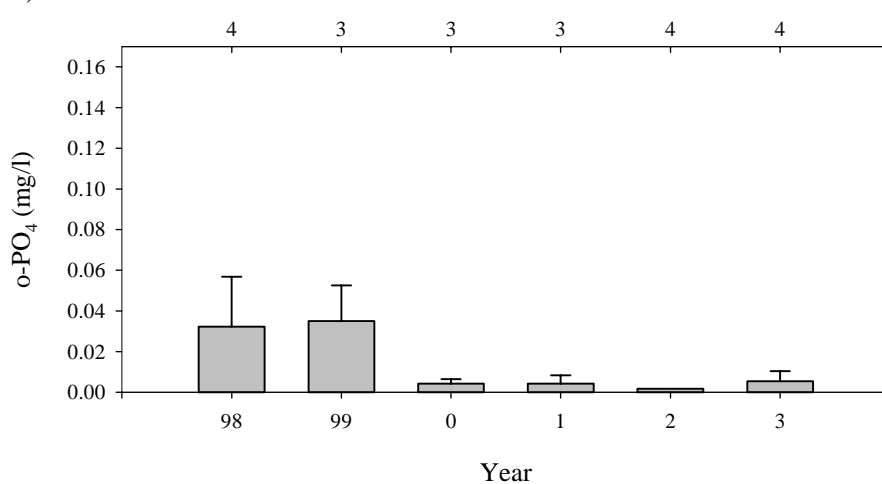


Figure 64. Annual Mean Total Nitrogen (TN) Levels within the North New River Canal Basin (Florida Department of Environmental Protection WBID 3277) from 1981 to 2003. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county environmental regulations, TN levels should be below the Broward County standard (1.50 mg/l) indicated by the dashed line. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

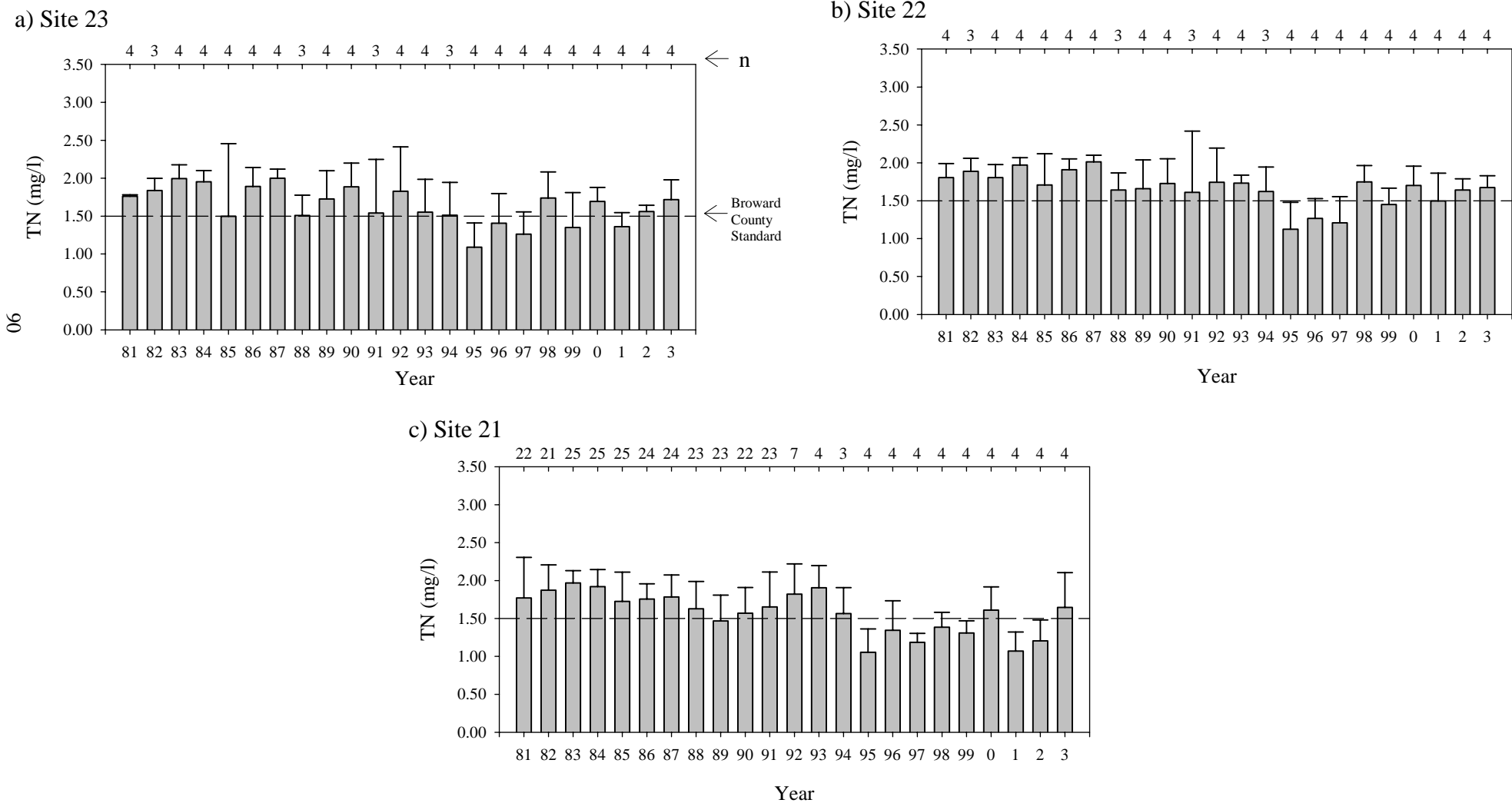
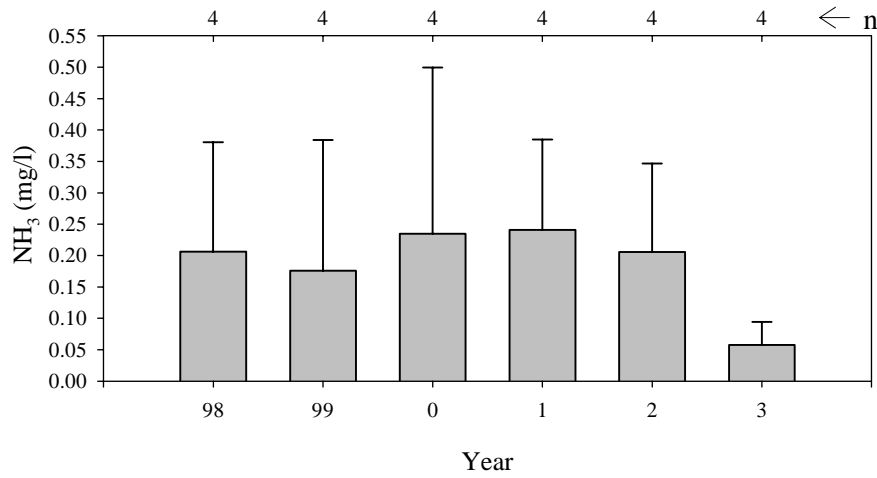


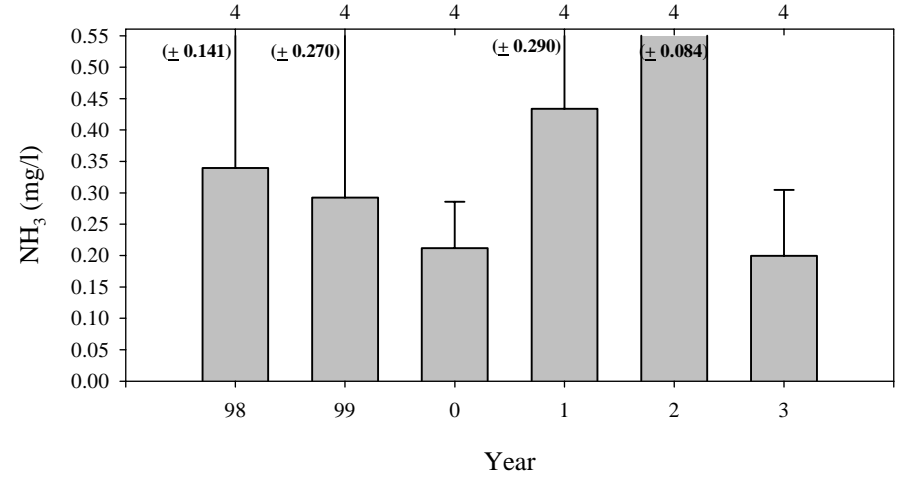
Figure 65. Annual Mean Ammonia (NH₃) within the North New River Canal Basin (Florida Department of Environmental Protection WBID 3277) from 1998 to 2003. Means and standard deviations (error bars) calculated from quarterly sampling with number of samples (n) for each year noted on upper x-axis. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

16

a) Site 23



b) Site 22



c) Site 21

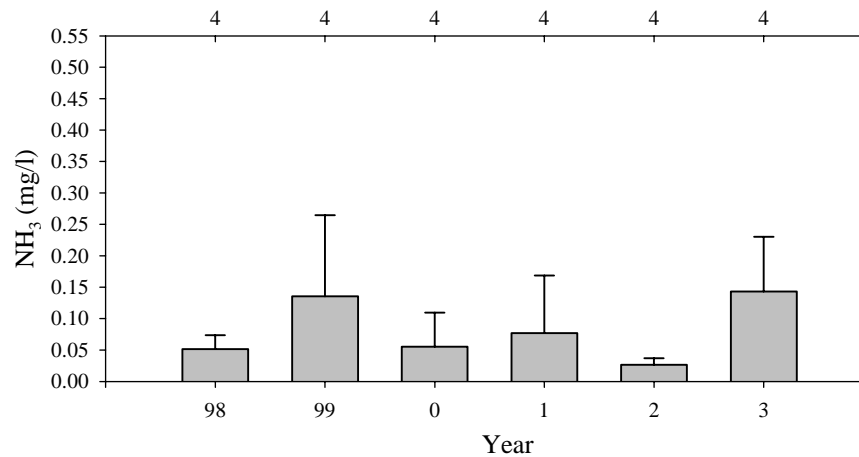
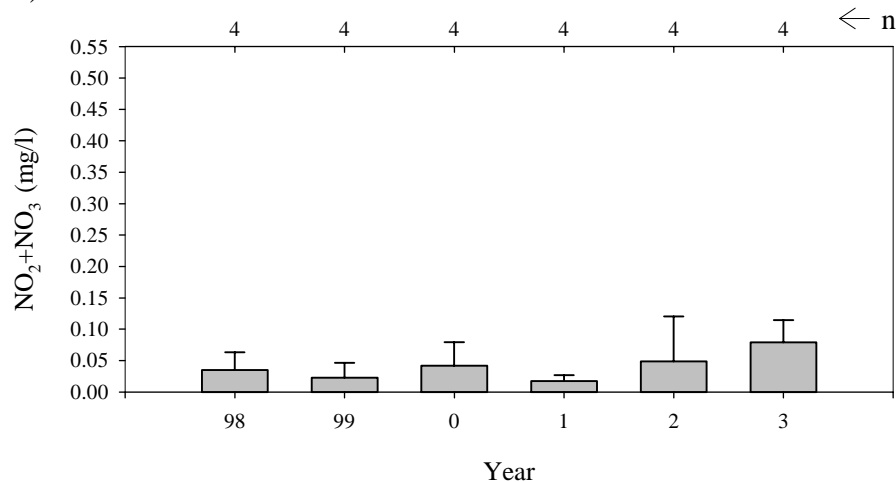


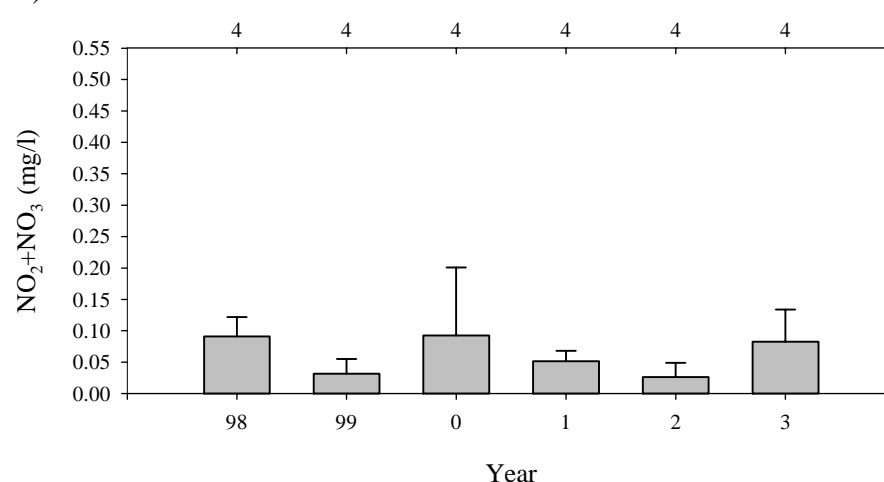
Figure 66. Annual Mean Nitrite+Nitrate-Nitrogen (NO_2+NO_3) Content within the North New River Canal Basin (Florida Department of Environmental Protection WBID 3277) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., $n=4$) unless noted on upper x-axis. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

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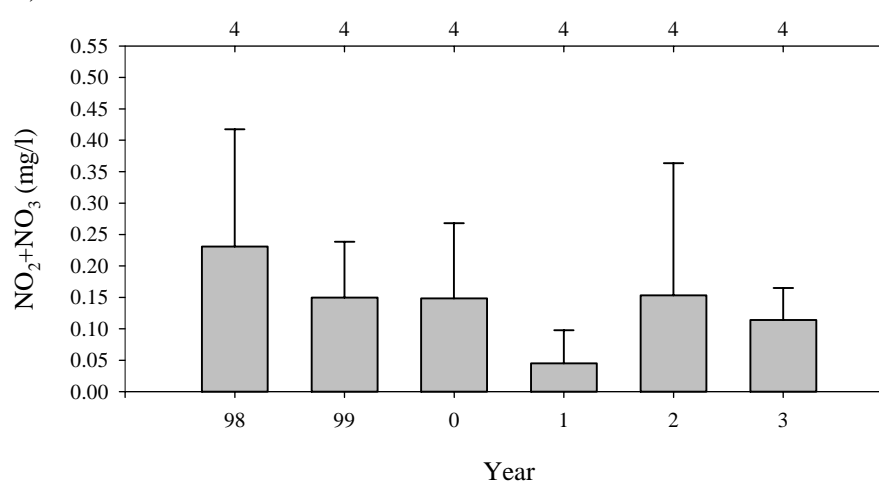
a) Site 23



b) Site 22



c) Site 21



10. Chlorophyll a

All annual chlorophyll a mean values were below the Impaired Waters Rule threshold value for freshwater canals (20 micrograms per liter, ug/l; [FDEP 2006b](#), Figure 67). Water bodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients. In fact, almost all chlorophyll a values from the canal were below 20 ug/l (Figure 67, individual data not shown). Site 22 typically exhibited the highest chlorophyll a concentrations but Site 23 had similar content in several of the monitoring years. The highest chlorophyll a content at each site was seen in the year of 2000.

11. Fecal Coliform

Fecal coliform (FC) content from 1973 to 2003 is shown as these graphs (Figure 68) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Most fecal coliform samples were within compliance of county ([Broward County 1996](#)) and state ([FDEP 2006a](#)) environmental regulations with a few exceptional events (e.g., Site 22 in 2000). Site 21 had the two highest exceedances but these were rare based on annual median values.

Figure 67. Annual Mean Chlorophyll *a* Levels within the North New River Canal Basin (Florida Department of Environmental Protection, FDEP, WBID 3277) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. The FDEP Impaired Waters Rule (Florida Administrative Code 62-303) chlorophyll *a* threshold value of 20 ug/l is shown by the dashed line. Waterbodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.

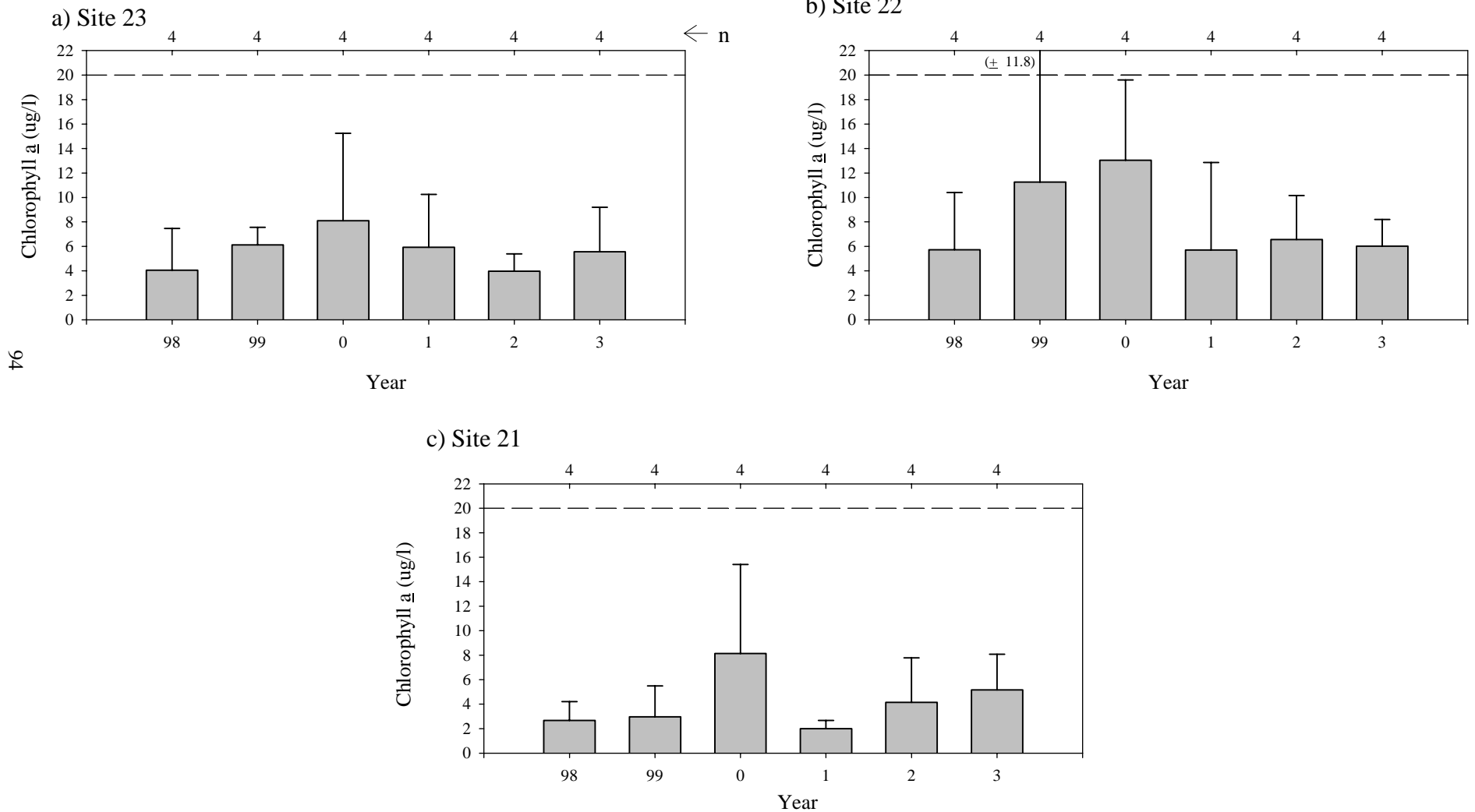
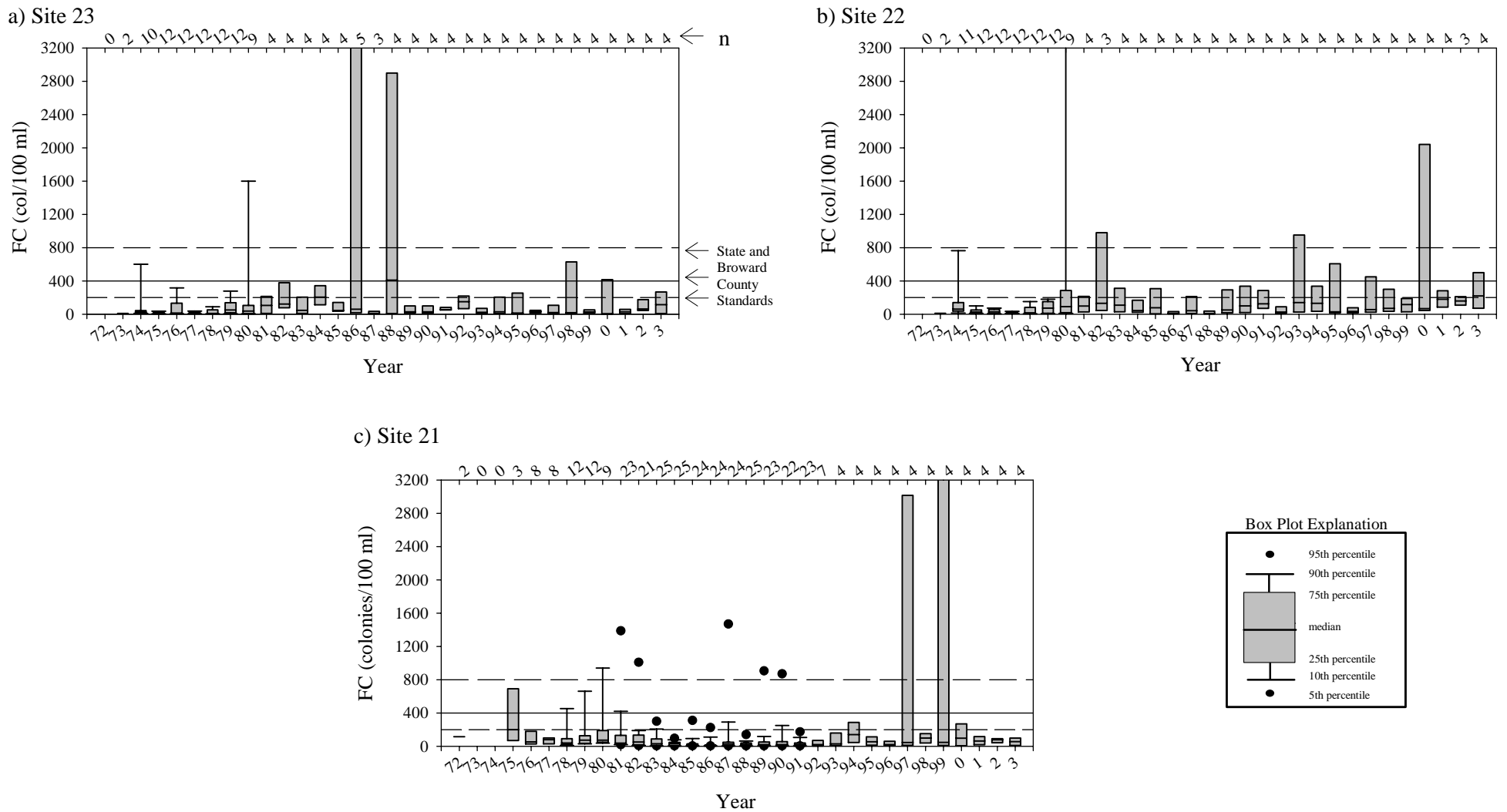


Figure 68. Annual Box Plots of Fecal Coliform (FC) Levels within the North New River Canal Basin (Florida Department of Environmental Protection WBID 3277) from 1972 to 2003. Medians and percentiles calculated from bi-weekly, monthly, and quarterly samples with the number of samples (n) noted on the upper axis. To be within compliance of state and county environmental regulations, levels shall not exceed a monthly average of 200 colonies per 100 milliliters (col/100 ml) nor exceed 400 (col/100 ml) in 10% of the samples, nor exceed 800 (col/100 ml) on any one day. Numbers in parentheses represent 75th percentile values that extend beyond y-axis. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow.



G. C-11 (South New River) East Canal (Florida Department of Environmental Protection, FDEP, WBID 3281)

1. Basin Description and Sampling Locations

With an area of 104 mi², the C-11 Canal Basin is the largest basin located entirely within the county. The basin is in southwest Broward County and is divided into western (81 mi²) and eastern (23 mi²) basins (Cooper and Lane 1987; Figure 69). The S13A effectively divides the C-11 Canal into typically western and eastern flowing segments that correspond to the respective western and eastern basins. The eastern portion of the canal is discussed in this chapter and the western in the following one (Section III.H.). The BCEPD has monitored one site (Site 27) on the eastern C-11 Canal since 1973. Site 27 is located immediately west of the SFWMD control structure S13A at Orange Drive and State Road 7 (US 441, Figure 69). Additional logistical information is provided in Appendix 1.

2. Specific Conductance

Site 27 yearly means ranged from 667 to 959 micromhos/centimeters (umhos/cm) over the last six years (Figure 70). Two annual (2000 and 2003) means were characterized by high variability caused by two unusually high (> 1400 umhos/cm) sampling observations observed during the dry seasons of each year.

3. Total Organic Carbon

Annual total organic carbon (TOC) means were slightly lower over the last two years at Site 27 in the C-11 East Canal (Figure 71). In addition, at least one observation over 20 milligrams per liter (mg/l) was observed each year from 1998 through 2001 while no TOC concentrations exceeded 17.5 mg/l in 2002 and 2003 (raw data not shown). The maximum annual mean (19.78 mg/l) was observed in 1998 and the lowest was in 2002 (14.06 mg/l).

4. Dissolved Oxygen

Dissolved oxygen (DO) values from 1973 to 2003 are shown as these graphs (Figure 72) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Annual DO averages have generally increased to Broward County compliance levels from 1998 through 2003 (Figure 72). In addition, the annual averages were within compliance of the state of Florida's criteria four out of last six years. However, the relatively high standard deviations illustrate that some single sample values are falling below both state and county criteria occasionally.

5. Total Phosphorus

Total phosphorus (TP) values from 1975 to 2003 are shown as these graphs (Figure 73) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)).

Figure 69. Broward County Environmental Protection Department's Surface Water Quality Monitoring Site on the Freshwater Eastern C-11 (South New River) Canal. The eastern C-11 drainage basin is depicted by the yellow color. Freshwater sampling site number 27 is west of the South Florida Water Management District's (SFWMD) coastal salinity control structure, S13. The SFWMD S13A separates the C-11 East and West Basins. Major cities in both sub-basins are labeled and depicted with the orange outline.

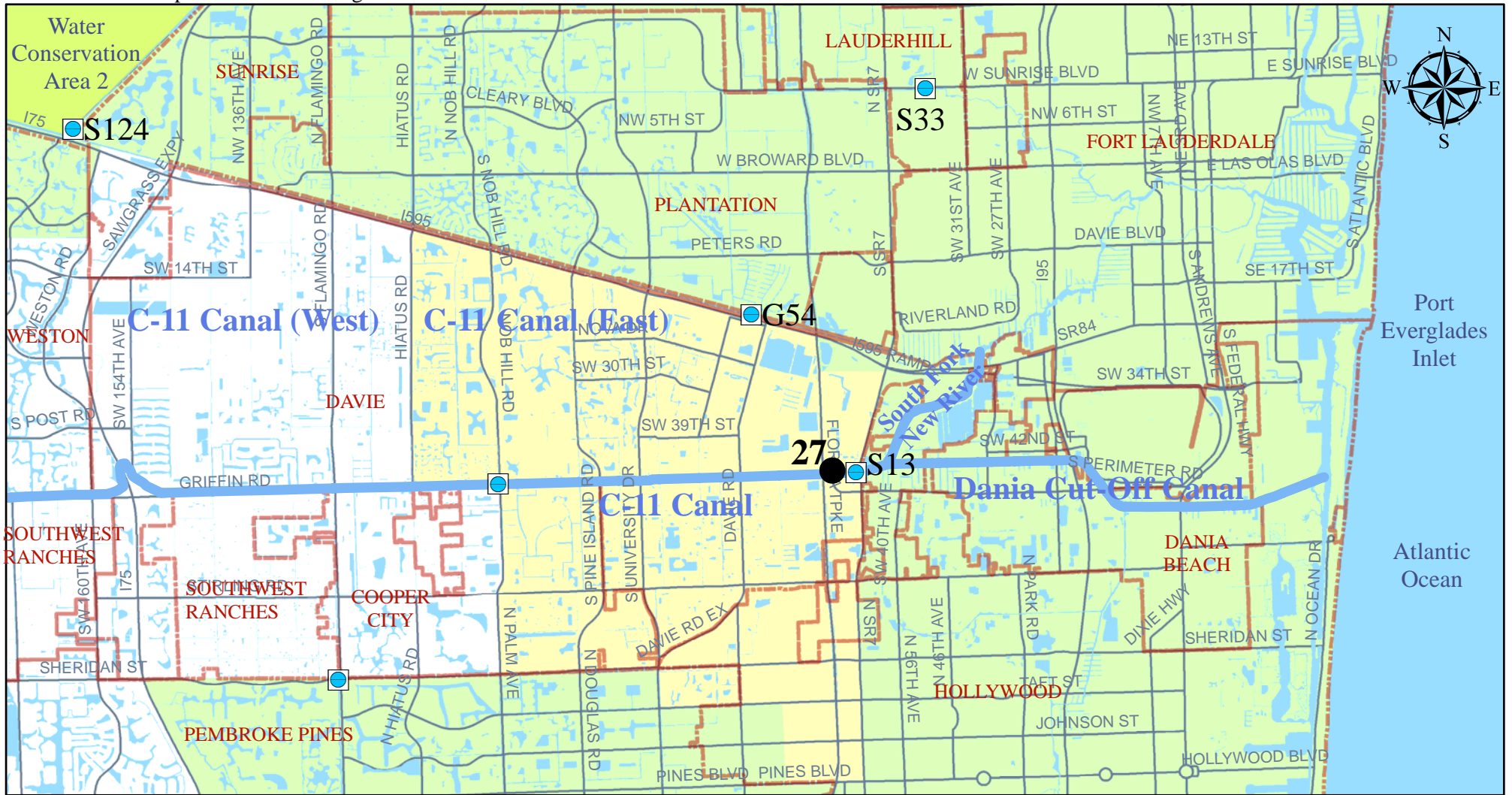


Figure 70. Annual Mean Specific Conductance (Cond) Levels within the C-11 East Canal Basin (Florida Department of Environmental Protection WBID 3281) from 1998 to 2003. Yearly means and standard deviations (error bars) for Site 27 calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis and values are shown in micromhos per centimeter (umhos/cm) at 25 degrees Celsius.

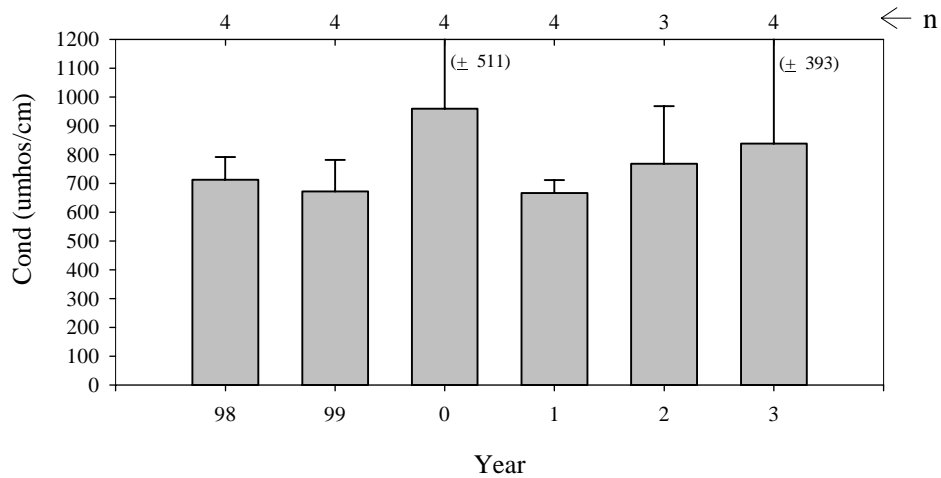


Figure 71. Annual Mean Total Organic Carbon (TOC) Content within the C-11 East Canal Basin (Florida Department of Environmental Protection WBID 3281) from 1998 to 2003. Yearly means and standard deviations (error bars) for Site 27 calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis.

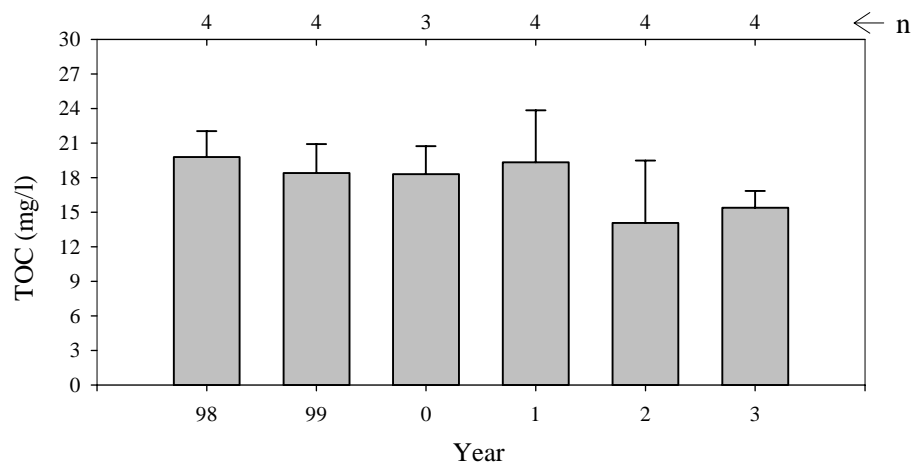


Figure 72. Annual Mean Dissolved Oxygen (DO) Content within the C-11 East Canal Basin (Florida Department of Environmental Protection WBID 3281) from 1973 to 2003. Means and standard deviations (error bars) calculated for Site 27 from quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county (BC) water quality standards, any sample should be equal to or above 4.0 mg/l (solid line), while the daily average should be greater than or equal to 5.0 mg/l (dashed line). State water quality criteria mandate all samples must be greater than or equal to 5.0 mg/l (dashed line).

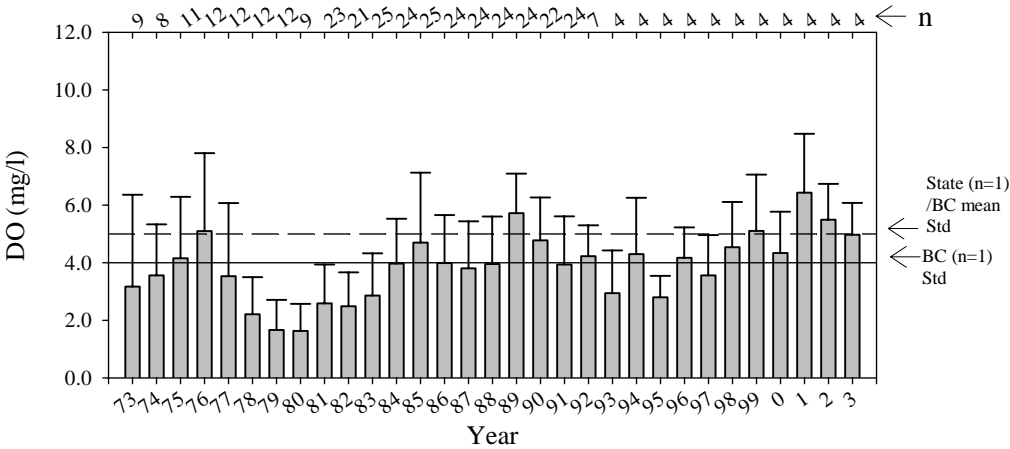
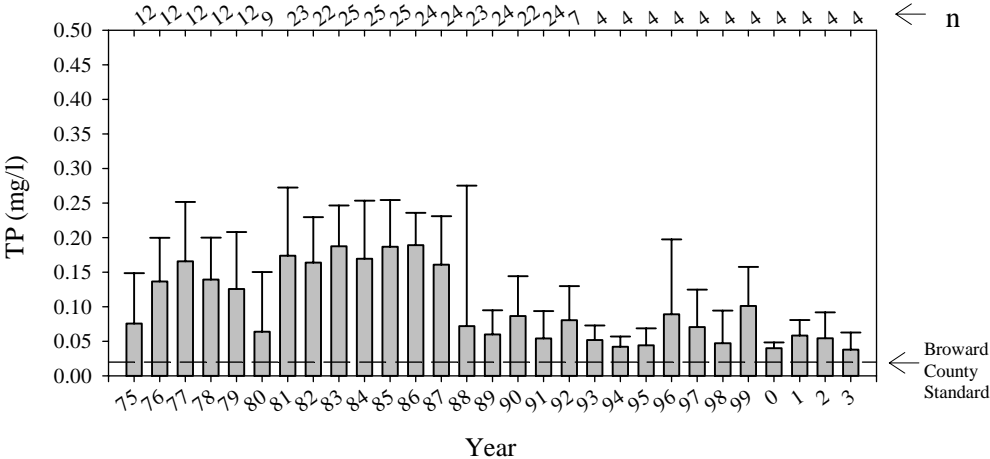


Figure 73. Annual Mean Total Phosphorus (TP) Levels within the C-11 East Canal Basin (Florida Department of Environmental Protection WBID 3281) from 1975 to 2003. Means and standard deviations (sd; error bars) calculated for Site 27 from all annual observations (n) available. The Broward County freshwater standard (0.020 mg/l) is indicated by the dashed line.



Since 1988, TP annual average values at Site 27 have peaked to near 0.10 mg/l and ebbed near 0.05 mg/l with no clear temporal pattern. Please note samples before 1988 were affected greatly by wastewater treatment plant discharges ([BCDPEP 2001](#)). Over the last six years, 1999 exhibited the highest yearly mean in the post wastewater treatment era while 2000 and 2003 revealed the lowest values (0.040 mg/l).

6. ortho-Phosphate

The ortho-Phosphate (o-OP₄) observations (Figure 74) are made more complex because BCEPD changed its method detection limit (mdl) from 0.030 mg/l to 0.00348 mg/l in 2000. Thus, the use of half the detection limit for samples which were below the mdl in 1998 and 1999 are an order of magnitude higher in concentration than mdls for 2000 through 2003. In addition, the practical quantitation limit, which is the mdl multiplied by four, was also higher by default because of a higher mdl.

The annual o-OP₄ concentration observed in 2000 was similar to the previous two years even with different detection limits (Figure 74). The following three years were characterized by annual averages less than 0.015 mg/l but a slight increase in o-OP₄ content was observed from 2001 through 2003.

7. Total Nitrogen

Total nitrogen (TN) values from 1981 to 2003 are shown as these graphs (Figure 75) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Annual mean TN content at Site 27 has only met the Broward County standard of 1.50 mg/l once in 1996. Over the last six years, 1999 through 2001 exhibited especially high concentrations nearing and exceeding 2.00 mg/l. Conversely, 2002 revealed the closest annual average near compliance of the 1.50 mg/l.

8. Ammonia-Nitrogen

Ammonia-nitrogen (NH₃) annual averages and standard deviations increased and decreased over alternating years from 1998 through 2003 at Site 27 (Figure 76). In 1999 and 2003, yearly means were near 0.300 mg/l with 1999 having an exceptionally large standard deviation due to an observation near 1.0 mg/l. This anomalous observation was measured 11 days after Hurricane Irene's landfall (October 15, 1999). The two lowest annual averages were seen in 1998 and 2002.

9. Nitrite+Nitrate-Nitrogen

Site 27's nitrite+nitrate-nitrogen (NO₂₊₃) concentrations exceeded 0.300 mg/l during all six years (see Figure 77). Standard deviations around the mean tended to be high and in some cases over half the average (note 2002, Figure 77). The maximum

Figure 74. Annual Mean ortho-Phosphate (o-PO₄) Content within the East C-11 Canal Basin (Florida Department of Environmental Protection WBID 3281) from 1998 to 2003. Yearly means and standard deviations (error bars) from Site 27 calculated from quarterly samples (i.e., n=4). The method detection limit changed from 0.030 mg/l to 0.00348 mg/l in 2000.

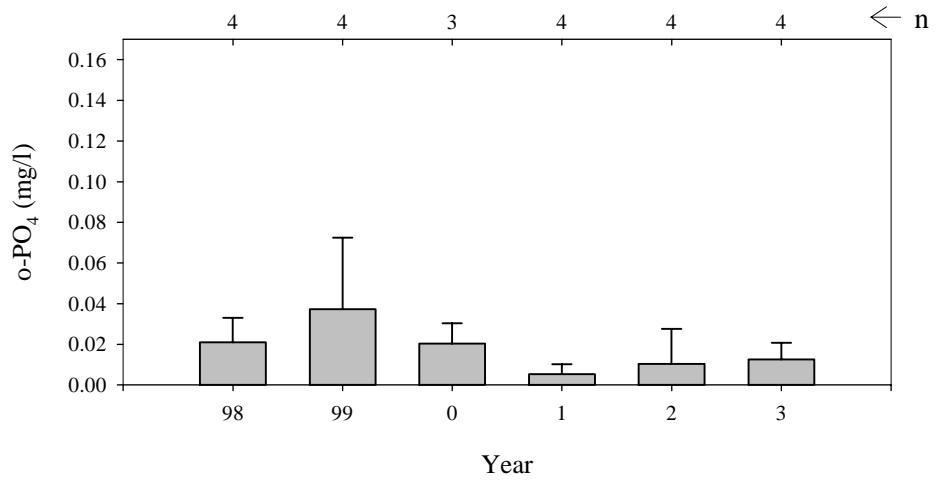


Figure 75. Annual Mean Total Nitrogen (TN) Levels within the C-11 East Canal Basin (Florida Department of Environmental Protection WBID 3281) from 1981 to 2003. Means and standard deviations (sd; error bars) calculated for Site 27 with all annual observations (n) noted on upper x-axis. To be within compliance of county environmental regulations, TN levels should be below the Broward County standard (1.50 mg/l) indicated by the dashed line.

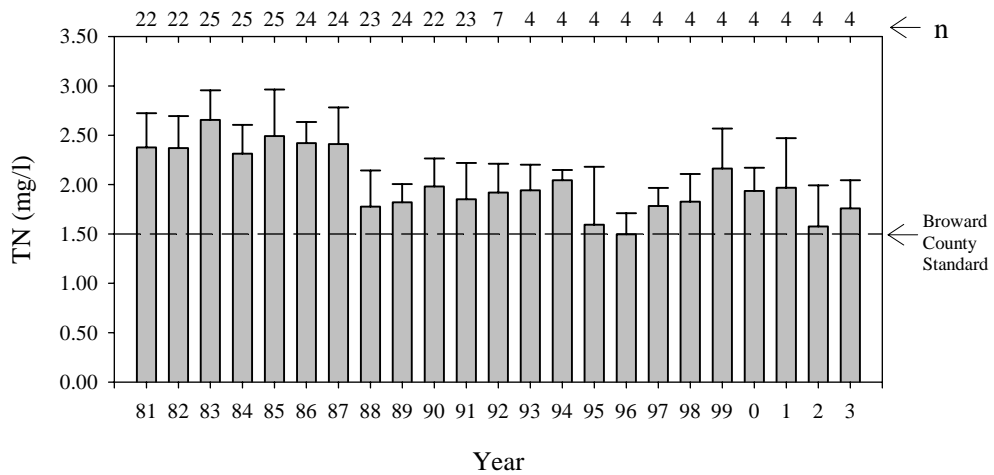


Figure 76. Annual Mean Ammonia (NH₃) within the East C11 Canal Basin (Florida Department of Environmental Protection WBID 3281) from 1998 to 2003. Yearly means and standard deviations (error bars) for Site 27 calculated from quarterly samples (i.e., n=4).

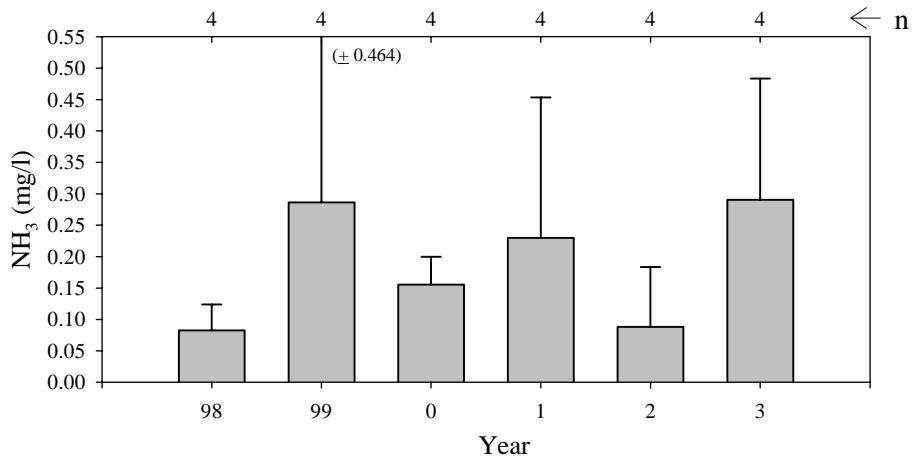
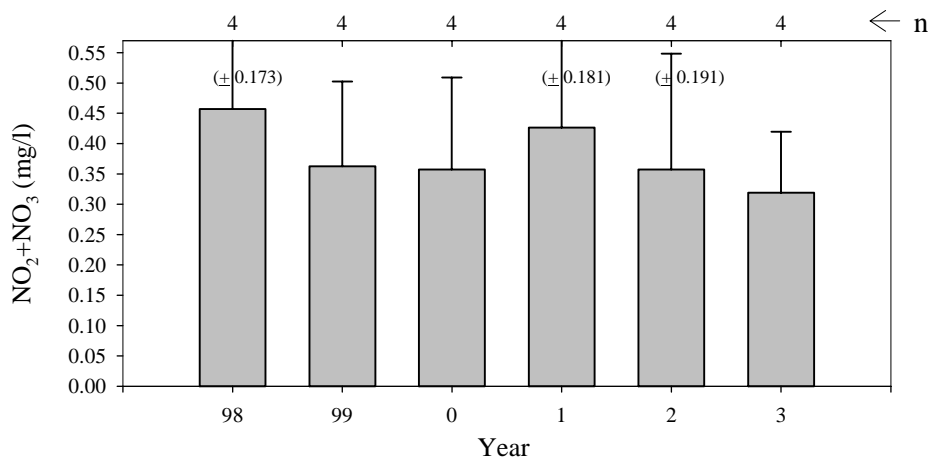


Figure 77. Annual Mean Nitrite+Nitrate-Nitrogen (NO₂+NO₃) Content within the Pompano Canal Basin (Florida Department of Environmental Protection WBID 3281) from 1998 to 2003. Yearly means and standard deviations (error bars) for Site 110 calculated from quarterly samples (i.e., n=4).



annual average was observed in 1998 and the minimum value was seen in 2003, yet no clear downward trend was observed between these two means.

10. Chlorophyll a

All annual chlorophyll a mean values were below the Impaired Waters Rule (IWR) threshold value for freshwater canals (20 micrograms per liter, ug/l; [FDEP 2006b](#), Figure 78). Water bodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients. The exceptionally high standard deviation observed in 1999 reflects two individual IWR exceedances of the IWR threshold. In addition, another IWR exceedance was also observed in 2002 (note high standard deviation). The remaining years (1998, 2000-2001, and 2003) were characterized by means and standard deviations below 10 ug/l (Figure 78).

11. Fecal Coliform

Fecal coliform (FC) content from 1973 to 2003 is shown as these graphs (Figure 79) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Since 1987, most fecal coliform samples were within compliance of county ([Broward County 1996](#)) and state ([FDEP 2006a](#)) environmental regulations for single sample (800 colonies per 100 milliliters, ml) and 'ten percent rule' (400 colonies per 100 ml) with a few exceptional events (1997 and 2003). Please note the monthly average must be computed with 10 samples within a month and the annual medians shown in Figure 79 are primarily calculated from four samples a year. In addition, the state of Florida DEP is using the 400 colonies per 100 ml criteria for inclusion of a waterway on the Impaired Waters Rule list ([FDEP 2006b](#)).

Figure 78. Annual Mean Chlorophyll *a* Levels within the East C-11 Canal Basin (Florida Department of Environmental Protection, FDEP, WBID 3281) from 1998 to 2003. Yearly means and standard deviations (error bars) for Site 27 calculated from quarterly samples (i.e., n=4). The FDEP Impaired Waters Rule (Florida Administrative Code 62-303) chlorophyll *a* threshold value of 20 ug/l is shown by the dashed line. Waterbodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients.

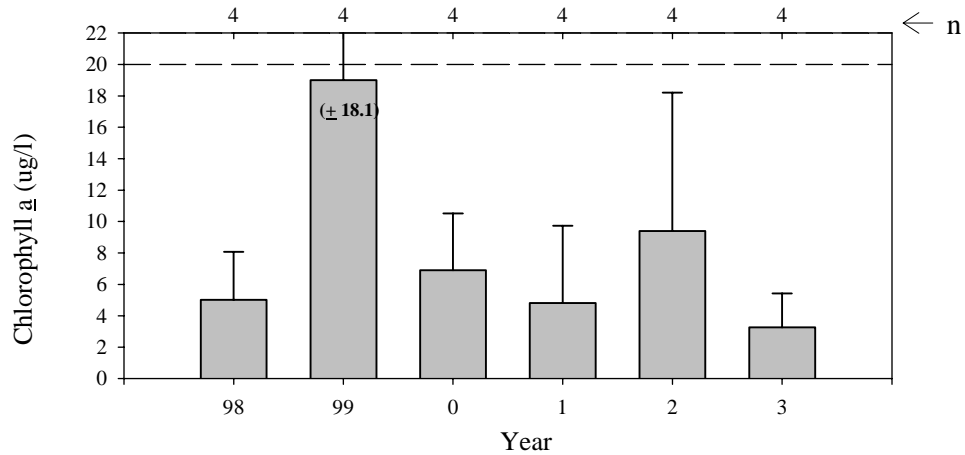
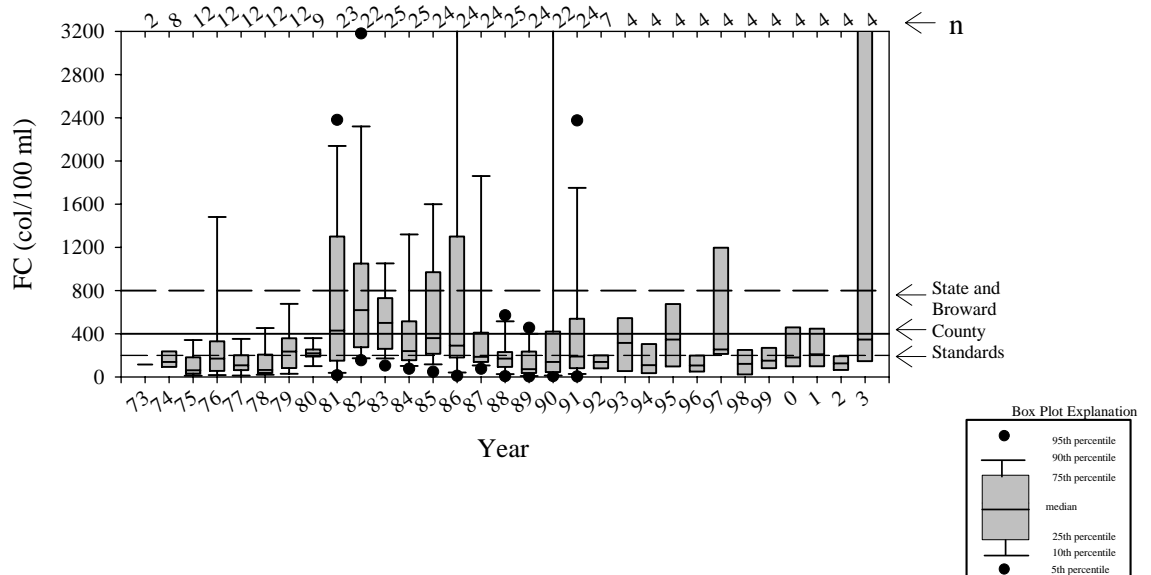


Figure 79. Annual Box Plots of Fecal Coliform (FC) Levels within the East C-11 Canal Basin (Florida Department of Environmental Protection WBID 3281) from 1973 to 2003. Medians and percentiles calculated from quarterly samples with the number of samples (n) noted on the upper axis. To be within compliance of state and county environmental regulations, levels shall not exceed a monthly average of 200 colonies per 100 millimeters (col/100 ml), nor exceed 400 (col/100 ml), in 10% of the samples, nor exceed 800 (col/100 ml) on any one day.



H. C-11 (South New River) West Canal (Florida Department of Environmental Protection, FDEP, WBID 3279)

1. Basin Description and Sampling Locations

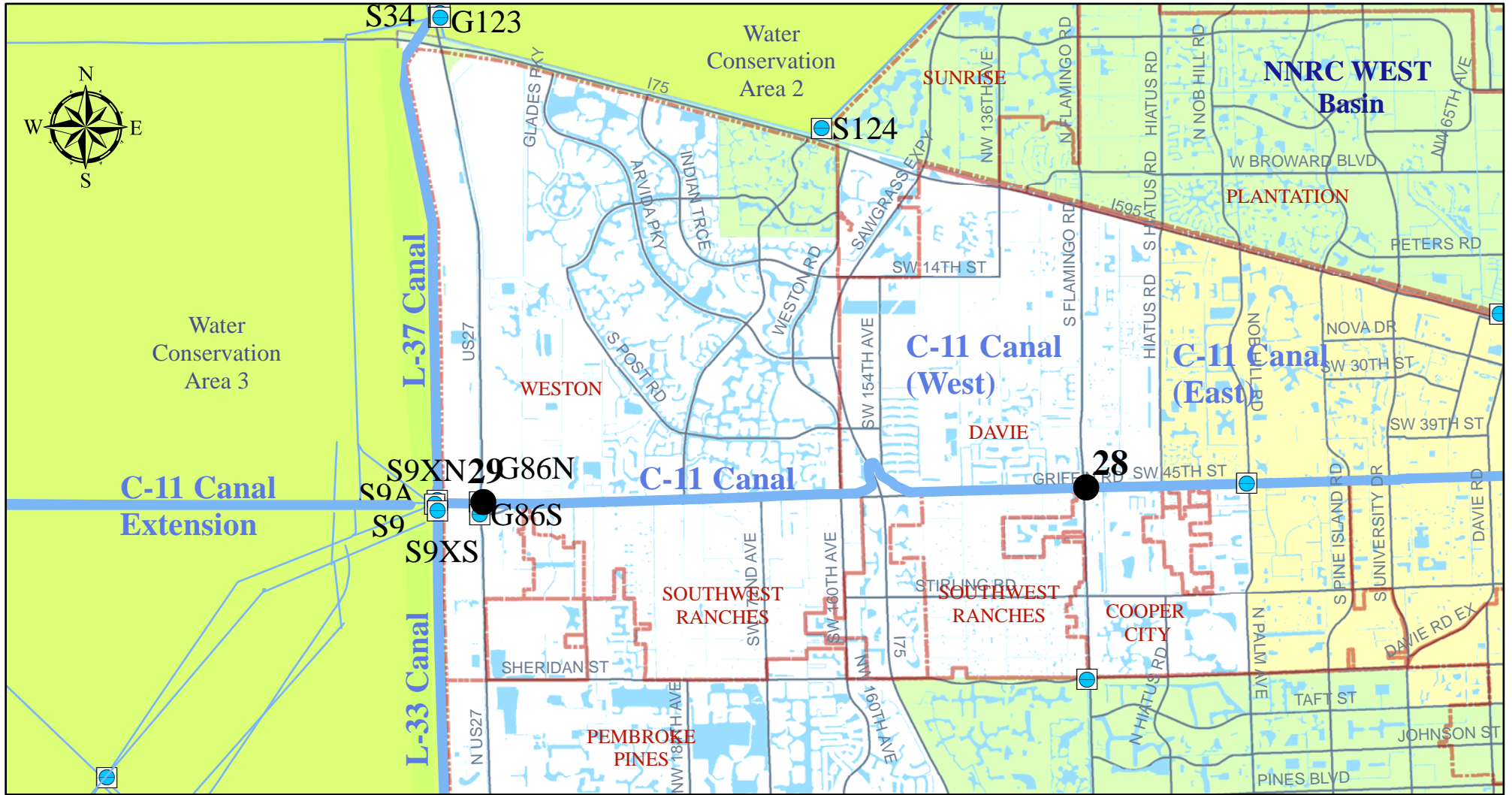
With an area of 104 mi², the C-11 Canal Basin is the largest basin located entirely within the county. The basin is in southwest Broward County and is divided into western (81 mi²) and eastern (23 m²) basins (Cooper and Lane 1987; Figure 80). The S13A effectively divides the C-11 Canal into typically western and eastern flowing segments that correspond to the respective western and eastern basins. The eastern portion of the canal is discussed in the previous chapter.

Elevation and subsequently the amount of water flow westward is controlled by the S9 pump structure while the eastern waterway's elevation and flow is controlled by the S13 which has both pump and gravity flow capacity. During certain hydrological conditions the S13A may be opened to allow western C-11 Basin water to flow to the east, in order to maintain barriers to salt water intrusion or for flood protection (Cooper and Lane 1987). The S9 is a three unit pump system (960 cubic feet per second capacity) that back pumps C-11 Canal water to the WCA 3A (Cooper and Lane 1987). In recent years, an additional structure, S9A, was added next to the S9 in order to capture more groundwater seepage water from the WCA 3A before it enters the C-11 Basin.

Water may also arrive to the C-11 Canal from the northern L-37 Canal via S-9XN which primarily collects seepage from WCA 3A. The L-37 Canal does not make a northern connection to the North New River Canal. The L-33 is south of S9 and connects to the C-9 Canal (see Section III.J). Flow direction (north or south) in the L-33 is dependent on the S9XS, S30, and S32. However, normal operations have the WCA 3A's seepage water in the L-33 flowing south to the C-9 Canal (Cooper and Lane 1987). Two gates also exist along the US 27 drainage ditch that is oriented in a north-south direction east of the S9. The G-86N and the G-86S are gated culverts that control the water elevation in the north and south drainage ditches, respectively. Within the southeast section of the Western C-11 Basin, the C-11S normally flows north along Flamingo Road into the main C-11 Canal. The G-87 is the drainage divide between the C-11 and C-9 Basins.

The BCEPD has monitored two sites (Sites 28 and 29) in the western C-11 Canal since 1972 (Figure 80). Site 28 is at the Flamingo Road bridge while Site 29 is farther west at the US 27 bridge. Additional logistical information is provided for each site in Appendix 1.

Figure 80. Broward County Environmental Protection Department's Surface Water Quality Monitoring Sites on the Freshwater West C-11(South New River) Canal. The western C-11 drainage basin is depicted by yellow color. Freshwater sampling site numbers 28 and 29 are west of the South Florida Water Management District's (SFWMD) water control structure S13A that separates the western and eastern C-11 Basins. Major cities are labeled and depicted with the orange outline.



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Legend

- Water bodies
- BCEPD Monitoring Sites
- Urban Boundary
- Miles
0 0.5 1 1.5 2
- Major Roads
- SFWMD Water Control Structures
- City Boundary
- Water Conservation Areas

2. Specific Conductance

Site 29 typically had slightly higher specific conductance annual averages than Site 28 in the C-11 West but the differences were not great (Figure 81). Yearly means ranged from 664 to 823 micromhos/centimeters (umhos/cm) in the canal and variability was typically low.

3. Total Organic Carbon

Annual total organic carbon (TOC) means were generally similar at the two monitoring sites in the C-11 West Canal (Figure 82). The majority of TOC values in the canal ranged between 15 and 18 milligrams per liter (mg/l). Site 29 did exhibit the only yearly average greater than 20 mg/l. Temporal patterns were not strong, however, the observations in 2002 and 2003 at Site 28 showed a slight pattern of lower TOC content than observed over the preceding four years.

4. Dissolved Oxygen

Dissolved oxygen values from 1973 to 2003 are shown as these graphs (Figure 83) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Annual DO averages have generally increased to Broward County compliance levels since 1990 but not the state of Florida's requirements at Site 28 from 1997 through 2003 (Figure 83). Site 29 annual DO averages were normally below both standards, but have been generally higher since 1995 than the 22 previous years. The only observations at or above the state's DO standard were associated with relatively high variability.

5. Total Phosphorus

Total phosphorus (TP) values from 1974 to 2003 are shown as these graphs (Figure 84) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Since 1988, TP annual values at both C-11 West sites were generally similar and tracked each other over time. In addition, from 1993 through 2003 annual average TP content has been near or at compliance with the Broward County TP standard with two exceptions observed in 1998 and 1999.

6. ortho-Phosphate

The ortho-Phosphate (o-OP₄) observations (Figure 85) are made more complex because BCEPD changed its method detection limit (mdl) from 0.030 mg/l to 0.00348 mg/l in 2000. Thus, the use of half the detection limit for samples which were below the mdl in 1998 and 1999 are an order of magnitude higher in concentration than mdls for 2000 through 2003. In addition, the practical quantitation limit, which is the mdl multiplied by four, was also higher by default because of a higher mdl. In general, Site 28's o-OP₄ content was slightly higher than seen further west at Site 29.

Figure 81. Annual Mean Specific Conductance (Cond) Levels within the West C-11 Canal Basin (Florida Department of Environmental Protection WBID 3279) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis and values are shown in micromhos per centimeter (umhos/cm) at 25 degrees Celsius. Sites are shown in a east to west orientation to show the typical canal flow direction when water control structures are operating.

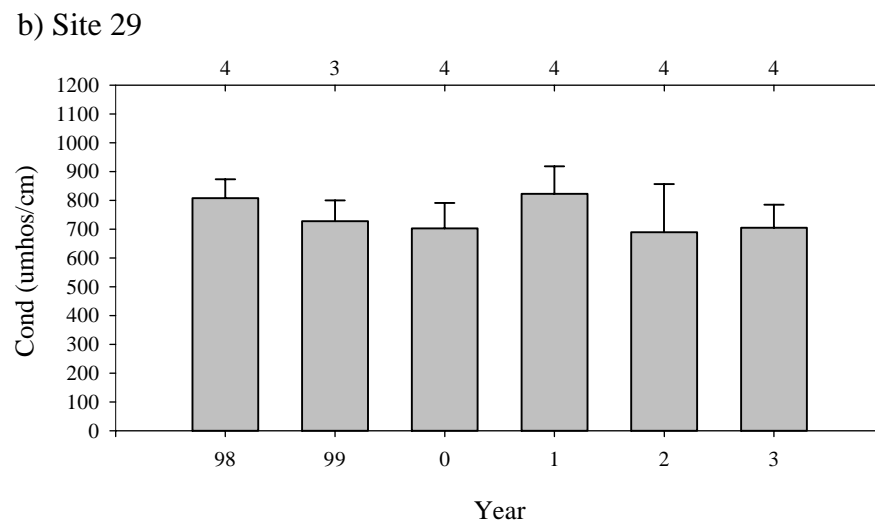
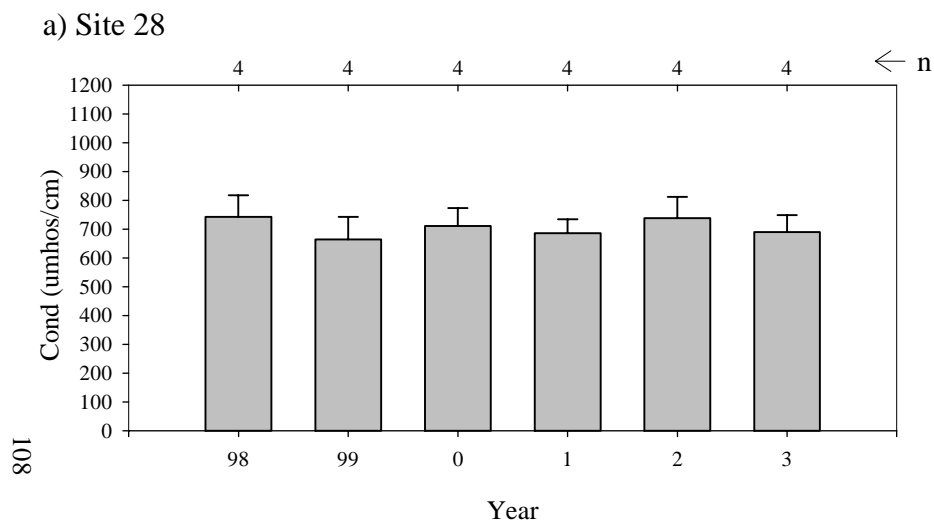
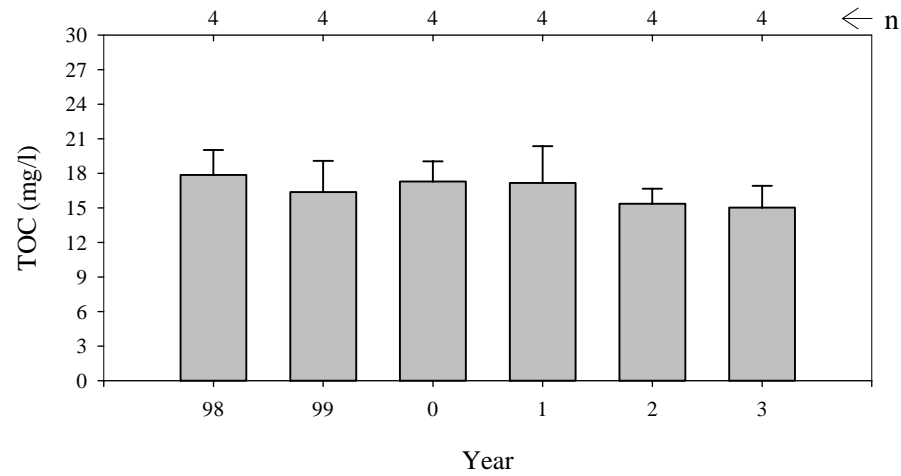


Figure 82. Annual Mean Total Organic Carbon (TOC) Content within the West C-11 Canal Basin (Florida Department of Environmental Protection WBID 3279) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. Sites are shown in an east to west orientation to show the typical canal flow direction when water control structures are operating.

a) Site 28



b) Site 29

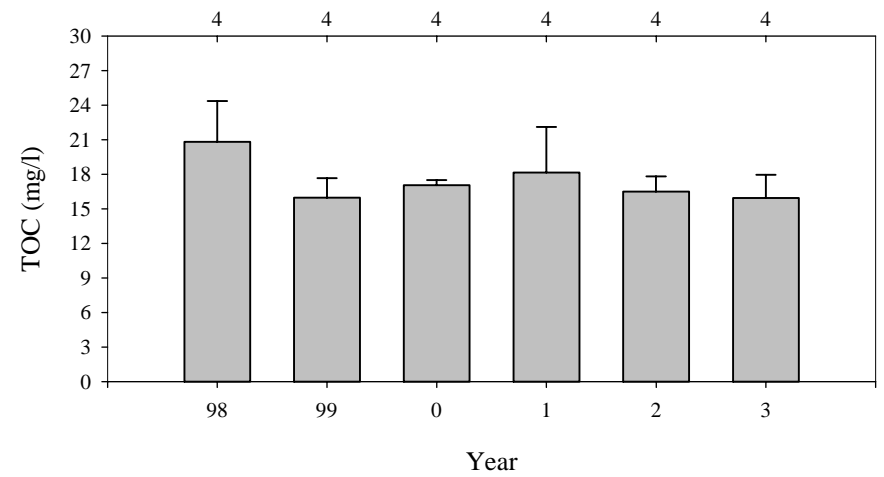
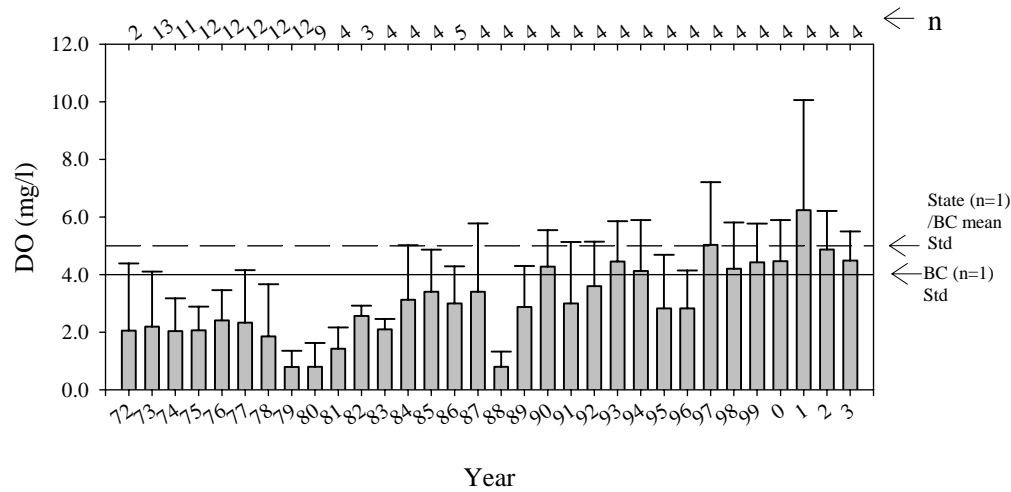


Figure 83. Annual Mean Dissolved Oxygen (DO) Content within the C-11 West Canal Basin (Florida Department of Environmental Protection WBID 3279) from 1972 to 2003. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county (BC) water quality standards, any sample should be equal to or above 4.0 mg/l (solid line), while the daily average should be greater than or equal to 5.0 mg/l (dashed line). State water quality criteria mandate all samples must be greater than or equal to 5.0 mg/l (dashed line). Sites are shown in a eastern to western geographical orientation to show the typical direction of the canal during periods of flow.

a) Site 28



b) Site 29

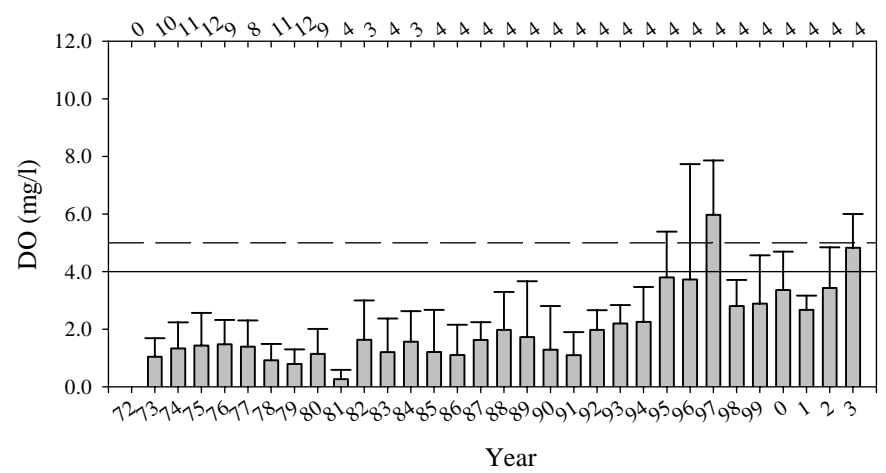


Figure 84. Annual Mean Total Phosphorus (TP) Levels within the West C-11 Canal Basin (Florida Department of Environmental Protection WBID 3279) from 1974 to 2003. Means and standard deviations (error bars) calculated from biweekly, monthly, and/or quarterly samples with the number of samples (n) noted on the upper x-axis. Numbers in parentheses represent standard deviation outside range of graph. To be within compliance of county environmental regulations, TP levels should be below the Broward County standard (0.02 mg/l) indicated by the dashed line. Sites are shown in an eastern to western geographical orientation to show the typical direction of the canal during periods of flow.

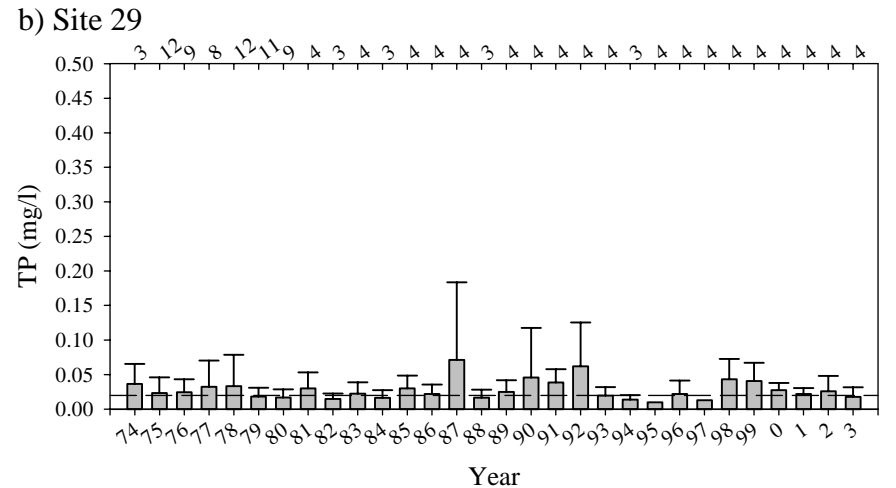
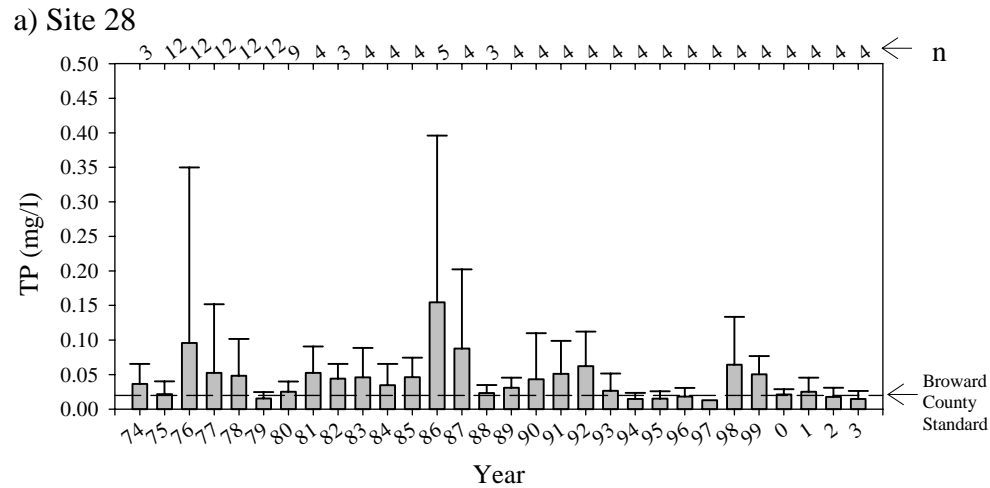
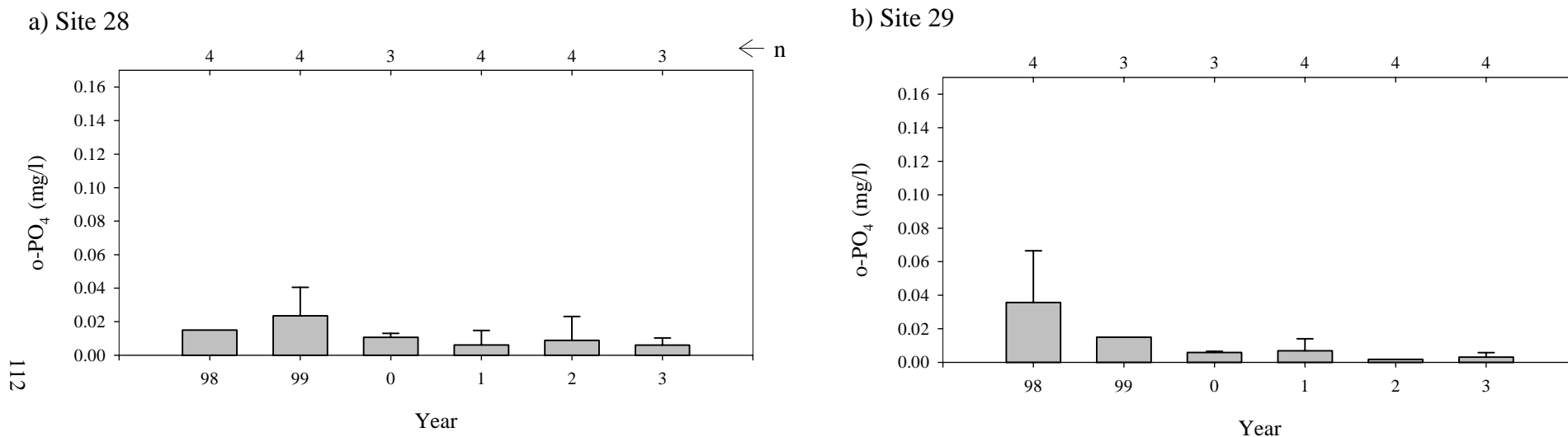


Figure 85. Annual Mean ortho-Phosphate (o-PO₄) Content within the West C-11 Canal Basin (Florida Department of Environmental Protection WBID 3279) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. The method detection limit changed from 0.030 mg/l to 0.00348 mg/l in 2000. Sites are shown in an eastern to western geographical orientation to show the typical direction of the canal during periods of flow.



From 2001 to 2003, sixteen of the twenty-three (69.5%) of observations at both sites were below the method detection limit.

7. Total Nitrogen

Total nitrogen (TN) values from 1981 to 2003 are shown as these graphs (Figure 86) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). With some exceptions (e.g., Site 28 in 1994) TN values have generally hovered around the Broward County standard of 1.5 mg/l at both Sites 28 and 29 since 1987. Temporal patterns were not readily observed and standard deviations were relatively similar within both sampling sites.

8. Ammonia-Nitrogen

Ammonia-nitrogen (NH_3) annual averages and variability were exceptionally higher at Site 29 than Site 28 (Figure 87). Site 28 with its lower content also showed the most consistency between years. Interestingly, Site 29 had its maximum average content in 2001 while conversely; Site 28 exhibited its lowest annual mean of the six year period during the same year.

9. Nitrite+Nitrate-Nitrogen

The spatial pattern of nitrite+nitrate-nitrogen (NO_{2+3}) concentrations in the C-11 West Canal (Figure 88) was generally opposite the pattern observed for NH_3 concentrations (see Figure 87). The highest NO_{2+3} concentrations were observed at Site 28 in the eastern portion of the canal while Site 29's annual means were typically at least 50 percent lower than Site 28. Site 28 also demonstrated the higher variability around the mean as compared to Site 29.

10. Chlorophyll a

All annual chlorophyll a mean values were below the Impaired Waters Rule threshold value for freshwater canals (20 micrograms per liter, ug/l; [FDEP 2006b](#), Figure 89). Water bodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients. In addition, chlorophyll a content was relatively consistent over time with the exception of one anomalous value (43.50 ug/l) that caused the excessively high standard deviation at Site 29 in 1999. Of the forty-eight samples collected from 1998 through 2003 in the canal, this was the only sample greater than 10 ug/l.

Figure 86. Annual Mean Total Nitrogen (TN) Levels within the West C-11 Canal Basin (Florida Department of Environmental Protection WBID 3279) from 1981 to 2003. Means and standard deviations (error bars) calculated from bi-weekly, monthly, and/or quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county environmental regulations, TN levels should be below the Broward County standard (1.50 mg/l) indicated by the dashed line. Sites are shown in an eastern to western geographical orientation to show the typical direction of the canal during periods of flow.

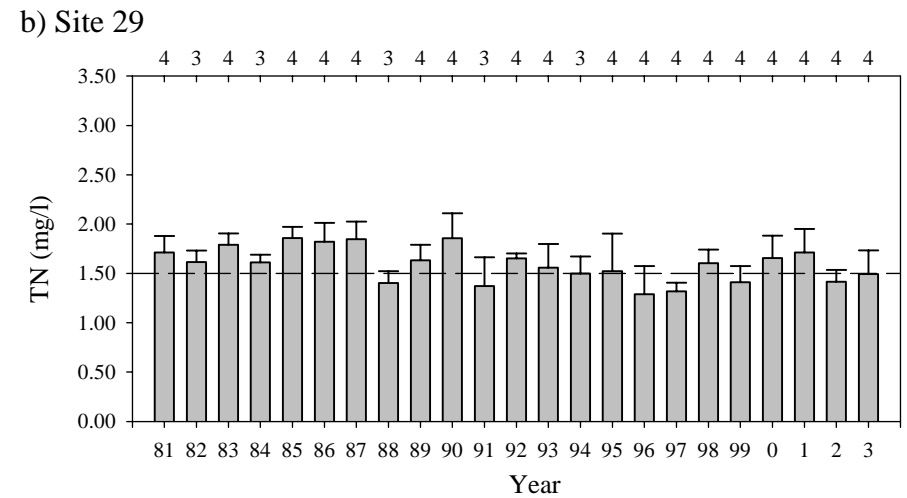
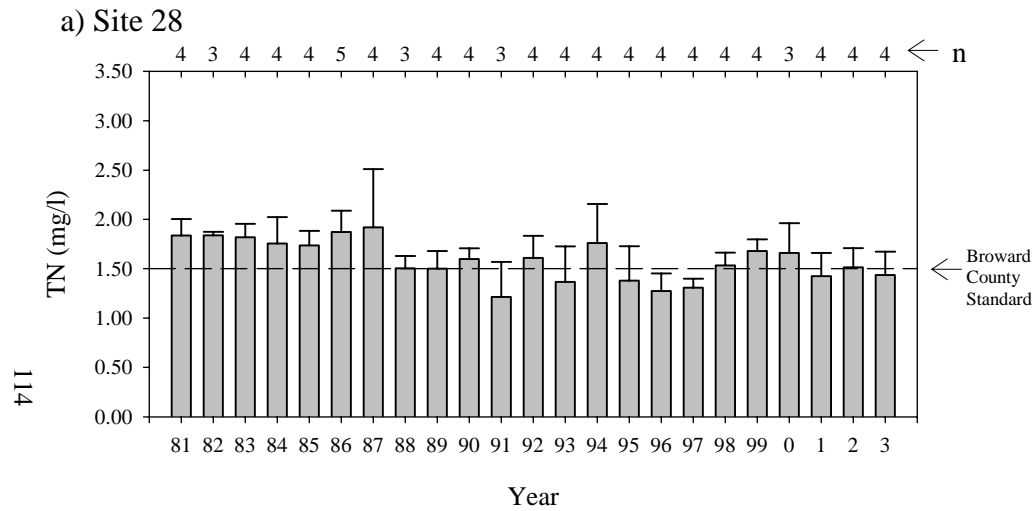


Figure 87. Annual Mean Ammonia (NH₃) within the West C-11 Canal Basin (Florida Department of Environmental Protection WBID 3279) from 1998 to 2003. Means and standard deviations (error bars) calculated from quarterly sampling with number of samples (n) for each year noted on upper x-axis. Sites are shown in an eastern to western geographical orientation to show the typical direction of the canal during periods of flow.

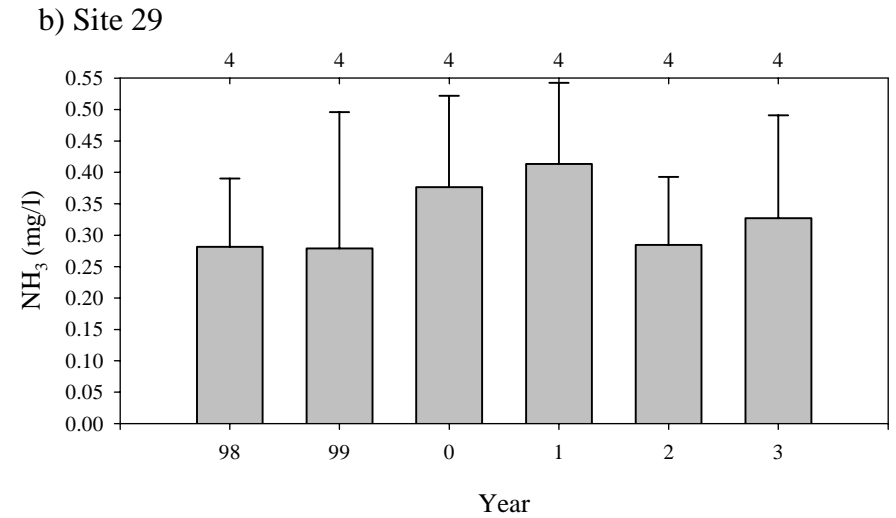
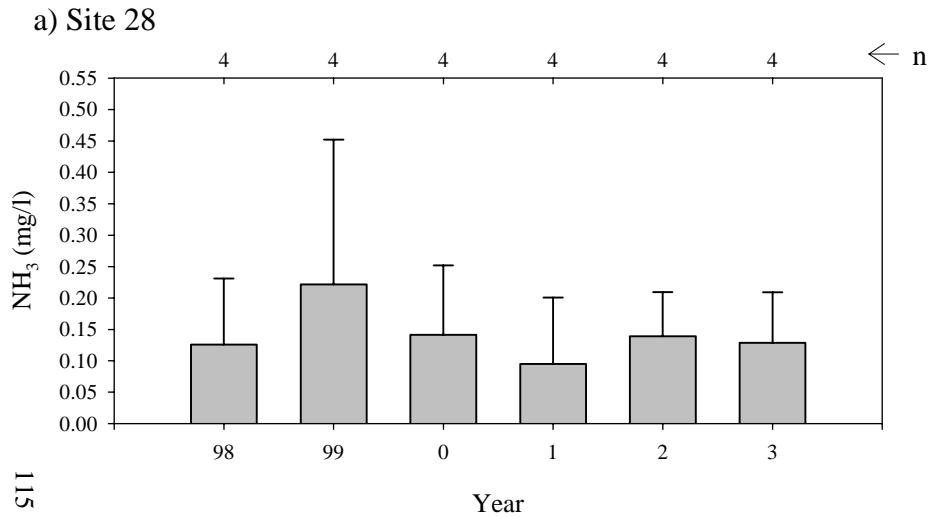
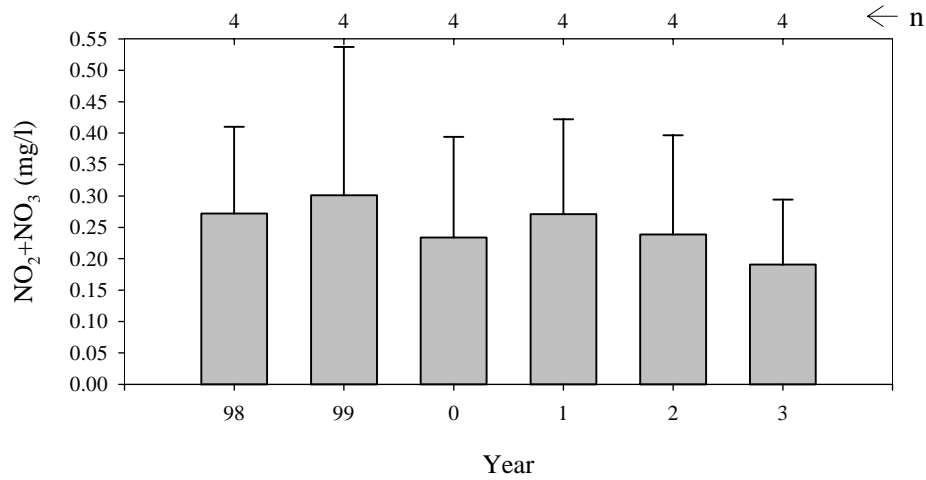


Figure 88. Annual Mean Nitrite+Nitrate-Nitrogen (NO₂+NO₃) Content within the West C-11 Canal Basin (Florida Department of Environmental Protection WBID 3279) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. Sites are shown in an eastern to western geographical orientation to show the typical direction of the canal during periods of flow.

a) Site 28



b) Site 29

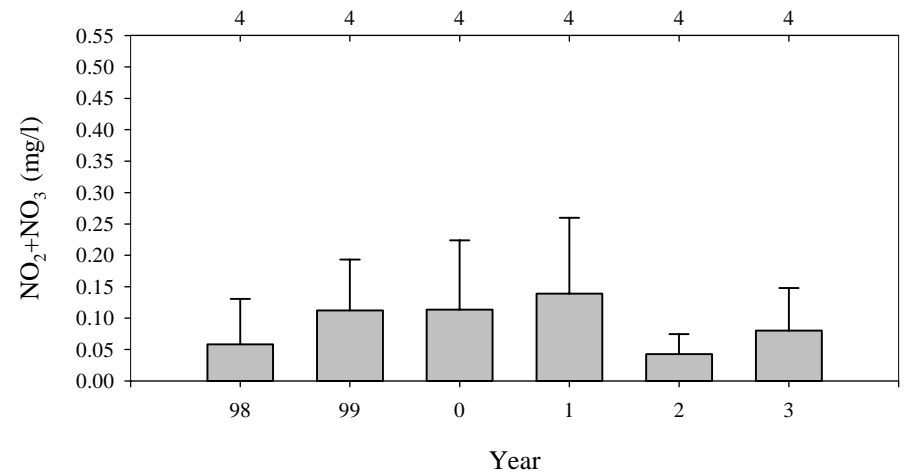
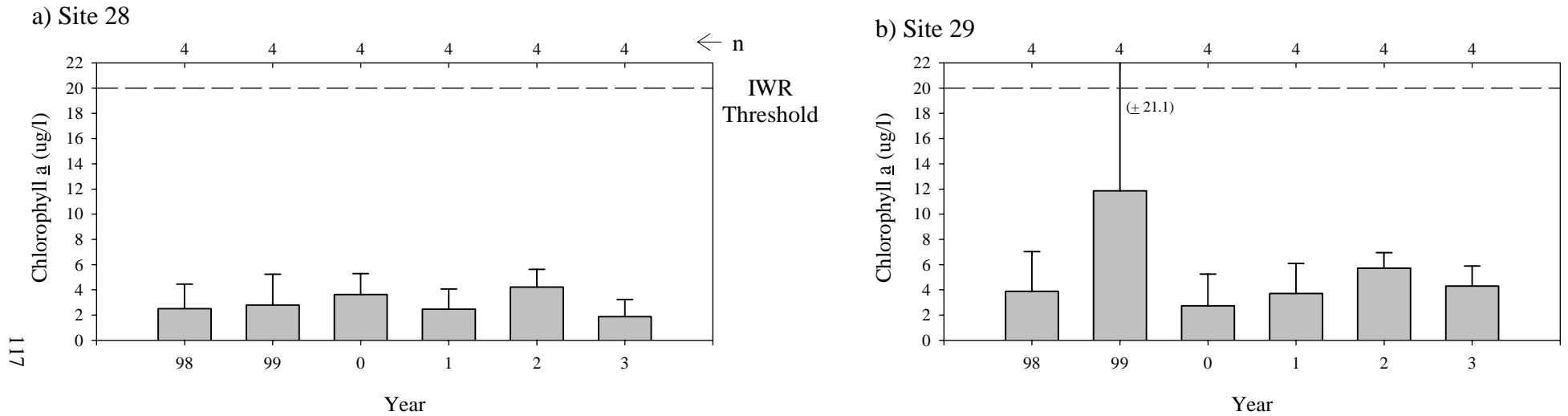


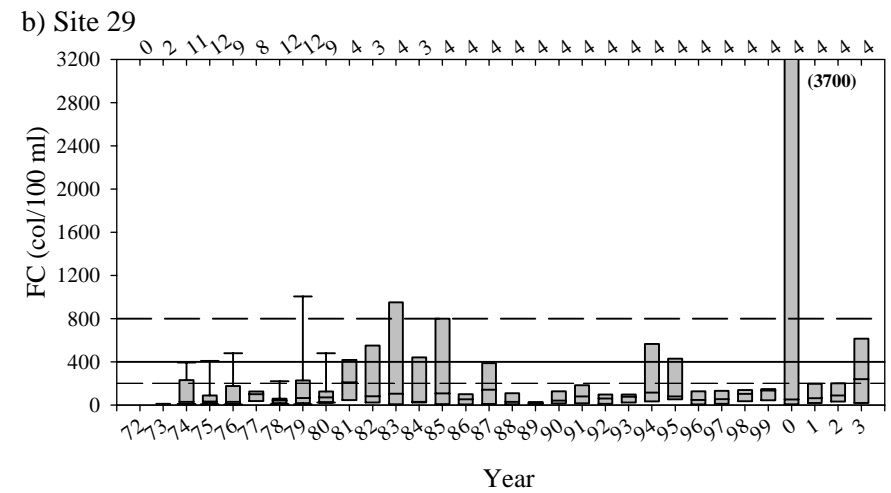
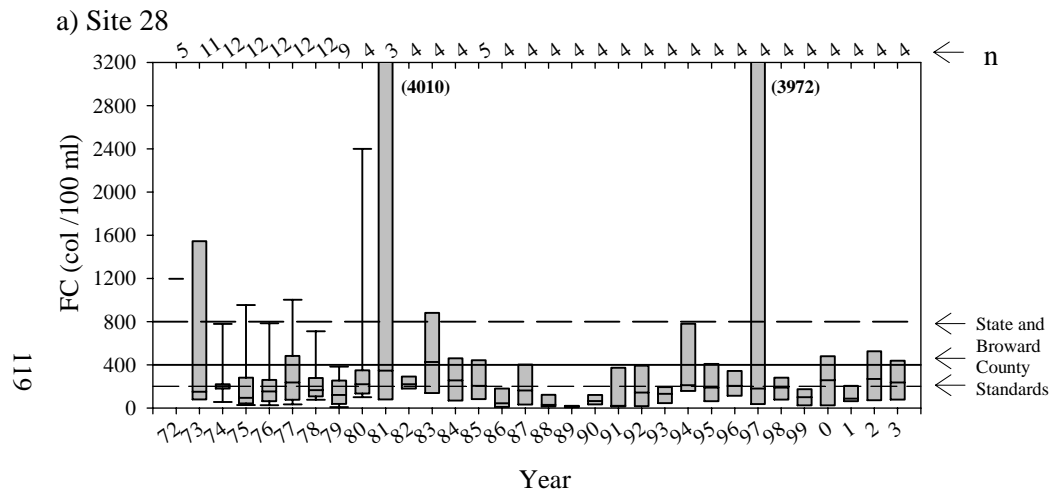
Figure 89. Annual Mean Chlorophyll a Levels within the West C-11 Canal Basin (Florida Department of Environmental Protection, FDEP, WBID 3279) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. The FDEP Impaired Waters Rule (Florida Administrative Code 62-303) chlorophyll a threshold value of 20 ug/l is shown by the dashed line. Waterbodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients. Sites are shown in an eastern to western geographical orientation to show the typical direction of the canal during periods of flow.



11. Fecal Coliform

Fecal coliform (FC) content from 1973 to 2003 is shown as these graphs (Figure 90) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Since 1985, most fecal coliform samples were within compliance of county ([Broward County 1996](#)) and state ([FDEP 2006a](#)) environmental regulations for single sample (800 colonies per 100 milliliters, ml) and 'ten percent rule' (400 colonies per 100 ml) with a few exceptional events (e.g., Site 29 in 2000). However, the fecal coliform medians at Site 28 were relatively higher than Site 29 and have been greater than the monthly average standard criteria (200 colonies per 100 ml) consistently since 1994. Please note the monthly average must be computed with 10 samples within a month and the annual medians shown in Figure are primarily calculated from four samples a year. In addition, the state of Florida DEP is using the 400 colonies per 100 ml criteria for inclusion of a waterway on the Impaired Waters Rule list ([FDEP 2006b](#)).

Figure 90. Annual Box Plots of Fecal Coliform (FC) Levels within the West C-11 Canal Basin (Florida Department of Environmental Protection WBID 3279) from 1972 to 2003. Medians and percentiles calculated from bi-weekly, monthly, and quarterly samples with the number of samples (n) noted on the upper axis. To be within compliance of state and county environmental regulations, levels shall not exceed a monthly average of 200 colonies per 100 milliliters (col/100 ml), nor exceed 400 col/100 ml in 10% of the samples, nor exceed 800 col/100 ml on any one day. Numbers in parentheses represent 75th percentile values that extend beyond y-axis. Sites are shown in an eastern to western geographical orientation to show the typical direction of the canal during periods of flow.



I. C-9 East and West (Snake Creek) Canal (Florida Department of Environmental Protection, FDEP, WBIDs 3283 and 3284)

1. Basin Description and Sampling Locations

The C-9 Canal drains a relatively large basin with an area of approximately 98 mi² (Figure 91). The majority of this basin lies within southern Broward County (59 mi²) and the remainder lies in northern Miami-Dade County (39 mi², Cooper and Lane 1987). In addition, the C-9 Basin is split into a western sub-basin (53 mi²) and an eastern (45 mi²) sub-basin which overlap the two counties. The total length of the C-9 Canal (approximately 20 miles) is almost evenly divided between the two counties.

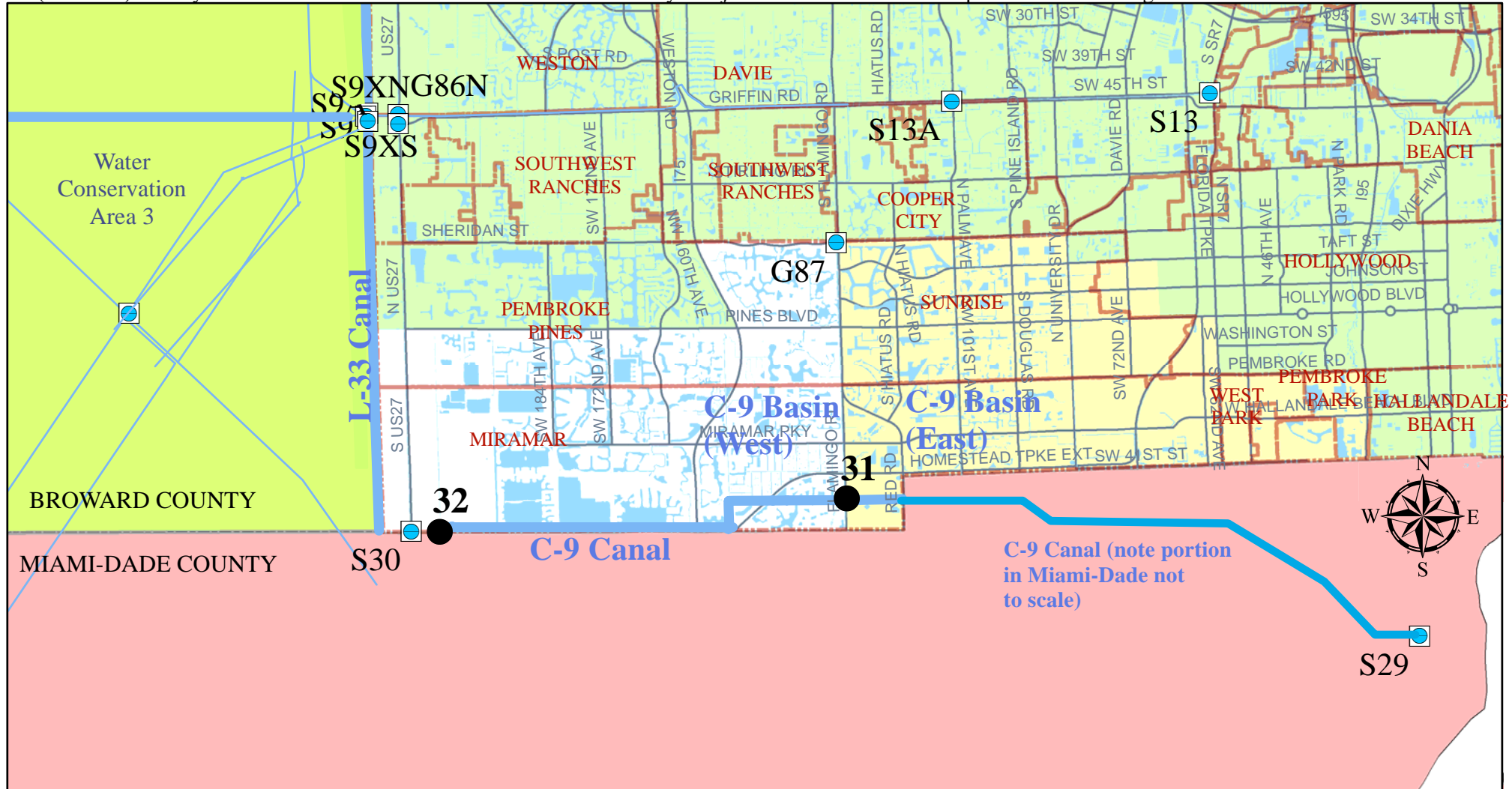
The flow in the C-9 Canal is normally to the east with a final discharge in Miami-Dade County (through SFWMD control structure S29) into the estuarine Maule Lake and Intracoastal Waterway (ICW)/North Biscayne Bay system. Several seepage control canals and structures determine the volume and rate of flow in the waterway. The L-33 Canal is oriented in a north-south direction and makes a connection at the westernmost end of the C-9 Canal (west of US 27). The S30 is immediately to the east of the confluence of the L-33 and C-9 canals. Water either moves east toward the ICW or is stored west of the S30 in the Water Conservation Areas. The S32 is located below the Broward County line and along with S30 and S9XS (see C-11 Basin, Section III.J.1) determine the L-33 Canal's stage which, in turn, controls the rate of seepage from WCA 3B (Cooper and Lane 1987).

Two sampling locations exist for the C-9 Canal - Sites 31 and 32. Site 31 is at the Flamingo Road Bridge west of the Miami-Dade County border. Site 32 is located at the US Highway 27 Bridge, immediately east of the S30. Appendix 1 details the geographical information for each site. At the time of this document's release, Site 32 represented Florida Department of Environmental Protection's WBID 3284 and Site 31 had been included in WBID 3283. However, both the Miami Dade Department of Environmental Resource Management and the Broward County Environmental Protection Department had submitted comments that Site 31 is actually more representative of the western basin (WBID 3284). The FDEP had yet to make a final determination of which WBID Site 31 would represent.

2. Specific Conductance

Sites 31 and 32 annual average specific conductance values were very similar with the exception of 2001 (Figure 92). Specific conductance values were typically between 600 and 700 umhos/cm at both sites and intra-annual variability was relatively low.

Figure 91. Broward County Environmental Protection Department's Surface Water Quality Monitoring Sites on the Freshwater C-9 (Snake Creek) Canal. The western C-11 drainage basin is depicted in white while the yellow color represents the eastern basin. In addition, both the east and west basins have significant southern portions located in Miami-Dade County. C-9 Canal sampling sites 31 and 32 are located far west of the South Florida Water Management District's (SFWMD) salinity control structure S29 located in Miami-Dade County. Major cities are labeled and depicted with the orange outline.

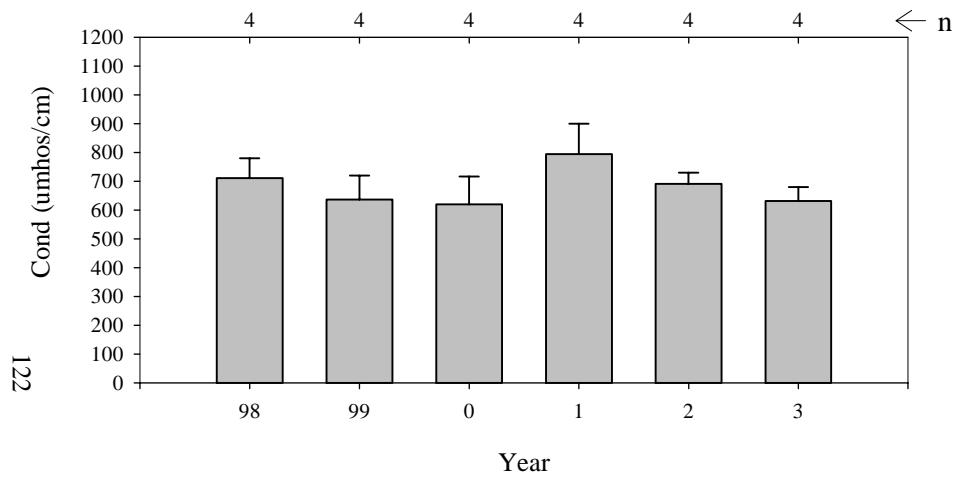


121

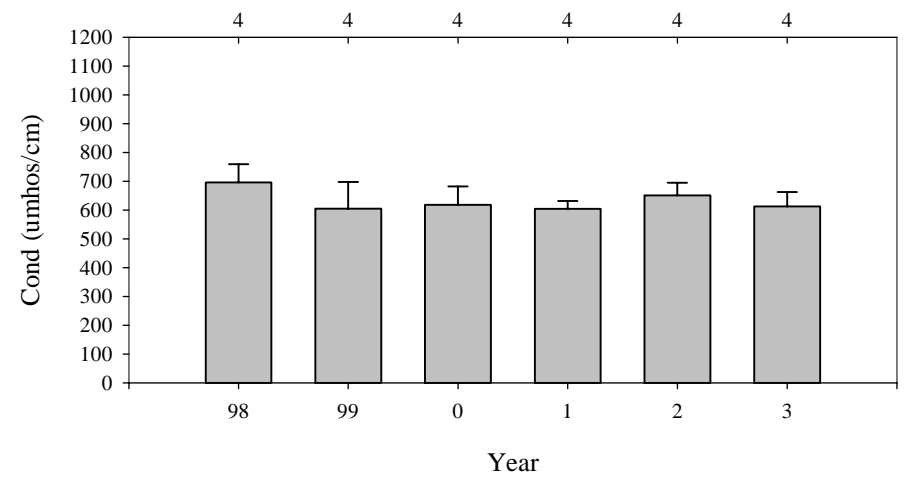
Water bodies	BCEPD Monitoring Sites	Legend	Urban Boundary	Miles 0 0.5 1 1.5 2
Major Roads	SFWMD Water Control Structures		City Boundary	

Figure 92. Annual Mean Specific Conductance (Cond) Levels within the Western (a) and Eastern (b) C-9 Canal Basins (Florida Department of Environmental Protection WBIDs 3284 [a] and 3283 [b]) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis and values are shown in micromhos per centimeter (umhos/cm) at 25 degrees Celsius. Sites are shown in a west to east orientation to show the typical canal flow direction when water control structures are operating. Note no physical control structure separates the western and eastern instream C-9 Canal.

a) Site 32, WBID 3284



b) Site 31, WBID 3283



3. Total Organic Carbon

The two sites tended to track each other over time with Site 31 having slightly lower total organic carbon (TOC) values about 50 percent of the time (Figure 93). The highest annual TOC average was seen in 1998 and the lowest in 2003 at both sites. However, there was not a strong downward trend over the six years.

4. Dissolved Oxygen

Dissolved oxygen (DO) values from 1973 to 2003 are shown as these graphs (Figure 94) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Although not at Broward County compliance levels, annual DO averages have generally increased at both sites since 1998. Site 31 was compliant with the state standard of 5.0 milligrams per liter (mg/l) in 2001 although the mean was characterized by high variability caused by an unusually high value in the supersaturated range (11.4 mg/l).

5. Total Phosphorus

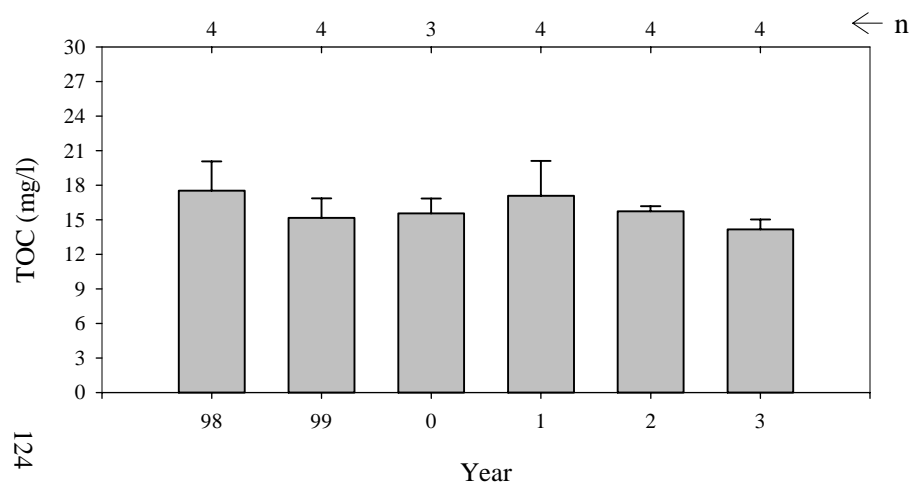
Total phosphorus (TP) values from 1974 to 2003 are shown as these graphs (Figure 95) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Throughout the period of record, TP annual values at both C-9 West sites were generally similar with Site 31 having slightly higher TP annual means. Site 32 had more annual means within compliance of the Broward County standard of 0.02 mg/l. In fact, Site 32 has seen its annual average at or below the 0.02 mg/l standard nine out of the last ten years. Site 31 was within compliance 60% percent of the time over the previous decade.

6. ortho-Phosphate

The ortho-Phosphate (o-OP₄) observations (Figure 96) are made more complex because BCEPD changed its method detection limit (mdl) from 0.030 mg/l to 0.00348 mg/l in 2000. Thus, the use of half the detection limit for samples which were below the mdl in 1998 and 1999 are an order of magnitude higher in concentration than mdls for 2000 through 2003. In addition, the practical quantitation limit, which is the mdl multiplied by four, was also higher by default because of a higher mdl. C-9 Canal o-OP₄ concentrations were very similar at both sampling locations. Values were very low from 2001 to 2003, with 64% of observations being below the method detection limit.

Figure 93. Annual Mean Total Organic Carbon (TOC) Levels within the Western (a) and Eastern (b) C-9 Canal Basin (Florida Department of Environmental Protection WBIDs 3284 [a] and 3283 [b]) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. Sites are shown in a west to east orientation to show the typical canal flow direction when water control structures are operating. Note no physical control structure separates the western and eastern instream C-9 Canal.

a) Site 32, WBID 3284



b) Site 31, WBID 3283

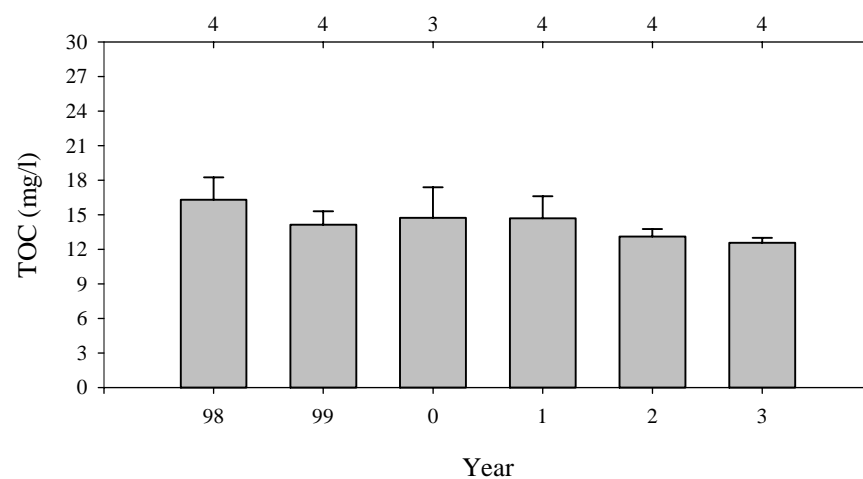
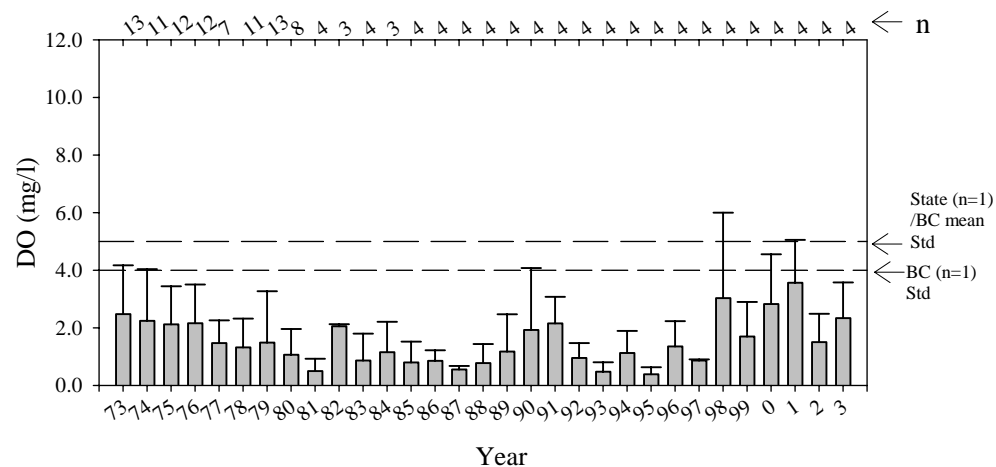


Figure 94. Annual Mean Dissolved Oxygen (DO) Levels within the Western (a) and Eastern (b) C-9 Canal Basin (Florida Department of Environmental Protection WBIDs 3284 [a] and 3283 [b]) from 1973 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. To be within compliance of county (BC) water quality standards, any sample should be equal to or above 4.0 mg/l (solid line), while the daily average should be greater than or equal to 5.0 mg/l (dashed line). State water quality criteria mandate all samples must be greater than or equal to 5.0 mg/l (dashed line). Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow. Note no physical control structure separates the western and eastern instream C-9 Canal.

a) Site 32, WBID 3284



b) Site 31, WBID 3283

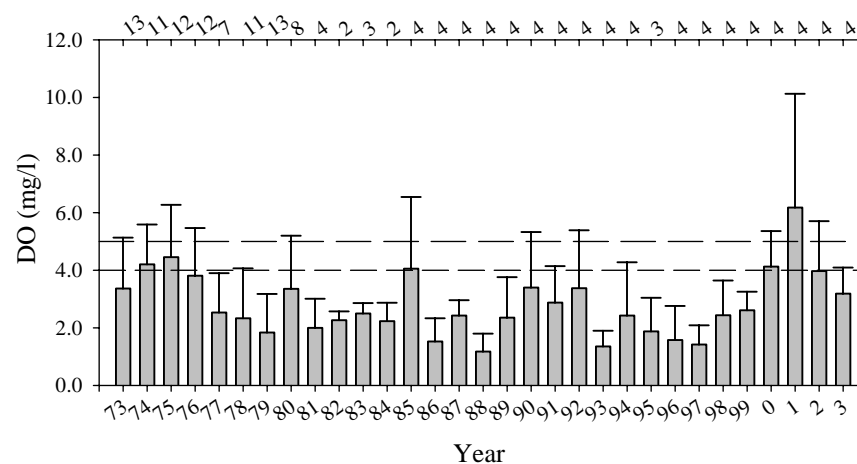


Figure 95. Annual Mean Total Phosphorus (TP) Levels within the Western (a) and Eastern (b) C-9 Canal Basin (Florida Department of Environmental Protection WBIDs 3284 [a] and 3283 [b]) from 1974 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. The Broward County freshwater standard (0.020 mg/l) is indicated by the dashed line. Sites are shown in a west to east orientation to show the typical canal flow direction when water control structures are operating. Note no physical control structure separates the western and eastern instream C-9 Canal. Values in parentheses indicate means and standard deviations above the y-axis.

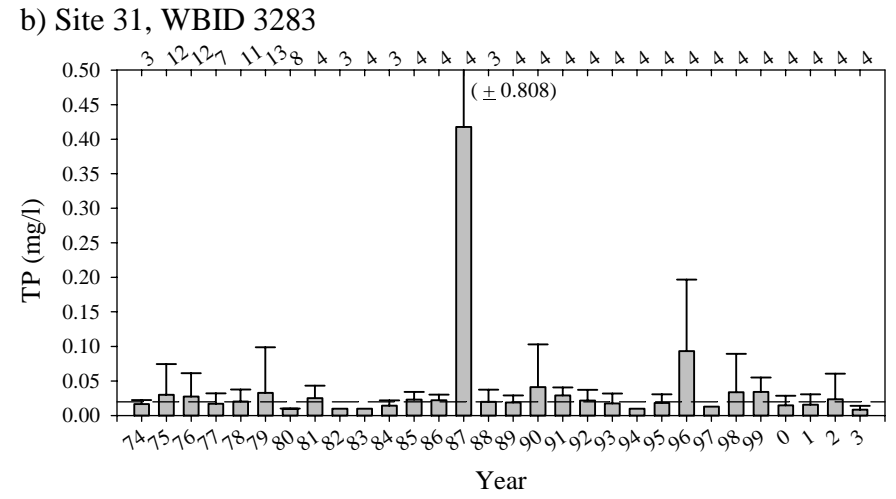
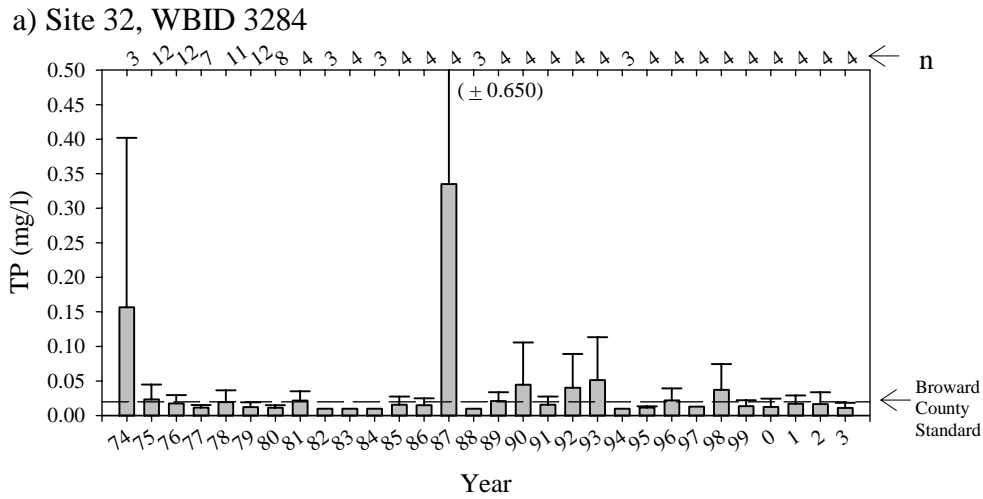
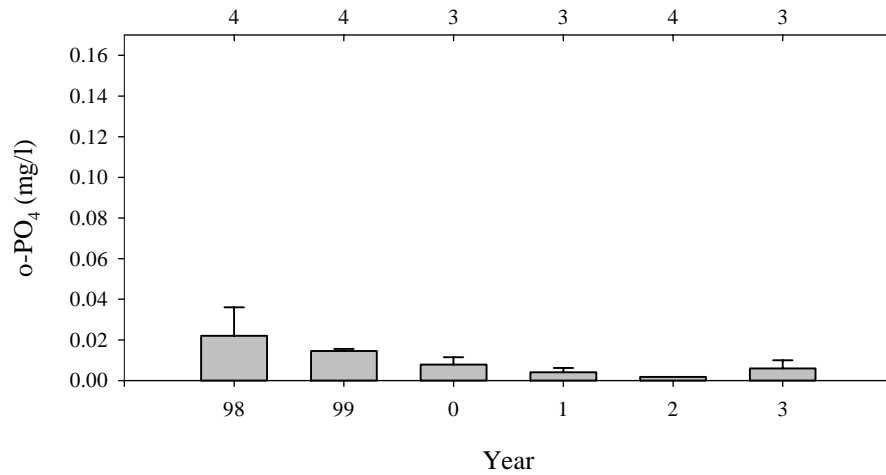
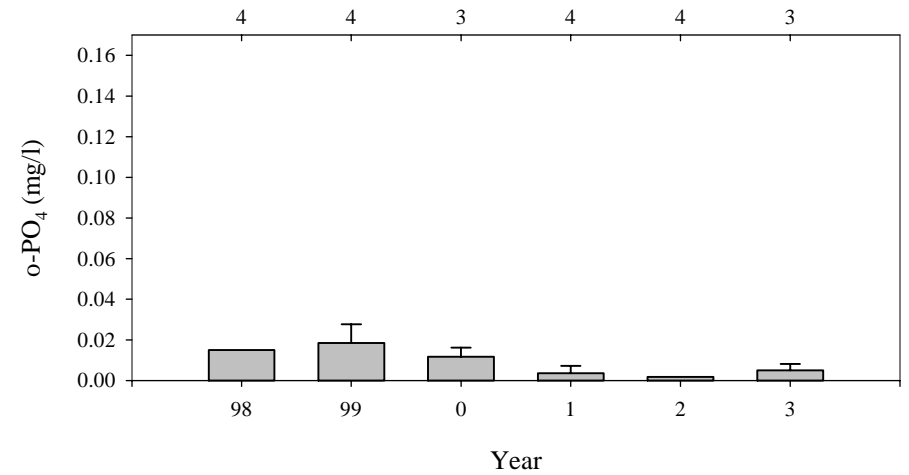


Figure 96. Annual Mean ortho-Phosphate (o-PO₄) Content within the Western (a) and Eastern (b) C-9 Canal Basin (Florida Department of Environmental Protection WBIDs 3284 [a] and 3283 [b]) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. Sites are shown in a west to east orientation to show the typical canal flow direction when water control structures are operating. Note no physical control structure separates the western and eastern instream C-9 Canal.

a) Site 32, WBID 3284



b) Site 31, WBID 3283



7. Total Nitrogen

Total nitrogen (TN) values from 1981 to 2003 are shown as these graphs (Figure 97) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). In general, annual TN averages have historically been similar at both sites. Furthermore, annual TN means have normally been below the Broward County standard of 1.5 mg/l at Sites 31 and 32 since 1981. Maximum annual values were very close to being within compliance and non-compliance has not occurred since 1987 within the canal. Since 1994, even the standard deviations have rarely exceeded the county numeric criteria.

8. Ammonia-Nitrogen

Ammonia-nitrogen (NH₃) annual averages were very similar at Sites 31 and 32 and generally tracked each other over time (Figure 98). The minimum annual value (0.121 mg/l) for the western C-9 Canal was observed at Site 31 in 2002. Both sites were characterized by one anomalously high value in 2001 that contributed to their maximum values for the past six years.

9. Nitrite+Nitrate-Nitrogen

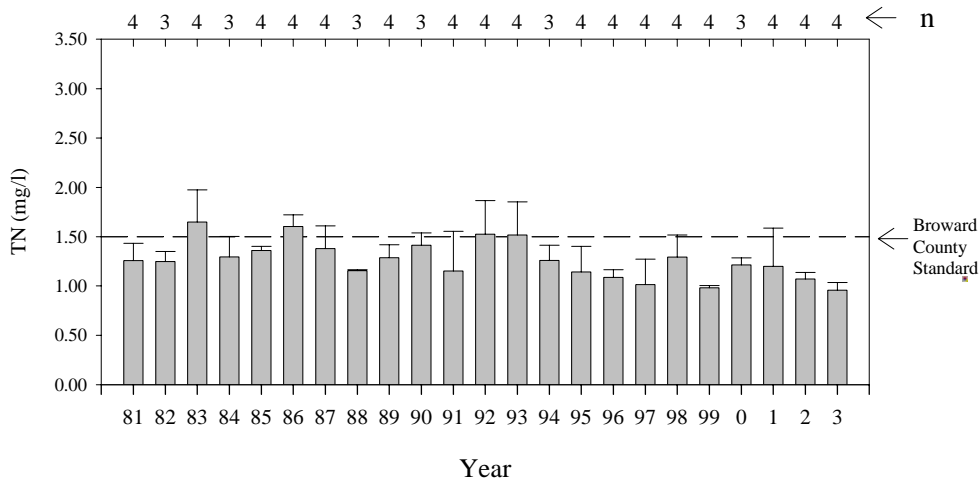
Unlike patterns observed with NH₃ content, Site 31 and Site 32 normally had different nitrite+nitrate-nitrogen (NO₂₊₃) annual mean concentrations. Higher NO₂₊₃ concentrations were observed at the eastern site 31 than the western site 32 (Figure 99). For example, half of six annual averages at Site 32 were below 0.01 mg/l. Conversely, Site 31 had two annual averages exceeding 0.1 mg/l and a minimum annual observation of 0.040 mg/l (in 2002)

10. Chlorophyll a

All annual chlorophyll a mean and individual values were well below the Impaired Waters Rule (IWR) threshold value for freshwater canals (20 micrograms per liters, ug/l; [FDEP 2006b](#), Figure 100). Water bodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients. With over seventy percent of chlorophyll a observations in the C-9 Canal (both sites) less than 2.0 ug/l or an order of magnitude below the IWR threshold, it would not appear the C-9 Canal is impaired for nutrients. For example, in 2003 seven of the eight observations in the C-9 Canal were below the method detection limit. However, at the time of this writing the WBID 3283 was being considered by the FDEP for nutrient impairment due, in part, to a decision on where to divide the WBIDs.

Figure 97. Annual Mean Total Nitrogen (TN) Levels within the Western (a) and Eastern (b) C-9 Canal Basin (Florida Department of Environmental Protection WBIDs 3284 [a] and 3283 [b]) from 1981 to 2003. Means and standard deviations (error bars) calculated from quarterly sampling with number of samples (n) for each year noted on upper x-axis. To be within compliance of county environmental regulations, TN levels should be below the Broward County standard (1.50 mg/l) indicated by the dashed line. Sites are shown in a eastern to western geographical orientation to show the typical direction of the canal during periods of flow. Note no physical control structure separates the western and eastern instream C-9 Canal.

a) Site 32, WBID 3284



b) Site 31, WBID 3283

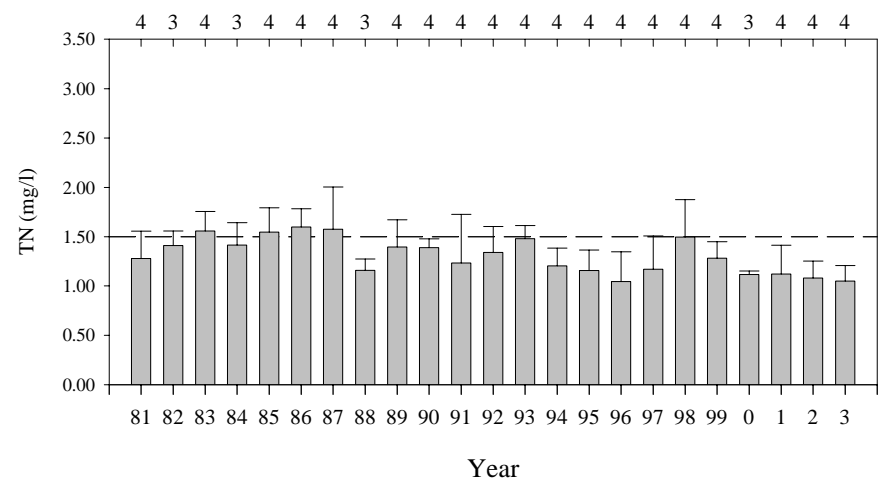
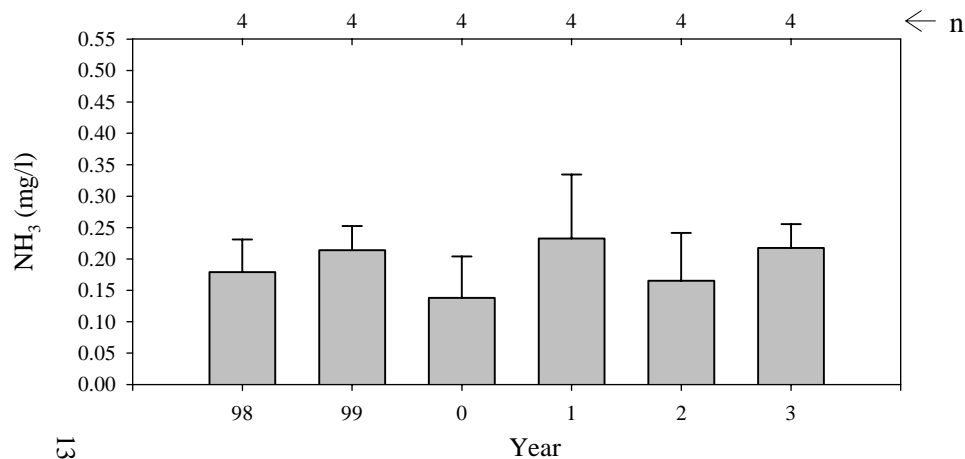


Figure 98. Annual Mean Ammonia (NH₃) Levels within the Western (a) and Eastern (b) C-9 Canal Basin (Florida Department of Environmental Protection WBIDs 3284 [a] and 3283 [b]) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. Sites are shown in a west to east orientation to show the typical canal flow direction when water control structures are operating. Note no physical control structure separates the western and eastern instream C-9 Canal.

a) Site 32, WBID 3284



b) Site 31, WBID 3283

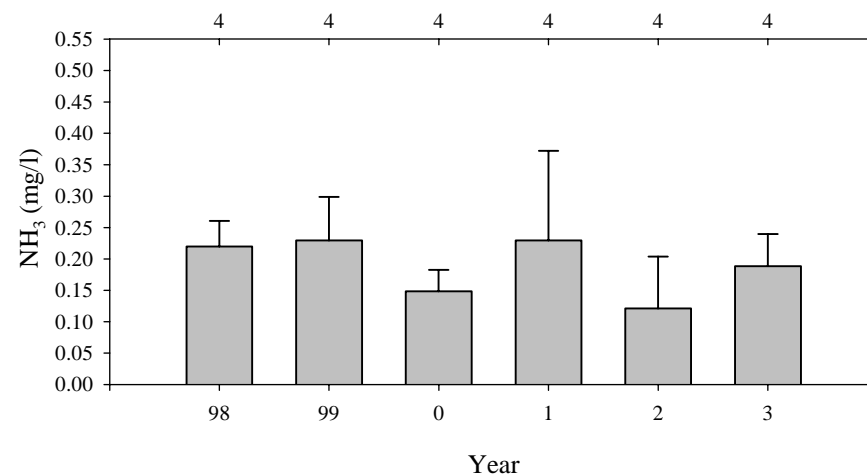
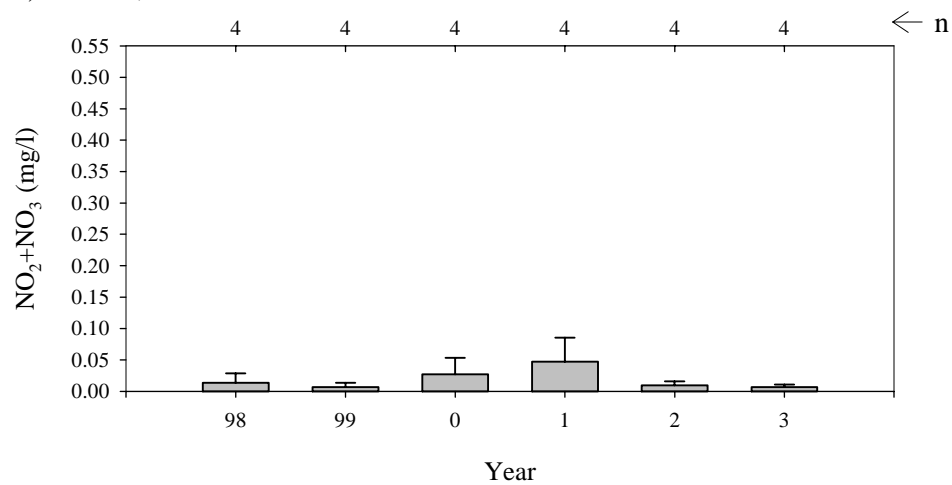


Figure 99. Annual Mean Nitrite+Nitrate-Nitrogen (NO₂+NO₃) Content within the Western (a) and Eastern (b) C-9 Canal Basin (Florida Department of Environmental Protection WBIDs 3284 [a] and 3283 [b]) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4) unless noted on upper x-axis. Sites are shown in a west to east orientation to show the typical canal flow direction when water control structures are operating. Note no physical control structure separates the western and eastern instream C-9 Canal.

a) Site 32, WBID 3284



b) Site 31, WBID 3283

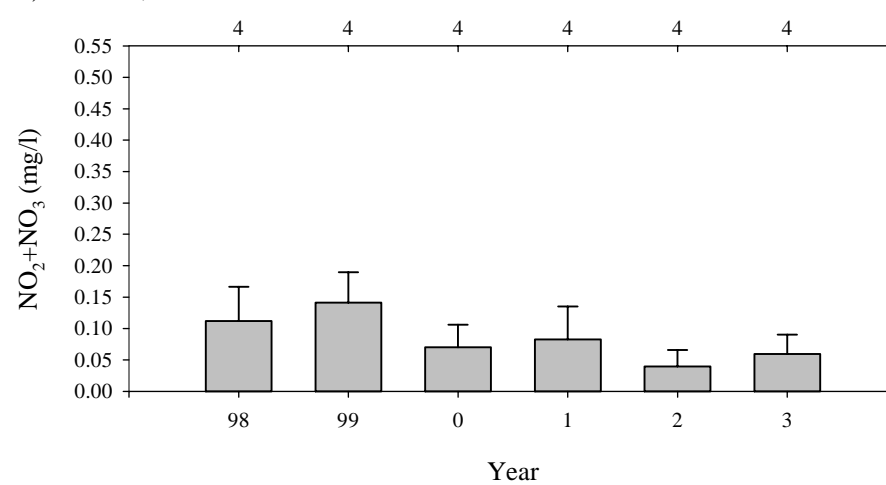
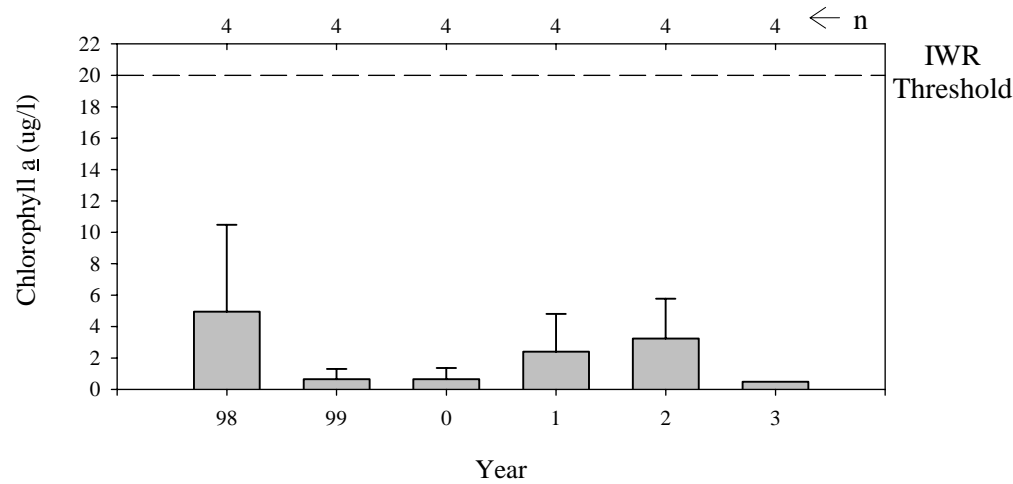
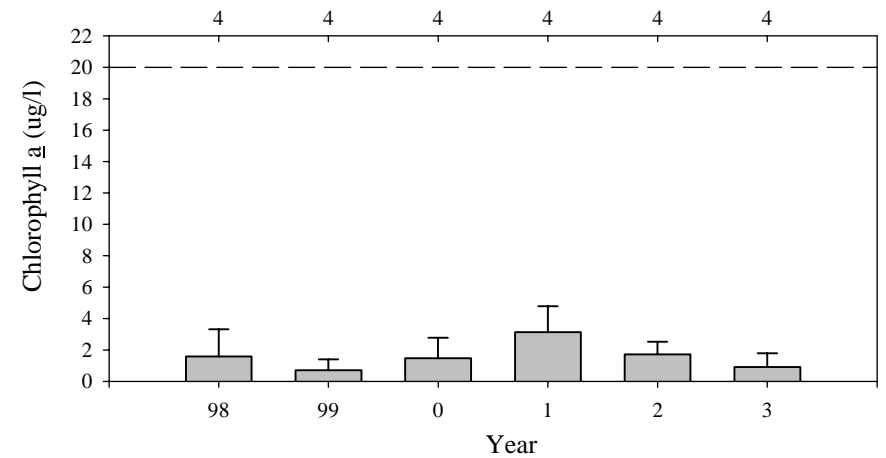


Figure 100. Annual Mean Chlorophyll a Levels within the Western (a) and Eastern (b) C-9 Canal Basins (Florida Department of Environmental Protection WBIDs 3284 [a] and 3283 [b]) from 1998 to 2003. Yearly means and standard deviations (error bars) calculated from quarterly samples (i.e., n=4). The FDEP Impaired Waters Rule (Florida Administrative Code 62-303) chlorophyll a threshold value of 20 micrograms per liter (ug/l) is shown by the dashed line. Waterbodies with values exceeding this threshold are considered impaired and potentially slated for a total maximum daily load for nutrients. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow. Note no physical control structure separates the western and eastern instream C-9 Canal.

a) Site 32, WBID 3284



b) Site 31, WBID 3283

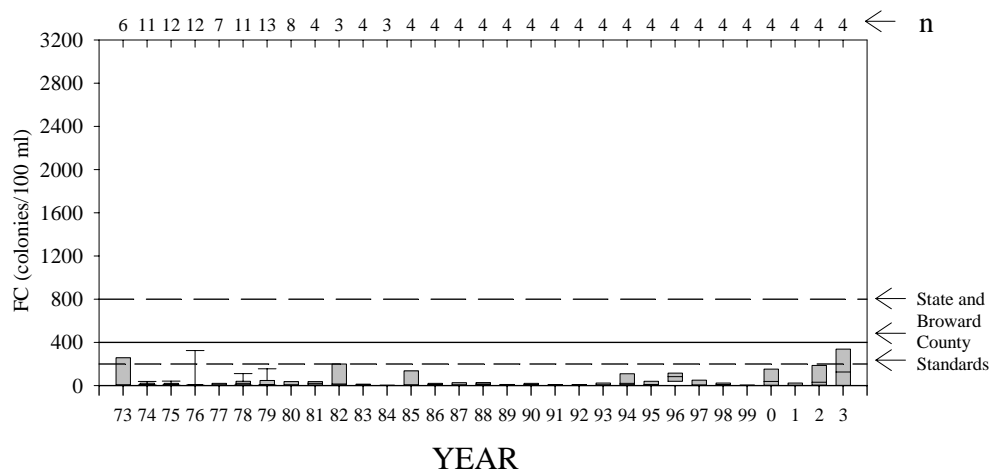


11. Fecal Coliform

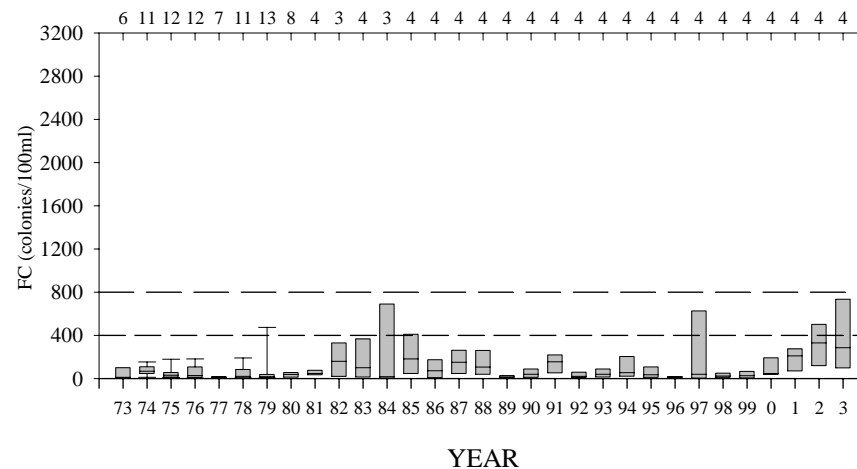
Fecal coliform (FC) concentrations from 1973 to 2003 are shown as these graphs (Figure 101) were available in the BCEPD's first water quality atlas ([BCDPEP 2001](#)). Since 1985, most fecal coliform samples were within compliance of county ([Broward County 1996](#)) and state ([FDEP 2006a](#)) environmental regulations for single sample (800 colonies per 100 milliliters, ml) and 'ten percent rule' (400 colonies per 100 ml) with rare exceptional events. However, the last few years have seen a slight trend towards increasing values, particularly at Site 31. While the median values are still below the 400 colonies per 100 ml criteria at both sites since 2000, this most recent period exhibited values that differed from the previous ten years and deserve watching during the next analysis.

Figure 101. Annual Box Plots of Fecal Coliform (FC) Levels Within the Western (a) and Eastern (b) C-9 Canal Basins (Florida Department of Environmental Protection WBIDs 3284 [a] and 3283 [b]) from 1973 to 2003. Medians and percentiles calculated from bi-weekly, monthly, and quarterly samples with the number of samples (n) noted on the upper axis. To be within compliance of state and county environmental regulations, levels shall not exceed a monthly average of 200 colonies per 100 milliliters (col/100 ml), nor exceed 400 col/100 ml in 10% of the samples, nor exceed 800 col/100 ml on any one day. Numbers in parentheses represent 75th percentile values that extend beyond y-axis. Sites are shown in a western to eastern geographical orientation to show the typical direction of the canal during periods of flow. Note no physical control structure separates the western and eastern instream C-9 Canal.

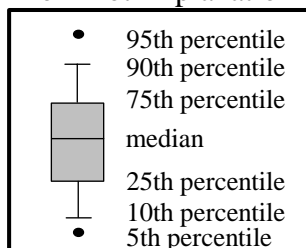
a) Site 32, WBID 3284



b) Site 31, WBID 3283



Box Plot Explanation



IV. Discussion

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

1. Determine (long-term and current) basin specific water quality conditions by analyzing data from each sampling site;
2. Determine compliance patterns with Broward County Code, Chapter 27 Article V water quality standards ([Broward County 1996](#));
3. Determine compliance patterns with the state of Florida's water quality criteria (Florida Administrative Code, FAC, 62-302, [FDEP 2006a](#)) and the Impaired Waters Rule (IWR, FAC 62-303, [FDEP 2006b](#));
4. Determine similarities and differences existing within each basin or region; and
5. Formulate monitoring questions, needs, and direction for better water quality management and protection of Broward County's surface waters.

The preceding chapters on each basin addressed each objective, especially the first three. The following text will primarily discuss all these objectives by comparing and contrasting all freshwater sub-basins.

A. Countywide Comparisons

The Broward County Environmental Protection Department monitors water quality in nine distinct freshwater sub-basins within the county and includes all or portions of the Hillsboro Canal, C-14 Canal, Pompano Canal, C-13 Canal, C-12 Canal, North New River Canal, Western C-11 Canal, Eastern C-11 Canal, and the Western C-9 Canal. The drainage areas, canal length, and monitoring site location are variable among the nine sub-basins. For example, three sampling sites exist along the fourteen miles of the urban portion of the freshwater North New River Canal, while one site covers the short 2.7 mile Pompano Canal.

Many natural and artificial variables also exist within and between the different sub-basins. The type of soils, geology, and overall elevation (land and water) vary within the county and have been described previously ([Fish 1988](#)). Perhaps of more recent importance has been the optimization and integration of sub-basins to augment public water supply, natural system hydration, and flood protection. Portions of water that were sent to tidal waters through SFWMD coastal salinity structures are now being redirected within and between specific drainage sub-basins. The development of Broward County's Integrated Water Resources Plan (IWRP) has formalized this county-wide effort among numerous stakeholders ([BCEPD 2005](#)). The IWRP influences canals countywide. Coupled with the need for aquatic plant management,

artificial hydrological canal management can contribute to variability within water quality data. The movement of waters from one canal can affect the water quality of the downstream waterway. For example, a previous study has documented the change in a freshwater, tidal estuarine waterbody (North Fork New River) in nutrient composition to reflect the artificially modified delivery of C-13 Canal water through a secondary canal system over four miles long ([BCDPEP 2003](#)). Coupled with the need for aquatic plant management, artificial hydrological canal management undoubtedly contributes to variability in water quality.

The eastern urban core is primarily 'downstream' of the western two thirds of Broward County (Water Conservation Areas, WCAs) in terms of ground and surface waters in the South Florida watershed (see Figures 1 and 2, Section I). Thus, the proximity and continuity to WCAs influences urban water quality and quantity and differs among the different sub-basins. The C-14 Canal, C-13 Canal, North New River Canal, western C-11 Canal, and western C-9 Canal are particularly influenced by groundwater seepage and direct canal connection to the WCAs 2 and 3. Conversely, the Pompano Canal, Eastern C-11 Canal, and the C-12 Canal are effectively truncated from any connection to the WCAs (Cooper and Lane 1987).

This section will investigate any differences and similarities between sampling sub-basin's main water quality characteristics described for each individual site and discuss possible natural and artificial mechanisms behind the observations.

1. Specific Conductance and Total Organic Carbon

Two parameters, specific conductance and total organic carbon (TOC), exhibited similar spatial patterns countywide and appeared to track the general hydrological components of the canal system. Overall, the specific conductance county median for all of Broward County from 1998 through 2003 was 651 micromhos per centimeter (umhos/cm) at 25 degrees Celsius (Figure 102) and the county median TOC for all canals was 17.1 milligrams per liter (mg/l, Figure 103). The specific conductance and total organic carbon values which were typically higher than the county median were observed primarily in the western most portions of the canals especially the Hillsboro, C-14, C-13, North New River and western C-11 Canals. These waterways either have a direct linkage to canals that traverse the Water Conservations Areas (WCAs) of western Broward County and/or highly influenced by groundwater seepage from the WCAs. High TOC concentrations (e.g., geometric mean 26 mg/l) have been observed by the USEPA in South Florida canals upstream of urban Broward County ([USEPA 1998](#)). A large proportion of the South Florida organic carbon is considered dissolved based on work by the United States Geological Survey ([McPherson et. al. 2000](#)). The 'iced-tea' color that characterizes much of the western Broward County canals, and to some extent eastern waterways, originates primarily from the dissolved organic carbon ([McPherson et al. 2000](#)).

Figure 102. Specific Conductance (Cond) Levels in Broward County's Freshwater Canal System. Box plots represent data collected at a site (x-axis) from 1998 through 2003. Sites within specific canals are grouped together (x-axis) and are shown from left to right in the typical direction of a specific canal's managed water flow. Values are shown in micromhos per centimeter (umhos/cm) at 25 degrees Celsius. The county median for all sites was 651 umhos/cm (dashed line, n = 492).

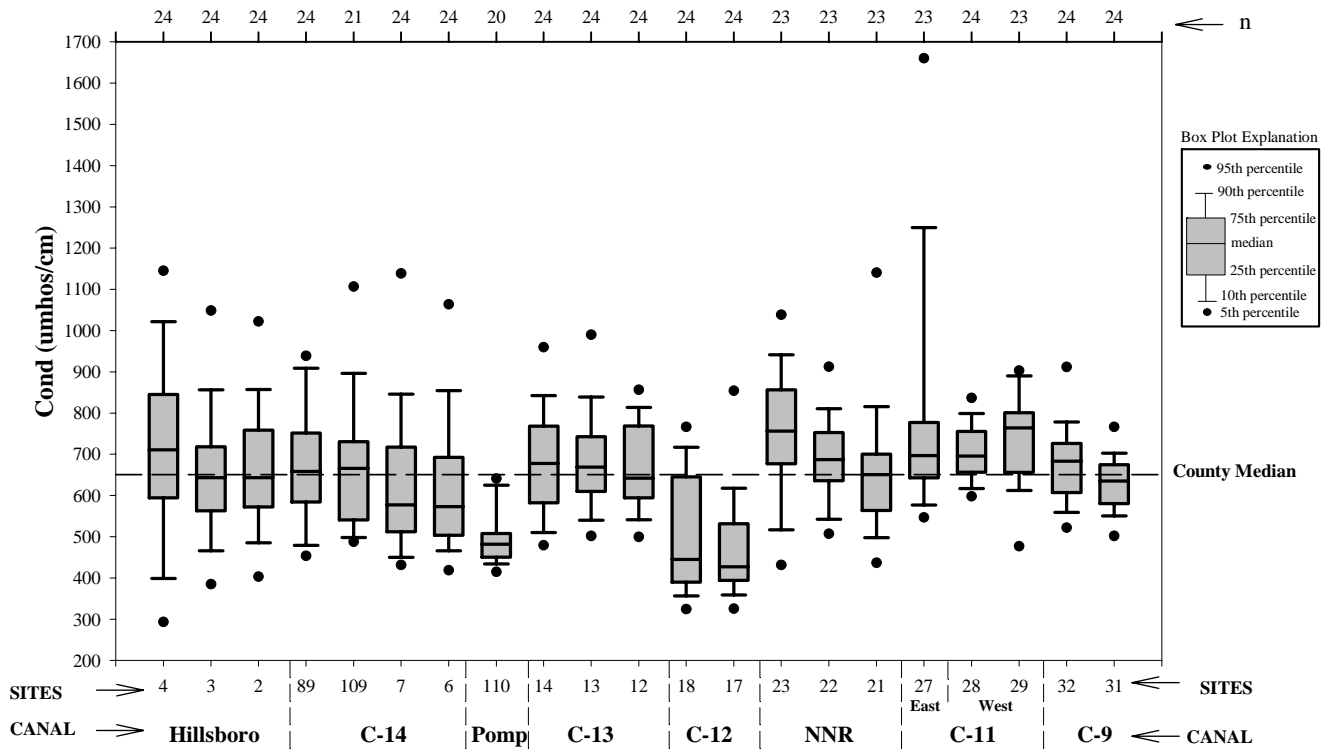
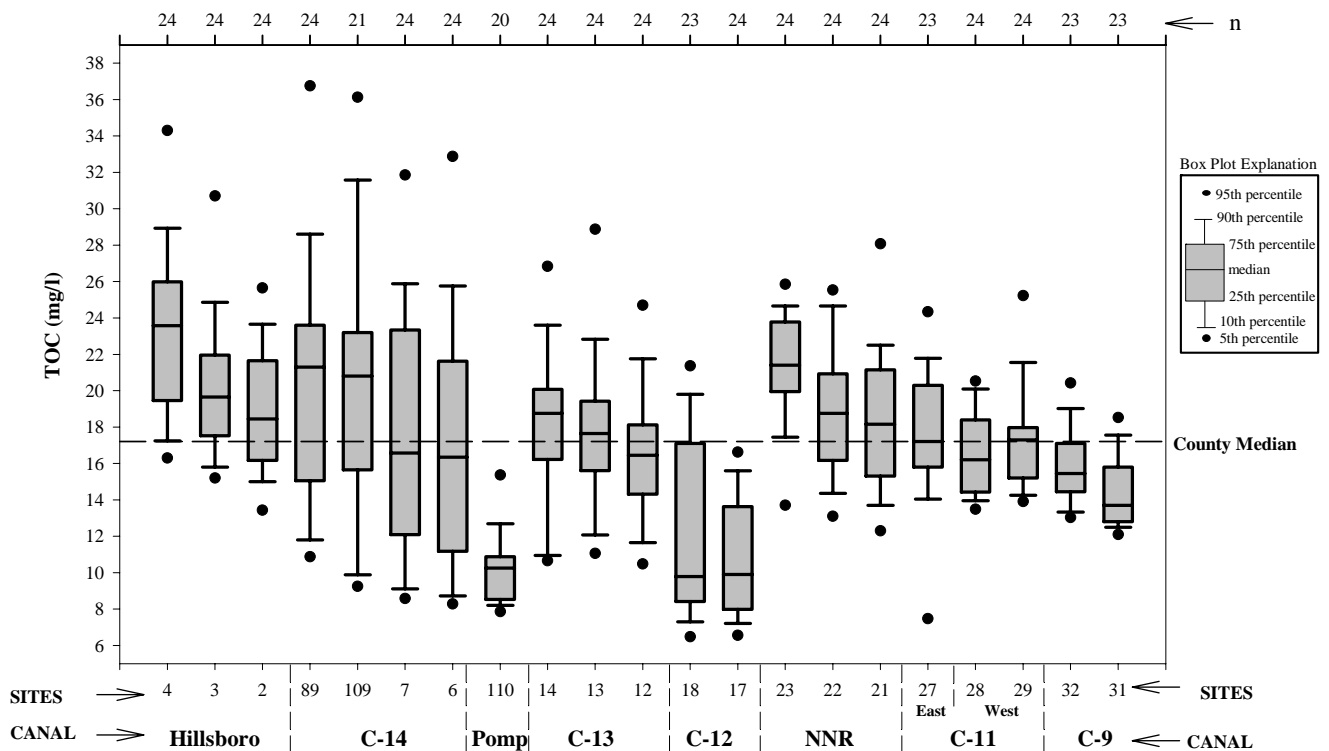


Figure 103. Total Organic Carbon (TOC) Content in Broward County's Freshwater Canal System. The box plots represent all data collected at a specific site (x-axis) from 1998 through 2003. Sites within specific canals are grouped together (x-axis) and are shown from left to right in the typical direction of a specific canal's managed water flow. The county median for all sites was 17.1 milligrams per liter (mg/l, dashed line, n = 493).



Conversely, the lowest specific conductance and TOC values were observed at the more hydrologically isolated systems of the Pompano and C-12 Canals (Figures 102 and 103). These two canals do not have a direct link to the Western Conservation Areas. In fact, the Pompano Canal's western control structure has not been opened in over a decade (South Florida Water Management District, personal communication). The flow of the C-12 Canal is extremely low compared to other Broward County canals ([BCDPEP 2003](#)).

2. Dissolved Oxygen

The overall county median was 5.09 mg/l which is within compliance of both state and county water quality standards (Figure 104). To be within compliance of county water quality standards, a sample should be equal to or above 4.0 mg/l at all times (dotted line Figure 104) and have a daily average greater than or equal to 5.0 mg/l (solid line Figure 104). State water quality criteria mandate all samples must be greater than or equal to 5.0 mg/l (solid line Figure 104). Figure 105 shows that 52.0% of all individual samples (n=490) were within compliance of both state and county standards from 1998 through 2003. While 28.2% of all samples were out of compliance of both sets of standards, the amount of samples that fell within the county single sample standard (greater than or equal to 4.0 mg/l) and state single sample standard (greater than or equal to 5.0 mg/l) was 19.8%.

With the exception of the Hillsboro Canal, the more northern canals (C-14, C-13, and C-12) had generally higher dissolved oxygen concentrations than the southwestern part of the county (North New River Canal Sites 22 and 23, C-11 Canal West, and C-9 Canal, Figure 104). The southwestern portion of the urbanized portion of Broward County has the county's lowest elevations and is especially influenced by groundwater seepage from the WCAs. From Fish's ([1988](#)) description of Broward County, "Surface water and ground water are considered the visible and hidden components of a continuous water body." Groundwater is typically low in dissolved oxygen. For example, Bradner et al. ([2004](#)) reported median dissolved concentration in South Florida groundwater as 0.15 milligrams per liter. Thus, groundwater interaction with surface water can be a significant reason for relatively low dissolved oxygen levels in South Florida canals as compared to the state's numeric criteria.

A previous study of Broward County canals ([BCDPEP 2001](#)) showed numerous statistically significant differences between wet and dry season dissolved oxygen content with highest values seen in the dry season. While some of these seasonal differences likely are affected by temperature, there are also seasonal relationships when canal water flows into the groundwater and when groundwater flows into canals because of the close continuity ([Fish 1988](#)). Typically during the dry season, groundwater elevation levels are more depressed and canal water migrates towards the groundwater. In the wet season, groundwater elevations typically increase and

Figure 104. Dissolved Oxygen (DO) Concentrations in Broward County's Freshwater Canal System. Box plots represent data collected at a site (x-axis) from 1998 through 2003. Sites within specific canals are grouped together (x-axis) and are shown from left to right in the typical direction of a specific canal's managed water flow. To be within compliance of county water quality standards, a sample should be equal to or above 4.0 mg/l at all times and have a daily average greater than or equal to 5.0 mg/l (solid line). State water quality criteria mandate all samples must be greater than or equal to 5.0 mg/l (dashed line). The countywide median equals 5.09 mg/l based on 490 samples.

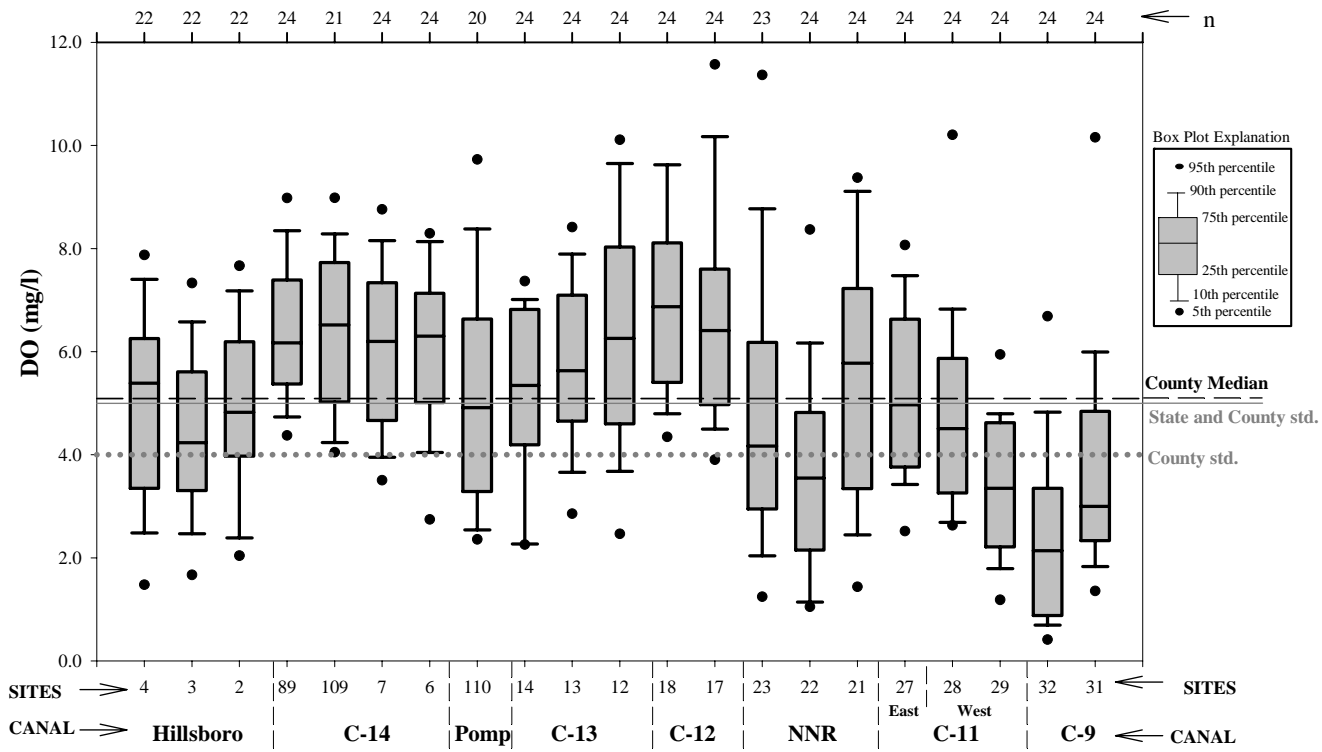
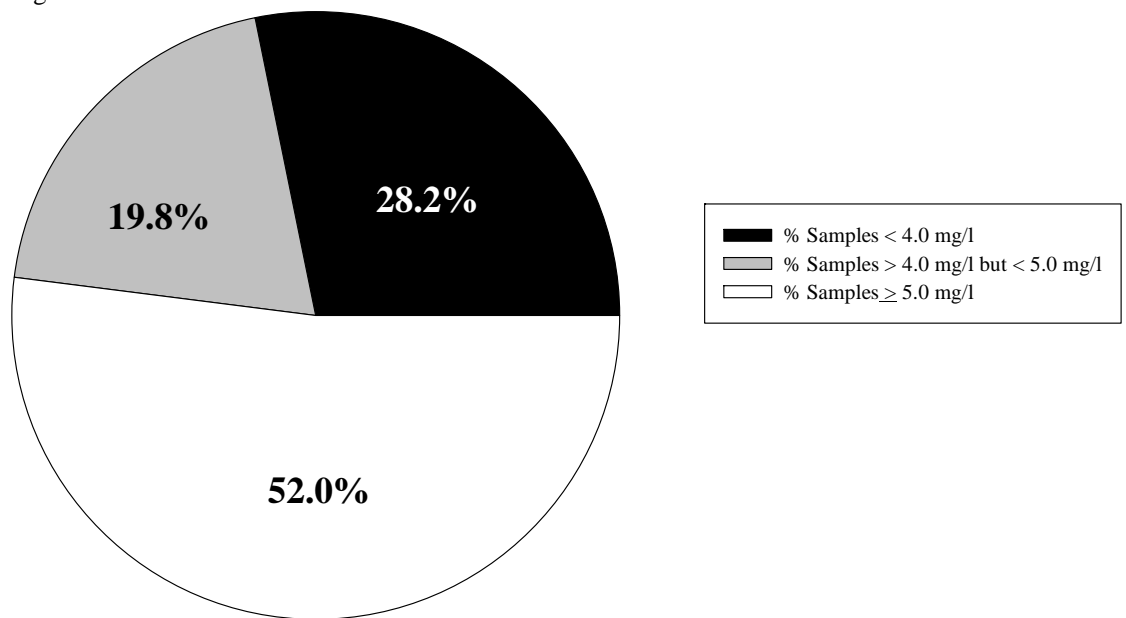


Figure 105. Percentage of Dissolved Oxygen (DO) Concentrations Within Compliance of Broward County and State of Florida Water Quality Standards. To be within compliance of county water quality standards, a sample should be equal to or above 4.0 mg/l at all times and have a daily average greater than or equal to 5.0 mg/l (solid line). State water quality criteria mandate all samples must be greater than or equal to 5.0 mg/l. The percentages are based on 490 samples collected from all Broward County freshwater canals during 1998 through 2003.



can migrate into the canal system. Thus, temperature and hydrology are two major seasonal and non-pollutant factors on dissolved oxygen dynamics of Broward County's canals.

3. Phosphorus

The eastern portion of the Hillsboro Canal (Sites 2 and 3) exhibited much higher total phosphorus concentrations than all other canals (Figure 106). The other canals with enhanced TP content tended to be more hydrologically isolated from the WCAs, such as the Pompano and C-12 Canals. In addition, the eastern C-11 Canal, distinct from the western C-11 Canal, also had some of the county's highest TP content. Waterbodies with close linkages to the WCAs (western C-14 sites 89 and 109, C-13, North New River, western C-11, and C-9 canals) had the lowest TP in the county. Overall, the county median was 0.031 mg/l (n=497).

Broward County has a numeric standard of 0.020 mg/l in its county code ([Broward County 1996](#)). A total of 31.6% of TP samples collected from Broward County freshwater canals from 1998 through 2003 were within compliance of the 0.020 mg/l criteria (Figure 107). Of the 68.4% of non compliant samples, 30.2% were less than twice the standard while 38.2% were twice the criteria. As can be seen from Figure 106, many of the samples over 0.040 mg/l were observed at the Hillsboro, Pompano, C-12 and Eastern C-11 Canals.

For orthophosphate, a comparison for the entire period of record (1998-2003) cannot be performed because of a major change in the method detection limit changed from 0.030 mg/l to 0.00348 mg/l in 2000. From 2000 through 2003, the county median was 0.0043 milligrams per liter (mg/l, dashed line, n = 332) and was highly influenced by 46.9% of samples being below the detection limit in all samples and one half of the detection limit was used in the graphical and calculation of median (and percentiles, Figure 108). The eastern part of the Hillsboro Canal had the highest concentrations of orthophosphate and the Eastern C-14 Canal (site 7) and Eastern C-11 (site 27) had orthophosphate values that were elevated above the county median.

4. Nitrogen

The western portions of most canal systems generally had the highest total nitrogen (TN) values in the county (e.g., Site 4, Hillsboro Canal, Figure 109). Water Conservation Area 2 typically has TN values over 2.0 mg/l ([Payne and Weaver 2004](#)) and thus, most water bodies downstream (i.e., western urban Broward County) of this major hydrographic feature are influenced by these enhanced values. The one exception is the eastern C-11 Canal (Site 27) which had the highest median TN content for the 1998 through 2003 time period. The lowest TN values were seen in the Pompano Canal and C-12 which are two canals not influenced by inflows from the Water Conservations Areas. Overall, 61.0% of 493 samples were within compliance of the Broward County's standard of 1.5 mg/l (Figure 110). Only 5.7%

Figure 106. Total Phosphorus (TP) Content in Broward County's Freshwater Canal System. Box plots represent data collected at a site (x-axis) from 1998 through 2003. Sites within specific canals are grouped together (x-axis) and are shown from left to right in the typical direction of a specific canal's managed water flow. The county median was 0.031 milligrams per liter (mg/l, dashed line, n = 497). To be in compliance with the county standard, samples should be below 0.020 mg/l (solid line).

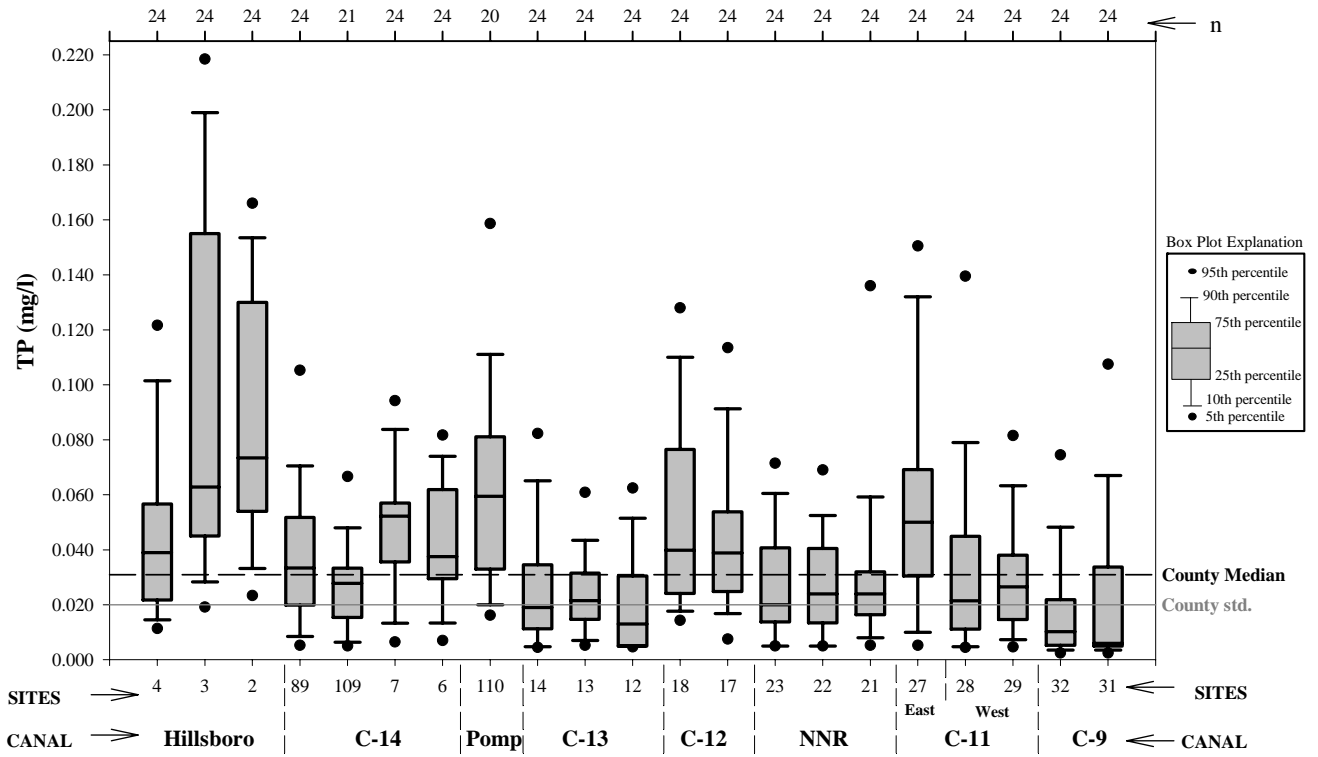


Figure 107. Percentage of Total Phosphorus (TP) Concentrations Within Compliance of Broward County Water Quality Standards. To be within compliance of county criteria, a sample should be below 0.020 mg/l. Percentages shown within gray and black are both out of compliance with the county standard. The gray area shows samples up to two times the standard and the black area depicting the percentage of samples over twice the standard. Currently, the state of Florida has a narrative nutrient criteria.

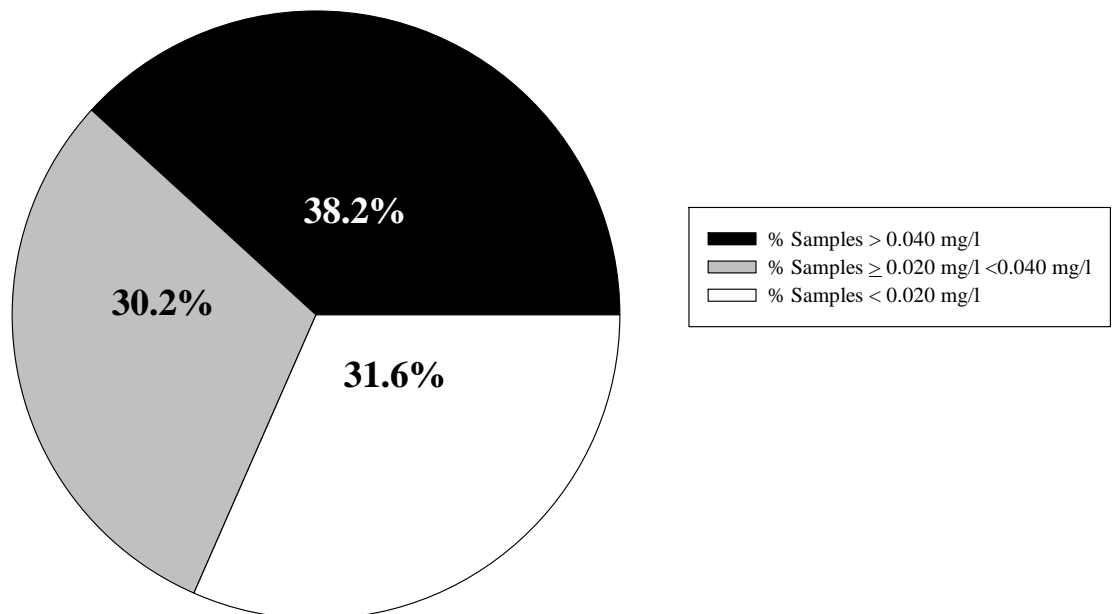


Figure 108. The ortho-Phosphate (o-PO4) Content in Broward County's Freshwater Canal System. Box plots represent data collected at a site (x-axis) from 2000 through 2003. Sites within specific canals are grouped together (x-axis) and are shown from left to right in the typical direction of a specific canal's water flow (when it occurs). The county median was 0.0043 milligrams per liter (mg/l, dashed line, n = 332). The method detection limit changed from 0.030 mg/l to 0.00348 mg/l in 2000. Thus, only the years 2000 through 2003 are shown. Note 46.9% of samples were below the detection limit in all samples and one half of the detection limit was used in the graph.

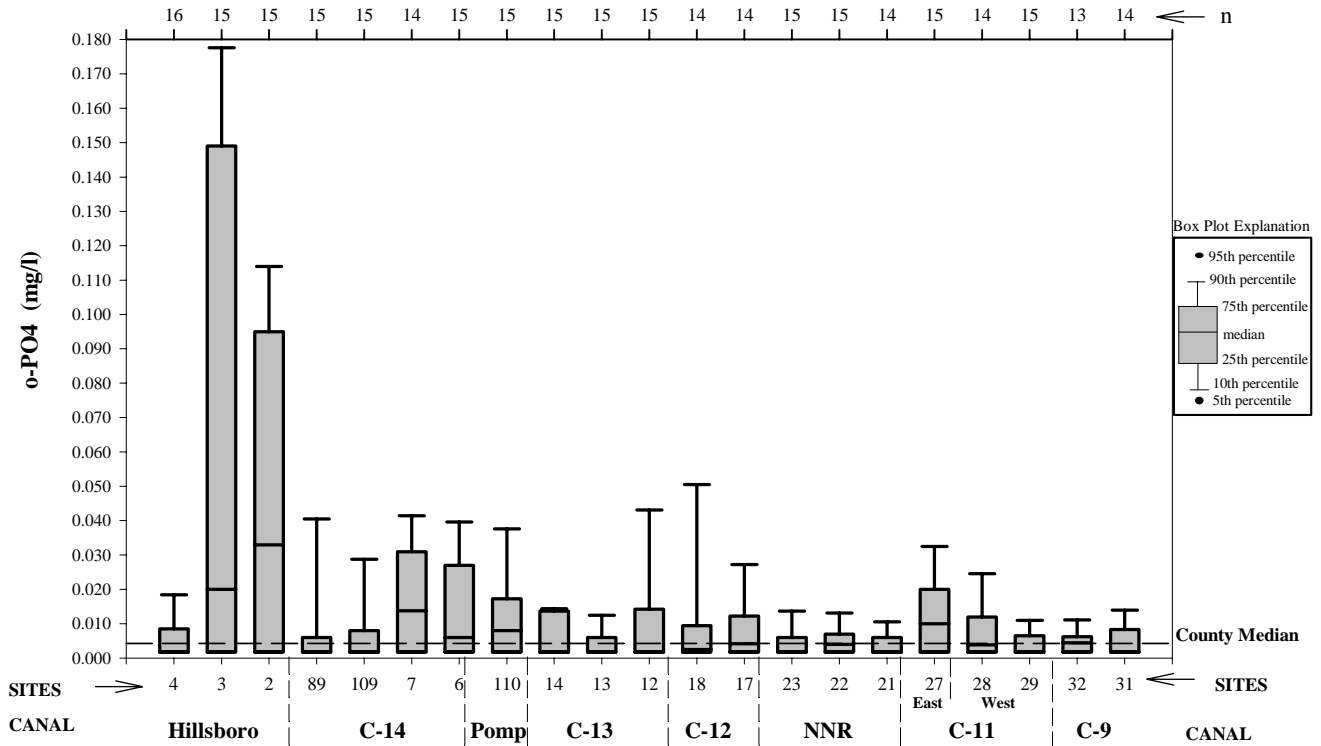


Figure 109. Total Nitrogen (TN) Concentrations in Broward County's Freshwater Canal System. Box plots represent data collected from 1998 through 2003. Sites within specific canals are grouped together (x-axis) and are shown from left to right in the typical direction of a specific canal's managed water flow. The county median was 1.41 milligrams per liter (mg/l, dashed line, n = 493). To be within compliance of the county standard, a sample should be below 1.50 mg/l (solid line).

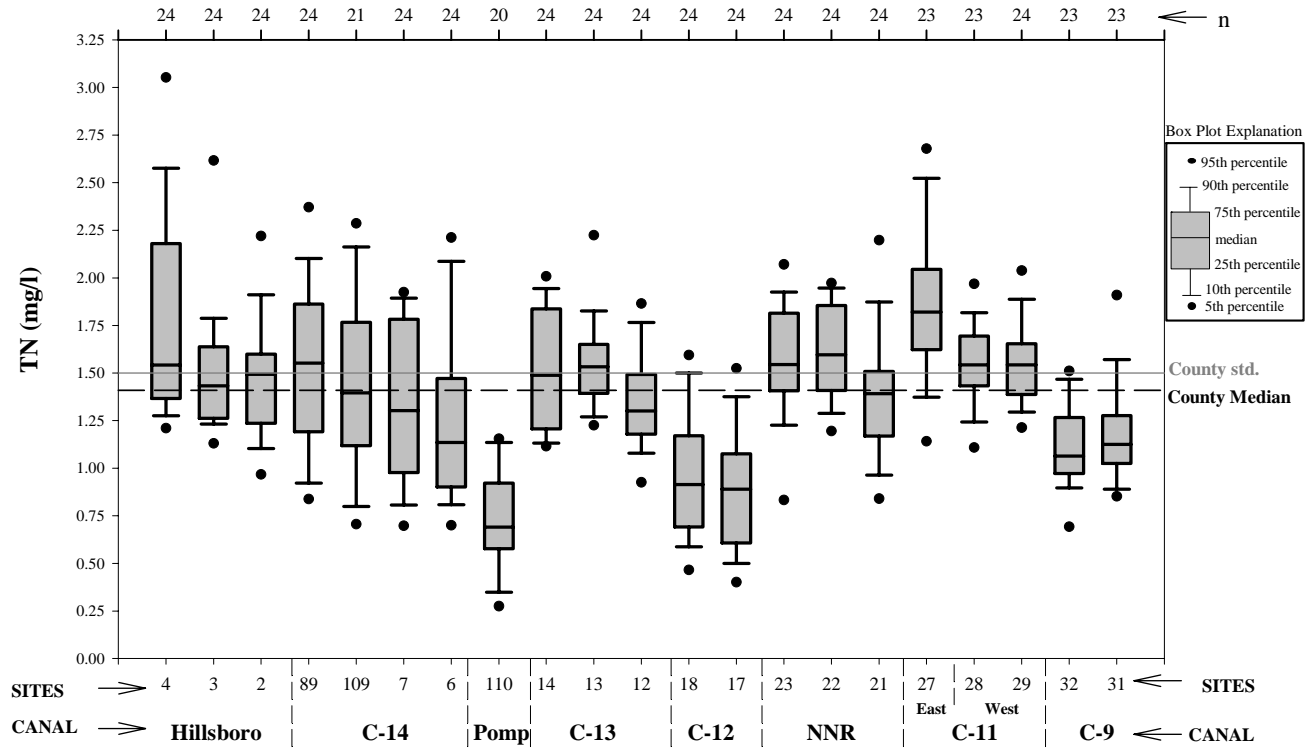
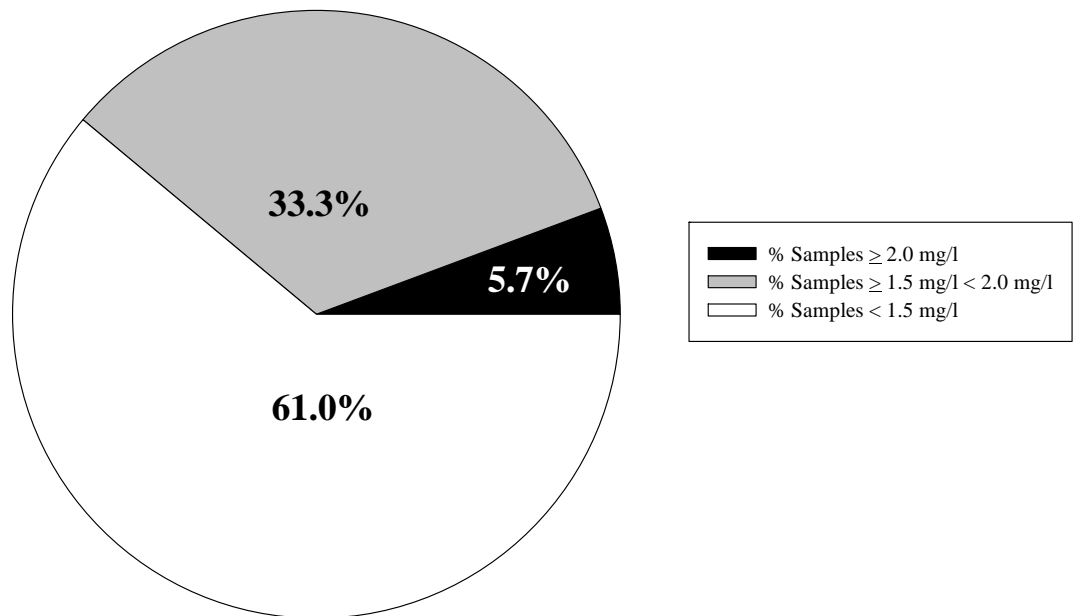


Figure 110. Percentage of Total Nitrogen (TN) Concentrations Within Compliance of Broward County Water Quality Standards. To be within compliance of county criteria, a sample should be below 1.5 mg/l. Percentages shown within gray and black are both out of compliance with the county standard. The gray area shows samples exceeding 1.5 mg/l but less than 2.0 mg/l and the black area depicts the percentage of samples equal to or greater than 2.0 mg/l.



of countywide samples were greater than 2.0 mg/l. From Figure 109, most of the TN values greater than 2.0 mg/l were observed at Site 4 on the Hillsboro Canal and Site 27 (Eastern C-11 Canal).

Total Nitrogen (TN) is a calculation of total Kjeldahl nitrogen (TKN) and nitrite+nitrate-nitrogen (NO_{2+3}). The median percentage of TKN that comprises TN was 94.6% for Broward County canals (data not shown). The TKN represents the sum of organic nitrogen (particulate and dissolved) and ammonia-nitrogen (NH_3). For Broward County canals, the median percentage of NH_3 comprising TKN is 6.6% (data not shown). Thus, the vast majority of TN in Broward County's freshwaters is in the form of organic nitrogen as compared to the dissolved inorganic fractions of NH_3 and NO_{2+3} .

Despite forming a small percentage of the overall TN content within the county, the concentrations of NH_3 and NO_{2+3} were variable within and between different canals (Figures 111 and 112). The NH_3 content was generally highest in the western portions of the canals (Figure 111). One important exception was Site 22 of the North New River Canal where some of the county's highest NH_3 values were observed. Site 22 is located immediately to the southeast of the southern terminal end of the WCA 2B and the high values observed here were likely influenced by seepage water from this portion of the Everglades. The other areas with enhanced NH_3 values including Site 29 (Western C-11 Canal), Sites 31 and 32 (C-9 Canal) and Site 14 (Western C-13 Canal) are also influenced by seepage water from the Water Conservation Areas.

Wetlands typically are low in dissolved oxygen which facilitates an environment for higher NH_3 than NO_{2+3} content. Exceptionally high NH_3 values have also been observed in some canals that flow into WCA 2 ([Weaver et al. 2003](#)). In addition, South Florida groundwater (also low in dissolved oxygen) has enhanced NH_3 levels as compared to studies from around the country due, in part, to an anoxic environment that is conducive to organic nitrogen being reduced to NH_3 ([Bradner et al. 2004](#)). Thus, all of these factors are likely lead to an exportation of NH_3 out of the WCAs eastward into the western edges of Broward urban canal system.

Near opposite of NH_3 values, NO_{2+3} values were typically highest in the eastern portions of a specific freshwater canal (Figure 112) and suggest the NH_3 is being transformed during travel time in the canal. This theory would need to be further documented with in-stream flow studies. The change in dissolved inorganic nitrogen form was particularly evident in the C-13 Canal NH_3 (Figure 111) and NO_{2+3} (Figure 112). Overall, Site 27 (Eastern C-11 Canal) had the highest median NO_{2+3} with Site 28 in the western C-11 having the second highest median. The C-9's Site 32, in the far southwest corner of the county, had the lowest NO_{2+3} content.

Figure 111. Ammonia (NH₃) Content in Broward County's Freshwater Canal System. Box plots represent data collected at a site (x-axis) from 1998 through 2003 and typically represent 24 samples. Sites within specific canals are grouped together (x-axis) and are shown from left to right in the typical direction of a specific canal's water flow (when it occurs). The county median was 0.080 milligrams per liter (mg/l, dashed line, n = 497).

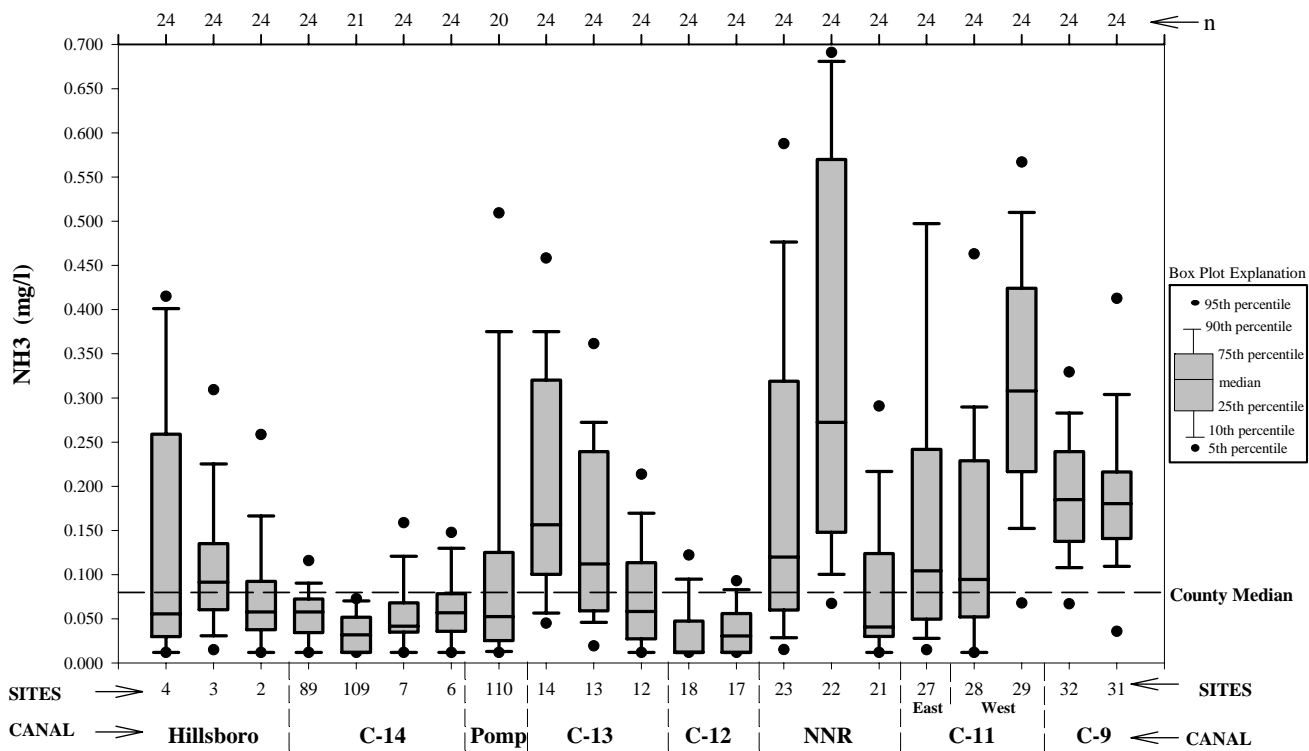
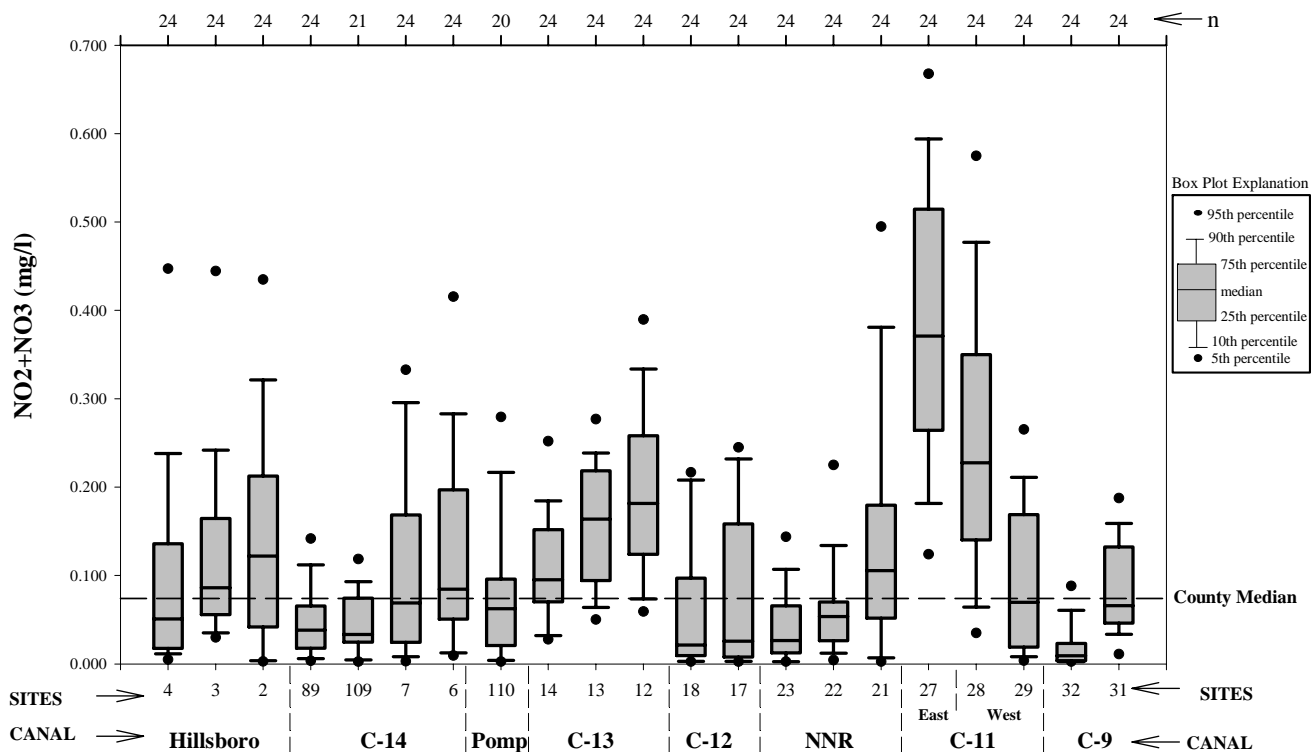


Figure 112. Nitrite+Nitrate-Nitrogen (NO₂+NO₃) Concentrations in Broward County's Freshwater Canal System. Box plots represent data collected at a site (x-axis) from 1998 through 2003 and typically represent 24 samples. Sites within specific canals are grouped together (x-axis) and are shown from left to right in the typical direction of a specific canal's managed water flow. The county median was 0.074 milligrams per liter (mg/l, dashed line, n = 497).



5. Chlorophyll a

Broward County canals typically have low levels of chlorophyll a based on the county wide median of 3.78 micrograms per liter (ug/l, n=497, Figure 113). Some of the highest concentrations were seen in the Pompano Canal (Site 110), Hillsboro Canal (Sites 2-4), and eastern C-11 Canal (Site 27), however, other canals had specific sites with rare but high values (e.g., Site 22 in North New River Canal). The low levels are especially noticeable when compared to the FDEP Impaired Waters Rule ([FDEP 2006b](#)) threshold of 20 ug/l for nutrient (phosphorus and nitrogen) impairment (Figure 114). Only 3.8 percent of 497 samples were greater than the 20 ug/l threshold and only 10.9% of those samples were even half of the threshold. At the time of this writing, only the Pompano Canal (WBID 3271) had been listed by the FDEP for a nutrient impairment based on chlorophyll a and a draft TMDL document had been released by FDEP ([Wu et al. 2007](#)).

The relatively low chlorophyll a concentrations in Broward County canals have a weak relationship with the observed nutrient content (Figures 115 a+b). A pattern did not exist from 1998 through 2003, where an increase in nutrients is closely correlated to an increase in chlorophyll a levels (regression analysis results: r^2 for total phosphorus = 0.135, n=500; r^2 for total nitrogen = 0.02, n=501). Broward County participates in the FDEP numeric nutrient criteria TAC, an effort to develop numbers for TN and TP for different waterbodies throughout the state and these regressions were part of that work.

Several reasons likely contribute to the weak relationship between nutrients and chlorophyll a and include water color and aquatic plant management. The tannic “ice-tea” color that is characteristic of most of Broward County’s freshwater canals likely provides a shading effect that can limit macrophyte and phytoplankton populations ([McPherson et al. 2000](#)). Despite the tannic color, floating aquatic macrophytes, including several nuisance species (e.g., *Hygrophila*), often flourish in Broward County canals. However, the presence of these algae requires aquatic plant management including the application of aquatic herbicides that affects the nutrient cycling in the canal as well as the phytoplankton populations and associated chlorophyll a levels. The BCEPD does not coordinate its quarterly sampling events with plant management activities.

The weak relationship between chlorophyll a and nutrients in South Florida canals is also affected by the highly managed flow regime of the waterways by the SFWMD for flood protection, water supply, and ecosystem restoration. This affects the residence time of water in a specific canal. Thus, canals which have high flow rates will unlikely have high chlorophyll a content as the phytoplankton do not have suitable time to establish. Conversely canals that have a low flow regime may tend to have higher chlorophyll a content as they effectively become linear ‘ponds’ during periods of zero or low flows. For example, the only Broward County canal designated with nutrient impairment by the FDEP (Pompano Canal) has no freshwater flow from its western end because of a closed water control structure. The

Figure 113. Chlorophyll a (Chl a) Content in Broward County's Freshwater Canal System. Box plots represent data collected at a site (x-axis) from 1998 through 2003. Sites within specific canals are grouped together (x-axis) and are shown from left to right in the typical direction of a specific canal's water flow (when it occurs). The county median was 3.78 micrograms per liter (ug/l, dashed line, n = 497). The FDEP Impaired Waters Rule (IWR, Florida Administrative Code 62-303) has a chlorophyll a threshold value of 20 micrograms per liter (ug/l, solid line) for possible nutrient impairment. Waterbodies with values exceeding this threshold may be considered impaired and potentially slated for a total maximum daily load for nutrients.

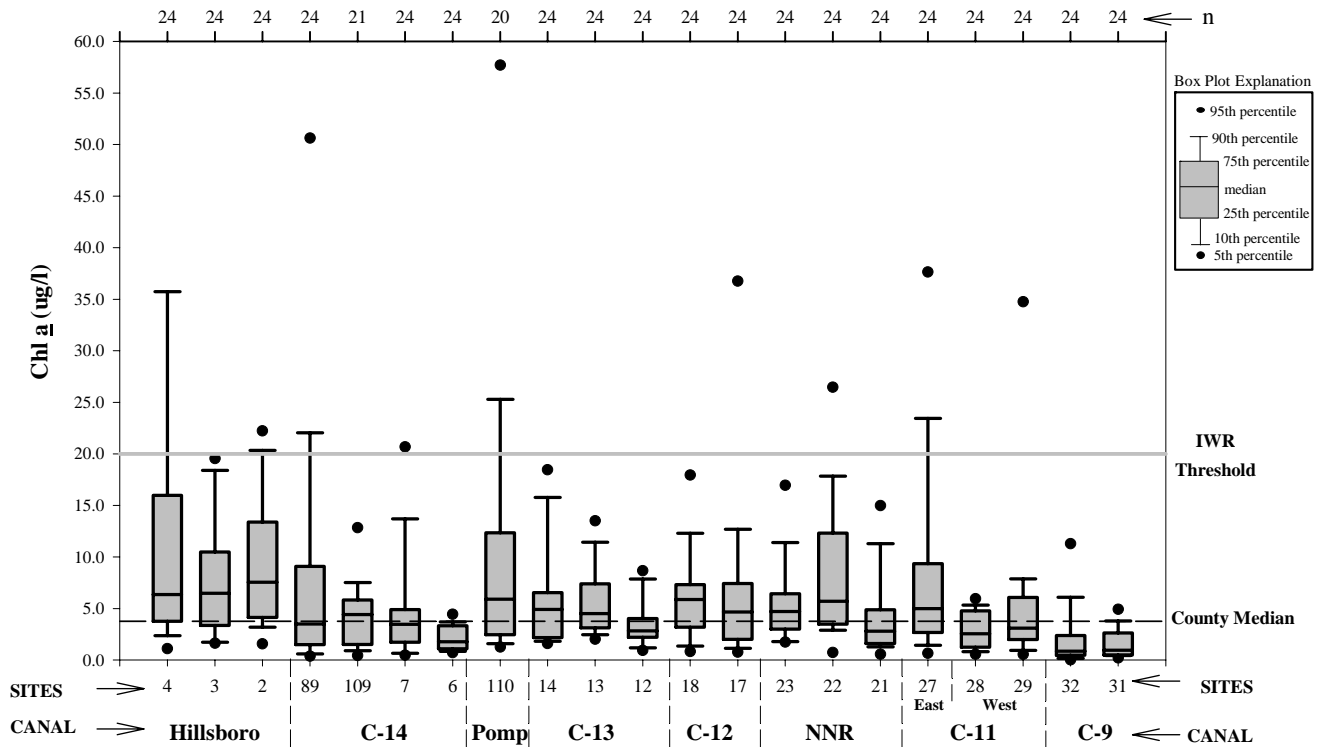


Figure 114. Percentage of Chlorophyll a (Chl a) Concentrations Compared to the Florida Department of Environmental Protection's Impaired Water Rule (FAC 62-303) Chl a Threshold. The 20 micrograms per liter (ug/l) is not a standard but instead is a threshold from which waters may be considered impaired if concentrations exceed that level. Both the white and grey areas are below the threshold of nutrient impairment while the black area represents the percentage of impaired concentrations.

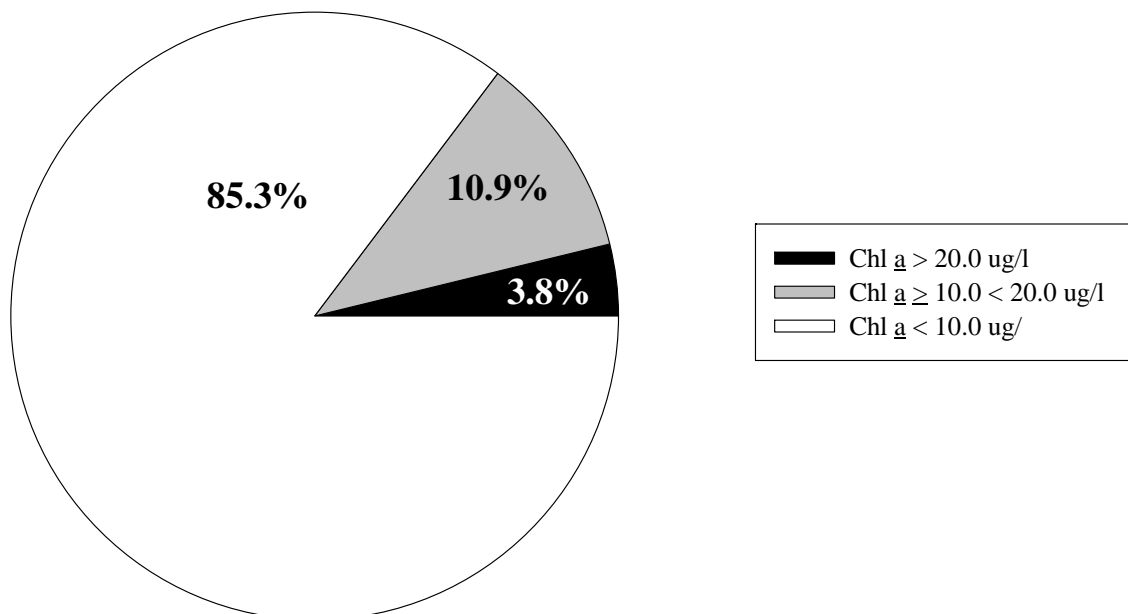
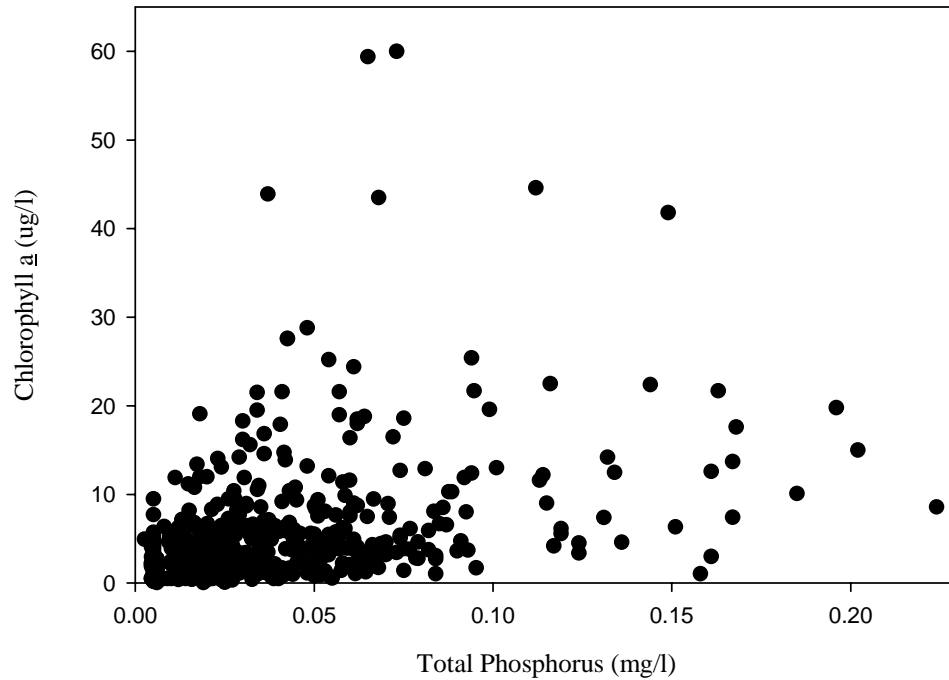
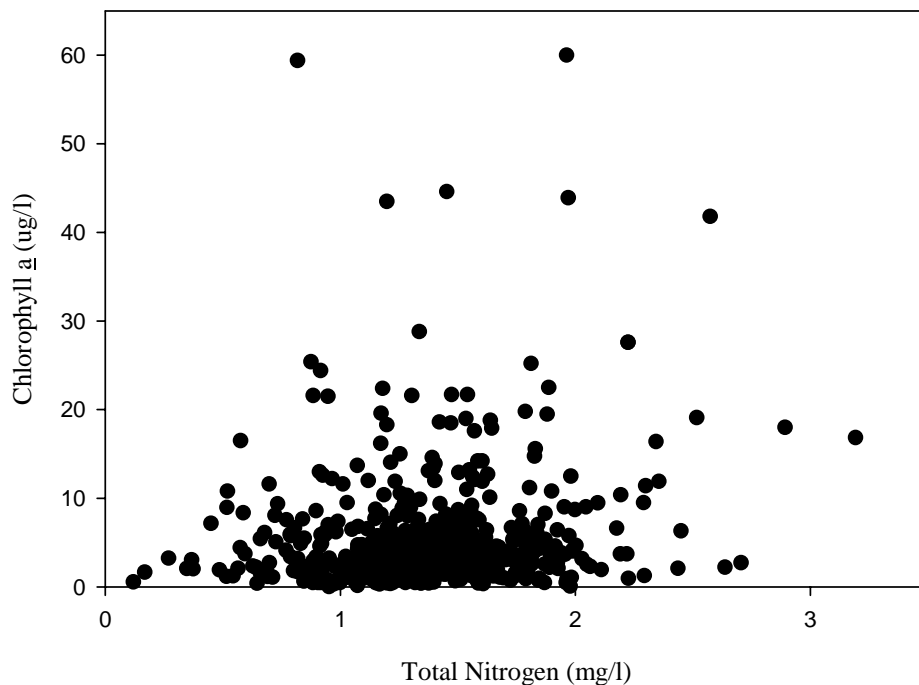


Figure 115. Relationships Between Chlorophyll a and Total Phosphorus (a) and Total Nitrogen (b) Content in Broward County Freshwater Canals. The scatter plots represent chlorophyll a and respective nutrient concentrations collected at the same location, date, and time at all urban Broward County primary canals. Each relationship was characterized by a weak correlation and thus, the regression line is not shown (r^2 for total phosphorus = 0.135, $n=500$; r^2 for total nitrogen = 0.02, $n=501$).

a) Total Phosphorus and Chlorophyll a



b) Total Nitrogen and Chlorophyll a



SFWMD is currently investigating the feasibility of improving and regularly opening this water control structure.

An increased efficiency in managing all types of canals (primary, secondary, and tertiary) countywide (e.g., Broward County's IWRP, [BCEPD 2005](#)) also means water masses once contained in one basin may be transferred to another, for example, to recharge wellfields (e.g., C-14 Canal water relocated to C-13 Basin for Prospect Wellfield in City of Ft. Lauderdale). Thus, it is possible for phytoplankton to potentially establish in a stagnant area and then be moved to another canal during water management activities. The FDEP (personal communication) initially believed this could be part of the nutrient impairment dynamics in the Pompano Canal.

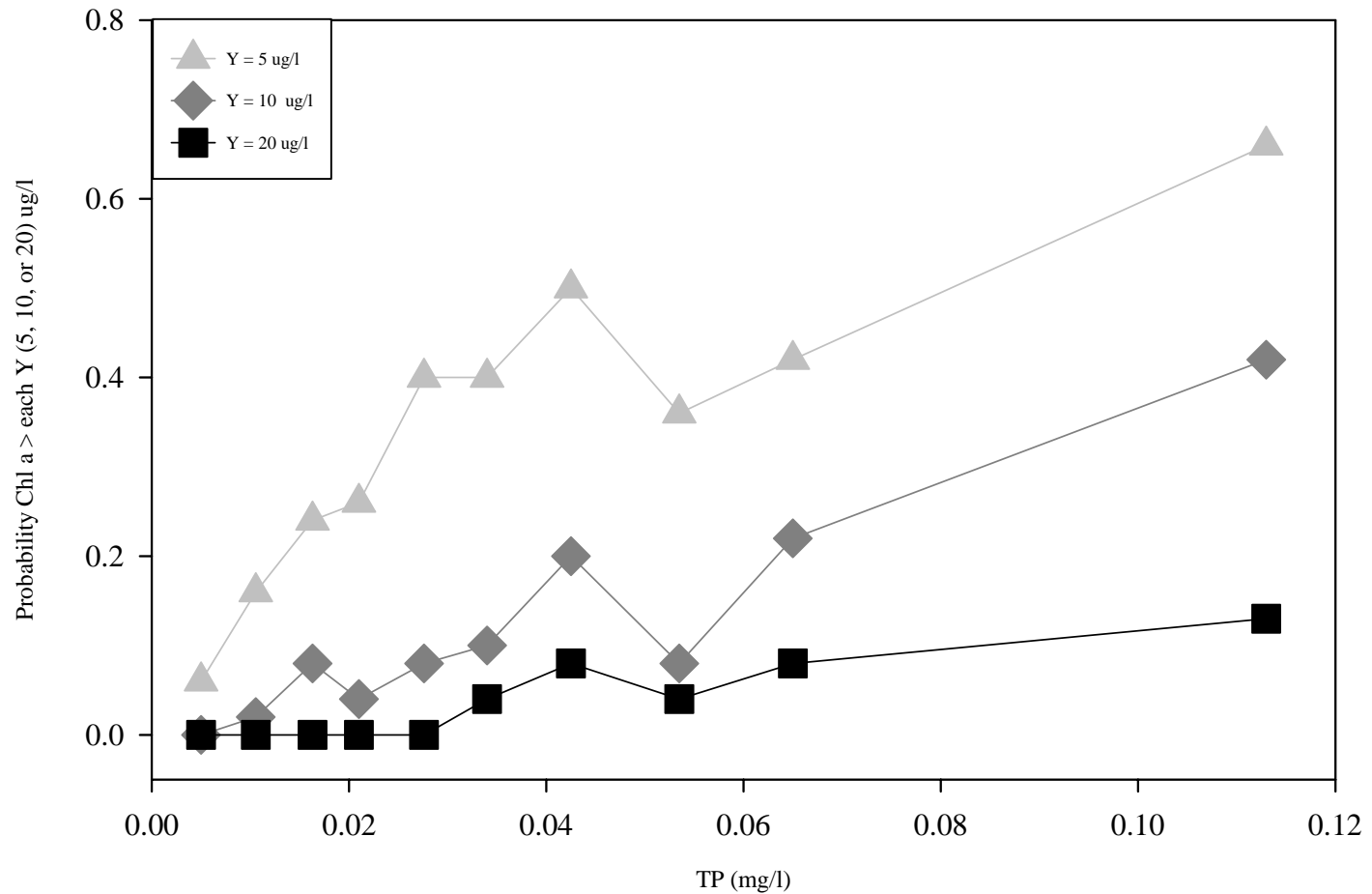
Despite all of this complexity, it is important to understand what nutrient regime is seen with the highest concentrations of chlorophyll a that may eventually lead to a waterbody being impaired under the IWR. One of the tools the FDEP numeric nutrient TAC has investigated is a probability analysis developed by Dr. Karl Havens (University of Florida). On October 29, 2003 Dr. Havens gave a presentation to the nutrient TAC to better understand the specific nutrient concentrations in lakes where chlorophyll a levels begin to reach certain thresholds ([FDEP 2003](#)). This tool is not predicting a certain chlorophyll a concentration associated with a nutrient concentration (i.e., regression analysis). Instead, this methodology focuses on the nutrient concentrations where the risk of certain chlorophyll a thresholds may be seen.

Figure 116 shows the results of this analytical tool being applied to Broward County canals for total phosphorus and chlorophyll a. The FDEP 20 ug/l IWR chlorophyll a threshold is not reached until a median TP of 0.034 mg/l (Figure 116) which coincidentally is near the overall county median TP value of 0.031 mg/l (Figure 106). The probability increased at TP median of 0.043 mg/l and then a slight leveling of probability is observed.

It is important to note only 3.8% of samples in the county exceeded the 20 ug/l chlorophyll a content (Figure 114). Thus, the overall risk for Broward County canals to exceed the IWR threshold is currently low and this reflects the influence of low nutrient levels coupled with the non nutrient variables listed above. This limits the probability tool to some extent; but the use of this tool gives good initial insight into the nutrient levels associated with high chlorophyll a content even though our predictive ability may be poor through regression analysis. Future analyses should continue to track the importance of TP content in the low 0.030 mg/l range to see if this is an important concentration for the possibility of high chlorophyll a content if other suitable conditions exist. In addition, the variability of specific basins may also be investigated as the current analysis was broad in nature (i.e., county-wide).

A final important factor of the low percentage of high chlorophyll a samples is also the possibility of nutrients not being assimilated in the freshwater canals, due in part

Figure 116. Probabilistic Approach for Chlorophyll a (Chl a) and Total Phosphorus (TP) Concentrations in Broward County Freshwater Canals. The data set was sorted by TP and a median TP was calculated for each increasing 50 observations out of all 503. Within the specific 50 observations, the occurrence of chl a values over the certain thresholds (5 micrograms per liter, ug/l; 10 ug/l, 20 ug/l) is summed and then divided by 50 to determine the probability of finding chl a values over that threshold with the specific median TP value. This method was developed by Dr. Karl Havens (University of Florida) and was presented October 29, 2003 to the Florida Department of Environmental Protection's Technical Advisory Committee on Numeric Nutrient Criteria (http://www.dep.state.fl.us/water/wqssp/nutrients/docs/TAC/tac3_karlhavens.pdf).



to high flow regimes, and primarily exported to the estuarine waterbodies of the county. This will be more fully investigated with the BCEPD's estuarine dataset analysis (in progress).

6. Fecal Coliform

Fecal coliform (FC) content was generally low in Broward County's freshwater canals from 1998 to 2003 (Figure 117). This was similar to observations in the 1990s in a previous study (BCEPD 2001). The county median was 67 colonies per 100 ml (n=493). Sites 6 (C-14 Canal), Site 27 (C-11 Eastern Canal) and Site 28 (Western C-11 Canal) had the highest medians in the county but even those values were below the 200 colonies per 100 ml criteria (monthly geometric mean with 10 samples, FAC 62-302). The monthly geometric must be computed with 10 samples within a month and the medians shown in Figure 117 are calculated from four samples a year. Overall, 77.9% of samples were below the 200 colonies per 100 ml criteria (Figure 118). Only 4.1 percent of fecal coliform samples countywide were out of compliance of county ([Broward County 1996](#)) and state ([FDEP 2006a](#)) environmental regulations for single sample standard (800 colonies per 100 milliliters, Figure 118).

The third criteria for the state of Florida DEP and Broward County is the 'ten percent rule' which means less than 10% of monthly samples can exceed 400 colonies per 100 ml criteria. Only 8.6% of samples were above this criterion (Figure 118) and typically only outliers at 90th percentile or higher were above this criterion at each sampling site (Figure 117). One of the important components of this criteria is the FDEP initially used the 'ten percent rule' in the IWR assessment (FDEP personal communication). The FDEP did not list any freshwater Broward County canals as impaired for fecal coliform ([FDEP 2007b](#)).

All parameters including fecal coliform collected by BCEPD are primarily taken under ambient conditions. The majority of samples are collected during sunny to partly cloudy days with no rainfall. However, due to sampling logistics of a long term program, some of the samples may be influenced by stormwater and could be the reason for the occasional fecal coliform spikes. The current water quality dataset has not been compared to meteorological or hydrological databases. This should be a future goal of the water quality assessments as stormwater runoff can contain high levels of fecal coliform from a number of sources in an urban environment.

Broward County residents should be aware the Florida Department of Health does not recommend swimming in the local waterways except for four parks with chlorinated beaches and the Atlantic Ocean. One of the main reasons for this is quarterly sampling does not typically capture rain events and may underestimate the actual fecal coliform content in a canal on any given day which can be quite variable. The FDOH does perform weekly sampling at Broward County's local beaches and the

Figure 117. Fecal Coliform (FC) Content in Broward County's Freshwater Canal System. Box plots represent data collected at a site (x-axis) from 1998 through 2003. Sites within specific canals are grouped together (x-axis) and are shown from left to right in the typical direction of a specific canal's managed water flow. The county median was 67 colonies per 100 milliliters (col /100 ml, dashed line, n = 493).

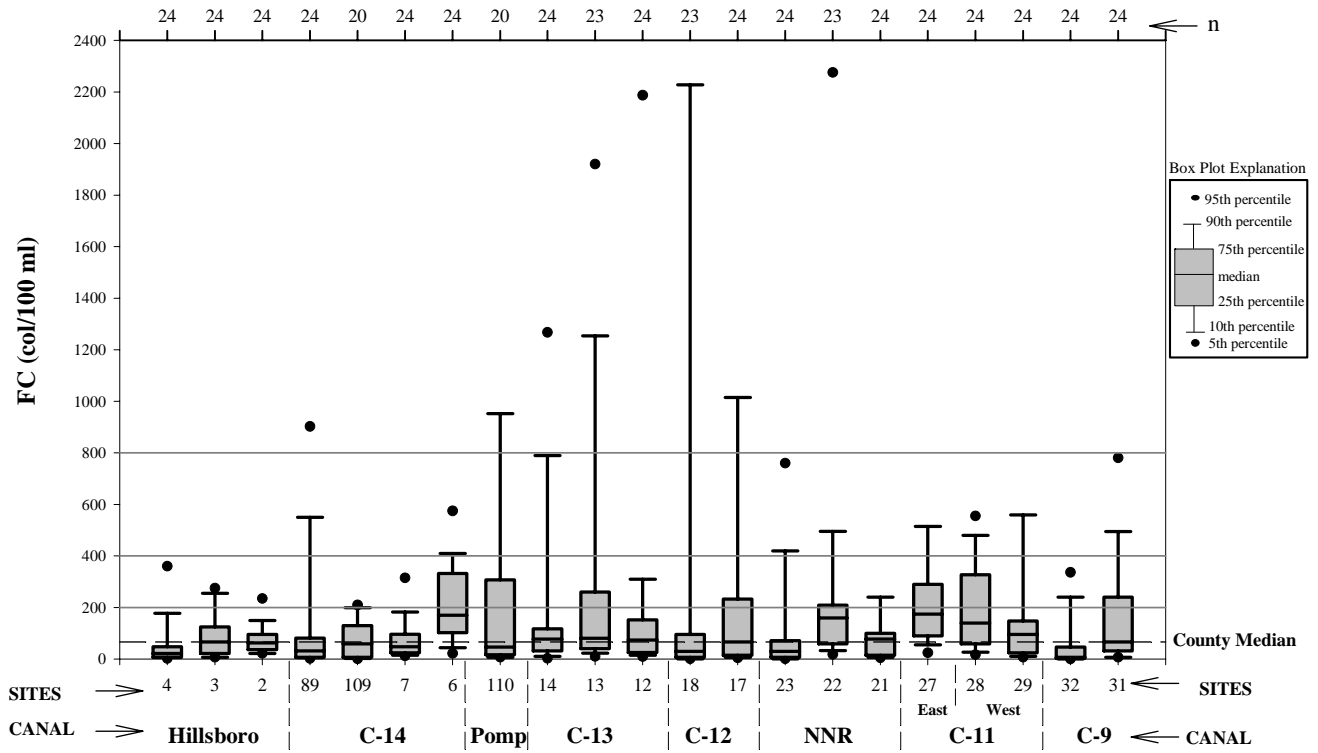
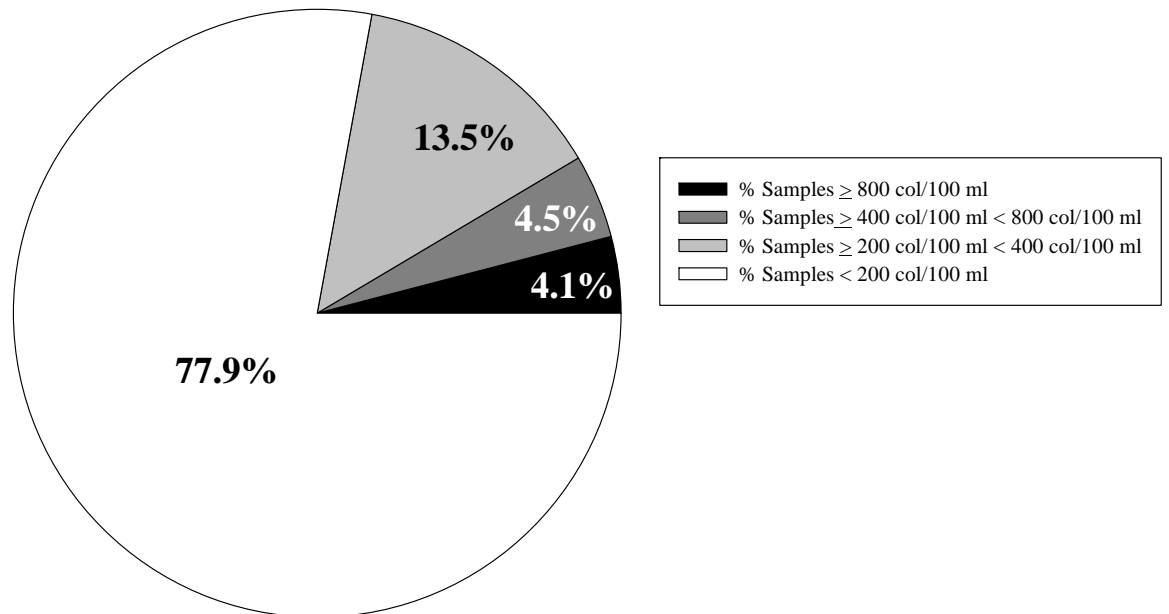


Figure 118. Percentage of Fecal Coliform (FC) Concentrations Within Compliance of Broward County and State of Florida Water Quality Standards. To be within compliance of state and county environmental regulations, levels shall not exceed a monthly average of 200 colonies per 100 milliliters (col/100 ml) nor exceed 400 (col/100 ml) in 10% of the samples, nor exceed 800 (col/100 ml) on any one day.



results from that work are available at their website ([FDOH 2007](#)). The FDOH works with local coastal cities on any possible beach closures because of high fecal coliform or another bacteriological parameter, enterococcus.

B. Future Monitoring Questions and Needs

The planning and implementation of the BCEPD Surface Water Quality Network has been a critical component in understanding the water quality of Broward County's urban eastern core since 1972. The network has evolved from primarily monitoring the impacts of human wastewater treatment plant (WWTP) discharges on surface waters to an ambient network from which data is used by federal, state, and local governments, academic institutions, private consultants, and other non-governmental entities. As the South Florida watershed has changed over the years, the data continuity of the network remains one of its largest benefits. The following present and future water quality issues that necessitate the network be continued to serve as the backbone of water quality monitoring in the county.

1. The FDEP IWR process

Over the last five years, perhaps the most critical use of the BCEPD database has been by the FDEP in the IWR process which is the state's total maximum daily load (TMDL) program ([FDEP 2007b](#)). As the FDEP or SFWMD do not regularly monitor water quality within the urban third of Broward County, the BCEPD network constituted almost the entire database from which the FDEP made their assessments.

The existence of current data was particularly important because many of Broward County's waterways had been listed by the United States Environmental Protection Agency in 1998 as part of a consent decree based upon archaic water quality data. As the FDEP used BCEPD data within the last 10 years for their planning list and 7.5 years for the verified list, the current BCEPD sampling allowed for a more accurate assessment of the primary canal's water quality. This led to a more accurate listing of impaired waters and delisted waters which are an important part of the overall TMDL process. The implementation of TMDLs can be very expensive. Thus, recent and accurate water quality data for listing assessments is very important.

The next five years will see a continued need for water quality data for the second round of FDEP assessments. Additional sampling may also be needed to augment the quarterly canal network to better understand basins which are listed for a TMDL. The BCEPD and FDEP partnered on such a project for the Pompano Canal in summer of 2006.

2. Comprehensive Everglades Restoration Plan Projects

Several Comprehensive Everglades Restoration Plan (CERP) and related projects are slated to begin construction within the next five to ten years that will directly influence water quality in the urban core (e.g., Broward County Water Preserve

Areas, [United States Army Corps of Engineers, USACOE, and South Florida Water Management District, SFWMD 2007a](#)) as well as potential indirect effects (e.g., WCA 3 Decompartmentalization ([USACOE and SFWMD 2007b](#))). These projects are both regional and local in scale and may provide water quality benefits or potentially, cause unintended local water quality challenges. The monitoring sites within the western most parts of the county will continue to be important to monitor these effects. Some canal specific sites (e.g., Sites 3 and 4, Hillsboro Canal) will be directly downstream of a CERP project (Site 1 Impoundment, [USACOE and SFWMD 2007c](#)) and will provide a focal point for specialized monitoring in the future.

3. Local Regulations, Best Management Practices, and Enforcement Actions

Through Chapter 27, the Broward County Environmental Protection Department has several regulatory programs that protect Broward County's surface water quality including through the Water Resources Division ([BCEPD 2007b](#)). The BCEPD surface water quality network helps track part of the successes of this program in two specific basins (C-13 and C-14) where the county has the most jurisdiction in a series known as the BCEPD Environmental Benchmarks Report ([BCEPD 2007c](#)). In addition, as eastern Broward County continues to redevelop the implementation of the BCEPD regulations should continue to improve surface water quality. This will likely be most evident in some smaller, older basins such as the Pompano Canal.

Other projects throughout the county are being undertaken to reduce pollutant loads to surface waters include NatureScape Broward "Between Sawgrass and Seagrass" which is "a vision for the community that starts in your own backyard. NatureScape is about creating Florida-friendly landscapes that conserve water, protect water quality, and create wildlife habitat" ([BCEPD 2007d](#)). These types of best management practices should over time also improve surface water quality and be tracked by continued ambient monitoring.

The BCEPD also has an enforcement powers under Chapter 27. The availability of a long and continuous background water quality database allows for an understanding of the severity of pollutant discharges and assists in determining potential penalties. In particular, turbidity violations during construction activities have often exceed over 100 nephelometric turbidity units (ntus) while ambient values are typically near 2 ntus. This background information has assisted the BCEPD is levying fines exceeding \$100,000 and, perhaps more importantly, has led to industry working proactively with BCEPD to reduce turbidity levels in discharges to surface waters.

4. FDEP Designated Uses and Classifications

In February 2006, the FDEP began a process to examine the designated uses and classifications of the states waterways including South Florida canals. The FDEP formed a Policy Advisory Committee (PAC) to discuss the main issues and make recommendations. From the FDEP web site ([FDEP 2007c](#))

“The current classification system has been in effect for more than 30 years. Scientific knowledge has advanced since then, better data on surface waters are available, and water quality protection programs have changed. Florida has an opportunity to improve the way we protect public health and aquatic life and habitats”

However, some concerns did arise suggesting this effort would lead to a lowering of water quality standards and the Broward County Board of County Commissioners (2006) passed a resolution in December of 2006 to ensure water quality would not be diminished in Broward County. The FDEP has since written a letter (FDEP 2007d) stating this is not the intended purpose of the PAC. However, there remains a possibility for many interested stakeholders to have different opinions on canals and their designated uses. The collection of water quality data by BCEPD can only benefit this process by providing accurate scientific information to support policy and regulatory decisions.

5. FDEP Numeric Nutrient Criteria

Another statewide process is the FDEP numeric nutrient criteria development (FDEP 2007a). Much of the freshwater county data used to date has been from BCEPD’s network. For example, Broward County freshwater canals tended to have much lower TP levels than reference streams (i.e., little human impact from development) from the northern part of the state (Broward County EPD presentation to the Numeric Nutrient TAC, August 19, 2005, FDEP 2005b). Some of the reasons for this are likely due to the geological and drainage characteristics of different watersheds but having the water quality data for the canals made a statewide comparison possible. Future numeric nutrient criteria efforts will benefit from the continued collection of nutrients and chlorophyll *a* in Broward County’s freshwater canals.

6. Alternative Water Supply

Broward County’s population in 2006 was nearly 1.8 million people, however, it is expected to grow to over 2.3 million people by 2030 (Broward County Office of Urban Planning Services Division 2007). Thus, augmentation of traditional methods of providing public water supplies (i.e., Biscayne Aquifer withdrawals) and the added volume of human wastewater are significant challenges for the South Florida watershed, including Broward County. Many alternative water supplies have been and are being investigated in particular by the SFWMD (2006).

Some of these technologies do pose potential surface water quality concerns; in particular direct discharges to canals (see FDEP 2006c). Policy and regulatory decision makers will need water quality datasets such as provided by the BCEPD surface water quality monitoring network to give good background ambient information on the primary canals. In addition, the BCEPD has also begun pilot sampling on secondary canal system to better understand the water quality of these smaller and shallower canals than the primary canal system.

7. Estuarine and Coastal Loadings

Most of the freshwater canal water quality network exists in freshwater canals that discharge into tidal estuarine reach through a SFWMD water control structure (e.g., North New River Canal). Many of these water control structures are five to seven miles west of the oceanic inlets. It is important to understand the connectivity between the freshwater and estuarine systems. A future project should consider looking at flow rates with the observed chemical concentrations for an estimate of estuarine loads. The proposed loading calculations would be coarse scale as the flow data are not measured by Acoustic Doppler Current Profiler (ADCP) but are estimates by the SFWMD due in part to the large expense of ADCP deployments.

Future monitoring should also consider tracking water masses entering the estuary from the freshwater canals to understand the fate and transport more quantitatively. As BCEPD has also initiated a Coastal Water Quality Monitoring Program sampling program, the connectivity of the 'Glades to the Sea' may also be more accurately described and determine to what extent freshwater discharges also may influence the coastal waters. This area of study is of particular importance in terms of the CERP projects mentioned above which may affect the future flows to the estuary. Although all freshwater quality sites are important, the freshwater sites immediately west of the control structures are particularly important for an understanding of estuarine and eventual coastal ocean loadings.

V. Conclusions and Recommendations

- Distinct differences in water quality were observed between and even within the same freshwater canals despite the canals having relatively similar morphology, climate, and surrounding land use (on a state-wide scale).
- Hydrologic variability and proximity to the western two thirds of the county (i.e., Water Conservation Areas) are two likely factors in the different water quality patterns. However, this relationship needs to be further quantified by looking at water quantity and quality values together in the future.
- In general, the western sampling sites (particularly the central to southern areas of the county) in a canal are more likely influenced by the Water Conservation Areas and have the highest specific conductance, highest total organic carbon, highest total nitrogen, and highest ammonia-nitrogen content. In addition, these canal areas typically had the lowest nitrite+nitrate-nitrogen, lowest total phosphorus, and lowest chlorophyll a across the county.
- The eastern sampling sites generally had the opposite characteristics of the western most areas, with exceptions for some parameters (e.g., total nitrogen in Eastern C-11 Canal). The lowest specific conductance, lowest total organic carbon, lowest total nitrogen, and lowest ammonia-nitrogen levels were generally observed in the eastern areas of canals. In addition, these canal areas tended to have the highest nitrite+nitrate-nitrogen, highest total phosphorus, highest dissolved oxygen, and highest chlorophyll a.
- The three canals (Pompano Canal, C-12 Canal, Eastern C-11) with no direct connection to the WCAs tended to have the poorest water quality in the county. The exception to this is the Hillsboro Canal that continues to have the highest nutrient content in the county as observed previously ([BCDPEP 2001](#)).
- The new monitoring site on the Pompano Canal also revealed elevated total phosphorus levels yet the canal had the lowest total nitrogen values in the county.
- Chlorophyll a values are typically low in the county and well within compliance of the state of Florida Impaired Waters Rule threshold value of 20 ug/l. The Pompano Canal is one important exception and has been determined to be impaired by the FDEP based on exceedance of the IWR chlorophyll a threshold for nutrients.
- Water flow, color, and aquatic plant management are likely major factors causing a weak relationship between nutrient levels and chlorophyll a concentrations.

- Fecal Coliform values tended to be low throughout the county and no freshwater canals have been listed as impaired for fecal coliform by the FDEP during their IWR assessments. Despite the relatively high level of fecal coliform standard compliance, swimming is still not recommended by the Broward County Health Department due, in part, to sampling intervals being on a quarterly basis and not weekly.
- In general, no strong temporal patterns were observed with most constituents. One exception was seen in the C-9 basin where dissolved oxygen content was at some of the highest ever recorded for the canal over the six year period.
- Several state, regional, and local regulatory, management, and policy initiatives are either presently occurring (e.g., IWR) or will be in the near future (e.g., CERP) that necessitate the continued implementation of the BCEPD Surface Water Quality Network.

The following are proposed to continue the development of enhanced water quality monitoring in Broward County.

- An analysis of water flow and meteorological data should be performed in the future with concurrent water quality data to better understand some of the variability observed within and between different canals.
- In addition, the BCEPD should determine if aquatic plant management activities are influencing the water quality observations by coordinating with local and regional managers on their activities.
- The probability assessment for chlorophyll a should be continued to understand at what nutrient concentrations the impaired waters rule threshold is being crossed.
- The Eastern C-11 Canal and Hillsboro Canal continue to have some of the highest nutrient content in the county. While these water bodies were not listed for impairment through the first IWR assessment, they are still possible candidates during the FDEP's second IWR assessment that is currently being performed.
- Furthermore, the potential impact of all freshwater canal discharging into the estuarine waters needs to be completed with an emphasis on the Eastern C-11 Canal and Hillsboro Canal.
- BCEPD should begin consultation with CERP water quality teams (e.g., RECOVER) to see where our current water quality sites can augment information on the progress and effects of CERP on local water quality.
- The BCEPD should consider joining the Regional Ambient Monitoring Program (RAMP) program of Southwest Florida which that was initiated by Tampa Bay Estuarine Program in 1992, but is now coordinated by the local governments that

run the monitoring programs. RAMP participants meet quarterly to collect water samples from a common container and has its own laboratory run the samples for a core group of parameters (TN, nitrite+nitrate-nitrogen, ammonia-nitrogen, TSS, TP, orthophosphate, color, turbidity, and chlorophyll a), and compare the results ([Tampa Bay Estuary Program 2006](#)). This program has led to regional data comparability and better management and protection of Southwest Florida water resources.

- The BCEPD should continue to coordinate with the Palm Beach and Miami-Dade Counties, particularly investigating how comparable our concurrent data collection sites are with each other. In addition, the TMDL process and CERP necessitate good regional coordination.
- The BCEPD should begin to post data on the Internet and investigate a USF Water Atlas approach to reporting the monitoring data ([University of South Florida 2007](#)).

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Appendix 1. Broward County Environmental Protection Department (BCEPD) Freshwater Canal Surface Water Quality Network Monitoring Site Locations.

<u>BCEPD SITE#</u>	<u>LATITUDE</u>	<u>LONGITUDE</u>	<u>DESCRIPTION</u>
2	26 19 40.8N	080 07 51.6W	HILLSBORO CANAL; WEST SIDE OF SALINITY CONTROL STRUCTURE (G56)
3	26 19 37.2N	080 12 10.8W	HILLSBORO CANAL; STATE RD. 7 (US 441) BRIDGE
4	26 21 10.8N	080 17 24.0W	HILLSBORO CANAL; BRIDGE TO SOUTHEAST GROWERS' ASSOCIATION
6	26 12 21.6N	080 07 58.8W	C-14 (CYPRESS CREEK) CANAL; DIXIE HIGHWAY BRIDGE
7	26 13 08.4N	080 10 15.6W	C-14 (CYPRESS CREEK) CANAL; SOUTH PALMAIRE DRIVE BRIDGE
8	26 13 48.0N	080 12 18.0W	C-14 CANAL; STATE RD 7 (US 441) BRIDGE
9	26 13 48.0N	080 15 10.8W	C-14 CANAL; UNIVERSITY DRIVE BRIDGE
12	26 10 22.8N	080 11 13.2W	C-13 CANAL; NORTHWEST 31ST AVE BRIDGE
13	26 10 22.8N	080 13 15.6W	C-13 CANAL; ROCK ISLAND RD BRIDGE
14	26 09 00.4N	080 15 25.2W	C-13 CANAL; UNIVERSITY DRIVE BRIDGE
17	26 08 06.0N	080 11 42.0W	C-12 (PLANTATION) CANAL; WEST SIDE OF SALINITY CONTROL STRUCTURE
18	26 08 06.0N	080 12 46.8W	C-12 (PLANTATION) CANAL; NORTHWEST 9TH DRIVE BRIDGE
21	26 05 49.2N	080 14 16.8W	NORTH NEW RIVER CANAL; WEST SIDE OF COASTAL SALINTIY CONTROL STRUCTURE (G54) ON THE NORTH SIDE, 1/4 MI WEST OF TURNPIKE

<u>BCEPD SITE#</u>	<u>LATITUDE</u>	<u>LONGITUDE</u>	<u>DESCRIPTION</u>
22	26 06 57.6N	080 19 01.2W	NORTH NEW RIVER CANAL; SW 125TH AVE BRIDGE (C15) BRIDGE
23	26 07 19.2N	080 20 34.8W	NORTH NEW RIVER CANAL; US 27 BRIDGE
27	26 03 57.6N	080 12 32.4W	C-11 (SOUTH NEW RIVER) CANAL; WEST SIDE OF COASTAL SALINTIY CONTROL STRUCTURE (S-13)
28	26 03 46.8N	080 18 50.4W	C-11 (SOUTH NEW RIVER) CANAL; FLAMINGO ROAD BRIDGE
29	26 03 39.6N	080 26 02.4W	C-11 (SOUTH NEW RIVER) CANAL; US 27 BRIDGE
31	25 57 50.4N	080 18 43.2W	C-9 (SNAKE CREEK) CANAL; FLAMINGO ROAD BRIDGE
32	25 57 25.2N	080 25 55.2W	C-9 (SNAKE CREEK) CANAL; US 27 BRIDGE
89	26 13 44.4N	080 16 55.2W	C-14 CANAL; CENTER OF CANAL W SIDE OF NOB HILL ROAD BRIDGE OVER N OF SOUTHGATE ROAD
109	26 13 19.2N	080 13 48.0W	C-14 CANAL. AT ROCK ISLAND ROAD BRIDGE
110	26 13 52.0N	080 07 38.0W	POMPANO CANAL; CULVERT WEST OF DIXIE HIGHWAY AT ATLANTIC BLVD.