SURFACE WATER QUALITY ANNUAL ASSESSMENT AND TREND REPORT FOR COLLIER COUNTY POLLUTION CONTROL DEPARTMENT

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Prepared for:

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EXECUTIVE SUMMARY

Over the last twenty years, Collier County has been one of the fastest growing areas in southwest Florida. Since 1980, the county-wide population has more than tripled in size and is currently an estimated 318,537 persons. Most of the growth has been confined to the western-central portion of the County in the city of Naples and surrounding towns - the largest urban center in the watershed. Marco Island, along the coast and just south of Naples is also heavily populated and smaller towns include Golden Gate, Immokalee Everglades City and Chokoloskee. While many of the natural and agricultural lands have been developed and urbanized, much of the central and eastern portions of the County (approximately 64%) are held in conservation by national preserves and state parks. Agricultural land uses are a predominant feature in north-central Collier County with citrus, tomatoes, and beef cattle among the majority.

Collier County's Pollution Control Department has monitored the water quality of surface waters throughout the county since 1988 under the requirements of the Collier County Growth Management Plan's Coastal Zone and Management Element (CZME) - Objective 2.2. Historical monitoring efforts utilized a seasonal "rotating basin" approach in which water quality stations were sampled four times during a year and repeated every five years. In 1998, the County began South Florida Water Management District-funded monthly sampling of 43 stations located throughout the watershed. This current sampling program monitors 21 water quality parameters including the standard measurements of temperature, salinity, pH, specific conductance and dissolved oxygen, as well as measurements associated with nutrients, water clarity and color. Quarterly monitoring of water hardness, alkalinity, heavy metals and several other elements is also conducted. In addition, flow velocities are measured for six of the largest basins where surface waters discharge to coastal water bodies. Flows and nutrient concentrations are used to determine nutrient loadings to coastal bay segments, including the Cocohatchee River Estuary, Naples Bay, Rookery Bay and Ten Thousand Islands.

The purpose of this report is to summarize background water quality conditions at the beginning of the monitoring effort in 1988; to compare these conditions to recent trends over the last eleven years to determine how these conditions have changed over time; and to relate significant changes in water quality to changes in land use throughout the watershed.

Eighteen of the thirty Collier County basins were included in a trend analysis to identify statistically significant trends in water quality conditions. In general, statistically significant trends for salinity were observed for most of the basins, all increasing during the period of analysis and likely caused by the dry years from 2007-2009. Among these were urban basins on the western side of the county, Naples Bay and Cocohatchee River, which also exhibited steep increasing trends in conductivity. These were the only steep increasing trends in any of the water quality parameters from 1999-2009. Increasing trends in pH were also observed for many of the basins in western Collier County including Cocohatchee Inland, Naples Bay, Rookery Bay Inland (East and West) and Faka Union (North and South) and as with increasing trends in salinity and conductivity may be attributed to low rainfall in recent years. The only decreasing trend in pH was for Gordon River Extension.

Dissolved oxygen was observed to decrease over time for the Ten Thousand Islands basin and Barron River Canal (which lies upstream) and for the Naples Bay Coastal basin. Biochemical oxygen demand increased for the Tamiami Canal basin. No improvements in dissolved oxygen or biochemical oxygen demand were observed from 1999-2009.

An increasing trend in total nitrogen and total phosphorus was observed in the central and eastern portions of Collier County in the Okoloacoochee Slough basin, Fakahatchee Strand, Camp Keais, Faka Union South and Ten Thousand Islands basins and corresponded with a similar increase in organic nitrogen, in the form of total Kjeldahl nitrogen, in these basins. In contrast, organic nitrogen exhibited shallow decreasing trends in some of the western basins including Rookery Bay Inland West, Cocohatchee Inland and Cocohatchee River. These decreases in organic nitrogen seemed to translate to a decrease in total nitrogen for the same basins though this trend was not statistically significant. Total phosphorus also increased in Naples Bay and Rookery Bay Inland East basins. The only significant trend in chlorophyll was a decrease for Faka Union North which was accompanied by a decreasing trend in inorganic nitrogen in this basin.

Turbidity decreased for several basin along the west-central coast of Collier County including, Faka Union North, Rookery Bay Inland West basin, Naples Bay basin and Cocohatchee River. Increased turbidity was observed for Okaloacoochee Slough, Fakahatchee Strand, Camp Keais, Rookery Bay Inland East and the Gordon River Extension.

Heavy metal concentrations were relatively stable throughout Collier County though there were several shallow trends that were significant. Decreases in copper concentrations were observed for Cocohatchee Inland, Faka Union (North and South), North Golden Gate and Tamiami Canal and decreases in arsenic were observed for Immokalee and Tamiami Canal. Arsenic increased in the Cocohatchee River and Fakahatchee Strand basins. No significant trends for iron were observed.

Climatological effects on water quality related to high rainfall were detectable as increased flows or as reduced concentrations of some constituents, such as chlorophyll, salinity and total nitrogen. Even low rainfall amounts had a similar effect, though the magnitude of the effect was less with lower rainfall. Seasonally, many water quality constituents increased in concentration through the dry season and were diluted at the start of the wet season. Annual trends in rainfall were related to many of the observed statistically significant trends in water quality, specifically increases in salinity and conductivity, which were likely driven by low rainfall amounts from 2007 to 2009.

Remarkably distinct land use patterns are apparent in Collier County and may be associated with some of the observed differences in water quality conditions among basins. The majority of urban land uses and coastal development occurred in the western part of the county, while the north-central portion of Collier County is dominated by agricultural land uses. Central and eastern Collier County remains largely undeveloped, consisting of vast areas of wetlands and uplands. Using principal components analysis, we identified three axes that cumulatively explained 75.3% of the variation in land use for Collier County basins. The first axis explained 31% of the variation and separated basins along a gradient of Wetlands Hardwood Forests, which were predominantly coastal mangroves. The second axis explained an additional 26.1% of the variation and further separated basins dominated by cypress wetlands (Wetlands Coniferous Forest) from basins developed for urban land use (Residential Medium Density). The third axis was characterized as a gradient of agricultural land use with basins containing cropland and pastureland and tree crops separated from basins with minimal or no agricultural land uses.

When the same analysis was performed to classify basins as a function of water quality condition, a very similar pattern emerged. Based on this analysis, 69.3% of the variation in water quality among basins was explained by the first three principal components. The majority of the variation (39.5%) was explained by the grouping of inland agricultural basins (Silver Strand, Immokalee, Okaloacoochee Slough, Camp Keais, Cow Slough, Barron River Canal and Corkscrew Marsh) which were identified as being distinct from the more coastal urban and natural basins based on lower pH, darker color, lower dissolved oxygen, higher total nitrogen concentrations and warmer water temperatures. Water quality for many of the coastal basins including, Naples Bay, Cocohatchee River, Ten Thousand Islands and Rookery Bay Inland East were very similar to one another. These basins were distinguished by higher salinities and total suspended solids than North Golden Gate, Cocohatchee Inland, Rookery Bay Inland West, Faka Union and Tamiami Canal. This separation explained an additional 16.7% of the variation among basins. The third axis explained 13.1% of the variation and was defined as a gradient of nutrients and dissolved oxygen along which most of the basins were separated from Silver Strand, Cow Slough and Immokalee which had higher nutrients and higher dissolved oxygen levels than the rest of the basins.

Among the factors influencing water quality in Collier County, measurable relationships exist for both land use and rainfall. One of the most obvious relationships between water quality conditions and land use was associated with agricultural lands in the northern portion of the county which, in general, had higher total nitrogen concentrations and a greater percentage of chlorophyll and dissolved oxygen exceedances than most basins. Water quality conditions in several of the basins characterized by natural land uses appeared to be linked to degraded conditions in some of these upstream agricultural basins. In contrast, urban basins such as Naples Bay Coastal, Gordon River Extension, and Cocohatchee River and Inland had more heavy metal and fecal coliform exceedances, higher turbidity and greater flows, likely a result of greater runoff from impervious surfaces. While urban, agricultural and undeveloped lands have characteristic differences in water quality, the association between changing land use and water quality is often difficult to detect, particularly since the implementation of stormwater management practices in the 1980s that has resulted in reductions in nutrients and suspended solids before runoff reaches, and can degrade, surface waters. The greatest land use change between 1999 and 2005 (8-11%) occurred in several of the urban basins in the western part of the County. Some of the smaller urban basins experienced as much as 30-45% change from natural to urban lands, but lacked data with which to assess associated changes in water quality. Few water quality trends were consistently associated among urbanizing basins, though increasing salinity and pH, and improving nitrogen concentrations were observed for Cocohatchee Inland and Rookery Bay Inland West; both of these basins had only 25% urban lands in 1988 and were urbanized rapidly through 2005 when >50% of both basins consisted of urban lands. Much of the land use change since 1988 has occurred in the urban basins of western Collier County, though many were already >70% urbanized by 1988 and those less urban basins had already exceeded the level of urbanization (20-30%) thought to result in the most apparent changes to water quality.

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1.0 PROJECT BACKGROUND

Collier County's Pollution Control Department (PCD) has monitored water quality in Collier County's surface waters since 1988 under the requirements of the Collier County Growth Management Plan's Coastal Zone and Management Element (CZME) - Objective 2.2. The purpose of report is: 1) to establish the background water quality conditions of the watersheds; 2) to determine how these conditions have changed over time; and 3) to relate changes in water quality to changes in land use.

Collier County encompasses approximately 2,305 square miles and 30 drainage basins (Figure 1.0-1). Over the last twenty years, Collier County has been one of the fastest growing areas in southwest Florida. Since 1980, the county-wide population has more than tripled in size from 85,971 to an estimated 318,537 persons in 2009, a 73% increase. Most of this growth has been confined to the western-central portion of the County. The City of Naples and surrounding towns comprise the largest urban center in the watershed though Marco Island, along the coast and just south of Naples is also heavily populated. Smaller towns include Golden Gate and Immokalee in the central part of the county, and Everglades City and Chokoloskee along the southern coast. While many of the natural and agricultural lands have been developed and urbanized, much of the central and eastern portions of the County are still held in conservation (approximately 64%) by national preserves and state parks, including Big Cypress National Preserve, Florida Panther National Wildlife Refuge, Fakahatchee Strand Preserve State Park, Picayune Strand State Forest, Collier-Seminole State Park, Rookery Bay National Estuarine Research Reserve and a portion of Everglades National Park. Agricultural land uses are a predominant feature in northern Collier County with citrus, tomatoes, and beef cattle among the majority in terms of acreage. These differences in land use affect water quality as a result of differences in run-off characteristics and chemical constituents (e.g., fertilizers, pesticides) associated with the various land use classes.

The majority of Collier County (95%) is drained by only half of the basins. The Tamiami Canal basin is, by far, the largest of the drainage basins composing 31% of the watershed within the county. Five other basins, L-28 Tieback, Fakahatchee Strand, Ten Thousand Islands, North Golden Gate and Okaloacoochee Slough, are each between 5-10% of the watershed. Ten basins drain less of the county (1-5% each) and include, Faka Union North and South, Camp Keais, Silver Strand, Corkscrew Marsh, Barron River Canal, Cocohatchee Inland, and the three Rookery Bay basins.

Water is crucial to the south Florida ecosystem and to the residents of Collier County, both in quantity and quality. In the presence of high growth rates, South Florida is challenged with managing flood control; water supply; and timing and quality of freshwater flows that will protect the aquatic ecosystem. Collier County has approximately 245 miles of canals that eventually drain into the coastal estuaries. The County's Growth Management Plan (GMP) recognizes the need to ensure the quality of water flowing into these estuaries and requires that *"All canals, rivers, and flow ways discharging into estuaries shall meet all applicable Federal, State, or local water quality standards"*.

To meet the requirements of the County's GMP, the Pollution Control Department took over the surface water quality monitoring network from the South Florida Water Management District's (SFWMD's) Big Cypress Basin Office in 1988. The network encompassed only 14 stations countywide that were sampled monthly in both fresh and estuarine waterbodies. The program was intended to provide baseline conditions for long-term monitoring and to establish existing water quality conditions.

During the 1990's the program was re-designed to concentrate sampling efforts into a specific basin each year and cover both the inland and estuarine portions of that basin. These monitoring efforts would then rotate annually to other basins in the following years. This basin rotation would be concluded in 5 years at which point the cycle would begin again. The monitoring frequency occurred on a "seasonal" basis when the most notable changes in water quality occurred—April (late dry season), June (dry-wet transition), August (wet season), and December (wet-dry transition).

In 1996, the estuarine portion of the monitoring program was discontinued due to lack of funding, but the inland portion remained on the five-year rotation schedule and "sentinel" stations were established in those basins that were not currently in the annual rotation.

In 1998, the SFWMD wanted to partner with local governments to execute a routine regional monitoring effort. With funding assistance from SFWMD, the surface water monitoring program expanded to forty-three (43) sites that were spaced county-wide and sampled monthly. Stations have been modified and added to this monitoring effort since 1998, but otherwise the program has remained essentially the same.

This purpose of this report is to summarize background water quality conditions at the beginning of the monitoring effort in 1988 and to compare these conditions to recent trends over the last eleven years. Relationships between water quality trends and changes in land use over time are presented to provide information that may be used for resource management.

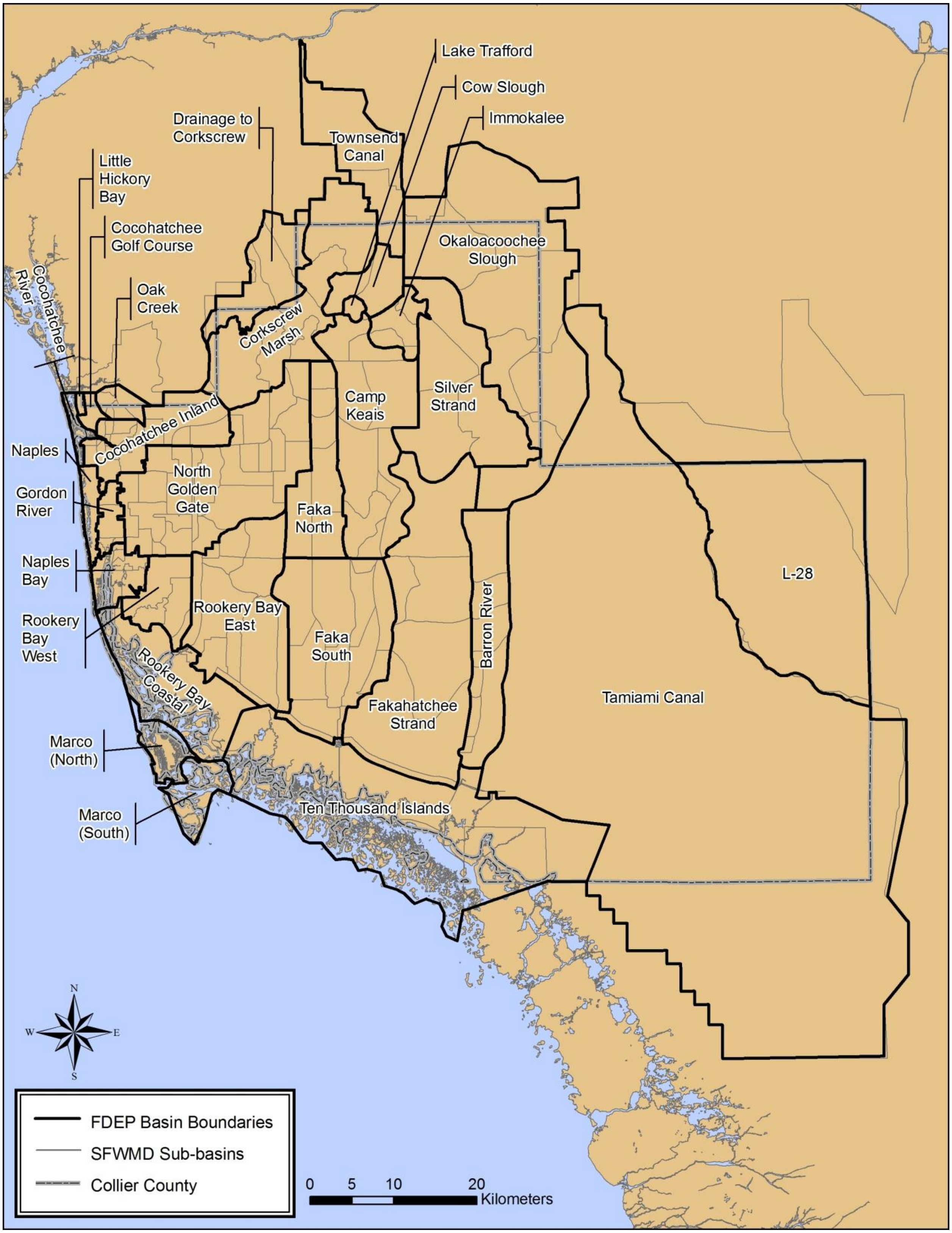

Figure 1.0-1 - Map of Florida Department of Environmental Protection (FEDP) drainage basins (WBIDs) located in Collier County.

2.0 METHODS

This section outlines the field and laboratory methods used to collect and analyze the data for rainfall, surface water flows and surface water quality. A description of sampling stations is also provided.

2.0.1 Water quality sampling

All field sampling activities during the period of record were conducted under the guidance of either a Florida Department of Environmental Protection approved Comprehensive Quality Assurance Manual or, more recently, a Field Quality Sampling Manual as specified in Florida Administrative Code Chapter 62-160 DEP-SOP-001/01.

Physical measurements of pH, dissolved oxygen, salinity, specific conductance, and temperature were obtained in-situ at one foot below the water surface. If bottom readings were recorded, these were recorded at one foot above bottom. For the current monitoring program (1998-present), bottom readings are only collected when total water depth exceeded one meter. Samples collected in tidal areas were done so on an outgoing tide. For more detailed field sampling protocols, refer to the Field Quality Sampling Manual (available from Collier County Pollution Control Department).

All laboratory analyses were performed by either Florida Department of Health certified laboratories or, more recently, laboratories having certifications through the National Environmental Laboratory Accreditation Conference (NELAC). The analytes typically measured are provided in Tables 2-1 and 2-2.

During the period of record from 1988-2009, there have been 176 water quality stations located throughout Collier County's 30 drainage basins (Figure 2.0-1). A table summarizing the number of samples collected by station and year is included in Appendix 2-1. The majority of stations had fewer than 30 samples collected and many of those were only sampled during one year. Forty-eight (48) stations sampled monthly since 1998 are used for the majority of the water quality analysis presented in this report (Table 2-3, Figure 2.0-1). Six additional stations with <30 samples were included for trend analyses which were conducted at the basin level for basins with ≥ 60 samples and at least 5 years of continuous monthly samples.

2.0.2 Statistical packages

Data summarization, statistical analyses and production of most tables, time series plots and boxplots was accomplished using the SAS v. 9.1 statistical software. Principal components analysis and similarity analysis of water quality and land use data were conducted using PRIMER v. 6.1.5. ArcGIS v. 9.3 was used for geospatial analysis of land use and creation of maps.

Table 2-1. Parameters analyzed from 1988-1998 on a "seasonal" basis.			
Historical "Rotating Basin" Sampling - Seasonal			
Dissolved oxygen	Fecal Coliform	Specific conductance	Total Kjeldahl Nitrogen
pH	Nitrate	Temperature	Total Phosphorus
Salinity	Nitrite	Ammonia	Total Suspended Solids
Secchi disk depth	Ortho-Phosphorus	Chlorophyll a, corrected	Turbidity

Table 2-2. Parameters analyzed monthly and quarterly from 1998 - present.			
Recent Sampling - Monthly			
Dissolved oxygen	Nitrite	Ammonia	Total Organic Carbon
pH	Ortho-Phosphorus	Chlorophyll a, corrected	Phaeophytin
Salinity	Total Phosphorus	Color	Total Suspended Solids
Secchi disk depth	Total Coliform	Fecal Coliform	Turbidity
Specific conductance	Total Dissolved Solids	Nitrate	Total Kjeldahl Nitrogen
Temperature			
Recent Sampling - Quarterly			
Alkalinity	Arsenic	Fluoride	Iron
Hardness	Cadmium	Magnesium	Lead
Calcium	Chromium	Silica, Dissolved	Zinc
Chloride	Copper	Sulfate	

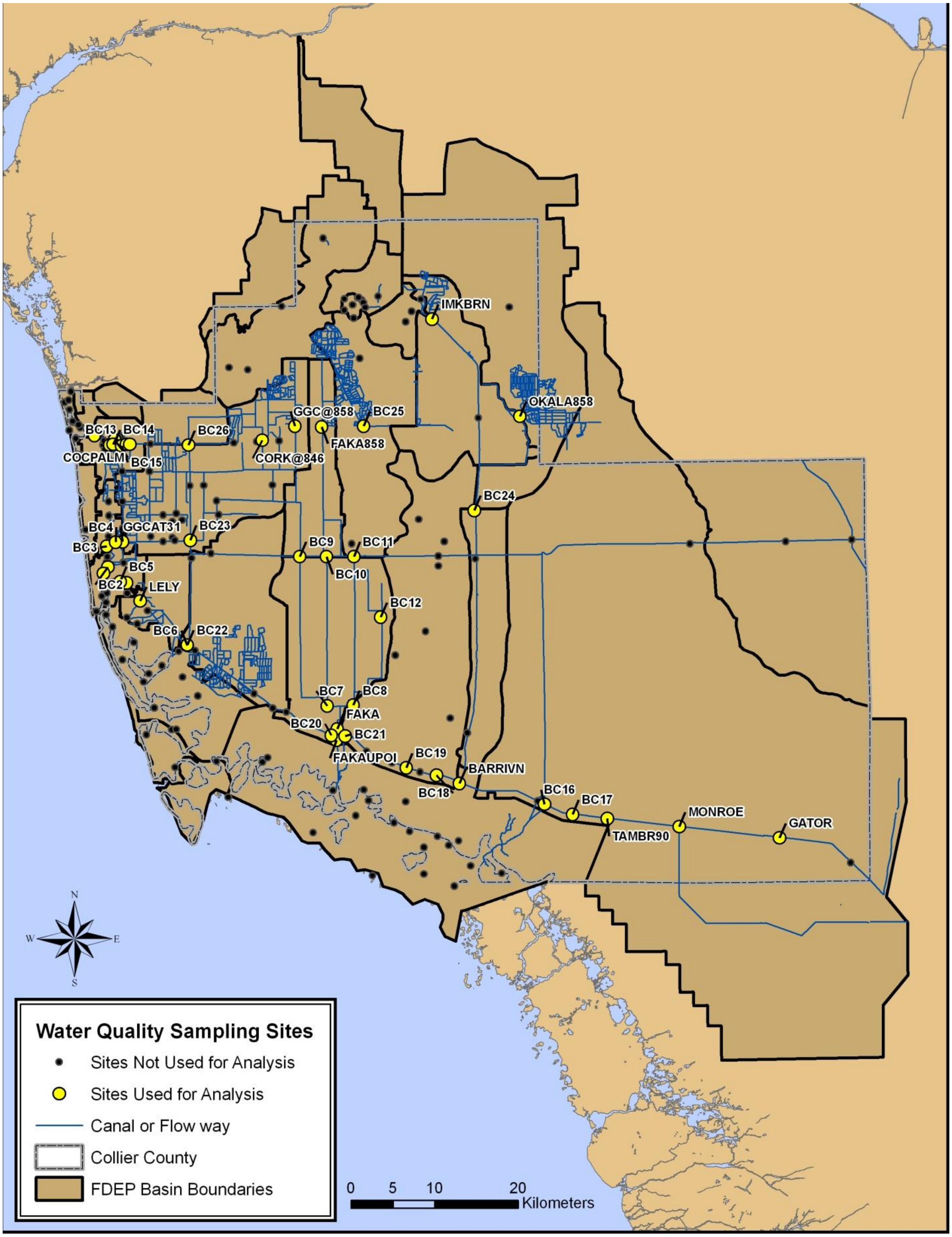

Figure 2.0-1 - Location of water-quality monitoring stations.

Table 2-3. Summary of water quality locations in Collier County (1999-2009). Stations with a consistent period of record greater than 5 years following the initiation of monthly sampling in 1999 were used for most of the analyses. Six additional station with $n < 30$ were included for trend analysis which was conducted at the basin level for basins with $\geq$ 60 samples and 5 continuous years of monthly samples.

BASIN Water quality station	Number of sample dates
BARRON RIVER CANAL	**102**
BC24*	102
CAMP KEAIS	**220**
BC11	109
BC25	111
COCOHATCHEE (INLAND SEGMENT)	**565**
BC14*	135
BC15	130
COCPALM	150
ECOCORIV	150
COCOHATCHEE RIVER	**266**
BC13	130
COCAT41	136
CORKSCREW MARSH	**146**
CORKN	36
CORKS	34
CORKSCRD	44
CORKSW	32
COW SLOUGH	**51**
IMKFSHCK	51
FAKA UNION (NORTH SEGMENT)	**338**
BC10	114
BC9	114
FAKA858	110
FAKA UNION (SOUTH SEGMENT)	**532**
BC12	69
BC20	108
BC7	108
BC8	108
FAKA*	139
FAKAHATCHEE STRAND	**356**
BC18	109
BC19	112
BC21	108
CHKMATE	27
GORDON RIVER EXTENSION	**140**
BC3	137
BC28	3
IMMOKALEE BASIN	**99**
IMK6STS	26
IMKMAD	35
IMKSLGH	38
NAPLES BAY (COASTAL SEGMENT)	**687**
BC1	130
BC2	137
BC4	129
BC5	131
HALDCRK	156
NB2	2
NB4	2
NORTH GOLDEN GATE	**557**
BC23	132
BC26	111
BC29	3
CORK@846	139
D2886	3
GGCAT31*	169
OKALOACOOCHEE SLOUGH	**109**
OKALA858	109
ROOKERY BAY (INLAND EAST SEGMENT)	**247**
BC22*	117
BC6	130
ROOKERY BAY (INLAND WEST SEGMENT)	**151**
LELY	151
SILVER STRAND	**65**
IMKBRN	65
TAMIAMI CANAL	**498**
BC16	113
BC17	106
GATOR	107
MONROE	105
TAMBR90	67
TEN THOUSAND ISLANDS	**226**
BARRIVN	109
FAKAUPOI	117

*Indicates water quality stations in closest proximity to flow gauges.

2.1 Climatological and Hydrological Methods

2.1.1 Rainfall

Rainfall data were retrieved from the hydrological database (DBHYDRO) for SFWMD rain gauges within Collier County during the period of record from 1989-2009 (Figure 2.1-1). Average monthly rainfall was then calculated for each basin using the inverse-distance squared method and the distances between the basin centroid and rain gauges within a 50-km radius. In most cases, at least 10-15 gauges were used to estimate rainfall for each basin. The distribution of rainfall data for each basin was plotted monthly to determine the distribution of rainfall amounts within each month of the year. Based on the observed monthly trends, we determined the temporal extent of the wet season for use in later analyses. A rainfall time-series was also plotted by basin for the period of record to examine long-term trends in rainfall within each basin across Collier County and to identify wet and dry years. Finally, monthly, annual and seasonal rainfall averages were summarized by basin in tabular form. These tables and figures are presented in Appendix 3-1.

2.1.2 Rainfall effects on hydrologic flows

The location of each flow gauge and the corresponding gauged basins draining to the Cocohatchee River Estuary, Naples Bay, Rookery Bay and the Ten Thousand Islands are shown in Figure 2.1-2. Flow data for each of these gauge stations are presented in two ways: 1) Hydrologic flows were summarized in tabular form for the period of record from 1989-2009 for each station. 2) Time-series plots were created to display flow patterns over time for each station to allow comparison of rainfall and flow and to identify periods of high and low flows that could be related to variations in rainfall among basins. Some stations had multiple gauges on various water control structures, in which case, mean daily flows were summed by location to obtain the total mean daily flow. Summary tables and time-series plots are included in Appendix 3-1.

2.1.3 Hydrologic flows and nutrient loading estimates

Flows were measured at six locations throughout Collier County by gauges located near the basin outfall to coastal waters. Five of the six gauges were located on water control structures which prevented interference from tidal flows at these locations. Using paired flows and water quality data, nutrient loading estimates were made for the Cocohatchee River Estuary, Naples Bay, Rookery Bay and Ten Thousand Islands (Figure 2.1-3). Flow data from the Tamiami Canal basin was not included due to the presence of tidal influence at this location; therefore nutrient loading estimates for the Ten Thousand Islands do not include flows from this basin. However, flows from this basin are presented in the Results.

Mean daily flows (in ft^3/sec) were summed for all gauges in each basin and multiplied by the number of days in the month to calculate hydrologic loads from each of the gauged basins. Months where flows averaged a negative value were set to zero as a negative flow does not contribute a load to the downstream waterbody. Nutrient concentrations from instantaneous water quality samples were then used to estimate monthly loads for total nitrogen and total phosphorus based on hydrologic loads. When flows or nutrient concentrations were unavailable, the monthly mean for all years was used to estimate the average value for the missing month.

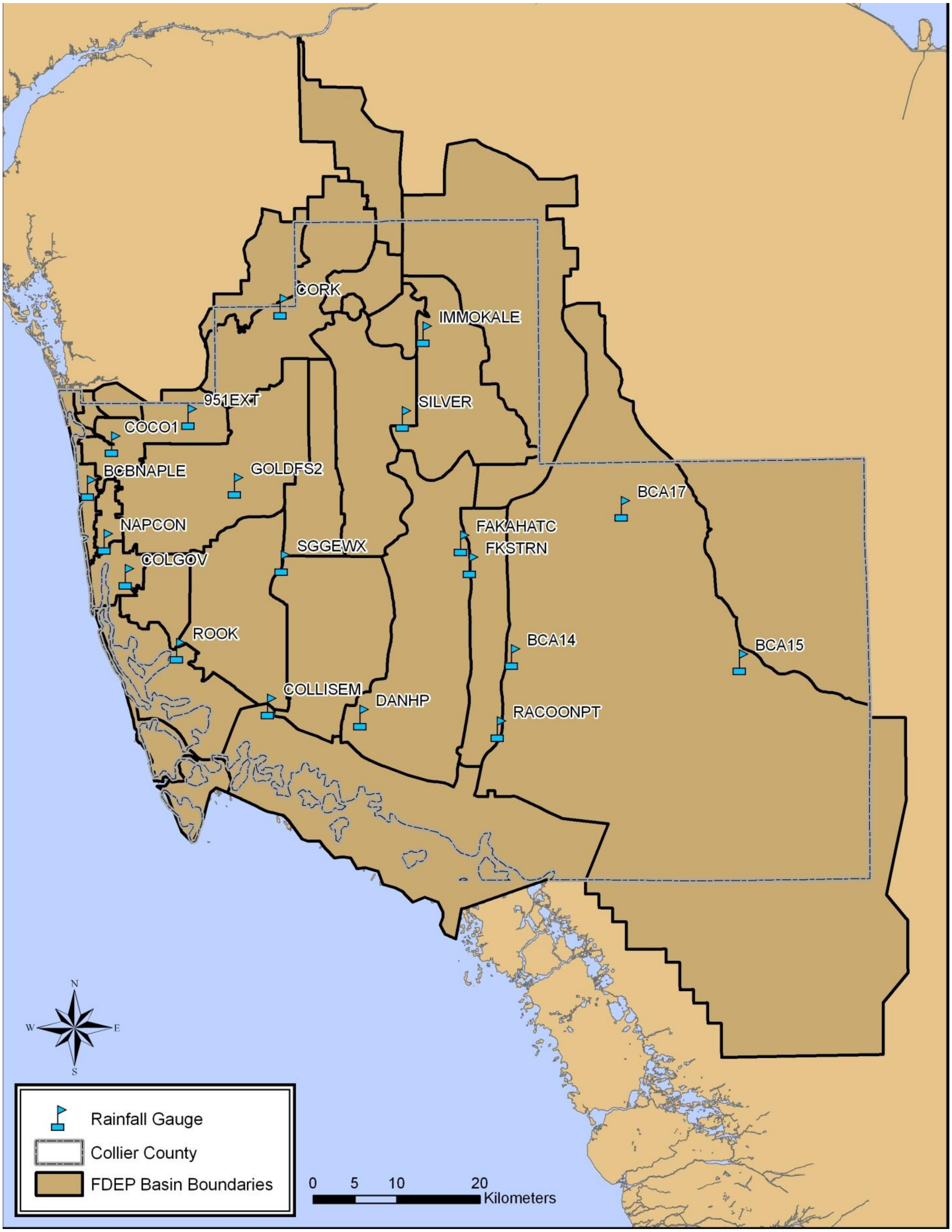

Figure 2.1-1 - Location of South Florida Water Management District rain gauges used to estimate monthly rainfall for Collier County basins.

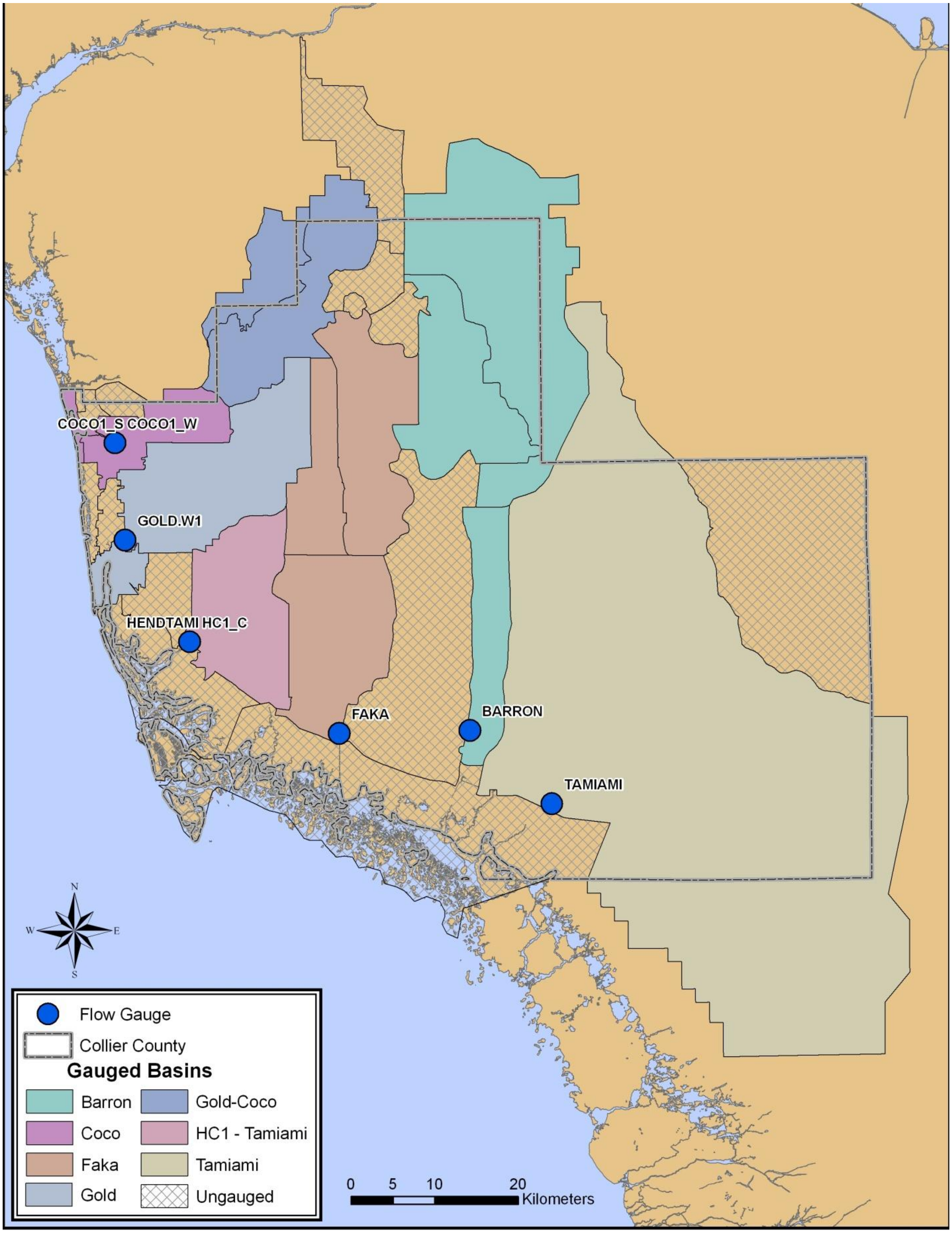

Figure 2.1-2 - Location of flow gauges. Gauged basins are indicated by color and identified by gauge name. The Corkscrew basins identified as "Gold-Coco" drain to both the "Gold" and "Coco" gauges. Cross-hatched basins are ungauged.

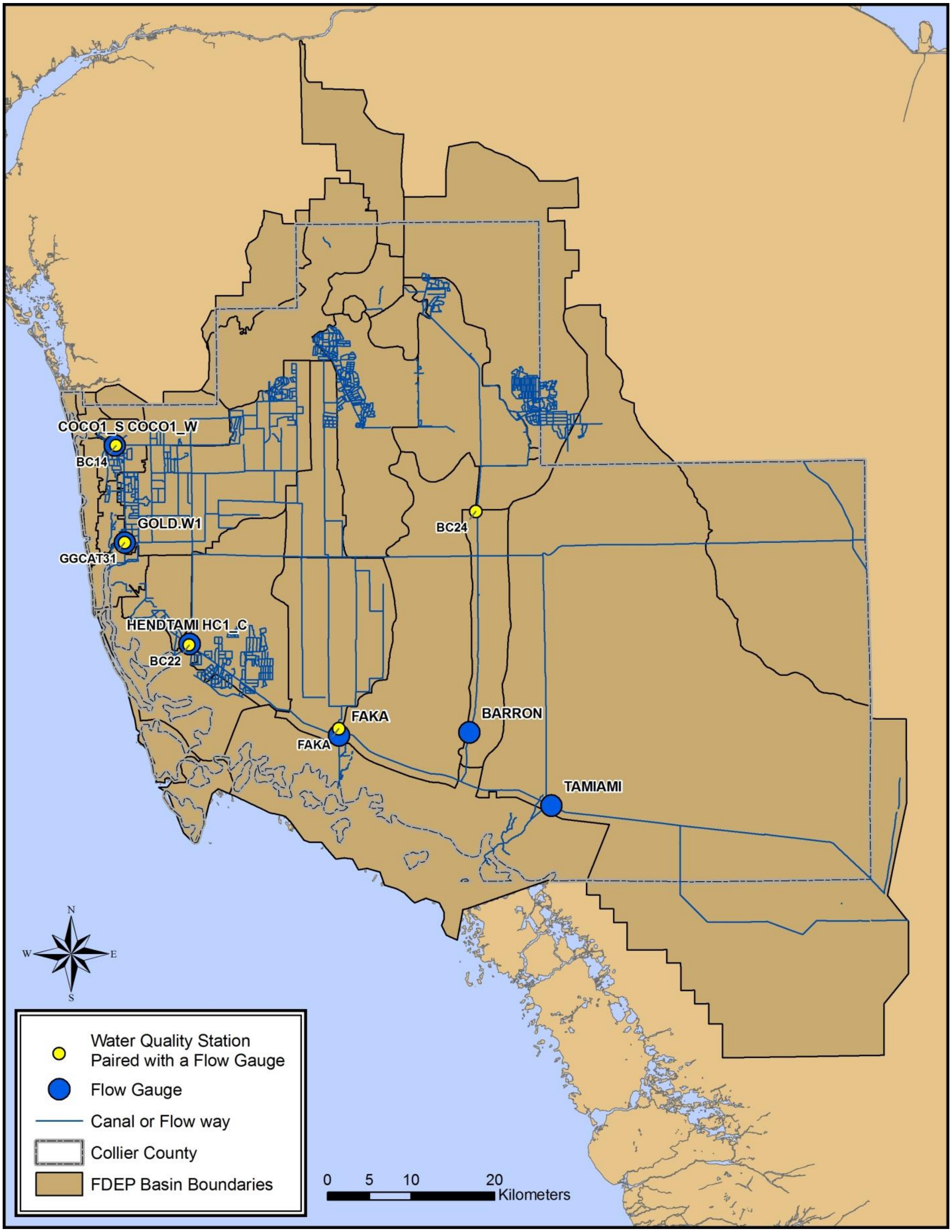

Figure 2.1-3 - Location of paired flow gauge/water quality stations used to estimate nutrient and hydrologic loads. Gauges are located on water-control structures except for the TAMIAMI gauge which was excluded due to interference from the tidal signal.

Table 2-4. Location of flow gauges and corresponding basins gauged within Collier County.

Flow gauge	Gauge abbreviation	Basins gauged	Basin size (km^2)	Period of record
Cocohatchee River (South and West)	COCO	Cocohatchee Inland, Cocohatchee River, Corkscrew Marsh (partial), Drain to Corkscrew (partial)	267 (117)*	1994-2009
Golden Gate	GOLD	North Golden Gate, Naples Bay Coastal, Corkscrew Marsh (partial), Drain to Corkscrew (partial)	483 (332)*	1990-2002
Henderson (Coastal and West) and Henderson-Tamiami Canal	HC	Rookery Bay Inland East	219	2001-2009
Faka Union	FAKA	Faka Union North, Faka Union South, Camp Keais	577	1985-2009
Barron River	BARRON	Barron River Canal, Silver Strand, Okaloacoochee Slough	863	1989-2009
Tamiami Canal	TAMIAMI	Tamiami Canal	2,083	1960-2009

*Basin size gauged by the COCO and GOLD stations includes 301 km^2 from Corkscrew Marsh and Drain basins. This area was divided in half and added to the basin size for both gauges.

2.2 Surface Water Quality Summary

Fifteen water-quality parameters were collected frequently and consistently enough during the period of record to provide an accurate representation of water quality conditions in the major basins. These parameters included the standard physical measurements of water temperature, pH, conductivity, salinity, and dissolved oxygen, nutrients, specifically total Kjeldahl nitrogen (organic), nitrite/nitrate (inorganic), total nitrogen and total phosphorus, measurements of clarity including total suspended solids, turbidity, color and secchi depth, and indicators of primary productivity and system metabolism, specifically biochemical oxygen demand (BOD) and water-column chlorophyll-a. In addition, several heavy metals, including arsenic, copper and iron, were summarized due to high levels in surface waters.

For the characterization of water quality conditions in each basin, all water quality samples (1989-2010) were used to examine monthly and annual patterns. Similarity and contrast in water quality conditions among basins were evaluated using cluster analysis of annual averages from 2001-2009 for parameters measured in all basins. Data were subset for this particular time period to allow for a complete set of samples for all basins (i.e., some basins lacked data for particular variables prior to 2001). The same dataset was used in a principal components analysis to determine which water quality parameters best described variation in water quality conditions among basins.

2.2.1 Comparison of surface water quality for historical vs. recent monitoring periods

The analysis of surface water quality trends was conducted for the period of time between 1999-2009 coinciding with the monthly sampling program. From the initiation of monthly sampling in 1999, sufficient sample size existed for long enough duration to allow for trend analysis. Prior to 1999, sample effort spatially and temporally was limited and annual sample sizes were considerably smaller for each basin.

Informal description of trends for the 1989-2008 time period was accomplished by examining the distribution of values for each water quality parameter for two time periods during historical "rotating basin" sampling, 1989-1992 and 1995-1998, for the basins with sufficient sample size during those periods. To relate trends in water quality from the historical period (1989-1998) with those from the current period (1999-2009), historical water quality was compared to current water quality from 2001-2004 and 2006-2009.

2.2.2 Multivariate analysis of surface water quality data

Spatial trends in water quality were examined by performing several multivariate analyses consisting first of a cluster analysis to identify groups of similar basins based on their annual average water quality conditions. Principal components analysis (PCA) was then used to determine the water quality parameters that best characterized each group of basins. Principal components analysis defines the first PC axis as the combination of water quality parameters that provides the greatest separation of points on the plot and thus explains the greatest amount of variation in the dataset. Subsequent axes are similarly determined with less variation explained for each additional axis. The relative position of each basin on the plot is an indication of their similarity in terms of water quality. Closely positioned basins are more similar than more distant basins. Additional information can be gained by examining the location of basins on the plot relative to PC axes and comparing those locations to the water quality parameters that define the axis. Water quality variables with coefficients >0.35 were considered to be explanatory.

2.3 Trend Analysis for Surface Water Quality

Temporal trends in water quality were assessed using time-series analyses to examine short-term (monthly and annual) and long-term (period of record) trends in water quality conditions at the basin level. The surface-water quality parameters summarized above in Section 2.2 were used for the period of time that spanned 1989-2009 and were assessed to determine their suitability for trend and status analysis. Based on period of record and number of samples for individual sampling stations, the dataset was reduced from 176 stations to 56 by removing stations from basins that had fewer than 60 samples and less than five consecutive years of monthly water quality data. Nineteen of the 30 basins in Collier County were represented by the 56 water quality stations used in the trends analysis. These 19 basins covered nearly 90% (4500 km^2) of the 5200 km^2 within Collier County. If the data met the requirements for inclusion then the following assessment was made to determine the analysis path:

• A data point was defined for the purposes of assessing sampling sizes as the mean of all stations and sampling levels (surface, middle, bottom) within a basin;

• Trend testing was performed for the period of record corresponding to the beginning of monthly water quality sampling provided at least 60 samples and 5 years of monthly data were available for analysis.

One of the nineteen basins (Cow Slough) was removed at the start of the trend analysis due to low sample size (<60 samples).

In addition, trend analysis was performed for several heavy metals including arsenic, copper and iron which were deemed issues of concern in Collier County surface waters. Arsenic in groundwater is a growing issue in Collier County potentially stemming from the use of an arsenic-based herbicides, particularly within the Cocohatchee (Inland Segment), Gordon River Extension, and Naples basins. Copper has been reported to be a problem in urbanized estuaries—especially Naples Bay where the National Oceanic and Atmospheric Administration's Mussel Watch program (Kimbrough et al. 2008) reported the highest concentrations of copper in Florida. At present, iron is the cause of impairment in Barron River Canal, Cocohatchee River, Naples Bay Coastal and North Golden Gate.

All of the trend analyses for this section were completed using a seasonal Kendall Tau approach. This approach removes seasonal trends that are common in water quality data as a result of seasonal fluctuations in temperature and rainfall and allows better resolution of increasing or decreasing trends in the data, independent of seasonal trends. The core statistical testing procedures were provided by the Environmental Protection Agency's (EPA's) seasonal Kendall Tau Fortran programs available from the EPA Laboratory in Corvallis, Oregon. The authors developed statistical software to drive these core programs, and produce the automated outputs.

Trend tests were conducted on monthly water quality samples collected at stations throughout Collier County. In most cases, only surface measurements were taken, but when both surface and bottom measurements were taken, these values were averaged to produce one value per station each month. The procedure applied to the trend testing produces a series of graphical outputs in the detailed statistical appendices for each step in the analysis. The sample figures below (Figures 2.1-4 to 2.1-10) provide an explanation of the results of the trend analyses found in Appendix 3.3.

=Barron River Canal

var	ax2	display_start	display_stop	seasonality	corr_1	corr_2	autocorrelation	unadj_Tau	unadj_Pwithout	unadj_Pwith	unadj_Slope
CHLA	(ug/l)	1	10	Y	N	N	N	0.091	0.231	0.357	0.000
COLOR	(CU)	121	130	Y	Y	N	N	-0.038	0.659	0.828	0.000
COND	(uOhm/cm)	81	90	Y	Y	N	N	0.029	0.741	0.826	1.367
DO	(mg/L)	91	100	Y	N	N	N	-0.226	0.008	0.046	-0.118
NO3NO2	(mg/L)	111	120	N	N	N	N	-0.166	0.059	0.146	-0.002
PH	(SU)	71	80	Y	Y	N	N	-0.115	0.160	0.192	-0.008
SALIN	(ppt)	11	20	Y	Y	N	N	0.043	0.612	0.728	0.001
TEMP	(C)	21	30	Y	N	N	N	-0.010	0.923	0.875	0.000
TKN	(mg/L)	101	110	N	N	N	N	0.158	0.128	0.173	0.035
TN	(mg/L)	31	40	N	N	N	N	0.164	0.133	0.140	0.046
TP	(mg/L)	41	50	N	N	N	N	0.128	0.197	0.324	0.002
TSS	(mg/L)	51	60	Y	N	N	N	0.303	0.000	0.031	0.000
TURB	(NTU)	61	70	N	N	N	N	0.051	0.541	0.664	0.025

var	adj_Tau	adj_Pwithout	adj_Pwith	adj_Slope	Tau	p	slope
CHLA	0.09063	0.23066	0.35686	0.000	0.09063	0.23066	0.000
COLOR	-0.03812	0.65862	0.82849	0.000	-0.03812	0.65862	0.000
COND	0.02926	0.74114	0.82605	1.367	0.02926	0.74114	1.367
DO	-0.22581	0.00764	0.04617	-0.118	-0.22581	0.00764	-0.118
NO3NO2	-0.16609	0.05854	0.14591	-0.002	-0.16600	0.05900	-0.002
PH	-0.11458	0.15987	0.19181	-0.008	-0.11458	0.15987	-0.008
SALIN	0.04348	0.61243	0.72775	0.001	0.04348	0.61243	0.001
TEMP	-0.01020	0.92305	0.87483	0.000	-0.01020	0.92305	0.000
TKN	0.15816	0.12825	0.17283	0.035	0.15800	0.12800	0.035
TN	0.16384	0.13281	0.13983	0.046	0.16400	0.13300	0.046
TP	0.12775	0.19731	0.32371	0.002	0.12800	0.19700	0.002
TSS	0.30345	0.00003	0.03145	0.000	0.30345	0.00003	0.000
TURB	0.05089	0.54113	0.66402	0.025	0.05100	0.54100	0.025

Figure 2.1-4 - Example table summarizing the results of surface-water trend analyses.

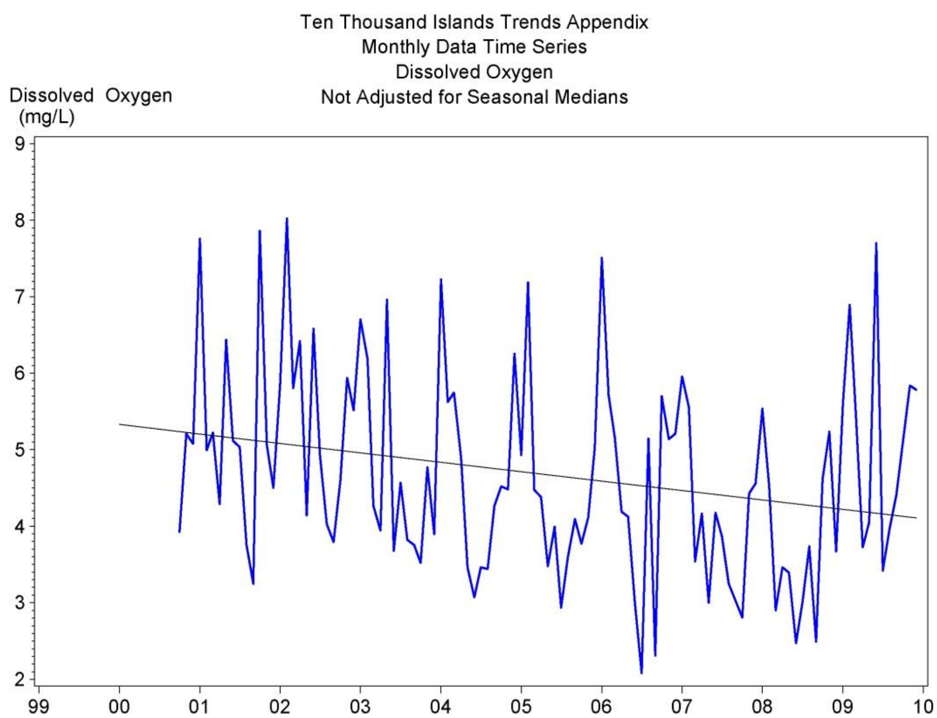

Figure 2.1-5. Sample trend results output for step 1.

Figure 2.1-4 presents an example page from one of the summary tables found in Appendix 3-3. This table summarizes the progression of the trend analysis as tests for seasonality and autocorrelation are conducted and as adjustments for these factors, when they exist, are made. When the p-value is <0.05, the slope is considered significant for the water quality parameter being tested.

In the first step of each trend analysis a time series plot of the raw data is prepared for the period of record. Figure 2.1-5 provides a sample page of the actual output. This figure provides a valuable time-series of the trends in the data.

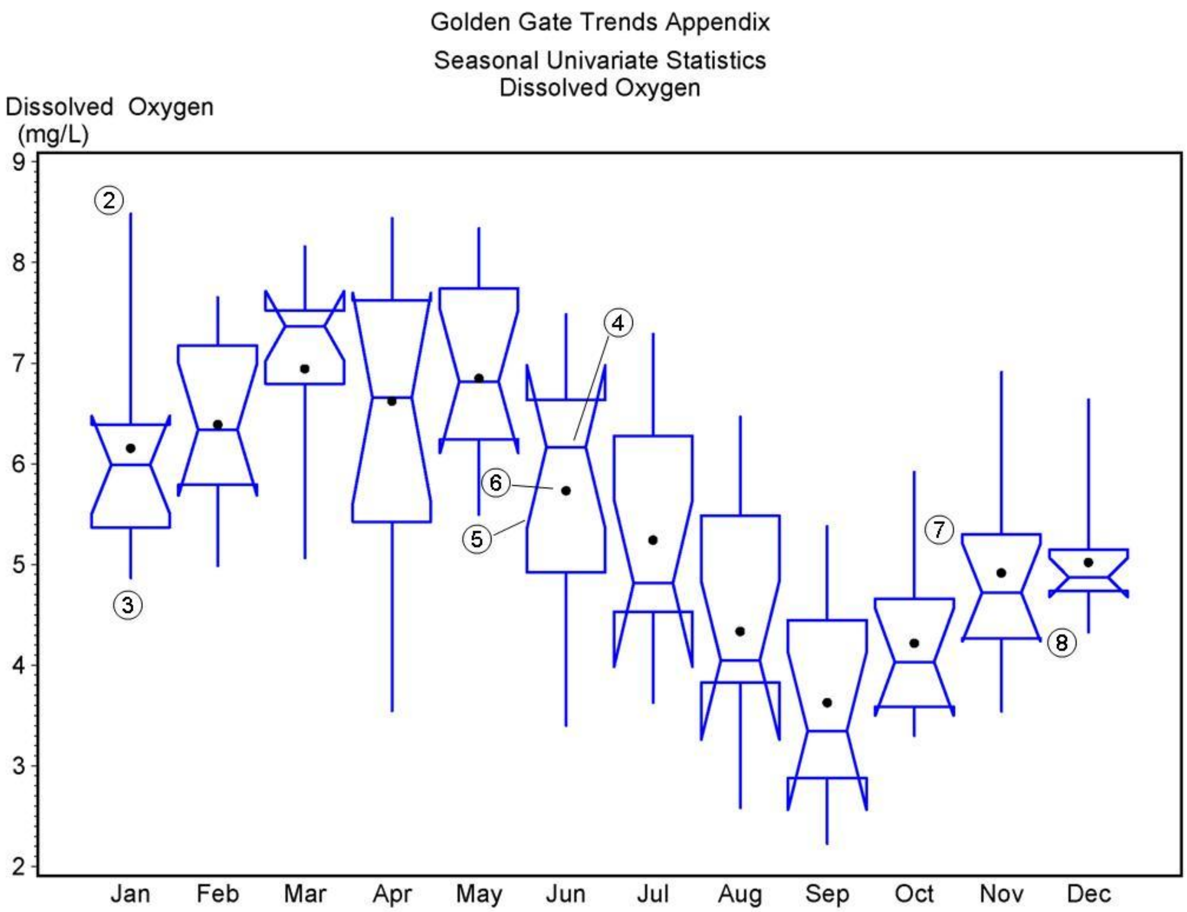

Figure 2.1-6. Sample seasonal univariate results output for step 2 (annotated labels are circled, and are not part of the actual outputs).

In the second step of the trend analysis, the time series data are averaged to monthly values, and a complete set of univariate statistics is calculated to present the seasonality of the data on a monthly intra-annual basis. Figure 2.1-6 presents an example page from the results of the second step and provides a valuable overall view of the seasonality of the data. The annotated labels indicate the following features: 2 = the maximum value, 3 = the minimum value, 4 = the median value, 5 = the lower 95% confidence limit of the median value, 6 = the mean value, 7 = the 75th percentile, 8 = the 25th percentile. If the confidence limits around the medians for any pair of months do not overlap, then the medians are considered to significantly different at an alpha level of 0.05.

In the third step of the analysis, a correlation analysis is performed for each monthly value, the previous month's value, two months prior, etc., until correlation statistics have been calculated for all previous months up to 15 months prior. A table of these values is provided in the output (not shown).

In the fourth step of the analysis, a determination is made as to whether seasonality exists in the time series of data. An operationally defined and objective test to identify the presence of seasonality was applied.

A correlogram is provided as part of the output (example in Figure 2.1-7). If a correlation value on this plot is statistically significant then it will lie beyond the confidence limits shown. If the data presented by the plot have seasonality, then one would expect the 6-month lag values to be negatively correlated and the 12-month lag values to be positively correlated.

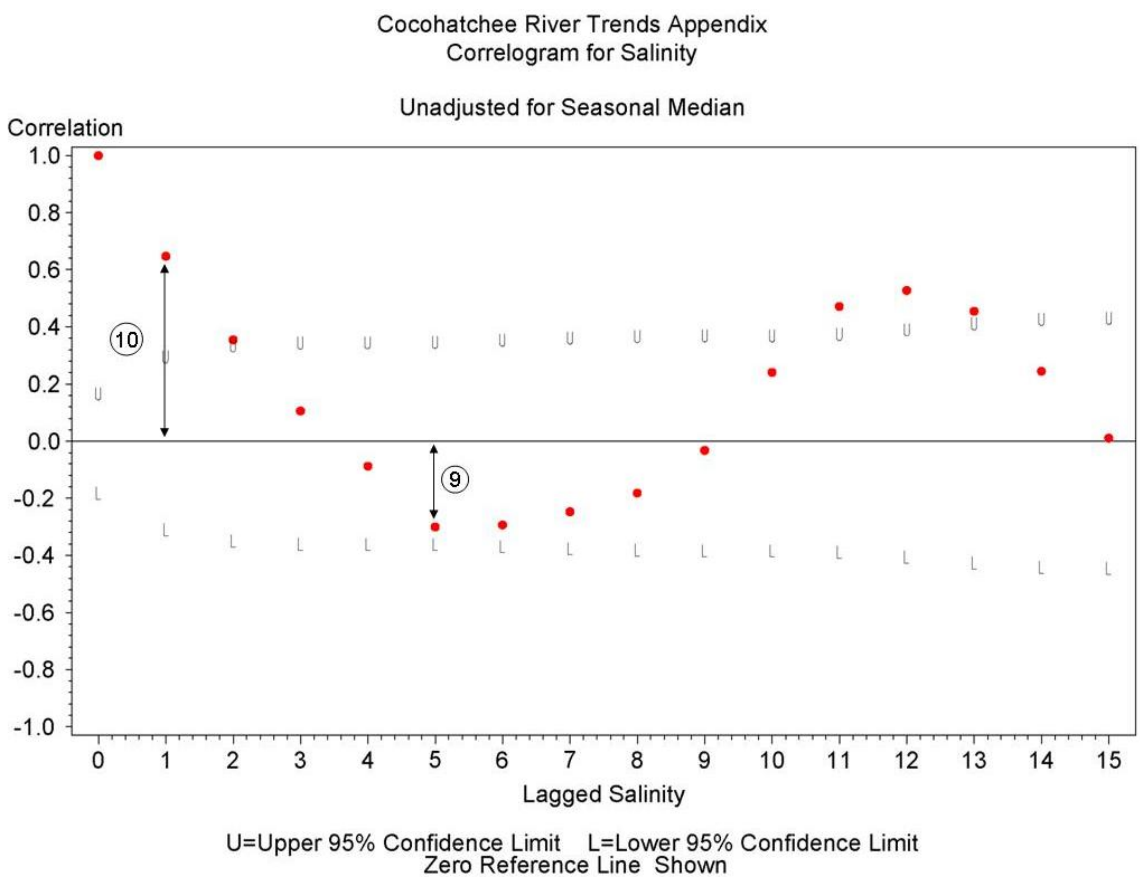

Figure 2.1-7. Sample seasonality test information output for step 4.

The objective test measures the proportional distance between the zero line and the lower 95% confidence limit for the 6-month lag correlation (label 9), and the proportional distance between the zero reference line and the upper 95% confidence limit for the 12-month lag correlation (label 10). If the sum of distance 9 and 10 are greater than 1, or if distance 10 is greater than 1 then seasonality is determined to exist.

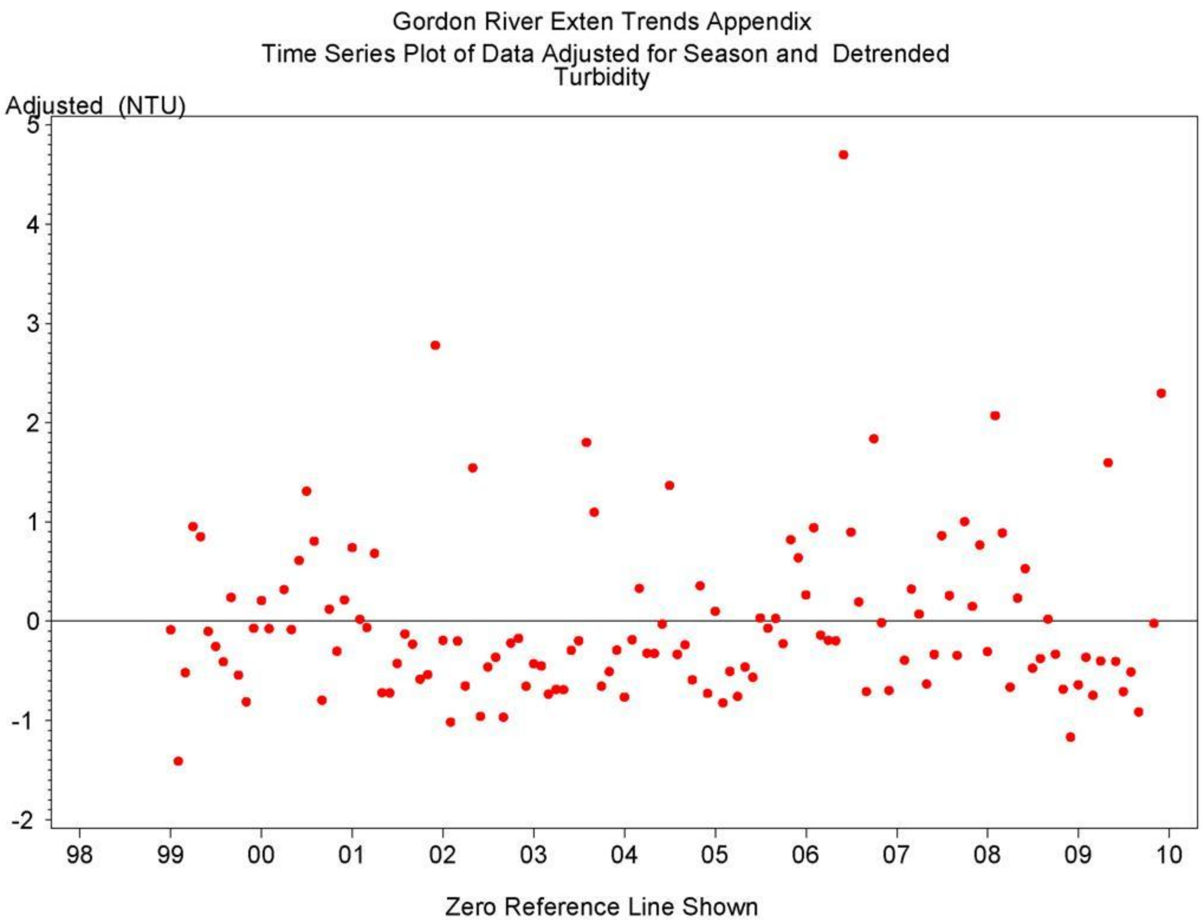

Figure 2.1-8. Sample of the season adjusted and de-trended data.

If the data are determined to be seasonal, then the data are adjusted for season by subtracting the median monthly value from each data point. The season-adjusted data are then applied to a Kendall Tau. The Kendall Tau test determines the slope of the time series of data, and p-values for various data conditions. Tables of these values are provided in the results (examples not shown). However, in all cases summary trend tables are provided in the appendices showing the appropriate p values, slopes, and significance results for each trend.

The next step is to test the data for autocorrelation in a similar fashion to that completed to identify seasonality. In the first phase of this analysis, the season adjusted data are de-trended by removing the effects of the slope identified. A diagnostic figure is then provided of these data (Figure 2.1-8).

In the next step of the analysis, the season adjusted and de-trended data are prepared in the form of a correlogram to test for the presence of autocorrelation in the time series. Figure 2.1-9 presents an example of this page of the detailed output. If both the 1-month lag (label 11) and the 2-month lag (label 12) are significantly correlated with the present values, then the data are identified as auto-correlated and an adjustment is made to the p-value.

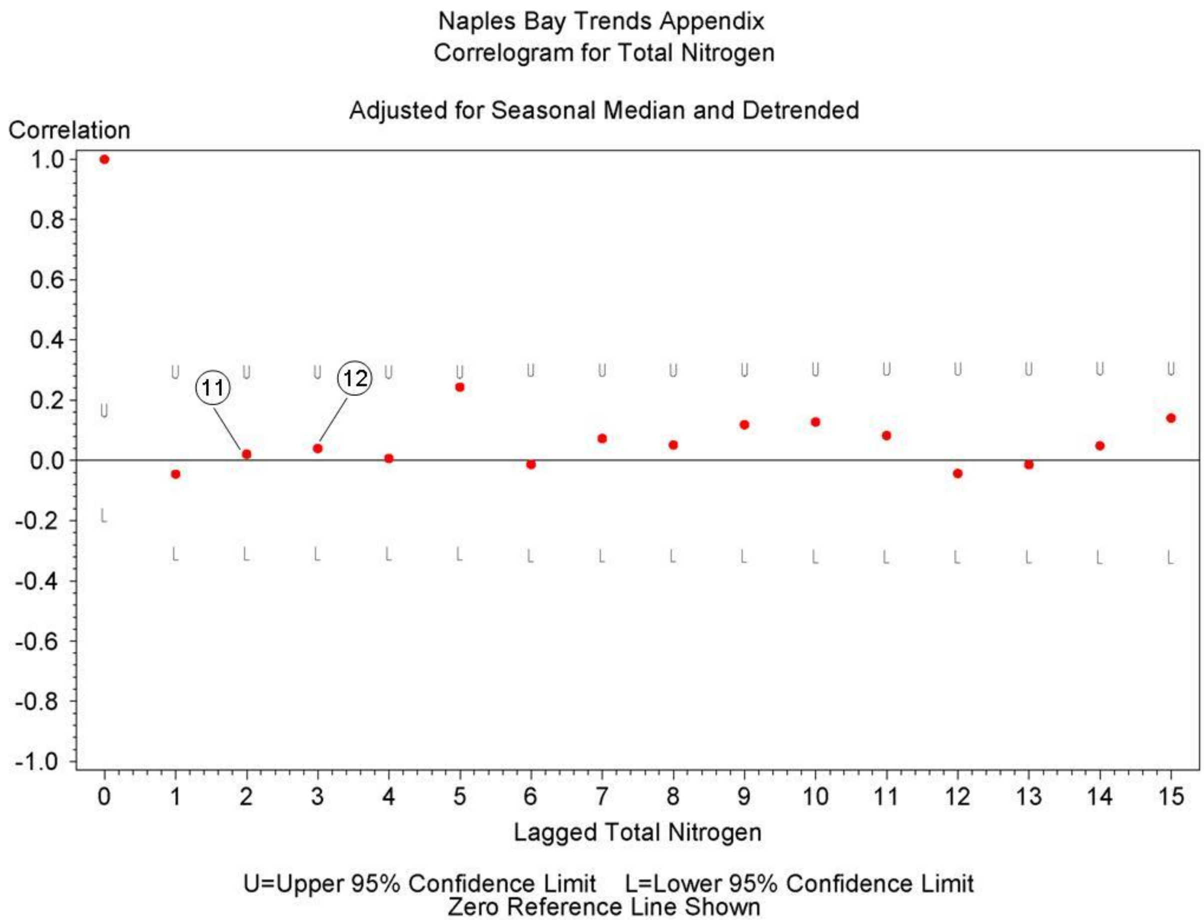

Figure 2.1-9 - Sample autocorrelation test figure.

In the final step of each trend analysis the appropriate p-value (corrected for auto-correlation if necessary), significance assessment (based on alpha = 0.05), slope, autocorrelation assessment (present/absent), and seasonality assessment (present/absent) of the trend analysis are compiled from the pages of output and tabulated in a summary table of trend test results.

Trend tests were conducted at the basin-level using the monthly average of all stations (surface and bottom readings) within a basin. The seasonal Kendall Tau methods were applied as previously described. The detailed trend results were then summarized into various utilitarian tables in the appendices (sorted and subset in different manners). Figure 2.1-10 presents an example page from one of these summary tables. A comprehensive set of maps is presented in Results Section 3.3.5 of this document, and statistical detail pages are provided in Appendix 3-3.

Faka Union North Trends Appendix

Autocorrelation Statistics for Chlorophyll a

Adjusted for Seasonal Median and Detrended

Lagged Chlorophyll a	Correlation	Standard Error	Upper Limit	Lower Limit
0	1.000	0.091	0.183	-0.183
1	0.206	0.158	0.316	-0.316
2	-0.040	0.160	0.321	-0.321
3	0.109	0.160	0.321	-0.321
4	0.172	0.161	0.322	-0.322
5	-0.034	0.163	0.325	-0.325
6	-0.090	0.163	0.325	-0.325
7	-0.046	0.163	0.326	-0.326
8	-0.014	0.163	0.326	-0.326
9	-0.046	0.163	0.326	-0.326
10	0.151	0.163	0.327	-0.327
11	0.064	0.164	0.329	-0.329
12	-0.006	0.165	0.329	-0.329
13	0.103	0.165	0.329	-0.329
14	0.022	0.165	0.330	-0.330
15	-0.055	0.165	0.330	-0.330

Figure 2.1-10 - Sample of the correlation summary tables included for each basin and parameter.

2.4 Methods for Land Use Analysis

Land use geodatabase files for the years 1988, 1995, 1999 and 2005 were obtained from the South Florida Water Management District for characterization of land use/land cover and analysis of land-use change over time within each FDEP waterbody basin (WBID) in Collier County. To avoid difficulties associated with comparing changes in land use between previous and current WBID designations, only the current WBID designations were used for the entire time period from 1988-2009. Using ARC GIS 9.3, land use shapefiles were clipped to the FDEP basin boundary to allow land use identification for each WBID. The area of each land use polygon in each WBID was determined and exported to SAS v. 9.1 statistical software where the percent composition of each land use class was calculated by basin and year at two levels: 1) FLUCCS Level I condensed to Urban, Agriculture, Upland and Wetland to provide a general summary of the natural and developed areas in each basin, and 2) FLUCCS Level III, which allowed for more specific differentiation among urban, agricultural, and natural land use classes. Land use characterization was also conducted within a 100-m buffer on both sides of the surface water feature (i.e., canal or stream) using FLUCCS Level III classification to provide a summary of the primary land uses directly connected to surface waters.

In addition to the descriptive analysis of land use and land-use change over time, Collier County basins were plotted using principal components analysis (PCA) to identify groups of basins with similar land use composition (FLUCCS Level III) during the years 1988, 1995, 1999, and 2005. Using this technique, principal components (PC) axes were defined as gradients of land use along which basins were plotted.

Principal components analysis defines the first PC axis as the land use that provides the greatest separation of points in ordination space (i.e., on the plot) and thus explains the greatest amount of variation in the dataset. Subsequent axes are similarly determined with less variation explained for each additional axis.

The relative position of each basin with respect to other basins on the plot is an indication of their similarity in terms of land use composition. Closely positioned basins are more similar than basins that are positioned more distantly on the plot. Additional information can be gained by examining the location of basins on the plot relative to PC axes and comparing those locations to the land uses that define the axis. Land use classes with coefficients >0.35 were considered to be explanatory.

3.0 RESULTS

3.1 Climatological and Hydrological Conditions

3.1.1 Rainfall

Rainfall is an important ecosystem driver in estuarine and coastal systems. Rainfall events are shown to significantly stimulate primary productivity when directly deposited in estuaries and coastal waters (Paerl, 2002). Rainfall itself is a significant source of directly deposited biologically available nitrogen and phosphorus to watersheds, rivers and estuaries (Paerl, 2002). Rainfall directly impacts flow in coastal ecosystems. Under normal flow conditions, estuaries and coastal systems act as filters reducing water-column nutrient concentrations through production. During increased rainfall and higher flows, estuarine and coastal ecosystems often experience higher nutrient loading. Increased loading combined with lower residence times often lead to nutrient enrichment and increased production, consequently resulting in eutrophication (Galloway et al. 2003, Painting et al. 2007). The magnitude and timing of freshwater inflows affect the amount of nutrients and organic matter that enters a water body such that increased productivity may occur after a period of increased flows and downstream of its introduction. Sediment loads to a water body are also increased during high flows. Increased sediment loads may be associated with increased loadings of contaminants such as metals and organic compounds that bind to smaller particles.

Below, we present a summary of the annual and inter-annual variations in rainfall and subsequent variability in flow. Tables and figures summarizing annual, monthly and seasonal variation in rainfall are presented by basin in Appendix 3-1.

3.1.2 Annual variation in rainfall

During the study period, the highest total rainfall for the study area was during 1991, 1994, 1995, 2001, 2003 and 2005, with rainfall exceeding 60 inches at most sites during these years. Dry years in 1990, 1996, 2000, 2004 and 2007 typically had annual rainfall amounts of less than 45 inches at most sites.

The basins receiving the most rain each year, on average, were Corkscrew Marsh (54.4 inches) and Drainage to Corkscrew (53.8 inches). The lowest average annual rainfall was at Cocohatchee River (49.0 inches) and Immokalee (48.3 inches).

Total annual rainfall ranged from 27.3 inches in 1990 at Immokalee to 81.2 inches in 1995 at Drainage to Corkscrew. Total rainfall throughout the study area was variable, but higher annual rainfall totals were typically found in the north-central part of the county. Corkscrew Marsh had six of the wettest years in 1991, 1992 and 2002 through 2005, when total annual rainfall amounts ranged from 62.3-71.7 inches.

Coastal basins typically had low annual rainfall totals, particularly Naples Bay and Cocohatchee Golf Course which had some of the lowest annual totals observed in the county. However, Naples Bay had some of the highest monthly totals with >25 inches of rain during a single month in 2001 and 2005, despite the low totals there (Figure 3.1-1).

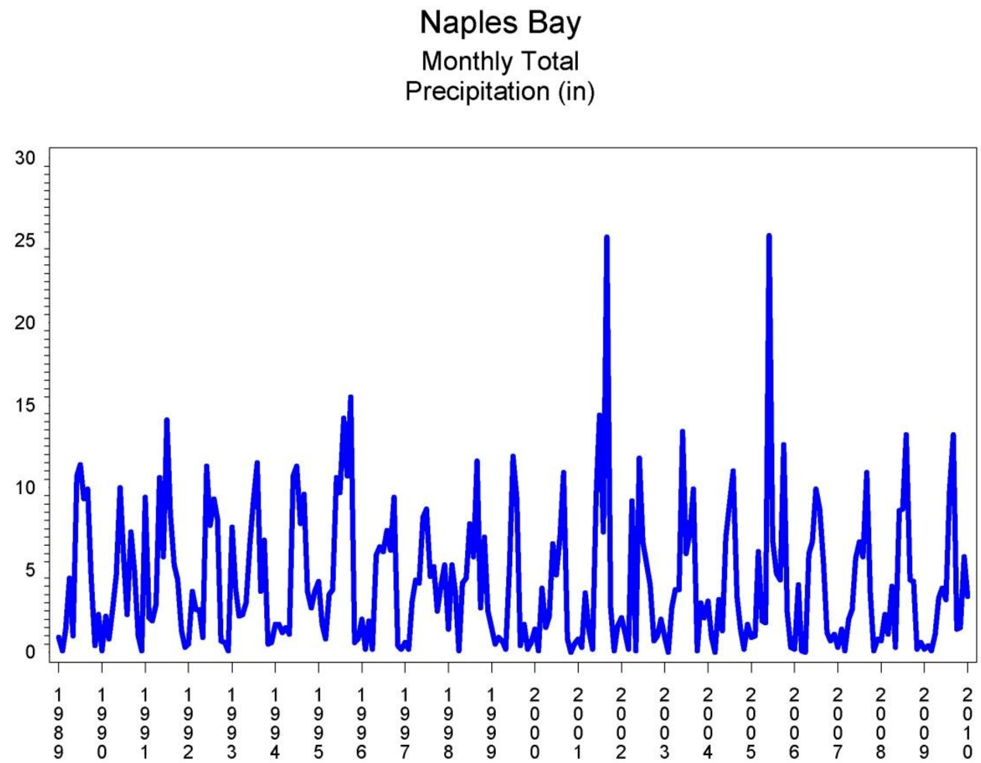

Figure 3.1-1 Time-series plot of annual rainfall variability for Naples Bay. Note the contrast between wet years (2001, 2005) and dry years (2000, 2007).

3.1.3 Seasonal variation in rainfall

Monthly rainfall for 1989-2009

Monthly rainfall from 1989-2009 was greatest from June through September and ranged from 0.1 to 25.0 inches, with peak rainfalls most frequently observed in June and July. The highest average monthly rainfall amounts occurred in the Corkscrew Marsh (Figure 3.1-2) and Drainage to Corkscrew basins with 1.7 to 3.6 inches during the dry season and 7.7 to 11.5 inches during the wet season.

Basins with low average monthly rainfall included Cocohatchee Golf Course and Cocohatchee River, with wet season averages between 8.1 and 8.7 inches and dry season averages between 1.5 and 3.7 inches per month.

Seasonal rainfall (wet vs. dry seasons) for 1989-2009

Lowest average rainfall during the entire study period during the dry season (October through May) was found at Cocohatchee Golf Course with a mean of 17.3 inches. Lowest average rainfall during the wet season (June through September) was found at Tamiami Canal with 31.0 inches. Highest average rainfall amounts during both the wet and dry seasons were recorded for Corkscrew Marsh, with 20.1 inches during the dry season and 34.7 during the wet season.

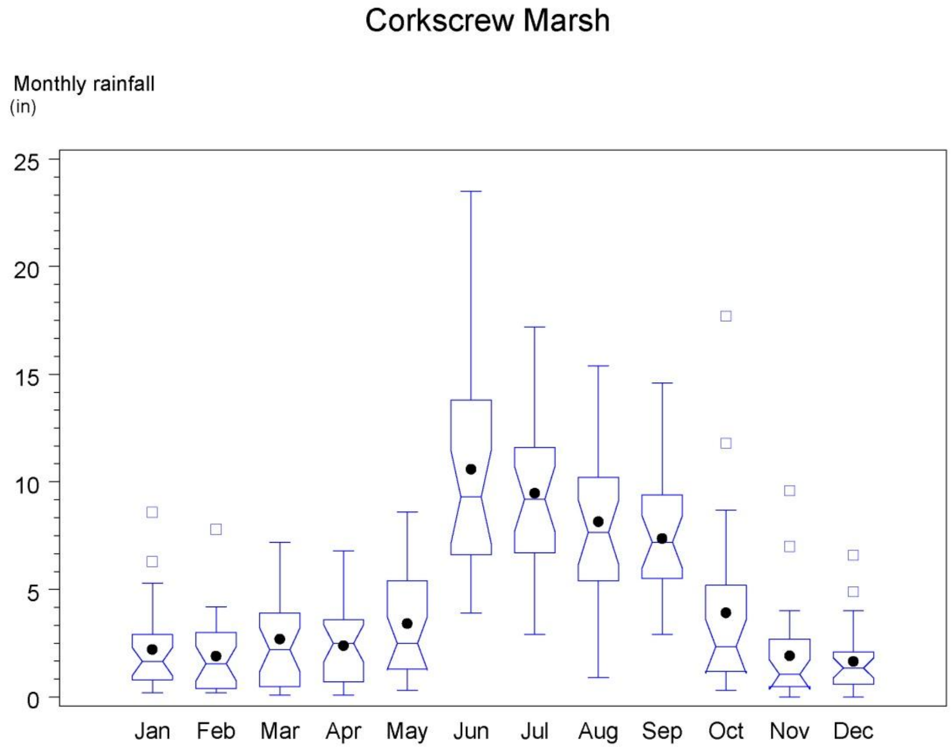

Figure 3.1-2 Monthly variability in rainfall amounts for Corkscrew Marsh (1989-2009).

3.1.4 Rainfall effects on hydrologic flows

Flow is a critical component in maintaining the health and function of aquatic ecosystems. Coastal, estuarine and riverine systems and the habitat they contain are structured by the physical process of water and sediment that are transported within the system. Coastal, estuarine and riverine systems depend on freshwater inflow because freshwater is a major source of nutrients (Scavia and Bricker, 2006). The rate of freshwater can influence hydraulic residence time and hence the time available for nutrients to react in the estuary. Flow may affect chlorophyll by increasing chlorophyll abundance via enhanced nutrient supply, changing the location of peak chlorophyll abundance, or decreasing chlorophyll abundance and residence time. During times of low freshwater inflow, the chlorophyll maximum is typically located further upstream than during times of high flow. Low flow also allows a longer residence time for chlorophyll and other nutrients.

Higher flows are associated with increased nutrient loadings, which are typically followed by increased chlorophyll abundance. During high flow conditions, flushing is more rapid and residence time in the river is reduced (Flannery et al., 2002). At times, high flows can be excessive, depending on the morphology of the estuary or river. Very high flows may not result in higher chlorophyll abundance due to the relationship between the residence time of water within the system and uptake and growth rates of the phytoplankton community. Additionally, flow can impact the nekton and benthos either by physical factors or indirectly by affecting salinity or other environmental factors. Vegetation including macroalgae and submerged aquatic vegetation can also be affected by changes in flow conditions (Gallegos, 2001). Changes in flow can be an important factor in reproduction and composition of species by recharging soil water and shifting boundaries between salt tolerant and freshwater species (Gallegos, 2001).

3.1.5 Annual variation in rainfall and flow

Throughout Collier County, annual rainfall was well correlated with hydrologic flows. Not surprisingly, years of high annual rainfall corresponded to high flows with lower flows observed during years of low rainfall. However, the effects of rainfall on flows differed on both spatial and temporal scales throughout the region, with differences in flow within a given basin related to differences in cumulative rainfall in that portion of the county. Figure 3.1-3 presents a time-series of flows for each flow gauge location.

Annual flows from 1999 through 2009 for the Barron River Canal averaged from 41 to 77 cfs. The highest flow years were 1999 and 2005 with average mean flows of 77 and 63 cfs. This corresponded with high basin rainfall of 63 and 56 inches as measured in the Barron River Canal Basin. Low flow years were 2000, 2007 and 2008 with average mean flows of 41cfs, 30 cfs and 40 cfs respectively. During 2007, rainfall was low at the corresponding rain gauges with 47 inches measured at Barron River Canal, 33.9 inches at Okaloacoochee Slough and 34.1 inches at Silver Strand.

Annual flows from 1999 through 2009 for Cocohatchee basin averaged from 2.9 cfs to 96 cfs. The highest average yearly flow years were 2003 and 2005, with flows of 96 cfs and 72 cfs. During 2003, rainfall in the basin was high, measuring in excess of 56 inches at four of the gauges and 71 inches at one. During 2005, rainfall was in excess of 60 inches in three of the five rain gauges and in excess of 70 inches in the remaining two. Lowest flows were during 2007 at 2.9 cfs and 2009 at 11.9 cfs. Rainfall followed suite, with all five gauges measuring under 42 inches of total annual rainfall during 2007 and less than 50 inches of total annual rainfall in 2009.

Annual flows from 1999 through 2009 for the Faka Union basin averaged from 210 cfs to 570 cfs. Highest flow years were 2001 and 2005, with flows of 570.4 cfs and 546 cfs. Rainfall during 2001 and 2005 were the highest during the study period for all three gauges. In 2001, Camp Keais, Faka Union North and Faka Union South had rainfall of 59.1, 64.5 and 69.9 respectively. During 2005, rainfall was also high at all three gauges, measuring 64.2 for Camp Keais, 67.2 for Faka Union North and 58.3 for Faka Union South. Low average flow occurred during 2000, measuring 210 cfs, and during 2007, measuring 141 cfs. Rainfall during those years was the lowest of the study period for all three gauges, ranging between 37.9 and 47.3 inches.

Annual flows from 1999 through 2002 for North Golden Gate averaged 157 to 411 cfs. Highest average yearly flows were during 1999 and 2001, with means measured at 377 and 412 cfs respectively. During 1999, rainfall at Corkscrew Marsh, Drainage to Corkscrew and North Golden Gate were high, with total annual rainfall measured at 70.6, 67.0 and 57.1. Rainfall at Naples Bay was lowest during the entire period of record, measured at 33.1 inches. During 2000, flow averaged 157 cfs and rainfall was under 50 inches at all gauges in the basin (Corkscrew Marsh, Drainage to Corkscrew, Naples Bay) with the exception of North Golden Gate, measured at 54.0 inches.

Annual flows from 2001 through 2009 for Henderson Creek averaged from 0 to 33 cfs. Highest average yearly flows were during 2001 and 2005, with means of 33 and 24 cfs respectively. This corresponded to highest annual rainfall measured for Rookery Bay Inland East, with 68.1 inches during 2001 and 63.7 inches during 2005. The lowest flow measurement of 0 cfs during 2007 corresponded to the lowest annual rainfall of 41 inches.

Annual flows from 1999 through 2009 for Tamiami Canal averaged from 222 - 1112 cfs. Highest average yearly flows were during 2002 at 933 cfs and 2005 at 1112 cfs. Rainfall in the Tamiami Canal basin was high during these years, measured at 61.6 inches during 2002 and 65.1 inches during 2005. Highest measured rainfall during the study period was during years 1999 at 67.2 inches with an average annual flow at 856 cfs and 2001 at 61.5 inches with an average annual flow of 758 cfs. Lowest average annual flows were during 2007 at 222 cfs and 2009 at 300 cfs. Rainfall during 2007 was 43.5 inches and during 2009 was 45.6 inches. Lowest annual rainfall during the study period was in 2000 at 37.0 and corresponding flows were 384 cfs.

3.1.6 Inter-annual variation in rainfall and flow

During the study period, flows within each the six basins varied predictably with lower flows during the dry season (October through May) and higher flows during the wet season (June through September). Maximum flows observed within a single location in Collier County reached 6,010 cfs and periods of no flow (0 cfs) were observed at each gauge. Boxplots of the monthly distributions of flow values for 1999-2009 is presented for each flow gauge in Appendix 3-2 and an example of these plots is shown below in Figure 3.1-4 for the gauge station on the Faka Union Canal.

Flows in the Barron River Canal (1999-2009) followed typical seasonal patterns with highest flows during the wet season and lowest flows during the dry season. Flows at the BARRON gauge in this basin ranged from 0 cfs to 258 cfs and were lowest, on average, in April (32 cfs) and May (23 cfs). Flows increased in July to a mean of 63 cfs, after increased rains in June, peaked in September at a mean of 93 cfs and declined in November.

Flows in the Cocohatchee River (1999-2009) ranged from 0 to 582 cfs at the COCO gauge station. Flows were lowest during April and May, with means of 9.3 and 7.7 cfs respectively. High flows occurred from July through November. Highest flows were during August and September, with means of 101 cfs and 138 cfs respectively.

Flows recorded during 1999-2009 from the FAKA gauge in the Faka Union Canal ranged from -398 to 2265 cfs. Flows were lowest during April and May, with means of 47 and 32 cfs, respectively. High flows occurred from July through November. Highest flows were during September and October, with means of 661 cfs and 900 cfs respectively.

Flows in the North Golden Gate basin (1990-1999) at the GOLD gauge ranged from -182cfs to 3058 cfs. Flows were lowest during April and May, with means of 37 and 38 cfs respectively. High flows occurred from July through October. Highest flows were during August and September, with means of 892 cfs and 903 cfs respectively.

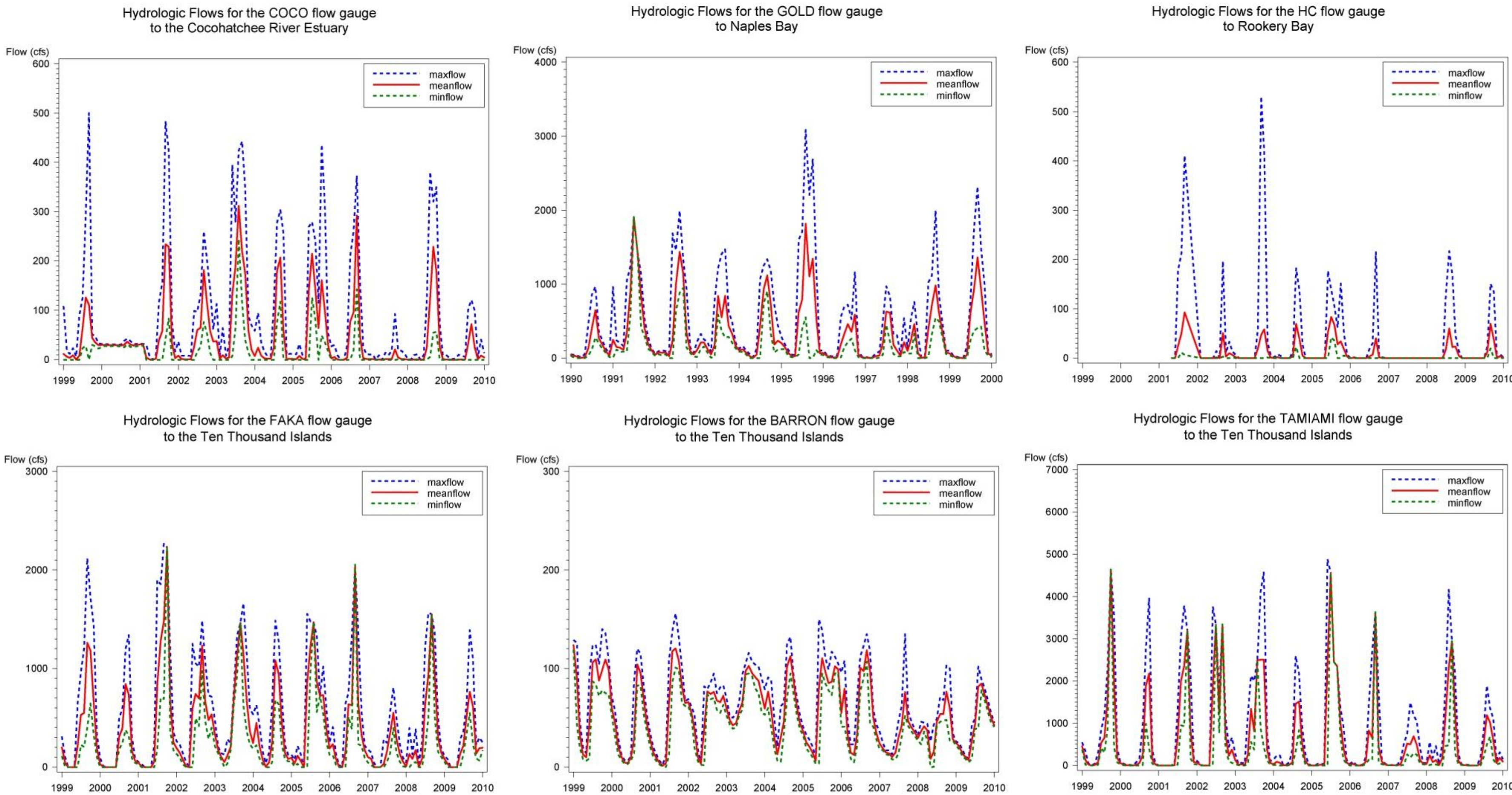

Figure 3.1-3 Hydrologic flows for the gauged basins.

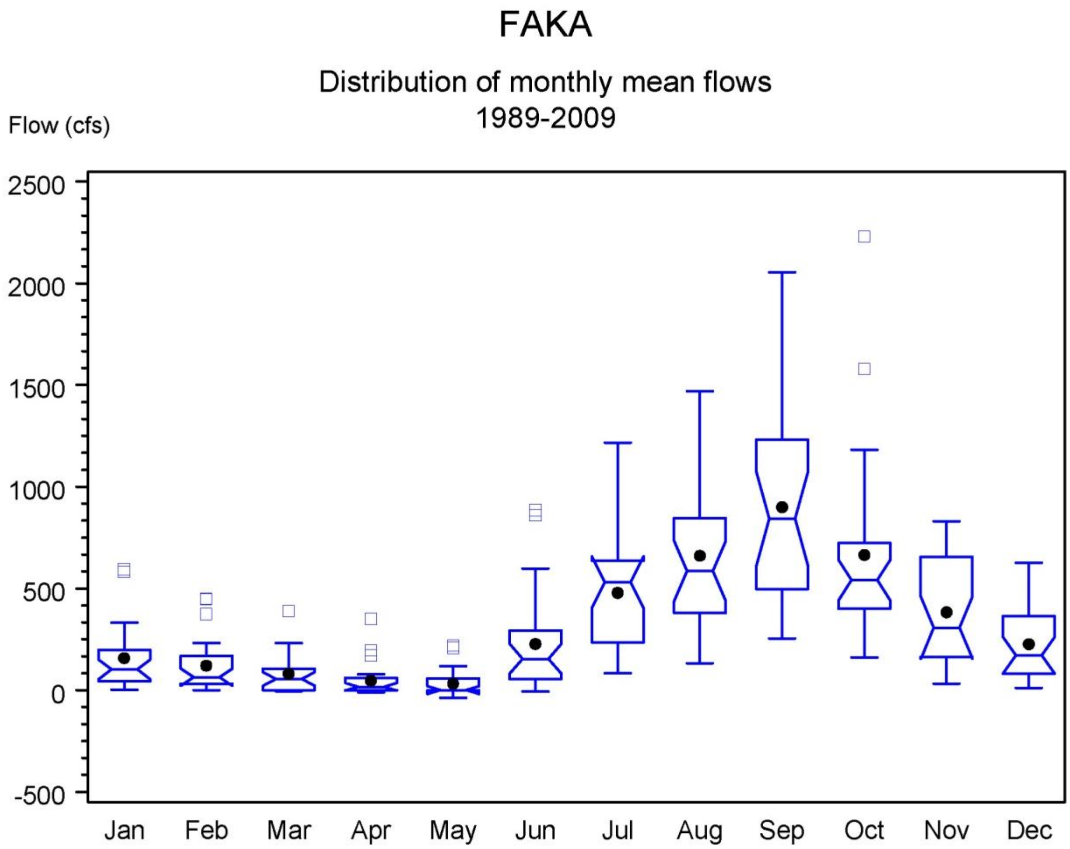

Figure 3.1-4 Monthly distributions of hydrologic flows for the FAKA gauge on the Faka Union canal.

Flows on Henderson Creek in the Rookery Bay basin (1999-2009) ranged from 0 cfs to 530 cfs. Flows were lowest at the HC gauges during January and February, with means of 0.3 cfs. High flows occurred from July through October. Highest flows were during August and September, with means of 32 cfs and 43 cfs respectively.

Flows in the Tamami Canal basin (1999-2009) ranged from 0 cfs to 6010 cfs. Flows were lowest during April and May, with means of 44 and 42 cfs respectively. High flows occurred from July through October. Highest flows were during August and September, with means of 1017 cfs and 1587 cfs respectively.

In summary, annual rainfall was directly correlated to flow in each of the gauged basins. High annual rainfall years corresponded with high flow and low rainfall years corresponded with low flow. Flow and rainfall were different on both spatial and temporal scales throughout the region, with different basins having high and low flows in different years based on differences in cumulative rainfall. Flow followed typical seasonal rainfall cycles, with high flow during wet months and low flow during dry months. Although flow followed rainfall throughout the basins flow within each basin varied greatly in magnitude. In order to determine differences in flow between basins a further investigation of impacts to flow would need to be determined. Differences in amount of rainfall reaching basins can be related to land use. For example, percent impervious surface can translate to altered hydrology in upstream tributaries and act to increase peak discharge, increased "flashiness" and reduced lag time between precipitation events and peak flows. These changes can negatively impact the biota, changing both quantity and quality of runoff.

3.2 Nutrient Loading Estimates for Gauged Basins

Fourteen of the 30 basins comprising 71% by area (4,792 km^2) of Collier County are gauged by six flow gauges (Figure 2.1-2) which, with the exception of the **TAMIAMI** gauge, are placed on the upstream side of water control structures located near the confluence of the canal and the coastal estuary. There is not a control structure within the Tamiami Canal basin which consequently allows tidal flows to interfere with the collection of accurate freshwater flow data from this basin. As a result, we excluded the Tamiami Canal basin and estimated flows for the remaining thirteen basins which comprised 36% and 2,409 km^2 of Collier County.

Time-series plots of loads are presented below in Figures 3.2-1 – 3.2-4. In the results below, total nitrogen and total phosphorus loadings are reported as annual loads in tons. Summary tables of monthly and annual loads by receiving waterbody (total load and unit-area load) are included in Appendix 3-2.

3.2.1 Loads to Ten Thousand Islands

Flows from Barron River Canal, Silver Strand and Okaloacoochee Slough are gauged by the **BARRON** gauge which accounts for 863 km^2 and the largest gauged basin area. Loads from these basins are received by the Ten Thousand Islands (Figure 3.2-1). The peak annual hydrologic loads for this basin were observed in 2003 with 64.5 million m^3. Total nitrogen (TN) and phosphorus (TP) loads during this year were 70.2 and 7.3 tons, respectively. Loads during 2002 and 2004-2006 were nearly twice as high as subsequent years and ranged from 64.5-69.1 tons TN and 2.4-5.2 tons TP. From 2007-2009, nutrient loads were considerably less for TN ranging from 39.8-54.5 tons and slightly less for TP at 2.8-3.9 tons. Loads from these basins to Ten Thousand Islands were lowest during 2007.

Flows from the 577 km^2 area occupied by Faka Union (North and South) and Camp Keais are gauged by the **FAKA** gauge and also discharge into Ten Thousand Islands (Figure 3.2-1). Hydrologic loads from these basins ranged from 130-361 million m^3. Nutrient loads ranged from 78.2-213 tons TN and 2.1-5.8 tons TP with the highest TN loads in 2005 and TP loads in 2006. The lowest hydrologic loads and TP loads were in 2007. Peak loads from Faka Union and Camp Keais were substantially greater than those contributed by Barron River Canal, Silver Strand and Okaloacoochee Slough (Figures 3.2-5, 3.2-6) despite the difference in basin size.

3.2.2 Loads to Rookery Bay

Rookery Bay (Inland East) is gauged by the **HC1_C**, **HC1_W and HENDTAMI** gauges which collectively measure flows from 219 km^2 through three water control structures located near the mouth of Henderson Creek (Figure 3.2-2). These loads are received by Rookery Bay Coastal. The highest hydrologic loads were in 2005 totaling 21.4 million m^3. Loads in 2003-2004 and 2008-2009 were substantially less and ranged from 8.9-10.6 million m^3 and even less in 2002 and 2006-2007 with hydrologic loads <5.5 million m3. No flow and no loads (0.0 million m^3 and 0.0 tons) was recorded from Henderson Creek in 2007. Nutrient loads from the Rookery Bay Inland East basin ranged from 0.0-20.1 tons TN and 0.0-0.5 tons TP during the period of record but were typically between 4.4 and 8.8 tons TN and 0.1-0.2 tons TP.

3.2.3 Loads to the Cocohatchee River Estuary

Cocohatchee River and the Cocohatchee Inland segment constitute 117 km^2 and are gauged by the **COCO1_S** and **COCO1_W** gauges as are portions of Corkscrew Marsh and the Drainage to Corkscrew basin which cover 301 km^2 (Figure 3.2-3). The latter two basins also partially drain to Naples Bay and North Golden Gate. For the purpose of standardizing loading estimates by basin area, it was assumed that 50% of the area of the Corkscrew basins drained to the Cocohatchee River estuary and the other 50% drained to Naples Bay. Loads from the Cocohatchee basins enter the Cocohatchee River estuary. Loads to the Cocohatchee River were by far the highest during 2003 when the hydrologic load reached 87.2 million m^3 which delivered 77.7 tons of TN and 3.4 tons of TP. Loads were less than one-tenth the annual maximum during 2007 with hydrologic loads of only 2.6 million m^3, TN loads of 2.2 and TP loads of 0.5 tons. Hydrologic loads during 2002, 2004, 2006 and 2008 were comparable among years and ranged from 38.9-43.9 million m^3. During the same years, TN loads were 32.3-40.0 tons and TP loads were 1.2-2.7 tons. Loads during 2005 were slightly higher than the average, but loads in 2009 were relatively low though still much greater than the lowest year, 2007.

3.2.4 Loads to Naples Bay

Naples Bay receives loads from the Naples Bay and North Golden Gate basins which occupy 332 km^2 and are gauged by the **GOLD.W1_W** gauge (Figure 3.2-4). Gauge data for the Golden Gate/Naples Bay basins ranged from 1990-2002 with maximum hydrologic loads observed during 1991, 1995, 1998 and 1999 ranging from 284-347 million m^3. Nutrient loads during those years were 278-342 tons TN and 11.3-58.5 tons TP. Smaller loads were recorded the remaining years with hydrologic loads of 139-249, TN of 113-238 tons and TP of 12.5-36.8 tons. The smallest loads were observed in 1990 and 2000.

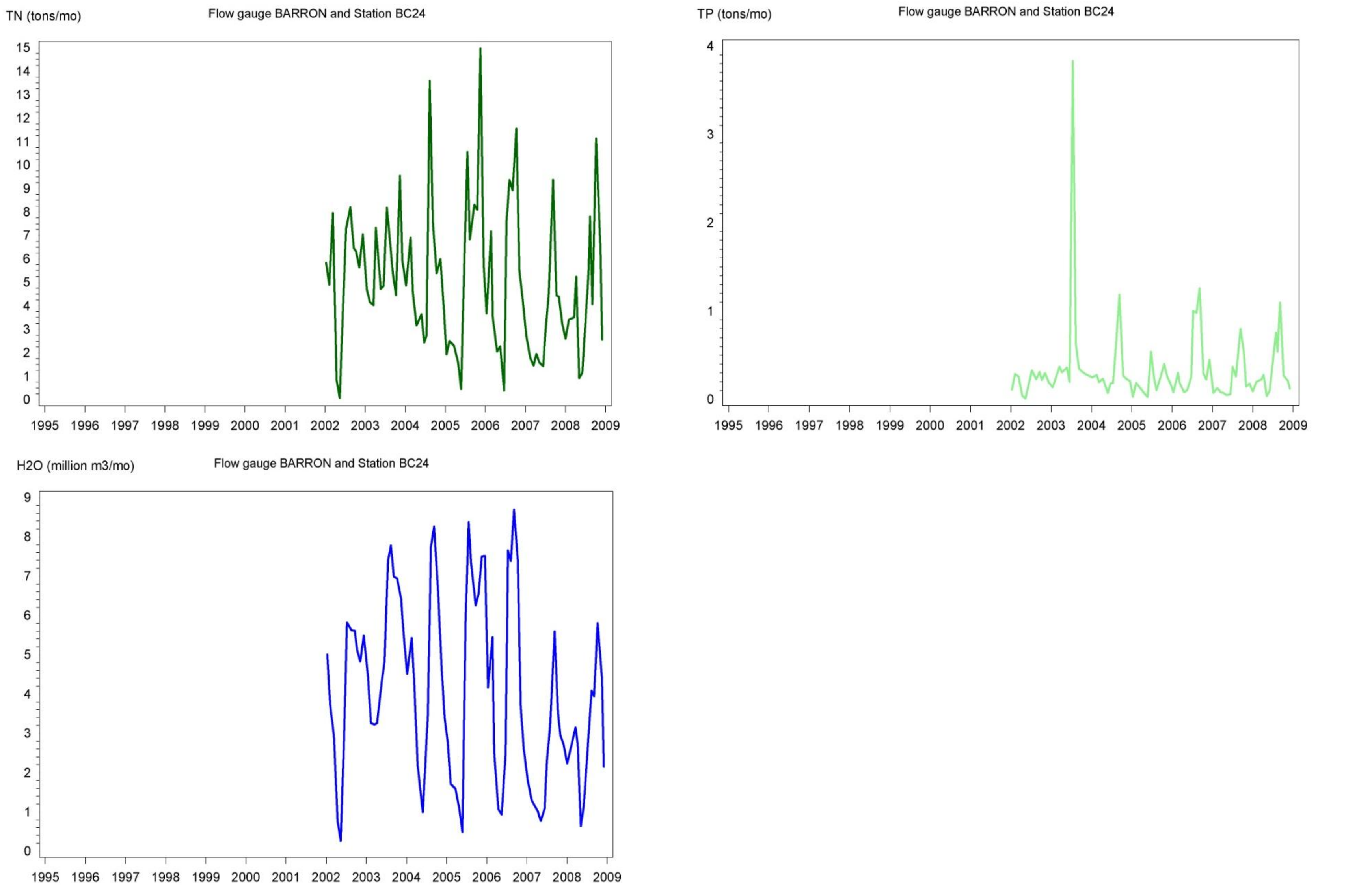

Figure 3.2-1 – Nutrient and hydrologic loads to Ten Thousand Islands based on gauged flows and monthly concentration estimates for total nitrogen and phosphorus from the Barron River Canal (BARRON) gauge station.

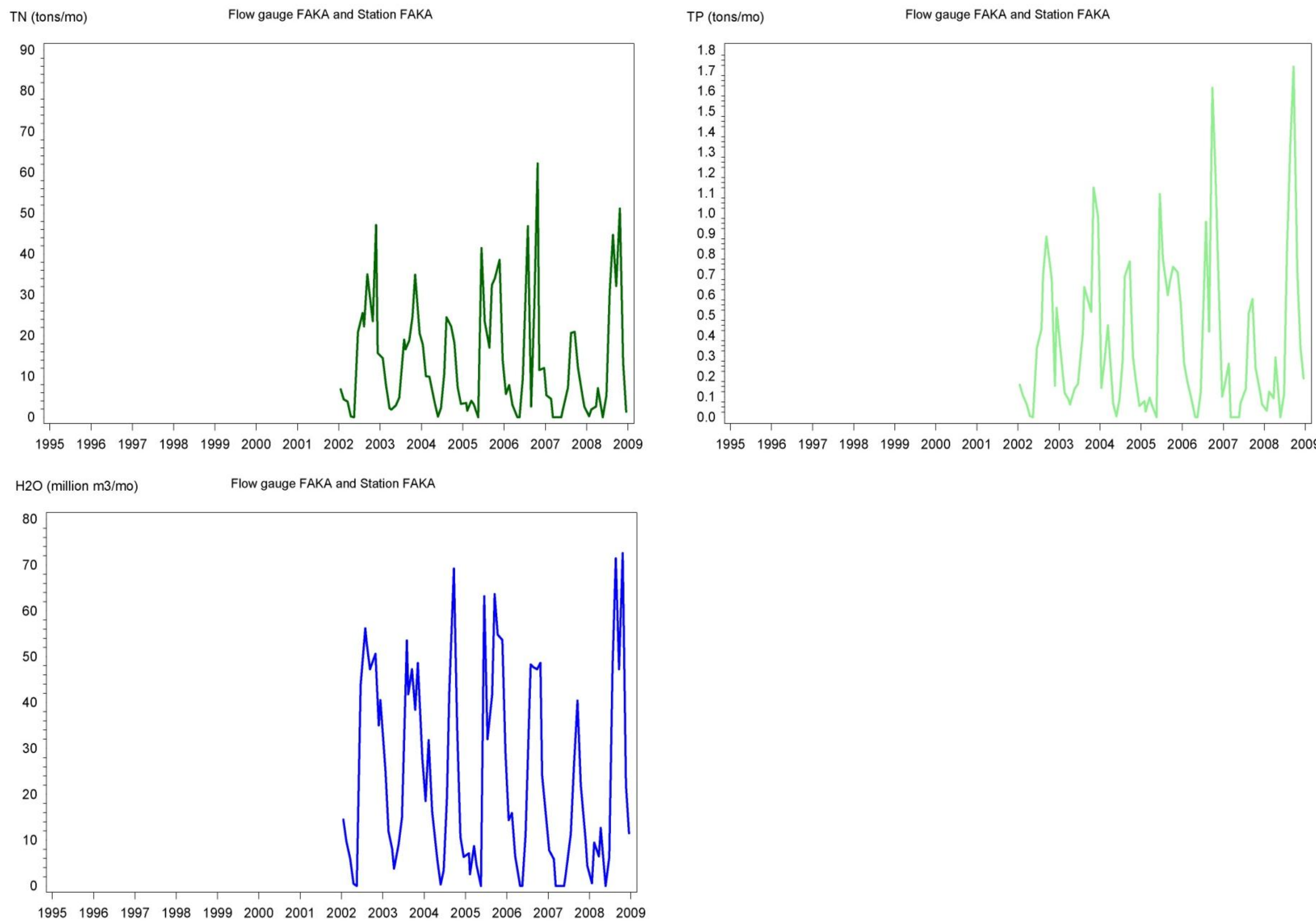

Figure 3.2-1 (continued) - Nutrient and hydrologic loads to Ten Thousand Islands based on gauged flows and monthly concentration estimates for total nitrogen and phosphorus from the Faka Union (FAKA) gauge stations.

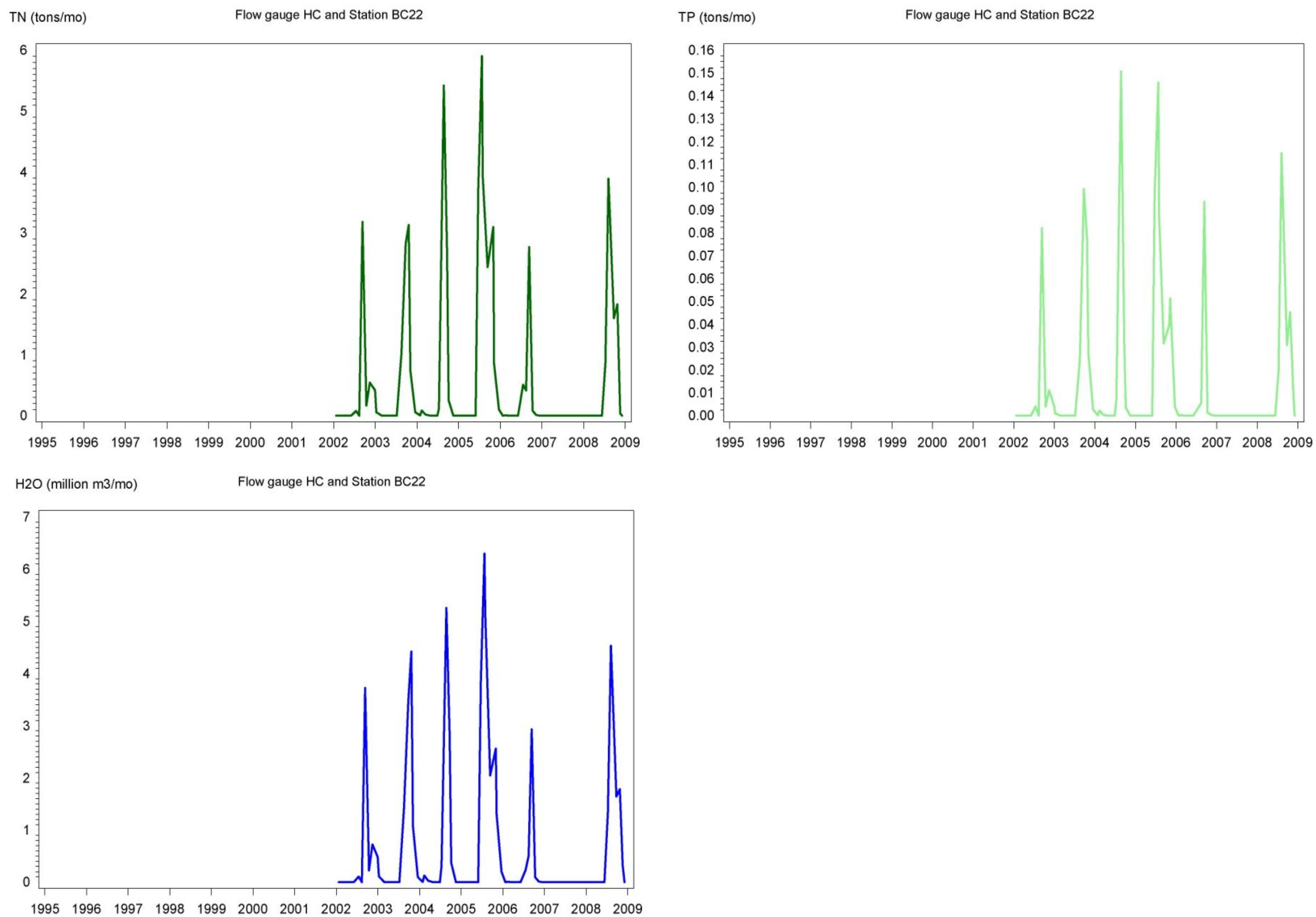

Figure 3.2-2 - Nutrient and hydrologic loads to Rookery Bay based on gauged flows and monthly concentration estimates for total nitrogen and phosphorus from the Henderson Creek (HC) gauge stations.

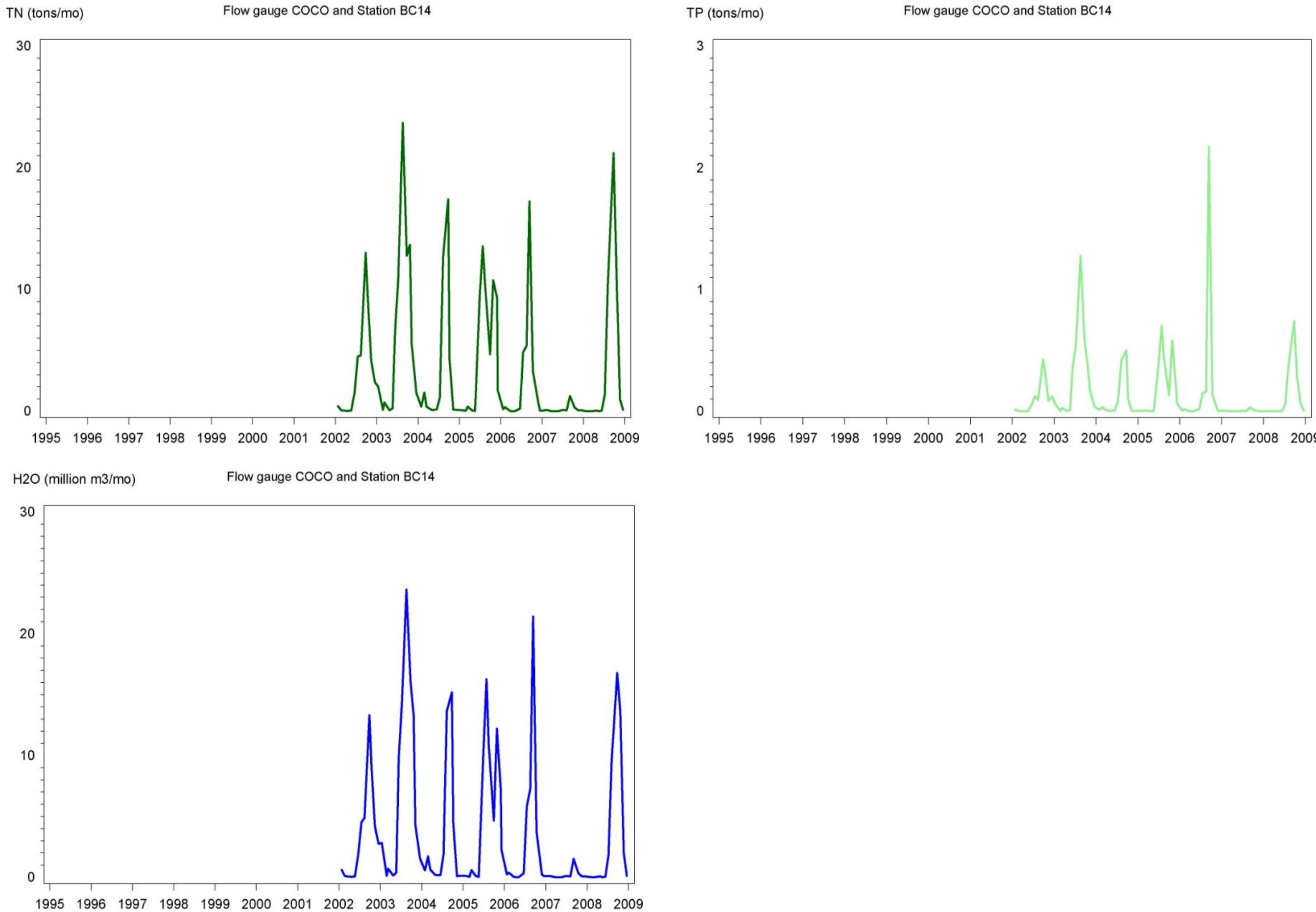

Figure 3.2-3 - Nutrient and hydrologic loads to the Cocohatchee River Estuary based on gauged flows and monthly concentration estimates for total nitrogen and phosphorus from the Cocohatchee River (COCO) gauge stations.

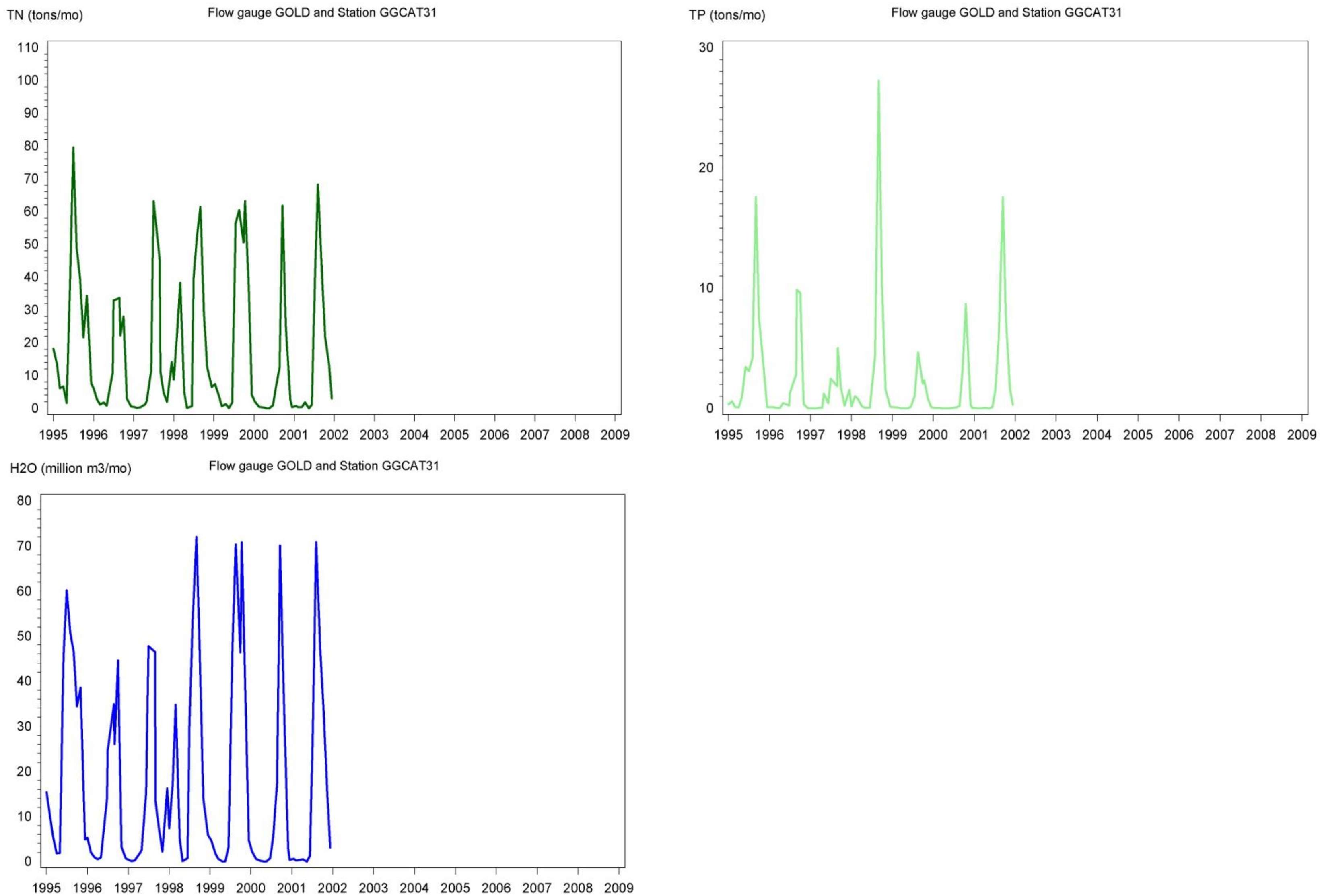

Figure 3.2-4 - Nutrient and hydrologic loads to Naples Bay based on gauged flows and monthly concentration estimates for total nitrogen and phosphorus from the Golden Gate (GOLD) gauge station.

3.2.5 Comparison of hydrologic and nutrient loads by basin

When standardized by basin area, the greatest loads were contributed to coastal waters from the Golden Gate/Naples Bay basin during the period from 1995 through 2001 (Figure 3.2-5 and Figure 3.2-6). Nutrient loads during this period ranged from 23-71 tons/100 km^2 for TN and 2-12 tons/100 km^2 (Table 3-1). In 2002, gauged flows were discontinued from this basin. From 2002-2009, the basins draining through Cocohatchee River and Faka Union delivered the highest nutrient loads to the coastal waters. Annual total TN loads ranged from about 1-29 tons/100 km^2 for Cocohatchee River and 14-36 tons/100 km^2 for the Faka Union watershed. TP loads for these basins were 0.02-1.3 and 0.4-1.0 tons/100 km^2, respectively. In contrast, the Barron River Canal/Okaloacoochee Slough, Silver Strand watershed contributed much smaller loads that were comparable to those from the Rookery Bay Inland East watershed. TN loads from the Barron River watershed were 5-8 tons/100 km^2 compared to those from Rookery Bay which were 0-9 tons/100 km^2. TP loads ranged from 0.3-0.8 and 0.0-0.2 tons/100 km^2, respectively.

Based on these estimates, the largest contributor of non-point source loads to Ten Thousand Islands is the Faka Union/Camp Keais watershed, while the Cocohatchee River delivers similarly large nutrient loads to coastal waters. If it is assumed that the Golden Gate/Naples Bay watershed continues to deliver nutrients to Naples Bay at a rate similar to that observed in the 1990s, then this watershed is the largest source of non-point source nutrient loads per unit area.

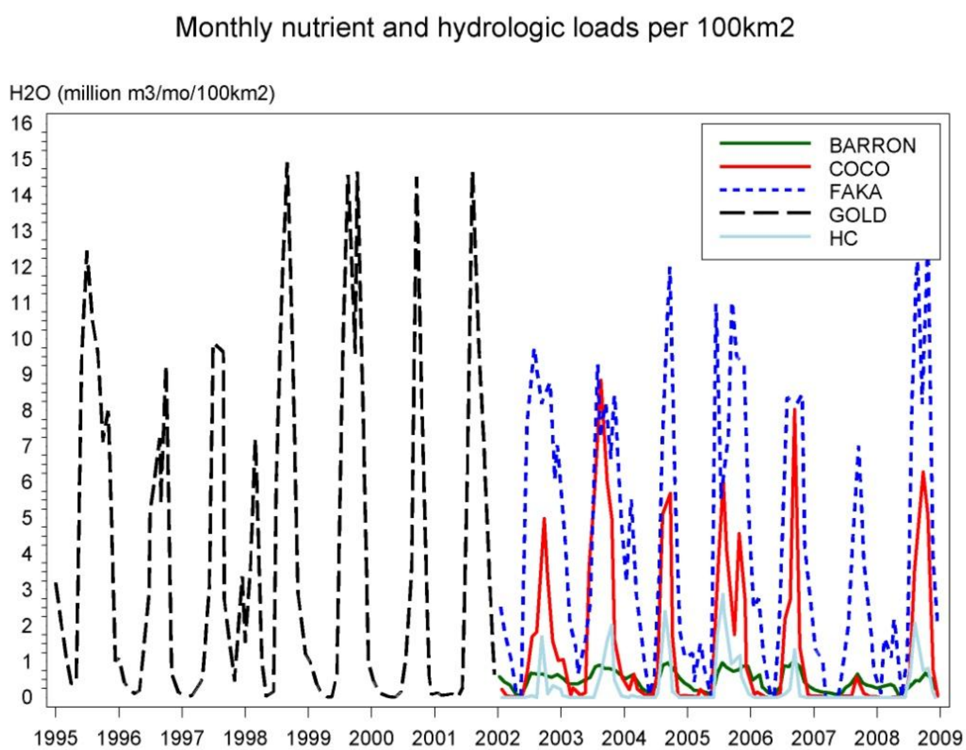

Figure 3.2-5 - Hydrologic loads per-unit-area for gauged basins in Collier County.

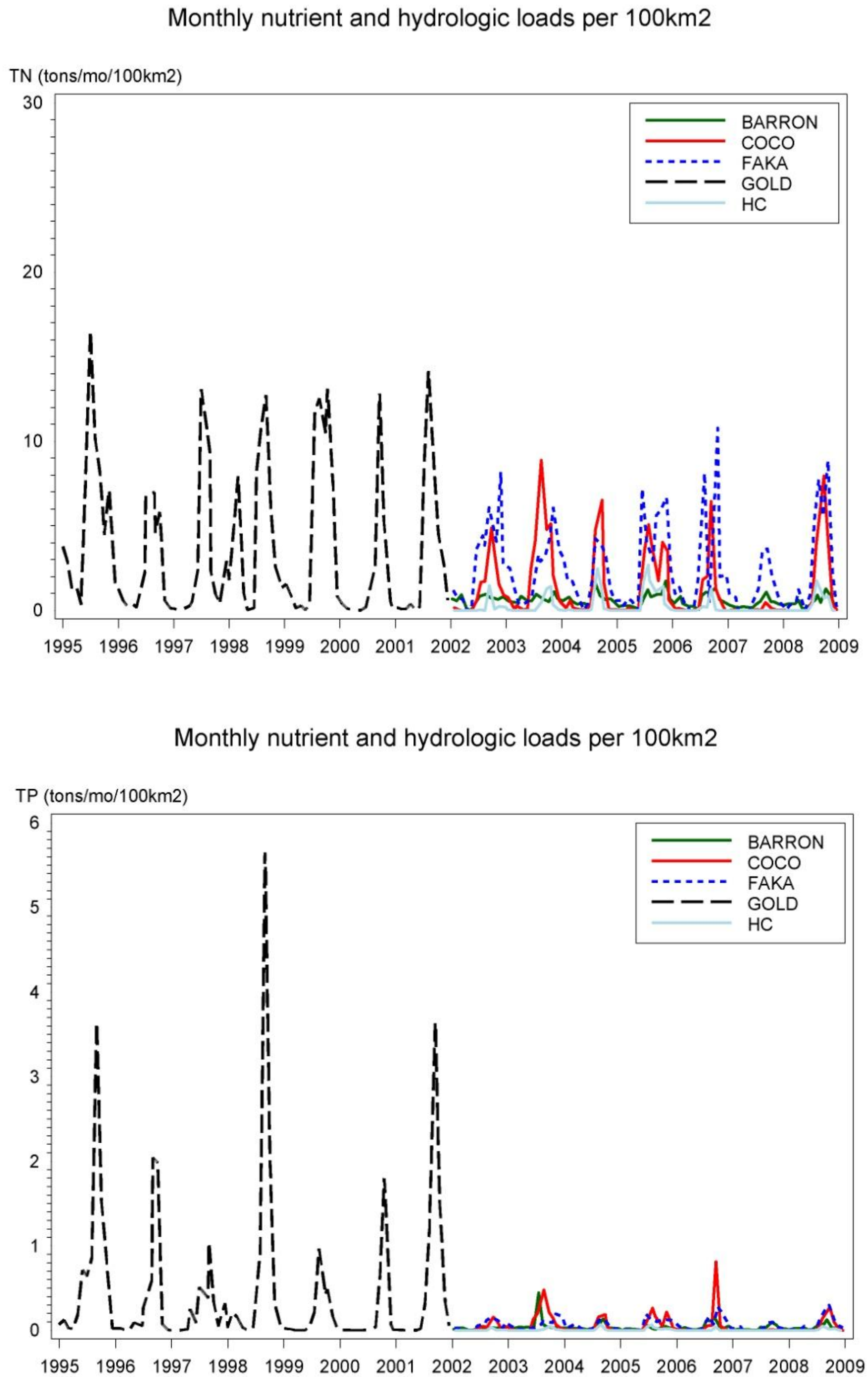

Figure 3.2-6 - Nutrient loads per-unit-area for gauged basins in Collier County.

Table 3-1. Annual nutrient and hydrologic loads per-unit-area for gauged basins in Collier County.

		2002	2003	2004	2005	2006	2007	2008	2009
site									
COCO	TNload (tons_100km2)	15.0	29.1	14.3	22.7	12.1	.809	17.0	2.57
	TPload (tons_100km2)	.463	1.28	.447	.933	.998	.020	.564	.107
	H2Oload (10^6 m3_100km2)	15.5	32.7	14.6	24.3	14.8	.960	16.5	3.98

		2002	2003	2004	2005	2006	2007	2008	2009
site									
BARRON	TNload (tons_100km2)	7.48	8.14	7.52	8.00	7.69	4.61	6.31	5.65
	TPload (tons_100km2)	.286	.846	.453	.282	.604	.320	.454	.332
	H2Oload (10^6 m3_100km2)	5.57	7.47	6.26	6.61	6.27	3.18	4.22	4.32
FAKA	TNload (tons_100km2)	35.6	29.3	22.5	37.0	32.9	13.9	33.0	35.2
	TPload (tons_100km2)	.705	.883	.572	.935	1.01	.368	1.01	.406
	H2Oload (10^6 m3_100km2)	61.9	57.2	44.7	62.6	48.0	22.5	53.3	34.8

		2002	2003	2004	2005	2006	2007	2008	2009
site									
HC	TNload (tons_100km2)	2.00	3.58	3.91	9.16	1.73	.000	3.75	4.00
	TPload (tons_100km2)	.048	.106	.089	.208	.048	.000	.102	.076
	H2Oload (10^6 m3_100km2)	2.40	4.84	4.07	9.76	1.73	.000	4.39	4.22

		1990	1991	1992	1995	1996	1997	1998	1999	2000	2001
site											
GOLD	TNload (tons_100km2)	30.8	70.8	49.2	65.4	29.8	32.3	57.6	59.0	23.3	39.3
	TPload (tons_100km2)	8.63	12.1	7.62	8.70	5.15	2.99	9.77	2.33	2.58	7.11
	H2Oload (10^6 m3_100km2)	28.8	71.8	51.5	65.3	32.7	31.9	59.8	58.9	29.1	41.9

3.3 Surface Water Quality Results

In this section, we present:

- Characterization of water quality conditions by basin, reporting on short-term (seasonal and annual) and long-term (period of record) patterns in water quality.

- Comparison of water quality among basins and identification of groups of basins with similar water quality conditions with a description of the water quality parameters that explain much of the variability among groups.

- Results of the trend analyses of water quality at the basin-level, accounting for seasonality and autocorrelation in the data to provide a corrected assessment of water quality trends over time.

The results of this section are discussed in subsequent sections in the context of land use patterns (Results Section 3.4) and climatological and hydrologic events (Results Section 3.5) to provide potential explanations for the observed variation in water quality across Collier County.

Appendix 3-3 contains results of water quality analyses at the basin-level and includes: 1) summary tables of annual, monthly and seasonal values for each water quality parameter from 1989-2010, 2) boxplots summarizing the distribution of data for each water quality parameter for the historical and current sampling periods, 3) time-series plots and monthly boxplots summarizing the distribution of data for each water quality parameter from 1999-2009, and 4) the results of the trend analysis from 1999-2009. The sections below provide details of these results by FDEP watershed basin for Collier County.

3.3.1 Characterization and seasonality of water quality for Collier County basins

Water temperature, salinity and conductivity, dissolved oxygen and pH typically exhibited seasonality, while seasonal patterns were not observed for chlorophyll, nutrients (inorganic and organic nitrogen, total nitrogen and total phosphorus), water clarity (total suspended solids and turbidity) and biochemical oxygen demand.

Water temperature

The lowest monthly average temperatures were recorded at 14.0 – 22.8 °C during December and January with peak monthly temperatures averaging between 24.8 and 30.5 °C from May through September. There was little difference in water temperature among basins although several of the inland basins - Immokalee, Cow Slough, Corkscrew Marsh, Camp Keais and Okaloacoochee Slough - were 1-3 °C cooler than the other basins.

Salinity and conductivity

Most of the basins in Collier County can be considered freshwater (<0.5 ppt) or slightly oligohaline (0.5-5.0 ppt), including the majority of the coastal basins, due to water control structures near the mouth of the tributaries. Salinities in these basins typically do not exceed 0.5 ppt, on average, but for Golden Gate salinities >20 ppt were observed on several occasions. Coastal basins with water-quality stations downstream of the control structures could be considered mesohaline (5.0-18.0 ppt). Salinities in these basins are highest in April and May at the end of the dry season and lowest between August and November during the peak rainy season. Salinities averaging <18.5 ppt were observed for Cocohatchee Inland, Gordon River Extension, Faka Union South, Fakahatchee Strand and Rookery Bay Inland (East and West), although Fakahatchee Strand had an unusually high average salinity of 23.2 ppt in May (Figure 3.3-1). Cocohatchee River, Naples Bay and Ten Thousand Islands were meso- to polyhaline and typically exceeded 20 ppt during the dry season but were <10 ppt during the rainy season.

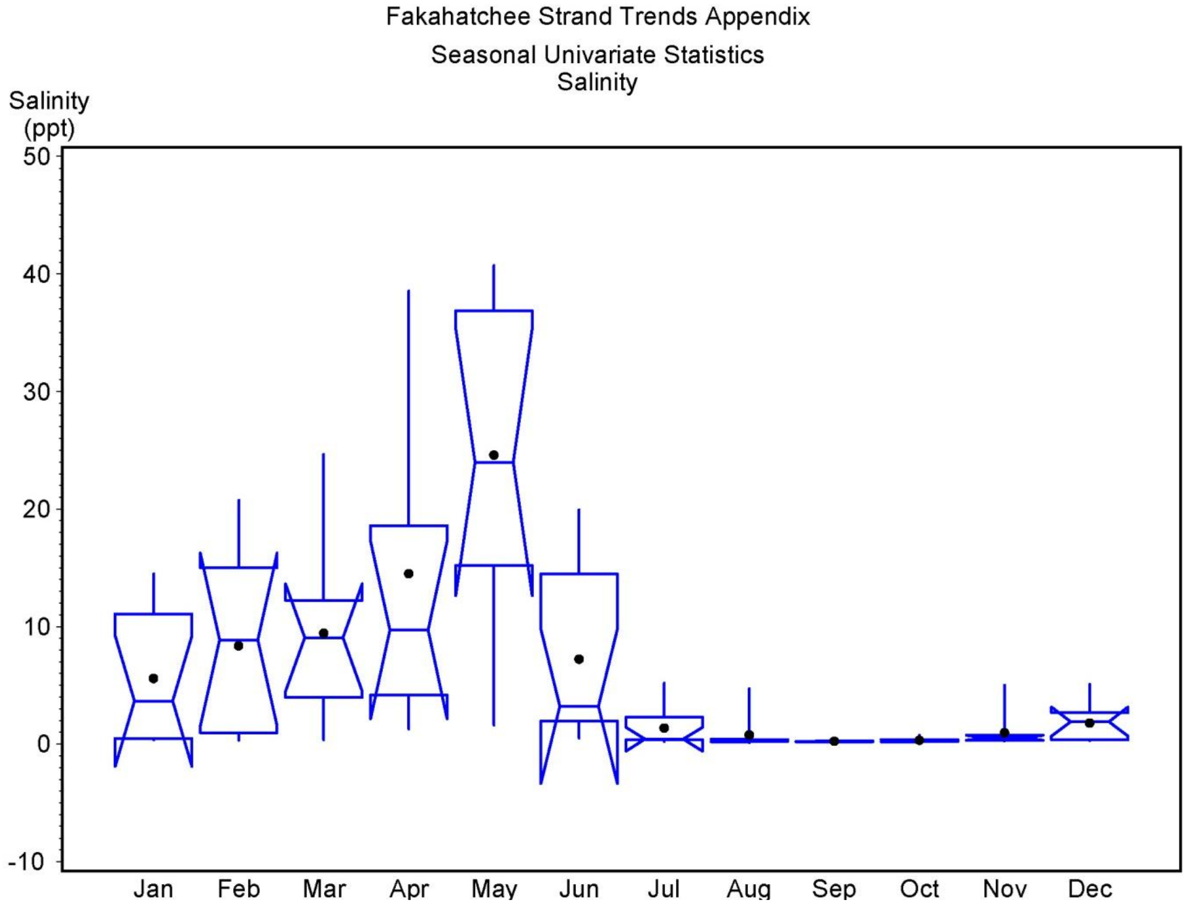

Figure 3.3-1 - Example of monthly boxplots for water quality parameters contained in Appendix 3-3. This plot depicts the seasonal pattern observed for salinity in Fakahatchee Strand.

Conductivity and salinity displayed similar patterns of seasonality. Inland basins and those basins where water quality stations were located behind water control structures had low conductivities ranging from monthly means of 200-1,200 uS/cm. These included Barron River Canal, Camp Keais, Corkscrew Marsh, Cow Slough, North Golden Gate, Okaloacoochee Slough, Tamiami Canal, Faka Union North, Immokalee and Silver Strand, the latter three basins displaying no apparent seasonality. Fakahatchee Strand, Gordon River Extension, Rookery Bay Inland East, Cocohatchee River, Naples Bay and Ten Thousand Islands commonly had monthly average conductivities >10,000 uS/cm and as high as 20,000-40,000 uS/cm during the dry season. Faka Union South, Cocohatchee Inland and Rookery Bay Inland West had intermediate conductivities ranging from 600-3,000 uS/cm though Faka Union South and Rookery Bay Inland West reached 10,000-13,000 uS/cm during the peak dry season.

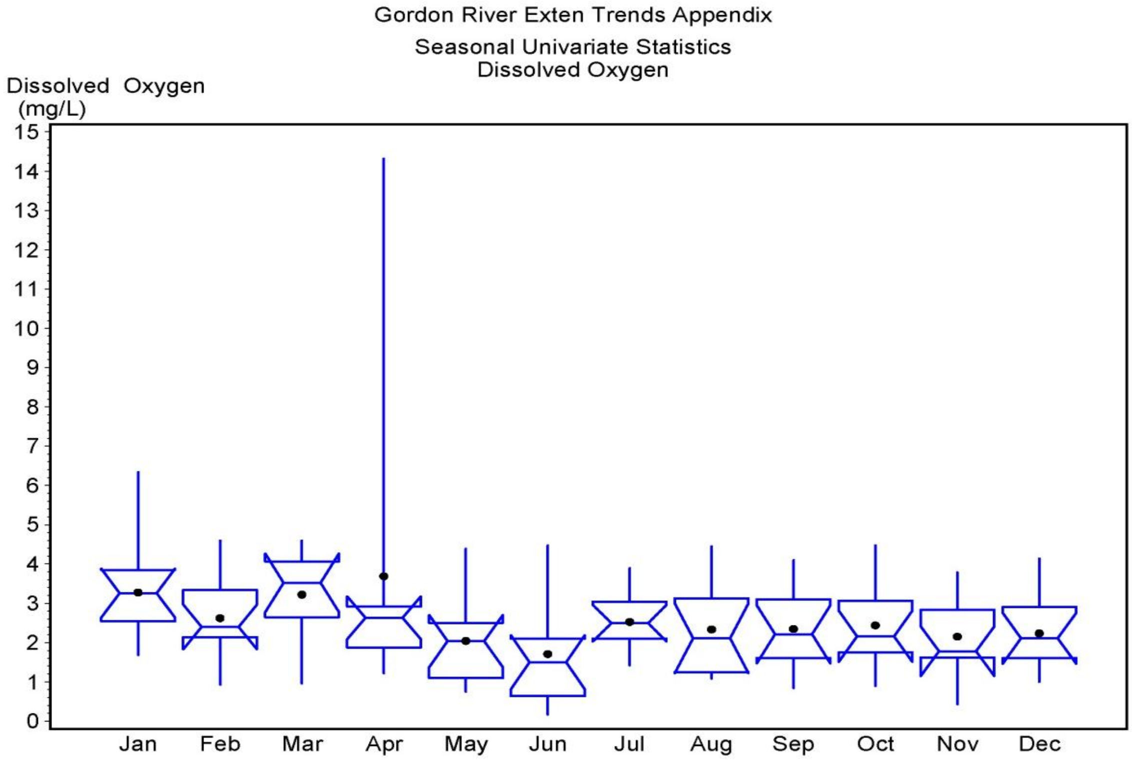

Figure 3.3-2 - Consistently low average monthly dissolved oxygen levels were observed for Gordon River Extension.

Dissolved oxygen and biochemical oxygen demand

Seasonality in dissolved oxygen concentrations was common for most of the basins, however there was a lack of a distinct seasonal pattern for Corkscrew Marsh, Immokalee, Gordon River Extension (Figure 3.3-2) and Tamiami Canal with consistently low (<5 mg/L, on average) or highly variable (2-9 mg/L, on average) dissolved oxygen levels in these basins. Dissolved oxygen was seasonally high during the colder months from January-April and lowest between July and September when water temperatures were highest (and oxygen saturation levels were lowest). Coastal and western basins had the highest monthly average levels for dissolved oxygen (4-6 mg/L, in general). These basins included Cocohatchee River and Inland, North Golden Gate, Naples Bay, Rookery Bay Inland (East and West), Faka Union (North and South) and Ten Thousand Islands. Lower dissolved oxygen levels (often <4 mg/L, on average) were more common in the northern and central portion of Collier County. Camp Keais, Cow Slough, Okaloacoochee Slough, Silver Strand, Fakahatchee Strand were among those basins with lower dissolved oxygen levels. Barron River Canal had some of the lowest average monthly levels, often between 2-3 mg/L.

Relatively low monthly values for biochemical oxygen demand (<2.2 mg/L, on average) were commonly observed for Faka Union (North and South) and Ten Thousand Islands. In general, monthly BOD was between 2.0-3.0 mg/L during most months and for most basins, though it was not uncommon to see BOD values exceeding 4.0 mg/L between March and May with values as high as 11.2 mg/L in Okaloacoochee Slough in April. Relatively high monthly values (>4.0 mg/L) were observed from March-May and from September-October for Barron River Canal, Camp Keais, Cocohatchee River, Corkscrew Marsh, Fakahatchee Strand, North Golden Gate, Immokalee, Rookery Bay Inland West and Okaloacoochee Slough.

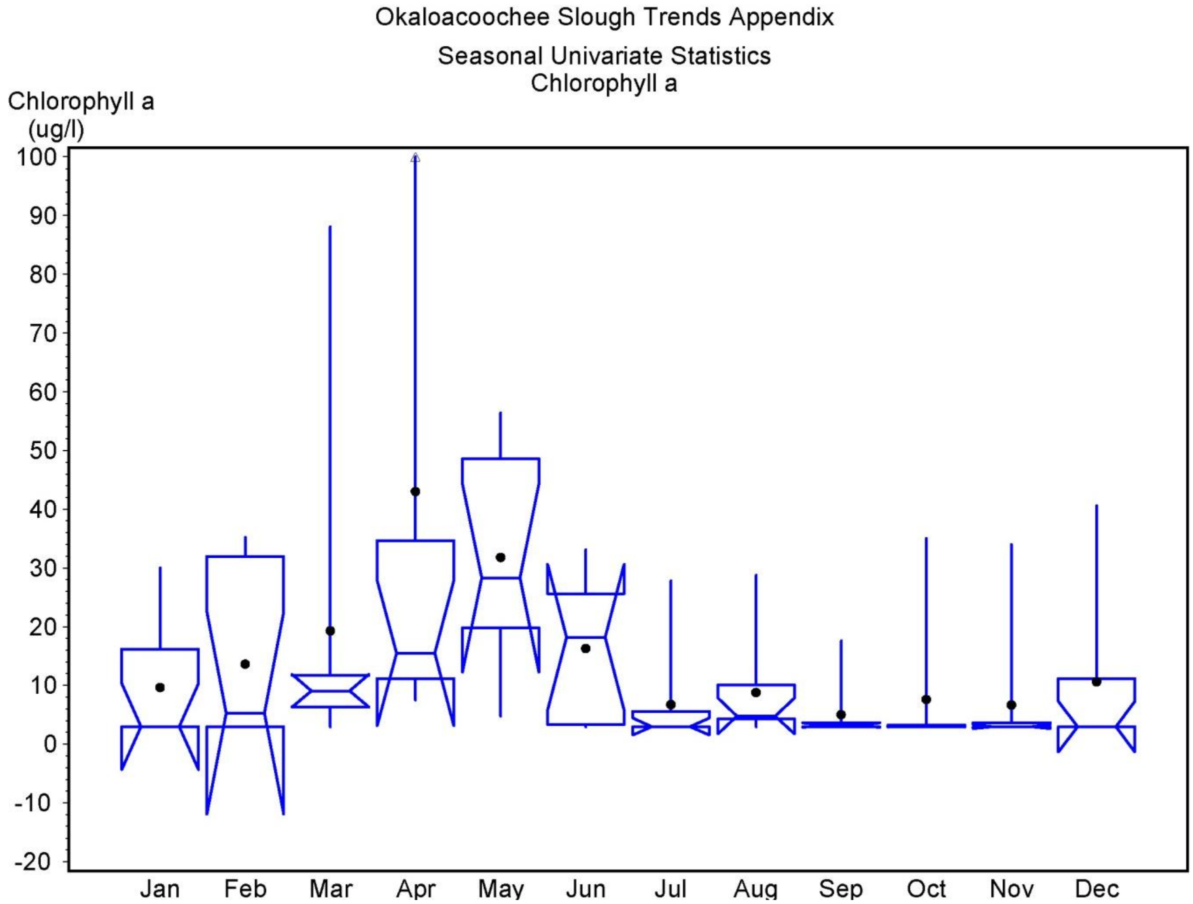

Figure 3.3-3 - Example of trends in chlorophyll for Okaloacoochee Slough.

Chlorophyll-a

Monthly-average chlorophyll levels were lowest between September-October or between December-January but not predictably for any of the basins. High monthly chlorophyll values occurred commonly between April and June but as with low values, there was little consistency among basins. High monthly values for most basins averaged 10.4-16.7 ug/L although the northern and central basins including Okaloacoochee Slough (Figure 3.3-3), Camp Keais, Barron River Canal, Fakahatchee Slough and Tamiami Canal had peak chlorophyll levels greater than twice that of most other months in those basins (19.3-42.0 ug/L). In contrast was a group of conjoining basins including Corkscrew Marsh, Faka Union North and North Golden Gate, as well as Ten Thousand Islands downstream of Faka Union, all of which had consistently low and relatively invariable chlorophyll levels ranging from 2.9-8.2 ug/L.

pH

pH levels varied spatially by basin with basins either having low pH (7.0-7.4 monthly average) or high pH (7.3-7.7 monthly average). Many of the inland basins had lower pHs including Barron River Canal, Camp Keais, Cow Slough and Okaloacoochee Slough, but Gordon River Extension and Cocohatchee River along the coast also had low pH levels. These basins also had little seasonality in pH levels, particularly Gordon River Extension, Cocohatchee River and Barron River

Canal. Tamiami Canal, Ten Thousand Islands and Naples Bay had higher pHs but also showed little seasonality in pH. When pH varied seasonally, it was lower during the rainy season from June to November. This was true for basins with higher pH including Rookery Bay Inland (East and West), Faka Union (North and South), Fakahatchee Strand, North Golden Gate and Immokalee. Two basins, Corkscrew Marsh and Silver Strand were distinct because of high variability in pH levels (6.8-7.8) and little discernable seasonality.

Total suspended solids, turbidity and color

Total suspended solids (TSS) were lowest for Barron River Canal, Corkscrew Marsh, Cocohatchee Inland, Cow Slough, Camp Keais, Faka Union (North and South), North Golden Gate, Rookery Bay Inland West and Tamiami Canal where monthly averages ranged from 2.0-9.0 mg/L, except for February in Cow Slough (16.0 mg/L) and May for Tamiami Canal (10.0 mg/L) and Camp Keais (12.5 mg/L). Faka Union had consistently low TSS concentrations usually less than 4.0 mg/L (monthly average). Fakahatchee Strand, Gordon River Extension, Immokalee, Rookery Bay Inland East and Ten Thousand Islands also fell within the same range of monthly averages (2.0-7.6 mg/L) but these basins had a higher frequency of months where average TSS was 5-10 times greater and ranged from 12.9-26.6 mg/L (see example in Figure 3.3-4). These high TSS levels commonly, but not always, occurred between April and June. The highest TSS levels were observed for Cocohatchee River and Naples Bay where monthly average TSS values ranged from 10.5-22.5 mg/L during the majority of months.

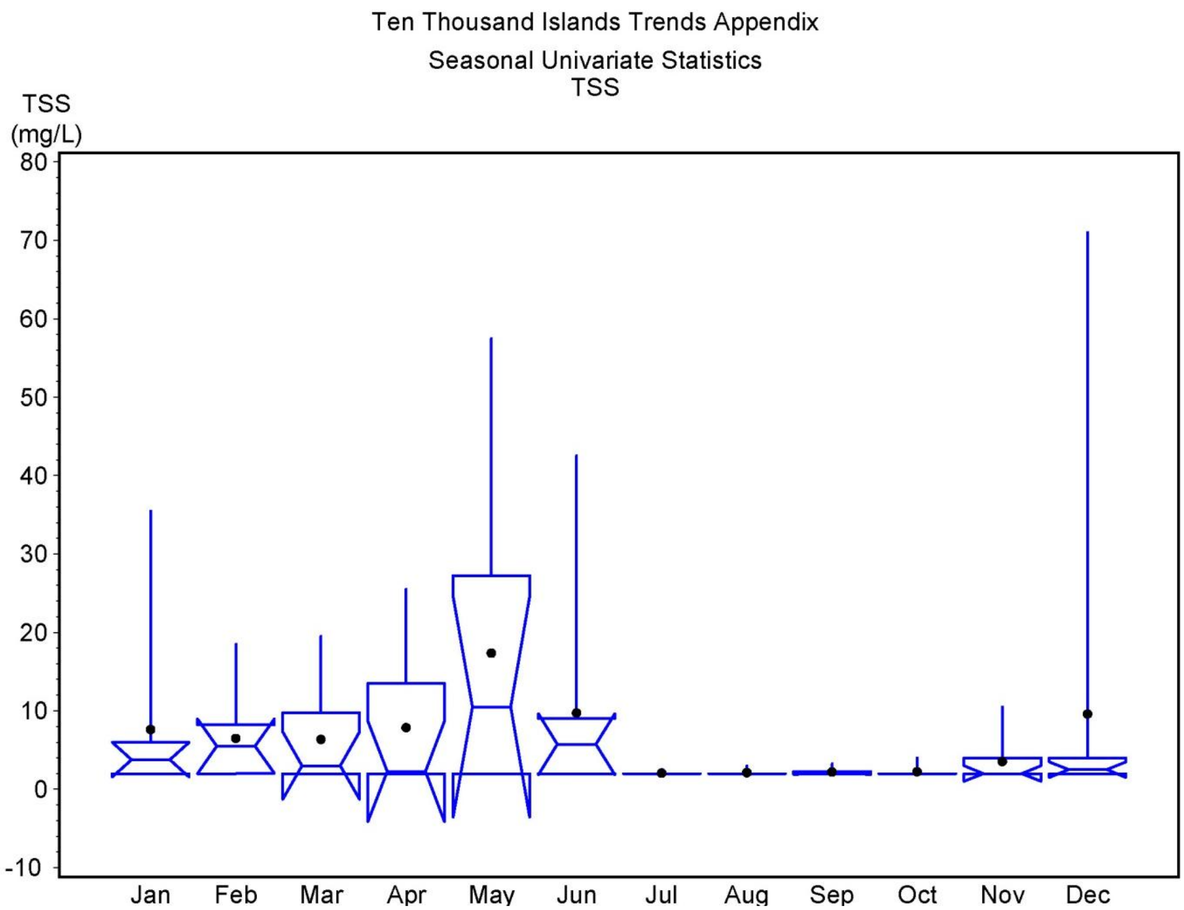

Figure 3.3-4 - Example of trends in total suspended solids for Ten Thousand Islands.

The lowest turbidity values were recorded for Faka Union (South), Camp Keais, Fakahatchee Strand and Tamiami Canal where values were frequently ≤1.5 ntu though values of 2.1-5.5 ntu were observed for the latter two basins between April and June. Turbidity in around the City of Naples in the North Golden Gate, Naples Bay, Cocohatchee Inland and Cocohatchee River basins was consistently highest, typically ranging between 2.0-5.0 ntu. The remaining basins (Barron River Canal, Okaloacoochee Slough, Gordon River Extension had intermediate monthly-average turbidities (1.5-3.0 ntu) with several higher turbidities observed as high as 10.6 for Okaloacoochee Slough in May. Insufficient sample size prevented summary of Immokalee, Cow Slough and Silver Strand.

Color values varied seasonally across Collier County with higher values during the wet season and lower values in the dry season. Coastal basins tended to have lower color (relatively better water clarity), than inland basins which tended to have higher color (relatively poor water clarity). The best water clarity, in terms of low color, was observed for Tamiami Canal and Ten Thousand Islands where average monthly color ranged from 28.1-72.5 platinum-cobalt units (pcu) with very few values >100 pcu. Low color (typically between 40-80 pcu) was also recorded for Faka Union (North and South), Rookery Bay Inland (East and West), Naples Bay, Gordon River Extension, Cocohatchee River and Cocohatchee Inland. Average monthly color for these basins exceeded 100 pcu only in Faka Union North and Rookery Bay Inland East and only during September. Higher color values (typically 80-120 pcu) and more frequent monthly maximums between 200-400 pcu

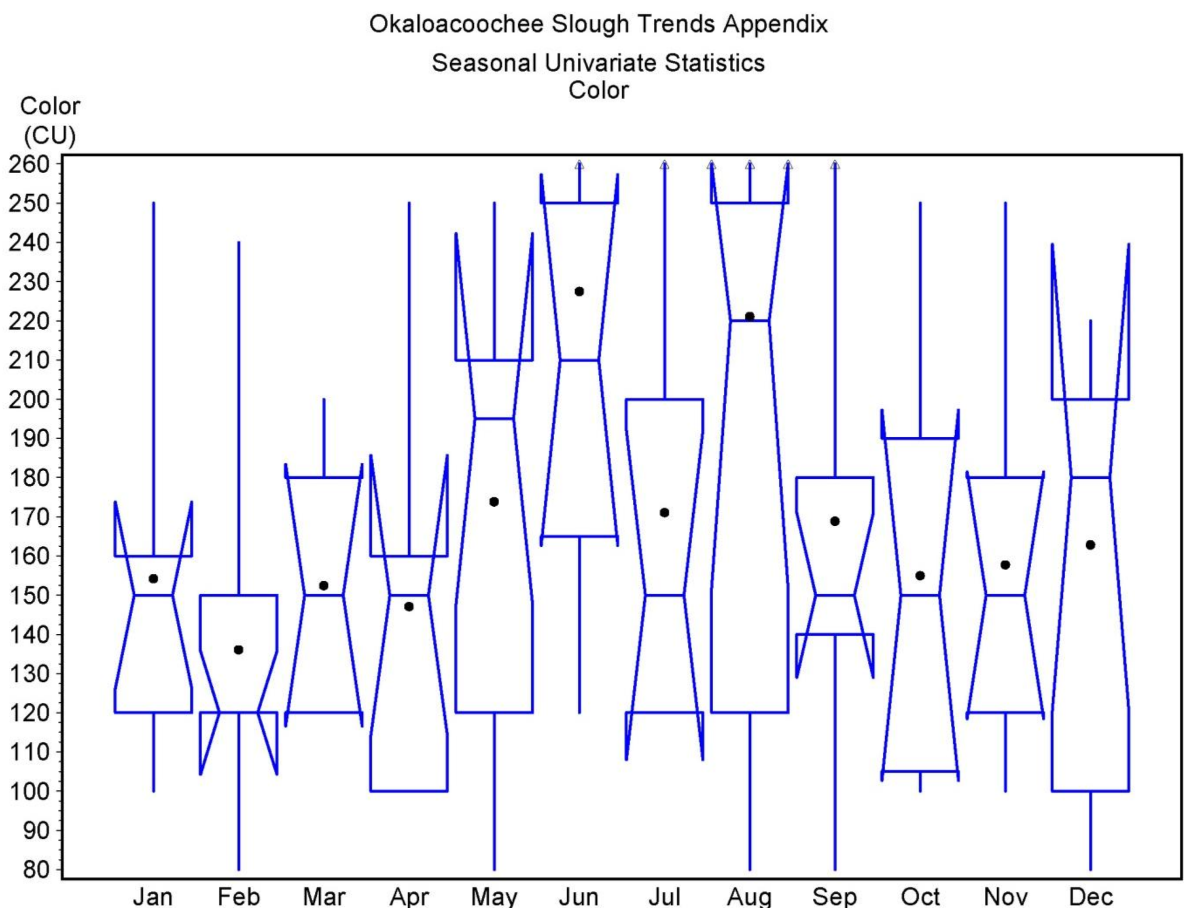

Figure 3.3-5 - Example of trends in color for Okaloacoochee Slough.

were reported for Camp Keais, Barron River Canal, Corkscrew Marsh, Fakahatchee Strand, North Golden Gate and Immokalee. Color reached between 124-183 pcu in these basins between August and October. The most inland basins had the highest color values, indicating poor water clarity. Color for Okaloacoohee Slough (Figure 3.3-5), Cow Slough and Silver Strand, adjoining basins in northern Collier County, typically ranged between 150-200 pcu with maximum monthly values often reaching 250-400 pcu.

Nutrients (Inorganic and organic nitrogen, Total nitrogen, Total phosphorus)

Nutrient levels did not typically display any discernable seasonality (see example in Figure 3.3-6). Inorganic nitrogen (nitrate-nitrite) was relatively low throughout Collier County, rarely exceeding a maximum monthly value of 0.2 mg/L for many basins. Even basins such as Cocohatchee River, Cocohatchee Inland, Corkscrew Marsh, Gordon River Extension and Rookery Bay Inland West with observed monthly maximums between 0.4 and 0.7 mg/L typically had monthly averages ≤ 0.1 mg/L. The exceptions were Immokalee and Silver Strand, both of which were located in northern Collier County, and both of which had inorganic nitrogen levels that were often between 0.3 and 0.9 mg/L with monthly maximums from 1-3 mg/L. While inorganic nitrogen concentrations did not appear to be strongly seasonal, several of the western basins around Naples (Cocohatchee Inland, North Golden Gate, Gordon River Extension, Naples Bay and Rookery Bay) appeared to have slightly higher inorganic nitrogen levels between September and February. Tamiami Canal and Cow Slough in other parts of the County also displayed a similar pattern.

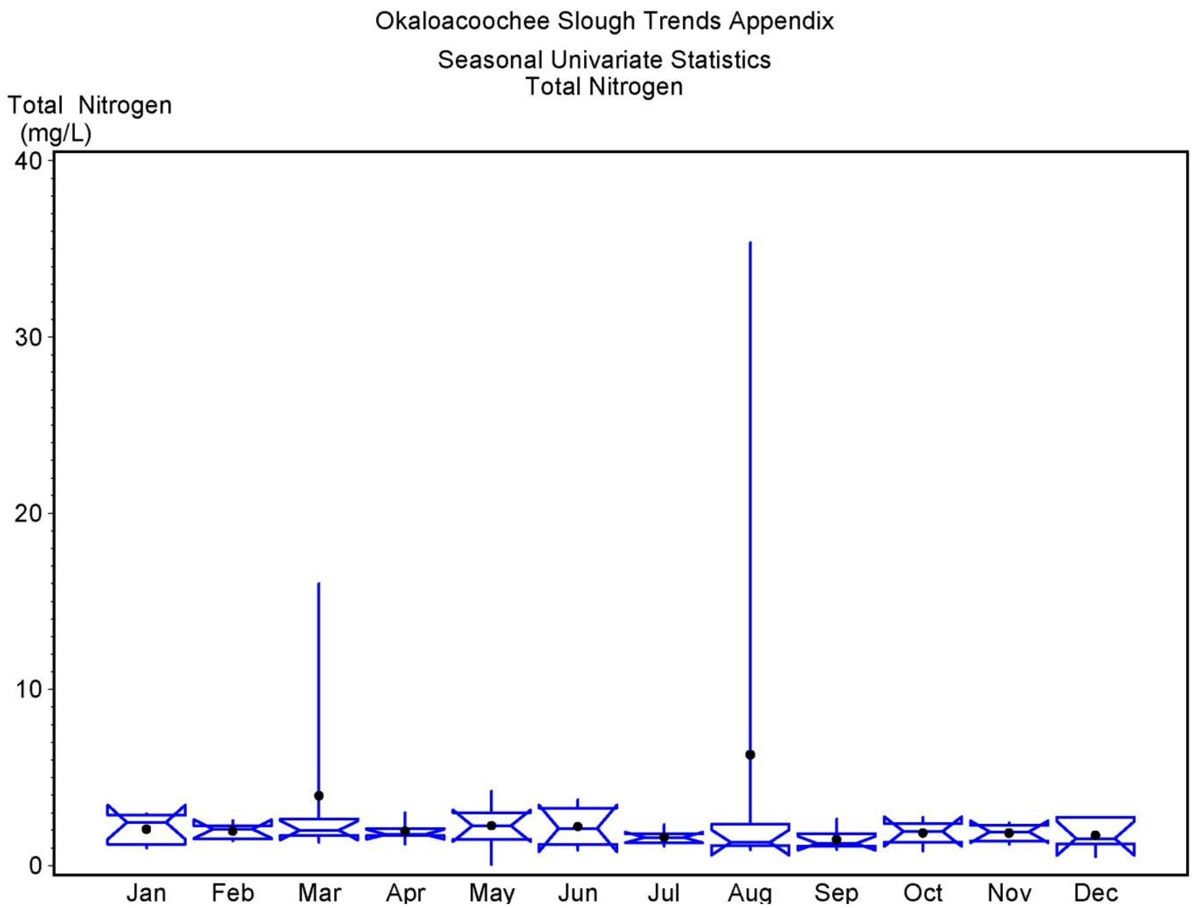

Figure 3.3-6 - Example of trends in total nitrogen for Okaloacoochee Slough.

Concentrations of organic nitrogen (measured as total Kjeldahl nitrogen; TKN) and total nitrogen (the sum of organic and inorganic nitrogen) did not appear to be seasonal, although maximum values for both were observed most commonly from March-May in the few cases that high variation for these nutrients occurred. Because organic nitrogen is a large percentage of total nitrogen, trends were nearly identical for both parameters. To avoid repetition, only observations for total nitrogen (TN) are summarized. Monthly-average TN levels ranged from 0.5-2.0 mg/L for nearly all basins with maximum monthly TN levels <3.0 mg/L in most cases. Lowest monthly TN concentrations (0.5-0.9 mg/L) were observed for Faka Union (North and South), Rookery Bay Inland East, Tamiami Canal and Ten Thousand Islands except May and November for Faka Union South (1.1 mg/L) and Tamiami Canal (1.0 mg/L), respectively, for which monthly average TN was slightly greater. The highest TN concentrations were observed for Okaloacoochee Slough where monthly averages ranged from 1.5-6.3 mg/L (Figure 3-#) and for Silver Strand where monthly averages ranged from 1.3-3.1 mg/L, and commonly averaged ≥2.0 mg/L for both basins. Monthly maximum TN values >10.0 mg/L and as high as 43.2 mg/L in Naples Bay were recorded for North Golden Gate, Gordon River Extension, Okaloacoochee Slough and Naples Bay.

Total phosphorus concentrations were very similar among most basins rarely exceeding a monthly average of 0.2 mg/L. Faka Union (North and South) and Fakahatchee Strand consistently had the lowest monthly average TP levels at <0.1 mg/L. The highest TP levels were observed for Cow Slough, Immokalee and Silver Strand which are adjacent basins, and for Cocohatchee Inland. Monthly averages commonly ranged from 0.3-0.6 mg/L and were highest for Silver Strand. Monthly maximums between 2.0-9.9 mg/L were recorded for Cocohatchee Inland and Immokalee and despite having the highest monthly average TP concentrations, monthly maximums at Silver Strand were relatively low (0.4-1.3 mg/L).

3.3.2 Identifying similarity in water quality conditions among basins

Collier County drainage basins can be separated into three distinct groups, one which includes several "interior" inland basins: 1) Okaloacoochee Slough, Corkscrew Marsh, Camp Keais, Barron River Canal, Silver Strand, Cow Slough, Immokalee, another which includes the coastal basins of 2) Naples Bay, Ten Thousand Islands, Cocohatchee River, Gordon River Extension and Rookery Bay Inland East and a third group of inland basins located centrally within the County and including Rookery Bay Inland West, Cocohatchee Inland, Faka Union (North and South), North Golden Gate, and Tamiami Canal (Figure 3.3-7 and Figure 3.3-8).

Interior inland basins were more variable than the centrally located inland or coastal basins in terms of annual water quality. Water quality in the Okaloacoochee basin was most variable from year to year, based on the dissimilarity in annual water quality conditions. Water quality in the Camp Keais and Barron River basins was also quite variable interannually, though these two basins were most similar to one another in terms of water quality.

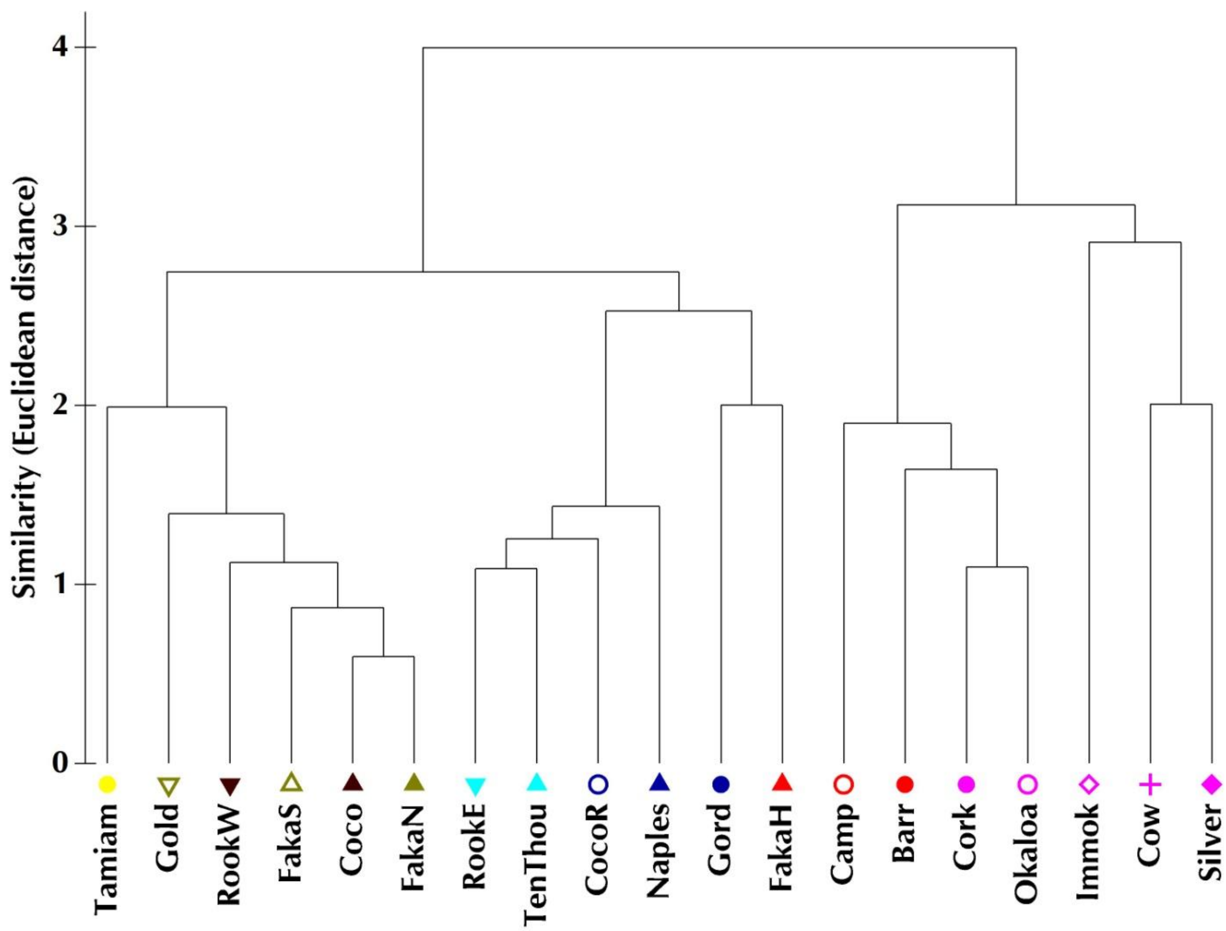

Figure 3.3-7 Cluster dendrogram showing similarity in water quality conditions among Collier County basins. Several parameters were excluded due to strong correlation with included parameters (biochemical oxygen demand, specific conductance, organic and inorganic nitrogen, secchi depth) or to allow the inclusion of basins with missing data (chlorophyll, turbidity).

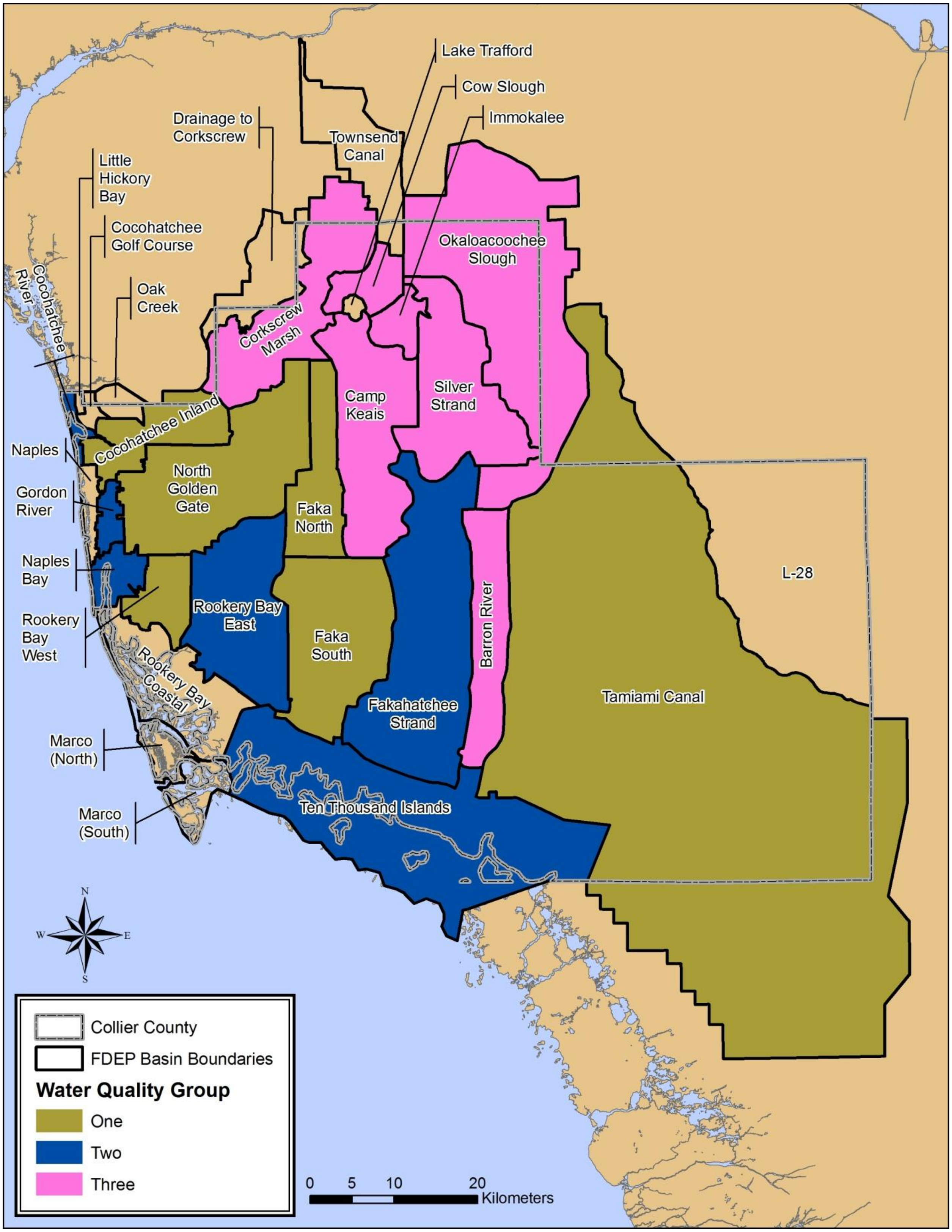

Figure 3.3-8 – Map of Collier County basins color-coded to indicate similar water quality conditions based on the results of principal components ordination of water quality data.

3.3.3 Discriminating water quality parameters

The initial principal components analysis (PCA, Figure 3.3-9) contained several basins which were outliers. Four of the basins displayed extreme deviation from typical interannual water quality during at least one year resulting in a greater than average distance between points on the ordination plot. Low rainfall during 2000 and 2007-2009 resulted in higher specific conductance, chlorophyll levels and nutrient concentrations (TN, TP) and darker color in Okaloacoochee Slough compared to previous years, which explains their location relative to the other basins on the PCA plot. In general, the same differences in water quality were observed for most of the basins these drier years, but several basins, including Okaloacoochee Slough happened to have the most extreme deviations from typical conditions.

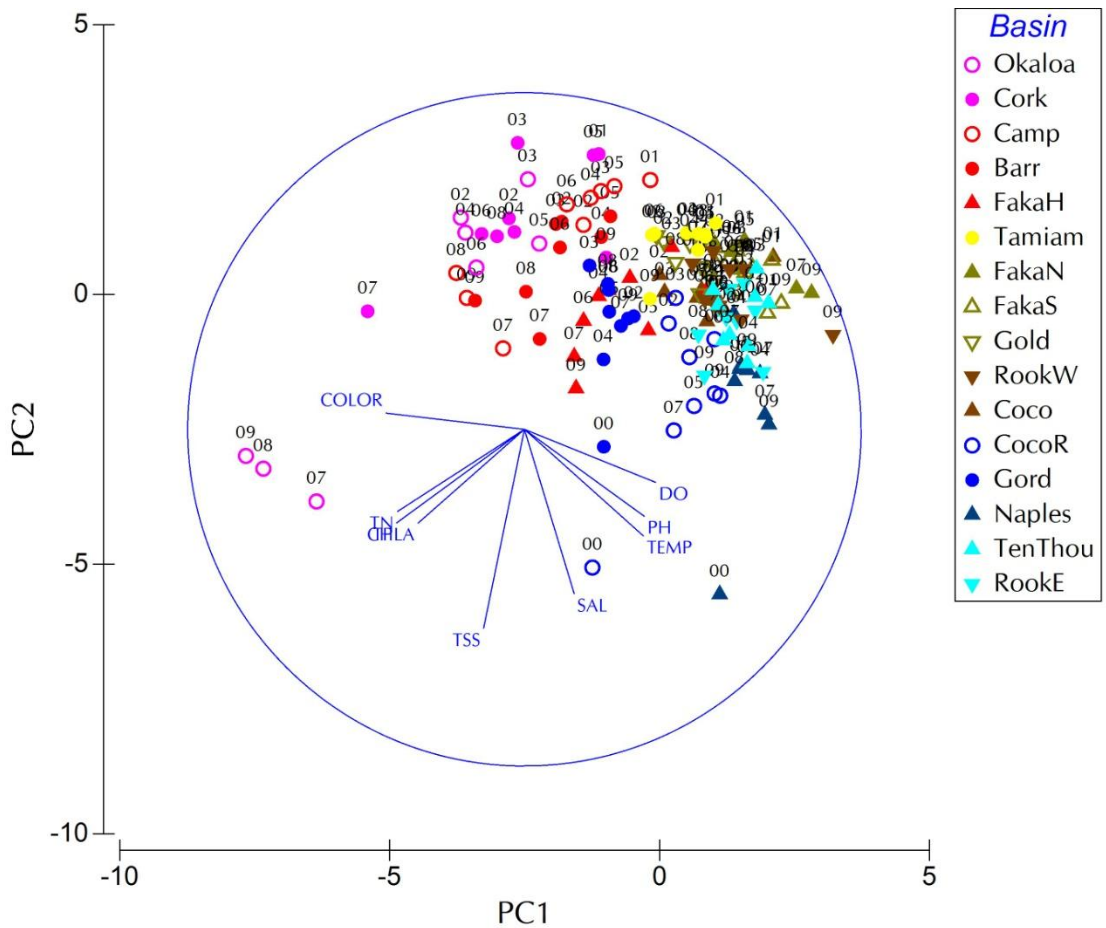

Figure 3.3-9 - Initial PCA showing the relationship among Collier County basins and water quality.

For several of the coastal basins, low rainfall during 2000 also resulted in deviations from typical water quality conditions, particularly for several parameters; higher salinities, total nitrogen and total suspended solids were observed in the Naples Bay, Gordon River Extension and Cocohatchee River basins.

The PCA was re-run after removing the outliers described above to better resolve patterns among the more similar basins (Figure 3.3-10, Figure 3.3-11, Table 3-2). Based on this analysis, 69.3% of the variation in water quality among basins was explained by the first three principal components (PC 1-3). The majority of the variation (39.5%) was explained by the separation of many of the northern, inland basins (Silver Strand, Immokalee, Okaloacoochee Slough, Camp Keais, Cow Slough, Barron River Canal and Corkscrew Marsh) which were identified as being distinct from the more coastal basins based on lower pH, darker color, lower dissolved oxygen, higher total nitrogen concentrations and warmer water temperatures (variables with eigenvalues >0.35). Gordon River Extension and Fakahatchee Strand were intermediate to the coastal and inland groups with water quality conditions that were central along the gradient and shared characteristics of both groups.

Among the coastal basins, Ten Thousand Islands, Naples Bay, and Rookery Bay Inland East were very similar and Cocohatchee River was more similar to these basins than to the others. These basins were distinguished from Faka Union, North Golden Gate, Tamiami Canal, Rookery Bay Inland West and Cocohatchee Inland by higher salinities and total suspended solids. PC2 explained an additional 16.7% of the variation among basins. The third axis (PC3) was defined as a gradient of increasing nutrients and dissolved oxygen along which most of the basins were separated from Silver Strand, Cow Slough and Immokalee. These three basins had higher total nitrogen and phosphorus and higher dissolved oxygen levels than the rest of the basins. PC3 explained 13.1% of the variation in the data.

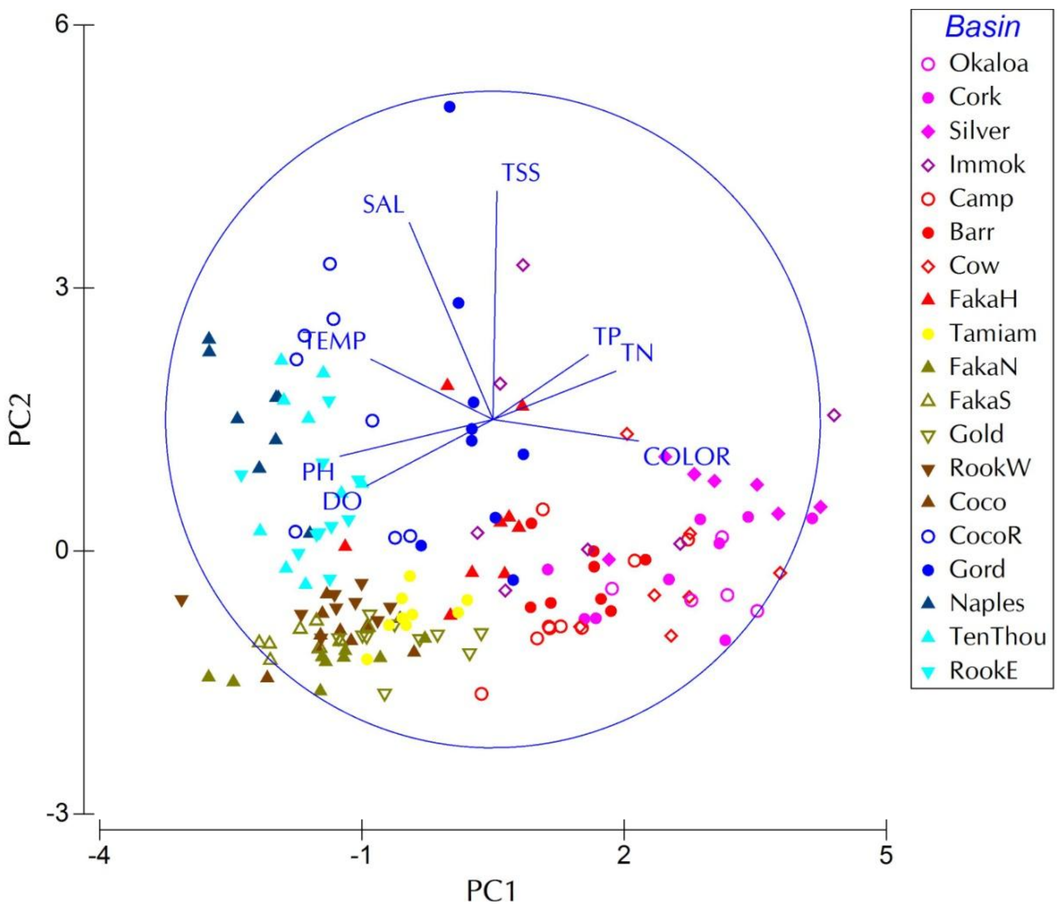

Figure 3.3-10 - Final PCA showing the relationship among Collier County basins and water quality relative to principal component axes 1 and 2.

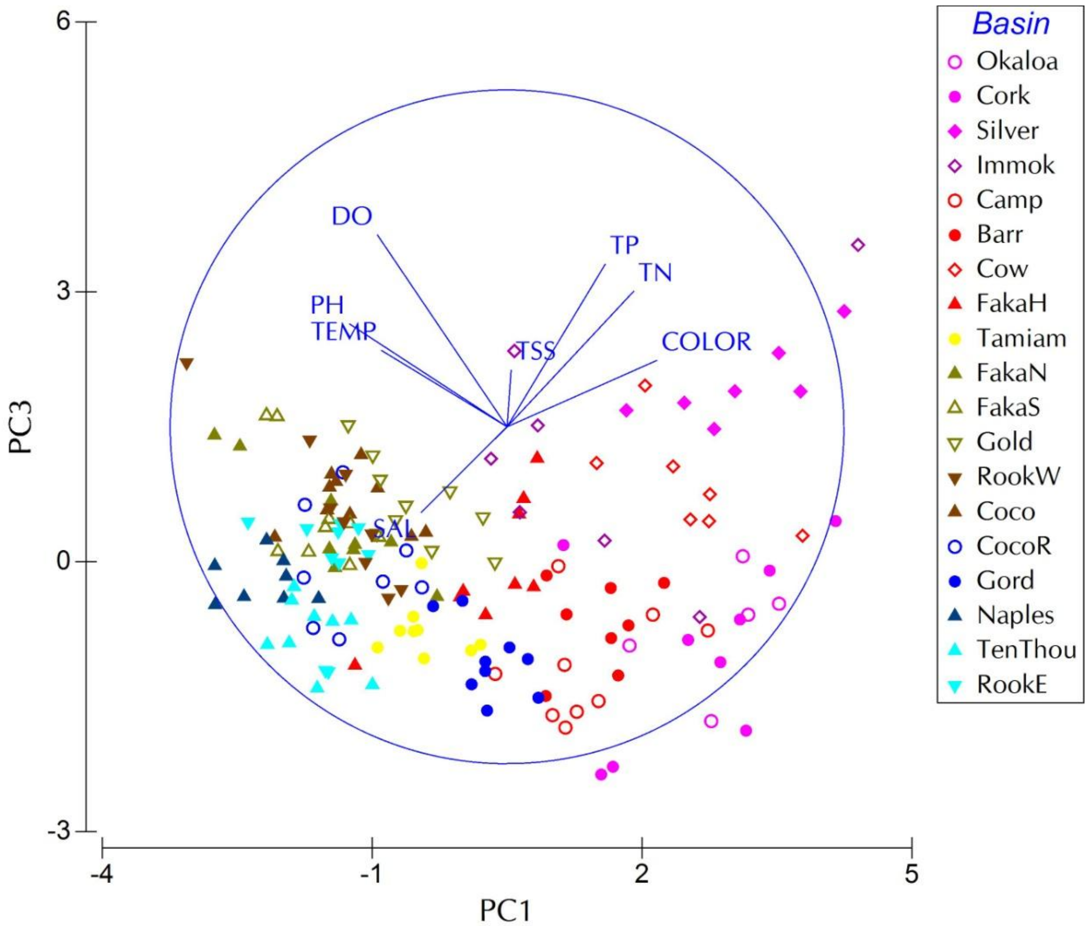

Figure 3.3-11 - Final PCA showing the relationship among Collier County basins and water quality relative to principal component axes 1 and 3.

Table 3-2 – Results of the final principal component analysis (PCA) describing the combination of water quality parameters that best explains the observed variation among Collier County basins (2000-2009). Variables with coefficients >0.35 were considered to be explanatory.

Eigenvalues

PC	Eigenvalues	% variation	Cumulative % variation
1	3.16	39.5	39.5
2	1.34	16.7	56.2
3	1.05	13.1	69.3
4	0.765	9.6	78.8
5	0.685	8.6	87.4

Eigenvectors

Coefficients in the linear combinations of variables making up PCs

Variable	PC1	PC2	PC3	PC4	PC5
TEMP	-0.374	-0.184	-0.227	0.643	0.074
PH	-0.469	0.112	-0.306	-0.294	0.010
SAL	-0.256	-0.601	0.255	0.327	0.078
DO	-0.386	0.202	-0.570	-0.058	0.166
TN	0.377	-0.148	-0.403	0.114	0.455
TP	0.292	-0.198	-0.484	0.149	-0.772
TSS	0.012	-0.697	-0.170	-0.564	0.122
COLOR	0.446	0.066	-0.198	0.191	0.378

3.3.4 Trends in water quality across Collier County

The following discussion details significant water quality trends by basin within Collier County for the period of record of water quality data collection from the start of monthly monitoring in 1999 through 2009. The results of an informal analysis of trends for the historical period (1989-1998) vs. the recent period (1999-2009) follow this section. A geographic reference map is provided in Figure 3.3-11 to orient the reader to the basin locations discussed in this section. The results of the water quality trend analysis for the period of record are summarized in maps of the Collier County basins showing significant trend results (Figures 3.3-12 – 3.3-28). A more detailed series of tables summarizing the trend results is included in Appendix 3-3.

For the purposes of this report, "shallow trends" are defined as statistically significant trends with a rate of change less than 5% of the median value per year, and "steep trends" are defined as statistically significant trends with a rate of change greater than or equal to 5% of the median value per year. Thus, "shallow trends" represent water quality conditions that are changing (either increasing or decreasing) at a lesser rate of change than the rate of change for "steep trends." These are relative terms, and the precise rates of change are presented for each station in the statistical detail appendices. The terms "steep" and "shallow" do not imply either ecological significance or the lack of ecological significance. Further, we differentiate trends based on the trend direction. The term "degrading trend" is meant to signify declining water quality condition rather than decreasing in magnitude whereas "improving trend" is meant to denote improving water quality rather than increasing in magnitude. It is important to note that an improving trend does not necessarily signify that the water quality parameter is within acceptable levels based on State Standards or the Impaired Waters Rule. Similarly, a degrading trend does not necessarily indicate that water quality conditions are degraded or in exceedance of the threshold. For most parameters increases in concentration mean degrading water quality but for some parameters (e.g., dissolved oxygen) increases are related to improving water-quality conditions. Therefore, on the maps, the color green indicates an improving trend while pink indicates a degrading trend.

The results of the trends analysis are reported below by basin. First, a description of the basin is given, including relative size in the watershed, location, connection to other basins and characteristic land uses based on recent data (SFWMD 2005 land use) to allow interpretation of the water quality trends in the context of various basin attributes. Then, the results of the trend analysis are presented with an emphasis on those parameters with significant trends over the period from 1999-2009. A more detailed land-use characterization is provided in Section 3.4. Only 1 of the 19 basins, Cow Slough, was excluded from the trend analysis due to an insufficient number of samples.

In general, statistically significant trends for salinity were observed for most of the basins, all increasing (degrading) during the period of analysis. Among these were Naples Bay and Cocohatchee River which also exhibited steep increasing trends (degradation) in conductivity. These were the only steep increasing (degrading) trends in any of the water quality parameters from 1999-2009. The primary factor causing the observed increasing trends in salinity and conductivity for so many of the basins across Collier County was likely the very low rainfall totals during the years 2007-2009. Faka Union North exhibited a shallow decreasing (improving) trend for salinity.

Shallow decreasing (improving) trends in color were observed for Faka Union North, Rookery Bay (East and West) and Tamiami, as well as Golden Gate and Cocohatchee River, while shallow increasing (degrading) trends in color were apparent for Okoloacoochee Slough and Fakahatchee Strand.

Dissolved oxygen was observed to decrease over time for the Ten Thousand Islands basin and Barron River Canal (which lies upstream) and for the Naples Bay basin. Degradation of dissolved oxygen levels on the order of 0.5-1.0 mg/L occurred in these basins from 1999-2009, which resulted in reductions from 5.3 to 4.4 mg/L for Ten Thousand Islands, 3.3 to 2.3 mg/L for Barron River Canal and 5.4 to 4.9 mg/L for Naples Bay. Biochemical oxygen demand increased for the Tamiami Canal basin, although this trend was probably the result of a peak in BOD in 2009 and a relatively short, 5-year time series. No improvements in dissolved oxygen or biochemical oxygen demand were observed from 1999-2009.

Increasing trends (improvement) in pH were observed for many of the basins in western Collier County including Cocohatchee Inland, Naples Bay, Rookery Bay Inland (East and West) and Faka Union (North and South). The only decreasing (degrading) trend in pH was for Gordon River Extension.

Decreasing trends (improvement) in dissolved inorganic nitrogen (nitrate-nitrite) occurred in the Faka Union North and Rookery Bay Inland West. An increasing trend (degrading) in total nitrogen and total phosphorus was observed in the central and eastern portions of Collier County in the Okoloacoochee Slough basin, Fakahatchee Strand, Camp Keais, Faka Union South and Ten Thousand Islands basins and corresponded with a similar increase in organic nitrogen, in the form of total Kjeldahl nitrogen, in these basins. Organic nitrogen (but not total nitrogen) and total phosphorus also increased (degrading trend) in the Tamiami Canal basin. In contrast, organic nitrogen exhibited shallow decreasing trends (improvement) for the Rookery Bay Inland West, Cocohatchee Inland and Cocohatchee River basins. These decreases in organic nitrogen seemed to translate to a decrease in total nitrogen for the same basins in the western portion of Collier County. Total phosphorus increased (degrading trend) in Naples Bay and Rookery Bay Inland East basins.

The only significant trend in chlorophyll was a decrease (improvement) for Faka Union North which was accompanied by a decreasing trend (improvement) in inorganic nitrogen in this basin.

Turbidity decreased (improved) for several basin along the west-central coast of Collier County including, Faka Union North, Rookery Bay Inland West basin, Naples Bay basin and Cocohatchee River. Increased turbidity (degrading) was observed for Okaloacoochee Slough, Fakahatchee Strand, Camp Keais, Rookery Bay Inland East and the Gordon River Extension. The only significant trend for total suspended solids was an increasing trend (degrading) in North Golden Gate.

Heavy metal concentrations were relatively stable throughout Collier County, but there were a few exceptions involving gradual trends in the western part of the county. Arsenic concentrations increased (degraded) for Cocohatchee River and Fakahatchee Strand and decreased (improved) for Immokalee and Tamiami Canal. Copper concentrations decreased (improved) for Cocohatchee Inland, Faka Union (North and South), North Golden Gate and Tamiami Canal, but were not found to increase (degrade) in any of the basins. No significant trends were observed for iron in any of the basins.

There were no significant trends for water temperature in any of the basins.

3.3.5 Trends in water quality by basin

Barron River Canal

Barron River Canal is a moderately sized basin (135 km^2) located downstream of Silver Strand and Okaloacoochee Slough in the central portion of the County. All three basins drain south into the Ten Thousand Islands (Figures 1.0-1 and 2.1-2). The Barron River Canal basin is largely dominated by natural land cover, primarily wetlands (95%) with some uplands as well (4%). Urban (<1%) and agricultural (<1%) land uses are minimal within this basin.

A shallow decreasing trend was found for dissolved oxygen. No steep increasing or decreasing trends were found in the Barron River Canal.

Camp Keais

The Camp Keais Basin is a relatively large basin (225 km^2) located in the central part of Collier County. This basin drains south to the Faka Union North and South basins which ultimately drain into the Ten Thousand Islands through the Faka Union Canal (Figures 1.0-1 and 2.1-2). The Florida Panther National Wildlife Refuge is located partially within the Camp Keais basin. Land use within the basin consists of natural land cover, both wetlands (48%) and uplands (12%), but is also heavily agricultural (40%). Less than 1% of the Camp Keais basin is urbanized.

Trends for the Camp Keais Basin are shown at the end of this section. In the basin, several shallow increasing trends were found including an increase in organic nitrogen, total nitrogen and phosphorus, and turbidity. None of the parameters were found to exhibit declining water quality trends.

Cocohatchee (Inland Segment)

The Cocohatchee drainage consists of three basins: Cocohatchee River, Cocohatchee Golf Course and an Inland segment. The Cocohatchee Inland basin is a moderately sized basin (105 km^2) located just inland of the river and golf course basins and centrally between the cities of Naples and Bonita Springs. This basin receives flows from Corkscrew Swamp upstream and discharges to the Cocohatchee River. Just over 50% of the basin has been urbanized, much of it as golf courses, though wetlands (36%) and uplands (5%) still exist there, as well. A small portion of the basin is used for agriculture (6%).

pH exhibited shallow increasing trends in the Cocohatchee Inland basin, while total nitrogen, Kjeldahl nitrogen and copper showed shallow decreasing trends. No steep trends were observed for any of the water quality parameters.

Cocohatchee River

The Cocohatchee River basin is a small drainage (12 km^2) located along the northwestern-most coast of Collier County. This basin receives input from Cocohatchee Golf Course and Inland basins, as well as from Corkscrew Swamp further upstream. Two state parks, Barefoot Beach State Preserve and Delnor-Wiggins Pass State Park are located at the mouth of the Cocohatchee River.

Land use within this basin is a mix of wetlands (59%) and urban areas (35%) with a small scattering of uplands (6%).

Statistical decreasing trends in color, turbidity, organic nitrogen and total nitrogen were observed for this basin. Salinity exhibited a shallow increasing trend as did arsenic, while conductivity exhibited a steep increasing trend. No other trends were observed for water quality in this basin.

Corkscrew Marsh

Corkscrew Marsh is one of the larger basins (214 km^2) and is located inland in the northern portion of the county. This basin drains to both the Cocohatchee Inland and North Golden Gate basins. The Corkscrew Marsh Sanctuary is a significant feature in the basin and contributes much of the natural land cover, primarily wetlands (61%) and some uplands (7%) that exists there. Agricultural land uses are also a sizeable portion of the basin (30%) though urban development is minimal (2%).

Conductivity and salinity have gradually increased over time from 1999-2009 in the Corkscrew Marsh basin. All of the other water quality parameters have remained consistent with no statistically significant trends during the analysis period.

Faka Union (North Segment)

The Faka Union basins consist of a northern and southern segment, both located in the central part of the Collier County watershed and divided by Interstate 75 (Alligator Alley). The Faka Union North basin receives flow from the Camp Keais basin and delivers it downstream to Faka Union South. This basin is moderately sized (111 km^2) but only half the size of Faka Union South. Land use within the Faka Union North basin is approximately one-third urban (34%) with significant wetland (39%) and upland (23%) land cover. A small amount of agriculture and barren land are found in this basin (3%).

A number of water quality parameters were observed to have shallow decreasing trends, including salinity, conductivity, color, copper, chlorophyll, inorganic nitrogen, and turbidity. pH exhibited a shallow increasing trend.

Faka Union (South Segment)

The southern segment of the Faka Union basin complex is relatively large in size (241 km^2) compared to most of the basins in Collier County and is twice as the size of Faka Union North. Flows from the Camp Keais and Faka Union North basins flow through Faka Union South and continue into the Ten Thousand Islands. This basin is located to the south of Interstate 75 and is almost entirely wetlands (96%) and uplands (4%). Less than 1% of the basin has been urbanized. Much of the Faka Union South basin is composed of Picayune Strand State Forest.

In contrast to Faka Union North, conductivity and salinity were observed to gradually increase over time in the Faka Union South basin. Organic nitrogen, total nitrogen and phosphorus displayed a shallow increasing trend as did pH. As with Faka Union North, copper exhibited a shallow decreasing trend in this basin. All other water quality parameters remained relatively consistent over time.

Fakahatchee Strand

As with most of the basins on the eastern side of Collier County, the Fakahatchee Strand basin is almost entirely wetlands (98%). This relatively large basin (382 km^2) contains the Fakahatchee Strand Preserve State Forest and a portion of the Florida Panther National Wildlife Refuge.

Arsenic, color, conductivity and salinity, organic nitrogen, total nitrogen and phosphorus increased gradually in Fakahatchee Strand from 1999-2009. No other statistically significant trends were identified for this basin.

Gordon River Extension

Gordon River Extension is a small basin (22 km^2) located on the western side of Collier County in the city of Naples. This basin is drains into Naples Bay to the south. Urban land uses predominate in the Gordon River Extension (86%), though some natural land cover can be found there in the form of wetlands (7%) and uplands (7%).

Increasing trends in salinity and turbidity were observed for the Gordon River Extension. A decreasing trend was observed for pH.

Immokalee Basin

Immokalee Basin is a small, rural watershed (35 km^2) located in the north-central region of the County. Like most of the basins in this part of Collier County, Immokalee Basin is dominated by agricultural land uses (49%), with some urban areas (22%) and natural land cover (wetlands (22%) and uplands (7%)).

Water quality remained relatively constant during 1999-2009 except for a shallow decreasing trend for arsenic.

Naples Bay (Coastal Segment)

The coastal segment of the Naples Bay basin is a small coastal basin (38 km^2) along the western edge of the County. Like the Naples basin to the north, the Naples Bay basin is heavily urbanized (90%) with minimal natural land cover in the form of wetlands (6%) and uplands (4%).

Decreasing trends in dissolved oxygen, turbidity and total phosphorus were apparent from the trend analysis. Salinity and pH displayed a shallow increasing trend in this basin, while conductivity displayed a steep increasing trend.

North Golden Gate

North Golden Gate is a large, urbanized basin (295 km^2) located on the western side of Collier County. The majority of flow passes through the North Golden Gate basin and move downstream into Naples Bay. Some flows in the northeastern part of the basin flow into the Cocohatchee Inland basin. Urban land uses occupy much of the basin (62%) though natural land uses consisting of wetlands (24%) and uplands (8%) make up almost one-third of the basin. Agriculture (6%) is a small part of the overall land use in North Golden Gate.

Shallow increasing trends were observed for total suspended solids while, shallow decreasing trends were observed for color and copper in this basin.

Okaloacoochee Slough

Okaloacoochee Slough is a very large rural basin (510 km^2) located in the predominantly agricultural north-central region of Collier County. This basin flows south into the Barron River Canal basin and then into the Ten Thousand Islands. Agriculture (42%), wetlands (45%) and uplands (12%) are most common in the Okaloacoochee Slough basin.

Color, organic nitrogen, total nitrogen and turbidity increased from 1999-2009. All significant trends were gradual in nature.

Rookery Bay (Inland East Segment)

The inland basins of Rookery Bay were quite different in size and patterns of land use. The eastern basin of the Rookery Bay Inland complex is relatively large (218 km^2) and undeveloped with wetlands (65%) and uplands (12%) comprising the majority of the basin. Agriculture was also present (15%) as was a minimal amount of urban land (8%). This basin drains into the coastal portion of Rookery Bay which is the location of the Rookery Bay National Estuarine Research Reserve.

A decreasing trend in color was observed for the Rookery Bay Inland East basin. pH, turbidity and total phosphorus increased gradually in this basin over the period from 1999-2009. No other statistically significant trends were observed for the Rookery Bay Inland East basin.

Rookery Bay (Inland West Segment)

Rookery Bay Inland West is a small basin (61 km^2) relative to most in Collier County and is considerably smaller than Rookery Bay Inland East. The subdivisions of Lely and Naples Manor are located in this basin and contribute to the much more prominent urban land uses (53%) compared to Rookery Bay Inland East. Despite the urban development, a substantial percentage of Rookery Bay Inland West consists of natural land cover including wetlands (35%) and uplands (9%). Only 3% of this basin is used for agriculture.

Rookery Bay Inland West had increasing trends for pH and salinity and decreasing trends for color, turbidity, inorganic nitrogen, organic nitrogen and total nitrogen.

Silver Strand

The Silver Strand basin is a large, agricultural basin (218 km^2) located in the north-central part of Collier County. Flows from this basin drain into the Barron River Canal where they mix with flows from the Okaloacoochee Slough located to the north of Silver Strand. Agriculture is the primary land use in this basin (67%) with wetlands (24%) and uplands (7%) also present. Only 2% of Silver Strand is urbanized.

Increasing trends in conductivity and salinity were observed for Silver Strand. None of the other water quality parameters displayed statistically significant trends.

Tamiami Canal

Tamiami Canal is, by far the largest basin in Collier County (2,383 km^2), occupying greater than one-third of the watershed. This basin is located on the eastern side of the County and contains a large portion of the Big Cypress National Preserve. Land use in the Tamiami Canal basin is dominated by wetlands (89%) with some uplands (7%) and minimal agriculture (4%). Flows from the Tamiami Canal basin are discharged to the south and into the coastal Ten Thousand Islands.

A slight increasing trend in biochemical oxygen demand, salinity, organic nitrogen and total phosphorus and decreasing trends in arsenic, copper and color were indicated by the results of the analysis. None of the other water quality parameters changed significantly from 1999-2009.

Ten Thousand Islands

Ten Thousand Islands is a very large coastal basin (543 km^2) occupying much of the southern coast of Collier County. This basin is separated from Rookery Bay Inland East, Faka Union South, Fakahatchee Strand, Barron River Canal and Tamiami Canal basins to the north by the Tamiami Canal and US-41. A considerable portion of the Florida Everglades drain into the Ten Thousand Islands basin. Close to 99% of this basin is comprised by wetlands which include the Ten Thousand Islands National Wildlife Refuge, Collier-Seminole State Park, and Everglades National Park.

Decreasing trends in dissolved oxygen were identified for the Ten Thousand Islands basin as was an increasing trend in organic nitrogen, total nitrogen and phosphorus.

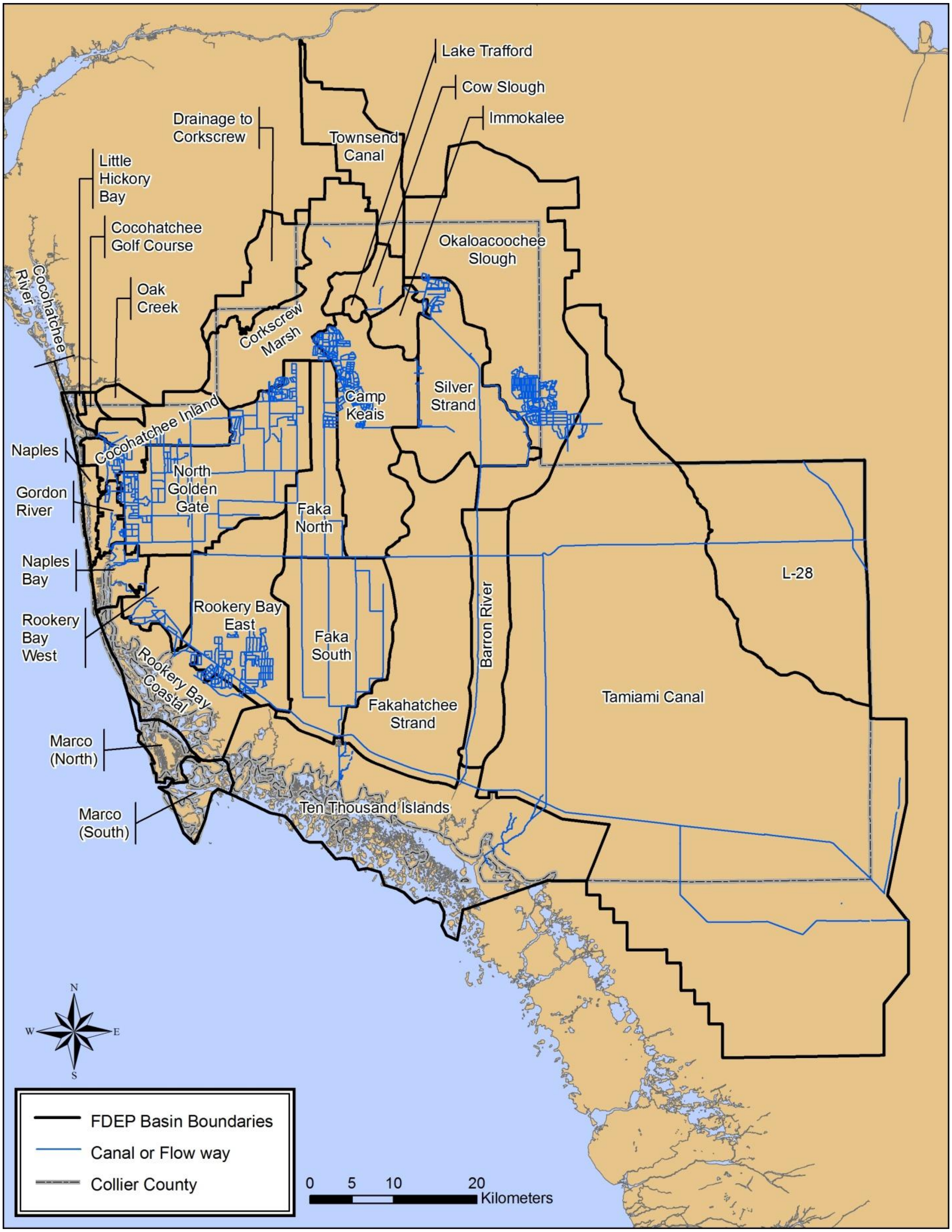

Figure 3.3-11 – Collier County basin map for reference with maps summarizing the results of water quality trend analyses. Major canals are shown to assist with interpretation of drainage pathways.

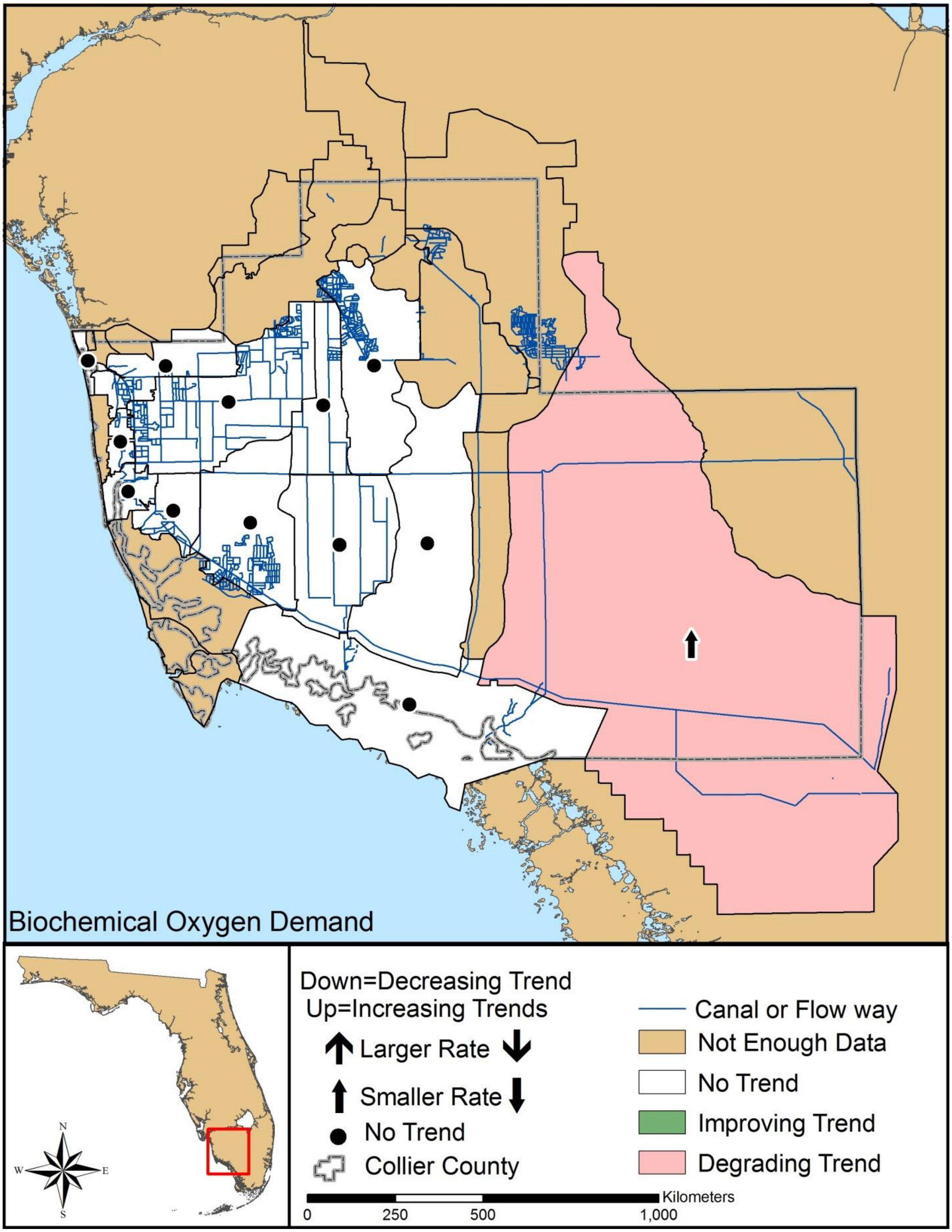

Figure 3.3-12 – Summary of trends for biochemical oxygen demand (1999-2009).

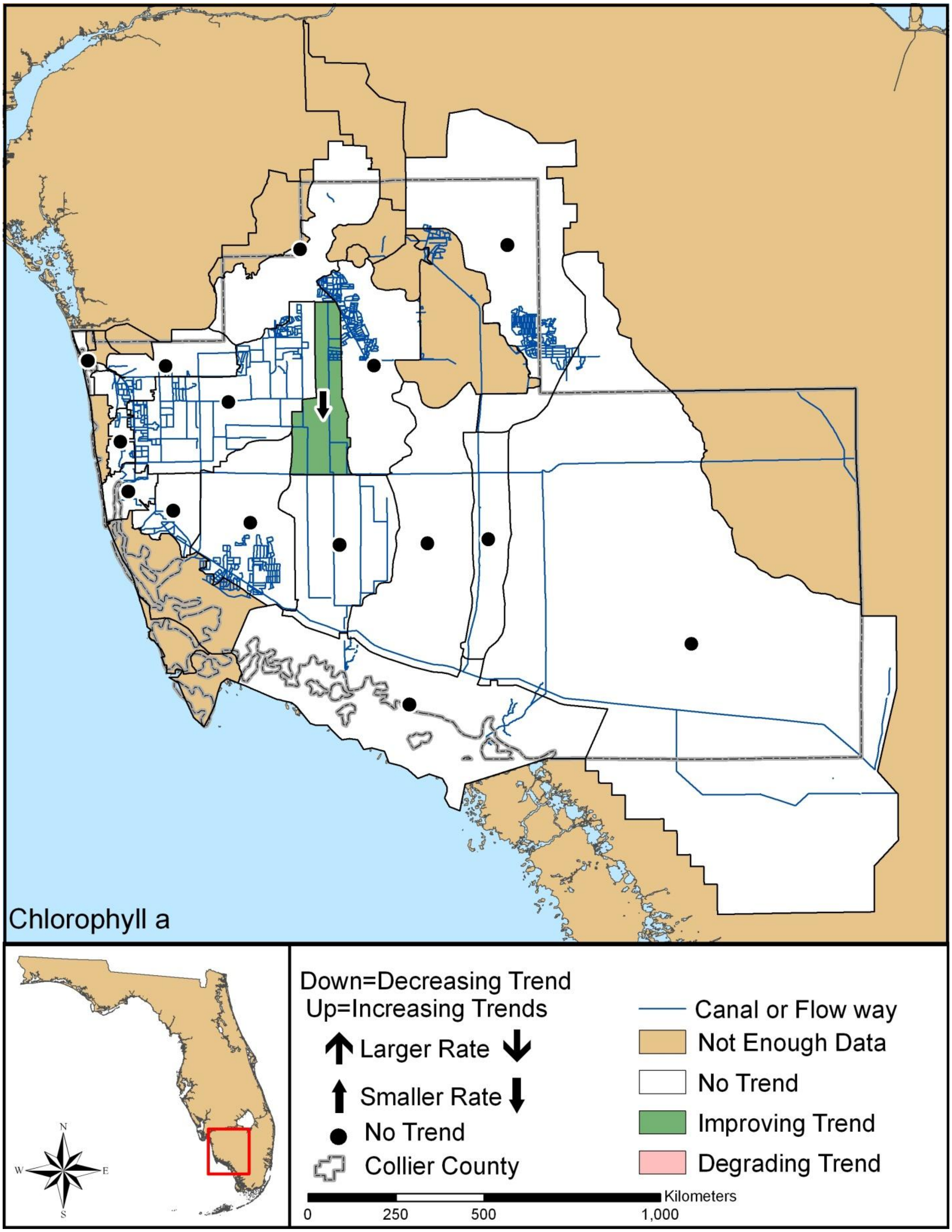

Figure 3.3-13 – Summary of trends for chlorophyll-a (1999-2009).

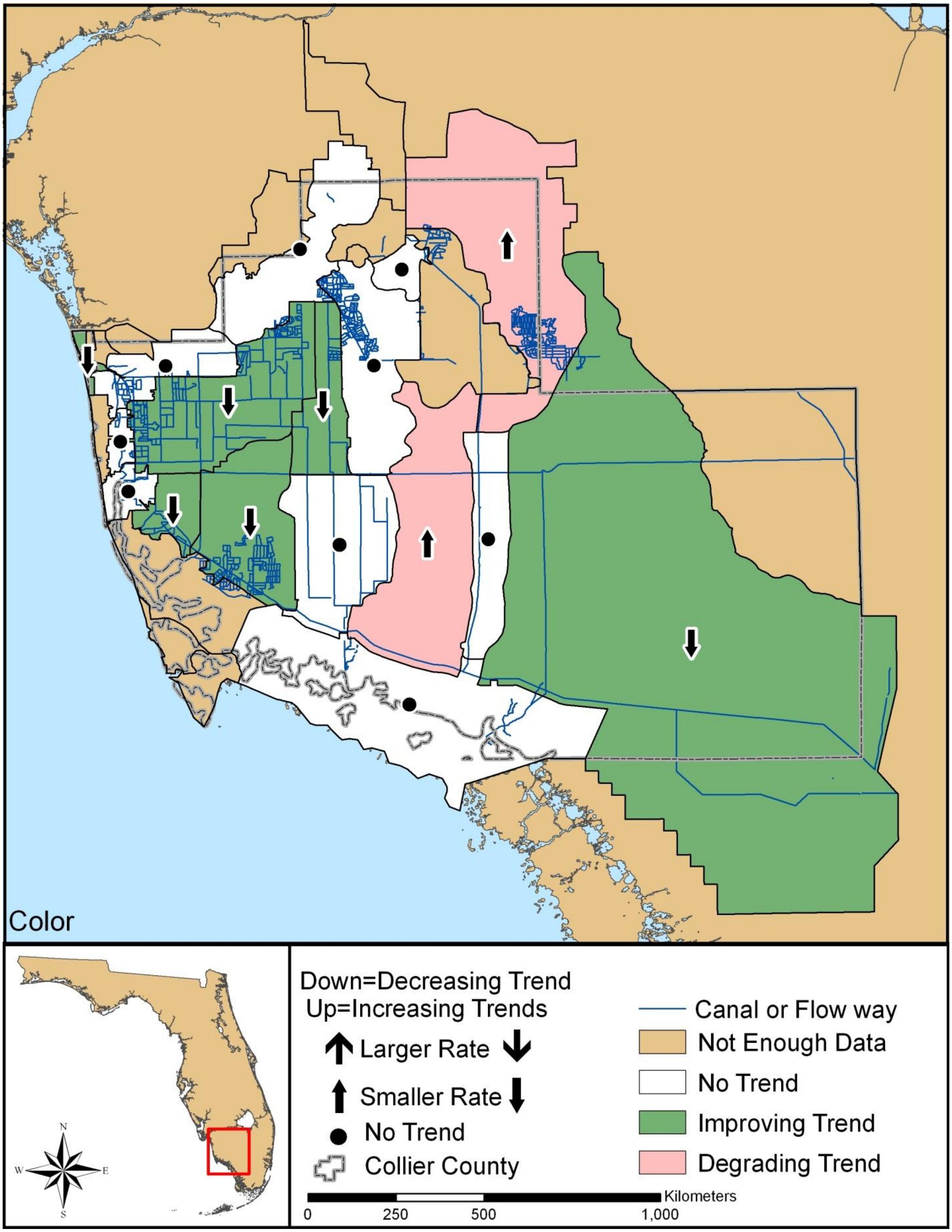

Figure 3.3-14 – Summary of trends for color (1999-2009).

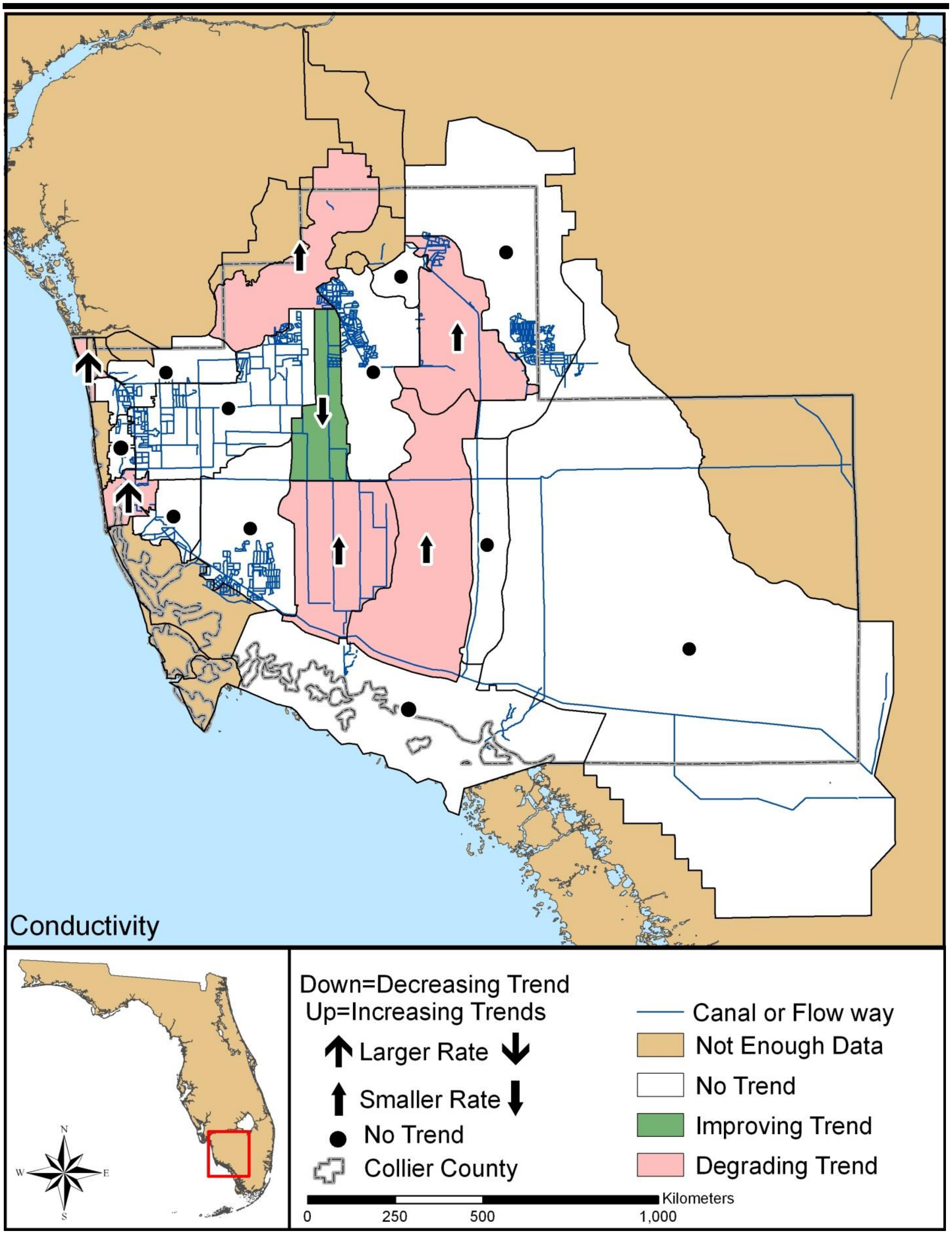

Figure 3.3-15 – Summary of trends for conductivity (1999-2009).

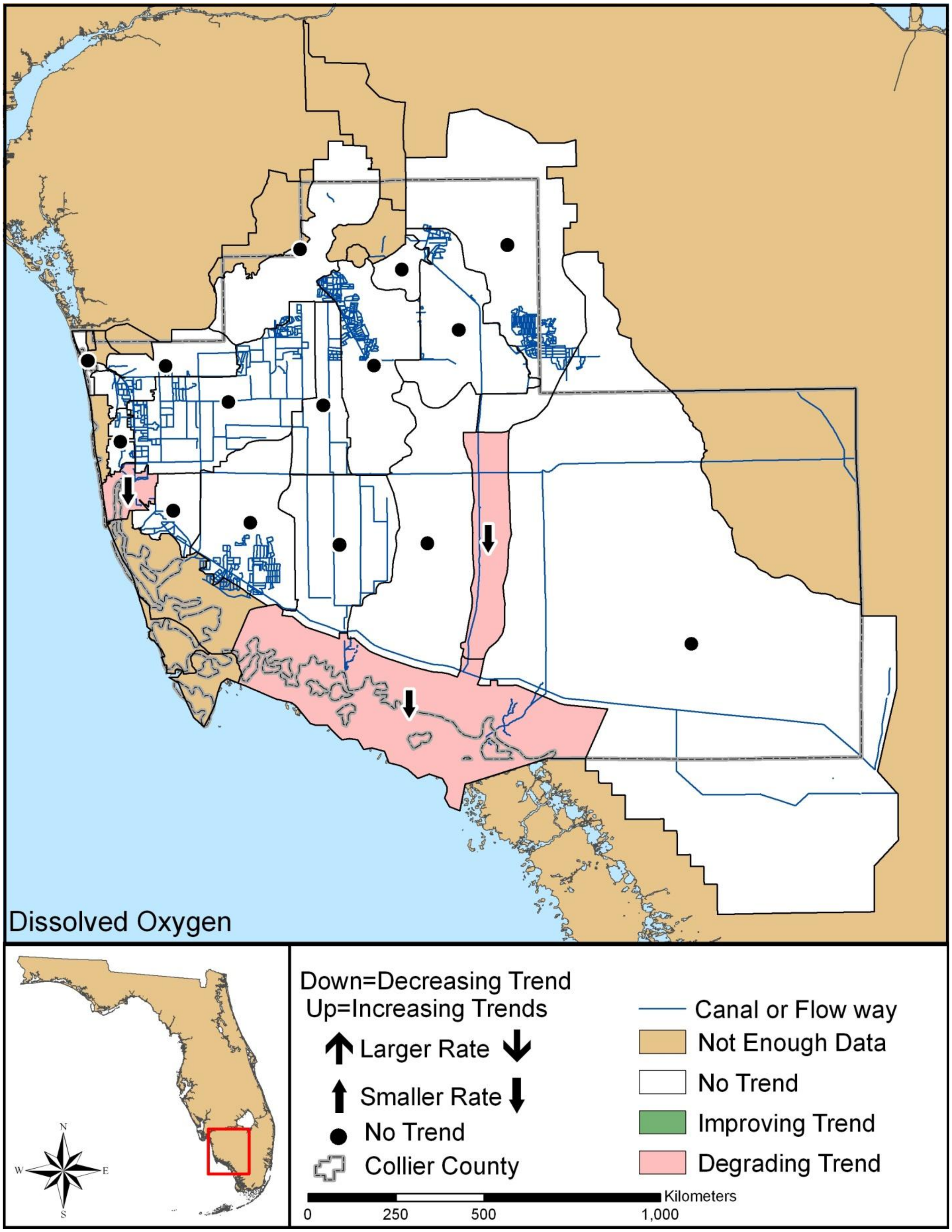

Figure 3.3-16 – Summary of trends for dissolved oxygen (1999-2009).

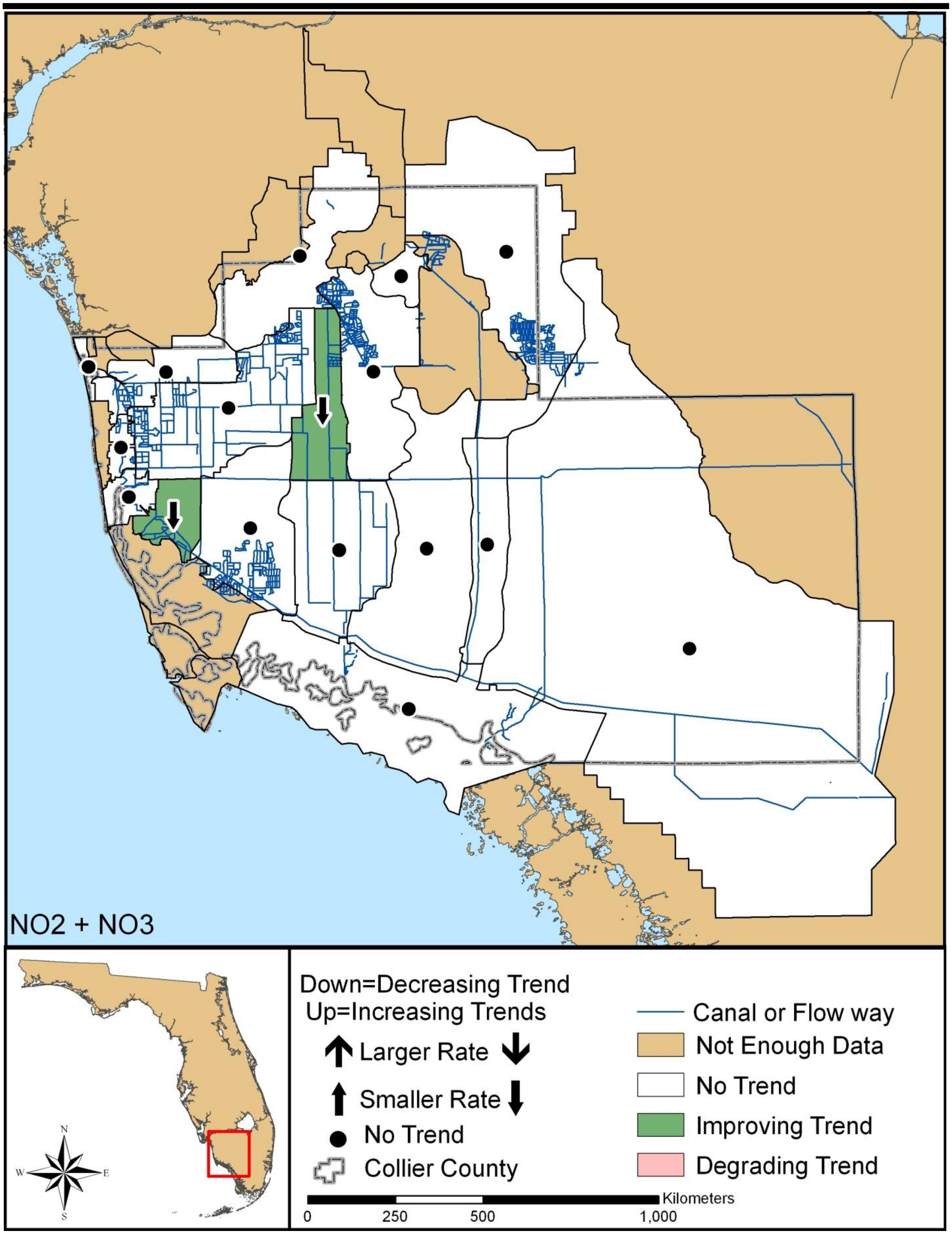

Figure 3.3-17 – Summary of trends for inorganic nitrogen (1999-2009).

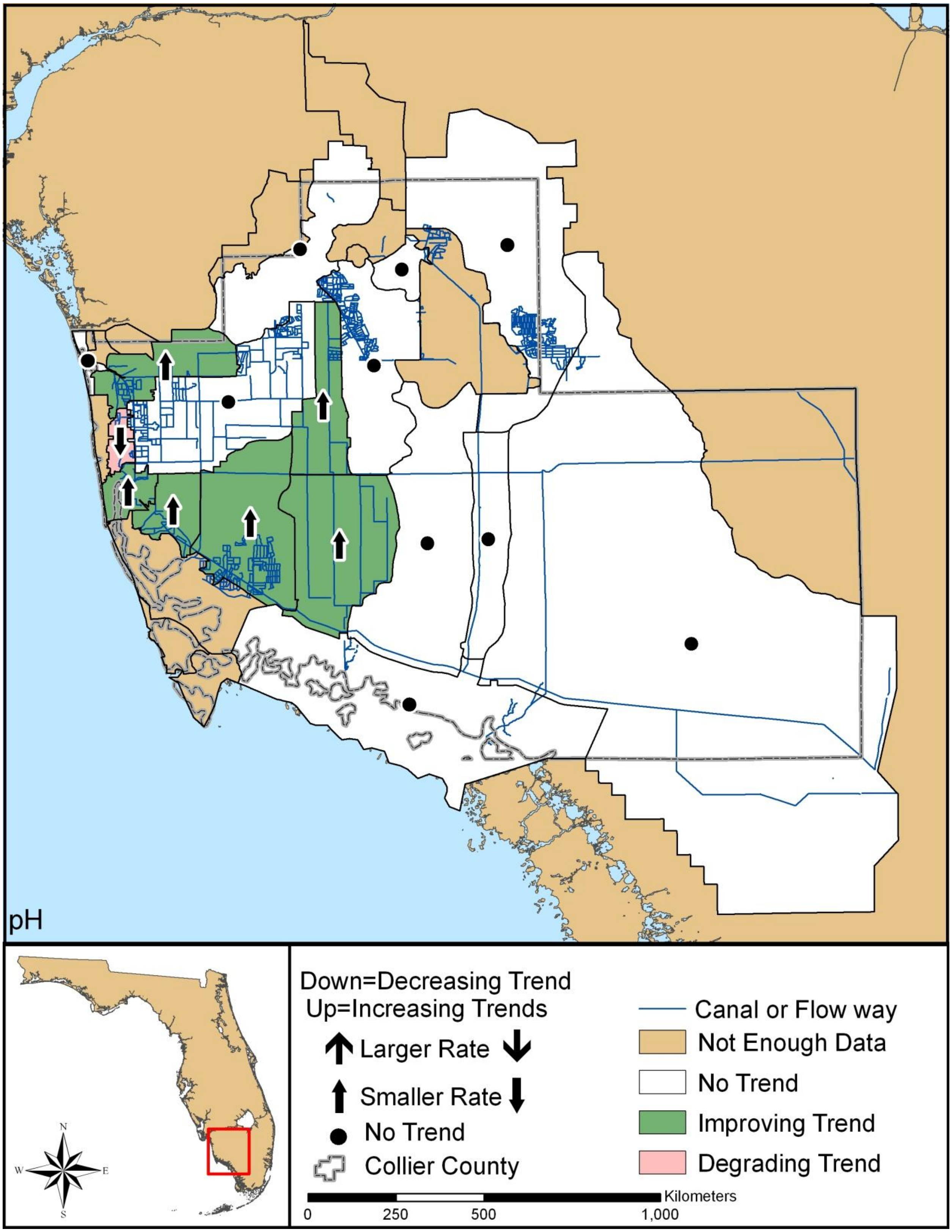

Figure 3.3-18 – Summary of trends for pH (1999-2009).

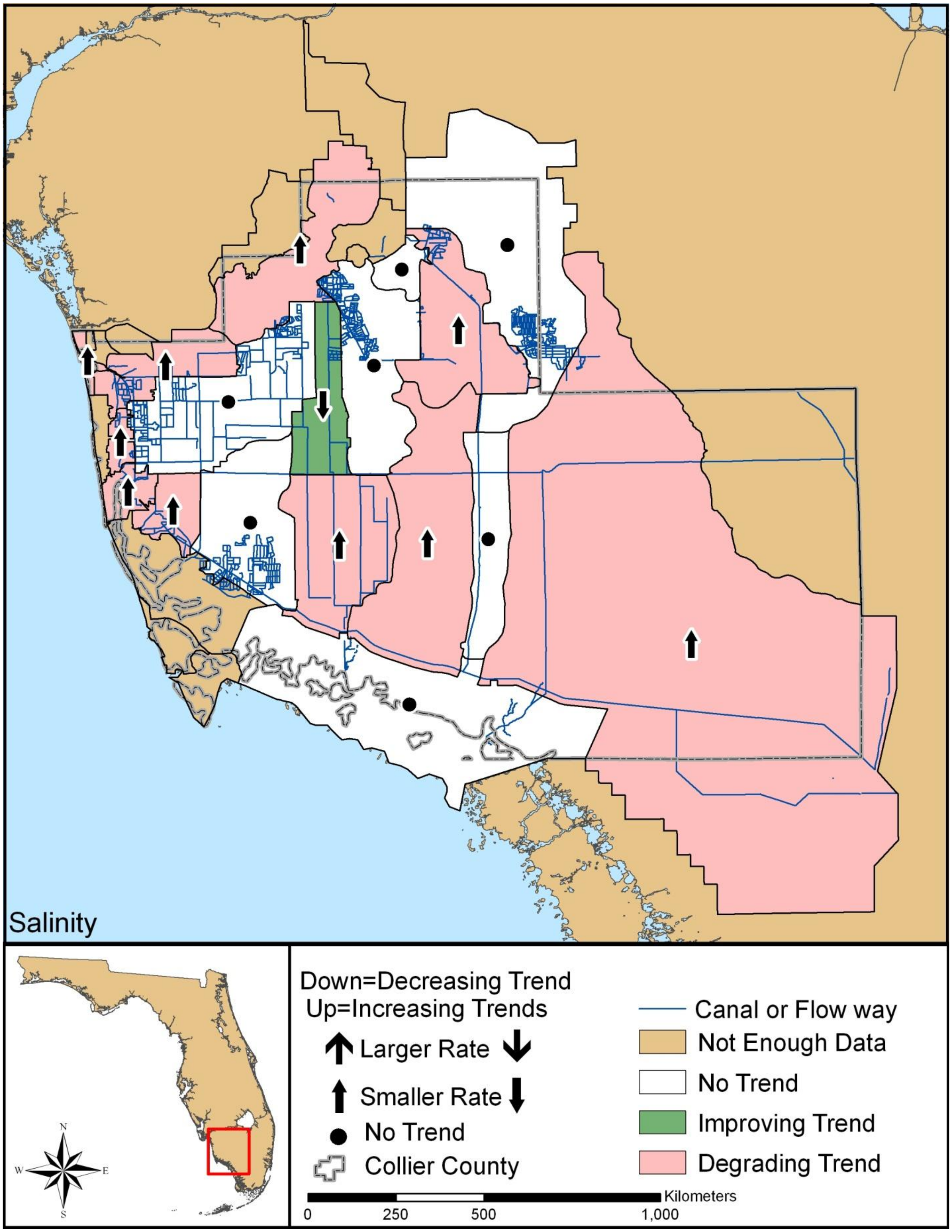

Figure 3.3-19 – Summary of trends for salinity (1999-2009).

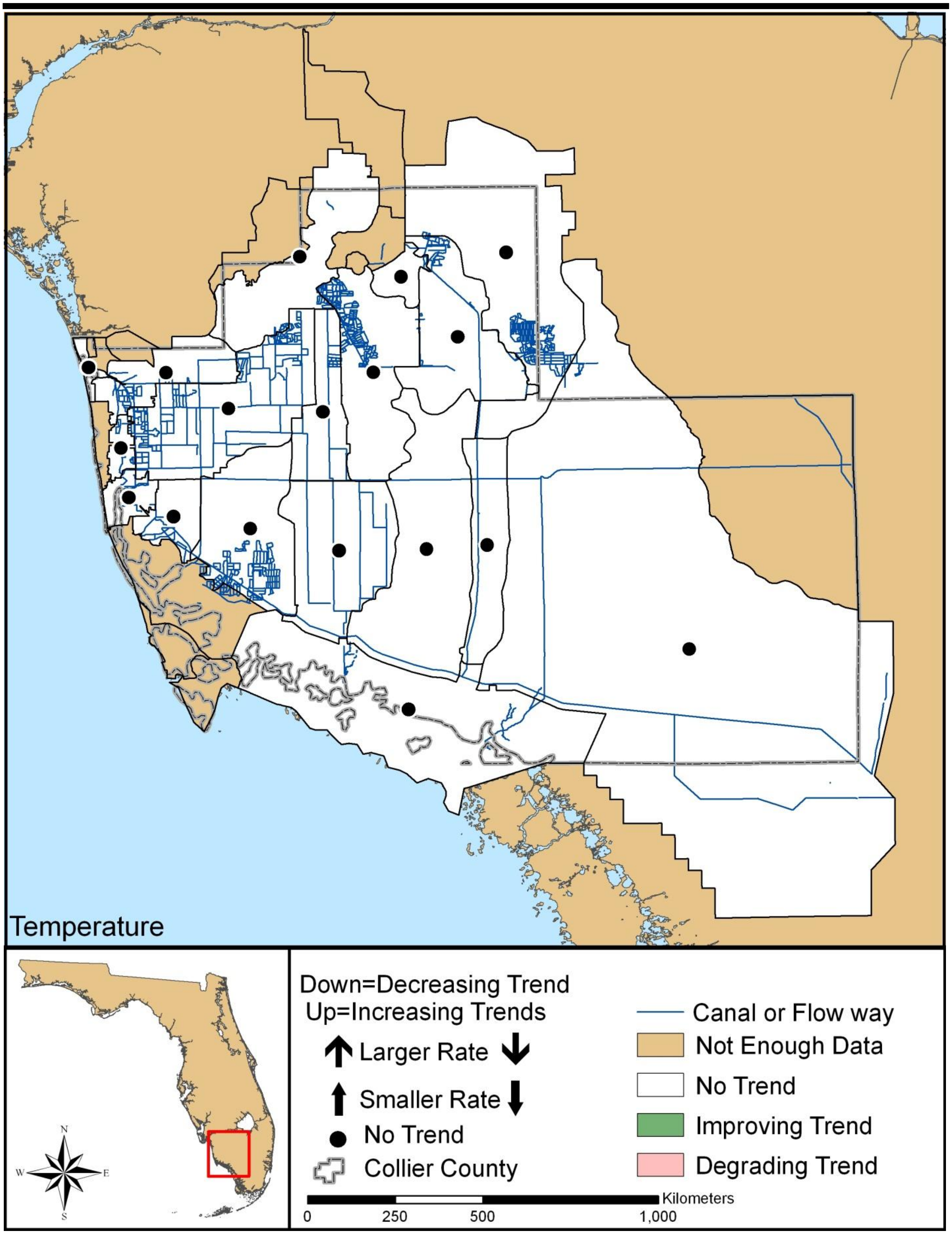

Figure 3.3-20 - Summary of trends for water temperature (1999-2009).

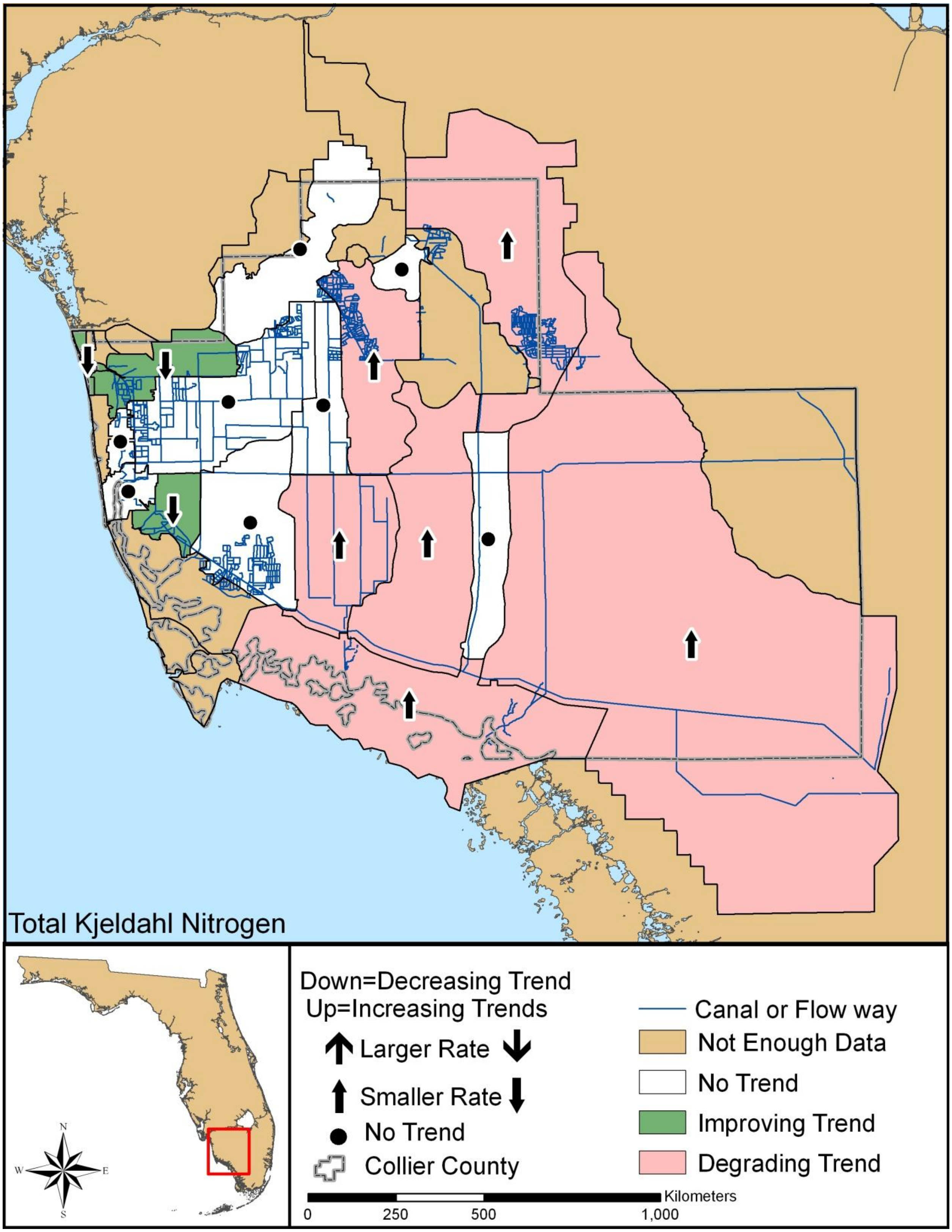

Figure 3.3-21 – Summary of trends for total Kjeldahl nitrogen (1999-2009).

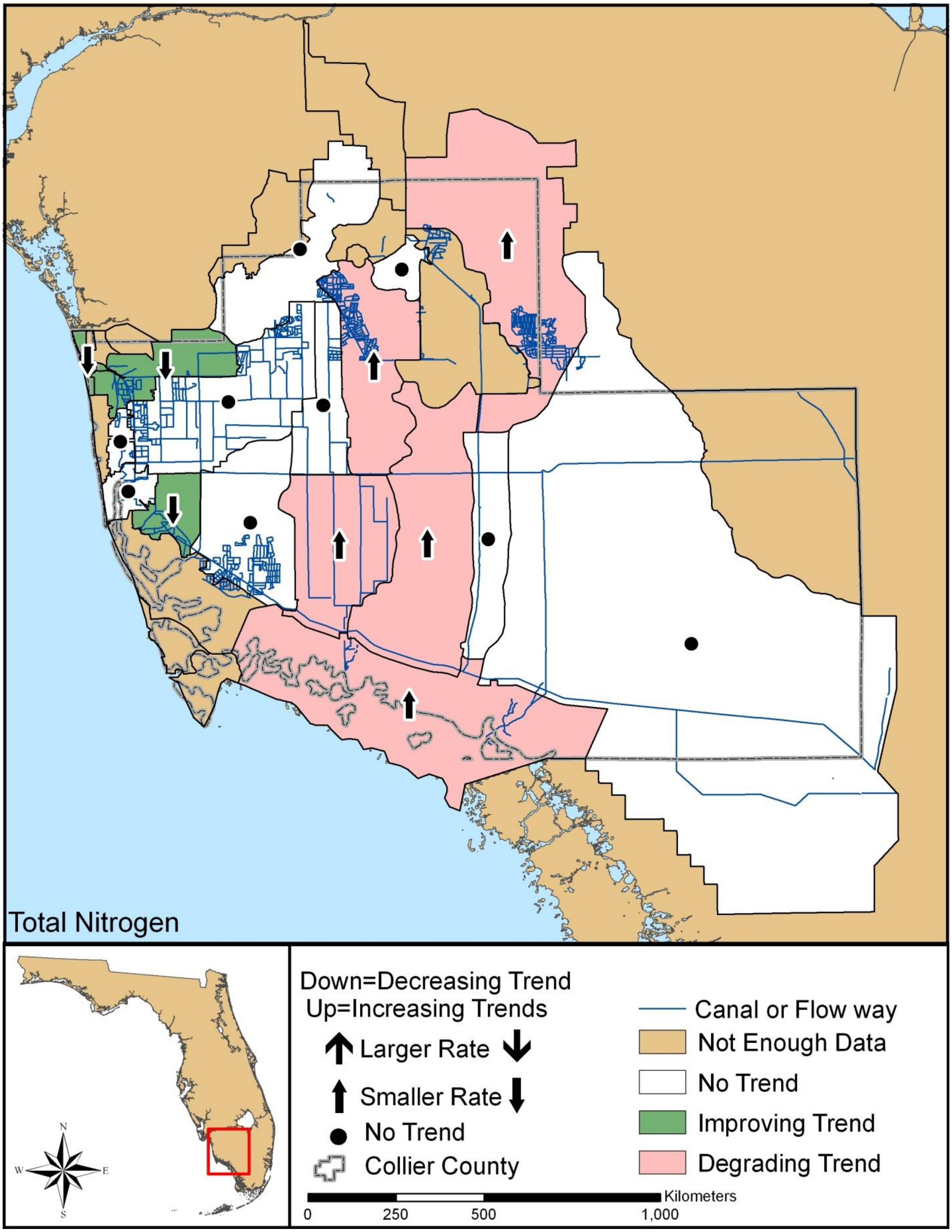

Figure 3.3-22 – Summary of trends for total nitrogen (1999-2009).

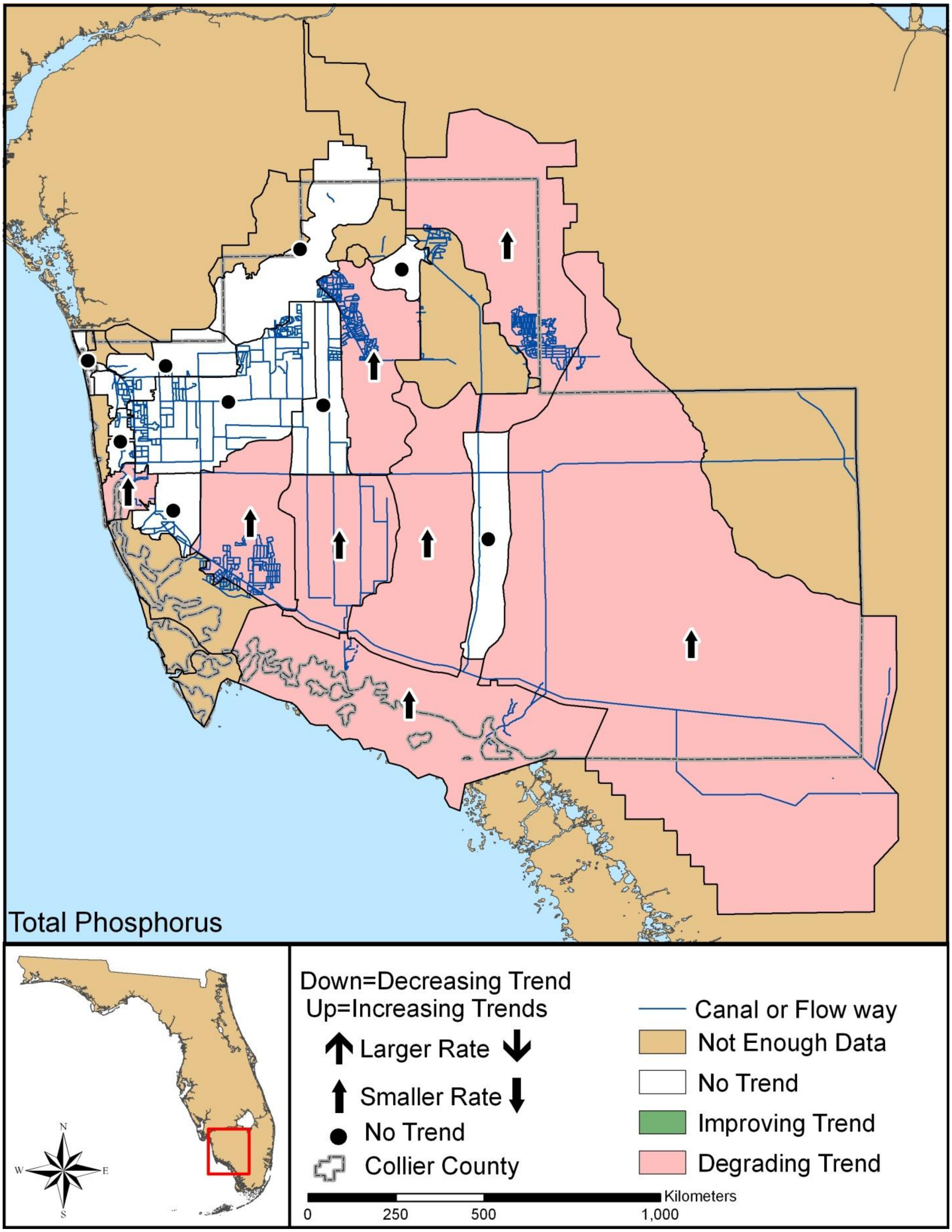

Figure 3.3-23 – Summary of trends for total phosphorus (1999-2009).

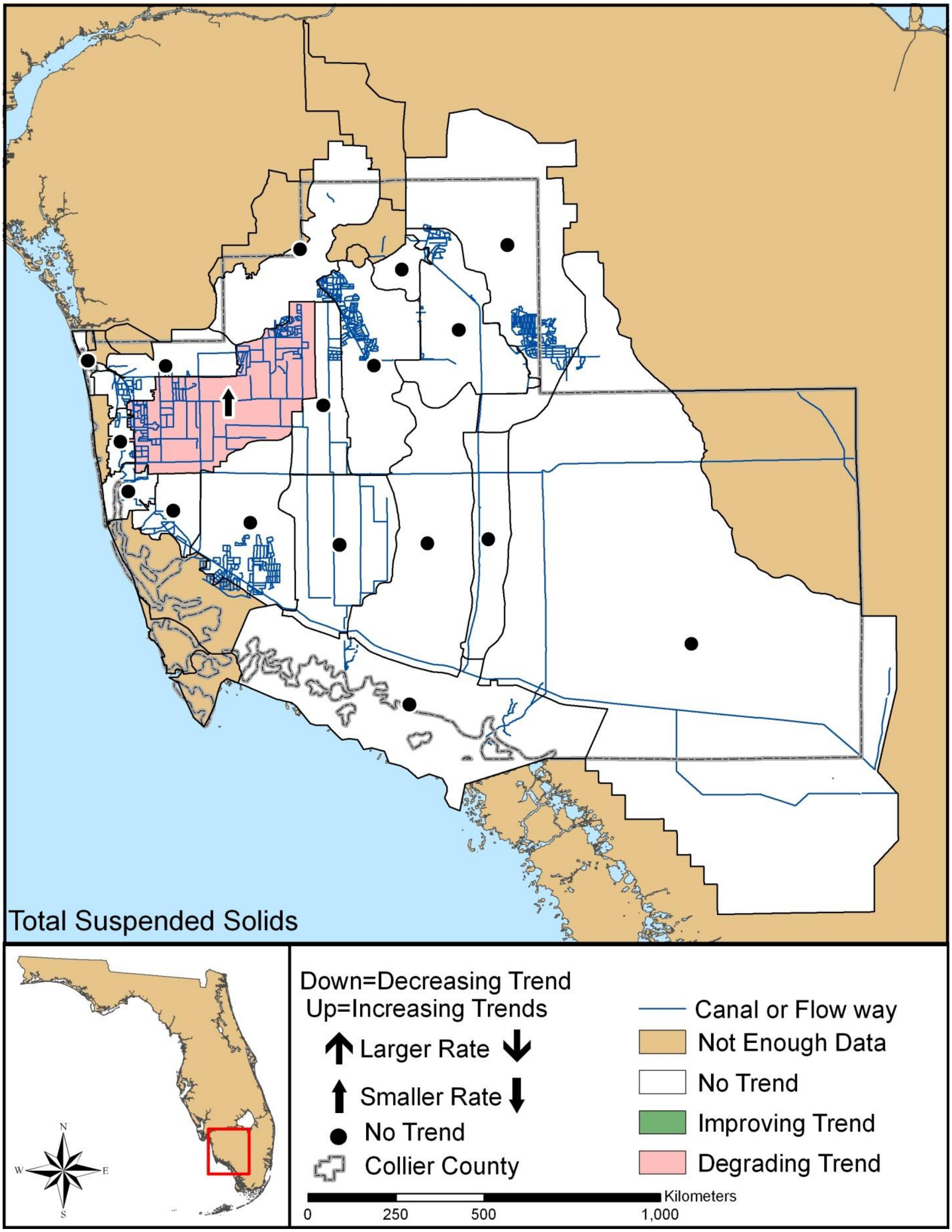

Figure 3.3-24 – Summary of trends for total suspended solids (1999-2009).

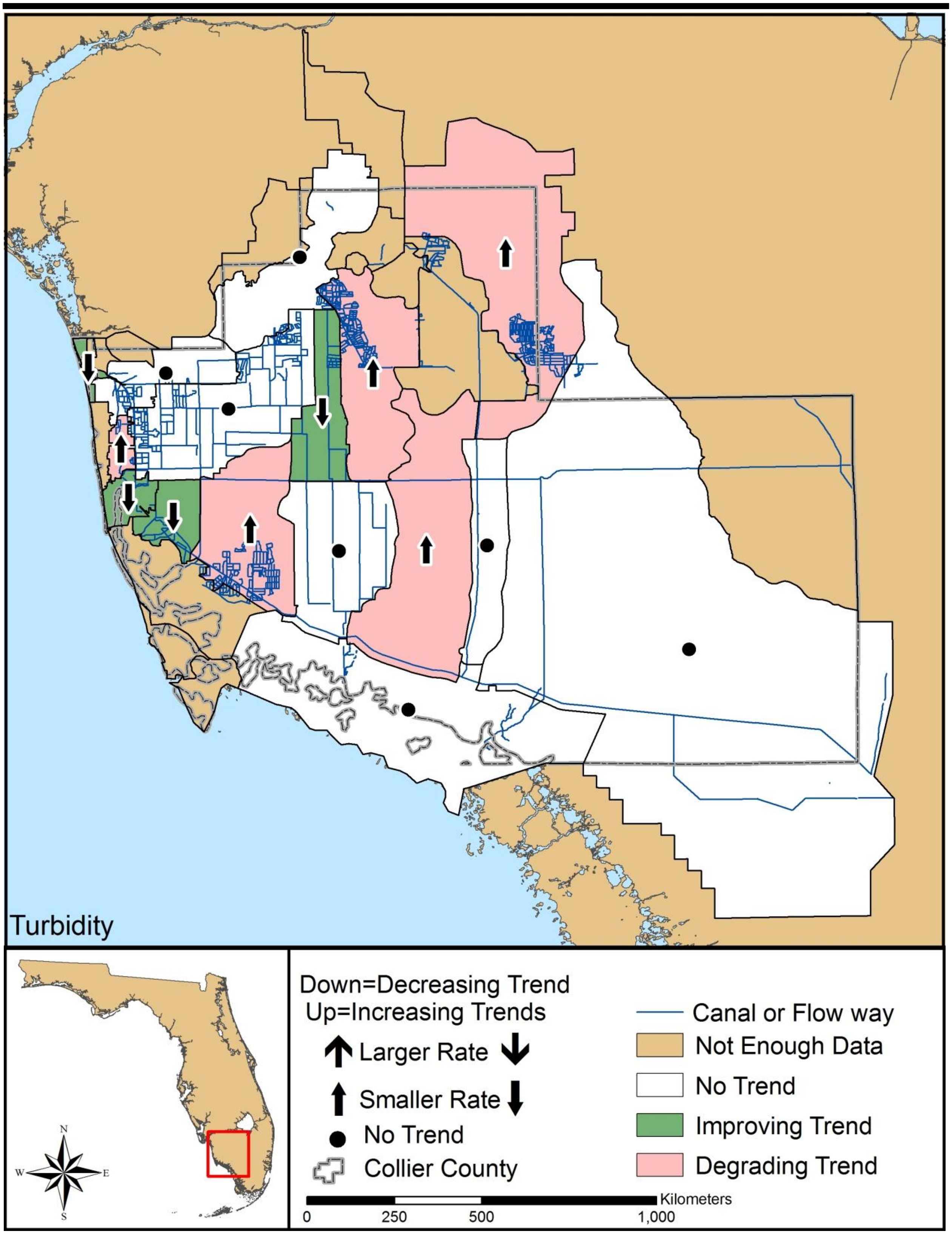

Figure 3.3-25 – Summary of trends for turbidity (1999-2009).

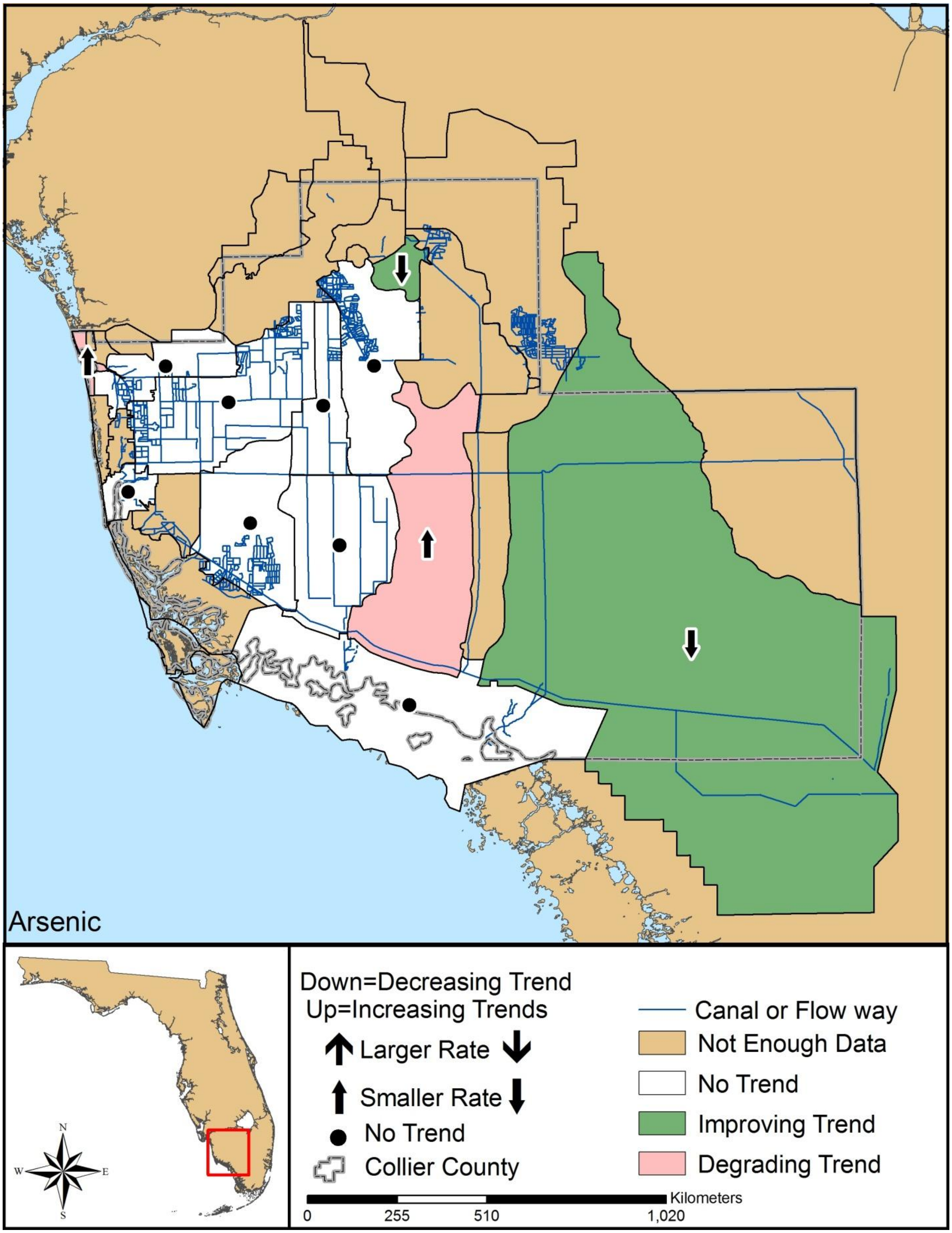

Figure 3.3-26 – Summary of trends for arsenic (1999-2009).

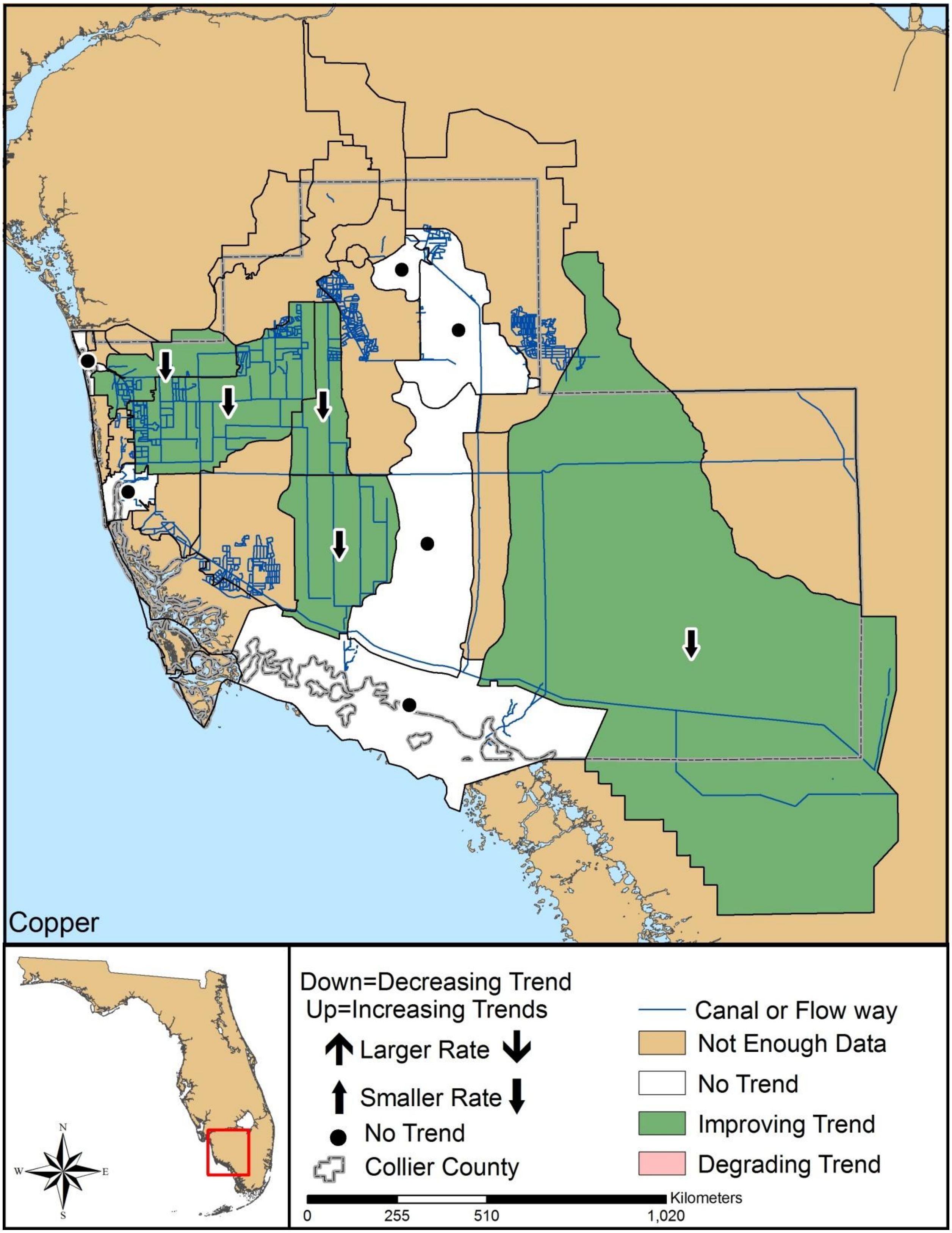

Figure 3.3-27 – Summary of trends for copper (1999-2009).

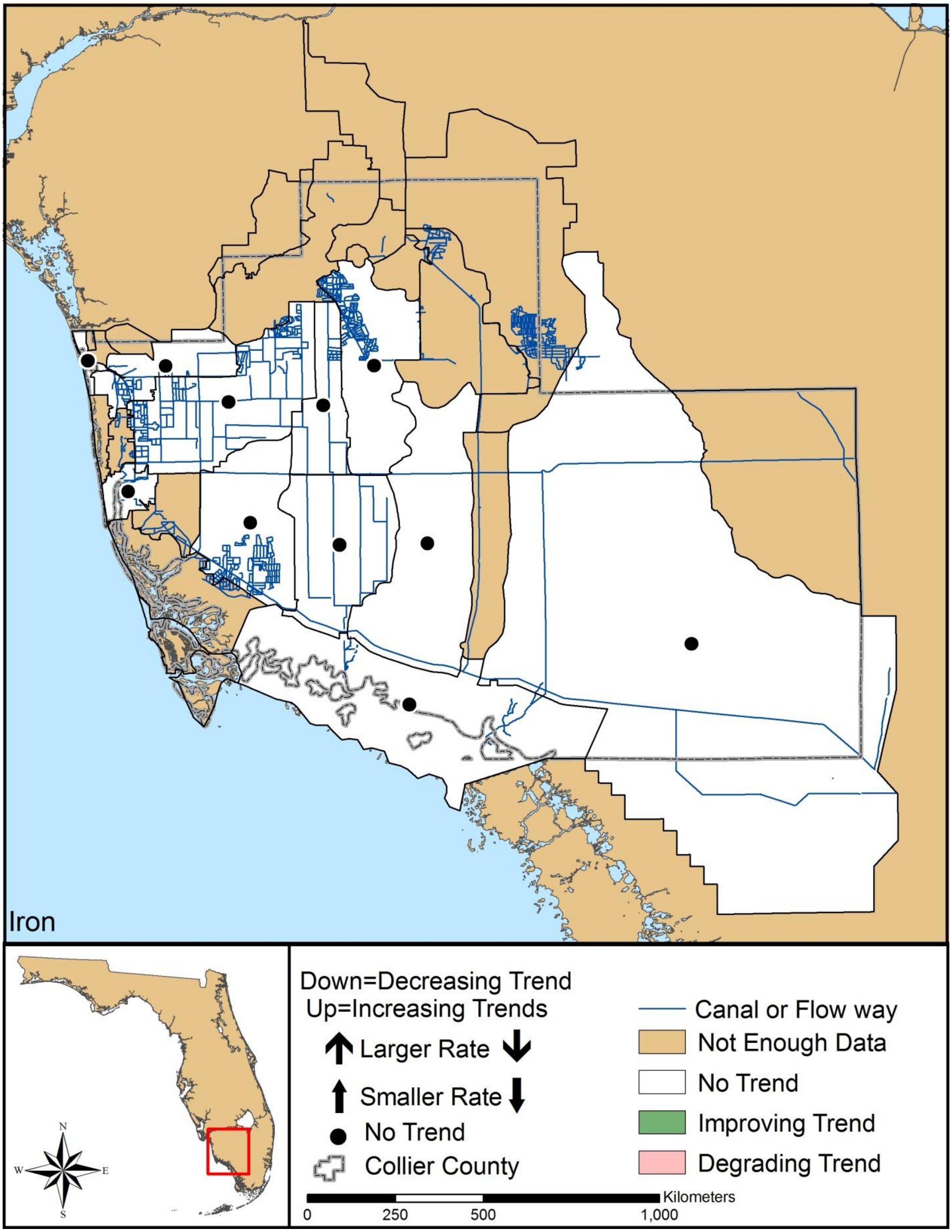

Figure 3.3-28 – Summary of trends for iron (1999-2009).

3.3.6 Comparison of water quality trends between historical and recent years

This section contains an informal comparison of water quality trends for the historical (1989-1998) and recent (1999-2009) time periods. Limitations due to the nature of the sampling design prior to 1999, when the sample design was changed from a "rotating basin" approach to a "monthly sampling" approach, prevented a formal analysis of water quality trends for the historical time period. However, this historical time period can still be compared to trends in the recent time period by examining the distribution of values for each water quality parameter by basin for those basins that were sampled frequently enough during the historical time period. The complete period of record (1989-2009) was subset into four periods representing two periods each in historical (1989-1992, 1995-1998) and recent time (2001-2004, 2006-2009). The distribution of values (see example in Figure 3.3-29, Appendix 3-3) was then compared among historical and recent periods by basin and water quality parameter to summarize potential changes in water quality between periods.

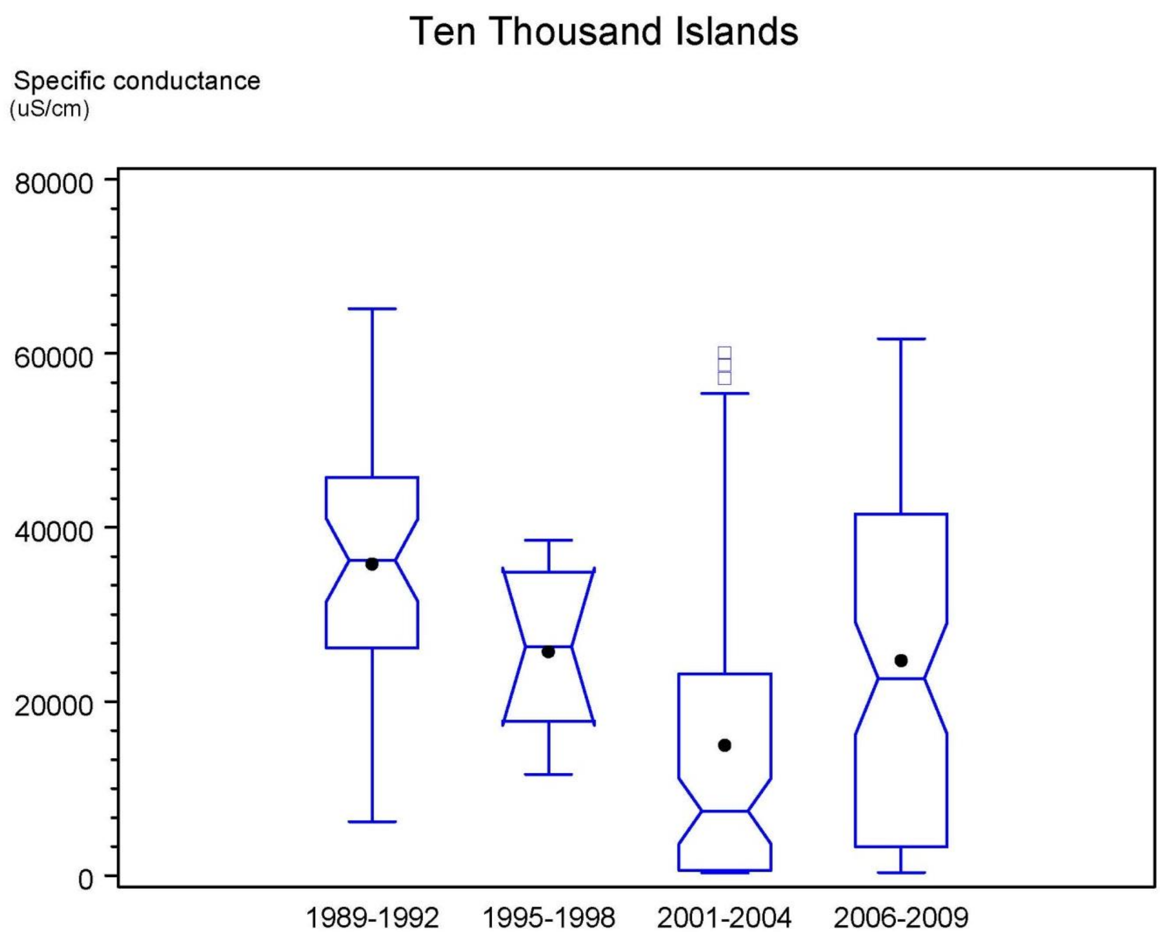

Figure 3.3-29 – Example boxplot comparing trends in water quality parameters among historical (1989-1998) and recent (1999-2009) time periods.

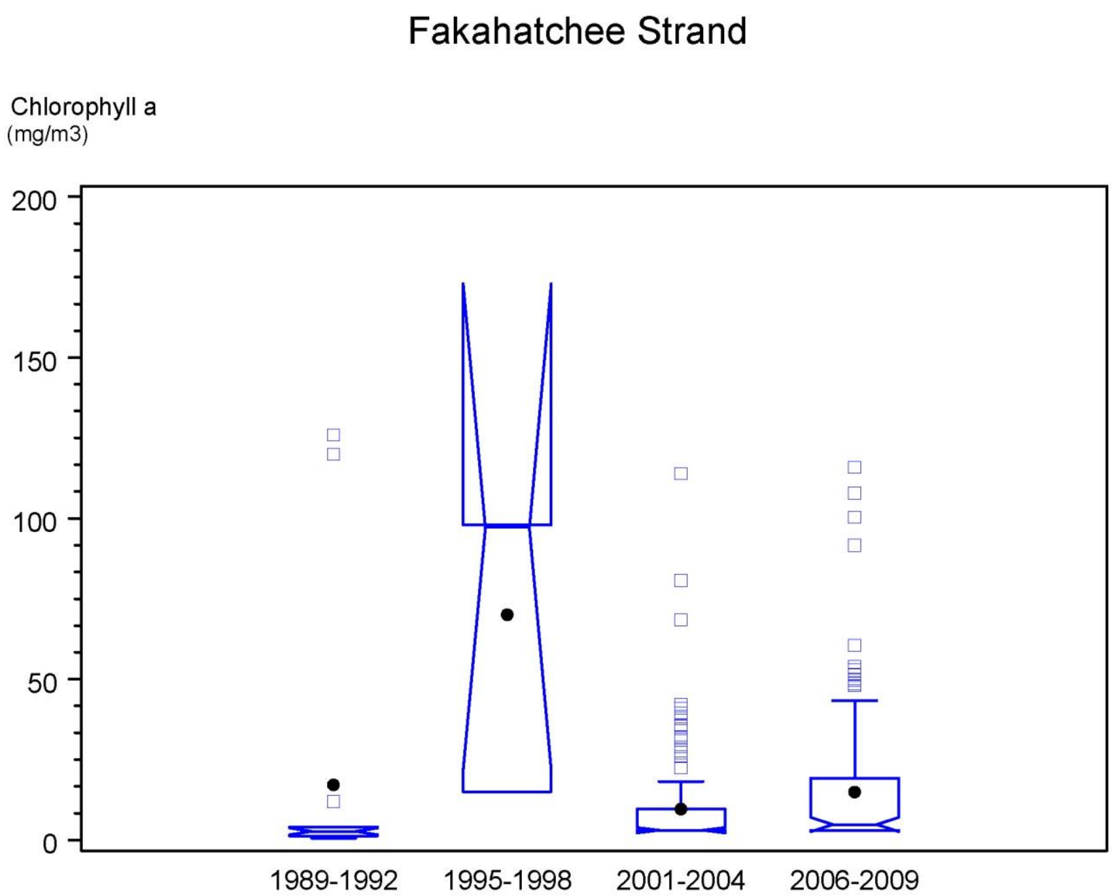

Figure 3.3-30 – Boxplot showing chlorophyll-a levels during the historical (1989-1998) vs recent (1999-2009) time periods.

Average chlorophyll levels were relatively constant in some of the basins, but were higher than average during the 1995-1998 time period. Chlorophyll concentrations in Fakahatchee Strand increased by approximately 50 mg/m^3 (Figure 3.3-30) during that period and Tamiami Canal increased by almost 20 mg/m3. Lesser increases on the order of 5 mg/m3 were observed for Rookery Bay Inland East and Gordon River Extension. Chlorophyll levels in subsequent years, however, were comparable to those observed prior to 1995.

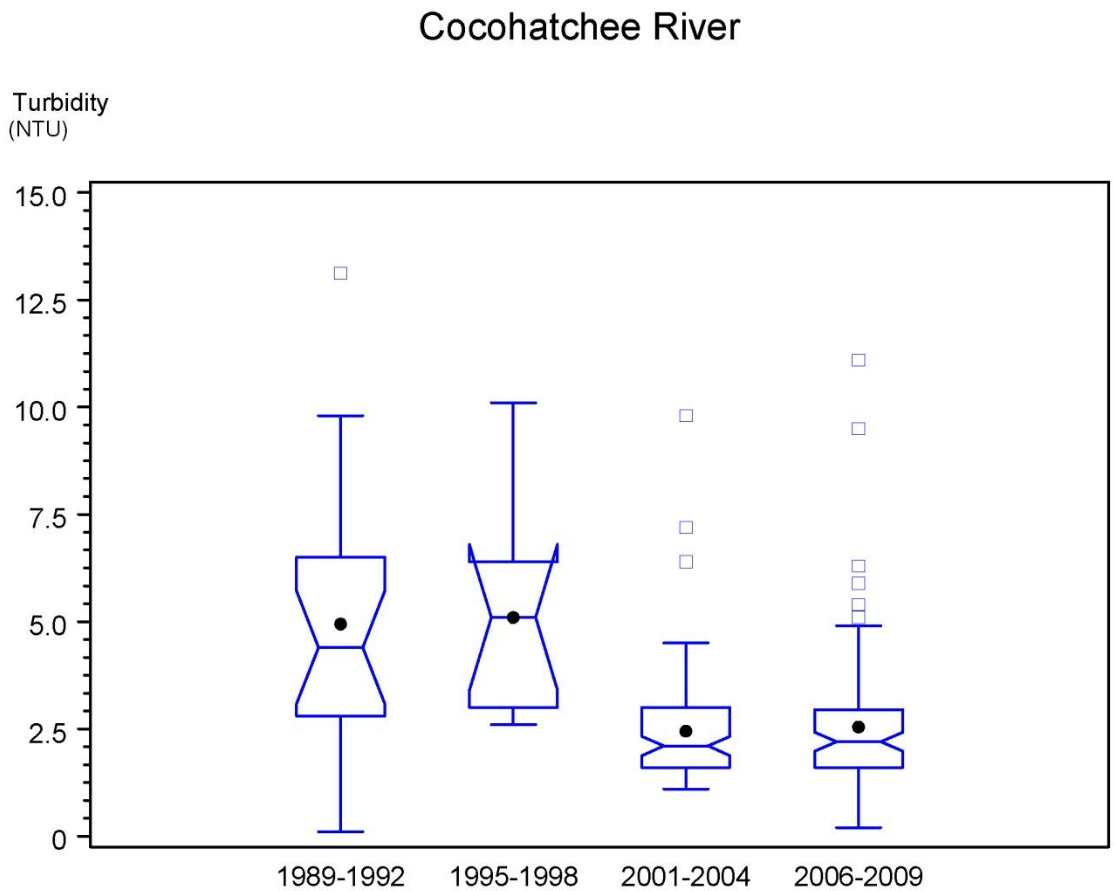

Figure 3.3-31 – Boxplot showing turbidity levels during the historical (1989-1998) vs recent (1999-2009) time periods.

Reductions in total suspended solids were observed between the historical and recent time periods for Cocohatchee River (Figure 3.3-31), Naples Bay and Ten Thousand Islands both in terms of average TSS concentrations and the frequency of high values. More frequent observations of high TSS values were apparent for Faka Union South, Fakahatchee Strand and Camp Keais. Similar trends for turbidity were observed for these basins. Although there were no apparent trends in TSS concentrations for Rookery Bay Inland (East and West), higher average turbidity levels were observed during the historical period for Rookery Bay Inland East and turbidity, on average was twice as high in Rookery Bay Inland West during the period 1995-1998 (approximately 4 mg/L vs. 2 mg/L).

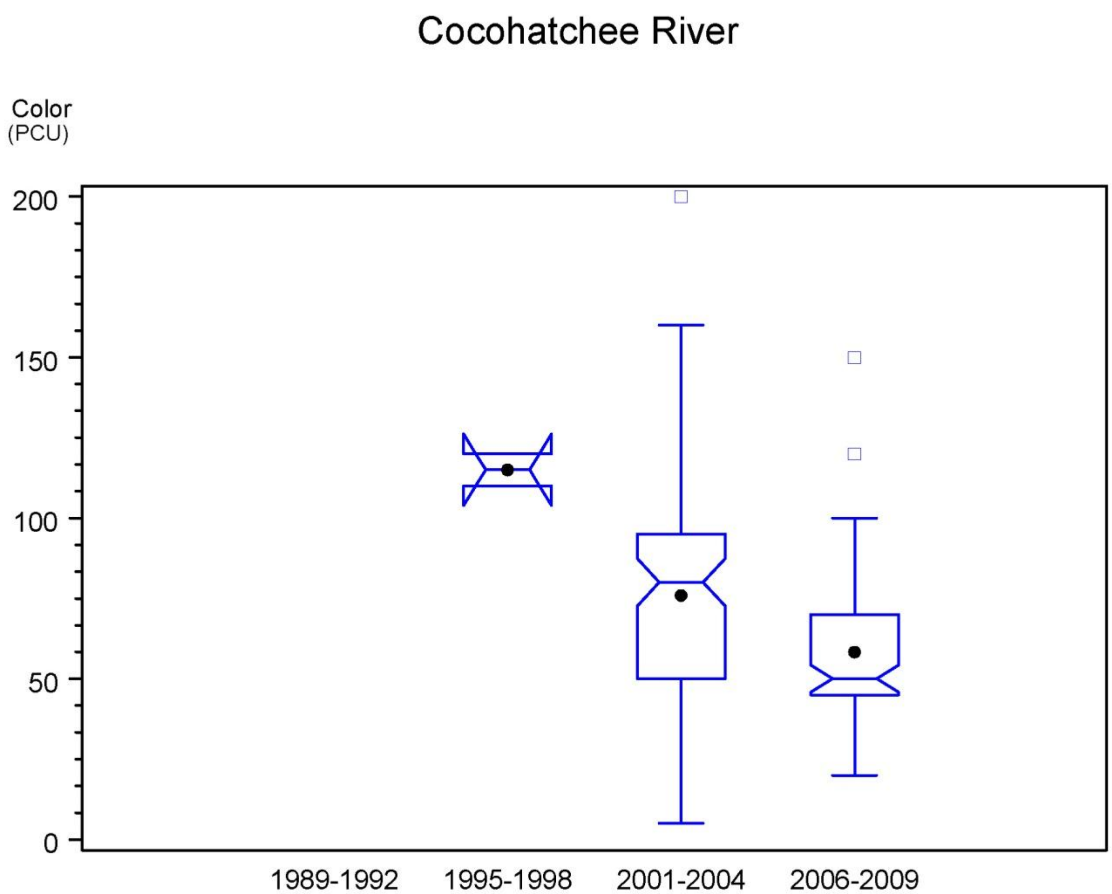

Figure 3.3-32 – Boxplot showing change in color from the historical (1989-1998) to the recent (1999-2009) time period.

An increase in color of about 25-50 pcu, on average, was observed between 1989 and 2006 for Gordon River Extension, North Golden Gate, Rookery Bay Inland West, and Faka Union South. In contrast, a decrease in color from approximately 120 pcu to 60 pcu was observed for Cocohatchee River between 1995 and 2009 (Figure 3.3-32).

Lower pH values were observed for most of the basins during the 1995-1998 time period when pH levels decreased from 7.5 to 7.0. During the recent time periods, however, pH levels were comparable to the pre-1995 time period. The exception was Ten Thousand Islands where pH decreased from about 7.75 to about 7.30 between 1998 and 2004 and remained low through 2009.

Average water temperatures were relatively consistent across the entire period of record.

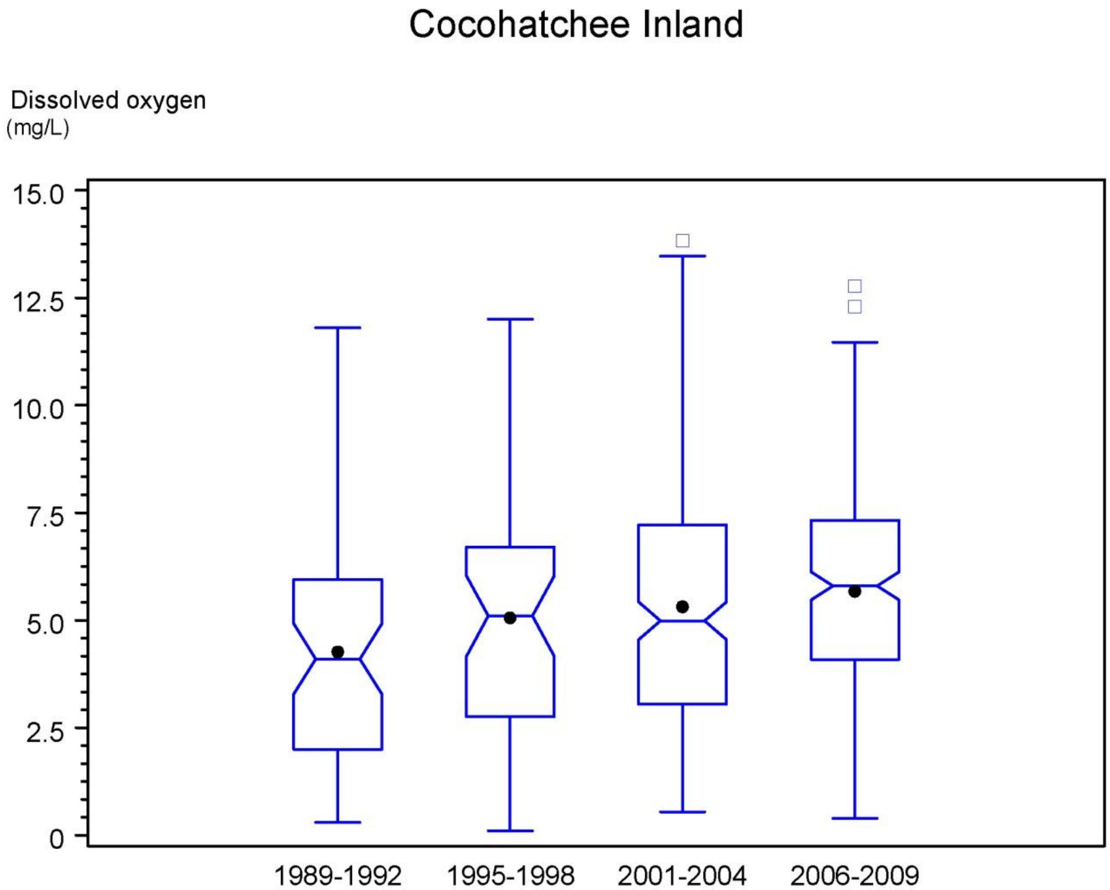

Figure 3.3-33 – Boxplot showing increase in dissolved oxygen for Cocohatchee Inland from the historical (1989-1998) to the recent (1999-2009) time period.

Average biochemical oxygen demand appeared to decrease from the historical period to the recent period for several of the basins. Reductions of 1-4 mg/L were observed between the historical period and the 2006-2009 period for Cocohatchee Inland, Gordon River Extension, Naples Bay, Rookery Bay Inland East, Faka Union South, Fakahatchee Strand and Tamiami Canal. During the historical period, average BOD levels were approximately 1 mg/L greater during 1995-1998 compared to previous years for Cocohatchee River and Naples Bay.

Increased BOD during 1995-1998 coincided with lower average dissolved oxygen levels (approximately 1 mg/L difference) in Faka Union South, Fakahatchee Strand, Rookery Bay Inland (East and West) and North Golden Gate. Average dissolved oxygen levels increased from approximately 4 mg/L to 6 mg/L in the Cocohatchee Inland basin during the period of record (Figure 3.3-33).

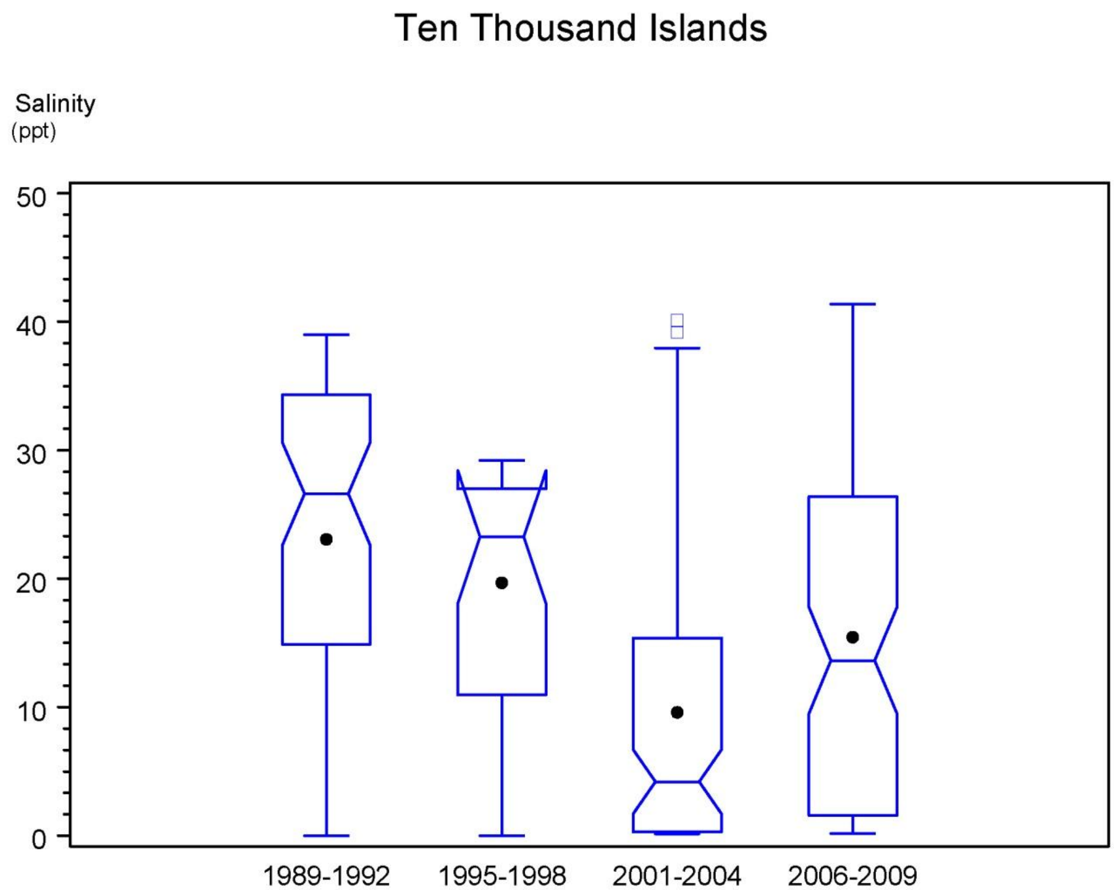

Figure 3.3-34 – Boxplot showing decrease in salinity for Ten Thousand Islands from the historical (1989-1998) to the recent (1999-2009) time period.

Salinity and conductivity changed dramatically in several basins between the historical and recent time periods with increases of 5-15 ppt observed for Gordon River Extension, Naples Bay, Fakahatchee Strand and Rookery Bay Inland East. Smaller increases in average salinity were observed for Cocohatchee Inland, Faka Union South and Rookery Bay Inland West, but salinities between 15-30 ppt and as high as 40 ppt were occasionally observed in these basins between 2001 and 2009. A decrease in average salinity was reported for Cocohatchee River between 1992 and 1995 when salinity decreased from 25 ppt to approximately 10 ppt. A similar decrease was observed for Ten Thousand Islands when average salinities dropped from approximately 20 ppt to 10 ppt between 1989 and 2004 (Figure 3.3-34). Similar trends were recorded for conductivity with changes of 10,000 to 30,000 uS/cm.

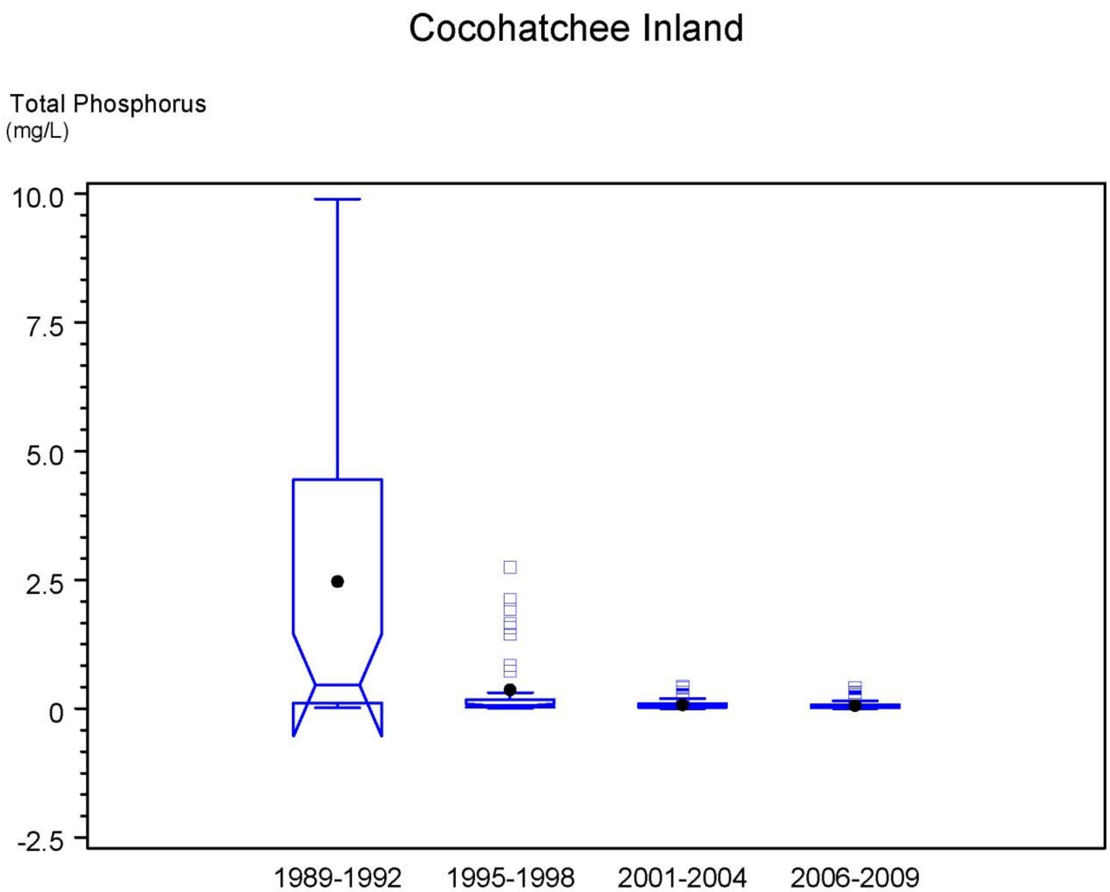

Figure 3.3-35 – Boxplot showing reductions in total phosphorus for Cocohatchee Inland from the historical (1989-1998) to the recent (1999-2009) time period.

Reductions in nutrient levels were apparent from the historical period to the recent period in several basins. Total nitrogen and TKN concentrations decreased by approximately 0.5 mg/L between 1998 and 2004 for Cocohatchee Inland, Gordon River Extension, Rookery Bay Inland East, and Tamiami Canal. In contrast, average TN concentrations increased for Cocohatchee River from approximately 0.75 mg/L in 1989-1992 to almost 1.75 mg/L in 1995-1998, though lower concentrations closer to 0.75 mg/L were observed in subsequent years. More frequent observations of greater than average TN concentrations were apparent for Fakahatchee Strand during the 2006-2009 period. A slight reduction in inorganic nitrogen was apparent for Gordon River Extension during the period of record when average concentrations decreased from 0.25 to <0.1 mg/L. Total phosphorus concentrations were greater during the 1989-1992 period than during subsequent years for most of the basins. During this time, most of the reductions were on the order of a 0.25 mg/L decrease in TP, but an even greater reduction from 2.5 mg/L to <0.5 mg/L was observed for Cocohatchee Inland (Figure 3.3-35). In addition, the frequency of observations considered to be unusually high (>2-8x the average TP concentrations) decreased from the historical time period to the recent time period.

3.4 Analysis of Land Use Patterns for Collier County Basins

In this section, we report the results of a land-use analysis which describes patterns of land use and land-use change that might explain some of the spatial and temporal variation in water quality across Collier County. Land use classes were obtained from the South Florida Water Management District and utilize the Florida Land Use\Land Cover Classification System (FLUCCS) codes. Changes in land use over time within a basin were related to water quality trends to provide insight into the potential causes of improved or degraded water quality. Appendix 3-4 provides land use characterizations for each FDEP basin including a summary of land use change from 1988-2005 for FLUCCS Level I and FLUCCS Level III, as well as a description of percent land use within a 100-meter buffer along the surface waters for the 2005 land use coverage.

3.4.1 Land use characterization for Collier County basins

The coastal basins along the western side of Collier County, including Naples, Naples Bay and Marco Island North have been predominantly urban basins since 1988 with 70-90% urban land use (Figure 3.4-1, Table 3-3). Golden Gate, Gordon River, and Rookery Bay Inland West, basins adjoining the Naples and Naples Bay basins, became more urbanized during this time period with 10-25% of the basin converted from natural to urban land uses. The most rapid land use changes were observed in the area just north of Naples in the Oak Creek, Little Hickory, Cocohatchee Golf Course and Cocohatchee Inland basins where 27-46% of the basin was urbanized between 1988 and 2005. The Oak Creek basin experienced the most dramatic change in land use with approximately 38% of the basin urbanized between 1999 and 2005. During the same time, agriculture in the Oak Creek basin decreased from 12% to <1% and natural land cover (uplands and wetlands) decreased from 52% to 25%.

The northern portion of Collier County is largely agricultural (30-90% cover per basin) including Camp Keais, Okaloacoochee Slough, Silver Strand, Townsend, Immokalee, Cow Slough, Corkscrew Marsh and Drainage to Corkscrew. These basins have not changed significantly from agricultural land use from 1988-2005, although an increase from about 45% to 56% in agricultural land use was observed for Cow Slough during that time (Figure 3.4-1). Corkscrew Marsh has agricultural land uses in approximately one-third of the basin but is otherwise natural.

Most of the basins in the central and eastern portion of Collier County, including Barron River Canal, Fakahatchee Strand, L-28 Tieback, Marco Island South, Rookery Bay Coastal, Faka Union South, Tamiami Canal and Ten Thousand Islands are all undeveloped basins with >85% natural land cover that have not changed during from 1988-2005 (Figure 3.4-1). Cocohatchee River, Rookery Bay Inland East and Faka Union North are largely natural basins (60-80% cover) located adjacent to predominantly urban or agricultural basins which accounts for the greater than average percentage of urban and agricultural land uses (20-30%) in these basins. In general, basins characterized by natural land cover have remained relatively unchanged during the period of record.

Note that inconsistencies with interpretation and/or classification of various land use classes (primarily upland and wetland land cover) resulted in estimates of percent composition that seem to incorrectly suggest changes in land cover from upland to wetland or urban to wetland between 1988 and 1995 for some basins. Also, differences in spatial resolution between the 1988 and 2005 coverages and more detailed land cover classification in 2005 may have introduced some of the apparent changes in land cover in Figure 3.4-1.

3.4.2 Relating land use change to trends in water quality

Development of natural lands for urban, industrial and agricultural uses is often associated with characteristic differences in water quality among land use classes. One of the most obvious relationships between water quality and land use was observed for agricultural lands in the northern portion of the county which, in general, had higher total nitrogen concentrations and a greater percentage of chlorophyll and dissolved oxygen exceedances than most basins. In contrast, urban basins in western Collier County had more heavy metal and fecal coliform exceedances, higher turbidity and greater flows than non-urban basins, likely a result of greater runoff from impervious surfaces. While urban and agricultural lands exhibit characteristic differences in water quality, the association between changing land use and water quality is often difficult to detect, for several reasons. Because most of the agricultural basins were developed prior to 1988, identifying changes in water quality related to agriculture is not possible. Changes in water quality related to urbanization may be undetectable as well, particularly since the implementation of stormwater best management practices (BMPs) in the 1980s. Through the use of BMPs, significant reductions in nutrients and suspended solids are possible before stormwater reaches and degrades surface waters.

Of the most rapidly urbanizing basins, North Golden Gate, Gordon River Extension, Cocohatchee Inland and Rookery Bay Inland continued to be developed as of the 2005 land use coverage. The greatest land use change between 1999 and 2005 (8-11%) was observed in these basins, as well as in some of the smaller urban basins such as Oak Creek, Little Hickory Bay and Cocohatchee Golf Course which experienced as much as 30-45% change from natural to urban lands, but lacked data with which to assess associated changes in water quality. Naples Bay Coastal is largely urbanized and experienced the least amount of change during this time period (2.5%).

Several statistically significant trends in water quality were identified for the most rapidly urbanizing basins as a result of the trend analysis presented in Results Section 3.3-4. Of the degrading trends, few were consistent across basins. Increases in salinity or conductivity for most of these basins are likely related to low rainfall from 2007-2009 as may be increases in pH. Degrading water clarity as a result of increasing concentrations of total suspended solids and turbidity for North Golden Gate and Gordon River Extension is the only other negative water quality trend observed in more than one of the urban basins.

Lack of a clear relationship between land use change (natural to urban) is likely a result of the fact that most of the urbanizing basins were already >70% urban when water quality monitoring began in the late 1980s. Many of the obvious changes to the physical and chemical attributes of natural lands, including water quality, occur very early during land development when only 10-20% of the basin has been urbanized (Schueler 1994, Arnold and Gibbons 1996, Holland et al. 2004). Two of the rapidly urbanizing basins, Cocohatchee Inland and Rookery Bay Inland West, however, are on the perimeter of the most urban basins in Collier County and were only ~25% urban in 1988 and have experienced a 30% increase in urban lands between 1988 and 2005. Though these basins are spatially distant, both shared many common trends in water quality including an increase in pH and salinity and a decrease in organic nitrogen and total nitrogen. Decreases in average total phosphorus concentrations were also observed during the historical monitoring period from 1988 to 1995 (Figure 3.3-35 and Appendix 3-3). However, increases in the frequency of higher than average nitrogen concentrations were observed for Cocohatchee Inland during the recent period (1999-2009) compared to the historical period (1988-1998). In general though, many of the water quality parameters appear to be improving over the period of record for both of these basins. While these shared patterns may be spurious, water quality monitoring of these basins should continue with these similarities in mind.

Table 3-3 – Summary of land use changes for Collier County basins (1988-2005) based on SFWMD land use coverages.

Basin	Basin size (km^2)	1988 Land Use			2005 Land Use			Change?**	Percent change to urban	2005 Dominant Land use
		Natural	Agricultural	Urban	Natural	Agricultural	Urban			
Lake Trafford	6.03	100%			100%			No	0%	Natural
Ten Thousand Islands	543.37	99%		1%	99%		1%	No	0%	Natural
L-28 Tieback	473.01	99%			99%	1%		No	0%	Natural
Fakahatchee Strand	382.44	99%			99%			No	0%	Natural
Barron River Canal	135.04	99%			99%			No	0%	Natural
Tamiami Canal	2382.62	97%	3%		96%	4%		No	0%	Natural
Marco Island South	43.77	96%		4%	97%		3%	No	-1%	Natural
Rookery Bay Coastal	156.34	89%	5%	6%	89%	2%	9%	No	3%	Natural
Faka Union South	240.60	78%		22%	99%		1%*	No	0%	Natural
Rookery Bay Inland East	218.50	76%	17%	7%	77%	15%	8%	No	1%	Natural/Ag
Corkscrew Marsh	214.14	64%	34%	2%	68%	30%	2%	No	0%	Natural/Ag
Cocohatchee River	12.49	68%		32%	65%		35%	No	3%	Natural/Urban
Faka Union North	111.09	60%	10%	30%	63%	3%	34%	No	4%	Natural/Urban
Camp Keais	225.45	60%	40%		60%	40%		No	0%	Ag
Okaloacoochee Slough	509.87	54%	46%		57%	42%	1%	No	1%	Ag
Silver Strand	217.86	34%	63%	3%	31%	67%	2%	No	-1%	Ag
Townsend	127.70	8%	91%	1%	12%	87%	1%	No	0%	Ag
Immokalee	35.39	32%	47%	21%	29%	49%	22%	No	1%	Ag/Urban
Cow Slough	47.66	47%	45%	8%	35%	56%	9%	No	1%	Ag/Urban/Natural
Marco Island North	34.29	7%		93%	8%		92%	No	-1%	Urban
Drain to Corkscrew	87.32	44%	54%	2%	35%	58%	7%	No	5%	Ag/Urban/Natural
North Golden Gate	294.55	31%	14%	55%	32%	6%	62%	No	7%	Urban
Naples	20.34	19%		81%	12%		88%	No	7%	Urban
Naples Bay Coastal	37.69	19%		81%	10%		90%	No	9%	Urban
Gordon River Extension	21.90	26%	2%	72%	14%		86%	Urbanizing	14%	Urban
Rookery Bay Inland West	60.93	67%	6%	26%	44%	3%	53%	Urbanizing	27%	Urban
Cocohatchee Inland	104.56	56%	19%	24%	41%	6%	53%	Urbanizing	29%	Urban/Ag
Cocohatchee Golf Course	8.72	70%		30%	37%		63%	Urbanizing	33%	Urban
Little Hickory	2.57	38%		62%	3%		97%	Urbanizing	35%	Urban
Oak Creek	19.18	57%	14%	29%	25%		75%	Urbanizing	46%	Urban

*A large portion of Faka Union South was zoned for urban development in 1988 but was never developed and remains natural lands.
**A basin was considered to be urbanizing if >10% of natural lands have been converted to urban lands between 1988 and 2005.

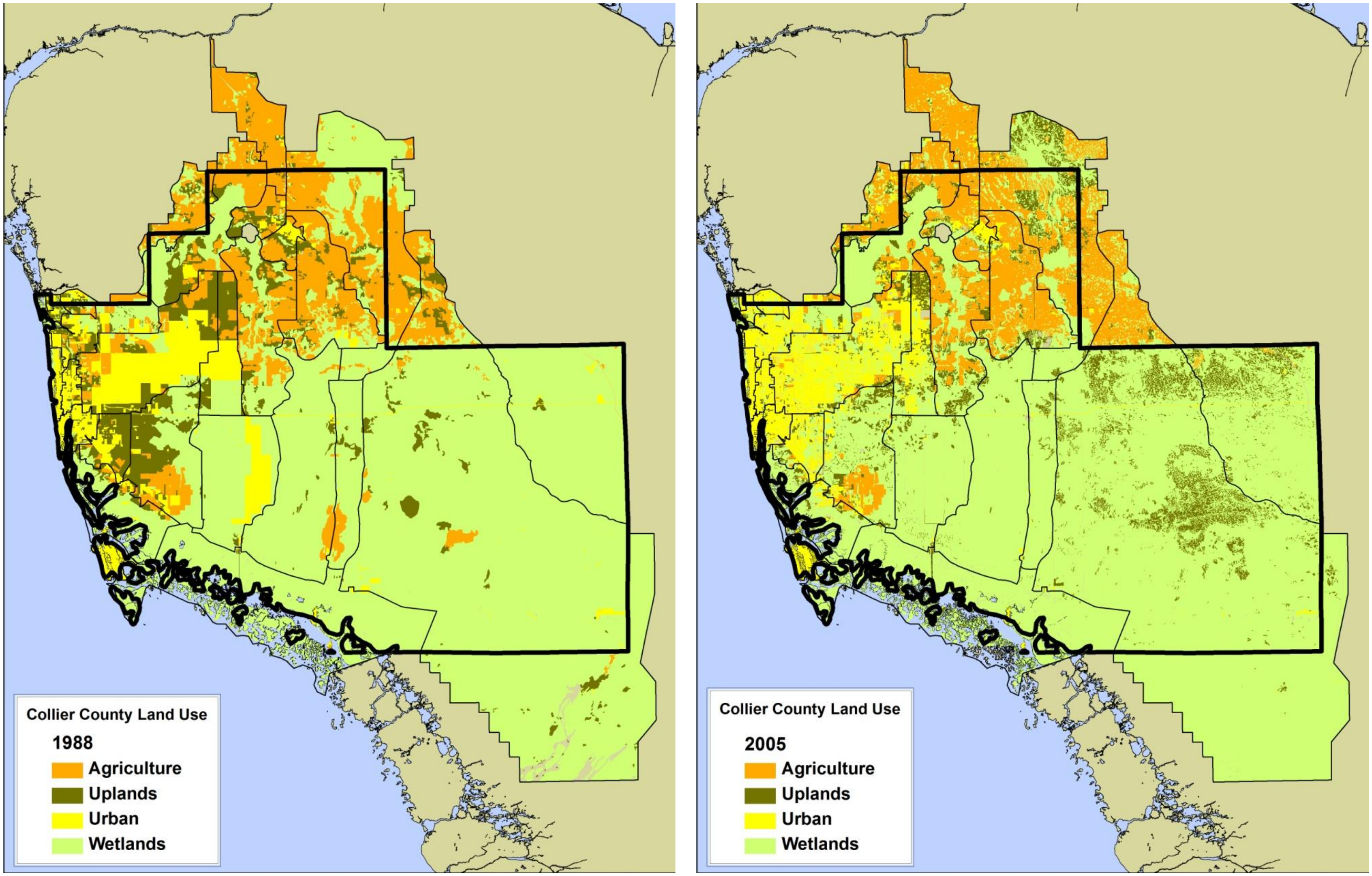

Figure 3.4-1 – Comparison of land use change in Collier County from 1988 to 2005 illustrating the conversion of natural land cover to urban land uses.

3.4.3 Land use ordination

Using principal components analysis, we identified three axes (PC1-PC3) that cumulatively explained 75.3% of the variation in land use for Collier County basins (Table 3-4). The first axis, PC1, was separated basins along a gradient of percent composition of Wetlands Hardwood Forest, which was predominantly composed of coastal mangroves (Figure 3.4-2). PC1 explained 30.8% of the variation. PC2 explained an additional 26.1% of the variation and further separated basins dominated by cypress wetlands (Wetlands Coniferous Forest) from basins developed for urban land use (Residential Medium Density). The third axis, PC3, was characterized as a gradient of agricultural land use with basins containing "Cropland and Pastureland" and "Tree Crops" separated from basins with minimal or no agricultural land uses. Axes beyond PC3 each explained <6% of the variation and were not considered.

Among the mangrove-dominated basins on the positive side of the PC1 axis (Figure 3.4-2) were those along the coast including Marco Island South, Ten Thousand Islands, Rookery Bay Coastal, Cocohatchee River and Faka Union South. Of these, the Marco Island South and Cocohatchee River basins had a greater percentage of urban land use than the other mangrove-dominated basins, as indicated by their higher position on PC2.

Cypress-dominated basins on the negative side of both PC1 and PC2 (Figure 3.4-2) were located in eastern and central Collier County including L-28 Tieback, Faka Union South, Tamiami Canal, Fakahatchee Strand, Barron River Canal, Rookery Bay Inland East, Corkscrew Marsh, Camp Keais and Faka Union North. At the other end of this gradient (on the positive side of PC2), and located on the western side of Collier County, were basins that had less cypress and greater percent cover by residential land uses including North Golden Gate, Rookery Bay Inland West, Cocohatchee Inland, Cocohatchee Golf Course, Oak Creek, Gordon River Extension, Naples and Naples Bay, Little Hickory and Marco Island North.

Results of the PCA analysis are presented in Figure 3.4-3 and illustrate the spatial relationship of basins in each of the land use groups delineated during the analysis. Basins characterized by a high percentage of agricultural land uses are located in northern Collier County and included Townsend, Silver Strand, Cow Slough, Drainage to Corkscrew, Okaloacoochee Slough, Immokalee, Camp Keais, and Corkscrew Marsh. Urban basins are located in western Collier County and the central, eastern and many of the coastal basins are primarily natural lands characterized by either cypress or mangrove wetlands.

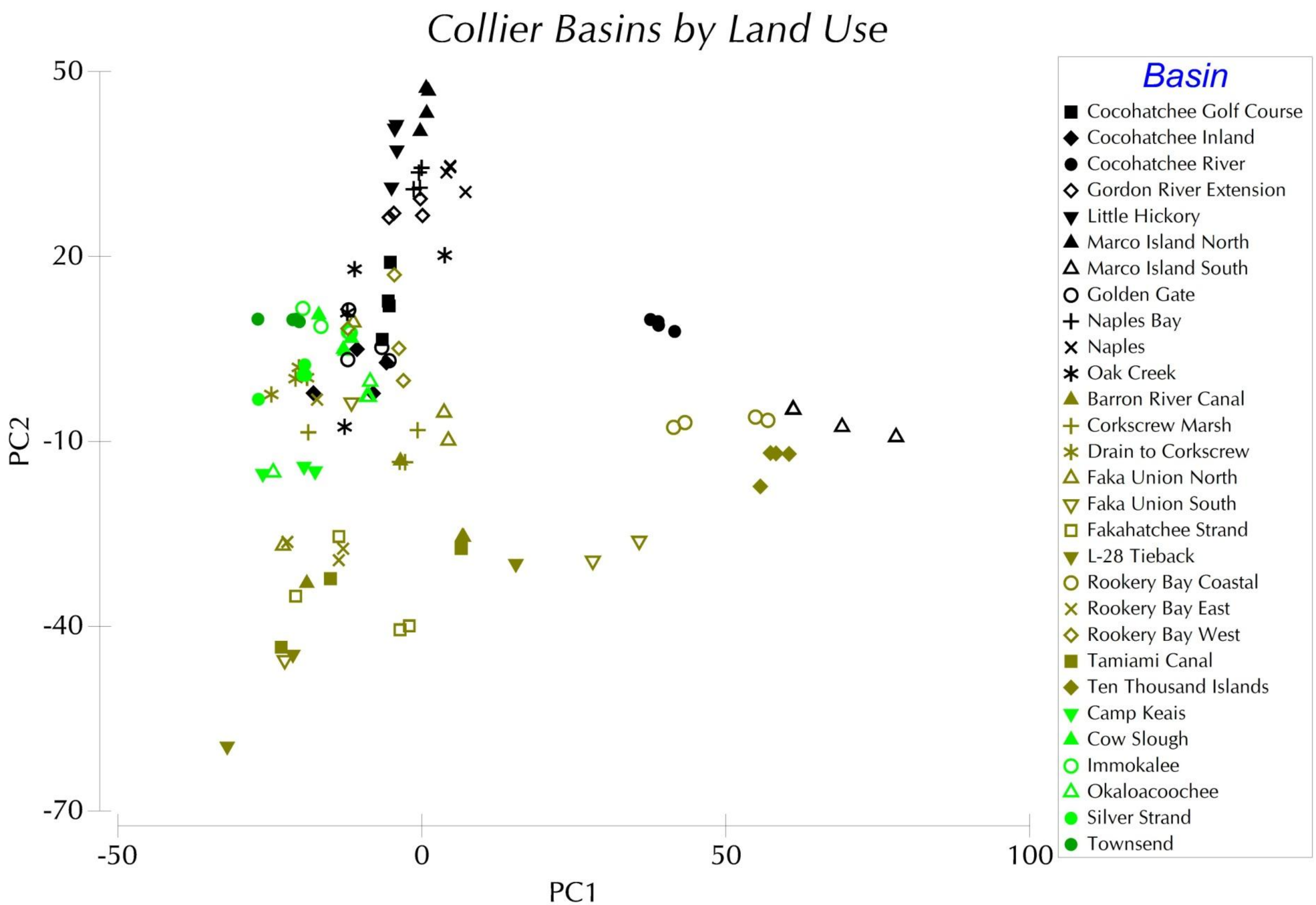

Figure 3.4-2 – Principal components ordination of Collier County basins by FLUCCS Level III Land Use. There are four points for each basin representing land use for 1989, 1995, 1999 and 2005.

Table 3-4. – Results of the principal components analysis (PCA) to identify the 2005 land use classes that best explain the observed variation among Collier County basins. Basins are plotted along gradients of land use (PCs) that separate basins by differences in land use. Land use classes that define each PC are indicated in BOLD.

Eigenvalues

PC	Eigenvalues	% variation	Cumulative % variation
1	594	30.8	30.8
2	503	26.1	57
3	353	18.3	75.3
4	102	5.3	80.6
5	92.6	4.8	85.4

Eigenvectors

Coefficients in the linear combinations of variables making up PCs

Variable	PC1	PC2	PC3	PC4	PC5
Commercial	0.00	0.11	-0.09	0.06	0.05
Commun	0.00	0.00	0.00	0.00	0.00
Cropland	-0.30	-0.03	**0.55**	-0.18	0.25
Disturbed	0.00	0.00	0.00	0.00	0.01
Extractive	-0.01	0.00	0.00	-0.02	0.00
Feed_Ops	0.00	0.00	0.00	0.00	0.00
Herb_Dry_Prair	0.00	0.00	0.01	-0.01	0.01
Industrial	-0.01	0.02	-0.01	-0.01	0.00
Institutional	0.00	0.02	-0.01	0.00	0.01
Mix. Range	-0.01	-0.01	0.00	0.00	-0.02
Non-Veg Wetl	0.05	0.00	0.01	-0.03	0.04
Nurseries	0.00	0.00	0.00	-0.01	0.00
Open_Land	0.00	0.03	-0.03	-0.09	-0.05
Open Land_Rural	-0.01	0.00	0.01	-0.01	0.01
Recreational	0.01	0.15	-0.13	0.02	0.06
Res_High	0.01	0.18	-0.15	0.10	0.09
Res_Low	-0.03	0.06	-0.03	-0.38	-0.14
Res_Med	0.00	**0.52**	-0.39	0.31	0.22
Special_Farms	0.00	0.00	0.00	0.00	0.00
Transportation	0.01	0.05	-0.04	0.01	0.03
Tree Crops	-0.18	0.03	**0.52**	0.43	0.26
Upl_Con_Fors	-0.08	0.04	-0.01	-0.33	-0.11
Upl_Fors	-0.03	0.02	0.04	-0.32	-0.21
Upl_Har_Fors	0.00	0.01	0.01	-0.02	-0.02
Upl_Mix_Fors	0.00	0.00	0.00	0.02	-0.02
Upl_Shrub_Brush	0.01	-0.01	0.00	0.01	0.00
Urban	0.00	0.04	-0.03	-0.01	-0.02
Utilities	0.00	0.00	0.00	0.00	0.00
Veg_Non-For_Wetl	0.03	-0.24	0.08	0.54	-0.66
Wetl_Con_Fors	-0.29	**-0.73**	-0.44	0.06	0.35
Wetl_For_Mix	-0.06	-0.05	-0.03	-0.09	-0.35
Wetl_Har_Fors	**0.89**	-0.23	0.15	-0.04	0.22

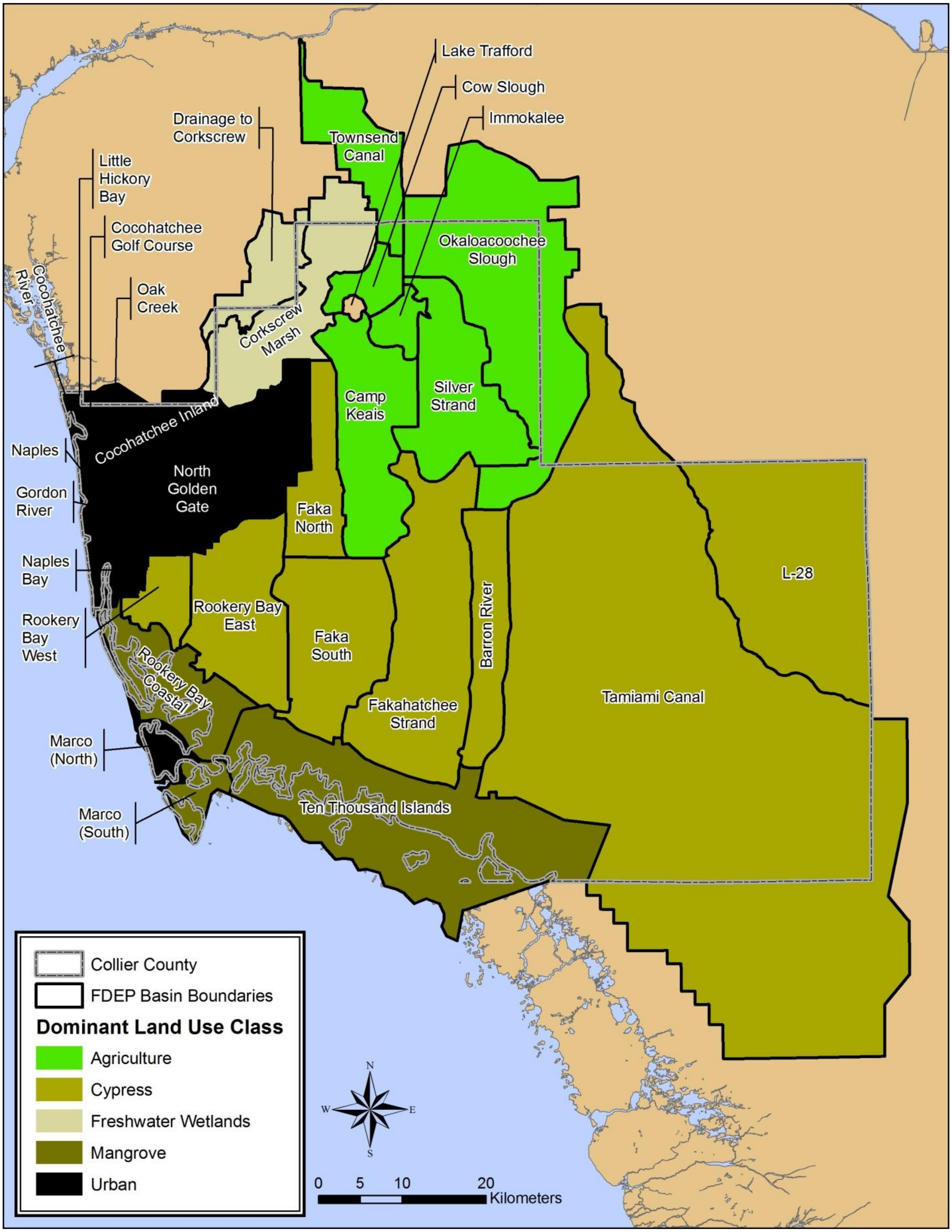

Figure 3.4-3 – Map of Collier County basins color-coded to indicate similar dominant land uses based on the results of principal components ordination of 2005 FLUCCS Level III Land Use.

3.5 Effects of Climatological and Hydrologic Events on Water Quality Trends

Major climatological events related to El Nino and tropical weather systems (i.e., tropical storms, hurricanes) have the potential to produce significant winds and rainfall which, in turn, can cause measurable deviations in water quality and flows. Several good examples of this were presented by Hagy et al. (2006) and Tomasko et al. (2006) who both documented significant increases in phytoplankton and declines in dissolved oxygen in Pensacola Bay and Charlotte Harbor, respectively, following the passage of major hurricanes in 2004. In this section, we provide an overview of major climatological and hydrologic events (e.g., significant rainfall, storms, drought, etc.) that may explain some of the observed variation in water quality across Collier County. First, we have identified years of above- or below-average total annual rainfall. Then on a finer scale, monthly rainfall peaks exceeding typical rainfall amounts are compared with water quality conditions in each basin. Finally, water quality data is examined for the months in which tropical storms and hurricanes affected the southwest Florida coast.

From analysis of rainfall trends in Section 2.1, wetter than average years (>60 inches) were recorded in 1991, 1994 and 1995 as well as 2001, 2003 and 2005. Drier than average years (<45 inches) were observed in 1990, 1996, 2000, 2004 and 2007.

During the dry months from October through May, typical monthly rainfall totals were between 0-5 inches. Between June and September, monthly rainfall was commonly observed between 5-15 inches. Based on these values, rainfall in excess of 5 inches during the dry months and 15 inches during the wet months was considered to be atypical.

3.5.1 Effects of rainfall on water quality

When examining the effects of rainfall events on water quality, continuous data may be necessary to detect a response as the temporal scale may be on the order of hours or days and the response may be short-lived. In order to relate tropical weather events, flow and water quality, we first identified the tropical storms and hurricanes that may have affected southwest Florida from 1999-2009 (Table 3-5). We then determined if rainfall amounts from each storm caused noticeable increases in monthly rainfall by examining annual plots of rainfall for each basin (Appendix 3-5). Finally, we examined changes in the magnitude of flows and water quality that may have resulted from the rainfall produced by these weather events. Specifically, we compared patterns in flow, chlorophyll-a, dissolved oxygen, total nitrogen and turbidity during the high rainfall event of June 2005 with those recorded during 2007 which was the driest year between 1999 and 2009. If major climatological events have a measurable effect on flows and water quality, the effect should be most obvious in a comparison of the most extreme conditions (i.e., wettest vs. driest periods).

Effects of high rainfall on flow and water quality

The most significant climatological event between 1999-2009 occurred in June 2005 when high rainfall totals between 15 and 25 inches were observed across Collier County. Peak flows resulting from these rains were observed for the BARRON and TAMIAMI flow gauges, but were not apparent at gauges further west. As a result of the high rainfalls, mean monthly flows in the Tamiami Canal increased from 0-4500 cfs between May and July 2005 while Barron River Canal to the west increased from about 5 to 110 cfs during the same time period. Increases in flow were also observed in the Faka Union Canal when flows increased from about 600-1300 cfs. Flows in

Table 3-5. – Summary of rainfall amounts at SFWMD gauges during tropical storms and hurricanes affecting Collier County from 1999-2009.

Storm	Category	Date	SFWMD Rain Gauge	Basin	Rainfall total (in)
Harvey	TS	9/29/1999	GOLDFS2	North Golden Gate	0.01
			COLLISEM	Ten Thousand Islands	2.01
Gabrielle	TS	9/14/2001	GOLDFS2	North Golden Gate	0.81
			COLLISEM	Ten Thousand Islands	0.33
Jeanne	2	6/26/2004	GOLDFS2	North Golden Gate	0.28
			COLLISEM	Ten Thousand Islands	0.02
			SGGEWX	Faka Union South	0.68
			BCA15	Tamiami Canal	0.01
			BCA17	Tamiami Canal	0
Charley	4	8/13/2004	GOLDFS2	North Golden Gate	0
			COLLISEM	Ten Thousand Islands	2.43
			SGGEWX	Faka Union South	1.85
			BCA15	Tamiami Canal	2.04
			BCA17	Tamiami Canal	1.18
Wilma	3	10/24/2005	GOLDFS2	North Golden Gate	6.03
			COLLISEM	Ten Thousand Islands	3.24
			SGGEWX	Faka Union South	5.42
			BCA15	Tamiami Canal	2.79
			BCA17	Tamiami Canal	4.15
Ernesto	TS	8/30/2006	GOLDFS2	North Golden Gate	3.91
			COLLISEM	Ten Thousand Islands	3.5
			SGGEWX	Faka Union South	8.38
			BCA15	Tamiami Canal	2.25
			BCA17	Tamiami Canal	4.58
Fay	TS	8/19/2008	GOLDFS2	North Golden Gate	7.69
			COLLISEM	Ten Thousand Islands	2.82
			SGGEWX	Faka Union South	5.18
			BCA15	Tamiami Canal	1.44
			BCA17	Tamiami Canal	2.23

Henderson Creek, draining to Rookery Bay Coastal increased from 0-180 cfs between May and July. Flows in the Cocohatchee River increased from almost 0 cfs to 180 cfs in response to the high rainfall amounts during June 2005; nearly 20 inches.

In June 2005, very noticeable declines in chlorophyll-a concentrations were observed for many of the basins potentially as a result of the high rainfall amounts in June 2005 (Figure 3.5-1). In many cases, chlorophyll-a concentrations decreased by almost 70% between May and July, as with Cocohatchee Inland (15 to 5 mg/L), Cocohatchee River (9 to 3 mg/L), Faka Union North (5 to 3 mg/L) and South (10 to 3 mg/L), Fakahatchee Strand (9 to 3 mg/L), Tamiami Canal (14 to 3 mg/L) and Ten Thousand Islands (13 to 3 mg/L). Even more extreme declines were observed for Barron River Canal (20 to 5 mg/L) and Okaloacoochee Slough (25 to 5 mg/L). Dissolved oxygen levels declined as well for many of the same basins from 6-8 mg/L in May to 2-4 mg/L in June for Barron River Canal, Cocohatchee Inland, Faka Union, and Golden Gate. Dissolved oxygen in Fakahatchee Strand and Okaloacoochee Slough decreased from 3-4 mg/l down to <1 mg/L. Total nitrogen decreased in some cases between May and June but usually not more than 0.5 mg/L. Changes were not observed for dissolved oxygen or TN in Tamiami Canal despite the extreme increase in flow from May to June 2005. Turbidity decreased by 1-3 ntu for Cocohatchee River, Okaloacoochee Slough, Rookery Bay Inland (East and West) and Tamiami Canal and increased from 2 to 8.5 ntu for Ten Thousand Islands between May and June. Otherwise, there were no clear trends for nutrients or turbidity.

Effects of low rainfall on flow and water quality

When the 2005 wet-year trends were compared with water quality from the driest year, 2007, many of the same sharp declines were observed for the same basins (Figure 3.5-2). From April to May, chlorophyll-a decreased by 50-70% for Cocohatchee River (25 to 8 mg/L), Ten Thousand Islands (11 to 4 mg/L), Golden Gate (16 to 5 mg/L) and Rookery Bay Inland West (15 to 6 mg/L) and decreased by an even greater margin for Camp Keais (110 to 20 mg/L) and Okaloacoochee Slough (140 to 30 mg/L). As observed during the high rainfall of June 2005, dissolved oxygen levels also dropped from May to June in 2007 though only by 1-2 mg/L compared to 3-4 mg/L during June 2005. These declines are likely more associated with increasing water temperature than with rain events.

3.5.2 Effects of tropical weather events on flows

Between 1999 and 2009, there were seven tropical weather events that resulted in measurable increases in rainfall from the previous months' total. Four tropical storms (TS) during August and September included TS Harvey (September 1999), TS Gabrielle (September 2001), TS Ernesto (August 2006) and TS Fay (August 2008). There were also three hurricanes: Hurricane Jeanne (Category 2, June 2004), Hurricane Charley (Category 4, August 2004) and Hurricane Wilma (Category 3, October 2005). Only Hurricane Wilma and Tropical Storms Ernesto and Fay resulted in appreciable rainfall amounts between 6-9 inches in a single day. The other storms resulted in <2.5 inches of rain and probably had a much less detectable effect on flows and water quality (Table 3-5).

Changes in flows were observed during many of these storm events, although the magnitude of the changes were not consistent among basins. As with the comparison of water quality to atypical rainfall events presented above, there were no clear patterns, within or among basins, suggesting that changes in water quality resulting from the passing storm were not detectable. Therefore, discussion here is focused on the relationship between storm events and gauged flows.

TS Harvey made land fall at Everglades City in September 1999 where it corresponded with a noticeable increase in rainfall (10-15 inches total) from the previous month in many of the central and eastern basins including Cow Slough, Okaloacoochee Slough, Silver Strand, Camp Keais, Barron River Canal, Fakahatchee Strand, and Tamiami Canal. During June of 1999, monthly rainfall totals equal to or greater than 15 inches were recorded for many of the same basins, Barron River Canal, Corkscrew Marsh, Fakahatchee Strand, Tamiami Canal and Ten Thousand Islands though these rain events were not associated with a named tropical system. No increase in flows was observed for the Cocohatchee River and only a slight increase in the Barron River Canal (80-110 cfs). More substantial increases in flow, however, were recorded for the Faka Union (600-1300 cfs) and Tamiami canals (800-4500 cfs) between August and October.

In September 2001, TS Gabrielle occurred during a month of high rainfall for the majority of Collier County with monthly rain totals between 10-20 inches, though rainfalls on the day of the storm were <1 inch in North Golden Gate and Ten Thousand Islands, even though the highest rainfall totals that month (~20 inches) were along the coast for Ten Thousand Island and North Golden Gate. July 2001 was also a very wet month, contributing to a wetter than average year, with rain totaling 10-15 inches across the county in July. Heavy rainfall between July and September 2001, including rain contributed by TS Gabrielle, resulted in an increase in mean flows in the Barron River Canal from 0-120 cfs. Concurrent increases from 75-230 cfs were observed in the Cocohatchee River, but increases in flow were much smaller, from about 50-70 cfs, in Henderson Creek. In the Faka Union Canal mean monthly flows increased slightly from 1300-1500 cfs, but doubled from 900-1700 cfs in the Golden Gate basin. Mean monthly flows in the Tamiami Canal increased from 2000-2400 cfs in September and increased again to 3200 cfs in October despite no additional major rain events.

There were two major hurricanes that affected the southwest Florida coast in 2004 during an otherwise dry year. Hurricane Jeanne occurred in June followed by Hurricane Charley in August. Rainfall amounts reaching 15 inches were recorded in the northeastern part of the county for the Cocohatchee River and Corkscrew Marsh basins, but otherwise rainfall totals did not typically exceed 10 inches. Relatively small increases in mean monthly flow were observed for Henderson Creek (0-70 cfs), Barron River Canal (30-100 cfs) and Cocohatchee River (0-180 cfs) when Hurricanes Jeanne and Charley passed Collier County. A larger flow response was observed in the Faka Union Canal (25-1200 cfs) and the Tamiami Canal (0-1500 cfs).

Hurricane Wilma resulted in significant rain for the northern part of Collier County (10-15 inches) when it made landfall at Marco Island in October 2005, but caused only a slight increase in rainfall from the previous month resulting in 5-10 inches total in the Rookery Bay Inland East, Faka Union, Fakahatchee Strand, Barron River Canal, Ten Thousand Islands and Tamiami Canal basins. No change in flow for most of the basins and only a relatively small increase in the Cocohatchee River (70-160 cfs) as a result of Hurricane Wilma.

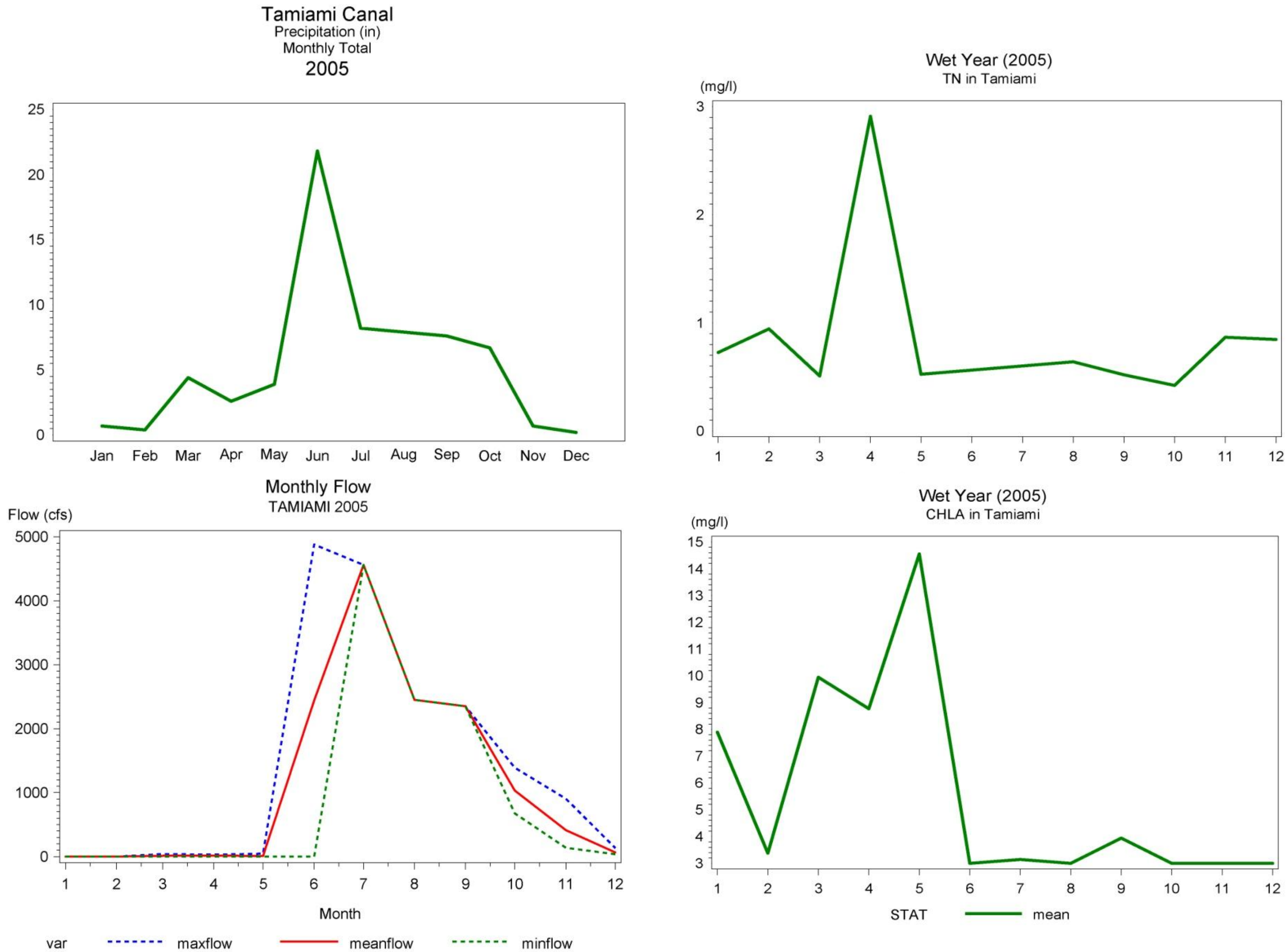

Figure 3.5-1 – Trends in rain, flow and water quality during "wet year" 2005 when >20 inches was recorded in June.

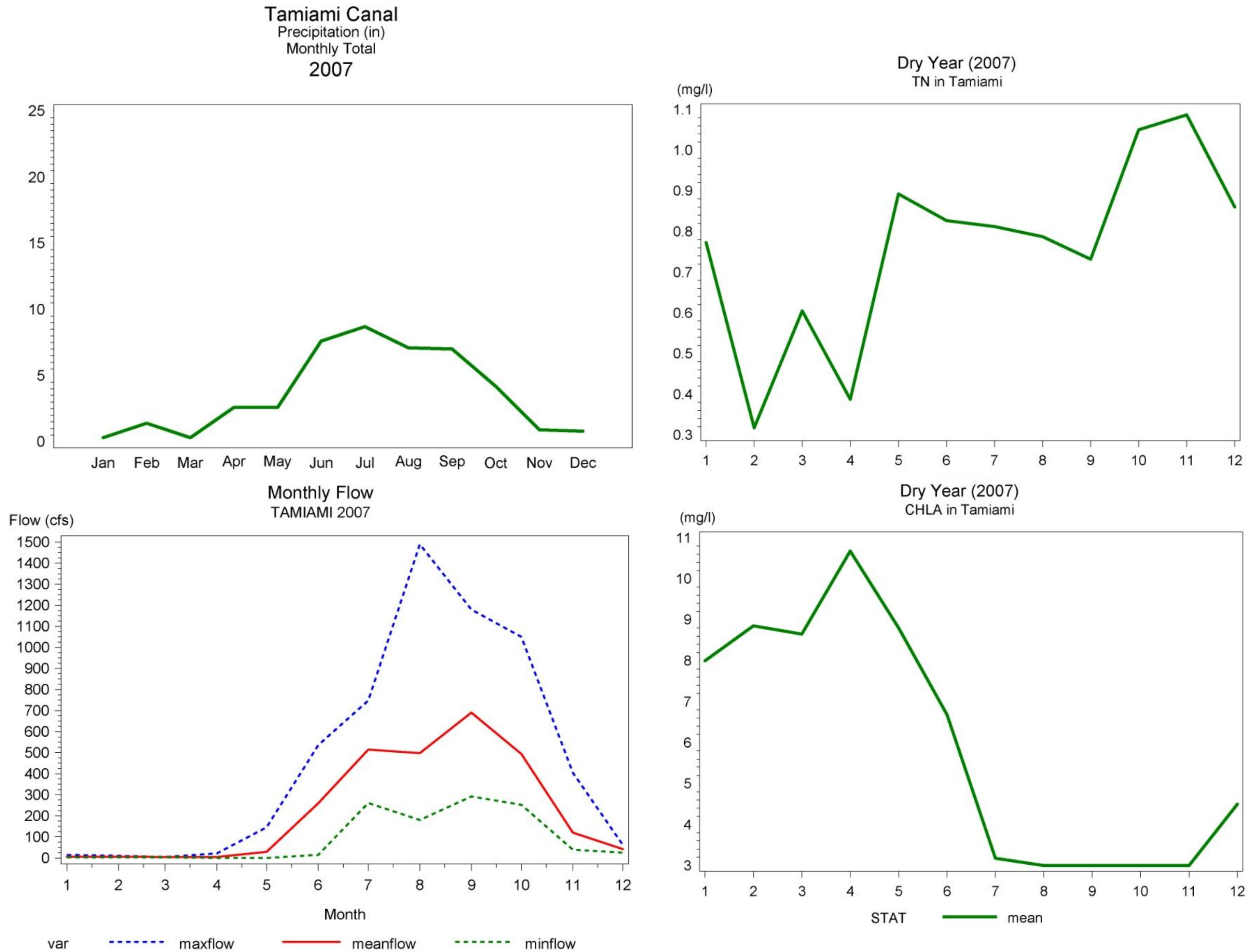

Figure 3.5-2 – Trends in flow and water quality during "dry year" 2007 when 15-25 inches of rain was recorded in June.

TS Ernesto passed over Collier County in late August 2006 and contributed to monthly rainfall totals between 10-15 inches for most of the central basins. Coastal basins from Cocohatchee River to Marco Island did not receive any detectable increases in rainfall from the previous month as a result of this storm, although flows in the Cocohatchee River increased from 100-290 cfs between August and September. Flows increased substantially in September in the Faka Union Canal (600-2000 cfs) and the Tamiami Canal (700-3600 cfs), but any increases in Henderson Creek and Barron River Canal were very minor (20-30 cfs).

TS Fay made landfall at Marco Island in August 2008 and resulted in monthly rainfall totals between 10-15 inches across most of Collier County. Despite the county-wide increases in rainfall associated with TS Fay, a flow response was only minor for Henderson Creek (<50 cfs) and was not detected in Barron River Canal. Larger changes in flow were observed for the Cocohatchee River (120-220 cfs), Faka Union Canal (900-1550 cfs) and Tamiami Canal (1200-2300 cfs).

Although tropical storms and hurricanes have the potential to produce significant daily rainfall totals that can result in quantifiable changes in water quality conditions and flows in the short-term, the extremely low frequency with which these events occur probably makes their impact much less significant than the seasonally heavy rains that are common in south Florida. High monthly rainfall totals during the wet season and frequent daily rainfall during these months, aside from that produced by tropical storms and hurricanes, are likely to have predictable impacts on water quality conditions in Collier County.

3.6 Basin Performance and Exceedances Relative to Water Quality Standards and Thresholds

Florida Administrative Code (F.A.C.) 62-302 Surface Water Quality Standards provides the water quality criteria for surface waters in the state of Florida. This rule was recently updated to provide a reclassification of the designated uses of the water bodies in Florida. A designated use is the present and future most beneficial use of a water body. Currently, water bodies in Florida may be used for one or all of the following designated use;

- CLASS I Potable Water Supplies
- CLASS II Shellfish Propagation or Harvesting
- CLASS III Fish Consumption; Recreation, Propagation and Maintenance of a Healthy, Well-Balanced Population of Fish and Wildlife
- CLASS III-Limited Fish Consumption; Recreation or Limited Recreation; and/or Propagation and Maintenance of a Limited Population of Fish and Wildlife
- CLASS IV Agricultural Water Supplies
- CLASS V Navigation, Utility and Industrial Use

The Impaired Waters Rule (F.A.C. 62-303) is used to determine if water bodies are meeting their designated uses and define impairment so that corrective actions may be taken to improve water quality.

Established water quality standards include different targets based on the salinity of the water bodies. Freshwater is defined as chloride concentrations of less than 1500 mg/L while predominantly marine systems are defined as greater than 1500 mg/L. Dissolved oxygen (DO) standards for freshwater systems are set at "not less than 5.0 mg/L" and estuarine/marine systems are defined as "not less than 4.0 mg/L." DO is a very important limiting factor impacting freshwater and estuarine systems and can be used as an ecosystem health indicator. Cultural eutrophication, which is nutrient excess leading to overproduction of microalgae and associated trophic imbalances, is common in estuaries near human population centers. In eutrophic conditions, DO can exhibit extreme diel cycles. Photosynthesis via algae elevates DO levels in the water during the day but at night when respiration is high, DO levels can drop to dangerously low levels. Eutrophication can lead to periodic or long term hypoxia, defined as water column oxygen concentrations less than 2 mg O_2 l^{-1}, and anoxia in estuarine ecosystems. Fishes, crabs and shrimp will attempt to move away from hypoxic environments and few marine animals survive in prolonged exposure to anoxic conditions. DO levels are often quite variable in freshwater and estuarine system due to fluctuations in temperature, salinity, basin morphology and overall productivity.

Chlorophyll *a,* a pigment used in photosynthesis, serves as a measure of phytoplankton biomass (abundance) in estuaries. Planktonic algae provide a food source for filter-feeding bivalves (oysters, mussels, scallops, clams) and zooplankton (including the larvae of crustaceans and finfish). Chlorophyll *a* concentrations may also be used as a measure of overall ecosystem health. High amounts of chlorophyll *a* in estuarine waters are a primary indicator of nutrient pollution because excess nutrients fuel the growth of algae. High chlorophyll *a* values can be indicative of harmful algal blooms which adversely impact aquatic life and human recreation. There is currently no State standard for chlorophyll *a* in F.A.C. 32-302; however, the Impaired Waters Rule establishes chlorophyll *a* guidance concentrations of 20 μg/L for freshwater systems and 11 μg/L for marine systems. A water body is placed on the FDEP's planning list for further investigation of nutrient impairment when annual mean chlorophyll a levels are in excess of the guidance concentrations.

Fecal coliform concentrations are monitored in surface waters to protect human health. The threshold for impairment is based on the waterbody designation which is Class III for most of Collier County's basins. For Class III waterbodies, levels "shall not exceed 400 colonies/100 ml in 10% of the samples, nor exceed 800 on any one day". The same is true for Class II waterbodies (Cocohatchee River, Naples Bay Coastal and Ten Thousand Islands) which are designated for shellfish propagation or harvesting, but fecal coliform levels shall also not exceed 43 colonies/100 ml in 10% of samples.

Arsenic is used in arsenic-based herbicides and has been shown to be in high concentrations in some parts of Collier County particularly within the Cocohatchee (Inland Segment), Gordon River Extension, and Naples basins. Copper, even in small concentrations, can be lethal to invertebrates including shellfish and crustaceans and has been reported to be a problem in urbanized estuaries—especially Naples Bay where Kimbrough et al. (2008) reported the highest concentrations of copper in Florida. Iron is the cause of impairment in Barron River Canal, Cocohatchee River, Naples Bay Coastal and North Golden Gate.

The purpose of the following section is to examine exceedances of several water quality parameters often used to determine if a waterbody is impaired. Chlorophyll *a*, dissolved oxygen, fecal coliforms and several heavy metals including arsenic, copper and iron were considered. Frequency of exceedances was examined by basin and/or station across years to determine which basins may be most impacted. Tables and figures summarizing the results of these analyses are presented in Appendix 3-6.

3.6.1 Annual exceedances of chlorophyll *a*

During most years from 1999-2009, the percentage of basins exceeding the annual average chlorophyll threshold each year was relatively low (<10%) and never exceeded 20% of basins (4 basins) except in 2007 and 2009, both years of low rainfall (Figure 3.6-1). In general, most basins had no chlorophyll exceedances, but most of those that did were located in the northern and central region of Collier County.

Only 3 of 11 predominantly freshwater basins exceeded the chlorophyll threshold of 20 ug/L from 1999-2009. All of the exceedances were observed in basins in the northern part of Collier County where agricultural land uses are most prevalent (i.e., Barron River Canal, Camp Keais and Okaloacoochee Slough) and nearly all exceedances occurred during 2007 and 2009 (Figure 3.6-2).

Among predominantly marine basins, there were chlorophyll exceedances for 4 of the 6 basins, with Fakahatchee Strand exceeding the chlorophyll threshold of 11 ug/L during 4 of 11 years (Figure 3.6-3). Fakahatchee Strand exceeded the chlorophyll threshold during 2002, 2006, 2007 and 2009. Cocohatchee River (2001), Gordon River Extension (2002) and Rookery Bay Inland East (2008) each had 1 annual exceedance. No chlorophyll exceedances were observed for Naples Bay or Ten Thousand Islands.

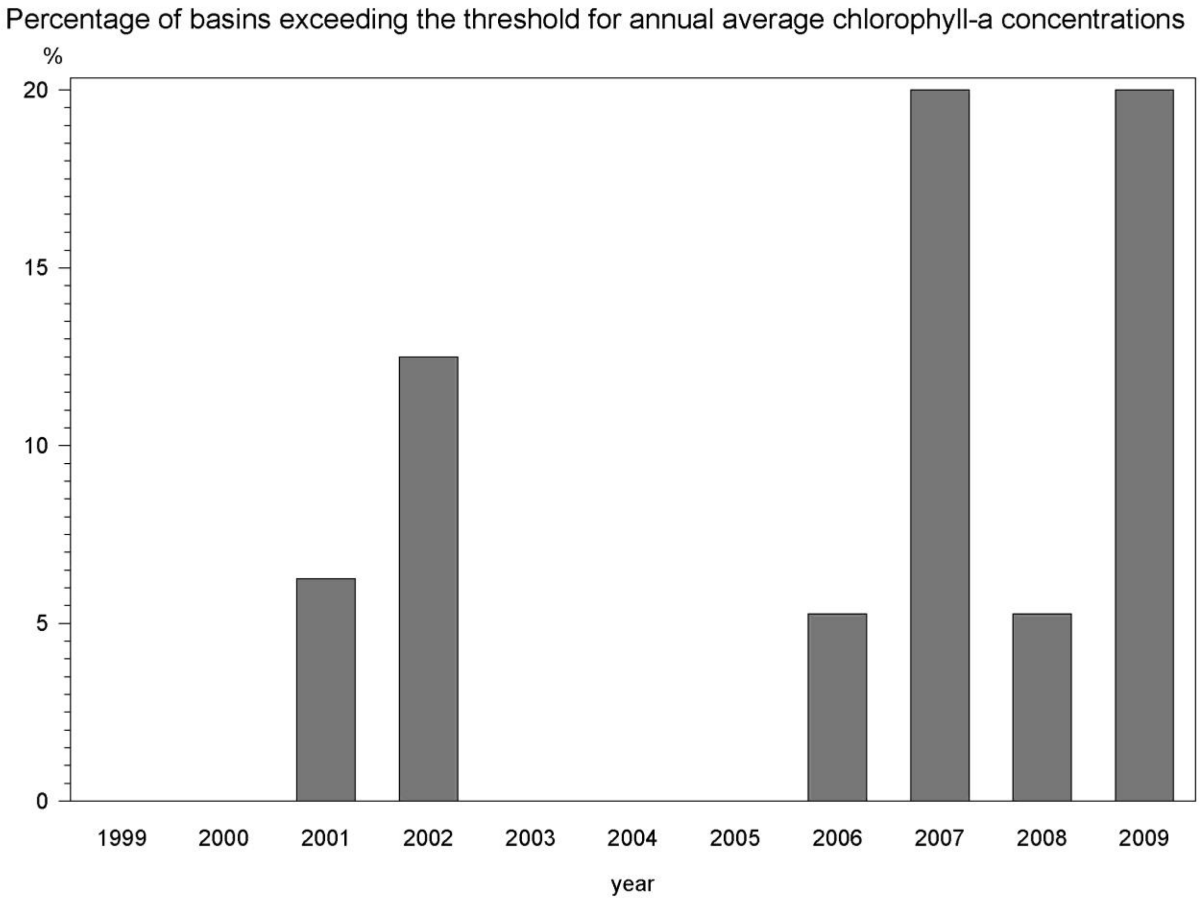

Figure 3.6-1 – Percentage of basins exceeding the chlorophyll-a threshold in a given year.

In summary, most of the chlorophyll exceedances occurred during 2002, 2007 and 2009, during which the lowest rainfall and flow were recorded. Low flow can increase residence time and thus the availability of nutrients, primarily nitrogen and phosphorus. These longer residence times and nutrient availability can lead to higher production and thus higher chlorophyll *a* measurements. The greatest number of chlorophyll *a* exceedances was observed for Fakahatchee Strand. This basin is directly downstream of the agricultural region where the majority of chlorophyll exceedances for freshwater stations were observed in Barron River Canal, Camp Keais and Okaloacoochee Slough.

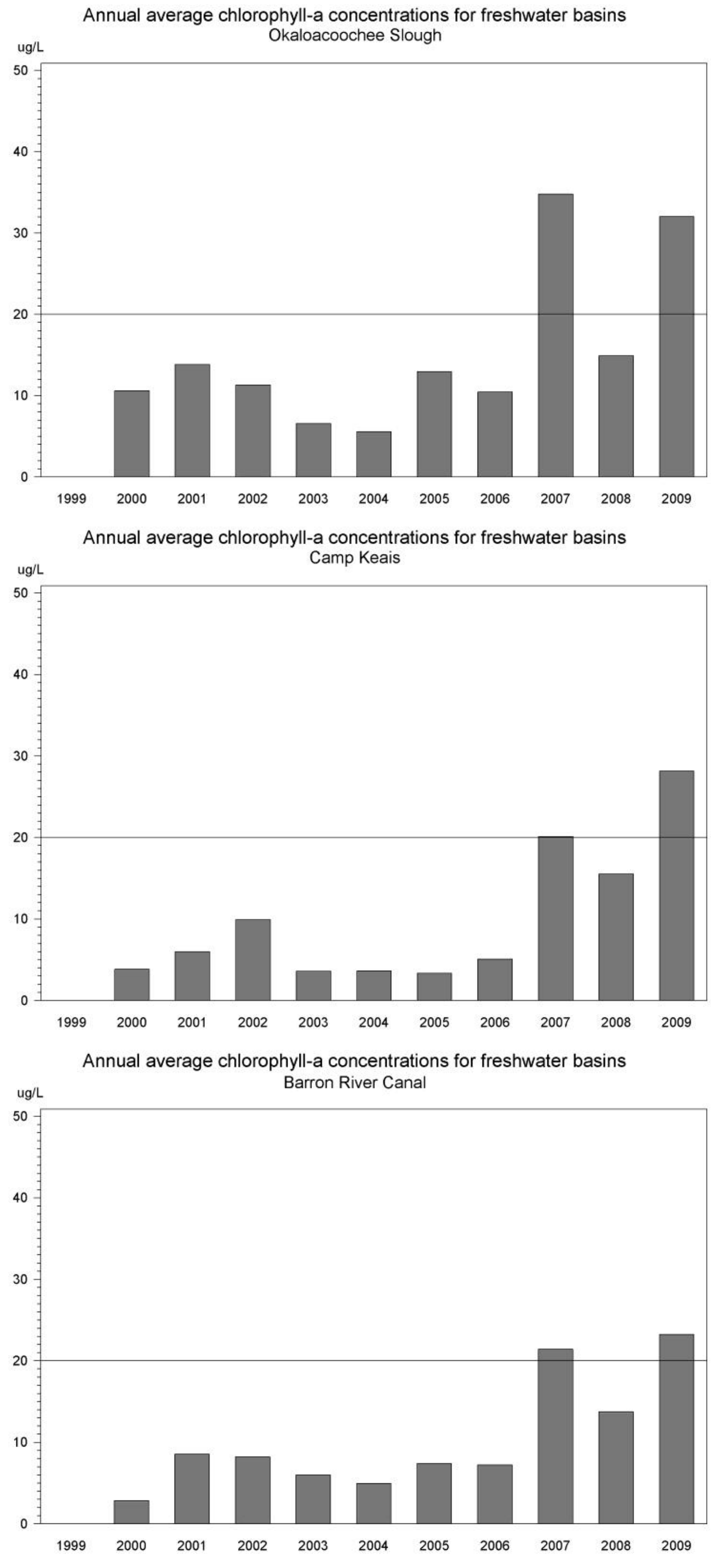

Figure 3.6-2 – Annual average chlorophyll-a concentrations for freshwater basins with exceedances. The horizontal reference line indicates the chlorophyll threshold of 20 ug/L used to determine impairment.

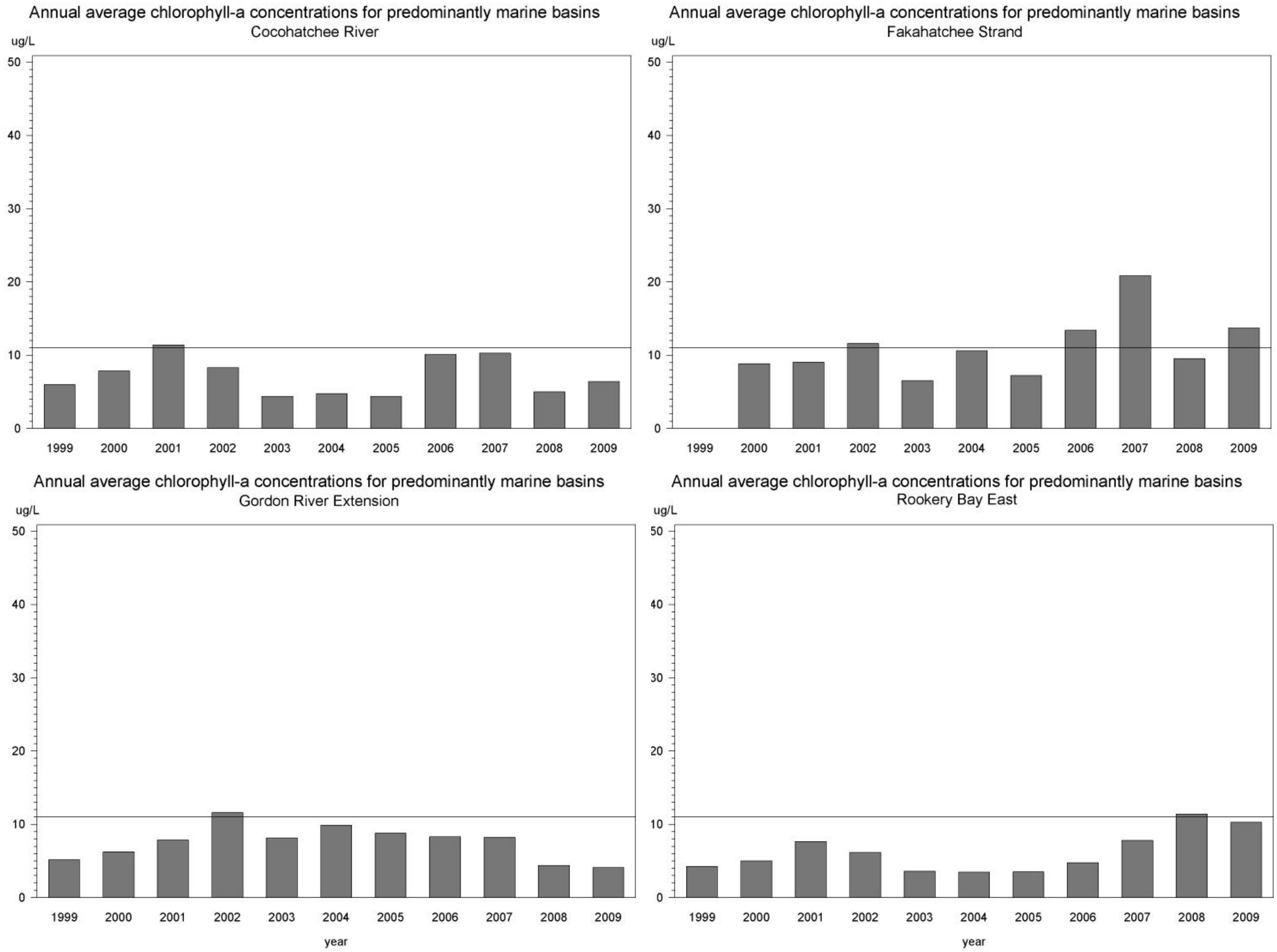

Figure 3.6-3 – Annual average chlorophyll-a concentrations for several predominantly marine basins. The horizontal reference line indicates the chlorophyll threshold of 11 ug/L used to determine impairment.

3.6.2 Annual exceedances of dissolved oxygen

The annual numbers of dissolved oxygen samples exceeding the state standard (5 mg/L for freshwater and 4 mg/L for marine waters) ranged from 28% to 60% of total samples over the entire study period. 2000 had the lowest number of exceedances with 87, of 306 total samples accounting for 28% exceedance (Figure 3.6-4). The highest number of exceedances was in 2003, with 447 of 742 total samples accounting for 60% of samples.

3.6.3 Exceedances by basin

Predominantly Marine Basins

At Cocohatchee River Basin, samples exceeded the state standard at both sampling stations for all years of the study period (2001-2009) with one exception at one of the two sampling stations in 2001. Sampling exceedance percentages for all other years ranged between lows of 17% and 12% (2005 and 2006) to a high of 60% (2003).

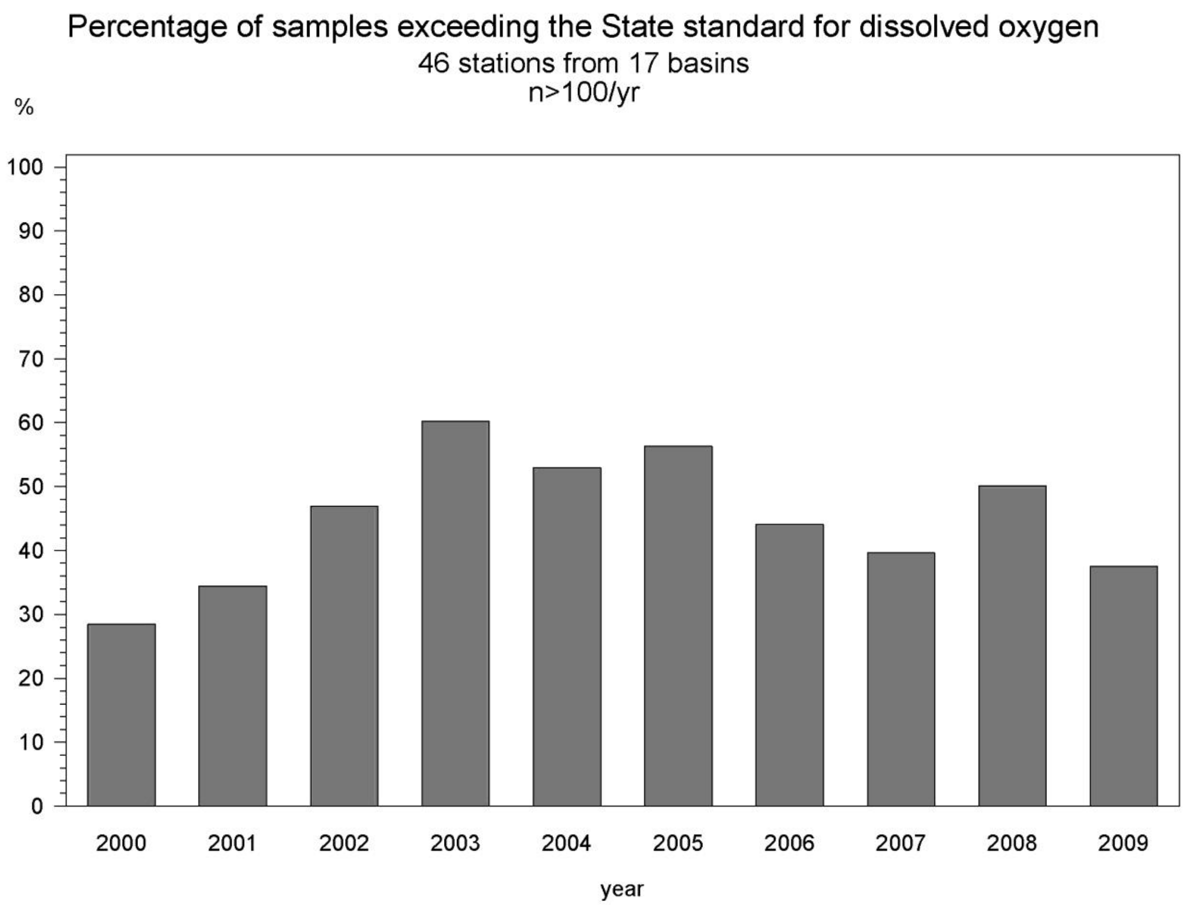

Figure 3.6-4 – Percent annual dissolved oxygen exceedances across Collier County.

In Gordon River Basin, the state standard was exceeded for all years of the reporting period (2001-2009) at the single sampling station, with percentages ranging from 62% in 2006 to 92% during 2009.

At Ten Thousand Islands, two sampling stations, exceedances were reported for all years of the study period (2001-2009). Dissolved oxygen exceedances ranged from 27% in 2002 to 54% in 2008.

Freshwater Basins

Dissolved oxygen samples in Barron River Canal exceeded the state standard throughout the study period, with sampling percentages exceeding the standard ranging in value from 40% in 2001 to 100% in 2003 (Figure 3.6-5). The values for the other years ranged between 83-94%.

In Camp Keais, dissolved oxygen levels exceeded the state standard throughout the study period. Dissolved oxygen exceedances ranged from 41% in 2001 to 97% in 2004 and 2008.

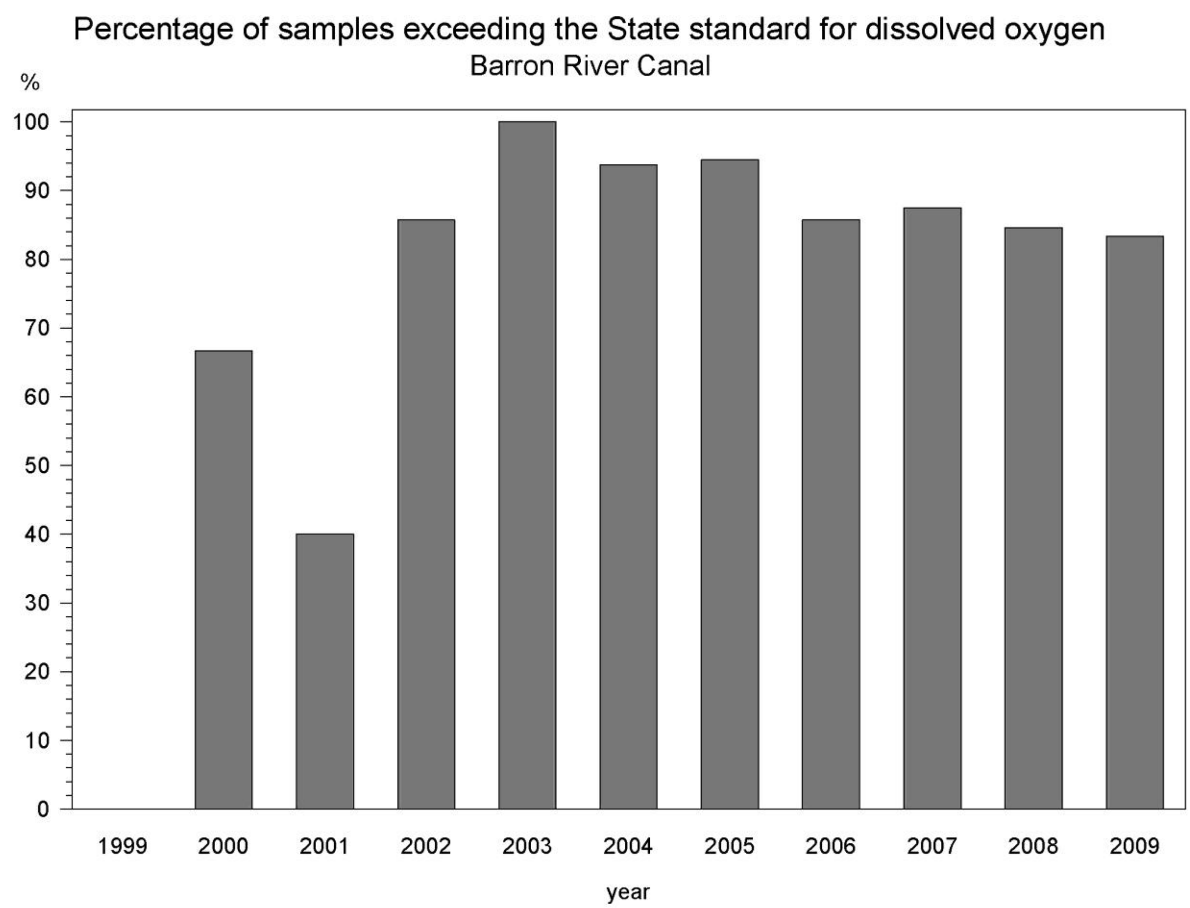

Figure 3.6-5 –Bar chart summarizing the high frequency of dissolved oxygen exceedances in Barron River Canal.

All of the stations in the Cocohatchee Inland basin exceeded the state dissolved oxygen standard consistently throughout the study period (Figure 3.6-6). The percentages of sampling exceedances generally ranged between 32% and 60% throughout the study site across the seven stations.

In Corkscrew Marsh, samples exceeded the state standard for dissolved oxygen consistently throughout the study period, with sampling exceedance percentages in the 80s for 7 of the 9 study years. The highest sampling exceedance percentage was in 2008 at 92%, and the lowest percentage was in 2009 at 67%.

Dissolved oxygen at Cow Slough exceeded the state standard was for all years of the study period (2003-2009), with sampling percentages ranging from 38% and 25% (2005, 2006) to 67% (2004, 2009) and 100% (2008) at the single sampling station.

Faka Union North had three sampling stations that collected data from 2001-2009. In 2009, two of these stations did not exceed state standards. For the rest of the period, all stations showed sampling exceedances, ranging from a low of 10% (2009) to a high of 58% and 56% in 2003 and 2005, respectively.

Faka Union South had five sampling stations for years 2001-2009. All sampling stations recorded sampling exceedances, with exceedance percentiles ranging from 16% in 2009 to 46% in 2003, 2005 and 2008.

Fakahatchee Strand had three sampling stations that collected data from 2001 to 2009. All sampling stations recorded exceedances ranging from 51% to 75%. Lowest exceedances occurred during 2006 and 2007 at 51%. Highest exceedances occurred during 2005 at 75%

North Golden Gate exceeded the state standard during all years of the study. Exceedances ranged from 15% to 58% of samples. Lowes exceedances were during 2009 and highest exceedances were during 2003 at 58%.

In Immokalee, the state standard was exceeded for all years of reporting from 2003 through 2009, with percentages ranging from 36% in 2009 to 89% in 2004.

Naples Bay had five sampling stations sampled from 2000 through 2009. The state standard was exceeded for all years of the reporting period. Lowest exceedances were found in 2009 at 24%. Highest exceedances were in 2003 and 2005 at 47% of samples.

At Okaloacoochee Slough, the state standard was exceeded for all years of the reporting period (2001-2009). Other than 2001, in which the exceedance percentage was 35%, the ranges for all years of the reporting period ranged between 77% (2006) to 100% (2003).

At Rookery Bay Inland East, two sampling stations, the state standard was exceeded for all years of the reporting period (2001-2009). Exceedance percentages ranged from 30% in 2006 to 54% in 2005.

At Rookery Bay Inland West, sampling station, the state standard was exceeded for all but the final year of the study period (2001-2009), with percentage values ranging from 25% in 2001 and 2002 to 92% in 2003.

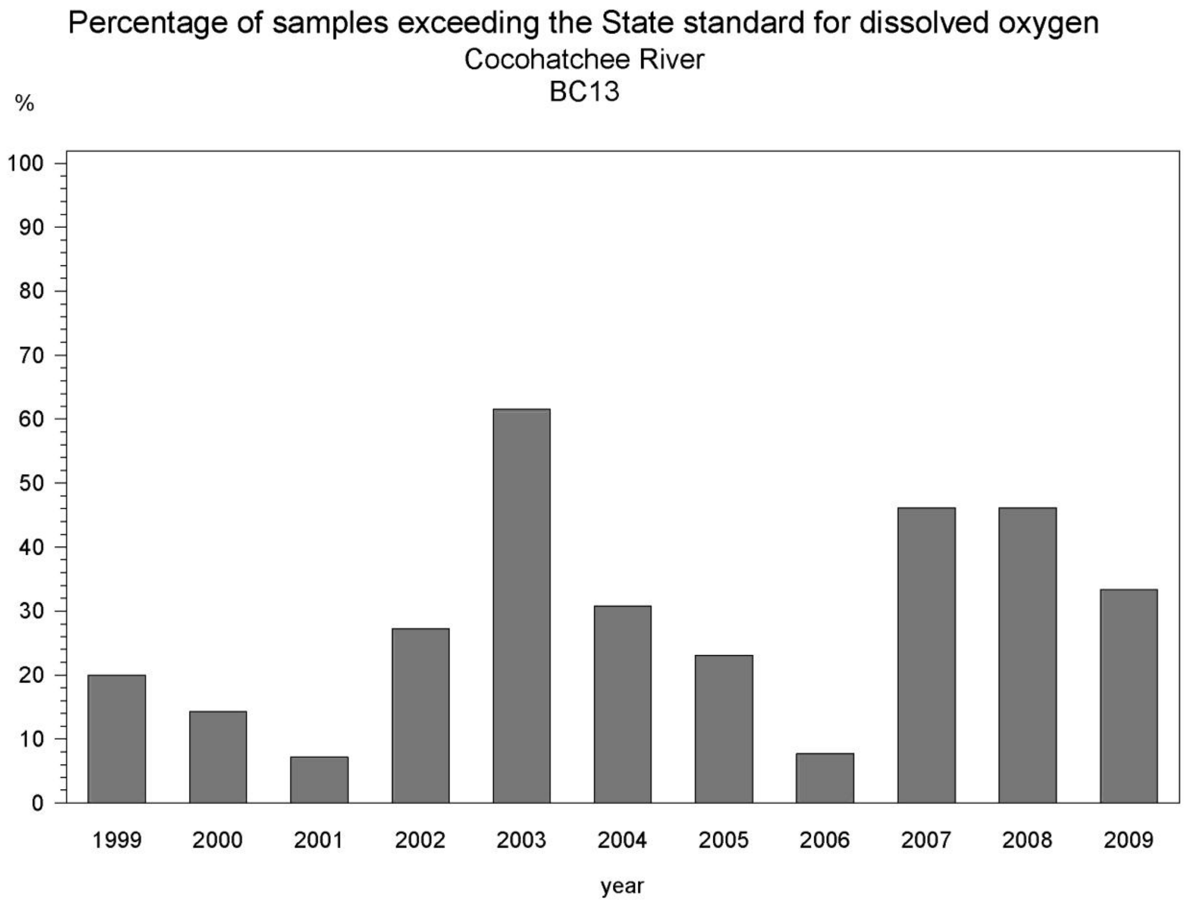

Figure 3.6-6 – Example bar chart summarizing the frequency of dissolved oxygen exceedances.

Dissolved oxygen at Silver Strand exceeded the state standard was for all years of the study period (2003-2009), with percentage values ranging from 50% and 42% (2004, 2007) to 100% (2008). All other years' exceedance percentage values were in the 70s.

Tamiami Canal had four sampling stations that collected data from 2001-2009. The state standard was exceeded for all years of the reporting period at all sampling stations, with exceedance percentage values ranging from 31% in 2009 to 86% in 2006.

Overall, dissolved oxygen exceedances were over 10% of total samples for all basins and all years except two – Cocohatchee River Basin had no exceedances in 2001 and Rookery Bay Inland West Basin had no exceedances in 2009. Similar to the results for chlorophyll a, the highest percentages of dissolved oxygen exceedances were found in inland basins predominantly used for agriculture, or downstream from agriculture areas, such as Barron Basin and Corkscrew Basin, with sampling exceedances in excess of 80% for most years. Exceedances in coastal basins such as Naples Bay and Ten Thousand were lower, generally ranging from 20-50%.

Previous studies demonstrated that high chlorophyll *a* concentrations and lower dissolved oxygen concentrations are typical in systems characterized by anthropogenic nutrient loading (Paerl, 2004, 2008, Turner, 2003). Nutrient loading and resulting high primary production can lead to periodic or long term hypoxia and anoxia when primary producers either exhibit extreme diel cycles of photosynthesis and respiration or when they die and undergo decomposition.

3.6.4 Annual exceedances of heavy metal thresholds

Arsenic concentrations never exceeded the threshold of 50 ug/L for any of the basins, however, peak concentrations that were considerably higher (10-20 ug/L) than baseline levels (typically <5 ug/L) for a given basin were observed in early 2004, 2005 and 2009 for many of the coastal basins including Cocohatchee River, Naples Bay, Gordon River Extension, Rookery Bay Inland East, Ten Thousand Islands and Fakahatchee Strand (Figure 3.6-7). Much lower concentrations were observed for inland basins with few to no deviations from the baseline concentration.

Copper concentrations for Class III freshwaters are required to be less than or equal to a threshold that is calculated as a function of water hardness ($CaCO_3$). Only two basins exceeded the copper threshold, Cocohatchee Inland (3 stations) and Rookery Bay Inland West (1 station). Several of these exceedances were observed in early 2005 for both basins (Figure 3.6-8). The threshold for Class II and Class III marine waters is ≤ 3.7 ug/L. Most of the Class II and III-M waterbodies exceeded the copper threshold on at least four dates. Naples Bay had the highest number of exceedances (all but 13 dates between 2000-2009) and is considered impaired. Cocohatchee River, Gordon River Extension and Ten Thousand Islands also had several exceedances from 2000-2009 (Figure 3.6-9).

Iron exceedances were, by far, the most common of the heavy metal exceedances in Collier County surface waters with coastal basins among the most frequently in exceedance of the iron threshold. Among the freshwater basins, Barron River Canal, Faka Union North and North Golden Gate had the most exceedances of the 1.0 mg/L threshold and exceeded the threshold nearly once annually (Figure 3.6-10). Coastal basins were often in exceedance of the 0.3 mg/L threshold for Class III marine waters at least once per year. Fakahatchee Strand and Rookery Bay Inland East were in exceedance during half of the sample dates, while Cocohatchee River and Naples Bay were in exceedance during most sample dates (Figure 3.6-11).

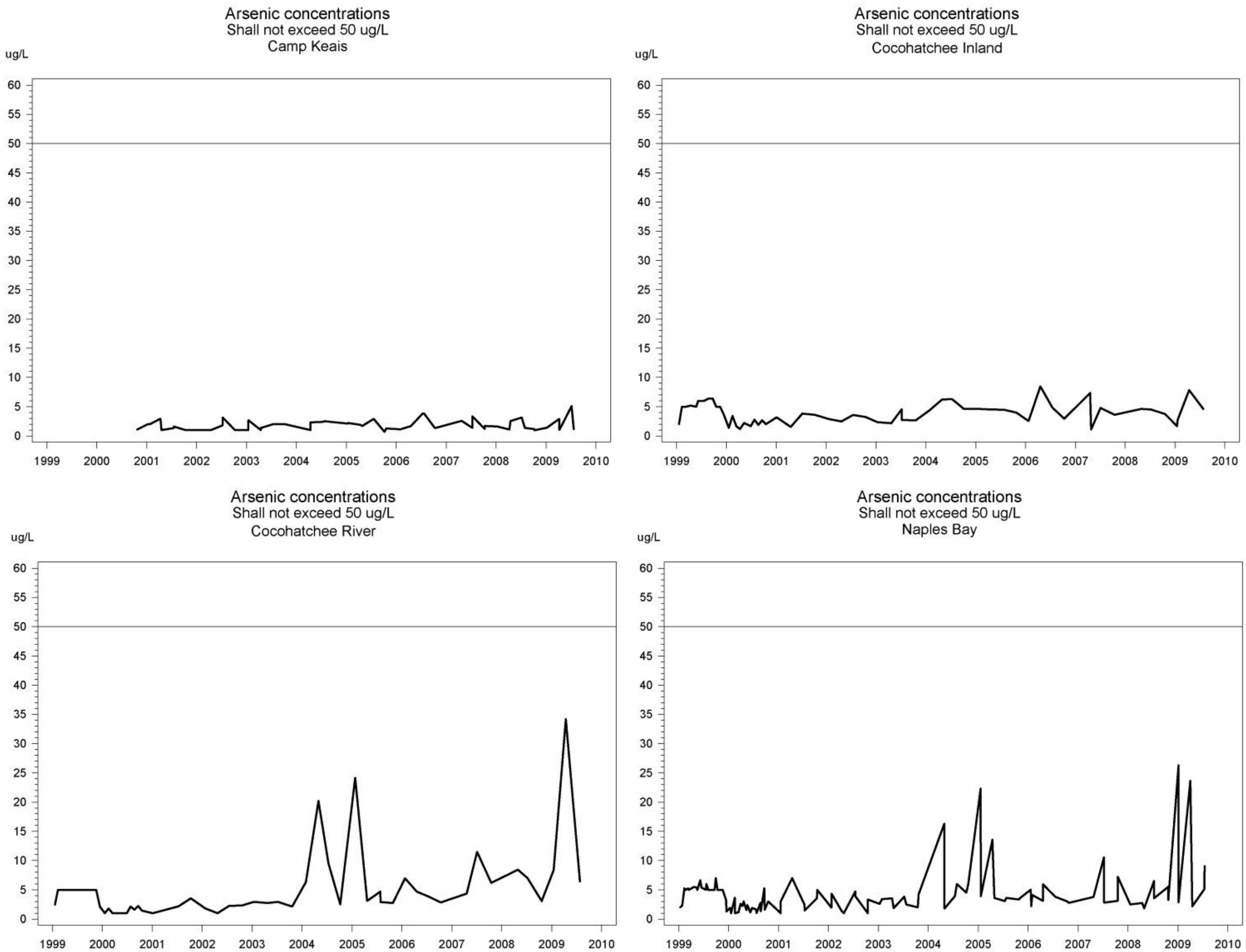

Figure 3.6-7 – Time-series plots of quarterly arsenic concentrations illustrating the peak concentrations for coastal basins in 2004, 2005 and 2009 and the lack of those peak concentrations for inland basins.

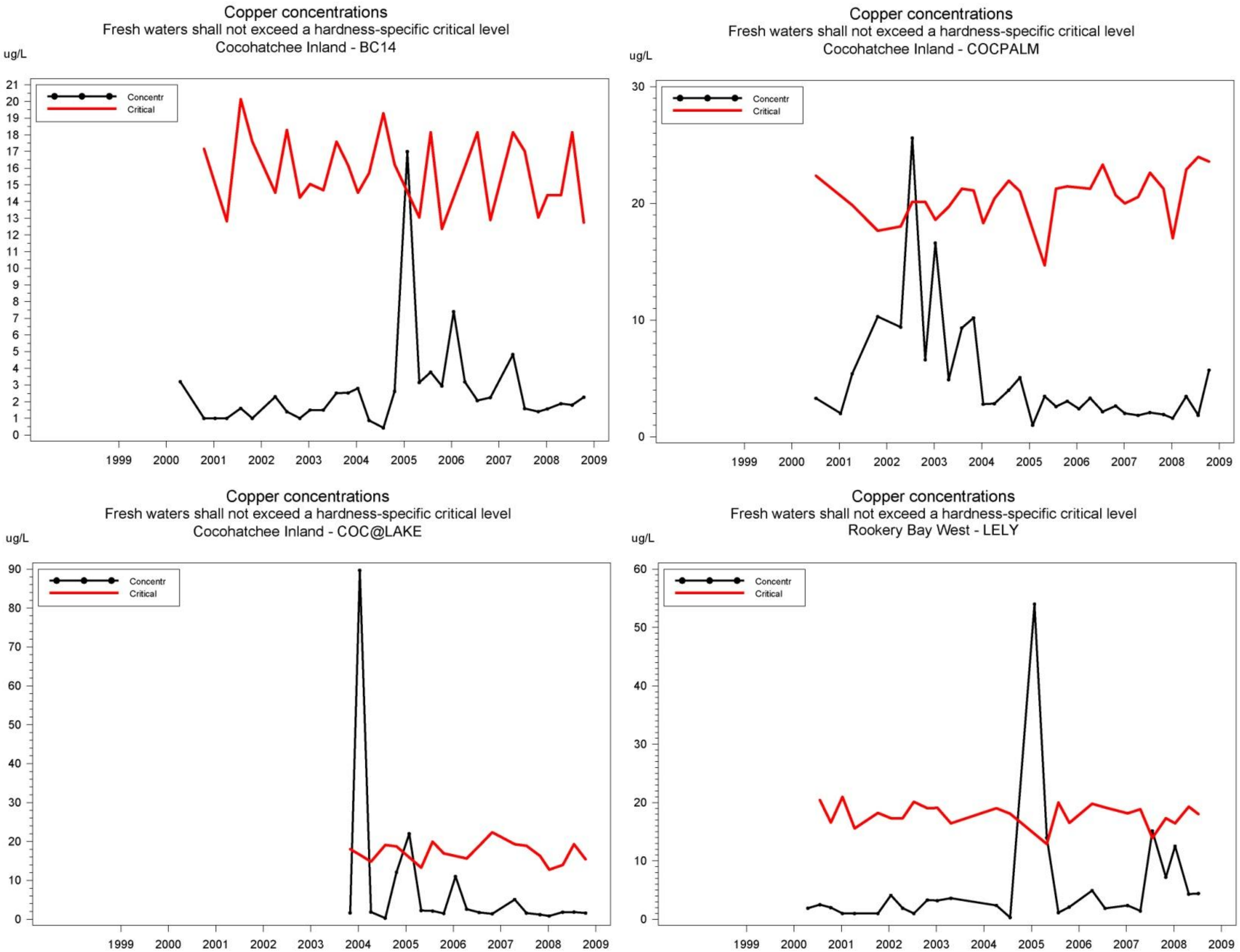

Figure 3.6-8 – Time-series plots of quarterly copper concentrations and critical concentrations showing exceedances for several predominantly freshwater basins. The critical concentration is based on water hardness at the time of sampling.

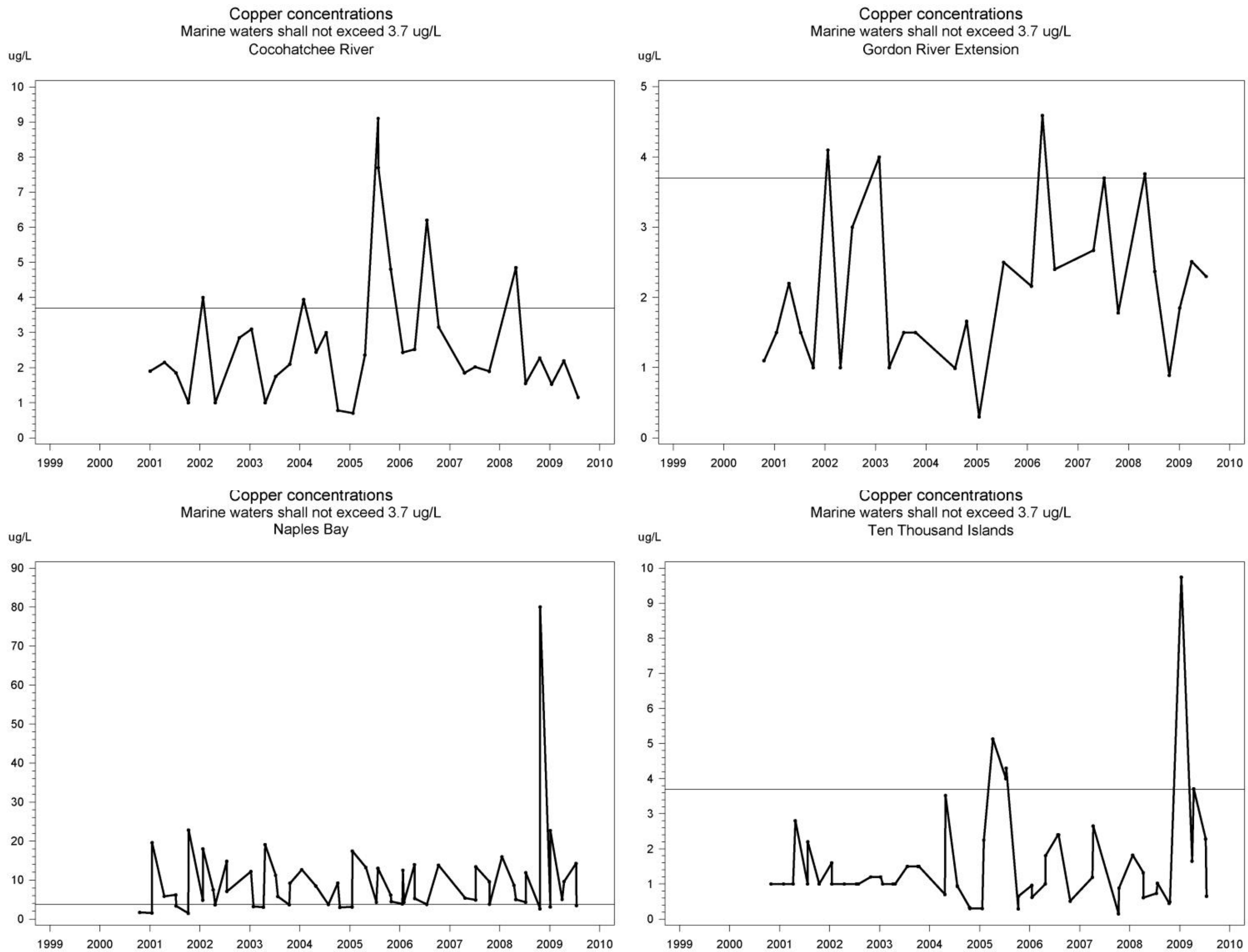

Figure 3.6-9 – Time-series plots of quarterly copper concentrations showing exceedances for several predominantly marine basins.

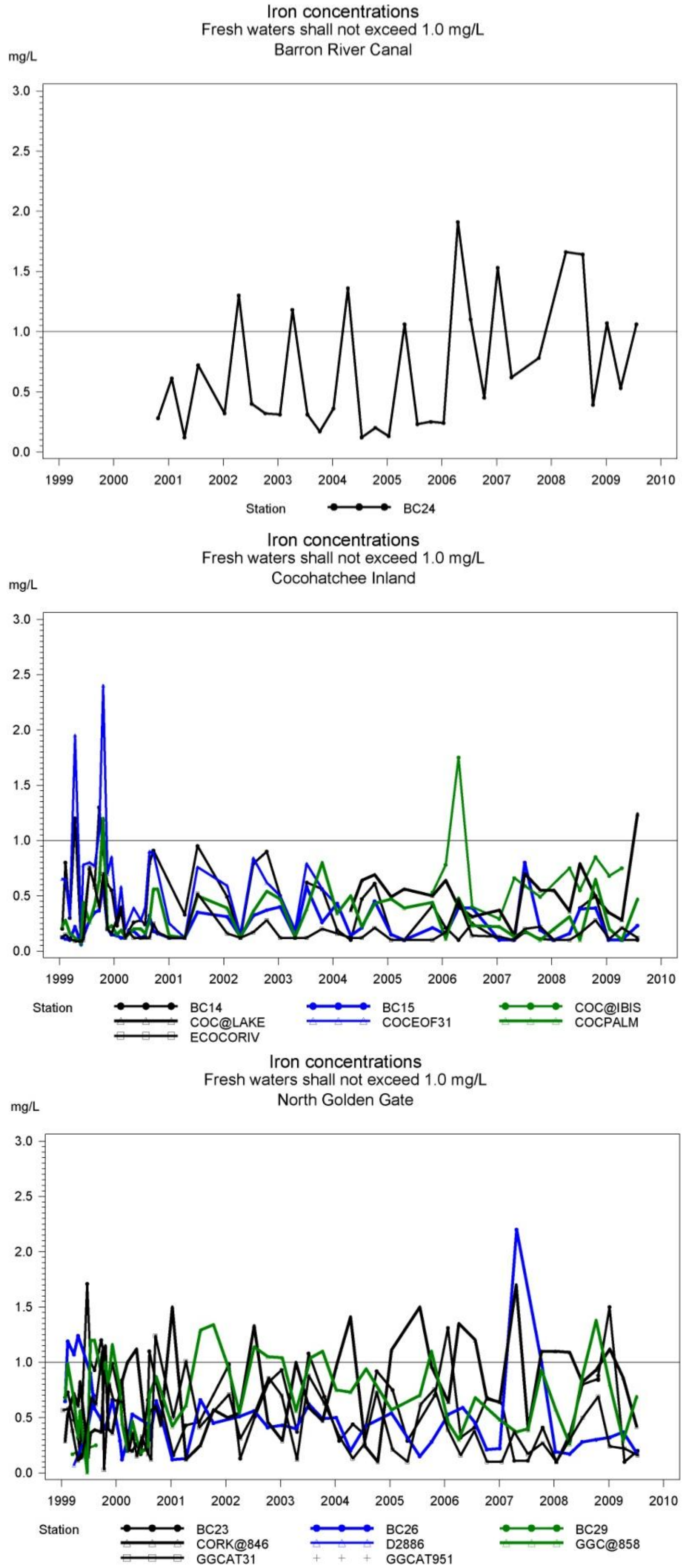

Figure 3.6-10 – Time-series plots of quarterly iron concentrations showing exceedances for several predominantly freshwater basins.

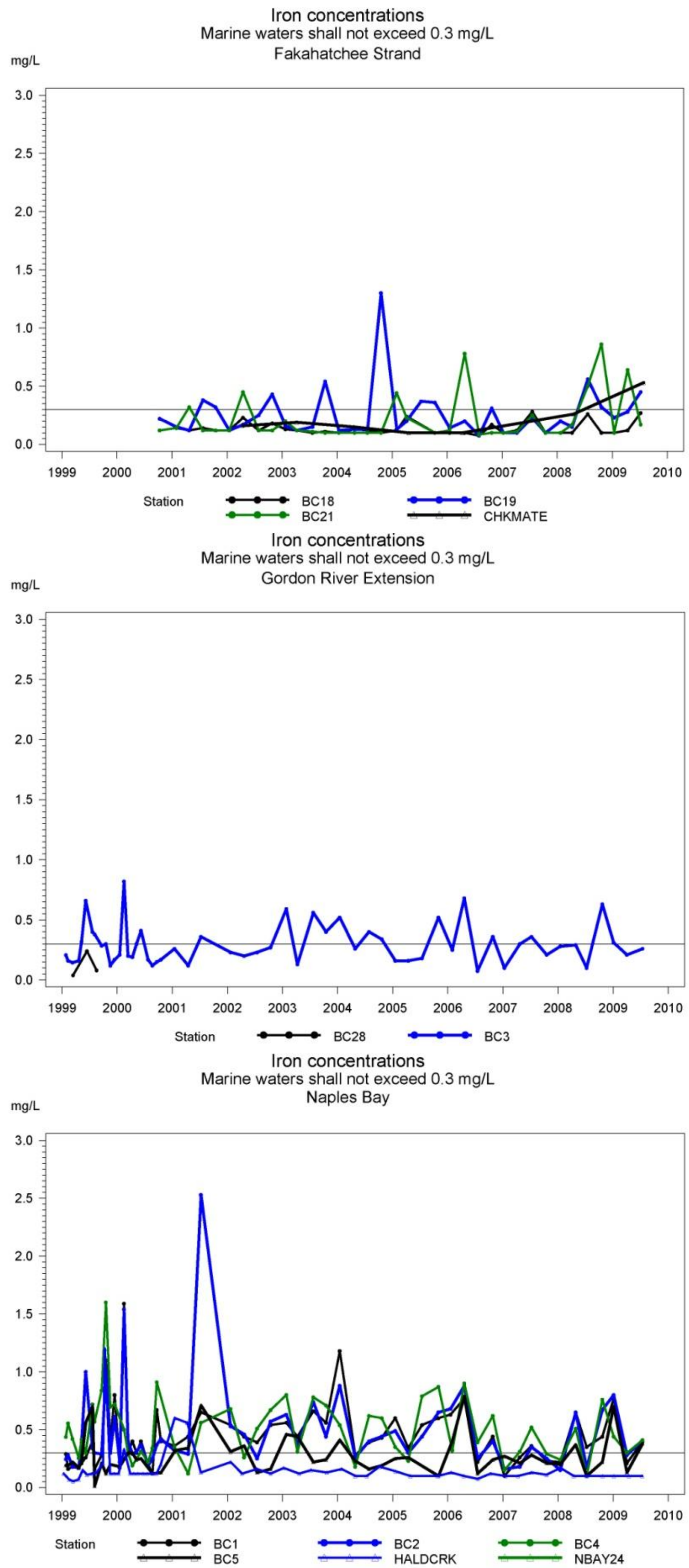

Figure 3.6-11 – Time-series plots of quarterly iron concentrations showing exceedances for several predominantly marine basins

3.6.5 Annual exceedances of fecal coliform thresholds

Seven of the 17 basins exceeded the 800 colonies/100ml daily threshold. Naples Bay had the highest number of exceedances at five between 1999 and 2003 (Figure 3.6-12). Gordon River Extension, along the same coast, had three exceedances in 2002-2003 and 2009. The remaining five basins had fewer than three fecal coliform exceedances. Three basins in the northcentral portion of Collier County, Barron River Canal, Camp Keais and Faka Union North, had a single exceedance in early 2007. Along the coast, Cocohatchee River, Naples Bay and Rookery Bay West each exceeded the fecal coliform threshold during the wet season of 1999.

Class III water bodies, both freshwater and marine, that are designated for recreation and healthy fish and wildlife populations are required to have fewer than 10% of samples in exceedance of 400 colonies/100ml. Only four basins, Gordon River Extension (1999, 2002, 2008), Corkscrew Marsh (2001, 2007), Barron River Canal (2007) and Rookery Bay Inland West (1999) exceeded this threshold. Class II waterbodies, marine waters designated for shellfish propagation and harvest, are required to maintain fecal coliform concentrations below 43 colonies/100 ml in at least 90% of samples or have exceedances in <10% of samples. Cocohatchee River and Naples Bay exceeded this threshold 25-85% of samples every year from 1999-2009, while Ten Thousand Islands exceeded the threshold every year from 2001-2009, except 2008 (Figure 3.6-13).

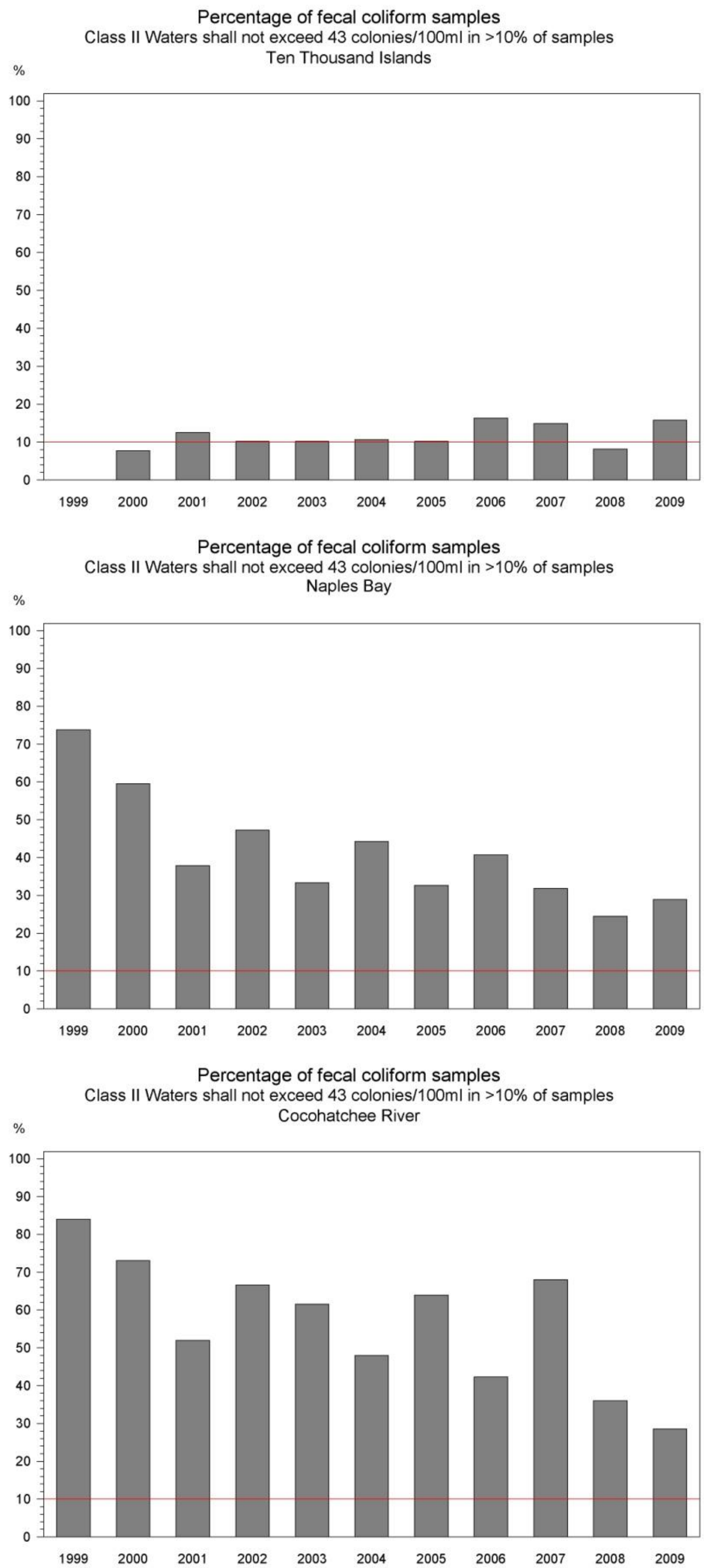

Figure 3.6-12 - Percentage of fecal coliform concentrations that exceed threshold level for Class II water bodies designated for shellfish propogation and harvest.

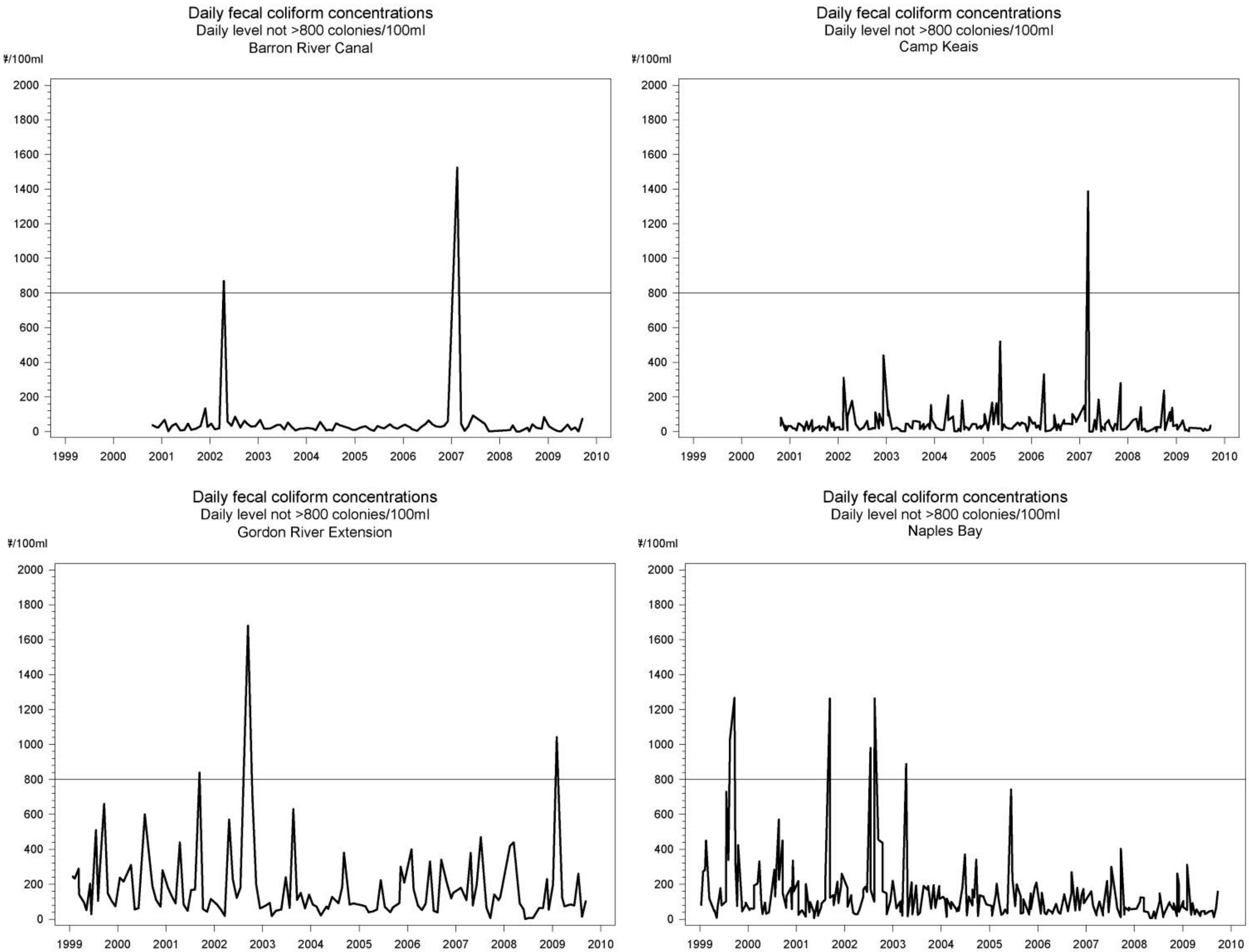

Figure 3.6-13 - Daily fecal coliform concentrations for several basins with threshold exceedances.

3.7 Inter-parameter Relationships between Water Quality Variables

3.7.1 Nutrient limitation at the basin level - N:P ratios

Nitrogen and phosphorus ratios are very important in determining the community composition of water bodies. For any aquatic ecosystem, three major factors control whether nitrogen or phosphorus is more likely to be limiting (NRC 2000):

1. the ratio of nitrogen to phosphorus in external nutrient inputs;

2. the preferential loss from the photic zone of nitrogen or phosphorus due to biogeochemical processes such as denitrification, sedimentation or absorption of phosphorus; and

3. the amount of nitrogen fixation.

Whether nitrogen or phosphorus is "limiting" depends on whether loading of either of these nutrients increases the rate of net primary production (NRC 2000). In 1934, Redfield determined that in estuaries phytoplankton require a carbon:nitrogen: phosphorus ratio of 106:16:1.

In fresh water systems the ratio of nitrogen/phosphorus is usually higher than 16/1. Therefore, phosphorus is usually most limiting to primary production in freshwater ecosystems. This becomes evident by examining the concentrations of the forms of nitrogen and phosphorus that are available for algal uptake. Little if any dissolved inorganic phosphorus (DIP) is generally found in relatively productive fresh waters while measurable concentrations of dissolved inorganic nitrogen (DIN) remain. Most marine systems are nitrogen limited because there are relatively low concentrations of dissolved inorganic nitrogen compared to dissolved phosphorus. Since Redfield's observations were published, research has shown that ratios from 10:1 to 20:1 for N:P are typically found in estuaries (Parsons et al. 1984). Howarth (1988) observed that the correlation between nitrogen and the primary production was better for estuaries that received nutrient concentrations with smaller N:P ratios than the one studied by Redfield. Studies concluded that estuaries receiving nutrient concentrations with high N:P coefficients were limited by phosphorus and only those with low coefficients are limited by nitrogen (Boynton et al., 1982). Boyton et al. (1982) and others (Paerl et al. 1985, 2002, 2004; Howarth 1988) compiled data on the ratio of inorganic nitrogen to phosphorus in a variety of estuaries. Of the 27 studied, 22 had N:P ratios below the Redfield ratio and may have been nitrogen limited (Howarth 1988). Because phytoplankton can assimilate some organic nutrient forms and all forms are relatively labile, it is useful to examine the ratio of total nutrient concentrations (TN:TP).

Assuming other factors such as light attenuation or residence time are not limiting, nutrient reduction in a water body will result in reduction in algal growth. Reducing phosphorus, however, will have no effect unless the reduction results in an N:P ratio of greater than 16/1. Phosphorus would then become the limiting factor. In contrast, a reduction of nitrogen will result in a reduction of primary productivity when the ratio is less than 16:1. There are exceptions to this general explanation. Some coastal areas are phosphorus limited due to strict phosphorus control measures or natural conditions and some freshwaters are nitrogen limited due to natural sources of phosphorus.

A variety of biogeochemical processes acting in both sediments and in the water column can result in alterations of the ratio of nitrogen and phosphorus in the water columns of aquatic systems. Processes such as sedimentation and denitrification tend to drive marine ecosystems towards nitrogen limitation. In marine and estuarine systems benthic remineralization and nutrient release often flux nutrients from the sediment to the water column and the result is concentrations of nutrients depleted in nitrogen relative to phosphorus. Additionally, studies have shown that during microbial decomposition phosphorus is released faster than nitrogen. This is believed to result from the ester bonds of phosphorus being easier to break than the covalent bonds of nitrogen (Paerl, 1988). The current study region is very unique in its geology in that it is a limestone-dominated watershed. In this watershed phosphorus availability can be limited by calcium carbonate absorption or by calcium precipitation.

3.7.2 Annual variation in N:P ratios

Annual N:P ratio bar charts are shown in Appendix 3-7 for the study period. N:P ratios in the study region ranged from 0 to >500. Figure 3.7-1 shows an example of the plots of mean annual N:P ratios for Barron River Canal included in the Appendix. Average N:P ratios varied from 13.6 in 1989 to 91 in 2005. As expected, coastal regions had lower values than the inland regions. For example, Naples Bay (Coastal Segment) had mean annual values ranging from 14-104. Cocohatchee Inland had values ranging from 7-318. Although there is variation in values between basins, numbers were variable across years with no clear trends. For all basins a majority of the values were elevated such that phosphorus limitation is clearly evident in all basins.

3.7.3 Inter-annual variation in N:P ratios

Inter-annual box and whisker plots of N:P ratios are shown in Appendix 3-7 for the study period. Seasonal differences were evident in five of the nineteen basins, including Cocohatchee River, Camp Keais, Tamiami Canal, Rookery Bay Inland East and Fakahatchee Strand, with higher N:P values during the wet season as compared to the dry season. For example, Figure 3.7-2 shows the Fakahatchee Strand basin monthly mean N:P ratios. Lowest mean values were recorded in May at 43 and increased during the wet season with mean values of 120 during July, 123 during August, 180 during September, 190 during October and 167 during November.

In summary, the basins' much higher N:P ratios in this study region show a strong deviation from typical Redfield ratios. High nitrogen values in relationship to phosphorus indicate a growth limiting deficiency of phosphorus. Due to the unique geology of the region, phosphorus availability is limited by absorption to calcium carbonate. High values found in this study were typical of those found in other studies near the region. A study by Noe and others (2001) investigated N:P ratios in the Florida Everglades and found averages from 90 - 545 in the wetland water column (Noe et al. 2001). A study by Conley (2000) reviewed data on riverine nitrogen loading into the Baltic Sea, Chesapeake Bay, Narragansett Bay and concluded that since 1900 nitrogen loading as measured by N:P ratios has increased at a rate of 66% higher than phosphorus. As anthropogenic sources of nitrogen have risen higher N:P ratios have become more prevalent in aquatic ecosystems (Turner et al. 2003).

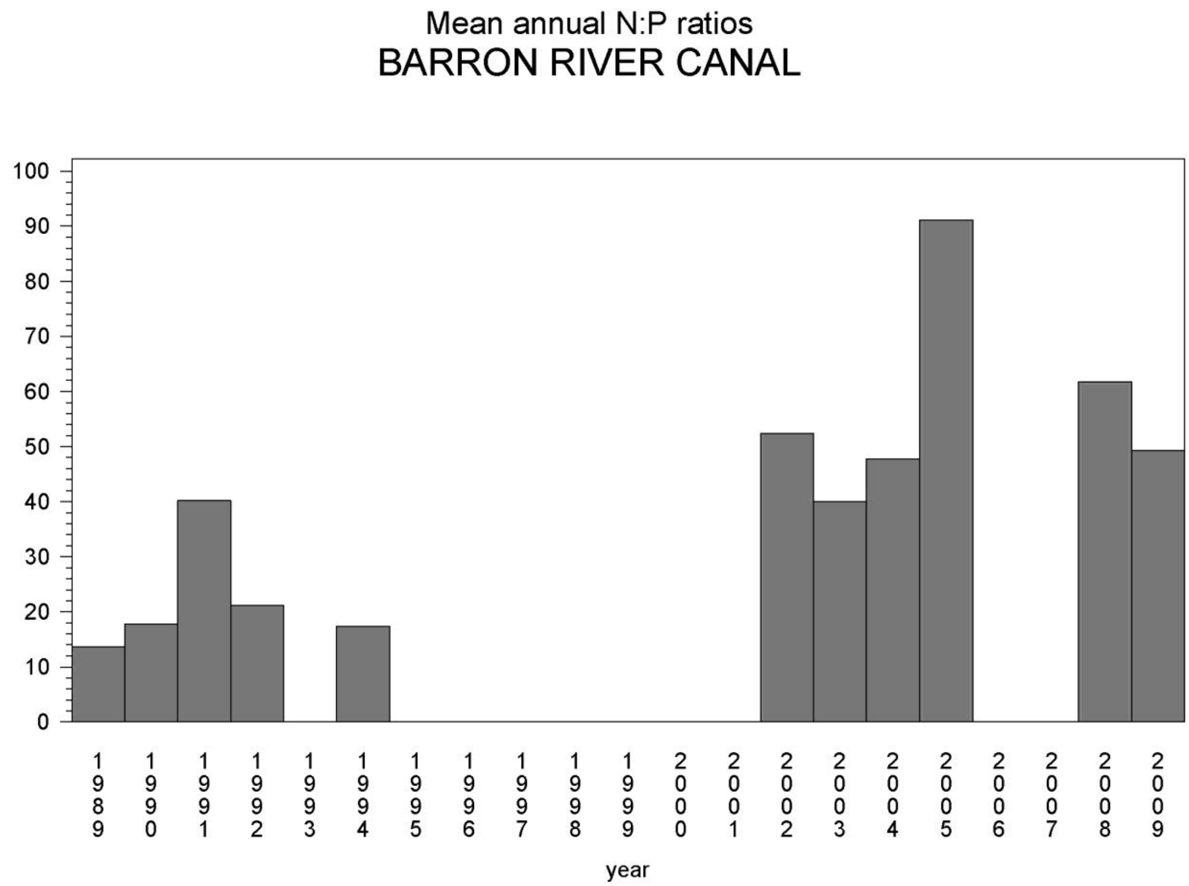

Figure 3.7-1 – Example bar chart summarizing annual N:P ratios for each basin.

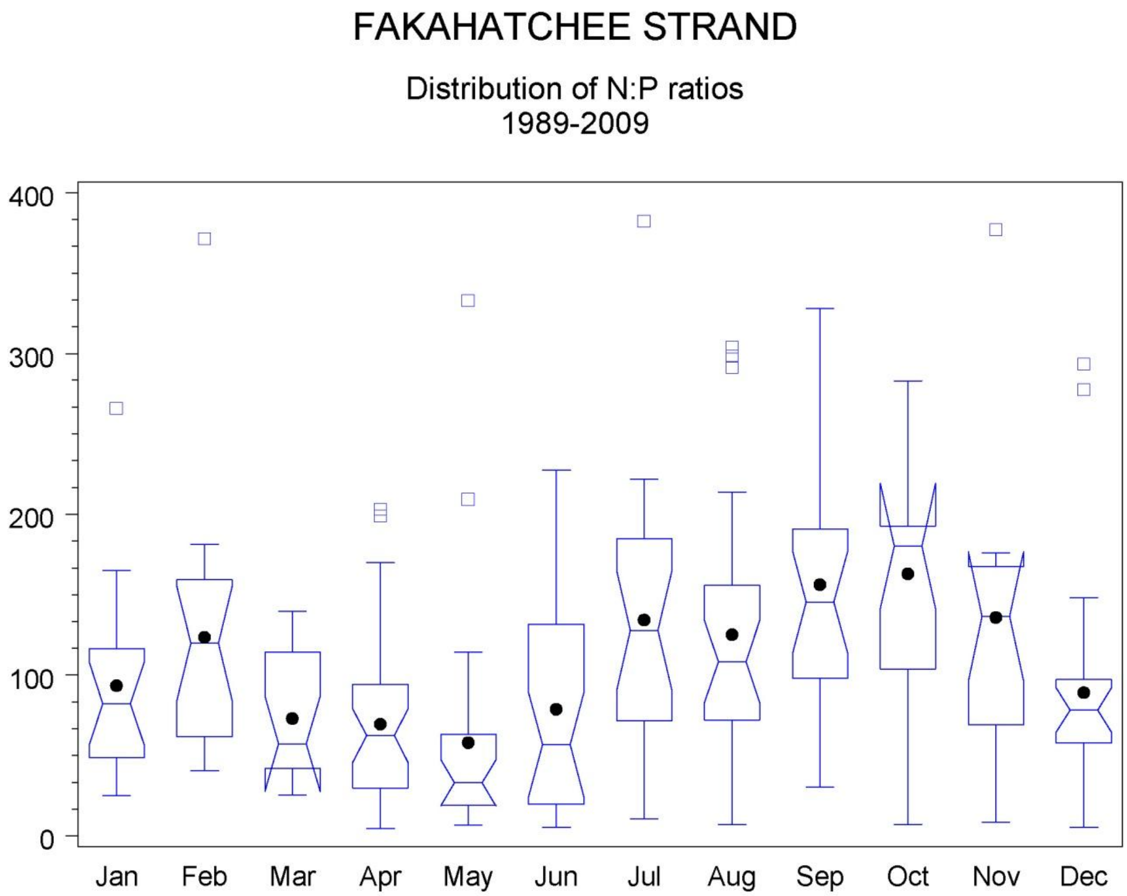

Figure 3.7-2 – Example bar chart summarizing monthly variation in N:P ratios for each basin.

3.7.4 Relationships between chlorophyll and nutrients

In general, there were few clear linear relationships between nutrient concentrations and chlorophyll *a* levels when these relationships were examined by station and basin (Appendix 3.7). This was because, in many cases, chlorophyll levels were low even at high nutrient concentrations. However, chlorophyll *a* levels typically exceeded 20 ug/L only when TN concentrations were greater than 0.7 mg/L (Figure 3.7-3) and when TP concentrations were between 0.02-0.04 or greater (Figure 3.7-4). In most cases, when TN concentrations were <0.7 mg/L, chlorophyll *a* levels were <20 ug/L. Similarly, when TP concentrations were <0.02 mg/L, chlorophyll *a* levels were <20ug/L.

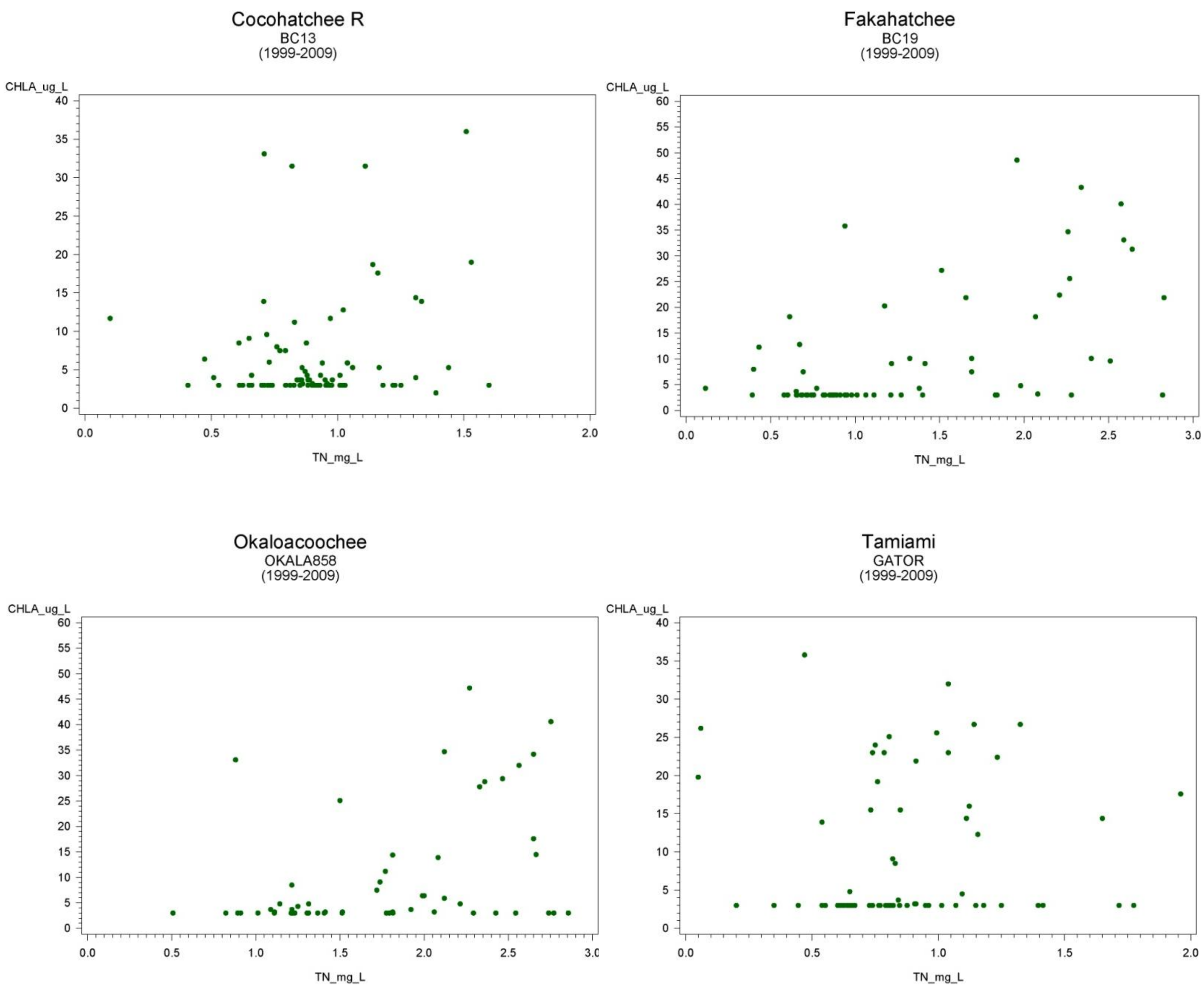

Figure 3.7-3 – Relationships between total nitrogen concentration and chlorophyll *a* at several water-quality stations.

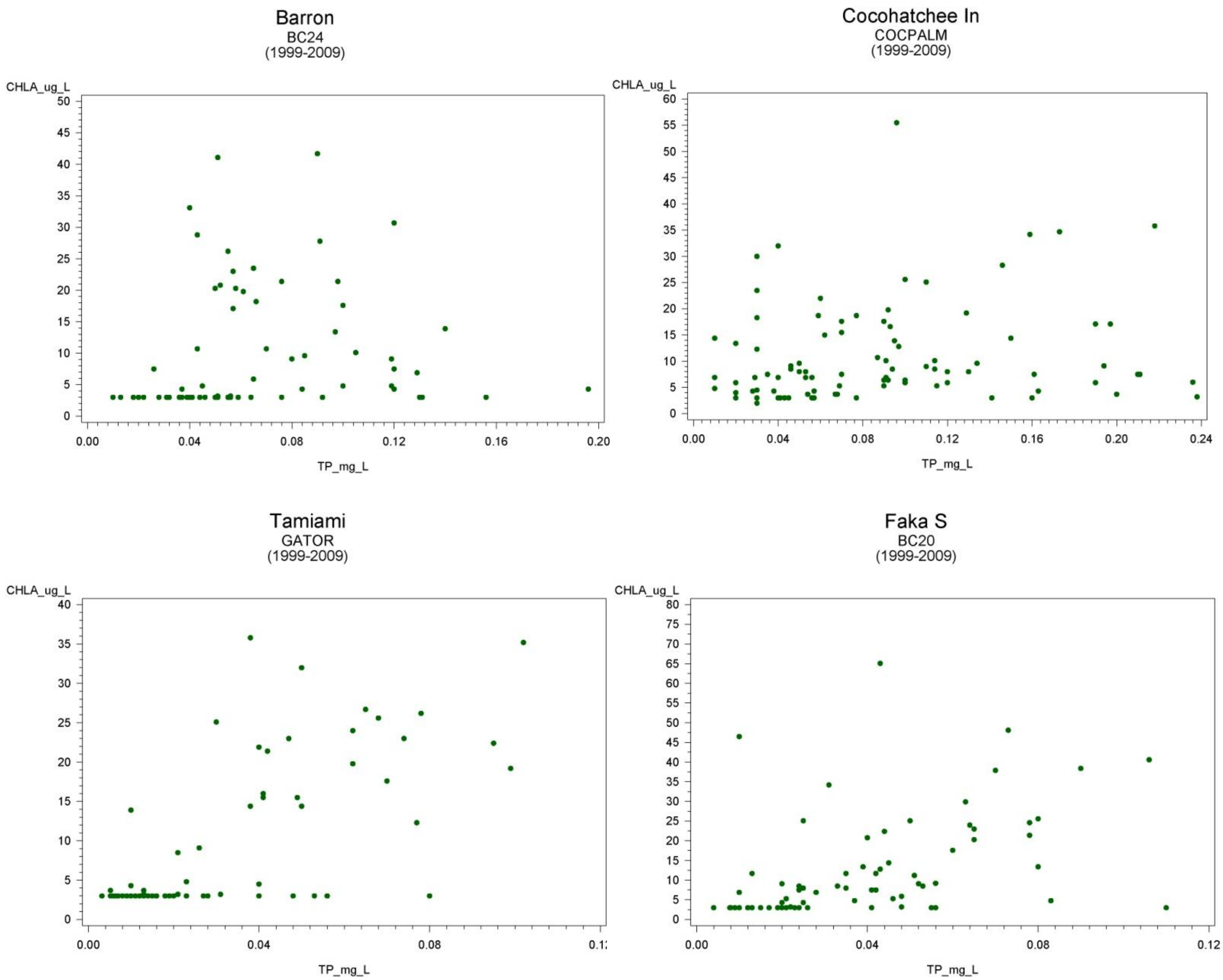

Figure 3.7-4 – Relationships between total phosphorus concentration and chlorophyll *a* at several water-quality stations.

4.0 CONCLUSIONS

- Statistically significant trends (both improving and degrading) were observed for all of the basins for at least one water quality parameter from 1999-2009, though most of the significant trends were shallow in nature, changing consistently but slowly over time. Only two steep trends were observed, both for increasing conductivity in the coastal basins of Naples Bay and Cocohatchee River. Despite significant trends, the magnitude of the change from 1999 to 2009 was relatively small. Trends are summarized below.
    - Increasing salinity was observed for 10 of the 18 basins examined. All of these trends can be explained by the relatively low rainfall amounts from 2007-2009 which resulted in less than average freshwater runoff to surface waters.
    - Statistically significant degrading trends in total nitrogen (and organic nitrogen) and phosphorus were observed for several of the interconnected northern and central basins including Okaloacoochee Slough, Camp Keais, Fakahatchee Strand, Faka Union South and Ten Thousand Islands. A possible explanation could be an increased fertilizer contribution from the northern agricultural basins that drain to the Ten Thousand Islands. No significant trends were observed for chlorophyll *a* however, as a result of increasing nutrient concentrations, though increasing turbidity was observed for several of these basins. Improving trends in total and organic nitrogen were observed for Cocohatchee Inland and River as well as Rookery Bay Inland West.
    - Improvements in water color (clarity) were observed for several of the basins in western Collier County including Rookery Bay Inland East and West, North Golden Gate and Faka Union North, as well as Tamiami Canal. Associated improvements in turbidity were observed for Faka Union North and Rookery Bay Inland West, as well as Naples Bay and Cocohatchee River.
    - Dissolved oxygen concentrations were relatively stable from 1999-2009 for most basins (~0.1 mg/L change), however, significant degrading trends were observed for Naples Bay (-0.5 mg/L), Barron River Canal (-1.0 mg/L) and Ten Thousand Islands (-1.0 mg/L).
    - Few degrading trends for heavy metals were observed, however, increasing arsenic concentrations were observed for Cocohatchee River and Fakahatchee Strand as the result of pronounced peak concentrations in 2009 in both basins. Despite few significant trends, heavy metal concentrations and the frequency of water quality exceedances were highest in many of the coastal urban basins.
- As expected, flows were greatest during the wet season (July-November) and least during the dry season (December-June). The highest flows were recorded for the Tamiami Canal basin (peak annual flows >2,000 cubic feet/sec) and the lowest flows from the Cocohatchee River, Barron River Canal and Rookery Bay Inland East basins (peak annual flows usually <300 cubic feet/sec).

- The greatest loads per-unit-area were contributed to coastal waters from the North Golden Gate/Naples Bay basins during the period 1995-2001, though gauged flows were discontinued in this basin in 2002. During the period 2002-2009, the highest nutrient and hydrologic loads per-unit-area were contributed by the Cocohatchee River/Inland and Corkscrew Marsh/Drainage to Corkscrew basins and by the Faka Union North/South and Camp Keais basins. Flows per-unit-area were much less from the Rookery Bay Inland East basin and the Barron River Canal/Okaloacoochee Slough/Silver Strand basins.

- There were few clear linear relationships between nutrients and chlorophyll *a* in Collier County basins, however, in many cases, chlorophyll *a* concentrations were below the impairment threshold of 20 ug/L when total nitrogen concentrations were <0.7 mg/L or total phosphorus concentrations were <0.02 mg/L.

- Climatological effects on water quality related to high rainfall were detectable as increased flows or as reduced concentrations of some constituents, such as chlorophyll, salinity and total nitrogen. Even low rainfall amounts had a similar effect, though the magnitude of the effect was less with lower rainfall.

- Three distinct regions of Collier County were identified based on multivariate analysis of land use and land cover: 1) basins in north-central Collier are predominantly agricultural, 2) western Collier is predominantly urban, and 3) eastern and central Collier is predominantly undeveloped and consists of natural land cover, including wetlands and uplands.

- Similar multivariate analysis of water quality parameters in each of the monitored basins identified similar groups of basins, but the primary differences in water quality among basins was between agricultural and non-agricultural basins. The inland agricultural basins had lower pH, darker color, lower dissolved oxygen, high total nitrogen concentrations and warmer water temperatures than basins in the rest of the county. Coastal basins had higher salinities and total suspended solids than the rest of the county, while inland, non-agricultural basins had lower salinities and suspended solids as well as higher pH, lighter color, higher dissolved oxygen, lower total nitrogen and cooler water temperatures.

- While characteristic differences in water quality were observed among urban, agricultural and undeveloped basins, the effects of land use change on water quality was less apparent due to: 1) implementation of stormwater management practices in the 1980s that has resulted in improved water quality in urban basins, and because 2) much of the change from natural to urban land use had already occurred since 1988 with many of the urban basins already >70% urbanized. Even the less urban basins had already exceeded the level of urbanization (20-30%) thought to result in the most apparent changes to water quality.

- Naples Bay is the most degraded basin in Collier County in terms of water quality and is verified impaired for dissolved oxygen, fecal coliforms, copper and iron. Though not impaired for arsenic, Naples Bay has among the highest concentrations in the county and has significant degrading trends for dissolved oxygen, turbidity and total phosphorus. These results are not unexpected given the high percentage of urban land uses in this basin and the relatively high flows to Naples Bay.

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